LANDSCAPE EVOLUTION ON SAN MIGUEL ISLAND, CALIFORNIA

by

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Dissertation Committee:

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FRONTISPIECE A

Airphoto, San Miguel Island, March 1969.

FRONTISPIECE B

Airphoto, San Miguel Island, March 1969.

ACKNOWLEDGMENTS

Many individuals, institutions and public agencies have contributed in one way or another to this study which began in 1964. Unfortunately, time tends to blur the memory in looking back, and I suspect it would be impossible to acknowledge all contributors, some of whom probably have forgotten themselves or never knew they contributed. To all involved, and the list is long, I thank you warmly. Several, however, deserve special mention because they made direct significant contributions to my research in various ways.

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CHAPTER I

INTRODUCTION

San Miguel Island is the westernmost of the eight islands off southern California known as the Channel Islands (Fig. 1). Four islands, San Miguel, Santa Rosa, Santa Cruz and Anacapa collectively comprise the insular subgroup known as the Northern Channel Islands. Anacapa* is small and mesa-like with steep encircling cliffs, and is covered with low shrubs and cactus. Santa Cruz and the eastern three-quarters of Santa Rosa Islands are large, mountainous, rugged and dissected, and are

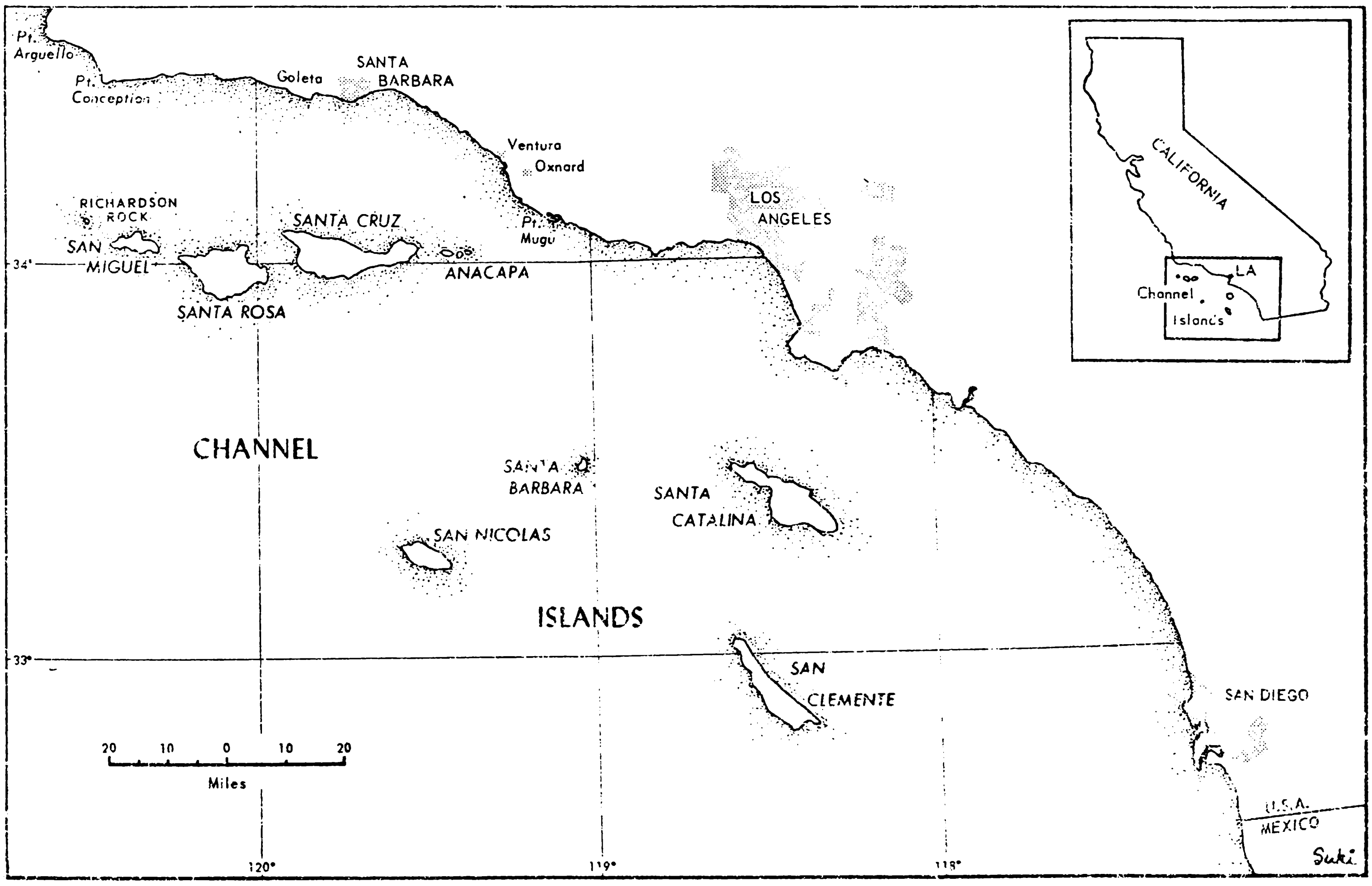

Figure 1. Location Map of California Channel Islands.

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*Anacapa is actually three small islands that are usually referred to in the singular.

covered with chaparral, oak-grass woodland, and in places support closed-cone pine stands.

On the other hand, the western third of Santa Rosa Island and San Miguel are distinctly different. Both are tablelands like Anacapa but larger and, where vegetation is present, support grass and herbs, green in the winter and spring, brown the rest of the year. Both have bizarre, intricately eroded landscapes. Great dunes everywhere alternate with dazzling white slabs of concrete-like caliche. An occasional elephant, human or sheep bone reflects the quickening change of biotic tenure. In places the wind strips away soil, caliche, sand and exhumes ghostly stands of calcified trunks and roots of ancient, long-buried vegetation. San Miguel and the western third of Santa Rosa are ghost landscapes, splendid in their eroded desolation.

This study, however, is limited to San Miguel Island. San Miguel is exposed to the full force of the strong winds and the cool California Current which sweep south of Point Conception, making it one of the most windy, foggy and wave-pounded areas on the west coast of North America; frequent bad weather and a remote location make for difficulty of access. However, the interested investigator who lives with troublesome problems of access and doing sustained work in the inclement weather is richly rewarded by a wide range of fascinating problems in geoscience in general and physical geography in particular. To the geomorphologist and pedologist especially, this tiny island offers a fantastic catalogue of research problems, for in addition to the features described in the previous paragraph the island has material that remarkably resembles tropical laterite in both massive and pisolitic form, magnificent exposures of Pleistocene eolianite and buried soils, bizarre fossilized groves of former vegetation, conspicuous cobble-boulder pavements perched on "self-swallowing" soils, spectacular and ubiquitous sand dunes capped by ancient shell middens, the debris of early man, unusual exposures of beachrock, concentrations of pygmy mammoth bones, marine terraces, extinct fossil plant imprints encased in tufa, an almost unique climate, and an ocean and wind-carved landscape that takes a kaleidoscope of forms.

This cornucopia of field evidence lends itself well to a study of landscape evolution on San Miguel Island. However, even in the face of abundant evidence one runs a risk in drawing absolute conclusions. Indeed, much of the evidence is not absolutely conclusive, and some is even flawed, but collectively it converges and forms a consensus in support of the conclusions drawn in this thesis. In other words, singly the pieces of the puzzle are blurred, but together they paint a clear picture of insular landscape evolution.

1. Purpose of the Study

It is the purpose of this thesis to analyze the distinctive landscape of San Miguel Island and to illuminate the intricacies of its evolution. To this end answers to the six following questions will be sought: To what extent is the distinctive geomorphic and pedologic landscape the result of climate and climatic change? Of structural or tectonic causes? Of marine processes? Of biogenic causes and events? Of pedogenic processes? What role has man played in the geomorphic evolution of the island?

To accomplish this goal I have organized the materials in this thesis around six major themes: (1) the character of present and past climates, (2) marine terraces, (3) biogeographic history and land bridges, (4) sand dunes and eolianites, (5) soils and paleosols, and (6) late Quaternary landscape modifications. With the exception of climate which is treated principally in Chapter Two, titled "The Physiographic Setting," each problem comprises an individual chapter. Chapters three, five and six (marine terraces, eolian sands, and soils) deal with the three most important and conspicuous geomorphic features on the island; these landscape features have been conditioned by climate, biogeographic factors, and late Quaternary events, which form the primary subject matter of Chapters two, four and seven. The six chapters (chapters two through seven) collectively contain information which sheds light on the six questions posed above regarding landscape evolution on San Miguel Island.

The reader will note that frequent references are made to certain Channel Islands other than San Miguel, and in several instances aspects of the mainland coast are considered. The reason for this is that San Miguel has not had an altogether independent history of evolution apart from the other areas. For example, San Miguel is topographically and structurally an extension of the west end of Santa Rosa Island and both islands were land-tied to Santa Cruz and Anacapa Islands during low sea level periods in the Pleistocene. Thus it is virtually impossible to treat only San Miguel Island in such contexts.

2. Justification for the Study

Research for this thesis began during a three-day visit to San Miguel in spring of 1964. At the time a general reconnaissance and exploration of the island was undertaken. Subsequent visits were made for the purpose of collecting data for a thesis. At one point in the initial stages of research the writer critically weighed several options for a thesis topic. One possibility was to develop a strong single problem-oriented theme which, in most geography departments in the United States, presently is either required or strongly recommended. It is a pleasant fact that the island is bristling with a wide spectrum of apparent and easily defined research problems each of which could have been developed into an appropriate thesis.

A second option was to develop a poly-thematic thesis dealing with broad aspects of the evolution of the island's unusual geomorphic and pedologic features in the context of a dynamic environment characterized by various past events and episodes. After carefully weighing both options for feasibility and desirability, a poly-thematic thesis was chosen for the following reasons:

1. The general surface features of the island have never been adequately described or explained in any manner, much less in a pedo-geomorphic context.
2. A process or single problem-oriented thesis would be difficult to execute without an appreciation and knowledge of the complexities of prehistoric, protohistoric, and historic

events which have left an indelible stamp on the island. Only a comprehensive or poly-thematic study can decipher these events.

3. Such a broad study should have maximum interdisciplinary value to members of the scientific community at large, particularly archaeologists who have lately shown great interest in the island.
4. A poly-thematic thesis should have wide utility for the National Park Service. For example the general pedo-geomorphic landscape of San Miguel is what gives the island much of its exciting character and charm and should figure prominently in the layout of future explanatory guide paths and trails if the island becomes an effective part of the proposed Channel Islands National Park. Thus, information gained from the proposed work will have maximum practical value to the public as well as the scientific community.

3. Previous Work

Scientific investigation of San Miguel began shortly after the Mexican War by Coast Survey personnel (Alden, 1852; Greenwell, 1858a, 1858b, 1858c, 1858d; Davidson, 1858, 1869; Forney, 1871) and thereafter it soon became known as an artifact hunter's paradise (Schumacher, 1875, 1877; Dall, 1874), a reputation that still remains. A book which described Canalino artifacts excavated on the island was published in 1921 (Heye) and references to the general archaeology were given in Rogers' (1929) book. The gross bedrock geology was first described in 1933 (Bremner) and supplemented by work in 1952 (Kennett, in Redwine, et al.), but it remained until 1969 (Weaver) before the total bedrock picture was confidently known. Studies on the surficial geology and soils have been initiated by the writer (Johnson, 1967, 1969; Johnson and Hester, 1972). The botany of the island was first described before the turn of the century (Brandegee, 1888; Le Conte, 1887; Greene, 1887) supplemented by later work (Hoffman, 1932; Eastwood, 1941). The Santa Barbara Botanic Garden (Ralph Philbrick) is currently carrying out botanical studies. A number of popular and scientific notes and articles on the natural history of San Miguel have been published since the turn of the century (e.g., Merriam, 1904; Holder, 1910; Wright and Snyder, 1918; Willett, 1910; Cockerell, 1937, 1938a, 1938b, 1938c, 1939a, 1939b; Allanson, 1955; Bonnot, 1928a, 1928b, 1931, 1951; Orr, 1950; Gleason, 1950, 1958; Miller, 1951; Collyer and Baxter, 1951; Hillinger, 1958; Holland, 1963; Van Gelder, 1965; von Bloeker, 1967; see also many articles in the 1967 symposium volume edited by R. Philbrick, 1967; Peterson and Le Boeuf, 1969; anonymous, 1969; Ashkenazy, 1970; Simpson and Gilmartin, 1970; Remington, 1971; Lopez, 1971; Marx, 1971; Johnson, 1971, 1972; Belous, 1972). The National Park Service has also published several articles on the Channel Islands (1959, 1963).

Elephant remains were occasionally found by infrequent visitors to San Miguel but the precise locations of the discoveries were not recorded, nor were detailed investigations ever carried out. The well known proboscidean remains of Santa Rosa Island absorbed the activities of interested paleontologists and related specialists (Stock and Furlong, 1928, 1929; Stock, 1935, 1943; Orr, 1956a, 1956b, 1956c, 1959, 1960a, 1960b, 1966, 1967, 1968), and speculators (Carter, 1956, 1959).

While San Miguel Island has long been known as a prolific supplier of artifacts, no archaeological excavations using modern techniques were carried out until those conducted by Rozaire beginning in 1964 (personal communication, 1967). Likewise, no mention was made of the unusual record of Quaternary sediments, paleosols and fossils expressed as geomorphology until 1967 (Johnson). This study is the first done on the general geomorphology and paleopedology of the island.

The dearth of scientific work done on San Miguel with a focus on geoscience is surprising in view of the island's proximity to the densely populated southern California littoral which has been rather intensively studied. There are several reasons for this seeming anomaly. One is that physical access to the island is difficult, is not regularly scheduled, and must be by boat or airplane. Both air and sea transportation are not only expensive but require considerable preliminary preparation that is normally not necessary for work on the mainland. Moreover, the infamously inclement weather of San Miguel often disrupts schedules to a degree that one never knows for sure if he will arrive or leave the island at all, much less on schedule. Additionally, support logistics for food, water, and shelter impose severe restrictions on field work carried out over a sustained period of time. Indeed this last factor is probably most responsible for the anomalous vacuum of research activity on the island.

Another reason is that political access to the island in the past and in recent years has also posed problems. Since World War II the island intermittently has been used as a bombing range by the U. S. Navy so that visits to the island prior to 1968 had to be in phase with such operations. The vagaries of military scheduling, the preliminary paper work and telephone calls necessary to gain legal access to the island combined with the exorbitant costs and physical constraints associated with sustained field work probably have discouraged not a few researchers.

CHAPTER II

THE PHYSIOGRAPHIC SETTING

This chapter provides a physiographic background to an understanding of landscape evolution on San Miguel Island. Of necessity it is a long chapter because in order to understand any complex landscape it is first incumbent to understand the full range of physiographic factors and nuances that produced it. After a brief discussion of the vital statistics and surface character of the island, the following physiographic factors will be treated: geologic structure, oceanography, climate and fire, and plants and animals.

The section on geologic structure shows to the reader how episodic tectonic activity and earthquakes have markedly affected the evolution of San Miguel and the other Northern Channel Islands. Two elements of oceanography, currents and water temperature, are treated because they influence the insular climate, and climate is known by geomorphologists to be one of the more important conditioners of all landscapes. In the case of San Miguel two climatic elements, precipitation and fire, are shown respectively to be cyclic and episodic in character. These elements have had a profound effect on the plants and animals of the island. Finally, animals and plants now present on San Miguel are treated because they are important factors in determining landscape stability and instability. For example if vegetation is removed by animals (or fire) in a windy environment erosion and landscape modification often ensue , and it is clear that this has happened many times on the island. A detailed investigation of past animals and plants and their probable effects on the landscape is made in Chapters 4 and 7.

4. Vital Statistics of San Miguel Island

San Miguel* is a small island, only 8 miles long by 4 wide (Fig. 1). It is 14,000 acres in area and roughly resembles an eroded triangle from the air. It lies 26 air miles due south from Point Conception, the nearest point on the mainland, and is three miles distant from Santa Rosa, the nearest island to the east. As mentioned, San Miguel is the westernmost of the Northern Channel Islands of California (sometimes called Santa Barbara Channel Islands). These islands form the southern boundary of the Santa Barbara Channel, a basin with depths of over 2,000 feet and a width averaging 30 miles and which separates the islands from the California mainland.

5. Topography and Surface Character of San Miguel Island

The Setting

San Miguel Island is surrounded by satellite islets and rocks, the largest being Prince Island whose ten acres rise boldly 296 feet above sea-level and guards the entrance to Cuyler Harbor on the north-central

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*The island is owned by the U. S. Navy but is presently administered by the National Park Service. San Miguel figures prominently in the proposed Channel Islands National Park which is planned to eventually incorporate all the Northern Channel Islands as well as Santa Barbara Island (the latter island and the Anacapas presently comprise the Channel Islands National Monument).

Politically, the island lies within the jurisdiction of Santa Barbara County, California. The nearest large population center is the city of Santa Barbara, 42 miles northeast.

coast (Photomaps 1-4 and Map 3 in pocket,* and Plate 12).** Some 1,000 yards off the northwest coast lies another islet, Castle Rock, which rises precipitously some 180 feet above the sea. Some 2.5 miles northwest of Harris Point lies Wilson Rock, a low wave-eroded outlier surrounded by a shoal area. Off Point Bennett at the west end of the island is an extensive shoal area with numerous rocks that conspicuously break the surface of the sea (Galleon Foul Area). Most distant of the satellites, lying some 6.2 miles northwest of Point Bennett is prominent Richardson Rock, 100 by 150 yards in area which rises by short rocky cliffs some 50 feet above the sea. Many other smaller islets and rocks break the sea about San Miguel. The effects of strong winds, waves and currents on these rocks, shoals, and the bold cliffs of San Miguel combine to create an inspiringly rugged seascape.

The Island

San Miguel is defined by some 27 miles of irregular shoreline which is alternately cliffed or of sand.*** From a vertical aerial view the island resembles an eroded isosceles triangle.

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*See Appendix A, first page, for a detailed discussion of the maps and airphotomosaics (in rear pocket) which accompany this thesis.

**The reader will note that this thesis is supplemented with numerous photographs of San Miguel dating from 1964 through 1969. The purpose for using considerably more than the usual number of photographs is twofold: One is to exemplify, supplement and clarify statements in the text; secondly, and most importantly, the use of numerous photographs will allow future researchers to view and clearly assess the physical and biological character of the island as it existed from 1964-1969.

***Quantitative data taken from U.S. Geological Survey, San Miguel Island East and West Quadrangles, 7.5 minute series (topographic). See Map 3.

In contrast to the rugged terrain, high mountain peaks and steep canyons that characterize Santa Cruz and Santa Rosa Islands (the west end of Santa Rosa excepted), San Miguel is topographically quite low and subdued. From a vantage point at sea it resembles a low tableland surmounted by two rounded hills (see cross-sections, Map 2). These are Green Mountain and San Miguel Hill with elevations of 817 and 831 feet, respectively. The tableland surface averages 300 to 500 feet in elevation and represents an uplifted Pleistocene marine terrace (Bremner, 1933). San Miguel is essentially a westward extension of Santa Rosa Island, separated in time by less than 10,000 years and in distance by three miles of water only 100 feet at the deepest. The west end of Santa Rosa Island and San Miguel are both marine platforms of similar elevation each of which is mantled with essentially identical Quaternary sediments and associated paleosols. Both also have abundant dunes and caliche terranes.

If a long axis traverse of San Miguel is made from Point Bennett on the west to Cardwell Point on the east, the following topography will be encountered (cf. Maps 2 and 3, Lithomap D). Traveling east from Point Bennett, a land-tied island, one crosses a narrow tombolo and enters the Hauling Grounds, a half mile wide sandy tract of beach sand, Pleistocene eolianite, and paleosols. This lowland terminates at Hammond Cliffs which abruptly rise 300 feet to a bench-like surface above. Upon sighting across this upper tableland, four things strike the eye: one is that there is a perceptible widening and general increase in elevation towards the central part of the island; two is that the terrace surface of the west end is not flat but consists of a rolling upland with several slight depressions; three, that in many places this rolling upland has suffered wind and water erosion and soil denudation to an extreme degree; four, that most of the western end is surfaced with sand deposits that alternate with bare caliche. Moving east across this surface one encounters an unbelievably barren landscape (Caliche Flats) which consists essentially of slabs of caliche scattered about a bare caliche surface (Plate 1f). Beyond Caliche Flats is a low area (The Spillway) through which the sea once flowed but now occupied by low northwest-southeast trending longitudinal dunes comprised of calcareous sand. The dune units are separated by many small interdune playas. The frequency of the calcareous dunes increase in an easterly direction (West End Dune Fields). The dunes in this area are both modern and Pleistocene in age, the sand source of the former being derived from the latter. The ancient calcareous dunes are now apparent only by their form and are capped with the caliche residue of a former soil whose surface horizons have been largely stripped away.

Prior to emplacement of the ancient dunes, streams which presently head on Green Mountain formerly flowed west towards Running Springs and probably emptied into the sea somewhere seaward of Travertine Cove.* After dune emplacement the streams were blocked and subsequently discharged (and still do) into the playa on Jackass Flats.

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*This interpretation is covered in detail in Chapter 5.

From Jackass Flats to Green Mountain is an area of grass-covered gentle slopes whose central parts are dissected by five west-flowing gullies. The Quaternary sediment cover here is very thin, frequently less than several feet, and is capped with a paleosol called the Green Mountain Soil. This paleosol is distinctive in that the surface horizon is cemented with iron and aluminum sesquioxides which takes a massive or concretionary-pisolitic form (Plates 16-35). The massive form is best displayed in Beckman Wash at locality 190 (cf. Map 5, Lithomap D), and the concretionary form at localities 151, 152, 85, 162 and 163. Both forms occur as surface lag "ironstone" over the area delimited by the dashed line on Lithomap 5 (Plates 22-25, 30). The ironstone surface of Jackass Flats was partly blanketed with dune sand during historic time (Plate 11) but is exposed in several gullies.

Looking east from Green Mountain one views on the left towards Harris Point an extensive dune area (Central Dune Fields), and ahead, the gentle slopes of San Miguel Hill, and to the right, deep ravines carved into Elephant Cliffs on the south edge of the tableland (Plate 36). It is from Green Mountain that the ground observer best gains a true perspective of what is clearly apparent from the air--the predominant northwest-southeast trend of the island's surface features. Most of the canyons and gullies, all of the dunes, Green Mountain, and certain stretches of coastline all display a northwest-southeast trend (this is shown in the airphotomosaics of Plate 11). Probably the major part of the pattern may be attributed to the effect of prevailing northwest winds on Pleistocene and recent dune sands, but structure and bedrock geology have also played a role. For example, most of the faults which transect San Miguel trend northwest-southeast. Additionally, the sedimentary strata all have a predominant northwest-southeast strike (Fig. 2). Thus, bedrock strike, the fault pattern and, especially, past and present prevailing winds are responsible for the lineations shown in Plate 11.

Between Green Mountain and San Miguel Hill is a windgap (Sandblast Pass) through which Pleistocene seas once passed, but which has since been mantled with wind-blown calcareous sand. Many recent dunes in the area are now being rapidly stabilized by grass, although stabilization is not yet complete.

Looking east from San Miguel Hill one views to the left another dune field on the northeast (East End Dune Fields), and a dissected central area comprising Willow Canyon and its tributaries (Plate 37b). The Gangplank borders this dissected area on the south and is distinguished by its smooth, rolling surface, gentle eastward slope, and its dense clay soils. To the right, off the deeply dissected southern edge of the tableland, are the South Cliffs beyond which lies a relatively flat depositional area (South Flats). From the vantage point of San Miguel Hill the viewer is impressed with the abundance of grass, smooth surfaces and low slopes which cover the eastern third of the island tableland. Here has been re-established the rich grassland about which earlier visitors spoke (the early historic period is covered in Chapter 7).

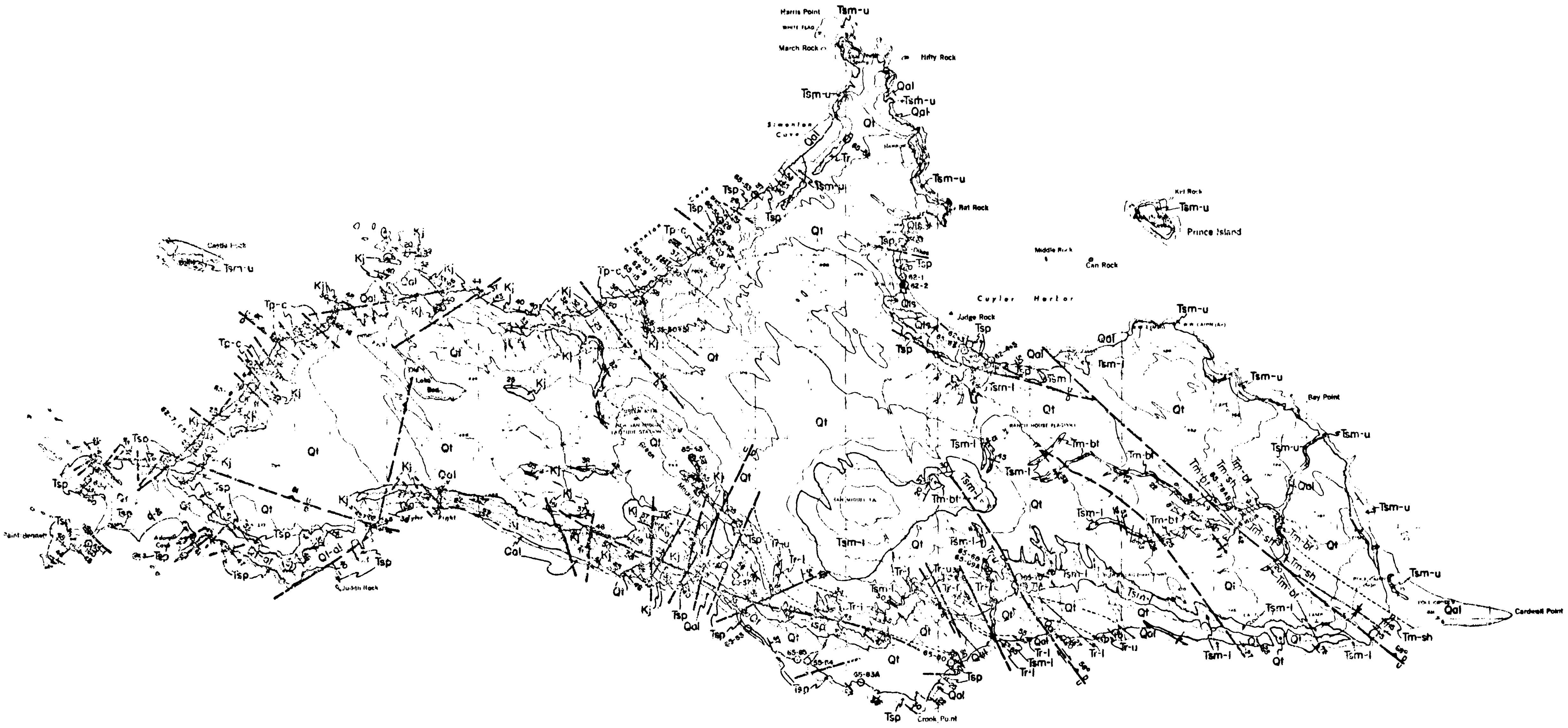

Figure 2. Map of San Miguel Island showing predominance of northwest-southeast trending faults; the strike direction of the sedimentary bedrock is northwest-southeast (after Weaver, <u>et al.</u>, 1969).

The eastern extremity of the island is marked by a sand spit which extends east from Cardwell Point, the terminus of our transect. As Chapter 7 will reveal, the spit and many other attributes of the general topography of the island have their origin in episodic historic events of the relatively recent past.

6. Regional and Local Structure and Bedrock Geology

The origin and evolution of the Northern Channel Islands of California has long been a matter of intense interest to earth and biological scientists. Anyone involved in sustained research on the islands must inevitably become sensitized to the role that seismicity and tectonics have played in shaping this insular landscape. However, in order to appreciate the possible local effects on the evolution of San Miguel Island one must first consider the regional and temporal aspects of seismicity and tectonics. The following section presents a brief overview of the subject.

Regional Structure

The Northern Channel Islands are usually thought of as a drowned western extension of the east-west trending Santa Monica Mountains of southern California. While this may be true in a topographic sense, it appears not to be structurally so simple and in fact may be incorrect. Recent studies suggest that during Miocene time the Northern Channel Islands block broke laterally away from the south side of the ancestral Santa Monica block and moved some 50 miles westward as a sialic raft, perhaps as a consequence of the collision of California with the East Pacific Rise. Accordingly, the Northern Channel Islands block is now viewed as an allochthonous micro-continent of granite veneered with Cretaceous-Eocene sediments which has no structural continuity with the west end of the Santa Monica Mountains (Yeats, 1968a, 1968b, 1969; Cole, 1970; Merschat, 1971; see also King, 1959, p. 172). In a regional sense the Northern Channel Islands are part of a large, complexly faulted east-west trending mountain and valley system (Fig. 3) which forms the Transverse Ranges structural and geomorphic province (Jenkins, 1938). The Transverse Ranges, one of the few east-west trending systems in the United States, break the regional continuity of the meridionally trending Sierra Nevada and Coast Ranges on the north with the Peninsular Ranges to the south (Fig. 4). The Northern Channel Islands comprise the seaward southwestern boundary of the Transverse Ranges.

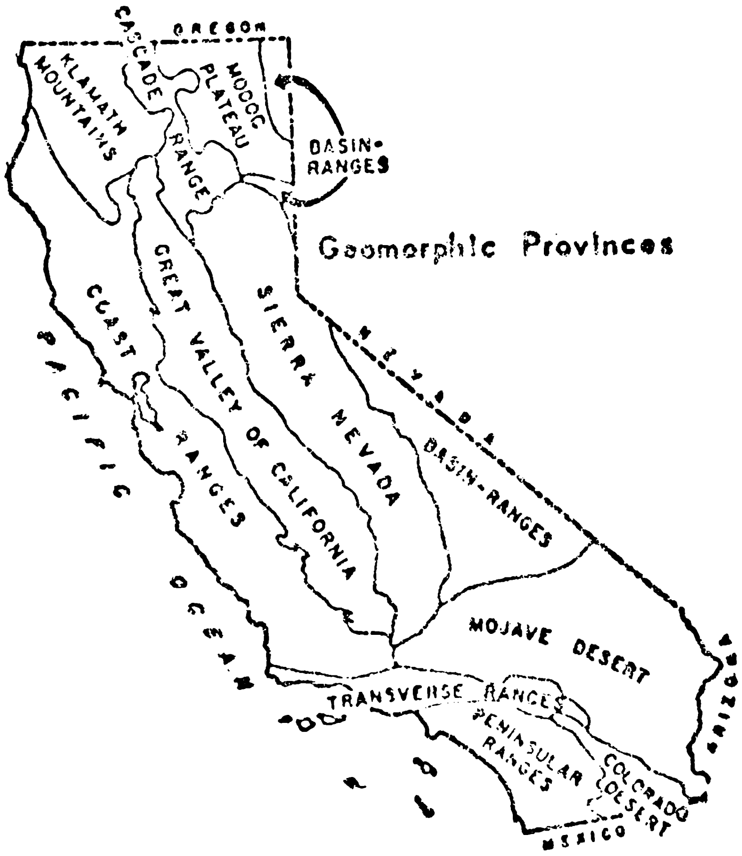

Figure 3. Geomorphic Provinces of California (after Jenkins, 1938).

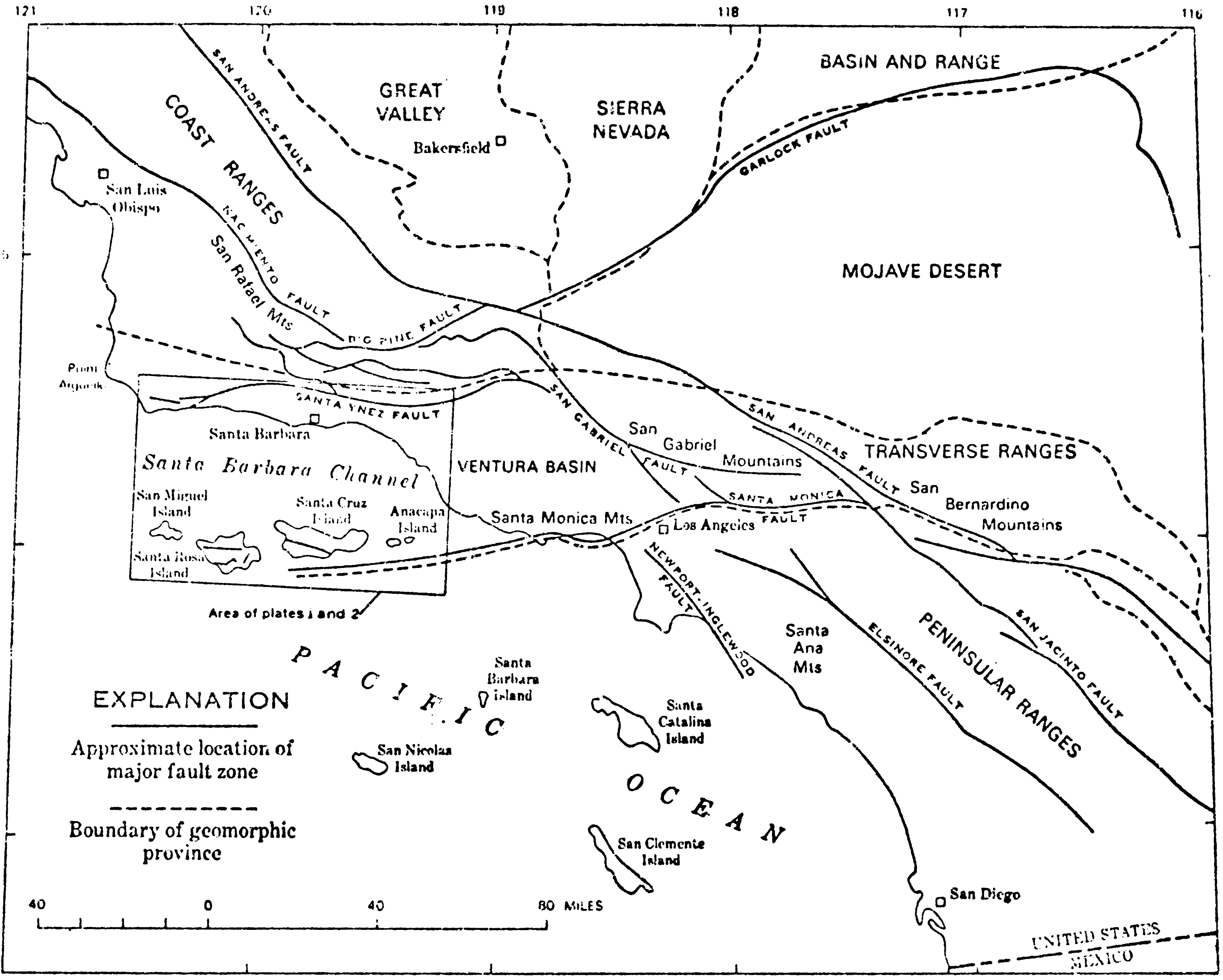

Figure 4. Index map showing major faults and geomorphic provinces of southern California (after Hamilton, et al., 1969).

The offshore portions of the Transverse and Peninsular Ranges are characterized by numerous basins and rises of fault origin (Fig. 5) expressed as a basin-range type of topography having no known shelf counterpart in the world. This horst-graben, largely submarine complex has been called the Continental Borderland (Shepard and Emery, 1941), and is defined on its seaward side by an unusually steep continental slope. The ramparts-like slope is continuous and unbroken except at San Miguel Gap; south of this gap the slope is called the Patton Escarpment, and north of it, the Santa Lucia escarpment (Fig. 6). The Santa Barbara Channel is the northernmost basin in the offshore complex and

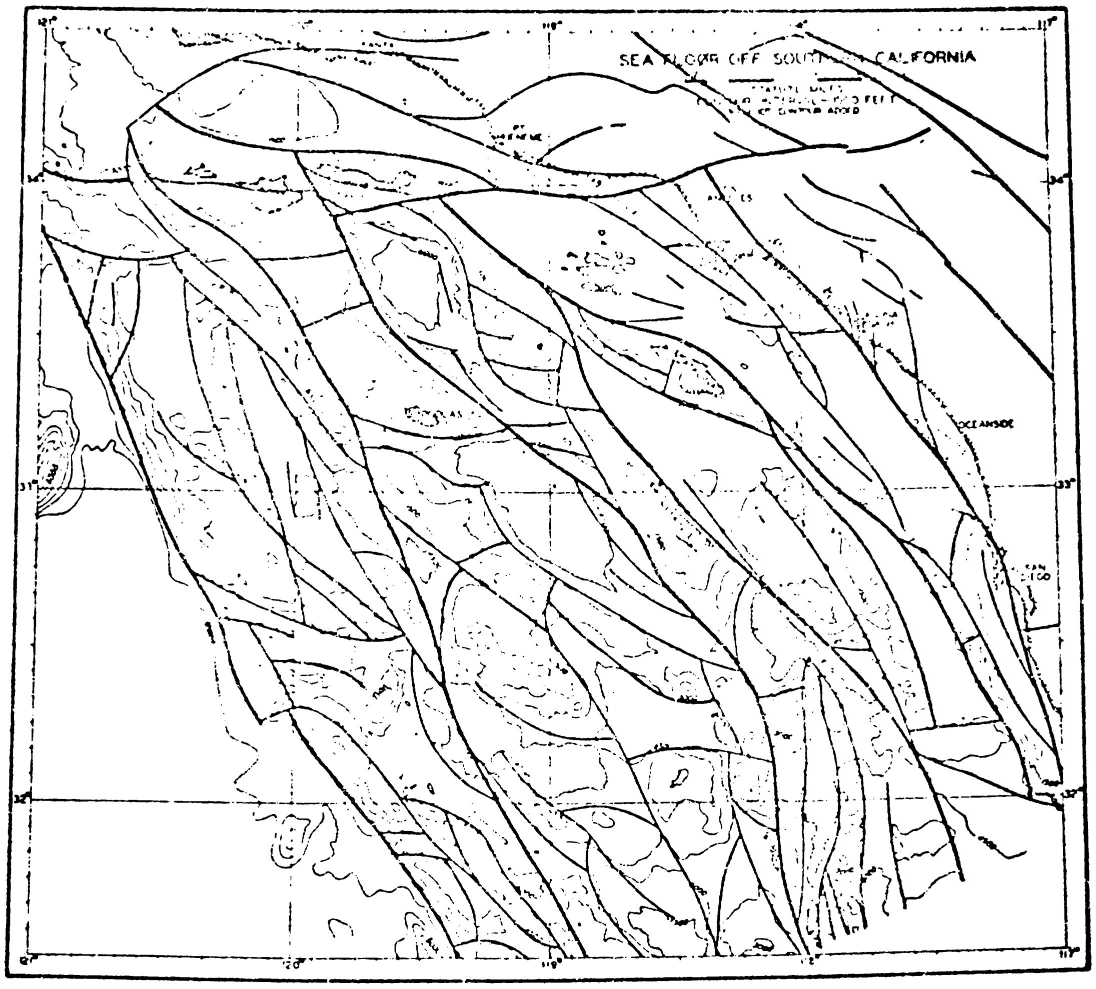

Figure 5. Fault map based chiefly on sea floor topography. Locally, positioning was aided by data on stratigraphy of the sea floor and by extension of known faults on land. Wide lines indicate long primary faults; narrow lines show shorter secondary faults, some of which may prove on future study to be the limbs of folds. Note that many of the secondary faults or folds have a more westerly trend than the primary faults. (After Emery, 1960.)

is bounded on the south by the Channel Islands Platform (von Huene, 1969) locally rising above sea level to form the Northern Channel Islands.*

The tectonic relationship between the Channel Islands platform and the Murray fracture zone, one of a series of great east-west trending

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*The submarine boundary between the Transverse and Peninsular Ranges probably coincides with the southern edge of the Channel Islands Platform (Jenkins, 1938) and the north wall of San Miguel Gap (von Huene, 1969). von Huene apparently would exclude elements of the Transverse Ranges from the Continental Borderland, restricting the latter term to only the shelf area defined by the Peninsular Ranges.

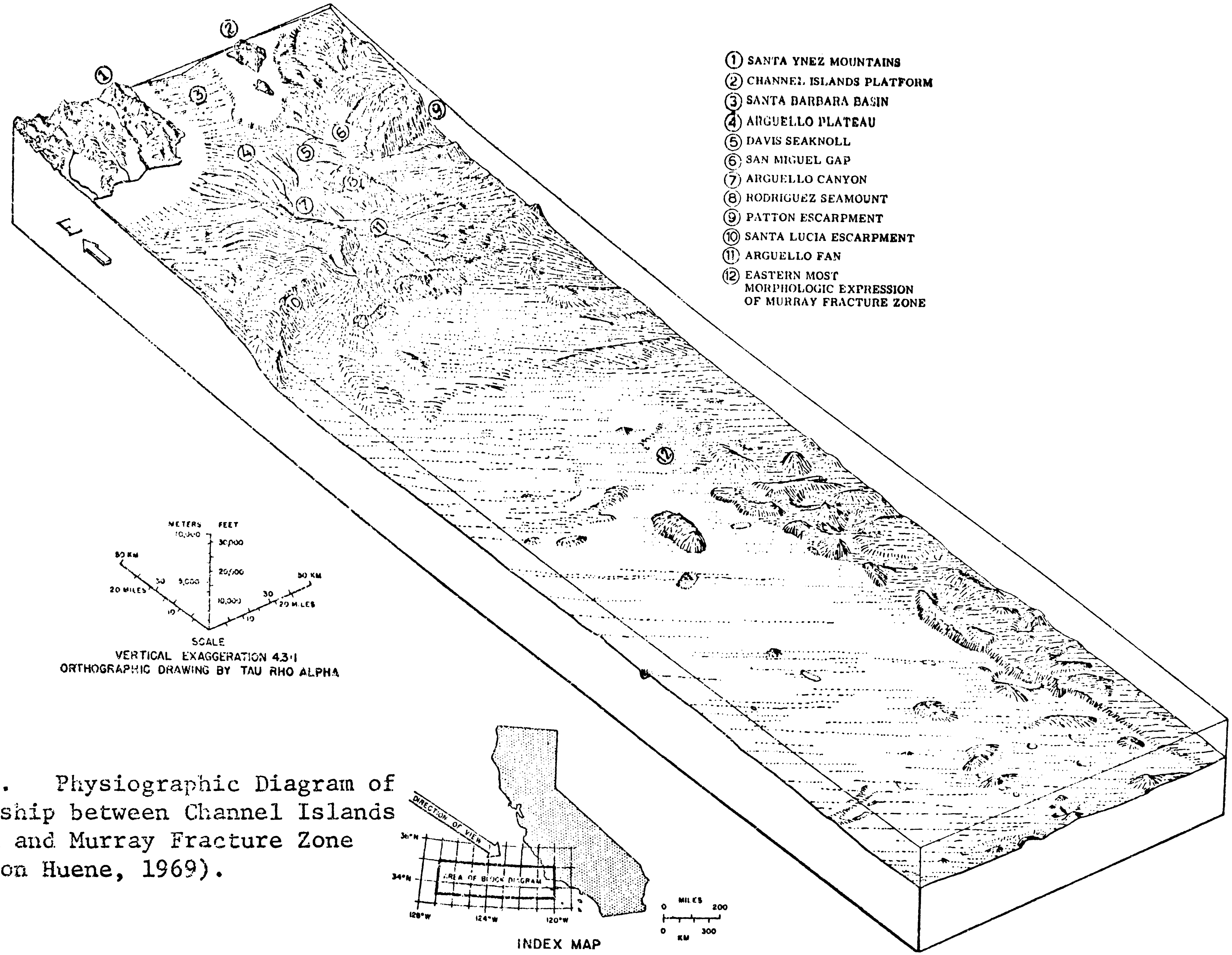


Figure 6. Physiographic Diagram of relationship between Channel Islands Platform and Murray Fracture Zone (after von Huene, 1969).

transform faults of the eastern Pacific basin (Fig. 7), has long been of interest and is problematic. It has been assumed that the Murray is a westward extension of the Transverse Ranges. Impressive bathymetric evidence has accumulated which supports such an assumption. The evidence is: (1) both the Murray and the Transverse Ranges are in general alignment; (2) the existence of San Miguel Gap, the only break in the Patton Escarpment, occurs about where the continental continuation of the Murray would be expected; and (3) the Clarion and Mendocino fracture zones are similarly aligned with continental features (Fig. 8). However, according to von Huene (1969) no direct structural continuity between the Murray and Transverse Ranges is apparent from seismic, magnetic, and gravity profiles made in the region. A study of San Miguel Gap by Wright

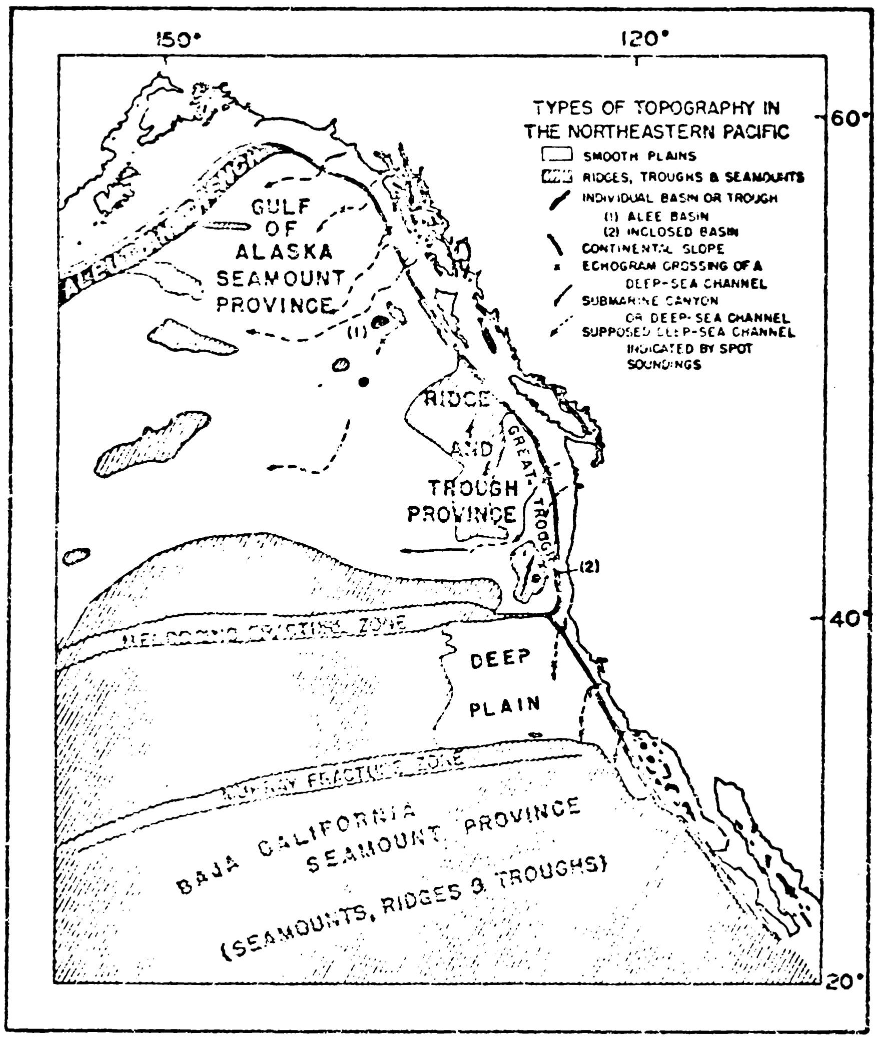


Figure 7. Regional variations in topography of the abyssal sea floor. (After Menard, 1955, Fig. 2).

(1967) likewise found no evidence supporting east-west structural continuities. The apparent absence of continuity is thought to reflect an independent development of the Transverse Ranges (and Channel Islands Platform) ". . . since at least mid-Tertiary time along an older structural trend continuous with the Murray fracture zone" (von Huene, 1969). The Transverse Ranges are believed to owe their history to late-Tertiary tectonic activity associated with the San Andreas fault system. This interpretation is supported by the extreme seismicity of the latter two systems (von Huene, 1969; Hamilton, et al., 1969) in contrast to the relative low incidence of seismicity along the Murray. The entire coastal region of California, of course lies within the tectonically unstable

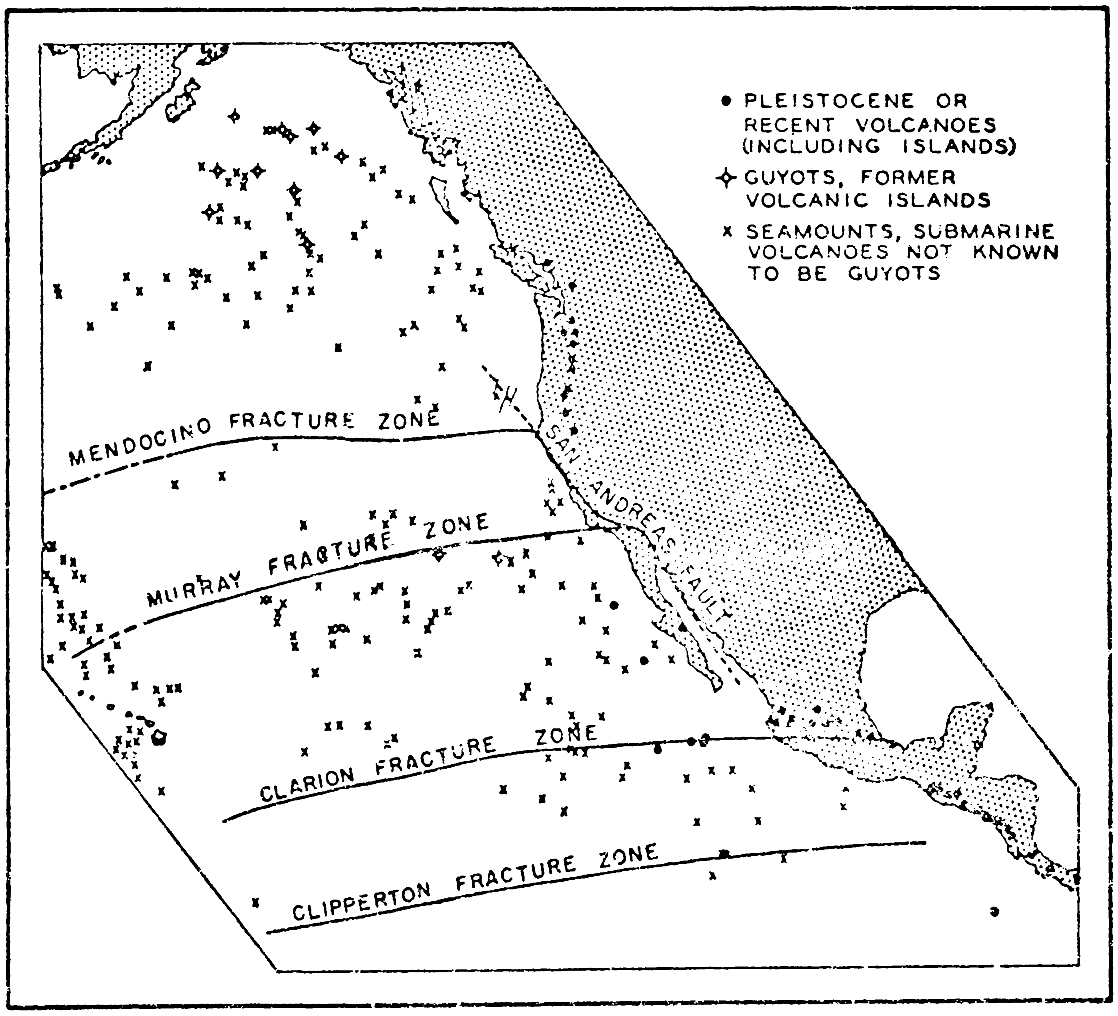


Figure 8. Fracture zones, seamounts, guyots, and known volcanoes of abyssal sea floor. (After Menard, 1956, Fig. 2).

circum-Pacific seismic and volcanic belt and has been tectonically mobile during much of Cenozoic time, reaching a maximum of activity during the Quaternary (Hamilton, et al., 1969).

Local Structure

West and northwest trending faults are the dominant structural features of the Northern Channel Islands and reach a maximum expression on Santa Cruz and Santa Rosa Islands (Map 6). The latter are each cut by large median faults whose displacements have left a profound topographic expression. Vertical movements of 7,800 feet are believed to have occurred along the Santa Cruz Island fault, whereas horizontal displacements along the Santa Rosa Island fault are estimated to be as much as 10 miles (Weaver, et al., 1969), although confusion as to particulars exists on these matters (Yeats, 1970). Additionally, the latter two islands and San Miguel are literally criss-crossed by smaller faults and San Miguel has historically recorded at least one fairly strong earthquake and several moderate ones (Hamilton, et al., 1969; Los Angele Times, April 22, 1895; see also Chapter 7 discussion on landslides). To appreciate the probable significance of tectonics in the geomorphic evolution of landforms in and around the Santa Barbara Channel the reader is referred to Figure 9. This figure shows that during the 33-year period 1934-1967 at least 259 earthquakes occurred, 27 of which were of magnitude 4 or greater (Richter scale). To gain a rough impression of what past activity may have been, if this time period is taken as typica

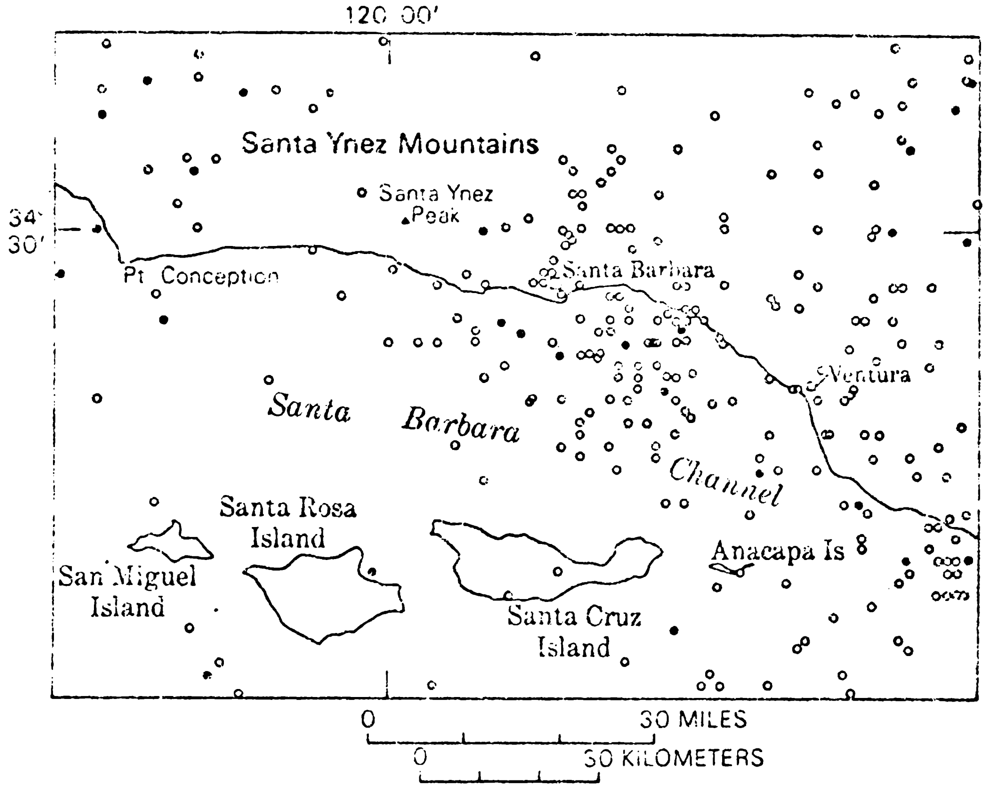


Figure 9. Epicenters of earthquakes in the Santa Barbara Channel region from 1934-67. o, magnitude less than 4; ●, magnitude greater than or equal to 4. (Hamilton, et al., 1969).

of late Quaternary Seismicity,* a simple calculation shows that during Holocene** time alone over 78,000 earthquakes are inferred, 8,000 of magnitude 4 or greater. The importance of this information becomes apparent when one considers that every earthquake signals some degree of earth slippage and deformation, either subsurface, surface or both. Thus it is clear that late-Tertiary, Pleistocene, and Holocene tectonic and seismic activity has played no small role in the evolution of the Channel Islands Platform and its associated submarine and subaerial landscapes.

---

*During a 3-month period in 1968, over 55 earthquakes occurred (Hamilton, et al., 1969) which were not included in these calculations. If such earthquake swarms are common then the frequency of earthquakes in the Santa Barbara Channel is actually much higher than the data of Figure 9 suggest.

**The Holocene Epoch began 10,000 years ago.

Bedrock Geology of San Miguel Island

The Northern Channel Islands may be thought of as a subaerial expression of a complexly faulted and folded east-west trending anticlinal uplift (Weaver, 1969; Vedder, et al., 1969). Whereas both flanks of the fault-bounded anticline are exposed on Santa Cruz and Santa Rosa Islands in the central part of the island chain, only the north flank outcrops on Anacapa and San Miguel Islands at the east and west ends of the chain (Weaver, 1969). In the western part of the island chain, the anticlinal axis turns and trends northwest.

The bedrock sequence of the Northern Channel Islands is comprised of Miocene to Cretaceous sedimentaries and volcanics, largely of marine origin, overlying a basement complex of diorite-intruded schist of pre-late Jurassic age (Weaver, 1969). No Pliocene rocks are known to occur on the Northern Channel Islands.

Turning now specifically to San Miguel, the bedrock geology of the island was described first in 1933 (Bremner), later in 1952 (Kennett, in Redwine, et al.), and again in 1969 (Weaver, et al.). As mentioned above, structurally the island represents the north flank of a folded and faulted anticline, whose axis here trends northwest-southeast. Thus the stratal complex on the island strikes generally northwest-southeast and dips generally northeast. While faulting presents a complex picture most traces trend northwest-southeast and coincide with strike direction (Fig. 2).

A summary of the pre-Quaternary bedrock geology is given here, modified from Weaver, et al., (1969).

SUMMARY OF BEDROCK GEOLOGY, SAN MIGUEL ISLAND

TERTIARY

Pliocene (absent on the Channel Islands Platform)
Miocene, Monterey Shale
    Shale Member; buff, punky, and siliceous shale; foraminifera
  Beecher's Bay Member; light gray tuffaceous volcanic sandstones
    and conglomerates; mollusca
  Oligocene, San Miguel Volcanics
    Upper Member; massive dacitic intrusives, flows and clastics
    Lower Member; basaltic flows with pillow structure (?)
      and dikes; volcanic sandstones and conglomerates
    Rincon Formation
    Upper Member; cream-colored, chalky, foraminiferal shale
    Lower Member; brown, gray, and greenish-buff shales, siltstones, sandstones and pebble conglomerates with mollusca
  Eocene, South Point Sandstone
    micaceous buff sandstones, siltstones, and interbedded shales;
      occasional corrugated bedding
  Paleocene, Undifferentiated Pozo-Canada Formations
    rhythmically bedded siltstones and shales; foraminifera;
    micaceous buff sandstones; cobble conglomerate

CRETACEOUS

Upper, Jalama Formation; foraminiferal gray shales; gray and buff
  flaggy sandstones, siltstones and shales; gray massive sandstones

7. Oceanography

The aspects of oceanography that bear most importantly on the study are ocean currents and water temperature because as indicated previously they influence the climate of San Miguel Island, and climate plays an important role in weathering, erosion, soil and vegetation characteristics.

Ocean Currents

San Miguel Island differs from the other Channel Islands in that it lies closest to, if not actually within, the cool southward-moving California Current. The island juts out westward just enough to intercept the eastern edge of the California Current which impinges on the northwest coast of the island (Fig. 10). Most of the California Current flows to the west of San Miguel, but part flows north around the island

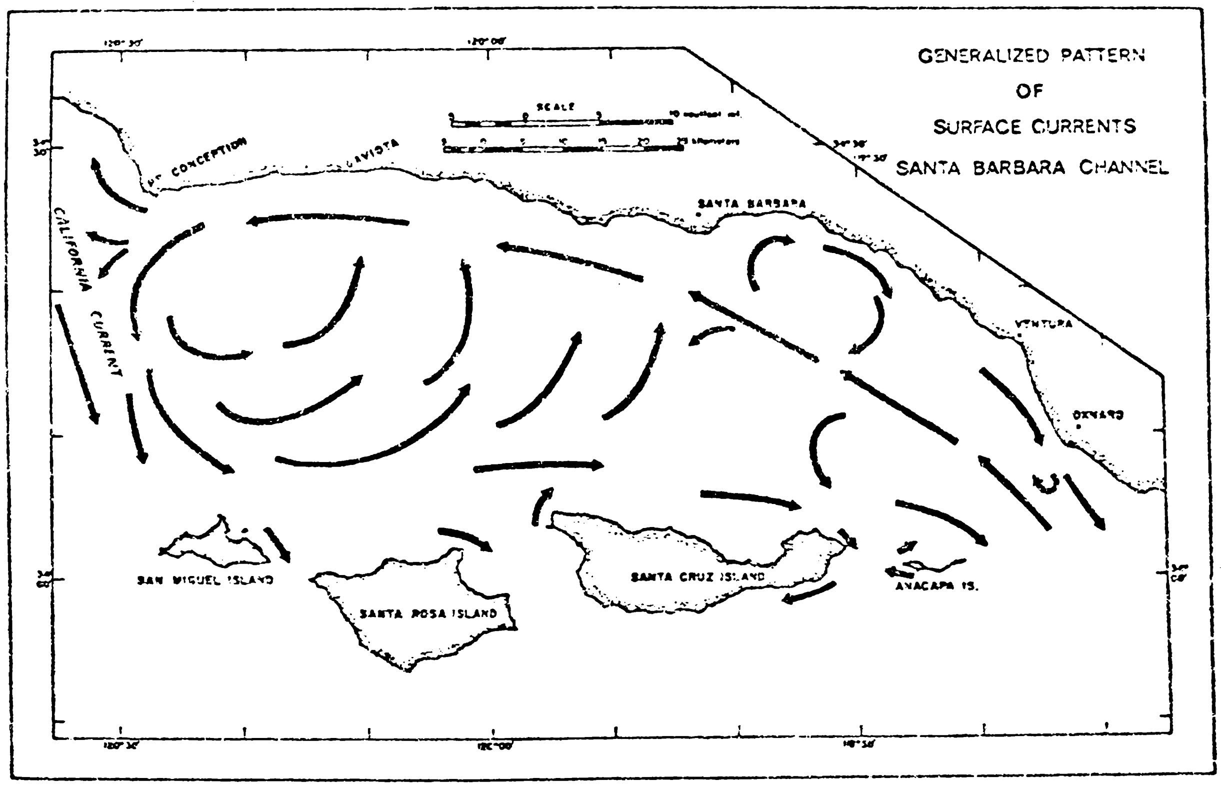


Figure 10. Average surface water circulation of Santa Barbara Channel. (courtesy of R. L. Kolpack, Oceanographer, Univ. of So. California).

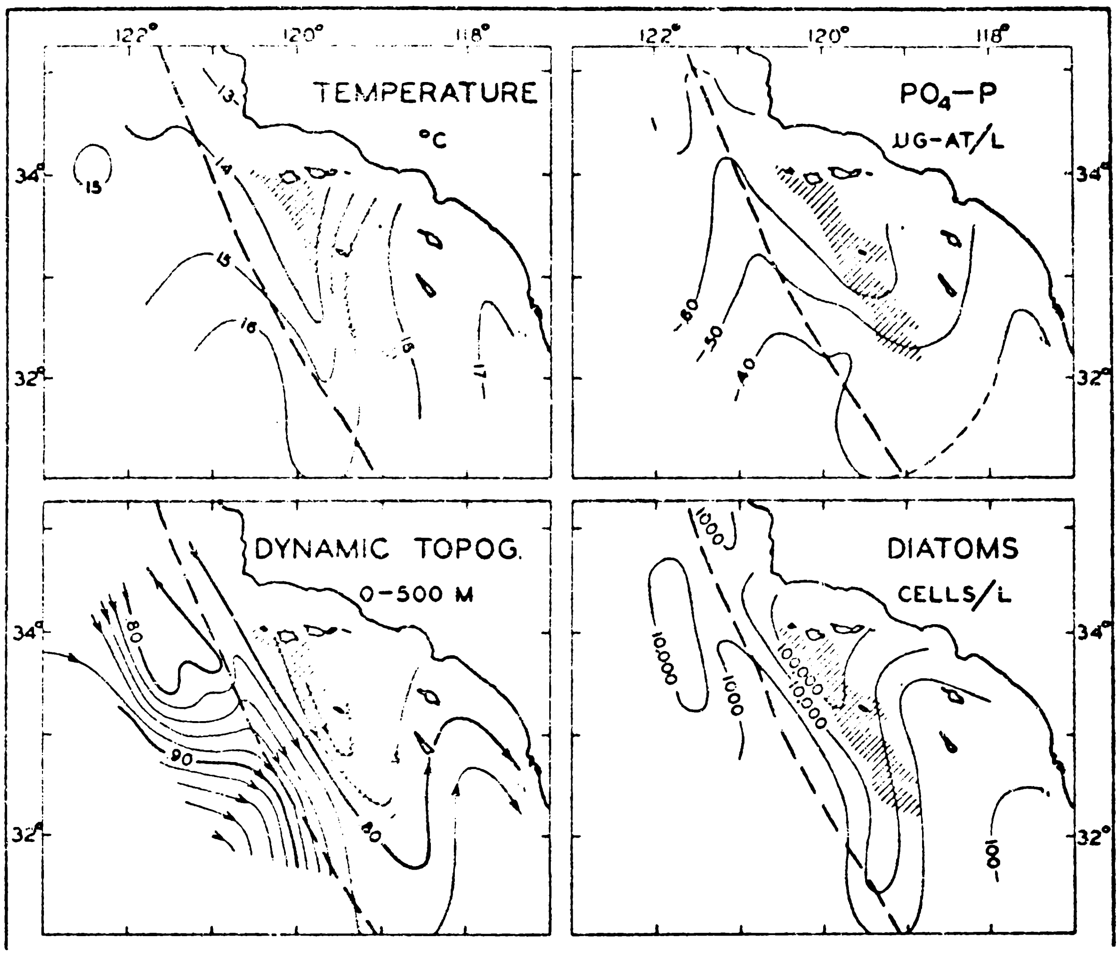
and sweeps through San Miguel Passage and part mixes with the southern arm of the large semipermanent, counterclockwise circulating eddy which dominates the surface circulation of the Santa Barbara Channel throughout much of the year. The arrival of abundant oil on the west end of San Miguel that I and others witnessed in March, several weeks after the widely publicized February, 1969, oil rupture at Union Platform A, shows that the channel eddy contributes some surface water to the island. As shown in Figure 10, San Miguel Island straddles the boundary between the semipermanent channel eddy and the California Current but is under the dominating influence of the latter whereas the other Northern Channel

Islands are increasingly influenced by the channel eddy with increasing distance to the east.

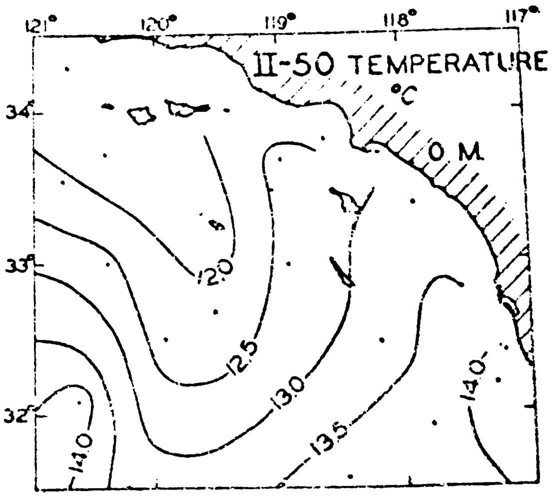
Water Temperature

To my knowledge, only general data exist regarding surface water temperatures in the vicinity of San Miguel Island. However, generalized maps showing surface isotherms for the West Coast of the United States are published periodically each year by the U. S. Coast Guard. These maps show that a marked temperature gradient exists in the Santa Barbara Channel, with warmer and cooler waters characterizing the eastern and western sectors respectively. Surface temperature data given by Emery (1960) show a similar picture (Fig. 11, a, b, and c). Figure 11 (a and b) is representative in that it shows a wedge of cold surface water extending southeast of San Miguel Island which almost certainly reflects the presence of the California Current and its cool upwelled waters; its trajectory south from Point Conception past San Miguel Island can be inferred. Carl Hubbs (1967) once reported the surface temperatures near the west end of Santa Cruz Island to be 8°C (the actual temperature was 7.1°C as explained below) cooler than in the Anacapa region and speculated that a temperature differential as great as 12°C ($\sim$ 22°F) may at times conceivably exist between Anacapa Island and the west end of San Miguel. During personal correspondence with Hubbs in January, 1971, in order to clarify his views of 1967, he wrote:

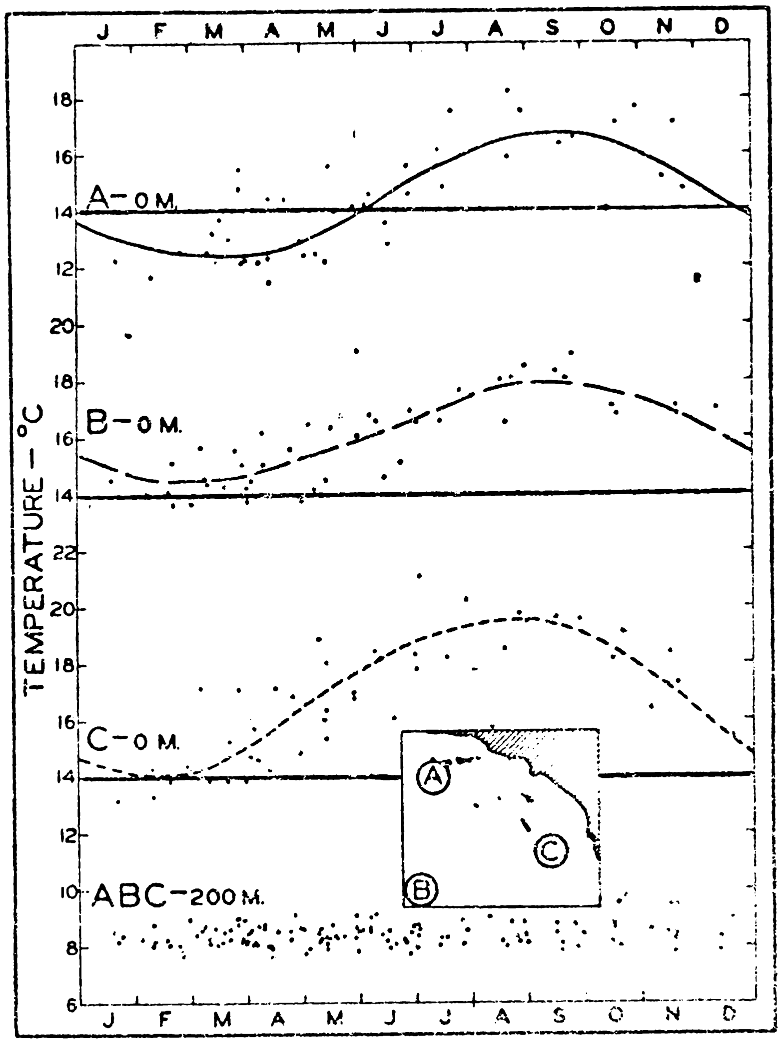
> I have checked over field notes, and find that my memory was a bit faulty. I assume that the temperatures referred to were those taken on a trip in 1954, when a semi-continuous



a.



b.



c.

Figure 11 a. Comparison of temperature, phosphate, dynamic topography and diatom concentration at the surface during E. W. Scripps cruise of June 7-16, 1938. Cross-hatched area is Santa Rosa-Cortes submarine ridge b. Regional pattern of surface water temperature during Marine Life Research cruise of February 1950. c. Annual variation of surface water temperature at three localities for 49 Scripps cruises during 1937-41 and 1949-52. Note reduced temperatures at A (after Emery, 1960).

> record was kept of readings on a towed thermister unit, that I ordinarily used for taking shore temperatures by casting from the shore. The actual extreme temperatures were actually close to the west end of San Miguel and the east end of Santa Cruz. The two readings were taken at about noon. The highest temperature recorded in the series was 19.21 on September 14, off the east end of Santa Cruz, and 12.11 off Adams Cove on September 18. So the actual difference between The extreme readings, which varied a few tenths of a degree from adjoining regions, was 7.1°C, rather than 8°.
>
> I suspect that I have other readings somewhere that would be somewhat more extreme, but I'm quite sure that the memory that I quoted was from this one trip when we took semi-continuous readings.
>
> I have indications that the temperatures around the Northern Channel Islands decrease more rapidly with depth than they do farther south, and I also have some indications that the temperature differential from west to east has been of long standing, because the species composition of mollusks in Indian middens, along with some paleotemperature determinations, are in line with this assumption.

The east-west temperature gradient along the Northern Channel Islands is noticeably reflected in the daily weather, climate, differences in biota, biomass concentrations, landforms, indeed practically the total environment. The west end of San Miguel Island, for example, has physiographical characteristics remarkably different from the east end of the Anacapas some 65 miles distant, and while other factors are involved, surface water temperature indirectly plays an important role in these differences. Interestingly, the marine biota of San Miguel Island seem to bear a closer affinity to the central California coast several hundred miles north than to Anacapa which lies at the same latitude as San Miguel. Hubbs makes clear this point:

> On San Miguel we find invertebrates and fishes of type that occur along the Monterrey coast. Dr. John S. Garth hinted at this [Garth, 1967] in connection with the invertebrates in which he has specialized. An example may be cited among the abalones as they occur intertidally: The red

> abalone predominates in the western end of the chain and the black abalone, which takes to warmer water, occurs toward the eastern end. And a very interesting point that we have found in examining the middens is that this same pattern has existed in the past for a long time. As we get to essentially cold water, the prime cold-water index fossil, Cryptochiton stelleri, is very abundant at Point Bennett on the western end of San Miguel and is replaced by warmer-water shells as we go to the eastward. There has been, therefore, a consistency in time in the temperature distributional pattern. (Hubbs, 1967).

8. Climate

Climate has left an indelible and profound stamp upon San Miguel Island so that any attempt at explaining the evolution of this insular landscape without critically examining the climatic factor would meet with limited success. Consequently, it seems proper now to review what is known about the weather and climate of San Miguel. Probably the best approach is to examine the regional climate of the Santa Barbara Channel, followed by a closer look at the weather and climate of San Miguel Island.

First, however, an explanation is in order for inclusion of data amassed in the sections on climate and fire, which may render certain pages tedious reading. The incorporation of these data is desirable for several reasons. First, the sections on precipitation, temperature, wind, fog, and stratus contain data that are largely unpublished and, except for the most diligent researcher with time on his hands, essentially unavailable; their acquisition required several years of archival research and letter correspondence. All of the graphs in these sections are based on these data. Thus, Channel Islands researchers should find these sections welcome. Secondly, these data give the reader a detailed, long-term weather and climatic picture of San Miguel and the Northern Channel

Islands heretofore unavailable. They also show why San Miguel has a climate unique to southern California, and why the weather elements, such as wind have left such a profound stamp on the landscape. Thirdly, the data on fire on San Miguel Island is necessary because it has been argued that fire is and has been an inconsequential factor in the ecology of the Northern Channel Islands (Orr, 1968, p. 69; Orr and Berger, 1966). The data presented here show that fire conversely has been a very important factor in landscape evolution on San Miguel Island.

Synoptic Summary

The Northern Channel Island region, like most of coastal California, experiences the marine phase of a Mediterranean type of climate. Winters are mild and cool characterized by frequent periods of sunny weather interrupted by low-pressure frontal systems arriving from the North Pacific. Most precipitation falls during the low sun season as rain associated with these transient frontal systems. Rainfall totals are low, with yearly averages from about seven inches on Anacapa Island to about 14 inches on San Miguel Island. Rain normally begins sometime during November or December and ends in April or May. As a rule the summer months are rainless and characterized by frequent low level stratus and fog conditions associated with a persistently cool moist marine layer of onshore-moving air. This layer markedly reduced evaporation and renders the sparse winter rainfall far more effective than what otherwise might be expected.

Temperatures are mild all year at low elevations in the Northern Channel Island region, with annual means ranging from 57°F on San Miguel to 59°F on Anacapa. Monthly mean temperatures have an annual range of 9.6°F on Anacapa and 7.4°F on San Miguel.

Winds on the Northern Channel Islands frequently are strong, particularly at the western end of the chain with a prevailing direction from the northwest during all reasons. However, this pattern is occasionally broken, most frequently in the fall by Santa Ana conditions, and by variable winds associated with transient lows during the winter. Figure 12 shows average wind streamlines for all of coastal and insular southern California.

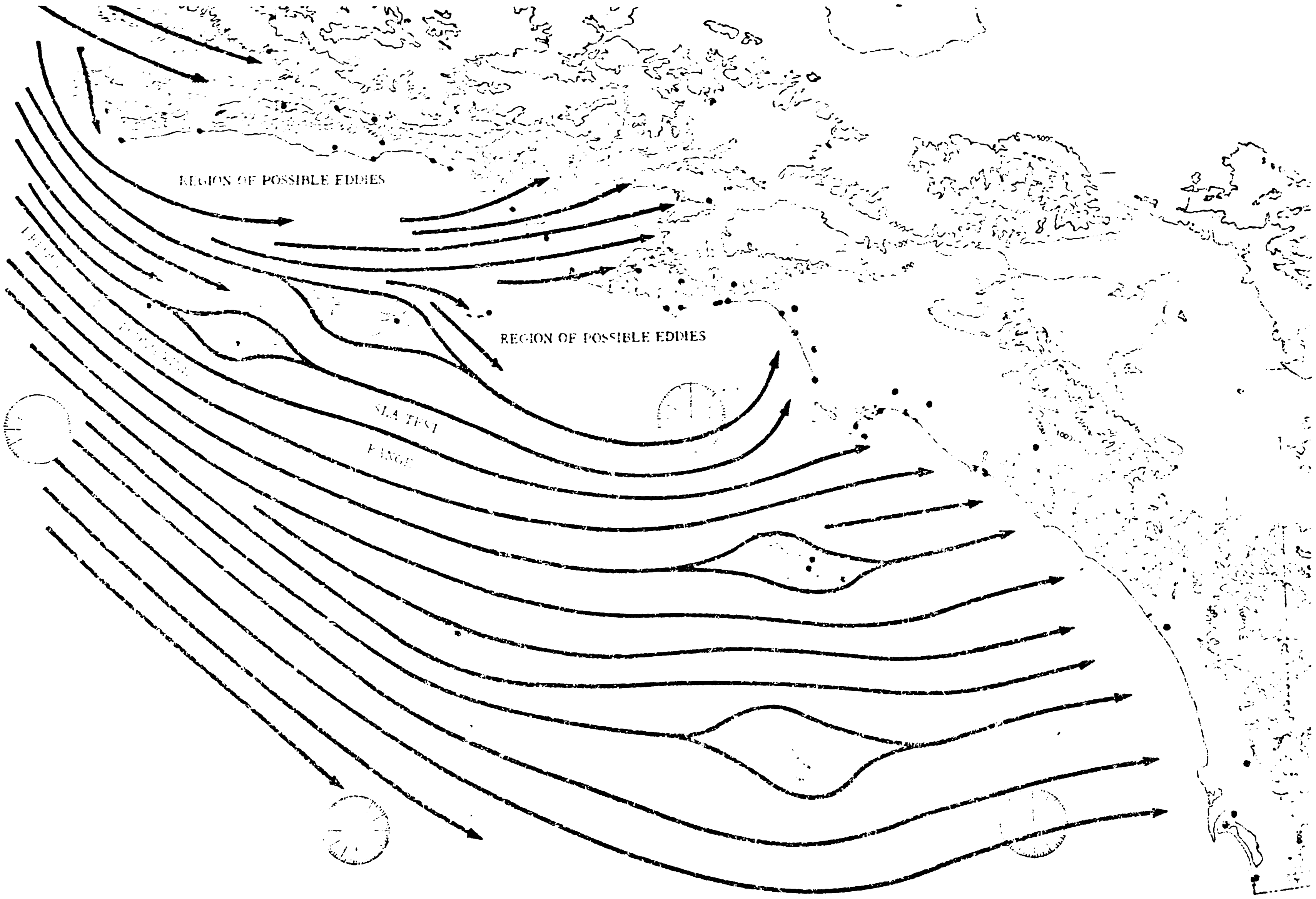
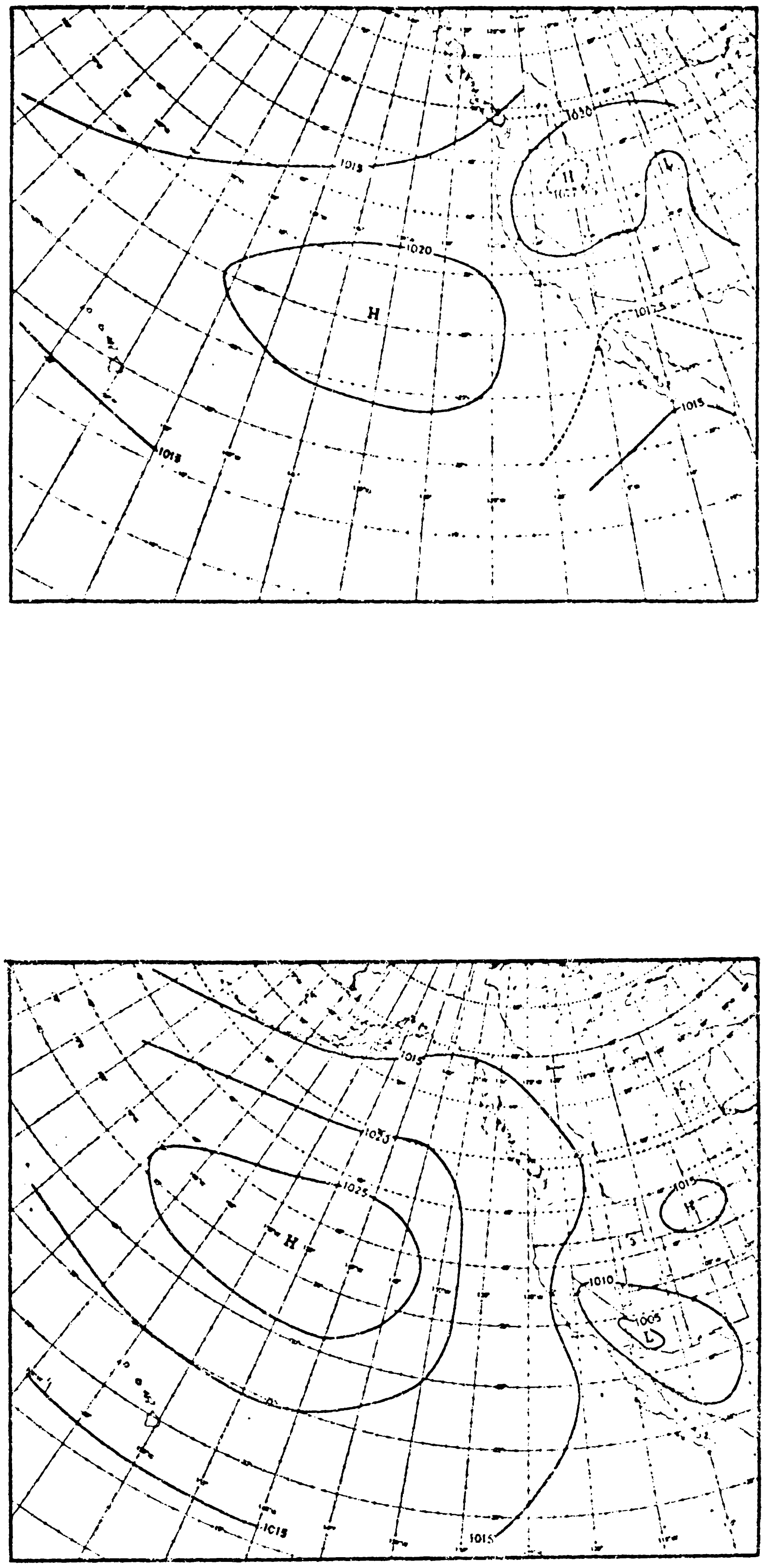


Figure 12. Mean annual wind streamlines, offshore southern California (after de Violini, 1967)

Regional Climatic Controls

The broad synoptic pattern sketched above is primarily a result of three all-important climatic controls, the Pacific High, the cool California Current with its associated upwelling, and the high sun thermal low of the interior valleys and deserts. The Pacific High is a semipermanent anticyclone of dry subsiding air whose eastern side spills onto the coast of California. During low sun periods the Pacific High weakens and is displaced equatorward allowing frontal systems generated in the North Pacific to sweep south of their usual northerly paths (Fig. 13a). As mentioned these transient lows supply California with most of its moisture during winter. As the sun rises higher in the early springtime the Pacific High intensifies and re-establishes its dominance. Concomitantly, a thermal low begins to form over the interior valleys and deserts of the extreme southwestern United States and northwestern Mexico (Fig. 13b). This dual system of an offshore high and an interior "heat low" generates an almost continuous flow of moist but stable onshore moving surface air during practically all the high sun season (Fig. 12) and frequently during part of the winter. This marine layer of air commonly is from 1,000 to 2,500 feet thick and is defined at its top by a semipermanent inversion produced by dry subsiding air aloft associated with the Pacific High. The moist marine layer is cooled from below and becomes stabilized as it moves over the cold upwelled surface waters associated with the southward moving California Current. Abundant airborne salt particles (condensation nuclei) of wave spray origin are mixed within the cool moist marine layer and result in frequent low level stratus



a.

b.

Figure 13. Normal sea level pressure (mb) for January, a., and July, b. (after DeMarrais *et al.*, 1964).

or fog during the spring, summer, and fall months. This condition also persists for short periods during the winter months.

It is important to note that the three weather producing factors noted above are each part of the global circulation. The Pacific subtropical anticyclone and the interior thermal low are both major elements in the global atmospheric circulation pattern. The California Current likewise is part of the great North Pacific oceanic gyre. Evidence is assembled later in this thesis to show that all three climatic controls probably were operative during most or all of the Quaternary, although probably at intensities different than at present.

Regional Precipitation and Temperature Pattern

Precipitation and temperature are the two most important weather elements which effect climate. This section will address the precipitation and temperature characteristics not only of San Miguel Island but on a regional scale as well. A regional analysis of precipitation and temperature is necessary for two reasons. First, it will be shown that while the precipitation varies somewhat around the Santa Barbara Channel, the general pattern is one of alternating wet and dry trends which extend back indefinitely in time, and which likely have played an important role in the vegetation, animal and fire characteristics of the island. Changes in vegetation, animal life and fire are shown in this and later chapters to have had a profound effect on wind and water erosion and the resulting surface character of the island.

Annual average temperatures and precipitation totals for nine coastal stations situated around the Santa Barbara Channel. including San Nicolas Island, are provided in Table 1 for purposes of comparison (for station locations see Fig. 1). The distribution of rainfall on and about the Northern Channel Islands seems somewhat anomalous. For example the data show that Santa Barbara experiences nearly 18 inches of precipitation per year whereas Goleta, a few miles distant, receives less than 15. Likewise, San Miguel Island receives over 14 inches whereas Anacapa and San Nicolas Islands record only about 7 and 8 inches

TABLE 1

Average Annual Precipitation and Temperature for Low Elevation* Stations Situated About the Santa Barbara Channel

Station	Precip. (inches)	Temp. (°F)	No. of Years	Period of Record**
Point Arguello Light	14.20	-----	13/--	1958-70
Goleta (Airport)	14.74	58.7	29/29	1942-70
Santa Barbara (City)	17.81	60.4	103/86	1868-1970
Ventura	14.72	----	85/--	1873-1970***
Oxnard	14.20	59.2	48/42	1923-70
Point Mugu	10.54	58.7	24/15	1947-70
East Anacapa Island	6.66	58.8	8?/8	1946(?)-54***
San Miguel Island	13.80	56.8	28/25	1894-1921***
San Nicolas Island	7.92	58.4	37/23	1934-70***

Data taken from U. S. Weather Bureau (ESSA), Climatic Summary of the U. S. to 1930, Section 17-18; Climatic Summary of the U. S., Supplement for 1931-1952, California; Climatological Data, Annual Summaries, 1953-1970; U. S. Weather Bureau, San Francisco, Calif., and Ashville, N. C.; de Violini (1967); and personal communication with the Geophysics Division, Pacific Missile Range, Point Mugu.

*The highest station elevation here is San Nicolas Island at 565 feet.

**Precipitation only.

***Discontinuous record, some months estimated.

respectively. Such variations can be largely (but not wholly) accounted for by two factors; (1) length and dates of the precipitation record, and (2) station location with respect to topography.

The importance of station location with respect to topography is well known. Other things being equal, stations lying at the base of mountain ranges and situated in the path of storm tracks receive more precipitation than do stations at the same elevation but which lie some distance in front of the mountains. The increase of precipitation is orographically induced and presumably begins somewhat in advance of the mountain mass. This may explain in some part at least why Santa Barbara, situated at the foot of the Santa Ynez Mountains, has significantly more precipitation than do the three island stations in Table 1. For example, when a cyclonic storm system approaches the coast off the Northern Channel Islands region, the air circulation is counterclockwise and tends to strike the east-west trending Santa Ynez Range from the southwest thereby orographically triggering rainfall amounts in excess of that normally associated with cyclonic systems that pass over landscapes of low relief. But, the presence of the Santa Ynez Range does not explain by Goleta, only a few miles from Santa Barbara and in the same location with respect to the Santa Ynez Range, receives three inches less precipitation. Nor does it explain why East Anacapa Island (6.7 inches) located at an equal distance from the mountains as San Miguel Island (13.8 inches) receives much less precipitation than the latter. In other words, the presence of the Santa Ynez Mountains explains partially but not wholly the anomalous mean precipitation pattern of the region as reflected in Table 1.

It is possible that the greater precipitation on San Miguel results in part from the greater elevation of the island (831 feet), which may induce a local orographic effect that East Anacapa (250 feet) either does not experience or experiences to a lesser degree.

The length and dates of the station records explains some of the variations in mean precipitation not explained by topography. In order to demonstrate this fact, and to establish the groundwork for a later detailed discussion on prehistoric climatology, it is necessary to refer to two papers on Los Angeles and San Bernardino hydrology by Troxell and Hofmann (1954), and Troxell _et al_. (1954). The authors of these excellent but neglected studies point out that in addition to the frequently observed great annual variations in Los Angeles and San Bernardino precipitation, there are recurring trends of wet and dry years that are cyclic in character. The cyclicity was made apparent when precipitation data for Los Angeles covering the period 1878 to 1952 were analyzed (Fig. 14). The analysis was done by computing the annual departures as a per cent from the 75 year mean (using climatological years July 1, 1877 to June 30, 1952) and cumulatively plotting these values to obtain a curve showing total accumulative departure from the mean. The authors point out that:

> The upper part of figure [14] gives the observed annual precipitation at Los Angeles for the entire 75-year period from July 1, 1877, to June 30, 1952. In the lower part, the cumulative departures from the 75-year average value are shown for each year since the beginning of the record in 1877. In this type of diagram, an upward trend represents a sequence of years in which the wet years predominate, whereas a downward trend indicates that the dry years predominate. By this means it has been possible to divide the annual precipitation

record into wet and dry periods. The average annual precipitation for each of these sequences is given across the upper part of figure [14]. These averages range from 9.99 inches for the 7-year sequence of 1945-51 to 20.32 inches for the 10-year sequence of 1884-93. (Troxell and Hofmann, 1954.)

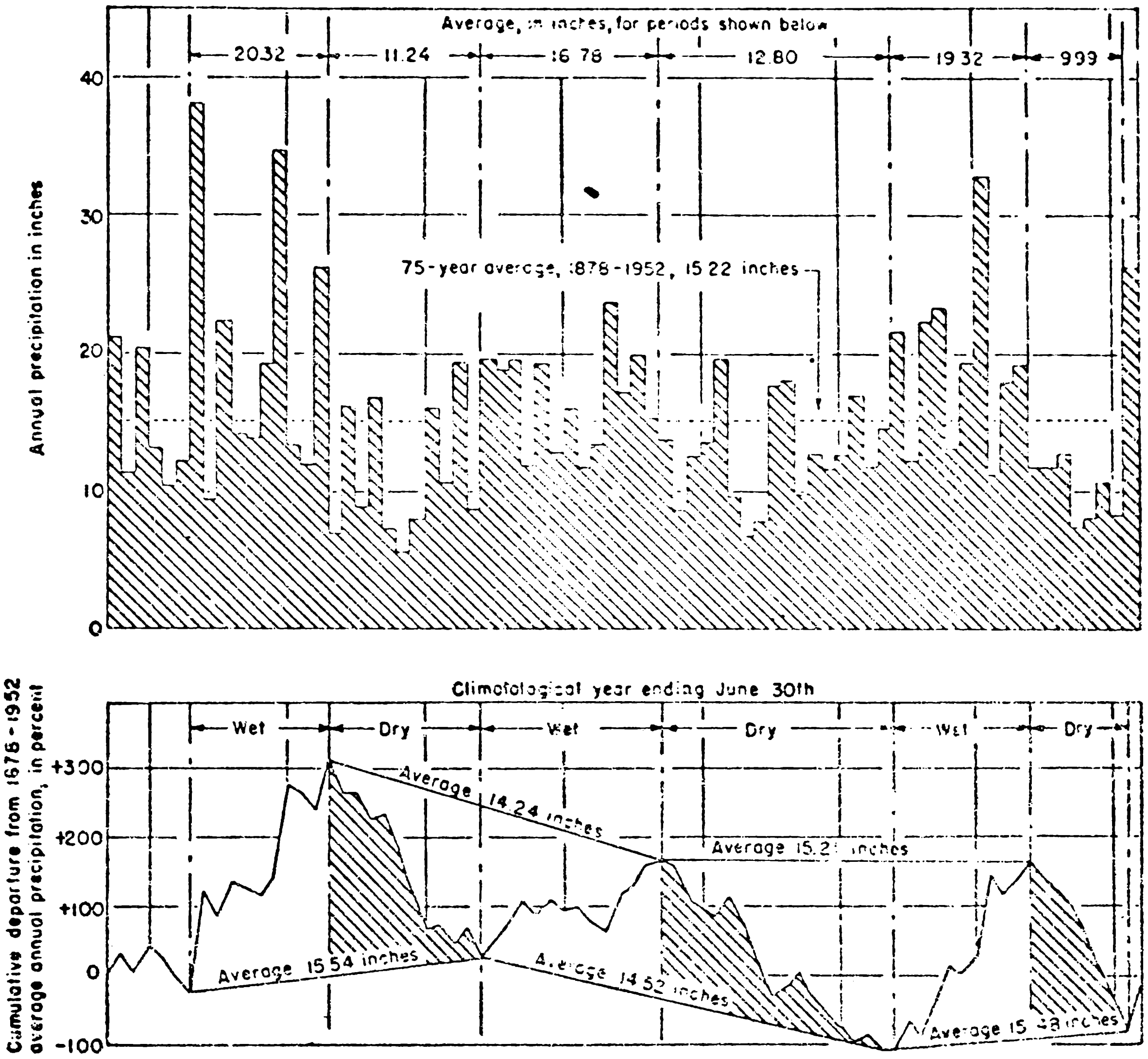


Figure 14. Annual precipitation at Los Angeles, California, for the period 1878 to 1952 (after Troxell and Hofmann, 1954).

Troxell and Hofmann then referred to the tree-ring chronology established by Schulman (1947) from Bigcone spruce in the mountains of southern California. By plotting the cumulative departure in per cent from the average annual tree-ring growth, which reflects past annual precipitation covering a 560 year span from A.D. 1385 to 1944, they realized the cyclic character of the wet and dry trends (Fig. 15). Overlap with the Los Angeles precipitation record covered 68 years, from 1878 to 1944. This absolute chronology, which shows well the recurring wet and dry year trends, goes back to about 157 years before Cabrillo the "discoverer" of California first landed on San Miguel Island in 1542.

In order to find whether Troxell and Hofmann's (and Schulman's) chronology could be extended to the Channel Islands, and perhaps to other parts of California, precipitation records for San Diego, Los Angeles, Santa Barbara, San Miguel Island, San Luis Obispo, Santa Cruz and San Francisco were collated and cumulative departure curves drawn

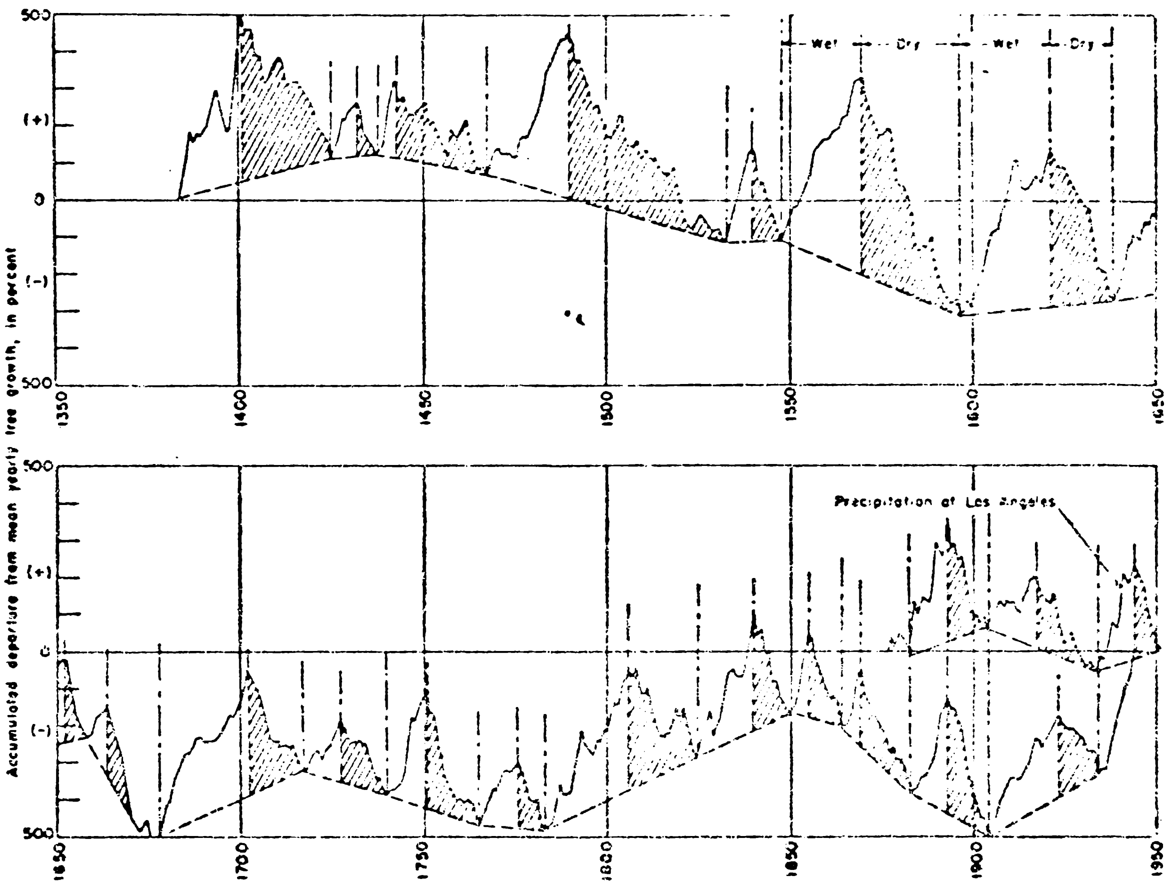


Figure 15. Wet and dry trends as indicated by the annual tree-ring growth of Bigcone spruce in southern California (after Troxell and Hofmann, 1954).

for each station (Fig. 16, a and b). The recurring wet and dry sequences are clearly indicated and a definite correspondence exists between all stations (due to time and space constraints the Santa Cruz and San Francisco stations were excluded from this study). Both San Diego and San Francisco have precipitation records which date from 1850, so that it was possible to extend the historical chronology back 28 years beyond Troxell and Hofmann's terminal date of 1878 for Los Angeles precipitation. Moreover, because 18 years have elapsed since the Troxell and Hofmann study, it also was possible to add 18 years of Los Angeles precipitation data to their chronology (1952 to 1970), which shows that their last dry trend really had not yet ended but lasted until 1964. The reader is reminded that Troxell and Hofmann used climatological years (July 1-June 30) in Figure 14 whereas for convenience I have used calendar years (Fig. 16a).

The tree-ring record of Figure 15 shows that dry cycles* range in length from as much as 43 years to as little as 6 years, with a median value of 15 years. The wet cycles are shorter, ranging from 24 to 4 years, with a median of 12 years. The median for a joint wet and dry cycle would be about 27 years (Troxell and Hofmann, 1954). These data may be used to show that length of precipitation record in Table 1 is

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*The wet and dry cycles perhaps should, _in sensu stricto_, be called wet and dry _trends_ or _sequences_ because for any given dry or wet sequence there invariably are several years of above or below normal precipitation respectively. However, because the trends are recurrent they are called cycles in this study.

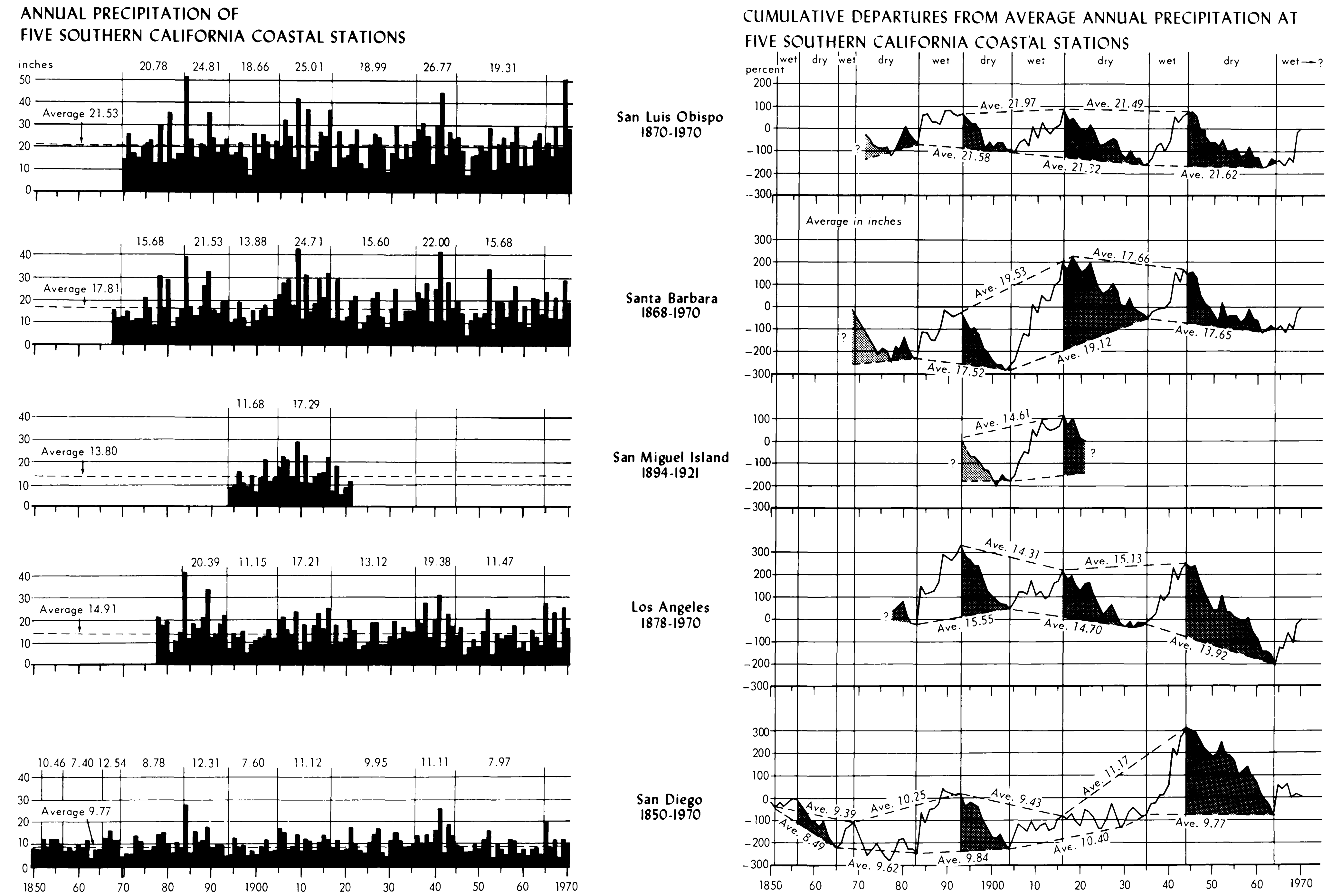

Figure 16

a. Precipitation records of various California coastal stations (calendar years).

b. Cumulative departures from average annual precipitation of stations in a., in per cent important in explaining variations in mean precipitation. For example, note that the precipitation records for Point Mugu and Anacapa (Table 1) both began during the latest dry cycle (Fig. 16a). Consequently, the precipitation record of Point Mugu is based on observations made during 18 dry cycle years but only 6 wet cycle years, whereas the record of Anacapa is based entirely on dry cycle years. These data suggest that both Anacapa and Point Mugu probably have a higher annual precipitation than indicated in Table 1, and they probably would be in closer agreement if based on the same time periods.

As mentioned, Goleta, located but a few miles from Santa Barbara city, has an annual precipitation mean of 14.7 inches compared to 17.8 inches for Santa Barbara. The station record of Goleta began in 1942, two years prior to the onset of the latest dry cycle. Thus, of the 29 year record at Goleta, 19 of the years were dry sequence years, which may account for the discrepancy. The important consideration here is that, unless a station has a long record period, the annual mean precipitation may not be representative. Thus, precipitation records at Point Arguello Light, Goleta, Point Mugu, and East Anacapa Island almost certainly do not reflect the actual annual mean. In each case the mean should be higher. On the other hand, the annual mean recorded at Santa Barbara, Ventura, Oxnard and San Nicolas Island are probably close to the true long term mean. Regionally, San Diego and San Francisco with means of 9.77 and 21.58 inches respectively, each covering 120 years of continuous record, are the most dependable of all.

Weather and Climate of San Miguel Island

We may look at the weather and climate of San Miguel Island from both the synoptic and mesoscale perspective. In general terms the weather and climate that San Miguel Island experiences is very similar to the pattern that prevails at other stations situated around the Santa Barbara Channel as described above. In specific terms, however, certain factors combine to produce a weather-climatic pattern that sets San Miguel distinctively apart from other stations in the area. These interrelated factors are (1) cooler water temperatures, (2) relatively cool air temperatures, (3) the exposed location of the island with respect to Points Conception and Arguello to the north, (4) abundant stratus and fog, and (5) strong and persistent west-to-north winds. Also important is the fact that San Miguel is a low island which during much of the year is completely bathed by the cool, moist marine layer of rapidly moving air which sweeps over the island rather than around it.

To my knowledge only three other places have approximating but less extreme weather regimes and climates. They are the west end of Santa Rosa Island, and to a lesser degree San Nicolas Island and Point Reyes Peninsula in north-central California. Each is very windy and cool, and each has frequent fog-induced low visibility. Interestingly, in addition to having similar weather and climates, all three places have landscape characteristics that are very similar to those of San Miguel Island (e.g., low-elevation marine benches, extensive dune areas, and grass where vegetation is present).

Precipitation

The weather record for San Miguel covers 1894 to 1947, but is not continuous for that time. The periods of record and the weather observers are given in Table 2. Thus, the weather record for San Miguel covers the periods 1894-1921, 1938, 1940-1942, 1945-1946, and 1947, for a total record period of about 35 years. However, only the calendar years 1894-1921 and 1941 are essentially complete*. Injudicious use of the

TABLE 2

Period of Weather Records, and Observers
San Miguel Island*

Observer	Period
William G. Waters	March 1894 through March 1917
James R. Moore	April 1917 through February 1920
R. L. Brooks	March and April 1920
Mrs. Ada Russell	May 1920 through December 1921
Herbert S. Lester	February and March 1938, February 1940
Herbert and Elizabeth S. Lester	April 1940 through June 1942
U. S. Weather Bureau	December 1945 through June 15, 1946
U. S. Coast Guard	Broken Periods during the 1940's to February 1947
U. S. Navy, Point Mugu	Broken Periods 1969-

*Data from W. B. Forms 1083 and G. E. Stegall, National Climatic Center, Environmental Data Service, Ashville, North Carolina. In 1969 the U. S. Navy, Geophysics Division, Pt. Mugu, began weather recordings with a portable facility on the mesa overlooking Point Bennett, but the facility has been only intermittently operable (U. S. Navy, personal correspondence, 1970).

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*The 1894-1921 record has four months of estimated precipitation (see Table 3).

1938-1947 precipitation data may result in a biased climatic picture of the island. For example, the value of 13.80 inches of precipitation in Table 1 is based on the 28-year continuous record of 1894-1921 (Table 3) and does not include observations made during 1938-1947. The reason is because the 1894-1921 record includes 16 dry and 12 wet years (Fig. 16b), which is about the same as the median values mentioned earlier that were calculated from the tree-ring and regional precipitation data. If the discontinuous record of 1938-1947 were included (most observations were

TABLE 3

Precipitation Record** for San Miguel Island, 1894-1921
(Data from Climatic Summary of the United States, to 1930, and W.B. Forms 1009)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1894	*0.75	*0.60	0.40	0.34	0.34	0.11	T	0.00	0.79	0.12	0.30	4.80	8.54
1895	4.10	0.63	2.12	0.10	0.05	0.00	0.00	0.00	0.00	1.27	0.40	0.48	9.15
1896	5.37	0.00	2.25	0.93	0.90	0.00	0.16	0.10	0.21	0.60	2.52	1.36	14.40
1897	4.28	3.57	1.63	0.04	0.03	0.00	0.00	0.00	0.18	0.76	0.00	0.14	10.63
1898	1.84	0.91	0.39	0.02	0.71	0.70	0.14	0.04	2.70	0.23	0.20	1.16	9.04
1899	4.25	0.35	1.89	1.33	*0.00	2.00	0.00	0.00	0.00	1.40	1.56	0.65	13.43
1900	1.76	0.24	0.75	0.79	0.44	0.00	0.00	0.00	0.00	0.24	1.70	0.17	6.09
1901	2.33	1.89	0.20	0.98	0.05	0.00	0.00	0.00	0.30	2.98	1.85	1.70	12.28
1902	1.56	7.00	2.52	1.34	0.23	0.00	0.00	0.00	0.00	1.18	3.14	3.60	20.57
1903	0.65	3.92	3.99	0.70	0.00	0.18	0.00	0.00	0.00	0.30	1.30	0.00	11.04
1904	0.00	3.45	3.29	1.33	0.05	0.00	0.00	0.75	3.20	0.00	0.10	1.09	13.26
1905	2.20	6.54	3.25	0.85	0.80	0.00	0.00	0.00	0.49	0.00	2.50	0.14	16.77
1906	3.10	3.88	9.07	0.30	2.93	0.11	0.00	0.00	0.35	0.00	0.66	2.29	22.69
1907	8.51	1.94	4.62	0.06	0.00	0.00	0.00	0.00	0.33	2.89	0.00	1.83	20.18
1908	3.55	5.14	0.20	0.34	0.34	0.00	0.00	0.00	0.96	0.20	0.00	*1.95	12.68
1909	8.61	4.24	7.07	0,07	0.07	0.24	0.25	0.18	0.08	0.15	1.67	5.89	28.51
1910	1.75	1.40	3.06	0.22	0.05	0.19	0.29	0.04	1.67	0.21	0.40	0.56	9.84
1911	10.44	2.01	6.57	3.01	0.15	0.14	0.00	0.00	0.00	0.00	0.20	0.78	23.30
1912	0.47	0.00	6.32	1.60	0.80	0.00	0.00	0.00	0.00	0.24	0.05	0.00	9.48
1913	1.65	3.79	0.56	0.05	0.00	0.48	0.20	0.20	0.00	0.00	1.18	4.53	12.64
1914	6.57	2.32	0.90	0.83	0.00	0.00	0.00	0.00	0.00	0.19	0.13	3.78	14.77
1915	3.46	5.57	2.16	0.77	0.80	0.00	0.00	0.00	0.08	0.00	0.66	1.65	15.15
1916	10.77	1.81	1.46	0.00	0.00	0.00	0.00	0.00	0.65	1.56	0.14	5.10	21.49
1917	2.34	2,57	0.20	0.65	0.20	0.00	0.00	0.00	0.00	0.10	0.10	0.10	6.26
1918	0.46	6.07	7.54	0.00	0.00	0.00	0.00	0.00	0.18	0.06	2.20	1.55	18.06
1919	0.75	1.79	0.85	0.00	1.67	0.00	0.00	0.00	0.05	0.12	0.10	0.55	5.88
1920	0.80	2.28	2.00	0.58	0.00	0.21	0.00	0.00	0100	0.75	1.05	0.73	8.40
1921	3.53	1.28	1.83	0.12	1.40	0.00	0.00	0.00	0.50	0.30	0.00	2.78	11.74
Ave.	3.42	2.69	2.75	0.62	0.42	0.16	0.04	0.05	0.45	0.57	0.86	1.76	13.80

*Estimated
** in inches

made during the three wet period years of 1940-42), the new mean would reflect a wet period bias, much as the means of Anacapa, Point Mugu, Goleta and Point Arguello Light presently reflect a dry period bias.

The precipitation regime on San Miguel is, of course, closely related to the cyclic precipitation pattern for the whole region discussed earlier. A comparison of precipitation and temperature for coastal stations from San Diego on the south to Crescent City on the north, including San Miguel, is shown in Figure 17. These data and that of Figure 16a show clearly a gradual reduction in precipitation with decreasing latitude. Table 4 shows the monthly and annual means and extremes of precipitation for San Miguel Island. During this time the precipitation was almost entirely rain, with hail being reported only 12 times. Of the hail which fell, one observation was made in the month of December, four each in January and February, two in March, and one in May. Sleet was observed twice on February 2, 1903 and in January, 1941. No snow has been reported. Interestingly, Cabrillo's log mentions snow

TABLE 4

Summary of Precipitation Means and Extremes,* San Miguel Island

	No. of Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Greatest Monthly	31	10.77	7.00	9.07	3.01	2.93	2.00	.29	.75	3.20	2.98	3.14	3.82	28.51
Mean Monthly	28	3.42	2.69	2.75	.62	.43	.16	.04	.05	.45	.57	.86	1.76	13.80
Least Monthly	31	0	0	.20	0	0	0	0	0	0	0	0	0	6.09
Greatest Daily	22	3.50	2.75	3.36	1.41	1.25	.40	.14	.75	2.28	2.30	.80	3.13	3.50
No. Days with .01 inch or more	13	7	7	6	3	1	1	.5	.5	.5	2	2	6	35

*Data from unpublished "Climatic Summary of San Miguel Island," State Climatologist, San Francisco; W.B. Forms 1009 (1894-1921); and Climatic Summary of the U.S. to 1930.

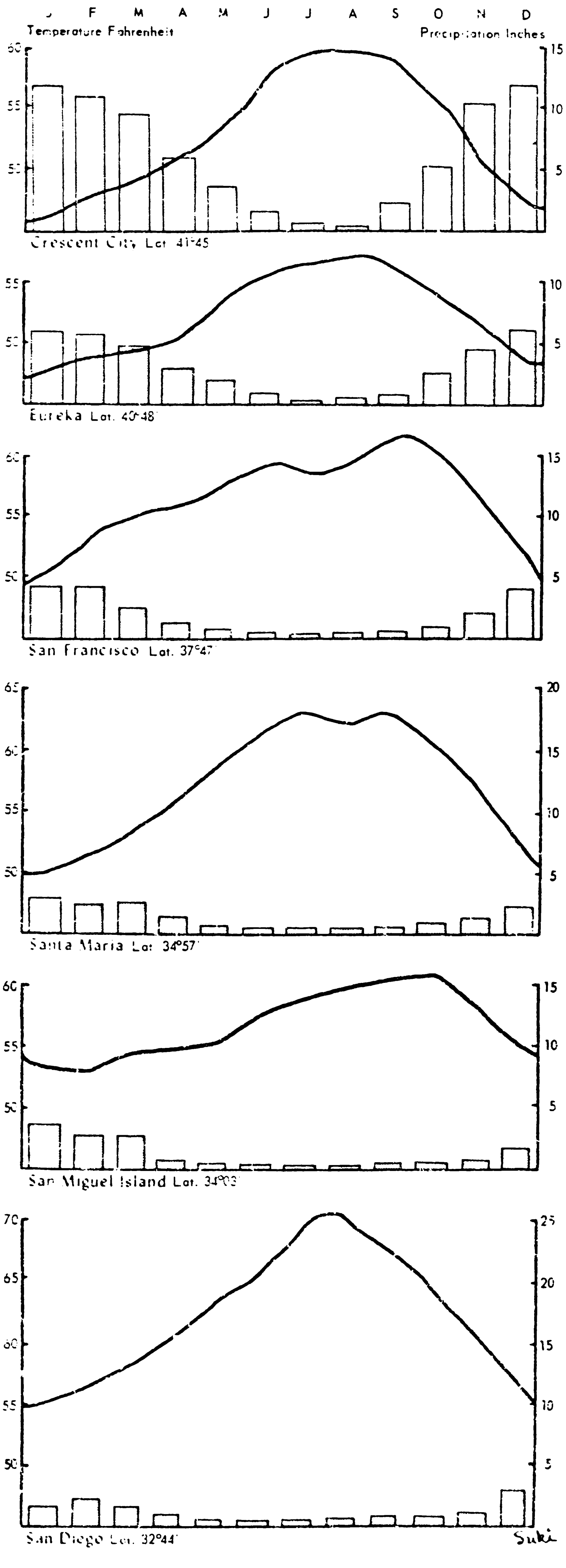


Figure 17. Climographs of California coastal stations, including San Miguel Island (modified after Cooper, 1967).

on the Northern Channel Islands during the winter of 1542-43, but one wonders if the islands were mistaken for the Santa Ynez Range, which experiences snow frequently. During the period 1894-1921, 34 thunderstorms were reported and the months in which they occurred are shown in Table 5.

TABLE 5

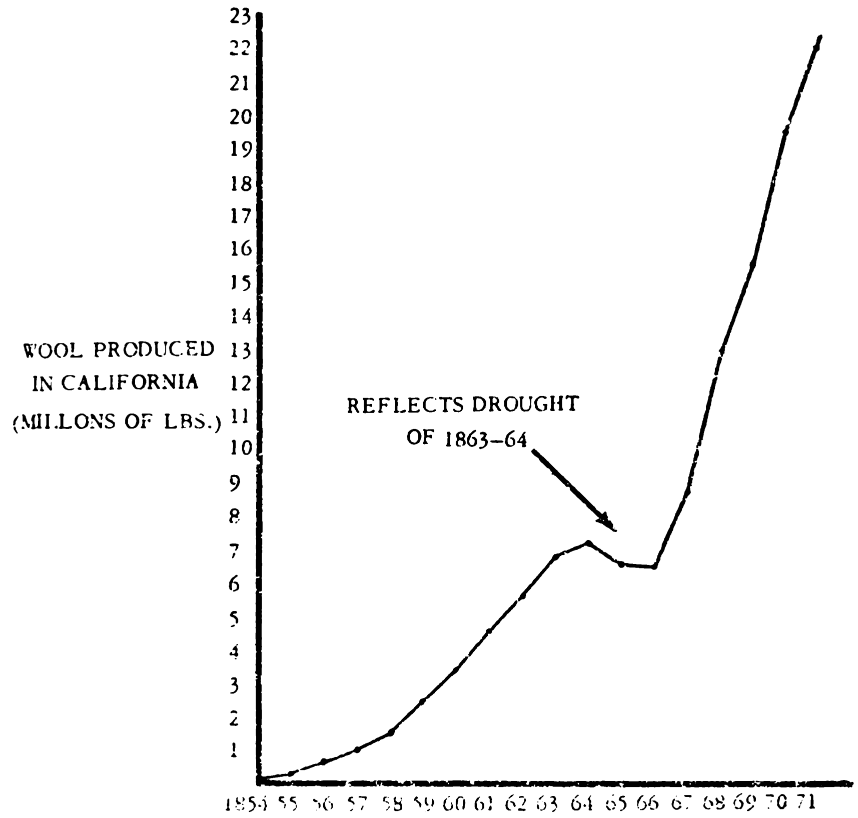
Monthly Occurrence of Thunderstorms* on San Miguel Island, 1894-1921

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total Storms Recorded
Number of Storms	9	5	2	1	2	1	2	2	5	3	0	2	34

*Data from W. B. Forms 1009.

Like the rest of southern California, the amount of precipitation which falls from one year to the next is extremely variable on San Miguel Island, regardless of whether a wet or dry cycle prevails. For example, in the years 1916, 1917, 1918 and 1919 rainfall in amounts of 21.49, 6.26, 18.06, and 5.88 inches respectively fell on the island. The wettest (28.84 inches in 1941) and driest (5.88 inches in 1919) years of record show a difference of 22.63 inches, almost twice the annual mean. The wettest month is January, with 3.42 inches and the driest is July with .04 inches. The rainfall for the four months of June through September averages only 0.7 inches which shows that summers are very dry.

As indicated, the original purpose for computing cumulative departure curves from mean annual precipitation for west coast stations was the prospect of tying the record of San Miguel into some kind of historic-prehistoric "precipitation chronology." Figures 15 and 16b show that within the historic period the years 1856-1864, 1969-1883, 1893-1904, 1917-1935, 1944-1964 were dry cycle years for coastal California and, we may infer, for San Miguel and the other offshore islands. Various lines of historical evidence illuminate the severity of droughts which frequently occur within the dry cycles. For example, Figure 18 shows the amount of wool produced in California during the period 1854-



Source of data: Hayes, 1872

Figure 18. Wool produced in California 1854-71.

71. During the years 1863-64, a great drought occurred (Kuhrts, 1906; Toland, 1965) which for some years economically disrupted a previously burgeoning wool industry (Hayes, 1872). Reference to the rainfall data of Figure 16a shows that 1863 was the year San Diego, the only southern California station whose record goes back that early, received its lowest recorded annual rainfall, 3.02 inches. San Miguel was by no means spared the effects of this low rainfall period, for George Nidever, owner of the island for about 18 years, stated that of 6,000 sheep, 200 cattle, 100 hogs and 32 horses present on the island in 1862, only 1,000 sheep, 20 cattle, a number of hogs, and 2 horses survived the drought of 1863-64 (Ellison, 1937).

During the dry cycle of 1869-1883 several droughts struck California, once in 1870-72 and again in 1877, and are reflected in the rainfall totals for those years at Santa Barbara and San Diego. (The ruinous effects of all these droughts are described in detail in Chapter 7.) The effect of the 1877 drought is suggested by the following statement in the Santa Barbara Index, date line March 22, 1877,

> About 25 thousand sheep will be slaughtered today on Santa Cruz Island. The hides and tallow will be preserved, but the mutton will be a loss. Scarcity of food induced by the want of rain, compels the sacrifice.

The dry cycle of 1893-1904 was highlighted by a drought in southern California at the turn of the century which according to one writer was,

> . . . one of the longest droughts in the history of southern California. It covered the years 1897 to 1900 (Lloyd, 1948).

In 1924, during the dry cycle of 1917-1935 Mr. Robert L. Brooks, lessee of San Miguel Island for many years, found it necessary to remove all the sheep from the island because of two consecutive years of low rainfall covering 1923-24 (Brooks, personal communication, 1965).

The last dry cycle, 1944-1964, was the longest since precipitation records have been kept. To obtain an impression of how this dry cycle may have effected San Miguel we note that for the years 1949-1964 San Nicolas Island recorded an average annual precipitation of only 6.26 inches. In 1947 Santa Barbara received only 3.99 inches, the lowest for the 103 year period of record. Commenting on this latest dry trend, Bailey (1966) stated, ". . . we do not know when the present drought will end, or even if it will end." In retrospect we know, of course, that it did end and the data of Figures 15 and 16b strongly suggest that future droughts and dry cycles will also end.

Looking back in time at the precipitation record of southern California as expressed by the cumulative departure curves of tree rings (Fig. 15) we find that 20 dry cycles have occurred since A.D. 1385. The dry cycles were severe and exceptionally long in duration during the period from A.D. 1401 to A.D. 1638 but since the latter date dry cycles have been markedly less severe and of shorter duration.

Interestingly, Cabrillo first dropped anchor in Cuyler's Harbor on San Miguel on October 1542, a dry period year. His choice of San Miguel as his California "headquarters" is in part due to the excellent harbor (one of only two natural good harbors between San Diego and San Francisco, the other being the Isthmus at Catalina) and partly due, probably, to good weather at the time. San Miguel frequently experiences fine weather in the fall. As the next few pages will show, had Cabrillo arrived in the spring or summer he probably never would have stopped. Indeed, he probably would have avoided San Miguel. Thus he would not have broken his limb, as he did on San Miguel in October 1542, nor would he have died as a result of the injury, as he did the following January 1543; neither would he now be buried there, as presently believed.

Temperature

Reference to Table 1 shows that San Miguel experiences a mean annual temperature of 56.8°F, 1.9 degrees less than Goleta and Point Mugu, 2 degrees lower than East Anacapa, 2.4 degrees lower than Oxnard, 3.6 degrees less than Santa Barbara, and 1.6 degrees less than San Nicolas Island. Table 6 shows monthly and annual temperatures for the 28 year period 1894 to 1921. Figure 19 shows the same data expressed as annual temperature curves. Table 7 shows a summary of temperature means and extremes for San Miguel. Figure 20 shows the mean annual temperature curve of San Miguel compared to temperature curves of Goleta, East Anacapa, and San Nicolas Island.

The curves clearly show several ways in which the mean monthly temperature regime of San Miguel differs markedly from the other stations. First, the summertime temperatures of San Miguel are significantly lower than other stations. Second, while all stations show a

TABLE 6

Annual, Monthly Mean, and Monthly Range of Temperature During 1894-1921, San Miguel Island*

DATE	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
1894	—	—	52.2** 14.5***	55.7 17.6	57.4 16.4	56.6 14.2	58.4 15.6	60.4 13.5	62.5 13.4	61.2 13.6	57.0 14.3	53.6 11.0	57.5 14.4
1895	54.9 6.6	57.2 3.0	53.4 12.0	55.6 13.3	56.6 13.0	60.5 16.5	61.8 13.2	61.6 13.0	61.3 14.7	60.3 13.2	59.2 18.3	54.6 17.3	58.1 12.8
1896	55.2 13.7	57.0 19.5	56.0 15.9	53.8 14.7	57.2 14.4	59.6 16.5	64.0 15.0	61.8 12.0	61.0 12.1	60.0 12.2	56.2 12.0	55.6 13.0	58.1 14.3
1897	52.6 12.9	51.6 10.7	50.8 12.5	56.8 16.1	58.1 14.4	59.8 14.6	60.9 14.2	59.9 11.4	61.6 11.9	58.6 12.0	56.2 13.0	—	57.0 13.1
1898	49.7 13.2	53.6 11.9	53.6 13.9	57.2 16.7	54.0 11.0	59.1 13.9	60.1 13.2	60.8 11.0	59.3 11.2	60.1 13.7	53.8 14.9	53.8 15.3	56.3 13.2
1899	53.4 12.9	52.2 12.5	56.1 15.4	54.6 13.5	—	58.2 13.5	58.7 12.2	59.1 19.0	54.8 20.9	61.0 13.2	58.4 11.3	55.9 15.8	56.6 14.6
1900	56.4 12.7	55.2 13.9	50.8 20.5	54.9 12.6	54.6 19.7	57.7 20.4	60.9 17.2	62.2 16.6	63.6 17.8	61.2 12.9	61.2 14.5	58.4 15.6	58.1 16.2
1901	53.8 12.4	55.4 13.3	56.7 15.2	53.3 12.4	55.1 11.4	58.4 14.4	59.7 11.6	58.6 12.3	57.8 11.7	61.3 12.6	58.0 10.2	58.4 6.3	57.2 12.0
1902	53.8 10.1	51.8 6.5	50.3 8.2	53.0 9.8	54.4 10.2	53.3 8.8	53.5 8.7	59.4 8.7	57.5 9.1	59.8 9.1	55.2 7.8	52.6 9.9	54.6 8.9
1903	55.2 10.1	50.0 12.3	53.0 10.3	54.2 11.1	55.2 9.2	58.6 10.2	57.2 10.1	59.6 9.8	61.6 9.7	61.3 9.8	58.4 7.8	57.2 12.5	56.8 10.2
1904	56.2 10.9	53.6 8.3	53.5 11.5	56.7 11.3	55.7 8.6	59.9 13.8	59.8 11.4	60.9 9.4	64.9 9.8	63.1 10.5	61.3 11.3	57.5 10.4	58.6 10.6
1905	55.5 8.7	55.9 9.3	57.5 8.2	55.5 9.2	55.8 12.2	55.0 9.7	58.0 14.9	—	57.9 13.8	60.0 11.7	59.1 10.1	53.7 11.6	56.7 10.9
1906	53.9 9.8	56.5 9.2	55.2 10.0	55.6 10.3	55.3 8.4	58.4 10.5	60.0 10.7	60.6 9.3	60.7 10.2	60.0 10.8	56.2 11.1	53.5 7.0	57.2 9.8
1907	49.9 8.2	55.8 8.3	52.9 10.0	54.8 7.7	—	55.3 9.8	59.9 11.3	59.9 8.3	59.2 9.1	59.3 8.2	56.7 9.3	—	56.4 9.0
1908	53.3 9.4	50.7 8.6	55.0 12.0	55.5 11.0	53.2 10.5	54.9 10.2	59.0 11.2	60.1 10.2	59.6 9.4	57.8 10.8	55.7 7.6	—	55.9 10.1
1909	53.9 6.5	51.6 8.4	52.0 10.9	57.0 15.2	53.8 11.0	56.3 11.9	57.0 10.6	56.9 9.6	62.8 12.7	61.1 11.8	56.7 10.5	52.4 10.8	56.0 10.6
1910	50.0 12.9	52.4 12.8	53.6 7.9	53.7 9.2	55.0 8.7	55.3 10.4	58.5 12.0	60.6 14.9	59.2 10.6	62.0 13.9	56.1 7.0	54.0 8.2	55.9 10.7
1911	51.3 9.8	50.0 8.4	57.6 4.3	55.4 3.7	56.4 3.8	56.2 3.7	56.2 9.9	56.3 7.6	58.4 9.1	59.0 9.5	59.2 11.7	54.2 10.7	55.9 7.7
1912	55.2 9.4	54.0 9.3	51.2 9.1	52.1 9.6	55.0 9.9	56.5 10.0	56.2 9.9	58.1 11.4	59.6 11.7	61.2 13.6	58.8 12.2	53.0 9.9	55.9 10.5
1913	50.5 11.0	52.0 9.4	53.0 12.4	52.8 10.0	54.0 9.1	56.0 7.9	61.4 10.3	61.2 9.5	63.2 11.7	62.0 12.1	59.0 8.7	52.7 8.8	56.5 10.1
1914	53.2 8.0	54.6 10.5	59.7 13.0	56.6 9.8	55.9 8.8	56.6 10.7	56.4 7.9	58.3 9.0	59.2 10.8	63.0 12.5	62.0 14.2	53.1 10.4	57.5 10.5
1915	53.3 10.4	53.0 8.6	57.6 11.1	55.4 8.6	54.5 12.6	53.0 5.5	58.4 9.1	65.1 18.2	60.8 9.7	57.5 10.0	57.6 11.7	54.6 10.9	56.7 10.5
1916	49.6 7.8	56.0 12.3	55.9 11.6	55.3 11.8	53.3 9.6	56.7 11.0	57.2 9.8	56.8 9.9	57.6 8.8	56.0 9.9	57.2 15.1	53.0 13.2	55.4 10.9
1917	—	55.0 14.3	52.4 12.1	53.6 11.0	52.6 8.4	52.6 11.6	61.9 13.0	59.0 8.5	63.2 12.5	62.2 9.2	61.4 14.5	61.8 16.2	57.9 11.9
1918	57.1 13.2	53.2 11.3	55.4 11.3	57.1 13.4	54.4 11.1	59.6 12.4	59.1 9.4	61.8 11.3	62.6 12.7	67.0 13.0	59.9 12.2	56.8 14.3	58.7 12.1
1919	59.4 16.1	52.0 8.3	52.8 10.6	54.0 9.3	55.5 9.2	55.7 10.4	57.3 9.6	58.7 9.4	61.2 10.6	61.2 15.0	59.7 17.0	58.0 17.4	57.1 11.9
1920	55.9 12.6	55.7 12.2	53.6 11.7	53.6 11.5	53.7 10.0	57.8 10.7	57.0 10.5	60.4 10.9	59.8 10.8	59.4 12.7	58.3 12.8	55.2 11.5	56.7 11.5
1921	53.2 12.6	49.8 11.1	55.5 10.8	55.2 12.3	54.0 9.7	57.5 9.8	59.2 9.5	59.2 9.5	61.4 12.9	62.1 13.6	56.4 13.6	53.8 10.7	56.6 11.4
TOTAL	1396.4	1445.8	1517.3	1539.0	1430.7	1595.1	1647.7	1617.3	1692.3	1699.2	1625.9	1379.4	1591.9
Monthly Mean	53.7	53.6	54.2	55.0	55.0	57.0	58.9	59.9	60.4	60.7	58.1	55.2	56.8
Monthly Range	10.8	10.5	11.7	11.6	10.8	11.5	11.5	11.3	11.8	11.8	12.0	12.0	11.4

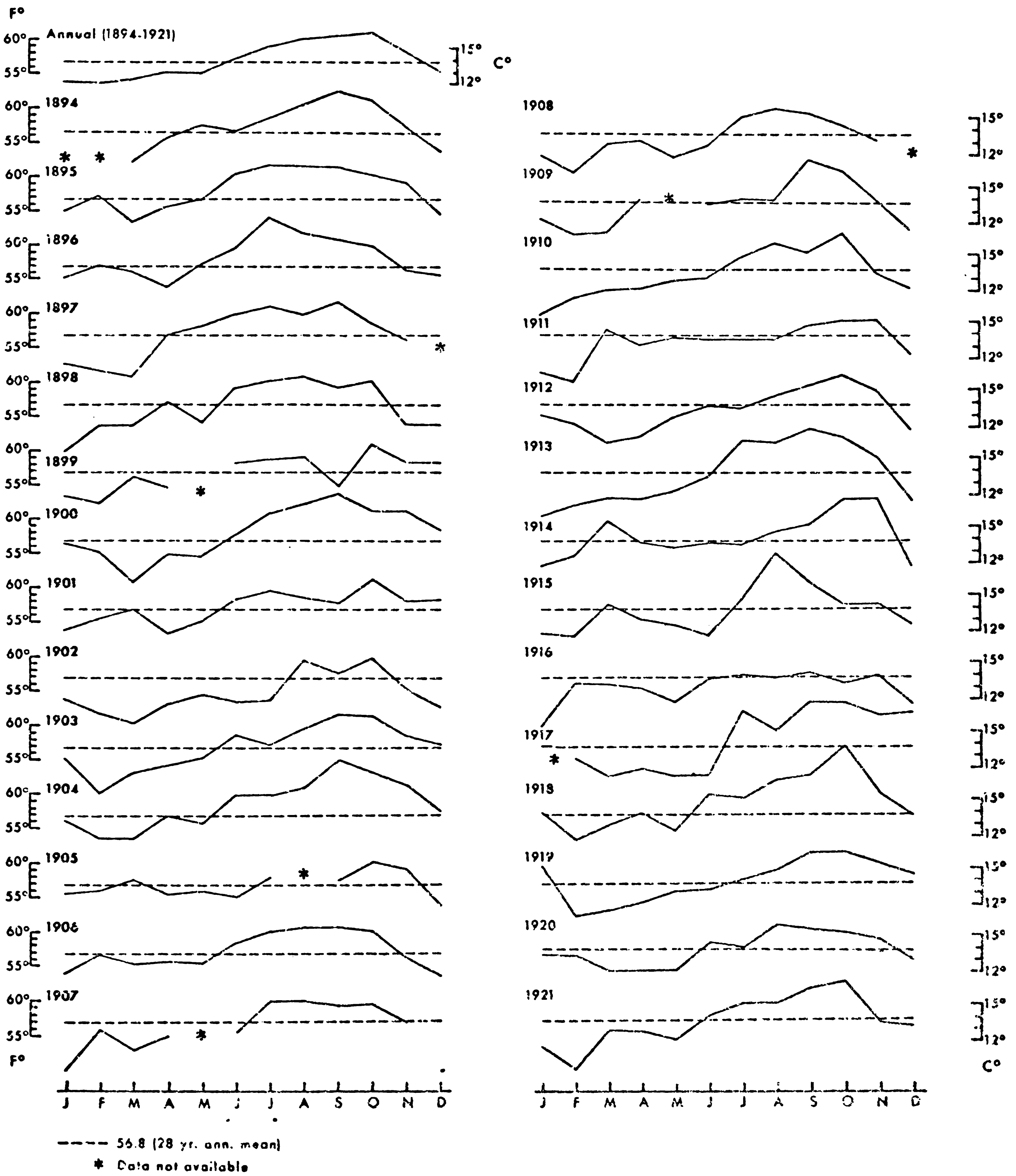


Figure 19. Annual temperature curves, San Miguel Island, for the 28 year period 1894 to 1921 (data from W. B. Forms 1009).

TABLE 7

Summary of Temperature Means and Extremes,* San Miguel Island

	No. of Years	J	F	M	A	M	J	J	A	S	O	N	D	Year
Highest	25	86	85	87	92	101	90	81	89	102	95	96	90	102
Mean Daily Maximum	20	59.0	58.2	60.1	60.2	60.3	62.2	64.3	65.1	66.3	66.9	64.4	60.7	62.3
Mean Daily	25	53.4	53.0	54.2	54.8	55.1	57.1	58.7	59.7	60.5	60.8	58.0	55.2	56.7
Mean Daily Minimum	20	48.5	48.5	48.9	49.4	50.1	51.7	53.0	54.4	55.3	54.8	52.2	49.3	51.3
Lowest	25	31	31	37	40	38	40	46	37	40	46	39	33	31

*Data from unpublished "Climatic Summary of San Miguel Island," California State Climatologist, San Francisco; W.B. Forms 1009.

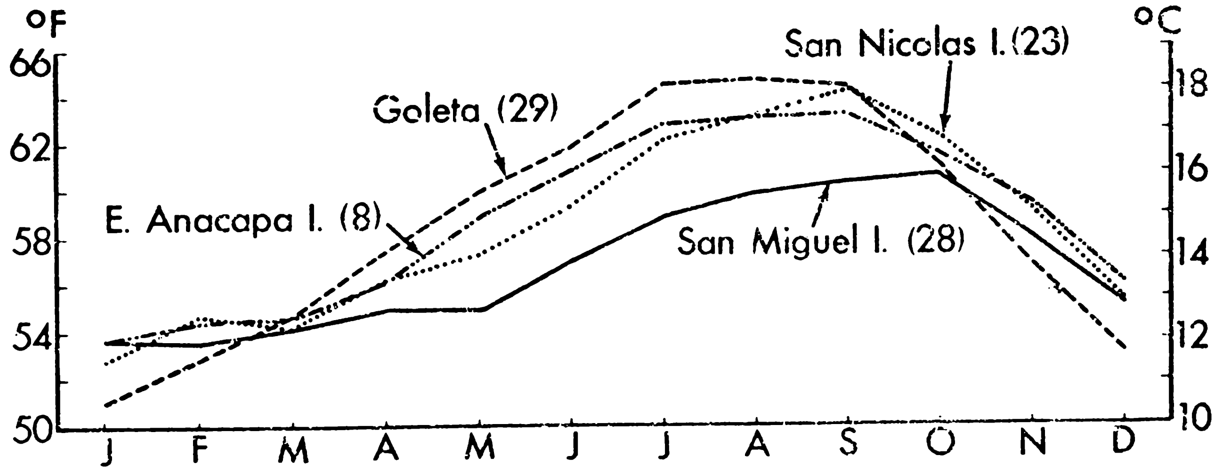
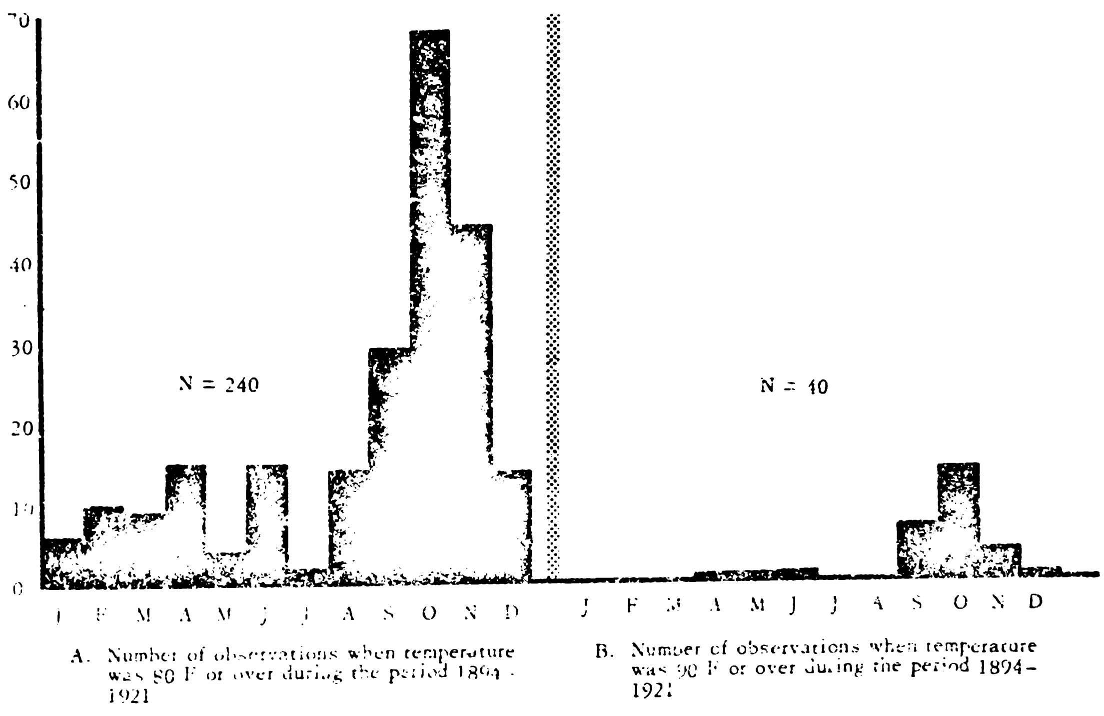


Figure 20. Mean annual temperature curves of Goleta and San Miguel, San Nicolas and East Anacapa Islands. The numbers after the stations refer to the length of record in years (data from de Violini, 1967; Geophysics Division, Pacific Missile Range, Point Mugu, Calif.; unpublished climatic summaries of San Miguel and San Nicolas Islands, California State Climatologist, San Francisco; Climatological Data, California, 1953-70; Climatic Summary of the U.S., to 1952); W.B. Forms 1009).

seasonal temperature lag, San Miguel's is significantly longer, more intensive, and doesn't peak out until October. Third, an early springtime temperature rise is observed for all stations except San Miguel, which experiences a depressed temperature rise until after May. Fourth and last, the curves show that there is less annual temperature variation on San Miguel than at the other three stations.

There are three primary reasons why San Miguel has a markedly different temperature regime than other coastal stations in the region. One is that the waters which sweep the island are cooler as indicated above in Section 5. Water is a great air temperature modifier and cooler ocean water simply means cooler overlying air. Another reason is that the limited surface area of San Miguel is not enough to allow for any large scale daytime thermal heating that might alter the temperature regime. And third, since the island has a maximum elevation of only 831 feet (most of the island is less than 500 feet), it usually lies within the cool marine layer of air which dominates the region. The marine layer of air, cooled during its passage over upwelled water off Point Arguello and the mouth of the Santa Barbara Channel, sweeps completely over San Miguel Island driven by brisk northwest winds that buffet the island throughout much of the year.

Occasionally, however, the marine layer of air disappears whenever the thermal inversion zone, which normally occurs at an altitude of 1,000 to 2,500 feet, is depressed to sea level by dry subsiding air aloft. When this happens the temperature on San Miguel may rise into the 80's and 90's. For example, data collated from Weather Bureau Forms 1009 show that during the 28-year period 1894-1921 the temperature on San Miguel rose to 80°F or above 240 times; skies were clear during 95 per cent of these observations. Clear skies and high temperatures are a fair indication that the marine layer has been temporarily destroyed (cloudy or partly cloudy skies are common when the marine layer is present). Also at such times the winds tend to be variable, a condition expected from subsiding high pressure air. Although Table 7 shows that high temperatures may occur at any time of the year, they are very infrequent in the winter, spring and summer months. For example, of the 240 times that temperatures reached 80°F or above during the years 1894-1921 two-thirds occurred between August 24 and December 10 (Fig. 21). Of the 29 times during 1894-1921 that temperatures of 90°F or above occurred, 24 (86 per cent) were in September and October. Clearly,



A. Number of observations when temperature was 80 F or over during the period 1894-1921

B. Number of observations when temperature was 90 F or over during the period 1894-1921

Figure 21. 21a and 21b show occurrence by month of temperature greater than 80°F and 90°F respectively for the period 1894-1921, San Miguel Island (data from W. B. Forms 1009).

the autumn months are the warmest of the year on the island (see also Fig. 20). The hottest temperature ever recorded during the total time of record (1894-1947) was 102°F on September 17, 1913; the only other 100-plus temperature occurred on May 25, 1896 (101°F).

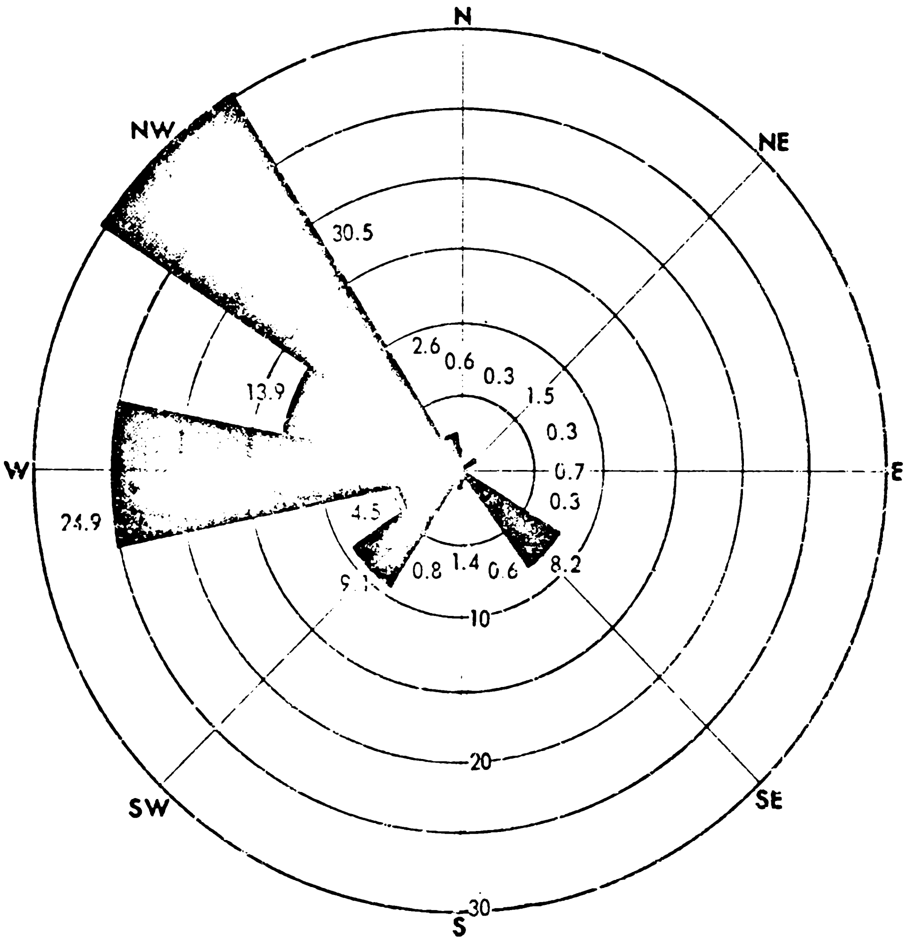
Low temperatures may also occur at any time during the year as indicated by Table 7, although temperatures that approach freezing occur only rarely during the winter months of December through March. The lowest temperature recorded on San Miguel during the broken period 1894-1947 was 31°F (3 times, February 2, and 15, 1903, and in January 1941), although frost was recorded on at least five additional occasions (March 16, 1895, December 26, 1918, January 3-4, 1919, and January 12, 1921).

The average monthly range in temperature for 1894-1921 was 11.4°F; the highest mean annual temperature was 58.7°F in 1918 whereas the lowest was 54.6°F in 1902 (Table 6). Such a small monthly and annual range in temperature reflects the buffering effects of the California Current which washes San Miguel.

Wind, Fog and Stratus

Those aspects of weather that invariably leave lasting impressions on visitors to San Miguel are the frequent fogs and low stratus, and characteristically strong persistent surface winds that blow predominantly from the west to northwest quadrants. Fog or low stratus often accompanies moderate to strong winds which, when coupled with the island's bizarre landscape, presents to the visitor an eerie but beautiful, not to be forgotten experience. The combinations of inclement weather and bizarre landscape and the fact that San Miguel is comparatively little visited due to difficulty of access has created for the island a reputation of mystery and enchantment.

Although the winds which sweep San Miguel have been observed to blow from all compass points, the predominant direction during all months is from the north-to-west quadrant. A total of 9,880 wind observations made once daily between 4:30 and 6:00 p.m. during 1894-1921 show the wind to blow from this quadrant 73 per cent of the time (Fig.



Wind Rose, San Miguel Island, 1894 - 1921, 9880 observations taken once per day between 4:30 and 6:00 PM.

Figure 22. Wind rose for San Miguel Island, 1894-1921, based on 9,880 observations taken once per day between 4:30 and 6:00 p.m. (data from W. B. Forms 1009).

TABLE 8

Mean Annual Wind Directions, 1894-1921, San Miguel Island
9880 Observations*

	DIRECTION																
YEAR	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	CALM
1894	6	6	15	4	4	3	30	6	1	2	5	3	14	82	101	20	0
1895	4	4	5	1	6	0	33	5	2	1	17	8	13	25	231	8	0
1896	6	3	2	2	6	2	24	8	4	10	13	5	28	35	194	24	0
1897	2	1	6	0	5	0	23	2	7	0	6	14	24	69	129	46	0
1898	6	2	2	1	9	1	36	2	6	2	16	2	37	45	122	76	0
1899	6	5	6	9	6	2	28	4	7	1	22	32	39	47	68	52	0
1900	3	1	6	3	4	2	41	2	8	3	31	20	66	42	124	5	0
1901	0	0	11	3	4	0	50	0	3	1	20	34	84	84	69	1	0
1902	5	0	3	0	5	0	26	0	4	0	14	13	90	38	105	1	0
1903	0	0	2	2	2	3	18	3	7	2	24	12	87	115	87	0	0
1904	2	1	2	0	2	0	24	0	11	3	41	25	106	67	81	1	0
1905	1	0	5	4	2	2	32	3	5	5	23	19	36	130	63	4	0
1906	0	0	5	0	0	3	38	1	4	18	46	39	92	47	63	6	0
1907	1	1	3	0	0	0	26	1	1	3	31	23	94	86	32	2	0
1908	2	0	6	0	0	0	18	0	1	1	11	39	120	99	38	0	0
1909	3	0	8	0	1	0	38	0	7	0	69	0	131	0	108	0	0
1910	0	0	3	0	0	0	27	0	5	0	93	10	95	4	127	0	0
1911	2	0	5	0	2	0	45	0	6	0	57	5	77	3	163	0	0
1912	0	0	6	0	3	1	14	0	1	11	57	13	167	10	80	3	0
1913	0	0	2	0	0	0	30	8	5	3	26	20	158	57	55	1	0
1914	0	1	6	0	0	1	22	4	5	0	14	7	270	33	52	0	0
1915	1	0	10	1	1	5	35	5	2	6	8	11	119	47	114	0	0
1916	0	0	3	2	0	1	24	3	7	1	17	31	76	107	94	0	0
1917	0	0	6	1	0	0	12	0	8	1	42	41	133	30	58	1	0
1918	0	0	7	0	0	1	30	0	5	2	48	5	102	29	131	0	5
1919	6	0	7	0	0	0	23	0	2	0	50	14	49	18	194	2	0
1920	2	0	4	0	1	0	30	0	11	2	34	1	99	19	162	1	0
1921	1	0	5	0	1	0	31	0	4	0	43	2	101	6	169	2	0
TOTAL	59	25	151	33	67	27	808	57	142	78	878	448	2459	1373	3014	256	5
%	.6	.25	1.53	.33	.68	.27	8.2	.56	1.4	.79	9.1	4.5	24.9	13.9	30.5	2.6	.05

*Data from W.B. Forms 1009.

TABLE 9

Monthly Percentage Frequency of Wind Direction*
February 1940-June 1942, San Miguel Island

	J	F	M	A	M	J	J	A	S	O	N	D
N	2.3	12.8	5.3	3.8	5.5	5.0	6.0	7.0	4.5	3.5	3.8	3.0
NNE	4.0	7.0	5.4	3.3	6.5	3.5	7.0	6.0	3.3	6.7	4.0	2.0
NE	6.0	3.6	4.6	8.0	5.3	5.3	0	0	0	10.0	4.3	1.0
ENE	10.8	8.5	5.8	0	3.5	0	4.0	2.5	9.0	10.0	13.5	10.0
E	8.9	11.3	14.8	0	0	3.5	0	0	1.0	4.4	6.4	5.6
ESE	8.0	12.8	11.3	10.3	14.0	2.5	7.0	0	3.0	7.0	16.0	10.0
SE	9.8	12.7	3.5	8.8	2.5	3.0	11.0	2.0	7.0	4.0	5.3	9.9
SSE	22.0	19.7	17.1	19.2	17.3	8.0	8.5	0	7.8	15.5	12.0	18.9
S	7.3	12.7	11.0	6.0	5.5	11.0	3.5	0	5.4	8.1	7.0	7.5
SSW	12.0	12.4	17.6	11.3	9.3	6.0	8.2	10.0	7.5	8.3	7.3	8.6
SW	8.6	9.8	10.7	8.7	9.2	9.5	20.0	0	5.2	6.2	4.8	6.2
WSW	9.4	6.8	11.8	10.2	10.2	9.0	21.5	10.6	9.2	9.1	8.4	7.6
W	4.9	10.8	9.9	12.3	12.8	8.0	13.8	9.7	8.5	6.9	8.1	9.2
WNW	13.3	16.0	18.7	17.6	22.1	19.3	19.9	18.6	17.6	16.6	17.5	15.7
NW	8.1	13.3	20.6	22.7	23.6	25.2	16.3	13.8	12.4	12.2	13.2	7.8
NNW	17.1	19.0	23.8	23.5	23.8	22.6	15.2	19.9	21.6	17.8	18.1	24.5
Calm	0	0	0	0	0	0	0	0	0	0	0	0
Total No. of Obs.	244	287	364	349	363	356	243	226	240	457	239	215

*Data from Uniform Summary of Surface Weather Observations, Part A, San Miguel Island, California (National Climatic Center, Asheville, N.C.)

22, Table 8). Additional information provided by Table 9 shows the mean direction of wind by month expressed as a percentage. These data show that the winds blow predominantly from the north-to-west quadrant during all months.

Annual wind velocity data (speed and direction) collected during 1940-42 based on 3,447 observations are expressed in Figure 23 and show that winds from the northwest quadrant prevailed 74 per cent of the time. A summary of wind velocity data for the period 1940-42 is given in Table 10. These data show that 49 per cent of the time the wind blew 16 miles per hour <u>or greater</u> and during such times blew from the northwest quadrant almost 90 per cent of the time. Table 11 shows monthly wind speed expressed as a percentage in speed groups. These data show that the spring and summer months are by far the windiest, May being the windiest with a mean wind speed of 21.1 miles per hour. The strongest winds, greater than 47 miles per hour, occur in the winter months but the strongest <u>persistent</u> winds occur from March through August.

These data give a striking picture of the strength and persistence of northwest winds on San Miguel, and an insight into why some early settlers referred to them as the "trade winds" (Dall, 1874; Yates, 1902). After reviewing wind data of stations along the whole of the west coast, from Vancouver Island to Baja, California, Cooper (1967) concluded that San Miguel Island and North Head, Washington, are the windiest of all.

The persistence of the northwest wind is due to the combined action of the semipermanent Pacific High of the north Pacific and the thermal

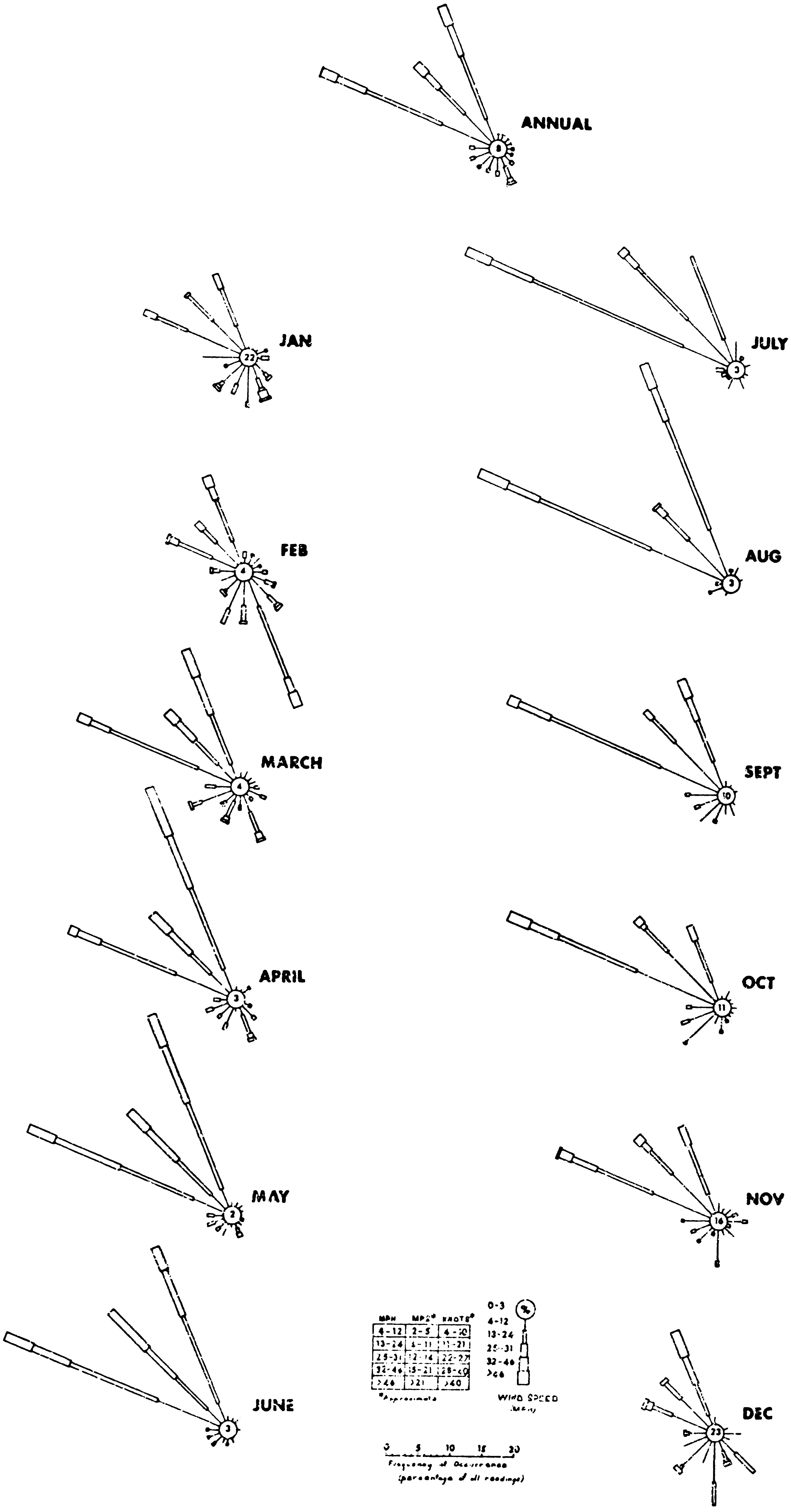


Figure 23. Wind velocity (speed and direction) based on 3,447 observations for the period February 1940-June 1942, San Miguel Island (data from Uniform Summary of Surface Weather Observations, Part A, San Miguel Island, California, National Climatic Center, Asheville, N.C.).

TABLE 10

Mean Annual Wind Velocities, February 1940-June 1942, San Miguel Island
3447 Observations

Vel. Dir.	0-3 MPH	4-15	16-31	32-47	Over 47	Total all Obs.	Total Vel.	Ave. Vel.	Total Obs. 3 MPH & Over	%
N	21	31	1	2		55	342	6.2	35	1.6
NNE	13	24				37	190	5.1	24	1.1
NE	13	23				36	171	4.0	23	1.1
ENE	3	22	1			26	209	8.0	23	0.8
E	13	25	7			45	362	8.0	32	1.3
ESE	3	24	6			33	349	10.6	30	1.0
SE	21	50	15	1		87	811	9.3	66	2.5
SSE	2	61	73	13	1	150	2742	18.3	148	4.4
S	27	71	18			116	974	8.4	89	3.4
SSW	5	76	20	1		102	1169	11.5	97	3.0
SW	43	87	9	3		142	1104	7.8	99	4.1
WSW	7	93	15	1		116	1172	10.1	109	3.4
W	20	90	15			125	1097	8.8	105	3.6
WNW	16	380	500	87	2	485	18187	18.5	968	28.6
NW	55	252	244	74		625	10772	17.2	570	18.2
NNW	5	175	473	108		761	16421	21.6	756	22.1
Calm	3					3				0.1
TOTAL	270	1484	1397	290	3	3447	56072	16.3	3174	XXXX
%	7.8	43.1	40.6	8.4	0.1	XXXX	XXXXX	XXXX	XXXX	100

*Data from Summary of W.B. Forms 1083 provided by National Weather Records Center, Asheville, North Carolina.

TABLE 11

Percentage Wind Speed by Month,* February 1940-June 1942,
San Miguel Island

	MONTH											
MPH	J	F	M	A	M	J	J	A	S	O	N	D
Calm	0	0	0	0	0	0	0.8	0	0	0	0	0
1-3	21.7	4.1	3.8	2.5	2.2	2.8	2.4	2.6	9.5	11.5	16.3	23.2
4-12	45.5	42.9	30.8	28.7	19.6	23.6	28.8	32.3	42.5	47.4	43.1	42.8
13-24	24.2	39.0	40.7	37.5	37.7	37.6	53.1	43.4	32.5	28.3	28.0	21.4
25-31	6.1	8.7	15.3	17.7	26.9	19.9	9.4	12.3	10.8	8.0	8.7	5.5
32-46	1.6	5.2	9.3	13.5	13.5	16.0	5.3	9.3	4.6	4.9	3.3	6.5
47 and over	0.4										0.4	0.5
Total 4 MPH & over	77.8	95.8	96.1	97.4	97.7	97.1	96.7	97.3	90.4	88.6	83.6	76.7
Mean wind Speed MPH	10.7	14.8	17.6	19.0	21.1	20.2	16.7	17.4	14.2	12.9	12.5	11.4
Total Obs.	244	287	364	349	363	356	243	226	240	247	239	215

*Data from Uniform Summary of Surface Weather Observations, Part A, San Miguel Island, California (National Climatic Center, Asheville, N.C.

low which develops over the interior valleys and deserts, as described earlier. The wind velocities for which San Miguel is so well known are due to the intense, semipermanent pressure gradient which exists off Points Arguello and Conception to the north and west of San Miguel (Figs. 12 and 13). Apparently the wind which flows from the Pacific High across the Los Angeles plains and southern California coast toward the interior heat low converges (and speeds up) off Points Arguello and Conception and diverges (and slows) as it moves towards the southern coast. The winds north of Point Arguello apparently are physically forced around the transverse Santa Ynez Mountains into a confluence or Venturi situation offshore.

The prevailing north-to-west surface wind pattern is periodically broken up, primarily by four temporary conditions. One condition develops when a transient cyclone moves through the region with attendant veering or backing winds. Such low pressure systems are common in late fall, winter and early spring.

The well-known Santa Ana wind is another temporary condition which develops when compressionally heated winds flow from the interior plateaus and deserts. The most frequent time for such winds is in the fall; as mentioned earlier, rising temperatures are associated with Santa Ana conditions.

A third condition which alters the northwest flow occurs when actively subsiding air aloft forces the semipermanent inversion to sea level which thereby destroys the marine layer of air and gives rise to variable winds. Rising temperatures also frequently are associated with inversion breakup and subsiding air.

A fourth condition of infrequent occurrence that breaks up the northwest flow which should be mentioned develops when upper level, high sun tropical disturbances arrive from central Mexican waters. Such disturbances may reach the southern California area several times during any given summer. During the first week of July, 1969, my wife, Diana, and I experienced such a storm on San Miguel with attendant thunder and lightning. The west end of the island experienced heavy rain, but just a few drops were noted on the east end. The clouds were at considerable altitude and the surface air was hot and sultry, an experience new to me on the island, but one that probably occurs one or more times each summer as it does on the mainland.

Fog and low stratus are of frequent occurrence on San Miguel, though not so common as the northwest wind. Of 9,922 observations made during 1894-1921 the per cent of clear, partly cloudy, and cloudy skies were 56.4, 23.1 and 20.5 respectively (Table 12). It should be kept in mind that observations during this period were made only once daily, and although fog observations were recorded during the first few months of record in 1894 little mention of it was made in the ensuing 28 year period. Apparently fog was entered on W.B. forms 1009 under either the cloudy or partly cloudy category, probably depending on whether it was thick or patchy.

Of 3,448 observations made on a three or six hour basis between February 1940 and June 1942 (Table 13), light to moderate fog was

TABLE 12

Monthly and Annual Sky Conditions, 1894-1921, San Miguel Island
9922 Observations

	J		F		M		A		M		J		J		A		S		O		N		D		YEAR	
1894	NR		NR		19	0	20	6	17	1	18	9	13	2	14	8	21	3	17	12	11	10	7	13	157	64
					12		4		13		3		16		9		6		2		9		11		85	
1895	11	10	11	6	15	7	19	6	18	8	14	12	9	18	14	4	11	15	13	8	24	2	26	4	185	100
	10		11		9		5		5		4		4		13		4		10		4		1		80	
1896	16	6	24	4	15	10	22	4	22	9	21	7	14	16	15	12	15	8	16	10	17	5	16	11	213	102
	9		1		6		4		0		2		1		4		7		5		8		4		51	
1897	15	8	10	14	14	15	25	1	15	11	22	4	15	14	15	14	25	3	20	9	24	6	NR		200	99
	8		4		2		4		5		4		2		2		2		2		0				35	
1898	16	13	8	15	12	14	20	9	15	15	10	18	10	21	6	25	6	19	27	0	24	2	17	9	171	160
	2		5		5		1		1		2		0		0		5		4		4		5		34	
1899	18	6	19	4	14	5	13	14	NR		4	15	16	11	16	3	14	2	23	7	17	9	21	7	175	83
	7		5		12		3				11		4		12		14		1		4		3		76	
1900	10	18	19	6	16	0	15	8	20	4	19	0	21	0	14	9	24	4	15	15	17	9	28	1	218	74
	3		4		15		7		7		11		10		8		2		1		4		2		74	
1901	13	6	14	8	21	6	13	13	14	2	20	2	23	1	19	1	15	5	11	13	10	16	22	8	195	81
	12		6		4		4		15		8		7		11		10		7		4		1		89	
1902	19	10	11	8	13	12	17	8	21	9	23	5	9	20	12	8	13	12	5	16	15	9	8	12	166	129
	2		9		6		5		1		2		2		11		5		10		6		11		70	
1903	4	12	10	14	5	15	6	22	1	21	1	23	6	18	1	25	2	20	1	19	2	18	12	15	51	222
	15		4		11		2		9		6		7		5		8		11		10		4		92	
1904	22	5	10	13	10	16	21	7	7	19	9	19	6	20	8	19	16	10	12	18	20	10	17	13	158	169
	4		6		5		2		5		2		5		4		4		1		0		1		49	
1905	8	13	6	16	12	10	25	2	21	7	11	14	8	14	NR		11	12	17	12	18	9	21	9	158	118
	10		6		9		3		3		5		9				7		2		3		1		58	
1906	18	9	4	17	10	10	20	9	16	8	23	5	15	10	10	13	11	12	18	10	16	10	18	3	179	116
	4		7		11		1		7		2		6		8		7		3		4		10		70	
1907	13	8	16	4	15	9	15	5	NR		21	13	26	2	16	13	16	9	16	7	21	7	NR		165	77
	10		8		7		10				6		3		2		5		8		2				61	
1908	19	9	16	4	18	6	19	9	24	1	9	12	12	14	16	11	12	8	22	1	12	6	NR		179	81
	3		9		7		2		6		9		5		4		10		8		12				75	
1909	3	5	15	9	19	10	7	12	15	12	7	15	10	12	9	19	14	6	12	11	20	3	15	7	146	122
	22		4		2		11		4		8		9		3		19		8		7		9		97	
1910	17	7	13	9	12	15	16	13	16	9	14	14	10	14	16	10	10	3	16	9	17	7	22	7	179	117
	7		6		4		1		6		2		7		5		17		6		6		2		69	
1911	15	4	22	0	12	8	20	1	21	1	8	5	18	0	20	0	23	0	22	0	20	0	22	2	223	21
	12		6		11		9		9		17		13		11		7		9		10		7		131	
1912	15	1	19	0	21	0	21	0	28	0	24	0	28	0	31	0	22	0	29	0	24	0	27	3	289	4
	15		10		10		9		3		6		3		0		8		2		6		1		73	
1913	21	4	14	6	23	2	23	4	16	6	15	5	24	6	17	7	16	6	17	5	20	5	20	3	226	59
	6		8		6		3		9		10		1		7		8		9		5		8		80	
1914	17	4	23	1	23	6	22	6	21	6	23	6	13	12	16	6	27	1	28	2	25	1	25	1	263	52
	10		4		2		2		4		1		6		9		2		1		4		5		50	
1915	17	2	15	6	22	2	20	0	27	0	20	6	19	8	16	8	21	3	16	7	24	1	22	5	239	48
	12		7		7		10		4		4		4		7		6		8		5		4		78	
1916	21	3	15	6	19	5	26	3	24	3	19	7	14	9	12	5	18	2	19	4	26	3	16	5	219	55
	17		8		7		1		4		4		8		14		10		8		1		10		92	
1917	NR		16	4	27	3	25	0	24	2	26	1	29	0	18	5	22	3	22	3	26	2	17	7	252	30
			8		1		5		5		3		2		8		5		6		2		7		52	
1918	19	4	17	2	17	1	27	0	26	4	20	4	25	3	20	0	21	0	23	1	17	3	28	0	260	22
	8		9		12		3		1		6		3		11		9		7		10		3		83	
1919	26	1	17	4	18	6	20	1	21	1	25	1	18	3	18	8	19	3	25	3	23	2	22	3	252	36
	4		7		7		9		9		4		10		5		8		3		5		6		77	
1920	16	2	17	4	27	0	23	1	26	2	22	5	17	6	16	2	19	2	24	3	23	4	18	1	246	32
	13		8		4		6		3		3		8		13		9		4		3		12		88	
1921	19	2	26	0	23	2	30	0	18	1	24	1	22	2	17	0	13	7	22	1	20	2	16	4	250	22
	10		2		6		0		12		5		7		14		10		8		8		11		93	
TOTAL	398	173	407	184	472	195	550	164	494	162	462	228	450	226	402	235	457	178	508	206	531	161	483	153	5614	2295
	235		172		201		126		150		150		162		200		205		154		148		139		2043	
	49.4	21.5	53.3	24.1	54	23	66	20	61	20	55	27	52	29.4	48	28	54.4	21.1	58.5	23.7	63.2	19.1	62.3	19.8		
	29.2		22.5		23		15		19		18		18.7		23.9		34.4		17.7		17.6		17.9			

SAMPLE KEY: CR PC
CY

where CR = Clear
PC = Partly cloudy
CY = Cloudy

*Data from W.B. Forms 1009.

TABLE 13

Summary of Mean Percentages of Atmospheric Conditions for San Miguel Island, February 1940 - June 1942 (After W.B. Forms 1082-1083)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
						General Conditions							
Lt. & Mod. Fog	4.9	3.4	8.9	18.6	15.6	25.6	21.4	23.1	16.7	7.3	7.1	6.9	13.3
Dense Fog	11.7	10.1	8.4	6.7	11.6	21.1	41.9	28.3	12.1	5.2	6.7	9.2	14.4
Thick Haze, smoke, dust	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Precipitation	9.7	10.4	7.5	7.2	0.0	1.7	1.2	0.0	0.0	0.8	1.7	16.1	4.7
Thunder storms	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.1
						Ceiling Height							
0-300 ft.	14.9	11.9	7.8	8.2	12.2	23.9	43.2	30.4	11.7	5.7	6.3	9.5	15.4
301-600 ft.	1.2	2.4	1.1	3.5	2.8	7.1	2.5	1.8	0.4	0.8	2.5	4.7	2.6
601-1000 ft.	13.3	14.3	16.0	23.9	14.1	27.1	26.7	15.2	13.8	10.5	6.7	7.1	15.7
1001-2000 ft.	15.4	24.8	9.2	16.6	7.7	9.4	9.5	15.2	7.5	4.9	2.5	11.4	11.2
2001-3000 ft.	7.1	11.5	3.6	3.5	0.0	0.6	2.1	1.8	5.4	2.8	4.2	9.0	4.3
3001-9750 ft.	0.0	1.4	2.2	0.9	0.0	0.0	0.0	1.3	0.0	0.4	1.7	4.3	1.0
over 9750 ft.	48.1	33.6	60.8	43.4	63.2	31.9	16.0	34.4	61.3	74.9	76.3	54.0	49.8
							Visibility						
0-1/8 Mi.	11.7	9.7	8.1	6.4	11.6	20.9	42.5	28.3	12.1	5.3	6.3	10.6	14.5
1/5-1/4 Mi.	0.0	0.7	0.5	0.6	0.0	0.3	0.0	0.4	0.0	0.0	0.4	0.5	0.3
1/2-1 Mi.	2.1	0.3	0.8	2.2	0.0	1.7	2.0	0.0	0.0	0.0	0.4	1.8	0.9
1 1/4-2 Inc.	0.0	0.0	0.0	0.0	0.5	0.3	1.6	0.4	0.0	0.8	0.0	0.5	0.4
2 1/2-6 Inc.	4.0	8.1	17.0	22.3	23.4	35.1	23.5	23.5	19.6	9.7	10.4	5.1	16.8
7-9 Inc.	2.8	3.7	1.4	0.8	0.8	6.4	0.8	4.5	0.8	0.8	0.8	0.9	1.6
10 and over	79.4	77.2	72.2	67.4	63.6	35.4	43.6	42.9	67.5	83.4	81.7	80.6	65.5

reported 13.3 per cent and dense fog 14.4 per cent of the time. Table 13 shows that spring and summer months experience frequent fog, July being the foggiest with dense fog over 40 per cent of the time followed by August with dense fog 28 per cent of the time. The three summer months of June, July and August experience fog between 20 and 40 per cent of the time. This persistent spring and summer fog helps depress the annual temperature curve of San Miguel shown in Figure 20 and results in persistently high relative humidities. The high incidence of spring and summer fog and low stratus markedly reduces evaporation and augments the low winter rainfall. Mrs. Herbert Lester who lived on the island during the 1930's and early 1940's said that there were times when the sun was not visible for days on end due to persistent fog (personal communication, 1965). This agrees with my own experience on the island during intermittent periods from 1964 to 1969. Greene (1887) observed that "From the mountains behind Santa Barbara . . . on days when Anacapa, Santa Cruz and Santa Rosa were in bright and cloudless sunshine, only a low fog bank indicated the locality of San Miguel." During many auto and airplane trips along the Santa Barbara coast, I have witnessed similar scenes, although the island is, of course, in many instances visible as well.

Probably the most revealing information on the temperature, wind and fog regime of San Miguel is expressed in Figure 24. The graph shows a highly interesting relationship between two wind speed curves, the annual temperature curve, and a curve showing the incidence of fog-induced low visibility. The months of February through May show a marked increase

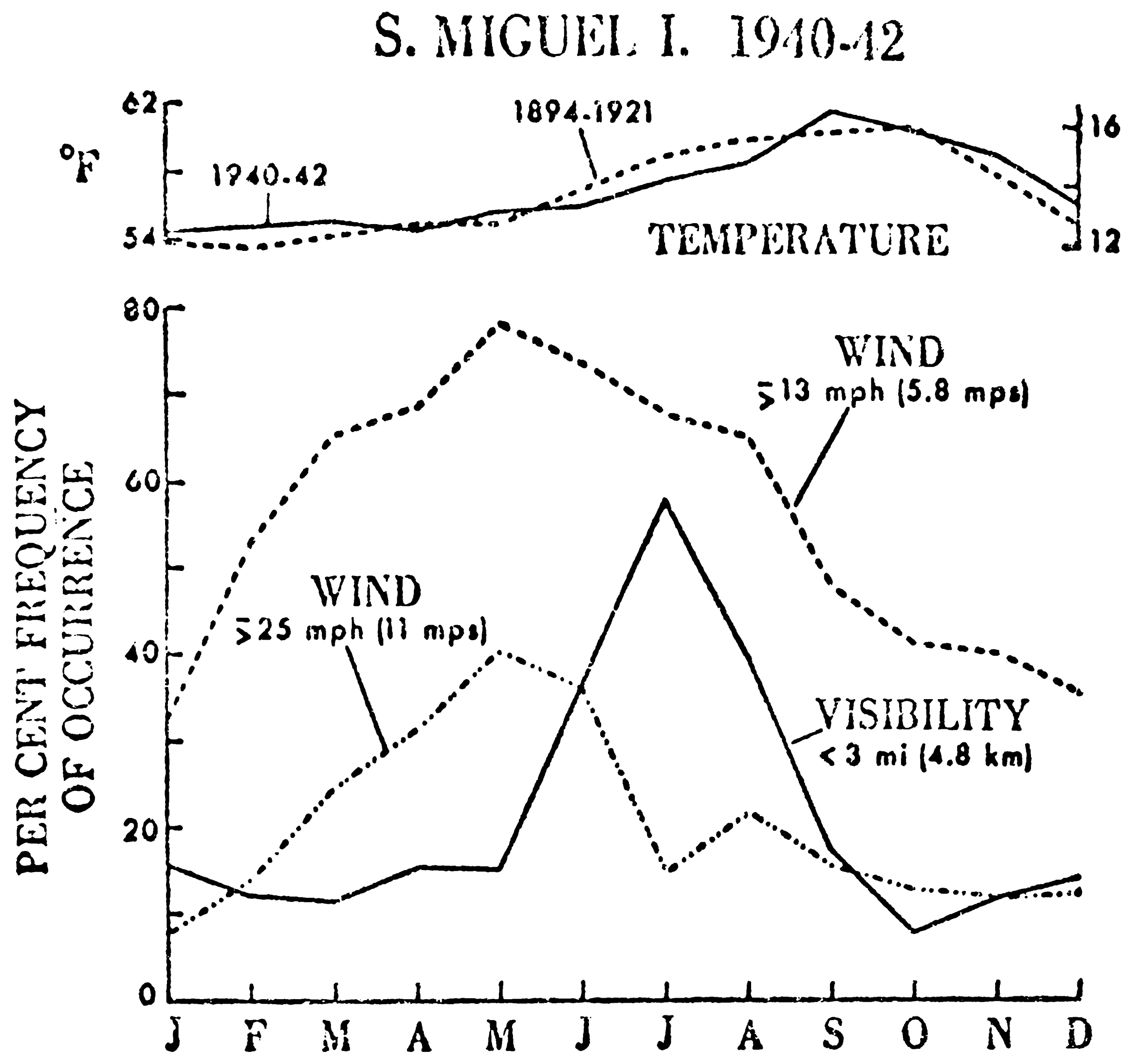


Figure 24. Relationship of annual means of temperature, wind speeds of 13 and 25 miles-per-hour or greater, and annual incidence of visibility less than one mile caused by fog. (Wind and visibility data from Uniform Summary of Surface Weather Observations, Part A, San Miguel Island, California, National Climatic Center, Asheville, N.C.)

in wind speed and frequency of occurrence at the very time that the temperature curve on San Miguel is depressed considerably below that of other nearby stations (see Fig. 20). The increase in wind speed probably induces upwelling which keeps water and air temperatures relatively low despite increased energy being pumped into the region by a sun that rises higher in the sky each day. When the winds taper off after the May peak, upwelling is concomitantly reduced and increasing thermal energy from the sun kicks the temperature curve up accordingly at this time. As the winds slow, conditions for fog tend to be maximized (note the decided July drop in the curve that shows wind intensity greater than 25 miles per hour which coincides with maximum fog-caused low visibility). The waters at the mouth of the Santa Barbara Channel are at this time still relatively cooler than the surrounding water and adjacent land. The latter rapidly heats up as the summer solstice approaches. Wind continues to decrease in intensity, upwelling and its effects are concomitantly reduced, and the regional surface temperature gradients are markedly reduced as August passes. Fog producing conditions are consequently minimized as summer ends and frequent warm, clear days occur through October. The data of Figure 24 lend strong support to Sverdrup and Fleming's (1941) model of wind-driven upwelling to explain the cold water found off Point Conception during the spring and early summer months, a model which has been questioned by Emery (1960, p. 102). High winds and associated upwelling also explain many facets of the island's unique climate, its large marine biomass concentration, and its consequent attraction to aborigines and, recently, scientists.

One of the best ways to gain a general insight to the climate of any area is to see what visitors have to say about it. As the following quotes show, most people speak disparagingly of San Miguel Island because of its inclement weather vis-a-vis strong winds and fog or low stratus.

> While on this island, we were much exposed to the grinding sand, driven in our faces like so much hail by a brisk northwest wind that lasted day and night during our four day's stay. The preparation of food at an open fire became impossible, and most of our provisions were thickly coated with sand (Schumacher, 1877).

> . . . the north-west winds whirl the sand in fog-like clouds that strike the practical eye with awe. . . . Sick and scaled by the exposure to the grinding sand, and under constant fear of losing our tents in the brisk blows that lasted day and night during our stay, we were glad to be able to charter a schooner which we found in port, owned by the Stock-raising Company (who were engaged shearing their starving sheep) . . . . (Schumacher, 1875.)

> This island . . . is nothing but a vast pile of continually shifting sand. The wind never ceases and a "calm" day there would be a storm most anywhere else . . . the sand ladened wind howls unceasingly (Wright and Snyder, 1918).

> . . . the hevy wind . . . blew during our entire stay. . . . After looking over some of the breeding colonies Owen and myself returned to camp leaving Howard on Prince Island with his blankets and expecting to return for him in the morning . . . however, the north-wester was howling again and we were unable to reach him for two days and then only with the aid of some Japanese abalone fishermen and their launch. . . . We remained on San Miguel 14 days, being unable to leave as soon as we had planned on account of rough weather (Willett, 1910).

> Winds harass San Miguel nearly every day in the year (Wheeler, 1944).

> In places the relentless [wind] erosion had attacked [human] burial plots, removing all of the finer material and leaving skeletons to fall apart, and roll about over the surface . . . [artifacts] have their entire surfaces more or less honeycombed, as a result of the sand blast to which they have been subjected . . . almost unbelievable havoc [has been] wrought . . . through the agencies of erosion (Rogers, 1929).

The following comments were made in a letter written November 30, 1871 on San Miguel by Stehman Forney, sub-assistant, U. S. Coast Survey, to his superior Benjamin Pierce, then Superintendent of the U. S. Coast Survey:

> The summer seems unprecedented with gales of wind and fog. Out of 204 days from April 12 to October 31st [there were] 153 [during which] I was unable to make any progress, from the constant strong gales day and

> night from the N.W. so violent that my tents could scarcely be secured, making it hopeless to attempt any field work, indeed the work executed has been accomplished under many adverse circumstances from the dampness of the atmosphere, fog and wind.

My own personal experience with the weather warrants comment. To cite one instance among many, during May 1969, I joined archaeologists Dr. Charles Rozaire and George Kritzman on a trip to San Miguel. We landed by helicopter in a strong wind near the north end of the dry lake. An Air Force surveying party of two men greeted us upon landing and returned to Point Mugu with the helicopter, but not without first warning us of the inclement weather they had experienced over the previous few days during which their tent blew down a number of times. During our stay the wind intensity increased and the stratus ceiling dropped to sea level resulting in moderate to dense fog. This windy fog prevailed for three days without let-up. During this time everything became soaked, the tents, our gear and clothes, and the grass. (Perhaps the greatest inconvenience, the one that has plagued my field work on the island, is the necessity of removing one's eye glasses every few seconds to wipe them free of excess salt particles and moisture and to remove sand and dust grains from the eyes. Under such conditions, which have prevailed during much of the field time allocated to this research, field work is practically impossible.) We were several days overdue leaving the island, which was in keeping with experience through the six-year intermittent field period of 1964-1969.

Fire

Although fire is normally thought of as more an ecologic than climatic phenomenon, conditions conducive to natural fires in southern California are climatically induced (high temperatures-low humidities) and fires may be started by lightning associated with thunderstorms. The purpose of the following discussion on fires is twofold. First, fire in a seasonally hot and dry region like California is a major factor in landscape modification through burning of vegetation which protects soil from the erosive effects of beating rains. Secondly, the presence of abundant charcoal in practically all of the fossil soils on San Miguel Island must be explained.

Fire is no stranger to the Northern Channel Islands, being historically documented on San Miguel, in 1967 when the Lester ranch house burned, on Santa Rosa (Orr, 1968) and on Santa Cruz (Williams, 1954; Dr. Carey Stanton, personal communication, 1971). These historic fires, however, were all man-caused. What about lightning-caused fires, have they ever occurred?

As a preview to the question of whether natural fires occur on the Northern Channel Islands, it is instructive to examine the record of natural fires on the adjacent mainland. During the ten-year period from 1961 through 1970 the Los Padres National Forest experienced a total of 125 lightning-caused fires.* Table 14 shows the years and months in

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*Personal correspondence, 1971, with J. Dillingham, Fire Dispatcher, U. S. Forest Service, Los Padres National Forest, 42 Aero Camino, Goleta, California. Mr. Dillingham also provided the data in Table 14 and information on the two coastal fires in the discussion which follows.

which the fires occurred. It is clear from the table that the months of June through October experience a high fire incidence, even though the Forest Service considers this a comparatively light lightning fire forest. According to the Forest Service, the majority of the lightning fires occur at higher elevations on the inland mountain ranges. However, lightning fires on the coast do occasionally occur. Two fires, both lightning-caused, have been recorded on the marine terraces along the Santa Barbara coast near Goleta, one on September 7, 1957 at 450 feet elevation west of San Jose Creek (T5N, R28W, Sec. 33) and another on October 2, 1968 in Glen Annie Canyon (T4N, R29W, Sec. 1) at 400 feet elevation.

TABLE 14

Lightning-Caused Fires: Los Padres National Forest, 1961-1970

Year	Total # of Fires	J	F	M	A	M	J	J	A	S	O	N	D
1961	22						1	1	20				
1962	1											1	
1963	3						1			2			
1964	6								4		2		
1965	18					2	2	2	12				
1966	15						4	2	7	2			
1967	29						5	1	14	9			
1968	10							3	3		4		
1969	15						1	4		10			
1970	6					1	1	2	2				
TOTAL	125					3	15	15	62	23	6	1	

Lightning-caused brush fires have also been reported in the Santa Monica Mountains. Three such fires occurred in September, 1967, and one in July, 1957; their locations are given below:

Sec. 22, T1N, R20W -- 9/1/67 (Potrero Valley area)

Sec. 14, T1N, R20W -- 9/29/67 (Potrero Valley area)

Sec. 34, T1N, R18W -- 9/28/67 (Malibu Lake area)

Sec. 26, T1N, R19W -- 7/10/57 (Lake Sherwood area)

This information was given in a letter dated January 24, 1972, by Captain J. Greer of the Conejo Valley Dispatch Center, Thousand Oaks, California who writes:

> . . . utility poles in those developed areas of the coastal plain and inland valleys seem to be a favored target to draw lightning strikes along our coastal area as it seems I hear of this happening anytime we have lightning activity associated with a storm.

Also on this matter, Mr. H. T. Anderson* writes:

> Your inquiry regarding the occurrence of lightning fires in the Santa Monica Mountains interests me. I first went to work in the Santa Monica Mountains for the Los Angeles County Forestry Department (now the L.A. County Fire Dept.) back in June of 1930. Except for four years I worked and lived in the area during this period. I cannot pinpoint the exact dates of the lightning fires that occurred but there were a few. I know of one about 1943 where a lightning bolt struck an oak tree in Agoura, blew it apart, and started a fire. I know because we responded to it. There were one or two others but I can't place the times or exact areas. I would say that lightning fires are of rare occurrence but all you would need would be one every 20 or so years to set fire to the mountains. The chaparral cover is usually burnt in a 25 to 30 year cycle and seems to have been developed by nature as a fire climax vegetation.
>
> I have walked every ridge and Canyon in the area and crawled through many miles of brush. I have yet to find a spot that did not show signs of old charcoal. In talking to the then 'old timers' I could find no one who remembered when

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*Mr. Anderson is Division Assistant Chief (ret.), Los Angeles County Fire Department and lives in Topanga, California; letter of January 11, 1972.

> some of the fire scars occurred. I am sure that nature has burnt these mountains many times before man was even heard of in these parts.

Although no record of lightning fires on the Northern Channel Islands exists per se, there is abundant evidence of lightning centers off the southern California coast. Such centers have been documented by flight controllers at the Los Angeles International Airport for at such times it is necessary that they route aircraft around them.* Such incidences are routinely reported to the National Weather Service which keeps a permanent record.** For example during the period from 1955 to 1966 a total of 66 lightning centers were reported off the southern California coast. The total number of occurrences by month is as follows:

J	F	M	A	M	J	J	A	S	O	N	D
4	1	8	3	3	1	14	3	9	13	7	0

Note that during these years over 40 lightning centers (60 per cent of the total) occurred in the months of June through October when conditions for brush fires in southern California are optimal (cf. Fig. 21). This computes to an estimated 3.3 potential lightning centers per year off the coast, or 330 per hundred years or 3,330 per millenium.

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*Personal communication, 1971, with D. M. Fuquay, Chief Research Meteorologist, U. S. Forest Service, Northern Forest Fire Laboratory, Missoula, Montana.

**Personal communication, 1971, with D. J. Haugen, Chief, Air Traffic Control Tower, Los Angeles International Airport: The 11-year record given here was furnished by Mr. Haugen and may be found in U. S. Naval Weather Service Command, Summary of Synoptic Meteorological Observation, North American Coastal Marine Areas, Vol. VII.

Thunderstorms occur occasionally on San Nicolas Island (de Violini, 1967, p. 58) and lightning has struck power lines on Catalina (M. J. Renton*, personal communication, February 22, 1972) and once even damaged the old Hotel Metropole in Avalon in the early 1900's. And, according to sources cited by Orr (1968, p. 69) lightning storms have also been observed over the northern islands many times. These observations are in agreement with early data collected on San Miguel. For example, on San Miguel Island 34 thunderstorms were reported during the 28-year period 1894-1921, 13 of which occurred during the months of June through October when conditions for natural fires are optimal (Table 5, Figs. 10 and 11). That computes to one thunderstorm during the dry season every 2.2 years, or 46 opportunities for fire per 100 years. According to the Forest Service the fire interval needed to maintain chaparral is only 3.3 fires per 100 years (Dodge, 1970). Where there is thunder there is of ccurse lightning, but whether it regularly strikes the ground or not is another matter. At any rate, if summertime thunderstorms occurred as frequently in prehistoric times as during 1894-1921 on San Miguel Island the opportunity for episodic natural fires clearly existed, in fact 460 opportunities every millenia.

Evidence of repeated natural fires on San Miguel Island during Pleistocene and Holocene times is conclusive. This evidence consists of abundant burned fossil vegetation, as for example partially charcoalized trunks still in growth position, and abundant charcoal in almost

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*Mr. Renton is Vice President of the Santa Catalina Island Company and has lived on the island 53 years.

all of the numerous Pleistocene fossil soils (paleosols) on the island. The in-situ charcoalized trunks have given radiocarbon dates of 17,370 ± 290, 17,730 ± 300, 20,130 ± 215, and greater than 40,000 radiocarbon years. Charcoal in paleosols but not associated with tree trunks in growth position has been dated at 6,450 ± 130, 9,360 ± 200, 9,750 ± 150, 14,430 ± 200, 21,480 ± 450, and greater than 40,000 radiocarbon years (Table 15).

Collectively the above data show that natural fires, though probably relatively rare on a short term basis, are in the long run periodically experienced on San Miguel and the other Northern Channel Islands. On the other hand it is almost certain that frequent fires were also started, either inadvertently or on purpose, by Indians and their early predecessors. Many of the aboriginal middens on the island show evidence of fire, and man has been on San Miguel Island for at least 8,000 years, perhaps far longer if Phil Orr's evidence on Santa Rosa Island is considered (Orr, 1956a, 1956b, 1960a, 1962a, 1962b, 1964, 1967, 1968; Orr and Berger, 1966). Unfortunately it is usually not possible to identify natural or man-set fires in the pedologic and stratigraphic record unless archaeological evidence is present.

One can say in retrospect that periodic fires are clearly documented in the late Quaternary record on the island, many of which almost certainly were set by humans, and some of which very probably were lightning-caused. Episodic fires have long been important in the environment of San Miguel Island.

TABLE 15 LIST OF RADIOCARBON DATES FROM SAN MIGUEL ISLAND, CALIFORNIA

Locality	Laboratory and Date	Description of Material Dated and Significance of Date
Simonton Cove		
SMI-171	UCLA-1458, >40,000 ry*	Charcoal collected 2 inches below top of lowermost (oldest) soil in that part of Simonton Cove where SMI-171 occurs.
SMI-172	I-4614, 21,480±450 ry	Charcoal randomly collected in Beachrock Soil. This date together with Wis-413 and I-4586 shows that probably all but the lowermost of the paleosols are within the range of the radiocarbon method.
SMI-174	I-4587, 6,450±130 ry	Abalone (*Haliotis rufescens*) shell; part of midden debris scattered throughout upper 15 inches of Abalone Soil; sample collected 8 inches below surface.
SMI-178	Wis-413, 20,130±215 ry	Charcoalized stump (probably *Rhus*) of subarboreal vegetation that grew in Simonton Soil immediately prior to time when Yardang Eolianite was emplaced.
SMI-179A	UCLA-1484A, 9,360±200 ry	Charcoal collected immediately below UCLA-1484B in Midden Soil.
SMI-179B	UCLA-1484B, 7,940±80 ry	Mussel (*Mytilus*) and abalone (*Haliotis*) midden debris collected throughout upper 20 inches of Midden Soil.
SMI-180	I-4586, 17,730±300 ry	Charcoalized stump (unidentifiable) collected from the lowermost part of Midden Soil. This date, together with Wis-413, suggests that the eolianite which lies between was emplaced rather rapidly.
SMI-248	I-5646, 5,070±105 ry	Pygmy mammoth bones collected in the modern soil at about 45 feet elevation along the lower slopes of Eagles Nest Cliffs. Bone collagen was the material dated.
SMI-256	I-4852, 7,580±140 ry	Mussel (*Mytilus*) and barnacle (*Balanus*) midden debris in upper 4 inches of Simonton Soil at Range Pole Canyon, overlain by 140 feet of eolian and fluviatile sediments.
Harris Point		
SMI-86	I-3717, 6,030±105 ry	Abalone (*Haliotis rufescens*) midden shell collected 20 inches below surface of modern soil.
SMI-87	I-4583, 9,750±150 ry	Charcoal, taken 20 inches below surface of modern soil about 40 yards west of I-3717.
Otter Harbor		
SMI-181	UCLA-1457, >40,000 ry	Charcoalized rhizoconcretion, formerly a trunk of subarboreal vegetation which grew in Simonton Soil, the lowermost and oldest paleosol in the Otter Harbor area.
Point Bennett		
SMI-177	I-4585, 17,370±290 ry	Charcoalized rhizoconcretion of former subarboreal shrub which grew in Point Bennett Soil. Poor preservation of wood structure allowed an identification only at level of "an angiosperm".
Upper Terrace, West End		
SMI-123	N-781, >37,800 ry	Pismo clam (*Tivela stultorum*) collected in terrace deposits about 290 feet above mean sea level.
Green Mountain Area		
SMI-131-133	I-4584, 14,430±200 ry	Charcoal collected from a truncated paleosol which overlies a buried "fossil forest" of rhizoconcretions which preserve evidence of a former subarboreal shrub type of vegetation.

* radiocarbon years before present

In summary, the historic and prehistoric climatic record of San Miguel Island reflects a repetition of events, or episodicity. Precipitation, temperature, wind, fog and even fire have definite seasonal, cyclic or episodic patterns of occurrence, and no evidence suggests a different pattern in prehistoric time.

9. Flora and Fauna

The biota of the Northern Channel Islands has long been of especial interest to professionals and layman alike. The presence of numerous endemic plants and animals has generated varying speculations on how long the islands have been isolated from the mainland, when in time the mainland connections were last broken, whether or not the islands were in fact ever connected to the mainland, when the islands were last connected to one another, and so on. Questions on whether the islands have served as local centers of biological speciation or are only repositories of relict populations that formerly were widespread on the mainland, or both, have also been raised. The presence of abundant pygmy elephant remains has led to the near unanimous conclusion among island researchers that the Northern Channel Islands were connected to the mainland during middle or late Pleistocene time. These and other provoking questions will be treated more fully in subsequent chapters. The following review will serve only as an introduction to the general flora and fauna.

Conditions bearing on the terrestrial biota of the islands differ in many respects from those on the mainland. Competition for nourishment and habitat may be greater owing to the relatively small area of islands, food itself (with respect to animals) may be different and restricted in variety, the climate is more temperate than on the mainland and insular isolation encourages inbreeding and restricts territoriality. For some forms (e.g., elephants) survival of the fittest is carried to an extreme degree on islands. If a species cannot readily adapt itself to changing environmental conditions, if it is unable to migrate to a more suitable habitat, then it must get along where it is--or perish. If taxa respond genetically to changing conditions then insular endemics may arise. However, insular endemics may also "arise" simply as a result of island-isolation of species which have been eliminated on the mainland for one reason or other. Such forms are then considered to be insular relicts. Often it is difficult, sometimes virtually impossible, to determine whether insular endemics are actually relict or reflect true genetic divergence. However, detailed statistical and other studies of existing island populations in regional context will often shed important light either way.

Several such studies were presented at the Symposium on the Biology of the California Islands held in 1965 and provide fairly convincing evidence that whereas some endemics are genetically divergent forms (Raven, 1967; Haller, 1967) others appear to be relictual in origin (Savage, 1967; Axelrod, 1967; Hubbs, 1967; Muller, 1967).

Flora

The vegetation of the Northern Channel Islands is in general quite varied and physiognomically very similar to that found on the adjacent mainland. The vegetation (Munz, 1959) varies from strand, marsh, scrub, and grassland types as on San Miguel, to the same plus coniferous forest, woodland-savanna, and chaparral on Santa Rosa and Santa Cruz Islands. Of the 11 vegetation types listed by Munz for all of California, eight are found on the Northern Channel Islands.

As might be expected, the north-facing slopes on the islands tend towards mesic conditions whereas the sun-struck slopes tend to be xeric (or less mesic) reflecting the east-west orientation of the islands. This directional aspect is strongly apparent in the vegetation. For example, on Santa Cruz and Santa Rosa Islands the closed-cone pine stands are restricted predominantly to north-facing slopes.

The floristic composition of the islands, on the other hand, is remarkably different than on the adjacent mainland. In 1965 a symposium on the biology of the California Islands was held in which it was brought out that a number of plants and some animals have continental species courterparts that are found farther north on the mainland, in some cases as much as 100 to 300 miles (Raven, 1967). Considering that the islands lie within a more effective maritime climatic regime than does the adjacent mainland (see for example, Fig. 20), such disjunct distributions are not surprising nor altogether unexpected. Insularity off California means lower temperatures and higher humidities which result in lower summertime evaporation, more effective wintertime precipitation, and thus more overall mesic conditions than the adjacent mainland. These maritime effects together with abundant north facing coastal slopes offer mesic habitats that are only duplicated farther north on the central California coast.

Endemism is another remarkable feature of the flora of the islands. It has long been known that the islands off California contain many endemic plants and animals. Of the 76 species, subspecies, and varieties of plants that are endemic to the southern California islands as a whole, 38 occur on the Northern Channel Islands, of which 23 are endemic only to the latter (Raven, 1967). The present flora, moreover, is missing a number of taxa that were present during late Wisconsin glacial time including such types as Douglas-fir and cypress, which are now found only as fossils.

Turning specifically to San Miguel, the botany of the island was first described by Greene (1887) and Brandegee (1888), and supplemented with later work by Hoffman (1932). These and other studies contain floristic data which have been collated and summarized by Trask (1941). Recent botanical work by Ralph Philbrick of the Santa Barbara Botanic Garden reveals that approximately 147 native vascular plants and some introduced species occur on San Miguel Island (Philbrick, personal communication, 1971).

Many of the plant species on San Miguel are common to coastal strand, coastal sage scrub, and to lesser extent fresh water march communities (Munz, 1959). Although no taxon is known to be endemic to San Miguel Island, nine of the 38 endemics that occur in northern group are present (Raven, 1967). They are:

Phacelia divaricata var. insularis
Castilleja hololeuca
Galium californicum var. miguelense
Galium catalinense var. buxifolium
Dudleya greenei

Astragalus miguelensis
Lavatera assurgentiflora
Amsinckia spectabilis var. nicolae
Malacothrix indecora

In summer, 1969, the writer discovered Ribes and Monterey pine (Pinus radiata) imprints* at Running Springs in travertine deposits of late Pleistocene and Holocene age. A shrub identified as "probably Rhus"** has been radiocarbon dated at 17,370 ± 290 ry***.

The present plant cover, where it exists, consists predominantly of perennial grasses and herbs that grow well on a sandy or clay substrate on rolling or gently sloping topography in exposed situations. Shrubs and bushes occupy many of the wind-protected arroyos and gullies. Certain parts of the island, however, are essentially free of ground cover, such as on dunes, stripped soils and caliche terranes (Plates 1, 2, 3).

Large areas of grassland cover the eastern third of the island and the area from Green Mountain west to the Dry Lake (Plates 4, 5, 6a) is characterized by many perennial types such as melic grass (Melica), salt grass (Distichlis), rye grass (Elymus), wheat (Agropyrum), needle grass (Stipa), blue grass (Poa), bromegrass (Bromus), and barley (Hordeum). Greene (1887) attributed the prevalence of perennial grasses on San

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*Identified by Jack Wolfe, U. S. Geological Survey, Menlo Park, California.

**R. C. Koeppen, botanist, Wood Identification Research, Forest Products Laboratory, Madison, Wisconsin.

***Radiocarbon years. See Table 15 for additional information on this and other C-14 dates.

Miguel to the winter rains and frequent summer fogs. He observed that many of these grasses, after being buried by encroaching sand dunes, have the ability to re-establish themselves. Many of the dunes on San Miguel that were active in former years are now stabilized and blanketed by grasses and herbs. Aerial photographs show that significant dune stabilization has occurred over the past several decades which in part can be attributed to the cessation of sheep ranching activities, and to the ability of grass to regenerate growth after burial (see photomaps 1, 2, 3 and 4, and Plate 7).

Of the herbaceous types, the locoweed or milkvetch (Astragalus miguelensis) is one of the more abundant and conspicuous on San Miguel. In some areas the locoweed seems to exert the initial influence of dune stabilization, as on Harris Point. In fact in most areas where dunes are (or are becoming) stabilized the locoweed is commonly found, and frequently precedes the establishment of grass. Probably one of the more lasting impressions one retains of the island during spring months is the constant crunching underfoot of the inflated Astragalus seed pods.

Coreopsis, (C. gigantea), with its conspicuous erect, fleshy stems is a showy herbaceous shrub that grows in canyons and on rocky headlands on the north slopes of the island. Harris Point, Nidever Canyon, and Hoffman Point display the best stands of Coreopsis, although the shrub may be found at many places on north-facing slopes. Many other members of the Compositae family are common to San Miguel, and are most conspicuous in spring when they present a pleasant and colorful display.

Several stands of prickly pear cactus (Opuntia engelmanni var. littoralis) occur on the south and east sides of San Miguel and at isolated points on the north bluffs; the most extensive stand occurs in South Green Mountain Canyon. Another succulent, iceplant (Mesembryanthemum), is an introduced genus with two species that occur abundantly at various places on the island.

Coyote bush (Baccharis pilularis, var. consanguinea) is the dominant shrub on the island and may be found in fair abundance along many arroyos, especially Willow Canyon and its tributaries and Nidever Canyon which flows north into Cuyler Harbor (Plate 8a, 8c). Two other shrubs, tree mallow (Lavatera assurgentifolia) and Lemonadeberry (Rhus integrifolia) also are present but rare (Plate 8c). Tree mallow was seen in 1969 at only one place, in the sand dunes on the approach to Point Bennett. Lemonadeberry is represented by only a few individuals at the mouth of Willow Canyon and at several restricted bluff localities on the north side of the island.

The only trees on the island are several Toyon (Heteromeles arbutifolia) and Arroyo Willow (Salix lasiolepis) both of which occur along several arroyos and washes (Plate 9b), specifically, Willow Canyon, Conroy wash, and North Green Mountain Canyon. Greene (1887) expressed the opinion that on a persistently windswept island like San Miguel one should not expect to find an arboreal vegetation. Some evidence supporting this view occurs near Christy's at the exposed west end of Santa Cruz Island where high winds have given the chaparral a markedly stunted form not much higher than a tall man's knee. By the same token, as on Santa Cruz Island, many places on San Miguel are wind-protected and would permit in arboreal vegetation more respectable than that which presently exists.

The character of the present vegetation, however, is different from that which existed formerly, even within historic times. The changes which have occurred largely reflect excessive aboriginal and post-aboriginal cultural pressures in the immediate past. Indeed, San Miguel offers a perceptive example of the effects of aboriginal burning, post-aboriginal overgrazing and cultivation, and other cultural activities in a wind-swept insular environment. A detailed insight of these changes is covered in Chapter 7.

Fauna

While it is true that compared to plants the animals of the Channel Islands are conspicuous in their lack of species diversity, they are by no means less interesting. Excluding man, at least 56 species of mammals and herpetofauna occur, 19 of which are known to have been introduced purposely or accidentally by man. Of the 37 remaining "native" species, seven are marine mammals*; 14 are land mammals, and 16 are herpetofauna (Bartholomew, 1967; von Bloeker, 1967; Savage, 1967). Only two extant

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*Including the sea otter which has been locally exterminated since after the turn of this century (Merriam, 1904). Claims of sea otter sightings, some made by professionals, on the Northern Channel Islands have been made from time to time.

taxa are endemic to the islands, one at the generic level, the other at the species level; respectively they are the island night lizard (Klauberina riversiana) and the Channel Islands fox (Urocyon littoralis) (Plate 15). Table 16 lists all the islands of southern California and the species that occur on them.

On the Northern Channel Islands 35 extant mammalian and herpetofaunal forms are known to occur of which at least 14 are known from San Miguel Island.* Sea mammals account for six of the 14, feral domesticates account for three, while one fox, a mouse, one salamander and two lizards account for the remainder. To this list should be added pygmy mammoth which lived on San Miguel during the latter part of Quaternary time.

At the west end of San Miguel Island flourishes one of the largest pinniped populations in the western Pacific south of the Pribilofs. As of 1970 approximately 21,000 pinnipeds made the island their temporary or permanent home (Robert DeLong, personal communication, 1971). Estimated pinniped populations per species is given in Table 17.

Included is a small breeding population of the Northern Fur Seal (Callorhinus ursinus) first discovered in 1968; the San Miguel breeding population is the only one known south of the Bering Sea.

Pinnipeds appear to have been on San Miguel at least intermittently for a long time. The calcareous eolianite which overlies Pleistocene

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*According to C. D. Voy (ca. 1893) a small skunk was caught in a trap some years prior to his visit to the island circa 1893. Also, on July 2, 1966, I saw a house cat in the rocks at Cuyler Slide.

TABLE 16

Mammalian and Herpetofauna* of the Southern California Islands**
(X = present; O = formerly present; E = endemic species)

	SMI	SRI	SCI	A	SBI	SNI	CAT	CLEM
SALAMANDERS								
Aneides lugubris							X	
Batrachoseps pacificus (Channel Islands Salamander)	X	X	X	X			X	
Batrachoseps sp.			X					
FROGS								
Hyla regilla		X	X				X	
LIZARDS								
Uta stansburiana			X	X		X	X	X
Sceloporus occidentalis (Island Fence Lizard)	X	X	X					
Klauberina riversiana (Island Night Lizard)					E	E		E
Eumeces Skiltonianus							X	
Gerrhonotus Multicarinatus (Western Alligator Lizard)	X	X	X	X			X	
SNAKES								
Thamnophis couchii							X	
Diadophis punctatus							X	
Coluber constrictor			X					
Lampropeltis getulus							X	
Pituophis melanoleucus			X				X	
Crotalus viridis							X	
Hypsiglena ochrorhyncha			X					
SEALS								
Mirounga angustirostris (Northern Elephant Seal)	X	X	?	X	X	X	X	X
Phoca vitulina (Harbor Seal)	X	X	X	X	X	X	X	X
Arctocephalus philippi townsendii (Guadalupe Fur Seal)	X	?	?	?	?	?	?	?
Callorhinus ursinus (Northern Fur Seal)	X	?	?	?	?	?	?	?
SEA LIONS								
Eumetopias jubata (Stellar Sea Lion)	X							
Zalophus californianus (California Seal Lion)	X	X	X	X	X	X	X	X
SEA OTTER								
Enhydra lutris	O	O	O	O	?	O	O	O
SHREWS								
Sorex ornatus (Adorned Shrew)							X	
BATS								
Myotis evotis (Big-eared Myotis)			X				X	
Myotis thysanodes (Fringed Myotis)								X
Myotis californicus (California Myotis)	?	X	X	?	?	X	X	X
Eptesicus fuscus (Big Brown Bat)			X					
Plecotus townsendii (Lump-nosed Bat)			X			X	X	X
Antrozous pallidus (Pallid Bat)			X				X	
Tadarida brasiliensis (Free-tailed Bat)			X					X
RODENTS								
Spermophilous beecheyi (California Ground Squirrel)							X	
Reithrodontomys megalotis (Big-eared Harvest Mouse)			X				X	X
Peromyscus maniculatus (Deer Mouse)	X	X	X	X	X	X	X	X
Microtus californicus (California Meadow Mouse)								X
FOX								
Urocyon littoralis (Channel Islands Fox)	E	E	E			E	E	E
SKUNK								
Spilogale gracilus (Spotted Skunk)	O	X	X					
KNOWN INTRODUCED SPECIES								
European hare (Lepus europaeus)				X				
European rabbit (Oryctolagus cuniculus)					X			
Harvest mouse (Reithrodontomys Megalotis)								X
Meadow mouse (Microtus Californicus)								X
Black and roof rats (Rattus rattus)				X			X	
Brown rat (Rattus norvegicus)							X	
House mouse (Mus musculus)							X	
Dog (Canis familiaris)	O	X	O	?	?	O	X	O
House cat (Felis catus)	X	X	X	X	X	X	X	X
Horse (Equus caballus)	O	X	X			O	X	X
Burro (Equus asinus	X							
Swine (Sus scrofa)	O	X	X				X	
Dwarf elk (Cervus nannodes)		X						
Snow deer (Capreolus pygargus)		X						
Mule deer (Dama hemionus)		X					X	
Goats (Capra hircea)	O			?			X	X
Sheep (Ovis Aries)	X	O	X	O	O	O	X	X
Buffalo (Bison bison)							X	
Cattle (Bos taurus)	O	X	X			O	X	O
EXTINCT SPECIES								
Pygmy mammoth (Elephas exilis)	OE	OE	OE			?		
Giant deer mouse (Peromyscus nesodytes	?	OE						
Peromyscus anyapahensis				OE				

*Largely after Bartholomew, 1967; von Bloeker, 1967; Savage, 1967.

**von Bloeker reported Gerrhonotus coeruleus from San Miguel but the species is not present in his collections which are curated at the Los Angeles County Museum of Natural History (J. W. Wright, Curator of Herpetology, personal correspondence, 1971).
Also, O'Neill (1939) mentioned the former presence of "wild, brown goats" on Anacapa but I have not seen other references that support the claim.

TABLE 17

Estimated Pinniped Populations, 1970, San Miguel Island*

Species	Population Estimate
California Sea Lion (_Zalophus californianus_)	Ca 15,000
Northern Fur Seal (_Callorhinus ursinus_)	Ca 375 (±?) 50
Guadalupe Fur Seal (_Arctocephalus phillippi townsendii_)	6-10 _male_ visitors annually (no females recorded--no permanent population)
Northern (Stellar) Sea Lion (_Eumetopias jubata_)	100 ± 50%
Northern Elephant Seal (_Mirounga angustirostris_)	5,000 ± 50%
Harbor Seal (_Phoca vitulina_)	500 ± 20%
	20,975 ± ?

*Data from Robert DeLong, Bureau of Commercial Fisheries, Seattle (Personal communication, 1971).

beach gravels at locality 4 (map 5 in pocket) yielded bones of a juvenile _Arctocephalus_ (identified by C. A. Repenning, U.S.G.S.). The bones consisted of four fragments of two innominate bones, the sacrum in two pieces, one flipper digit element, and a petrosum.

The Channel Islands fox is of particular interest because it is one of only two endemic land animals and it occurs on the six largest Channel Islands, namely San Miguel, Santa Rosa, Santa Cruz, San Nicolas, San

Clemente and Catalina.* According to von Bloeker (1967) there are three species of foxes that occur in Guatemala and extreme southern Mexico which bear closer affinities in skull morphology and size relationships to the Channel Islands fox than does the gray fox on the adjacent California mainland.

There is evidence to support the idea that the Channel Islands fox (Urocyon littoralis) initially was endemic only to the Northern Channel Islands, which during full glacial times was a single large island, and dispersed to the southern islands via aboriginal canoe, otter hunters, and early European settlers. This idea, originally set forth by Vedder and Norris (1963) cannot be proved but has support from several lines of evidence to be presented in Chapter 4.

Another mammal of interest is the Channel Islands skunk (Spilogale putorius) which occurs only on Santa Cruz and Santa Rosa Islands, but which also may have been present recently on San Miguel (see footnote, Table 16). According to Van Gelder (1965) there is little distinction other than size between the Channel Islands and mainland skunk, and

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*Discussion and further treatment of the Channel Islands fox may be found in the works of Baird (1857), Blake (1887), Rogers (1929), Grinnell (1933), Grinnell, et al. (1937), Stock (1943), von Bloeker (1967); and Remington (1971). Blake and Baird observed that the Channel Islands fox differed from the mainland gray fox in its color, much smaller size, and dentition. Rogers suggested that the last two characters reflected an isolated gene pool, elimination of strenuous activity associated with running down larger prey than is presently found (e.g., rabbits), and change of diet to where energetic mastication is no longer required. Stock thought the small size of the fox reflected either genetic divergence or a relictual origin stemming from prior insular isolation. A detailed discussion of the fox will be given in Chapter 4.

even less distinction between the Santa Cruz and Santa Rosa Islands forms. The matter of origin of the skunk also will be taken up in Chapter 4.

Besides man, the animal that has received the main focus of interest from bioscientists and geoscientists is the pygmy elephant. Ever since 1873 (Anonymous, 1873) when it was first announced that elephant remains were present on the Northern Channel Islands, intense discussion has centered on questions such as when did the elephants arrive? When was the mainland connection severed? How long were the elephants isolated? And, What happened to them? A question which to my knowledge has not been asked is, What effect, if any did a resident population of elephants have on the insular vegetation, soils, and geomorphology? For example, in recent years fluctuating levels of elephant numbers, in part drought related, have totally changed the character of the vegetation and soils in certain "ecological islands" in Africa. Because abundant elephant remains occur on San Miguel these questions are important. Indeed, the various late Pleistocene geohistoric interpretations and reconstructions of the Northern Channel Islands vis-a-vi land bridges and sea level fluctuations are based on the fact that elephants formerly were present. Detailed, discussion of these matters will be taken up in Chapter 4.

CHAPTER III

MARINE TERRACES

As noted in the previous chapter, one of the most distinctive aspects of the insular landscape of San Miguel is its mesa-like, marine terrace character. This tableland, which gives the island its major form, is a product of marine erosion under the influence of changing sea-levels during the Pleistocene. Because an understanding of how marine terraces form, their age, and how they relate to other marine terraces in California is critical to an understanding of the landscape evolution of San Miguel Island, this chapter is devoted to marine terrace origins, correlations, and characterizations.

Following a general introduction are two brief sections on terminology used to describe terraces and methods used to determine terrace levels. Because inconsistent use of terms and methods characterize certain previous studies of marine terraces these sections are necessary in order to minimize confusion. A section on terrace descriptions and interpretation follows, but was placed in Appendix A to preserve continuity in the text; the data, however, are important to the section in the text which follows that deals with terrace correlations and their ages. Also in this section, light is shed on the relations of San Miguel terraces to terraces on other islands and the mainland. There then follows a discussion of the modern marine terrace that is presently forming through the combined processes of mechanical, biological and geochemical weathering and erosion. Finally some of the Pleistocene and modern terraces have beachrock formed on their erosional surfaces, and its age and characteristics are discussed.

10. Pleistocene Terraces

As the Channel Islands Platform was gradually uplifted, Green Mountain and San Miguel Hill must have initially appeared as small islets, probably with steep cliffs comparable to Prince Island and Richardson Rock today (a general impression of how this landscape may have appeared may be obtained by substituting sea-level for the 500 foot contour on the surface profiles of Map 2). When it was that San Miguel first appeared as an island we may only speculate. If the Pleistocene Epoch began some 2 million years ago or more, as many now believe, and late Pleistocene spanned roughly the last third of that time (about 700,000 years),* then probably San Miguel was "born" as an island in late Pleistocene time, although a greater age cannot be ruled out. Since then the surf zone has passed over and etched the entire surface of the island mainly as a result of the semi-continuous rise of the Channel Islands Platform, but also because of glacially controlled eustatic sea-level oscillations. Thus, because the entire Pleistocene surface of the island has had previous experience as a beach it is not surprising to find beach deposits at any elevation.

There were several periods during the Pleistocene when world sea-level is believed to have been relatively stable, or at least eustatically oscillated much less than at other times (still-stands). It is thought that during still-stands and at times of eustatically rising

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*Until recently it has been conventional to consider the Wisconsin Glaciation as equivalent to "late Pleistocene." Some would also include the Sangamon Interglaciation. However with the widespread acceptance of an extended Pleistocene Epoch it seems reasonable to also extend the subdivisions of the Pleistocene.

sea-level, marine terraces were formed. Since the seas are interconnected, eustatic fluctuations of sea-level were worldwide. Terraces formed during such times are time-equivalent, thus correlative, and serve as worldwide geochronological datums. This picture becomes blurry in tectonically unstable areas like California where the difficulty lies in separating tectonic from eustatic terraces. Regardless of this inherent geographical difficulty marine terraces on the mainland and other Channel Islands have been actively studied, and some have been ecologically and radiometrically dated and correlated (Blake, 1856; Johnson, 1858; Lawson, 1893; Smith, 1900, 1933; Rode, 1930; Davis, 1933; Putnam, 1942, 1954; Woodring, et al., 1946; Upson, 1949, 1951; Alexander 1953; Bradley 1956; Poland, et al., 1956; Poland, et al., 1958; Hoskins, 1957; Orr, 1960a; Valentine, 1961, 1962; Merselis, 1962; Vedder and Norris, 1963; Lipps, 1964; Palmer, 1967; Valentine and Lipps, 1967; Veeh and Valentine, 1967; Lipps, et al., 1968; Valentine and Veeh, 1969). It would, of course, be desirable to locally and regionally correlate the terraces on San Miguel with other terraces, especially those that have been dated. However, before analyzing and attempting to correlate the terraces it is instructive to define the terms that will be used in describing them.

Terminology

The terminology used in this study is modified after Rode (1930), and Bradley (1957), and Orr (1960a), and is given in Figure 25, which shows the relationship of terrace elements.

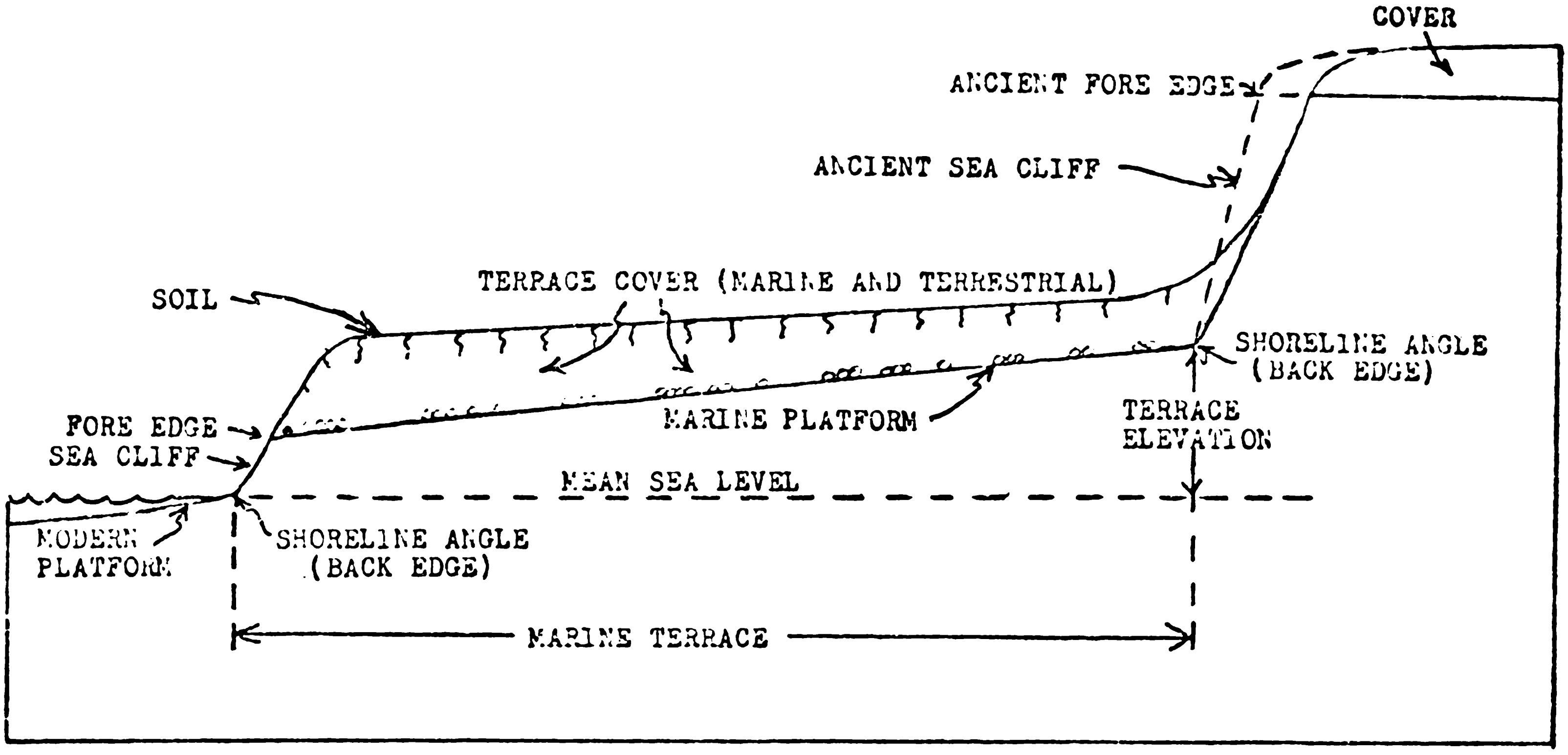

Figure 25. Marine terrace terminology modified after Rode, 1930, and Orr, 1960a. Due to weathering and erosion the ancient fore edge and sea cliff (dashed lines) have retreated landward (solid lines). The shoreline angle is considered by some to be the most important element of the marine terrace because it presumably approximates high sea-level or a sea-level stand during the Pleistocene.

In this study the terms shoreline angle (Davis, 1933; Bradley, 1956; Smith, 1960) and back edge (Lawson, 1893; Rode, 1930; Emery, 1958; Merselis, 1962) are used synonymously. The shoreline edge, or back edge, is the angular contact between the landward limit of the marine platform and the adjacent sea cliff. Marine platform is used in place of the strongly genetic terms surf-cut platform (Lipps, 1964), wave-cut platform (Bradley, 1957, 1958; Orr, 1960a, and others) and abrasion platform (Rode, 1930; Alexander, 1953), because evidence suggests that biological and geochemical factors as well as waves and mechanical abrasion are highly active agents of platform development (Emery, 1946, and this study). A marine platform is the bedrock beveled surface over which lies the terrace cover.

As far as the writer can determine, most investigators have conceptually associated a (one) marine terrace with a (one) marine platform. However, Orr (1960a) described a (one) marine terrace on Santa Rosa Island as having three associated marine platforms with shoreline angles at 25, 75, and 100 feet elevations. In hopes of avoiding the issue, if it is an issue, of which concept is best, for purposes of clarity and simplification a marine terrace in this study is assumed to have only one platform, one shoreline angle (back edge), one fore edge, and a Quaternary cover consisting of marine or non-marine deposits or, as is common, both.

Methods

Terrace elevations given in this study, with five exceptions, were determined by use of an Abney hand level. The five exceptions are elevations that were estimated from U.S.G.S. topographic maps (7.5 minute series with a 25-foot contour interval) and are noted in text. Originally it was planned to use a precision barometer to determine elevations but because of apparent rapid pressure changes on the island barometric readings were found to be unreliable. For example, in one instance, after a fore edge elevation had been measured barometrically, upon returning to sea-level the barometer registered 38 feet, whereas it has been set at zero one hour earlier at the beginning of the transect. In another instance, it was 25 feet off.

The most accurate way to measure terrace elevations is, of course, with a surveying transit and stadia, but this requires two people and takes much time. Because I had no field assistant, and due to the great amount of time involved in this method, the Abney level was necessarily employed and found to be satisfactory. Mean sea-level was used as the base level for each transect. While at the water's edge just prior to making a transect the hand level was sighted to the oceanic horizon and, if necessary, calibrated so that the spirit bubble indicated true horizontality. This operation was done in a crouched position so that the level was as close to sea-level as possible without getting it and the operator too wet. Also at this time, the time and date were recorded so that corrections for tidal variations could be made by consulting tidal tables.

Because unavoidable small errors are inherent in the hand leveling operation, both in estimating tide level at the outset of the transect and in the actual leveling operation itself, the elevations given in this study should be considered approximate. In order to check for accuracy several of the long transects were repeated, and the greatest discrepancy recorded was 3 feet (234 versus 237 feet elevation).

Terrace Descriptions and Interpretations

For convenience I have arbitrarily grouped the terraces on San Miguel Island into three types: high terraces (greater than 150 feet elevation), intermediate terraces (more than 30 feet but less than 150 feet elevation), and low terraces (less than 30 feet elevation).

Evidence for the highest sea level on the island occurs as residual rounded and wave-worked pebbles and gravels at about 800 feet elevation (topography map estimate) just west of the summit of San Miguel Hill south of the road. No marine shells or in situ organic marine debris were observed with the pebbles, and if originally present have probably long since been leached away. This is the oldest Pleistocene deposit recognized on San Miguel Island. No evidence of terrace debris was observed on the summit area of Green Mountain, which is locally veneered with a shallow soil.

The surface profiles on Map 2 show that San Miguel Hill has gentler slopes than Green Mountain, although both were formerly exposed to the erosive force of Pleistocene seas when they existed as small islets. The relatively gentler configuration of San Miguel Hill probably owes its origin either to its sheltered location behind Green Mountain with respect to prevailing wind and wave direction, or to differences in bedrock lithology, or both. Green Mountain is comprised predominantly of Cretaceous sandstone (Weaver and Doerner, 1969) and has slopes that are steepest on the northwest, north and northeast, whereas San Miguel Hill is underlain by volcanic rocks and has relatively smooth slopes in all directions.

The next highest beach deposit was observed on the west side of Green Mountain at about 500 feet elevation (topographic map estimate) overlooking Voy Canyon (SMI-13) above the cave. Abundant marine shells and rounded, wave-worn beach cobbles and boulders are present, some of which contain holes left by rock-boring mollusks. Another beach deposit at about the same elevation (topographic map estimate) occurs just above the dry falls along the bedrock-Quaternary sediment contact at the bottom of North Green Mountain Canyon at SMI-79. An unidentified vertebrate bone was observed here along with a few rounded, wave-worn pebbles and several marine shells.

Between elevations of 500 and 200 feet above mean sea-level numerous Pleistocene beach deposits are present at various places about the island, especially on the west, north, and east sides. They are particularly common between 200 and 350 feet elevation. However, because of time constraints placed on field work only several of the beach deposits were studied in any detail, though all that were seen were mapped and appear on Photomap 5, and the elevation of most was determined. A review of these beach deposits and marine terraces by locality is found in Appendix B. These locality descriptions begin at Voy Canyon on the south coast, continue west to Point Bennett, then northeast to Harris Point, Cuyler Harbor, and concluding with the east end terraces. A map showing localities where the descriptions and measurements were made is shown on the last page of Appendix B.

Because of time constraints placed on the marine terrace phase of field work only a general reconnaissance was made of the eastern third of the island and the south coast from Crook Point to Cardwell Point. The reconnaissance revealed a number of Pleistocene beach deposits exposed in Willow Creek and its tributaries, for example at SMI-61, 62, 66, just north of SMI-44, and in the northeast trending tributaries near SMI-116. The general marine terrace character of the landscape of the eastern third of San Miguel may be seen by reference to Plates 62-65 and to the surface profiles on Map 2 in pocket.

There are abundant fossiliferous beach deposits and topographic evidence of old shorelines on the upper mesa from Green Mountain west to Caliche Flats, and from San Miguel Hill east to the cliffs at Cardwell Point. Water-worn cobbles and boulders occur at many places along the bedrock-Quaternary contact in gullies which head on the west flank of Green Mountain and in tributaries of Willow Creek east of San Miguel Hill. These beach deposits and the lack of prominent sea cliffs on the smooth central slopes suggest gradual seaward progradation of old shorelines during slow emergence (or sea-level regression) at some early period in the history of the island.

One of the more unfortunate findings during the course of field work is that even though topographic evidence shows clearly that San Miguel has been shaped primarily by the sea there is a dearth of exposed shoreline angles. Indeed, although several shoreline angles of the 20-25 foot terrace are exposed, only one high terrace shoreline angle of the 325 foot terrace was observed, and nothing that could unequivocally be called an intermediate terrace shoreline angle was observed, although several at about 75 feet elevation were inferred. The reason for the dearth of exposed shoreline angles probably reflects the small area of the island, its small drainage basins and consequent lack of erosion and exposures (however, it is possible that further field work may yield additional information, particularly on the southeast side of the island which was little studied). It is worth noting that exposed shoreline angles are exceedingly rare along all the world's coasts, including mainland California (Palmer, 1967, p. 54).

In retrospect, the shoreline angles of two terraces were observed, one at about 20-25 feet elevation (low terrace) and the other at about 325 feet elevation (high terrace). In addition, an intermediate terrace shoreline angle that seems to approximate 70-75 feet elevation was inferred. This latter inference is thought to be fairly sound since in addition to the field data, visual inspection of air photos (see Plate 14) and topographic maps (Map 3) clearly show that at least one major intermediate terrace occurs along the five mile stretch of coast from Point Bennett to Harris Point. It is noteworthy that convincing evidence for a 100 foot terrace, which occurs on Santa Rosa (Orr, 1960a) and other parts of southern California (Hoskins, 1957; Merselis, 1962), was not observed on San Miguel. This is not to say that a terrace at that elevation is absent, but simply that no strong field evidence for it was seen.

Inferred environments at time of terrace formation were made only at high terrace localities SMI-245 in Busted Balls Cove, and at SMI-1 in Nidever Canyon. Warren Addicott studied the mollusks from these localities and was of the opinion that:

> . . . [The Nidever Canyon locality] represents a very shallow water, possibly intertidal depositional environment. Nearly all of the mollusks live on rocky surfaces or nestle in gravelly substrates associated with rocky areas.
>
> The assemblage from locality M4207 [Busted Balls Cove, SMI-245] also represents a shallow water depositional environment but the composition suggests that it is not an intertidal assemblage and represents a somewhat deeper water bathymetric environment than M4206 [SMI-1]. The abundant pelecypods are characteristic of sandy substrates and depths below the surf zone. On the other hand a few of the gastropods are rock-

dwellers and are known to be strictly intertidal in their modern distribution. These are represented, however, by only a few specimens and could well have been transported into the fossil assemblage.

Both assemblages consist of species that occur in the modern fauna of the southern California area suggesting that water temperatures were not appreciably warmer or cooler than at present during deposition of the terrace deposits.

Terrace Correlations and Ages

There are four ways that marine terraces may be locally and regionally age-correlated: (1) Topographically, using elevations of shoreline angles; (2) Stratigraphically, by analysis of the marine and terrestrial terrace covers; (3) Paleoecologically, using terrace biota; and (4) Radiometrically. In this study the first, third, and last methods were employed.

As mentioned earlier, in an area as tectonically unstable as southern California probably only the lowest (youngest) eustatic terraces would possibly be amenable to local, regional or worldwide topographic age correlation. One could reasonably argue that even the youngest terraces in a tectonically mobile area may be either tectonic in origin or have suffered tectonic modification. For example, a modern marine terrace on Montague Island in the Gulf of Alaska was uplifted almost 40 feet during the Good Friday earthquake of March, 1964. While apparently not as seismically active as the Alaskan coastal area, it has been shown (Chapter II) that the Santa Barbara Channel is highly mobile, 259 earthquakes having been recorded over a 33 year period. Earthquakes in the immediate Channel region rank among the strongest and most damaging (property-wise) in California, and have generated the two largest Tsunamis known on the west coast of the conterminous United States (Hamilton, et al., 1969). Paleosols that post date all the marine platforms on San Miguel have twice been dated at greater than 40,000 radiocarbon years before present, so that at least that amount of time has passed since the youngest platform was cut. In terms of potential seismicity, if the historical data of Figure 9 (Chapter II) are representative for the past 40,000 years then during this time the Channel region may have experienced over 300,000 earthquakes 30,000 of which were magnitude 4 or greater. Thus it is not surprising that post-Pleistocene marine terrace deformation on Anacapa Island and in Ventura County has been reported (Scholl, 1960; Putnam, 1942). Extensive Quaternary warping with terrace deformation has also been inferred on Santa Cruz Island by Weaver and Meyer (1969, pp. 103-104, 118), although certain of the inferences have been questioned (Yeats, 1970).

Viewed in this light it seems almost fortuitous that the 20-25 foot terrace on San Miguel has many approximate counterparts about the Santa Barbara Channel, in southern California, and the world in general. A low terrace that ranges from 20-30 feet and approximates 25 feet elevation measured from shoreline angle to mean sea-level has been reported on Santa Rosa Island (Orr, 1960a), San Nicolas Island (Vedder and Norris, 1963), west Anacapa Island (Lipps, 1964), Santa Barbara Island (Lipps, et al., 1968), Santa Catalina Island (Slosson and Cilweck, 1966; Bailey, 1941, p. 177), San Clemente Island (Merselis, 1962), possibly on Guadalupe Island (Hubbs, 1967) and in numerous places along the southern

California mainland (Hoskins, 1957; and Merselis, 1962) and throughout the world (Charlesworth, 1957, p. 1262; Fairbridge, 1961; West, 1968, pp. 153-157).

After reviewing world data on Pleistocene shorelines Fairbridge (1961) provisionally concluded that the worldwide 25 foot high sea-level was correlative with the Late Monastirian (late Sangamon Interglaciation) of approximately 90,000 to 95,000 years ago (extrapolated from Emiliani's 1955 $0^{18}/0^{16}$ temperature curve). Based on morphological studies of terraces on Santa Rosa Island, Orr (1960a) concluded that three eustatic platforms at 100, 25 and 75 feet were all of Sangamon Interglacial age. Because the 25 foot terrace on San Miguel Island has many local, regional and worldwide correlatives, it is probably glacio-eustatic in origin.* And although the question of precisely when the 25 foot high sea-level stand occurred is open to some question, we know from radiocarbon evidence that it was prior to 40,000 radiocarbon years ago, probably during the late Sangamon Interglaciation as suggested by Fairbridge.

The inferred 70-75 foot terrace on San Miguel has a clear correlative in southern California only on Santa Rosa Island, which Orr (1960a)

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*It should be noted that Hoskins (1957) has hypothesized (p. 32, 75 and 94) that most of the terraces along the mainland coast of southern and central California which range in elevation from 15 to 200 feet--and possibly up to 300 feet (according to his field survey data, pp. 32 to 36) are all segments of a once continuous single terrace formed by a single marine transgression and regression when sea-level was 50 to 100 feet higher than now in late Sangamon time (given at 70,000 to 90,000 years ago). Diastrophism and erosion are believed to have since destroyed the original continuity of the terrace. While Hoskins' hypothesis is commendably provoking, evidence from San Miguel and Santa Rosa Islands does not support it, since on these islands terraces at elevations of 25 and 75 feet occur in close vertical juxtaposition to one another, and thus are genetically distinct from one another.

called the Fox Platform. The 75 foot Fox and 25 foot Garanon Platforms are overlain by a cover of marine and terrestrial sediments termed the Santa Rosa Island Formation. The sequence of supposed eustatic events on Santa Rosa during Sangamon time postulated by Orr was summarized by Lipps (1964) whose modified version is as follows: (1) During the Sangamon Interglaciation sea level rose to about 100 feet and cut a platform. (2) The sea then dropped to a level close to its present position. (3) Sea-level rose to about 25 feet and cut the Garanon Platform (Oceanside Terrace of Merselis, 1962). (4) The sea then fell slightly which allowed the terrestrial facies of the Garanon Member to be deposited. (5) Sea-level rose rapidly to about 75 feet and cut the Fox Platform. (6) Then, at the end of Sangamon time, sea-level fell below the present level and the Fox Member was deposited. (7) During Wisconsin time the Fox Member was almost completely eroded away, possibly by an unrecorded interstadial high sea stand. (8) Sea-level fluctuated at levels below the present one and the Tecolote Member was deposited.

In the context of the present discussion, an interesting part of Orr's interpretation is that the 75 foot Fox platform was eustatically cut after (and is therefore younger than) the 25 foot Garanon Platform. I personally saw no evidence to suggest that the inferred 70-75 foot intermediate terrace on San Miguel postdates the 25 foot terrace, but this may simply be due to a dearth of corroborating exposures. Most interesting of all is the presence of a 75 foot platform on Santa Rosa and San Miguel Islands that is unreported elsewhere in southern California, with one exception to be explained. A 75 foot terrace was not observed on Anacapa or Santa Barbara Islands (Lipps, 1964, Lipps, et al., 1968), or on San Nicolas by Vedder and Norris (1963),* on San Clemente (Smith, 1898; Lawson, 1893--although an 80 foot terrace was recorded by Lawson, it was not subsequently measured by Smith who recorded terraces at 60 and 155 foot elevations). Neither has a 75 foot terrace been described on Santa Catalina (Lawson, 1893; Smith, 1933; Bailey, 1941, p. 184), from the Palos Verdes Hills by Woodring and others (1946)**, or anywhere else on the mainland (Davis, 1933; Upson, 1951; Hoskins, 1957; Merselis, 1962; Palmer, 1967), except along the Ventura coast where a terrace varies in elevation from 60 to 80 feet (Putnam, 1942). However, two factors caution against correlating this latter terrace with the Fox platform. One is that there is much doubt as to the actual elevation since Putnam measured terraces not from the back edge, but ". . . from their alluviated surfaces and are probably accurate to one contour interval" (p. 740). The other is that the Ventura area has been subjected to considerable tectonism and crustal deformation and the ". . . terraces of the Ventura region are the result of diastrophism rather than eustatic changes of sea level." (Putnam, 1942, p. 752.) Finally, there is no

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*A 75 foot terrace was reported by Kemnitzer (1933) on San Nicolas, but it is uncertain what part of the terrace was measured. Moreover, the detailed work of Vedder and Norris in 1963 has tended to supercede previous work.

**A "75 foot" terrace on Palos Verdes has been alluded to by Emery (1958, p. 56; 1960, p. 8) by reference to Kulp, et al., (1952) but the latter did not indicate where on the platform the elevation was measured.

evidence of a ubiquitous 75 foot terrace in other parts of the world (Fairbridge, 1961), although one at 70 feet has been reported by Stearns (1945) in the North Pacific, and by Cooke (in Upson, 1951) on the Atlantic coast. What all this seems to mean is that the 75 foot Fox platform probably is non-eustatic and may be locally and regionally unique to Santa Rosa and San Miguel Islands. This anomaly may be explained if the 75 foot terrace has a tectonic origin. If it is tectonic in origin then the Fox platform cannot be younger than the Garanon (Oceanside) platform, otherwise the latter also would have been tectonically affected. The problem has no immediate resolution until more field work is done on both Santa Rosa and San Miguel Islands.

Since high terraces in California are generally believed to have resulted from tectonism, no attempt is made to topographically correlate the 325 foot platform exposed in Nidever Canyon with others in the region.

As mentioned marine terraces may also be correlated paleoecologically. However, there is at present a wide range of physiographic habitats in the marine waters off southern California, as well as variable thermal and salinity habitats produced by upwelling. Because of this and the fact that waves and longshore currents tend to mix different habitat assemblages, limitations are imposed on specific paleoecologic interpretations in the region. Nevertheless, a general pattern is beginning to emerge that may be useful for terrace correlation. Recent workers have reported that a distinctive extinct fauna exists on the higher island terraces (above about 130 feet) that is not found on the lower island terraces or on any of the mainland terraces (Vedder and Norris, 1963; Valentine and Lipps, 1967; Lipps, et al., 1968; Valentine and Veeh, 1969). The extinct fauna is believed to indicate a lower Pleistocene or earlier age on the mainland. During a review of the fossil assemblages collected from 27 different island localities in southern California, Lipps and others (1968) found that 17 were from the higher terraces while 10 were from lower terraces. Fifteen of the higher terrace assemblages contain the extinct element, but none of the lower terraces contain it. This difference suggested to Lipps and his collaborators (1968) that the extinct forms were eliminated from the islands between the times of development of the higher and lower terraces. Interestingly, at least two of the extinct forms occur on San Miguel at the 235 foot high terrace fore edge at SMI-245. Warren Addicott, who studied the assemblages listed earlier, offered the following comments:

> These are essentially modern assemblages, comparable to faunal assemblages now living off the Channel Islands. All of the species identified in the collection from Nidever Canyon (loc. M4206 [SMI-1]) are still living; however, two of the specifically determined taxa from the northwest coast of San Miguel (loc. M4207 [SMI-245]) are extinct: Crepidula princeps and Calicantharus fortis. The Pleistocene marine terraces from the islands off southern California, particularly those from San Nicolas Island, have been considered to be of late Pleistocene age (Vedder and Norris, 1963, U. S. Geol. Survey Prof. Paper 369). A somewhat different view has been advanced in a series of papers by Valentine and Lipps (summarized in Lipps and others, 1968, Jour. Paleontology, v. 42, p. 291-307). They emphasize that the island terraces carry a small but distinct element of extinct mollusks that is not found on terraces below about 150 feet and which is not found on any of the mainland terraces. This suggests to them that the higher island terraces are older than the mainland terraces, are probably pre-Sangamon and possibly of early Pleistocene age. Vedder and Norris suggest, on the other hand, that the extinct element on the island terraces

> is relictual and that it does not occur on the higher mainland terraces because of facies [environmental] rather than temporal differences. Their conclusion that the higher island terraces on San Nicolas Island represent the later one-third of the Pleistocene epoch is not, however, necessarily in conflict with Valentine and Lipps' conclusions.
>
> The problem probably cannot be solved without further input from either planktonic foraminiferal correlations or radiometric age determinations. So far, radiometric age determinations have not shed much light on the absolute age of the higher terraces. There do seem to be excellent data pointing to an age of about 85,000 years for the lowest terraces at nearby San Pedro and older ages from terraces near Point Dume: 105,000 yrs. (33 meter terrace) and 185,000 yrs. (52 meter terrace) (Szabo and Rosholt, 1969, Jour. Geophysical Res., v. 74, p. 3253-3260). The latter are about 90 miles east of San Miguel. It is difficult to establish physiographic correlations between the mainland and San Miguel terraces because they are in a tectonically active area.

In a recent article Valentine and Veeh (1969) obtained three uranium series age estimates of fauna on one low and one high terrace on San Nicolas Island. Two age estimates of the low terrace were 120,000 ± 20,000 years and 120,000 years before present which suggests a Sangamon Interglacial age. The high terrace, which contained the extinct element, gave an age estimate of 200,000 years before present. While San Miguel and San Nicolas Islands probably do not have parallel tectonic histories, the fact that two extinct forms (Crepidula princeps and Calicantharus fortis) are found in the high terraces of both islands does suggest broad contemporaneity.

In retrospect the age of the 20-25 foot terrace on San Miguel is greater than 40,000 radiocarbon years B.P. and is provisionally correlated with the late Sangamon Interglaciation. The inferred 70-75 foot terrace on San Miguel is topographically correlated with the Garanon platform on Santa Rosa Island and is of probable Sangamon age, but its origin on San Miguel seems to suggest a different, possibly tectonic, history. Terraces higher than about 150 feet on San Miguel are in a broad sense paleoecologically and, indirectly, radiometrically correlated with other high island terraces whose fossil assemblages contain a distinctive extinct element; these older terrace faunas are probably of pre-Sangamon age, possibly of early-late Pleistocene or earlier age. Finally, on San Miguel Island there is no evidence whatever of the controversial post-Pleistocene high sea-level stand reported by others (see Curray, et al., 1970).

11. The Modern Terrace

Mechanical Abrasion

Most of the shore area of San Miguel Island is being actively eroded by the sea. Wave erosion is differential as shown by the patterns of wave refraction on airphotos, with headlands and promontories absorbing relatively more wave energy than coves and back-beaches. Erosion and cliff retreat is most active and the modern terrace best developed on the west and northwest coasts of San Miguel. As sea waves are produced by wind, and the prevailing wind is from the northwest, it is not surprising that erosion is greatest on the side of the island most affected by these winds. Wave abrasion is of course maximized in the surf zone, especially during episodes of high energy waves generated by storms and high swell out at sea. The surf zone migrates diurnally back and forth in concert with tidal cycles. Interestingly, because Pleistocene terraces are also best developed on the west and northwest coasts of both San Miguel and Santa Rosa, and on the west end of Santa Cruz, it is reasonable to infer a prevailing Pleistocene wave (and thus wind) direction that was also from the northwest. Dip directions of eolianites on San Miguel and eolianite distributions on the Channel Islands strongly support this inference as will be shown later.

One of the more interesting features on the modern terrace is the presence of flattish and undulating bedrock surfaces that are present at various places about the island, but which are best displayed on the northwest coast. Although no detailed field investigations of the surfaces were made, some general observations are worth reviewing.

The surfaces range in elevation from approximate normal high tide position to, in one case at least, more than 50 feet above mean sea-level. None of the surfaces seem to be the result of abrasion, as no cobbles, boulders or grinders of any kind are present, nor is there any indication they ever were present. Thus, the processes involved in the formation of the surfaces must be other than mechanical abrasion. Some of the surfaces exhibit solution pits (Plate 66) but others lack such pits entirely. The intertidal gastropod Littorina occurs on some but not all of the surfaces. Interestingly, efflorescenses of salt were seen on all of the surfaces.

Biological Erosion

The character and relations of the surfaces suggest that biological, biochemical and geochemical processes are involved in their origin.

There is a growing respect among coastal morphologists for the erosional efficacy of marine biota (Warme, et al., 1971; Ollier, 1969, p. 52), especially certain mollusks and echinoids. The animals involved are many, but probably most important are Littorina, rock boring mollusks, chitons, sea urchins, and certain worms. Biologically induced erosion may also be produced by the hold-fasts of kelp somewhat after the fashion of tree roots on land, although this idea is speculative as no documentation of this process exists to my knowledge. In addition, the bouyancy of kelp and its associated surging and yanking, especially during heavy swells and storms, probably also has some effect on the substrate, although no data are on hand to support this notion either. Details of some of the physical and biochemical processes involved have been given by Emery (1946, 1960), North (1954), Hills (1968) and others.

Emery and North have shown how Littorina mechanically erodes rocky coasts while grazing for algae that live on rocks. North concluded that one inch of rock per 100 years (1 ft./1200 yrs.) is mechanically removed by Littorina. Perhaps more important in their physical erosive effects are rock-boring mollusks which have been known to destroy more than 50 per cent of some rocks (Emery, 1960, p. 16). Sea urchins also are important rock eroders and their cup-shaped holes plus the smaller but deeper holes of pholads are a common sight during low tide along the southern California littoral.

On the other hand, the biochemical effects of Littorina and other animals (especially chitons) and plants on rocks are difficult to measure but may be far greater than one might suspect, perhaps greater than their mechanical effects. Emery (1946) has demonstrated their biochemical efficacy in producing solution pits, basins, and depressions on rock surfaces. Such "karst" features in non-carbonate rocks are very common along the mainland and island coasts of California, including San Miguel. Plate 66a and b show solution pits that are very similar to those described by Emery (1946) in which Littorina occur in abundance. In the case of Plate 66a and b, however, the process of biochemical solution seems to be concentrated along joints and planes of lithologic weakness which gives rise to linear and reticulate solution patterns. Furthermore, there is in Plate 66a suggestive evidence of several generations of solution surfaces.

The solution process has been shown by Emery to be cyclic occurring at low water at night when the water temperature drops. The ability of water to absorb carbon dioxide increases with a decrease in temperature. Also at night, plants cease their photosynthetic activity so that utilization of carbon dioxide ceases. Plants also liberate their own carbon dioxide at night which supplements that given off by Littorina and other animals. Cooler nighttime temperatures plus increased levels of carbon dioxide results in the formation of carbonic acid that acts as a solvent on many rocks.

Geochemical Weathering and Erosion

Biological, biochemical and biomechanical processes in conjunction with normal mechanical abrasion may account for most coastal erosion, but not all. A most unusual surface at the very end of Harris Point (Plate 54a) may have its origin in some process or processes other than those described above. The undulating surface has been "cut" across a highly jointed dacite porphyry (Plate 82b). It varies in elevation from about 25 to over 50 feet and is well above normal high and spring tide levels. Thus, no marine organisms live on the surface. It is, however, within the spray zone of storm waves as shown by the presence of abundant crusts of salt, in some cases several inches thick. A tongue test of various high areas of the surface where salt could not visibly be seen indicated that salt was present in each case. No organisms, grinders, pebbles, loose sand, soil or other products of weathering were observed on the surface. Except for sea gull droppings and ubiquitous salt the surface was clean. Apparently the surface is periodically swept clean by storm waves.

The origin of the surface is problematical but several tentative suggestions are offered. In the absence of grinders and organisms, both mechanical and biological processes may be discounted, unless the surface is of Pleistocene age and has been re-exposed in recent post-glacial time. If the surface is presently being formed, as it appears to be, then the processes involved must be geochemical, either related to sea water itself or the salt which precipitates from it. Soil water is an effective weathering agent of rocks through wetting and drying, base exchange, hydration and various other processes, but the effect of salt water on igneous rocks in a non-soil, sea spray context is to my knowledge little known. On the other hand, pressure caused by crystal growth upon evaporation of salt solutions has long been suspected of playing a role in weathering in deserts and on coasts, and data have gradually accumulated in support of the idea (Birot, 1968, p. 20, 97-98; Wellmann and Wilson, 1965; Cooke and Smalley, 1968; Tricart, 1959). Tricart, for example, concluded that salt crystal growth is a dominant process in the formation of shore platforms in Brazil where grinders are absent and where sea spray wetting is followed by rapid drying.

In addition to the pressure of salt crystallization, which is probably similar to that of ice (Hunt and Washburn, 1966), it has been shown that sodium chloride and most other salts possess thermal expansion coefficients that are considerably higher than those of common rocks (Cooke and Smalley, 1968)*. Once salt has crystallized in a crack, an increase in temperature will be attended by a disproportionate expansion of the salt with respect to the parent rock. Thus the pressure of differential thermal expansion of the salt is added to the pressure of crystal growth. Both of these salt weathering processes would be maximized by frequent wetting and drying and by frequent high temperatures. At Harris Point wetting and drying is episodic with storm waves and high swell and is frequent throughout the year. High air temperatures (above 80°F) also are episodic but are, on the other hand, infrequent in occurrence, being restricted largely to the fall months when they do occur (Fig. 21). Temperatures of rock surfaces, however, normally are far higher than ambient air temperatures so that weathering induced by differential thermal expansion of salt may be much more important on San Miguel than the data

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*Cooke and Smalley compared the thermal expansion coefficients of sodium chloride and other salts with the expansion limits of granite only; the expansion limits of the San Miguel Island dacites are not as yet known but they probably would be considerably less than that of sodium chloride because the dominant minerals of dacite (quartz and plagioclase) have comparatively low expansion coefficients.

of Figure 21 suggest. At any rate, even if the temperature were always low the incredible degree of fine criss-crossing fracturing of the dacite on Harris Point (Plate 82b) lends itself ideally to weathering on coasts does in fact occur anywhere it should by operating maximally on Harris Point today. Future research to shed quantitative light on the matter is planned.

The fact that salt crusts were observed on all the surfaces under consideration (cf. Plates 66 and 82b) suggests that salt weathering may play an important geochemical role in the truncation of marine platforms in general. Wherever and whenever salt crusts form the possibility exists that salt weathering is operating, so that in addition to the subaerial wave spray zone the process may be operating in the intertidal zone where evaporation and salt crystallization take place during low tide. These suggestions however also await final verification by quantitative field and laboratory analysis.

12. Beachrock

Beachrock is carbonate-cemented beach material, usually sand, which unless fossil, usually crops out at about sea level (Russell, 1967). It occurs along many tropical and subtropical coasts and is commonly considered a geomorphological feature restricted to low latitudes. Its general nature, origin, cement, and mode of occurrence have generated considerable interest and discussion among students of coastal morphology. Heretofore, the focus of beachrock studies has centered mainly on the West Indies, Brazil, the Mediterranean region, Australia, and certain islands of the Indian and Pacific oceans. Although casual references have been made to the presence of beachrock in Baja California (Walker and Thompson, 1968; Shepard and Dill, 1966), and in southern California (Russell, 1962), to the author's knowledge beachrock has not been described in California. The Channel Islands mark the northernmost reported occurrence of beachrock or related deposits on the Pacific Coast of North America. The following description and discussion of beachrock on San Miguel is modified from an earlier paper by the writer (Johnson, 1969).

The nature and mode of occurrence of beachrock on San Miguel Island reveal two unusual aspects which some may argue would technically set it apart from beachrock as generally pictured: (1) the material has formed _on_ a wave-cut marine bench, but not _in_ beach sand which normally seems to be a requirement for beachrock; and (2) particle size ranges from sand to boulders up to 60 cm in diameter.

Mode of Occurrence

Beachrock has formed at various places along the northwest coast of San Miguel Island directly upon marine platforms cut across moderately dipping marine sandstones, shales and conglomerates of Cretaceous and Eocene age (Plates 43c, 56-58). Because of poor exposures, it is not known for certain at any given locality whether the beachrock is formed on the 20-25 or the 70-75 foot platform, although probably most occurs on the latter. During its formation the marine platform became veneered with boulder, gravel, and sand deposits. Later, the sediments were exposed to subaerial modification either as a result of sea-level regression or tectonism, or both. In any event, the sea was lowered relative to land, and calcareous sand derived from the exposed shelf was blown across the former shoreline and episodically deposited in dune sheets. Subaerial diagenesis through solution and reprecipitation of sand-sized carbonate debris initiated induration of the sand sheets to eolianite. That sand sedimentation was episodic is shown by well-developed paleosols which lie between the separate the eolianite units (Plates 43c, 54b). Thus, beachrock formed upon the marine platform and at the base of the eolianite. It marks the platform eolianite interface.

The beachrock dips about 5° in a seaward (northwest) direction which coincides with, and is controlled by, the dip of the platform. Spring seepage of island groundwater occurs at the forward (seaward) edge of the relatively impervious marine bench. The groundwater-saturated zone, at least on this side of the island, lies just above the bench and coincides with the outcrops of beachrock. The geomorphologic picture, therefore, suggests that beachrock has formed, and perhaps still is forming, at the springline from carbonate-saturated groundwater. The level of groundwater presumably rises as the beachrock becomes increasingly indurated.

In Simonton Cove the Pleistocene marine platform extends below sea-level and in places may merge with the modern platform. In other places the sea has eroded the fore edge of the platform (Plate 56). Where the platform dips below sea-level, beachrock is undergoing active wave erosion (Plate 58a). The beachrock is dislodged as slabs are thrown back upon the beach probably by storm waves, and accumulates as beachrock shingle (Plate 57b, c).

Thickness, Morphology and Induration

The beachrock varies in thickness from a few centimeters to over 60 cm., with an average of about 25 cm.

Much of the exposed beachrock surface exhibits mechanically abraded ridgefurrow fluting (Plate 58b) which is a common characteristics of some beachrock deposits (McLean, 1967). On the other hand, some beachrock surfaces were devoid of fluting or other conspicuous solution features (Plates 56a, 43c). At Harford Canyon the exposed beachrock surface is almost sidewalk-smooth and, as it follows the canyon floor upstream, does indeed resemble a pavement. This has been produced by canyon erosion cutting downward through eolianite to the beachrock level followed by headward erosion. The result is a conspicuously flat carbonate-floored stream bed. Russell and McIntire (1965) have referred to such inland extensions of beachrock as "streamrock."

Composition and Parent Material

Because the beachrock marks the interface between a marine platform and overlying eolianite it tends to reflect certain properties of each. Of four random eolianite samples the average weight percentage of soluble carbonate was 55 per cent. The carbonate grains of eolianite consist almost entirely of sand-sized shell fragments and skeletal debris, mainly Mollusca and Foraminifera (Plates 73, 75-76). Such skeletal debris, derived from eolianite, comprises a significant part of the San Miguel beachrock while the remainder of the grains are detritus derived from the pebble and boulder conglomerate which overlies the bench (Plates 56a, 57a, c). At some beachrock outcrops the particles are primarily sand-sized but with subordinate pebbles scattered throughout. At other outcrops the particle size ranges from sand to large boulders.

Cement and Age

Thin sections of beachrock show the cementing matrix to be sparry calcite. Powder camera x-ray diffraction analysis of carefully collected matrix grains yielded a calcite pattern. Petrographic inspection of thin sections shows that void filling has not been completed. It is possible that beachrock may still be undergoing cementation; however, neither beachrock porosity values nor bicarbonate saturation analyses of groundwater were available for inclusion in the present study. Also, seasonal temperature values of groundwater have not yet been obtained. Such information when available will reveal whether cementation is occurring at the present time.

The question of when beachrock first began to form is open. Because extensive calcareous eolianite blankets most of the northwest side of the island, one would suspect that normal groundwater would have become saturated with bicarbonate and that this process would date from the time the eolianite was emplaced. The emplacement of the sand was roughly coincident with the subaerial exposure of the platform. Otherwise, had the sand been emplaced considerably later, one would expect colluvium from the upper sea cliff to have gradually covered the exposed bench. Colluvium, however, does not occur.

It is therefore possible that the onset of beachrock formation coincided with platform elevation and eolianite emplacement. Whether beachrock formation has been episodic or continuous since that event is also open to question, although evidence suggests that it probably has been episodic. The evidence is that during droughts certain springs dry up. In the absence of spring seepage, bicarbonate charged water would be absent and it is likely that no beachrock would form.

Origin of Beachrock on San Miguel Island

The geomorphological relationships surrounding beachrock formation on San Miguel Island seem clear. A marine platform veneered with sand, pebbles, and boulders was exposed to episodic subaerial eolian sedimentation of calcareous shelf sand following a relative drop in sea-level during the Pleistocene. The calcareous shelf sand, now eolianite, blanketed the bench and surface veneer of sediments. Rainwater and groundwater, upon passing through thick beds of calcareous eolianite, became saturated with bicarbonate. The bicarbonate saturated groundwater flowed seaward in response to the dip of the relatively impermeable platform and issued as springs along the platform-eolianite interface as shown in Figure 26. Because of carbon dioxide loss, possibly by evaporation, calcium carbonate was reprecipitated as calcite, and beachrock formed.

On San Miguel Island no relationship appears to exist between tidal range and beachrock as reported by other investigators in other parts of

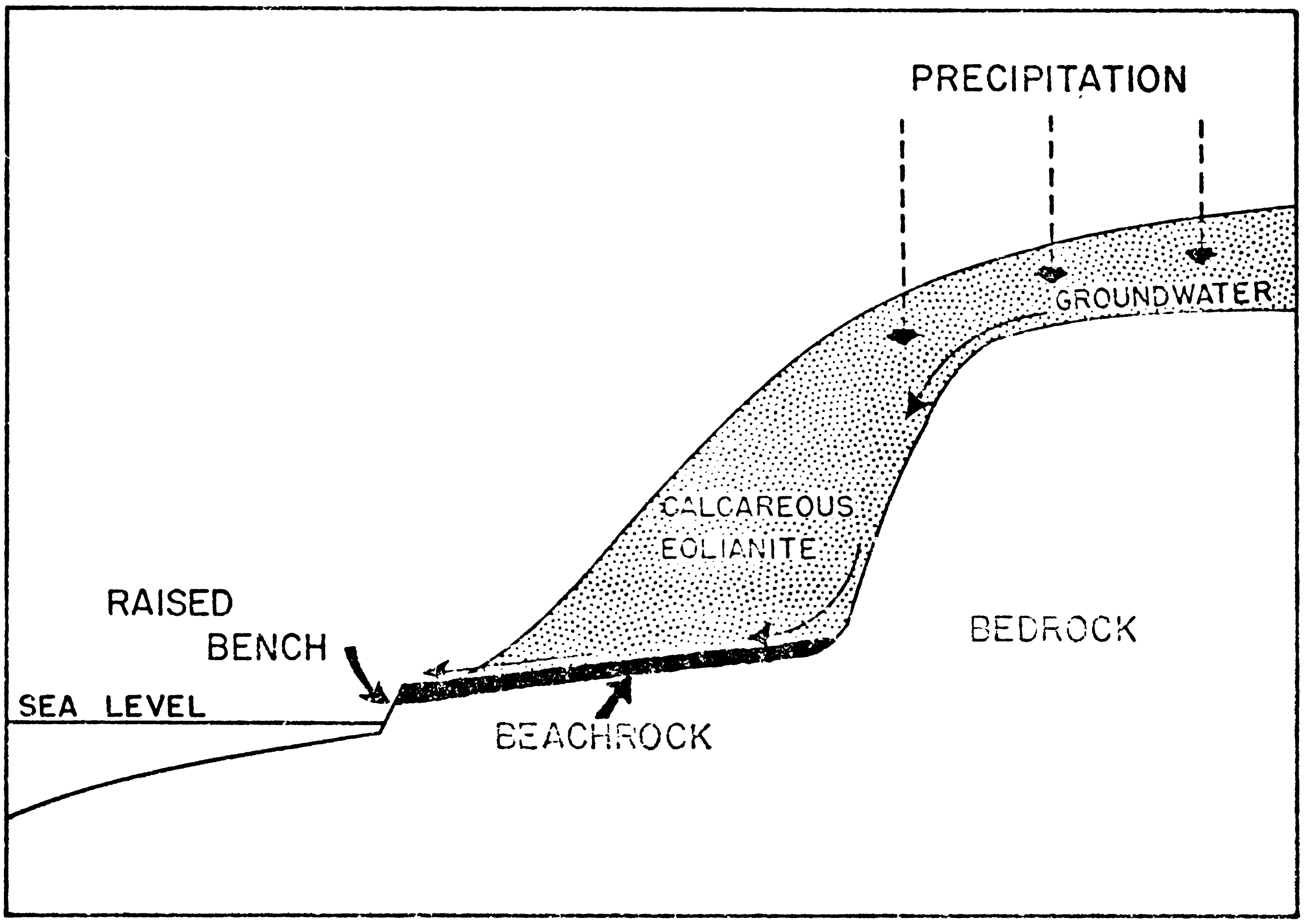

Figure 26. Diagram showing relationships between bedrock, beachrock, eolianite and groundwater on the northwest coast of San Miguel Island.

of the world (Russell, 1967). Groundwater levels on raised marine platforms often are not responsive to tidal variations, whereas such is not the case with sandy beaches.

Discussion

Earlier in this section it was stated that because beachrock on San Miguel Island was not formed in beach sand and is largely conglomeratic, some question may be raised as to whether it actually is beachrock. This statement deserves amplification.

Many investigators, although not all, have viewed beachrock as being genetically related to sandy beaches. In the early stages of geomorphological studies on San Miguel Island I planned to introduce the term "benchrock" to denote specifically beachrock-like material that forms on marine benches (platforms). I would have regretted this, much as Russell and McIntire regretted coining the term "streamrock" for beachrock-like material that crops out along streams inland from actual beachrock outcrops. Russell and McIntire (in Russell, 1967, p. 125-126) identified the problem when they found,

> . . . an equivalent layer around a lagoon north of Port Louis, Guadeloupe, and [we] do not care to confuse matters by calling it 'lagoonrock.' A more appropriate terminology would be to regard the entire genus as 'water-tablerock,' and to recognize outcrop locations as species. Even the specific term 'beachrock' is unfortunate because the beach plays only a passive role in its origin.

Their point is well made that beachrock, streamrock, lagoonrock, benchrock, and other related forms, are products of the same process and differ only in their site of formation, or location.

Finally, the conglomeratic nature of San Miguel Island beachrock and its formation on Pleistocene marine terraces are unusual features but not unique in occurrence. Conglomeratic beachrock occurs on the south coast of Jamaica (Russell, 1967) and St. Lucia (Russell, 1959). Beachrock also occurs on a Pleistocene marine terrace on the north coast of Puerto Rico (Russell, 1967). As more field work is done it is likely that beachrock, or better, water-tablerock, will be found in other places along the Pacific Coast of North America.

CHAPTER IV

INSULAR BIOGEOGRAPHIC AND GEOMORPHIC HISTORY OF SAN MIGUEL ISLAND: LAND BRIDGES AND BIOTIC DISPERSALS

No study of the geomorphic evolution of San Miguel Island would be complete without investigating the possibility of inter-island and mainland connections. Many island researchers, especially biologists and geologists, believe that questions relating to the absence or presence of Pleistocene land bridges are among the most important, as reflected by comparing the first three quotations (below) with the fourth.

> The beds of mammoth bones is such conclusive proof of a former land connection that no question can be raised in regard to it. (Fairbanks, 1897, p. 227.)
>
> Living elephants do not swim out to sea and cross marine barriers, and there is no reason for believing that the Californian mammoths of the Ice Age possessed different habits. . . . (Stock, 1943, p. 7.)
>
> . . . while we can easily imagine an Indian lad taking a pet fox (as they did with dogs) in a canoe to the islands, it stretches the credibility to imagine the importation of elephants by these means. (Orr, 1968, p. 16.)
>
> Nothing in the biological evidence speaks strongly for land connections as an explanation of modern distribution patterns, and it seems futile to build imaginary bridges where none are known to have existed and when the facts of the situation do not require it. (Savage, 1967, p. 224.)

In the context of the quotes we may ask, Was San Miguel ever connected to the other Northern Channel Islands? Or to the mainland by a land bridge? Were the Northern Channel Islands ever connected to the four southern islands of Santa Barbara, San Nicolas, San Clemente or Santa Catalina? Were the latter connected to one another and the mainland? Did the plants and animals on San Miguel and the other islands arrive by land bridges or by overwater dispersal? Did the aborigines play a role in insular biotic dispersals?

The purpose of this chapter is to shed light on these questions. Specifically it will be shown that in order to account for past and present plants and animals it is not necessary to invoke land bridges from San Miguel and the three other northern islands to the mainland or to the southern islands, or from the latter to one another or to the mainland. Much of the ensuing discussion will concern the other islands as well as San Miguel because it is difficult to isolate one island from another in the context of biotic dispersals and land bridges.

The importance of the chapter to this thesis lies in the following question: Was the middle and late Pleistocene geomorphic and biogeographic insular history of San Miguel unique, or did it parallel the histories of certain or all of the other islands? An answer to the question is important to an understanding of certain fundamental relations, such as the origins of the insular animals, including the pygmy elephants whose bones occur in great numbers on San Miguel. It will be shown in Chapter 7 that modern elephants in Africa are landscape modifiers of the first order, and Pleistocene elephants may have left an indelible stamp on the surface character of San Miguel. The pygmy elephants are thus important in their role as landscape modifiers and along with other animals, provide evidence on whether San Miguel has had a parallel history to, or was unique from, the other Channel Islands.

In 1965 a symposium on the biology of the islands was arranged and one of its purposes was to pool island researchers' ideas on the biotic history of the islands vis-a-vis the existence or absence of land bridges (Philbrick, 1967). Did the flora and fauna originate primarily by migration over water or land, or both? The opinions of the conferees ranged from those who believed that land bridges variously connected all the islands to the mainland (von Bloeker, 1967) to those who were skeptical of any land bridge at all (Savage, 1967). It would seem instructive to review evidence for and against land bridges on the Channel Islands to see what light may be shed on the matter. Much of the following discussion is necessarily limited to land bridge considerations as they concern the Northern Channel Islands, in particular San Miguel Island.

13. Geologic and Eustatic Evidence of Land Bridges

It is almost certain that the four northern Channel Islands were connected to one another during glacial times into a single super-island, called Santarosae by Orr (Fig. 27). This conclusion rests on the well

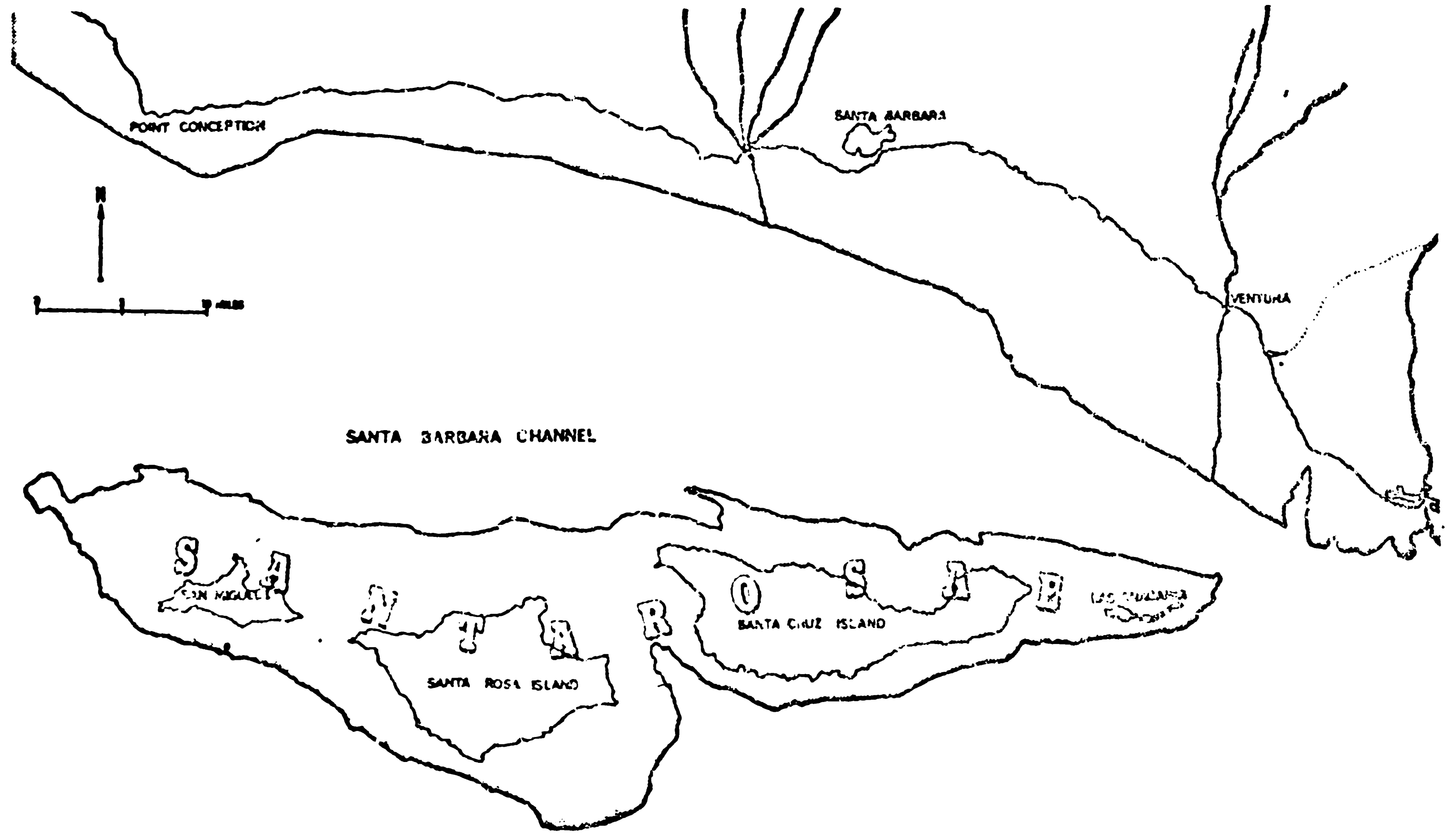

Figure 27. Santarosae; extent of Pleistocene land mass as defined by the 300 foot isobath (after Orr, 1968, p. 18).

known fact that sea-level was considerably lower during glacial periods. Best estimates of the lowest sea-levels range from 300 to 450 feet, whereas a drop of only 160 feet will join the four islands to one another. Figures 28 and 29 show the probable island-area relationships measured by depth and time back to 20,000 years ago. The super-island Santarosae broke up at the close of the Pleistocene by rising post-glacial seas.

On the other hand no mainland connection is suggested by the above eustatic reconstructions. Today sea-level would need to be lowered 760 feet before a landbridge would appear, and this is far lower than any reasonable estimate for glacially controlled low sea-level at any time during the Pleistocene. Actually, the channel-bottom physiography does not even hint at a former land bridge to the Northern Channel Islands. Copies of the original 1930-33 sounding charts were obtained and when bathymetric contours at 25-foot intervals were developed on the charts the deepest eastern third of the Santa Barbara Channel floor appeared as essentially flat surface ranging between 126 and 130 fathoms in depth (Hydrographic Surveys H-5849 and H-5030). This flat floor is flanked by steep, parallel-aligned escarpments which strongly suggest a tectonic origin (Fig. 30). Other researchers have envisioned a former peninsula extending west from the Port Hueneme-Point Mugu area which incorporated the four northern islands (Fig. 31) but no vestige of such a peninsula is apparent in the Santa Barbara Channel bathymetry. As discussed earlier in Section 6 of Chapter 2, contrary to popular opinion, the Northern Channel Island block has no apparent structural continuity with the western end of the Santa Monica Mountains, although this does not necessarily preclude the possibility of a former topographic link. Moreover,

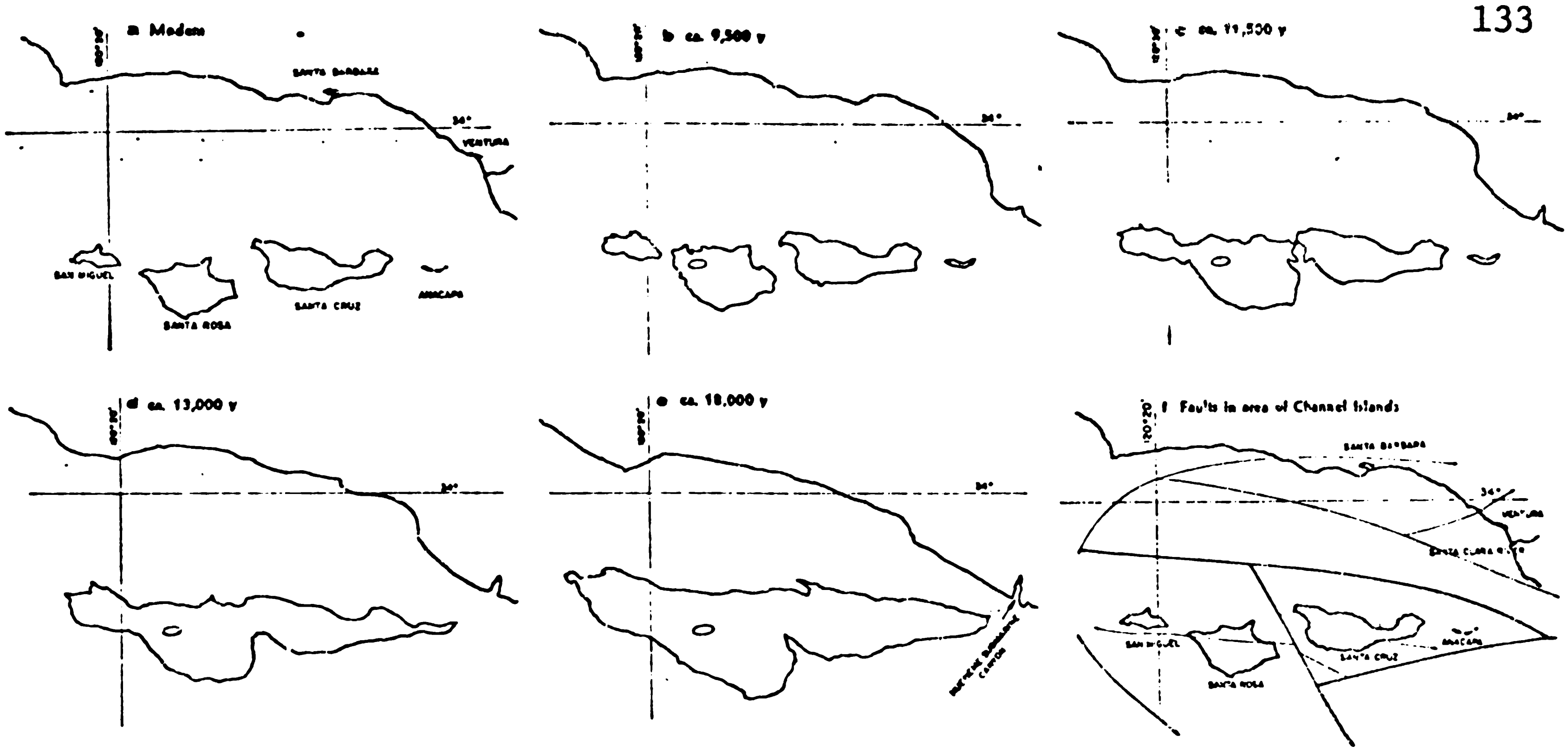

Figure 28. (a-e) Map sequence showing the changing land mass of the Channel Island complex, which includes Santa Rosa Island, during the last two decamillenia. Antedating this time span the area changed its size with the rising and falling level of the ocean. (a) Modern, (b) ca. 9,500 years ago, (c) ca. 11,500 years ago, (d) ca. 13,000 years ago, (e) ca. 18,000 years ago, (f) map of faults in the area of the Channel Islands. One of the faults runs directly through the middle of the strait separating the ancient island complex from the mainland (modified after Berger and Orr, 1966).

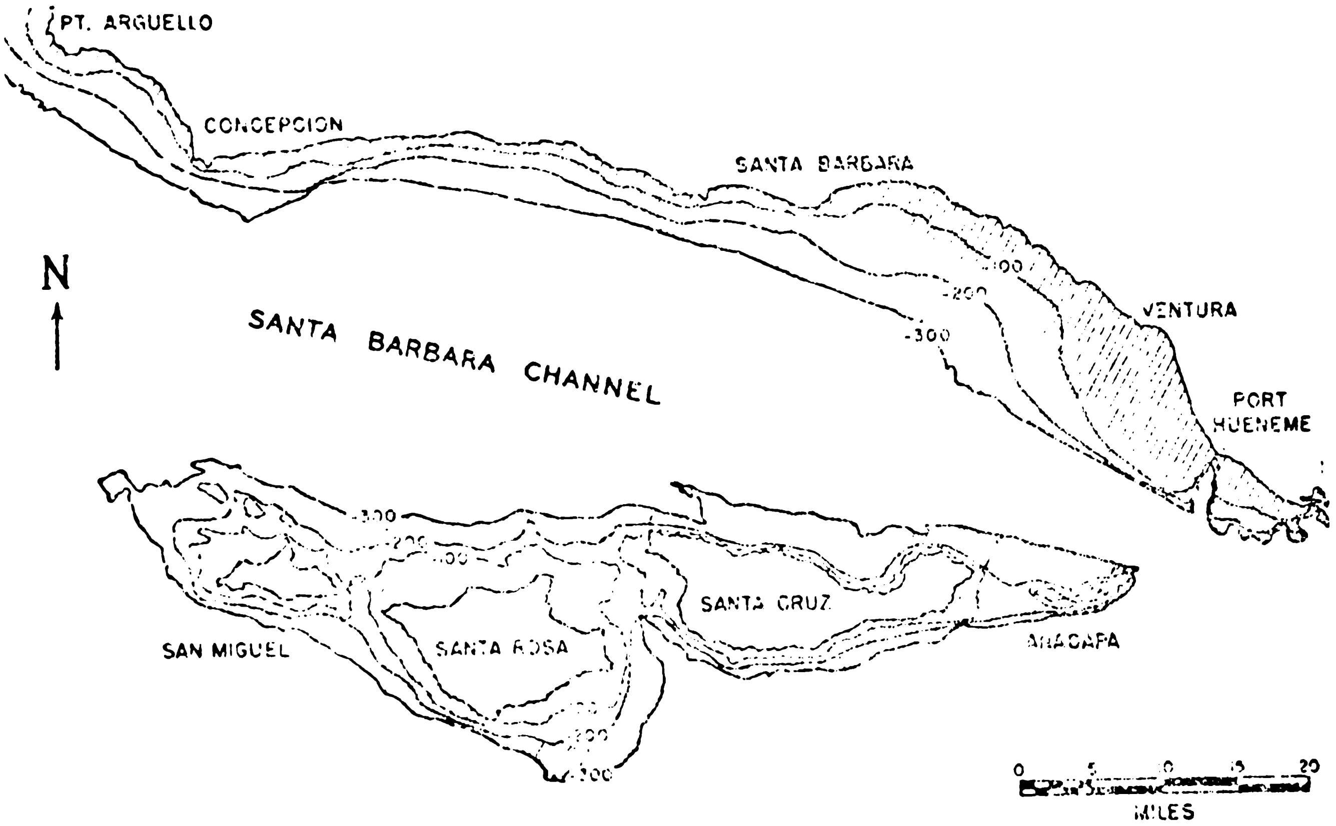

Figure 29. Santa Barbara Channel region, past and present. The lowering of sea-level by 100 foot increments is shown by shading. Best estimates of lowest glacial sea-levels range from 300 to 450 feet. The now separate islands were one large island as late as 12,000 years ago and the width of the Santa Barbara Channel was reduced to 4-6 miles (after Carter, 1959; caption modified).

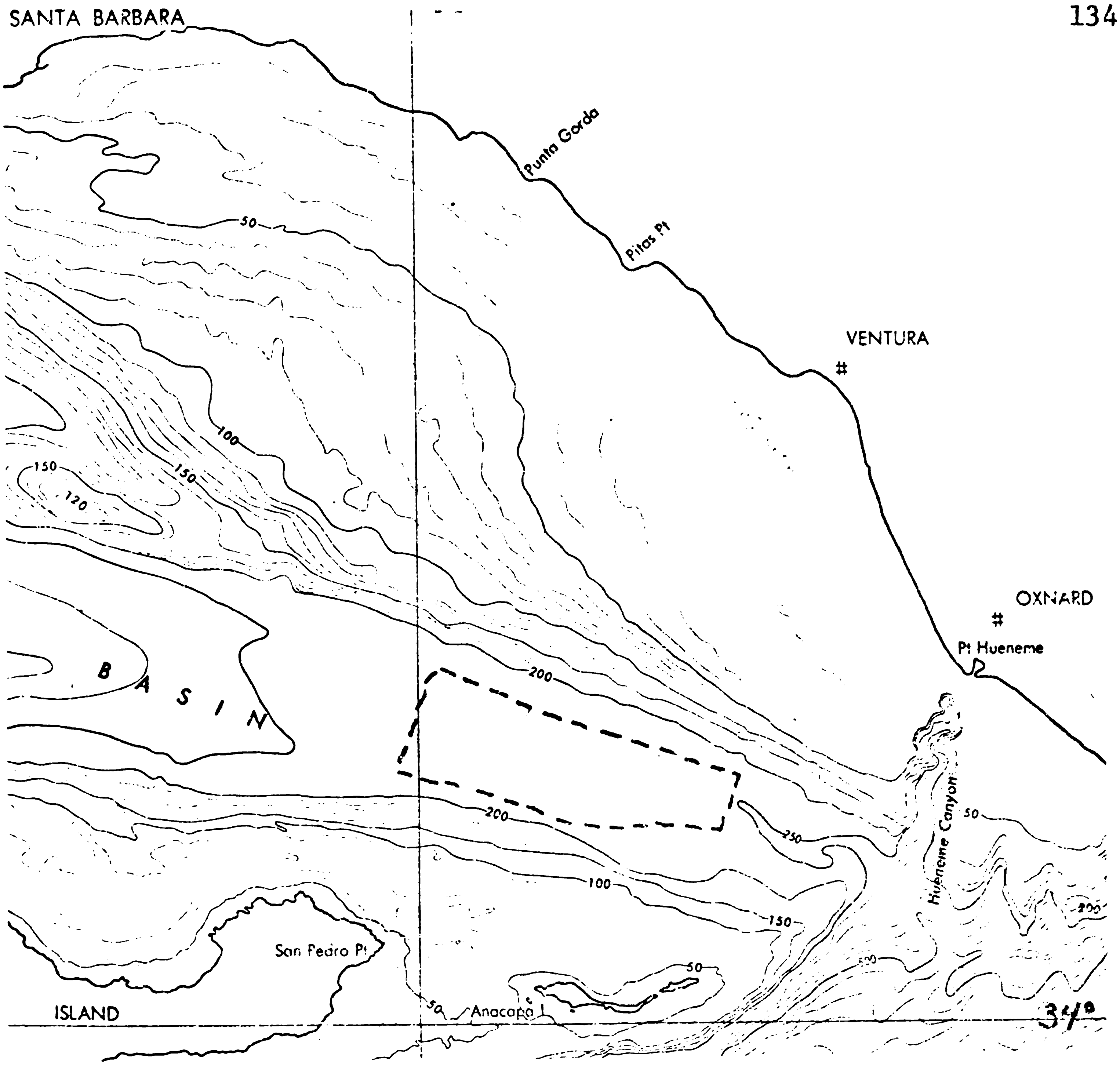

Figure 30. Portion of bathymetric map 1206N-15 showing the eastern third of the Santa Barbara Channel. The bathymetric contour interval is 10 meters to the 200 meter depth, and 50 meters beyond. The depth of the floor of the channel outlined by the dashed line varies between 755 and 780 feet (Hydrographic Survey Charts H-5849 and H-5030). This is an area nearly 50 miles square that is essentially flat, varying only 25 feet in maximum relief.

the Oxnard Plain from Point Mugu to the present mouth of the Santa Clara River (the region in which the former mainland link is usually inferred) is underlain by unconsolidated sands, silts and clays that range from 600 to 1800 feet thick which overlie marl of the Santa Barbara Formation (Thomas, et al., 1954, p. 24). Thus, there is no evidence that a link of bedrock extended westward from the Santa Monica Mountains as a

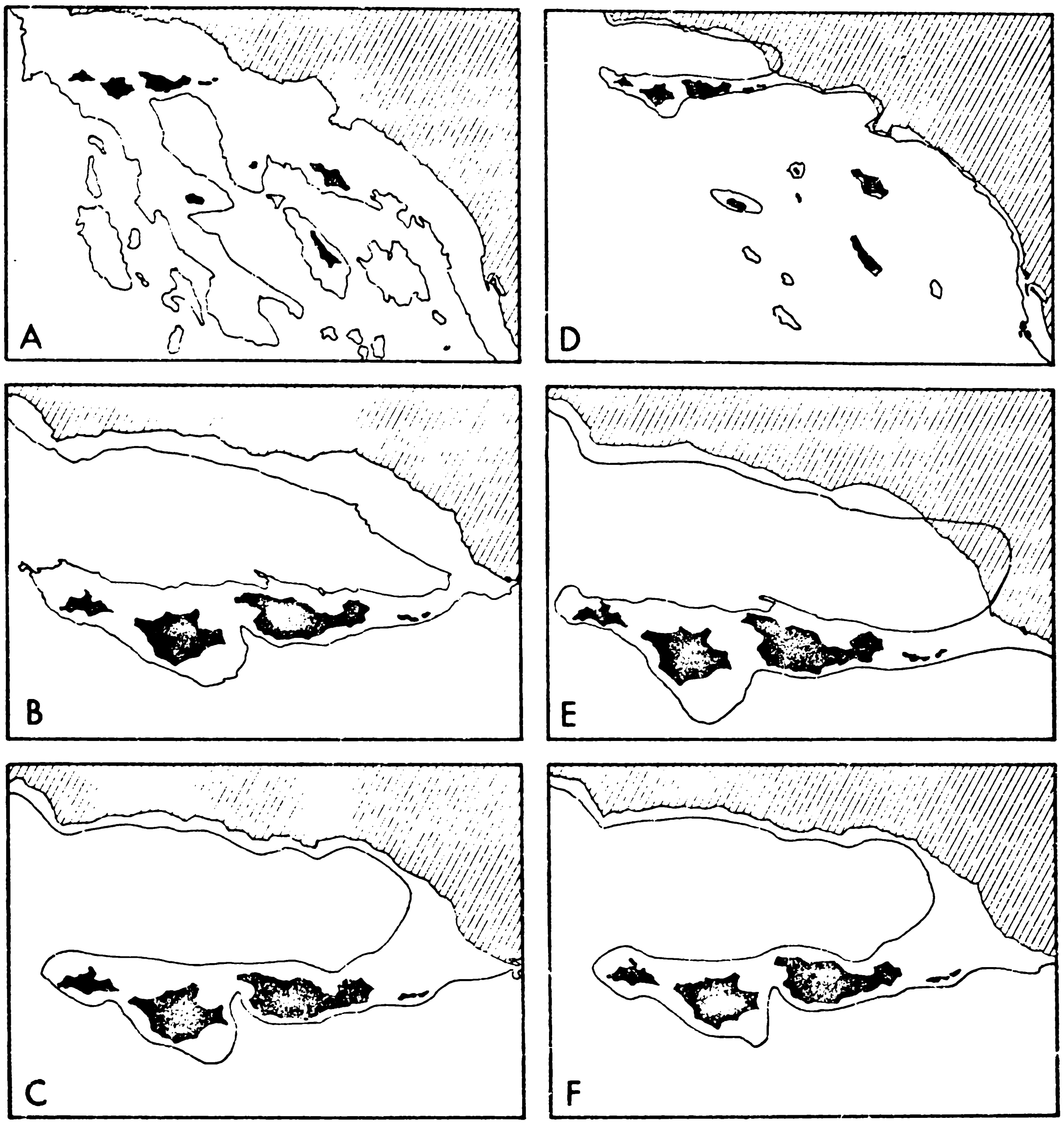

Figure 31. Reconstruction of Channel Island land bridges by various authors. A--early Pleistocene (Clements, 1955), B--early Pleistocene (Van Gelder, 1965), C--Pleistocene (Chaney and Mason, 1930), D--mid-Pleistocene (Valentine and Lipps, 1967), E--possibly mid- to late-Pleistocene (Remington, 1971), F--late-Pleistocene (Stock, 1943).

peninsula encompassing the Northern Channel Islands. If a link did occur, which seems very doubtful, it was completely obliterated, probably by large-scale tectonic subsidence of the Santa Barbara Channel floor, and perhaps subsequently masked by submarine alluvium from the Santa Clara and Ventura Rivers. Certainly the Channel area is tectonically mobile as has been shown, and some warping has occurred in late Quaternary times in the east Channel region (Scholl, 1960; Putnam, 1942). It is possible that the well documented mid-Pleistocene Pasadenan Orogeny which markedly affected the mainland played a role in the matter as Axelrod (1967) suggests, although according to Valentine and Lipps (1963,1967) the islands seem to have escaped its effects.

One other piece of geologic evidence seems to argue against a mainland connection. The presence of high elevation marine terraces on all the Channel Islands with the possible exception of Catalina suggests that since mid-Pleistocene or early-late Pleistocene time the islands have been rising slowly out of the sea, irrespective of glacio-eustatic oscillations. At the beginning of this rise San Miguel, Anacapa, and San Nicolas were completely submerged, and Santa Barbara and San Clemente Islands were almost or completely submerged; only Catalina and the higher parts of Santa Cruz and Santa Rosa may have remained above water, and conceivably may even have been land positive during all of the Pliocene and Pleistocene. For convenience this epoch of submergence may be called the <u>Island Submergent Period</u>. Elephants, whose remains on the islands provide the primary evidence for a land bridge, must have arrived on the Northern Channel Islands <u>after</u> the Island Submergent Period because the amount of land exposed during the Island Submergent Period (if any) would have been very limited, probably not enough to support an elephant population. This opinion is shared by others (Orr, 1968, p. 17; Valentine and Lipps, 1967; Weaver and Doerner, 1967). The general picture since has been one of increasing island emergence and increasing total island area from mid- to late-Pleistocene times, presumably culminating during low level Wisconsin seas of 20,000 to 14,000 years ago during which no mainland connection occurred. It is noteworthy that when land bridges are severed a reverse process of island submergence is normally expected, similar to that shown by Figure 28 when inter-island bridges which connected the Northern Channel Islands were severed by rising post-glacial seas. If a mainland connection did in fact exist at all it seems most reasonable that it was considerably prior to the Island Submergent Period, perhaps in early-mid or early Pleistocene time or even earlier. However, since mammoths apparently only arrived in North America by way of the Bering Bridge in mid-Pleistocene time (personal correspondence, C. Repenning, 1969; see also Weaver and Doerner, 1967, 1969; Valentine and Lipps, 1967) it is unlikely that they reached the islands at an earlier time.

By the same token, no geologic or eustatic evidence indicates that the northern islands were connected to the southern islands either. Depths of up to 1200 feet are recorded along the submarine ridge which runs between Santa Rosa and San Nicolas Islands* which is far lower than any reasonable estimate of negative Pleistocene glacio-eustasy. San Nicolas Island was wholly submerged in late-Pleistocene time (Vedder and Norris, 1963, p. 10) and much or all of Santa Barbara (635 ft. elev.) and San Clemente (1965 ft. elev.) were too as they have obvious terraces at elevations of 250 and 1500 feet respectively.

In summary, no geologic, structural, bathymetric, topographic or eustatic evidence presently supports the idea that the Northern Channel Islands were connected to the mainland or to any of the southern islands

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*Coast and Geodetic Survey Bathymetric Map 1206 N-15 (1967).

(or the latter with one another), but the four northern islands were almost certainly connected to one another.

14. Biologic Evidence of Land Bridges

As indicated, the views of the participants of the 1965 Symposium on the Biology of the California Islands vis-a-vis land bridges were mixed. Those who favored land bridges based their views largely on the faunal evidence. In regard to the botanical evidence, critical appraisal of it and the points made by the 1965 symposium participants plus other considerations show that land bridges were not necessary to explain either insular plant distributions or the endemic and relic character of the flora. The plants or their ancestors could have arrived on all the islands as over water migrants and or brought by birds. The most convincing evidence of this comes from Guadalupe Island which lies 157 miles from the nearest point on the mainland across water with depths of 12,000 feet (Moran, 1967). It is an oceanic island, a volcanic massif rising 15,000 feet from the deep ocean floor which apparently has never been connected to the mainland or to the Channel Islands 240 miles distant to the north. But, Guadalupe Island is older than the California Channel Islands, being middle Pliocene in age, and so has had a much longer time in which to aggregate its flora via air and water borne migrants (Moran, 1967; Raven, 1967; Hubbs, 1967). The idea of island colonization by plants via over water dispersal is by no means new and is invoked to explain the vegetation on many of the world's islands (Carlquist, 1965).

The symposium paper on floristics by Raven and discussions by Moran, Carlquist, Howell, Lewis, Haller, Thorne, Raven, Garth, and Hubbs plus other papers on Channel Islands biota (Raven, 1963) plus general considerations suggest that the character, make-up and distribution of insular vegetation are most easily explained by migrant over water dispersals in conjunction with the following limiting factors: (1) distance from the mainland (e.g., the Northern Channel Islands versus San Nicolas and San Clemente), (2) area (e.g., small San Miguel versus large Santa Rosa), (3) time (e.g., Pleistocene Northern Channel Islands versus Pliocene Guadalupe Island), (4) topography and diversity of habitats (e.g., a smooth and flattish San Miguel versus rugged Santa Rosa), (5) man, his animals, and native animals (e.g., Indians, shepherds, sheet, fox and elephant on San Miguel), and (6) genetic factors (e.g., intraspecific variation, the founder principle, etc.). But the main point here is that the botanical evidence does not require mainland connections.

The zoological evidence of land bridges, however, is more ambiguous. As indicated, von Bloeker (1967) would have long peninsulas linked to all the islands to account for the animals on them whereas Savage (1967) would have none (see also Peabody and Savage, 1958). It should be underscored that most postulated land bridges on the Channel Islands are based on the distribution and character of the native island land animals both extinct and extant.

Included on the Northern Channel Islands at the species level are the fox, skunk, three lizards, three snakes, two salamanders, a frog, four mice (two extant and two extinct species), and an extinct elephant for a total of 16 species of mammals and herpetofauna, 13 of which are still living (Table 16). The combined area of the four northern islands is presently 194 square miles whereas the area defined by the Pleistocene super-island Santarosae, calculated from the 100 meter isobath*, was 790 square miles (Fig. 32). The latter figure is over twice the 320 square mile area of the Santa Monica Mountains**, which at the time of European contact, had at least 70 mammalian and herpetofaunal species (Table 18 shows 36 mammals; Savage [1967] lists 34 herpetofauna).

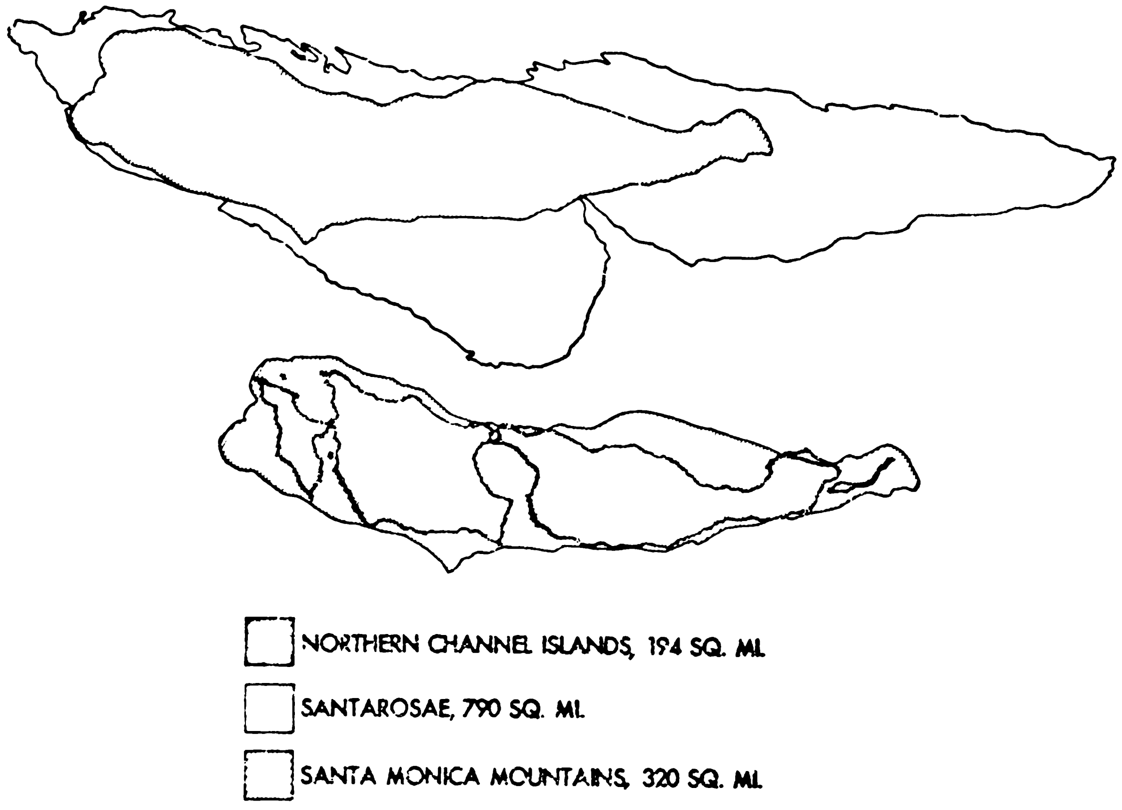

Figure 32. Comparison of total area of the Santa Monica Mountains with the Northern Channel Islands and Santarosae. At least 69 mammals and herpetofauna are native to the Santa Monica Mountains while only 13 animals occur on the Northern Channel Islands, islands that are recent residua of the much larger landmass of Santarosae whose area was 2.5 times greater than the Santa Monica Mountains.

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*Coast and Geodetic Survey Bathymetric Map 1206N-15 (1:250,000).

**U.S.G.S. Sheet NI11-4, Los Angeles, California, 1959 (1:250,000). The area of the Santa Monica Mountains was defined by the sea coast, Oxnard Plains, Ventura Boulevard (U.S. 101), the Los Angeles River in downtown Los Angeles, and the mountain-coastal plain interface in west Los Angeles.

TABLE 18

Mammals*and Herpetofauna of the Santa Monica Mountains

Sorex bendiri	marsh shrew
Sorex trowbridgii	trowbridge shrew
Notiosorex crawfordi	gray shrew
Scapanus latimanus	broad-handed mole
Lepus californicus	black-tailed hare
Silvilagus floridanus	eastern cottontail
Silvilagus bachmani	brush rabbit
Otospermophilus beecheyi	california ground squirrel
Eutamias merriami	merriam chipmunk
Sciurus griseus	western gray squirrel
Thomomys bottae	botta pocket gopher
Perognathus baileyi	bailey pocket mouse
Perognathus californicus	california pocket mouse
Dipodomys agilis	
Reithrodontomys megalotis	western harvest mouse
Peromyscus californicus	california mouse
P. boylii	brush mouse
P. eremicus	cactus mouse
P. truei	pinyon mouse
P. maniculatus	deer mouse
Neotoma fuscipes	dusky-footed wood rat
N. lepida	desert wood rat
Microtus californicus	california meadow mouse
Urocyon cinereoargenteus	gray fox
Canis latrans	coyote
Ursus chelan	grizzly bear
Procyon lotor	raccoon
Bassaricus astutus	ringtail
Mystela frenata	long-tailed weasel
Taxidea taxus	badger
Mephitis mephitus	striped skunk
Spilogale putorius	spotted skunk
Felis concolor	mountain lion
Lynx rufus	bobcat
Cervus nannodes	tule elk
Odocileus hemionus (hemionus columbianus)	mule deer

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*List of mammals taken from range maps of Ingles (1965); list of herpetofauna from Savage (1967).

Probably many or most of the extinct Pleistocene animals found in the La Brea Pits (Table 19) also ranged in the Santa Monica Mountains and coast as many of them have been found along the Santa Barbara and Ventura Counties mainland coast (Orr, 1968, p. 26; Jennings and Troxel, 1954, p. 40). If the extinct Pleistocene forms are included with the 36 mammals in Table 18 and Savages' 34 herpetofauna, then almost 100 mammalian and herpetofaunal species live or did live in the Santa Monica Mountain environs. While it is highly probable that not all these extant and extinct animals were living in the area at the time when the hypothesized land link to the northern islands occurred, those not present likely were represented by ecological equivalents. Only 13 of the animals in Tables 18 and 19 occur naturally on the Northern Channel Islands today, and Savage (1967) has mounted a persuasive argument that at least nine of these (the herpetofauna) originated by over water waif migration.

In terms of habitats the four northern islands show a wide variation in topography, elevation, exposure, vegetation, soils, and even climate (the interior valleys and upper slopes of Santa Cruz and Santa Rosa are climatically distinct from the low coastal terraces; anyone who has visited these islands for extended periods will attest to this). It is again worth noting that the Northern Channel Islands have eight of Munz' 11 vegetation types listed for California; strand, marsh, scrub, grassland, coniferous forest, woodland-savanna, and chaparral. So, the habitats are there but the animals are not. If the land bridge theory is valid, why did a peninsula as large as suggested by those shown in Figure 31, which presumably was as large or larger than Santarosae, retain so

TABLE 19

Mammals and Herpetofauna from the La Brea Tar Pits*

Mammals:	
Canis (aenocyon) dirus	dire wolf
Canis (aenocyon) milleri	wolf
Canis furlongi	extinct gray wolf
Canis orcutti	coyote
Canis andersonii	coyote
Tremarctotherium simum	short-faced bear
Ursus optimus	black bear
Smilodon californicus	saber-tooth cat
Panthera atrox	great cat
Felis daggetti	extinct cat
Onychomys torridus	grasshopper mouse
Equus occidentalis	western horse
Tapirus	tapir
Platygonus	peccary
Camelops hesternus	camel
Antilocapra americana	antelope
Breameryx minor	diminutive antelope
Bison antiquus	bison
Mammuthus imperator	emperor mammoth
Mammuthus columbi	Columbian mammoth
Mammut americanus	american mastodon
Paramylodon harlani	ground sloth
Nothrotherium shastense	small ground sloth
Megalonyx jeffersoni	ground sloth
Magalonyx milleri	ground sloth (from Palos Verdes Hills)
Herpetofauna:	
Clemmys	pond turtle
Sceloporus	desert scaly lizard
Xantusia vigilis	yucca night lizard
Bufo nestor	frog

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*List of animals taken from Stock (1958).

few animals when it was severed, supposedly from the western end of the Santa Monica Mountains? Why are there no native shrews, moles, rabbits, squirrels, chipmunks, gophers, wood rats, raccoons, ringtails, weasels, badgers, bobcats or deer on the norhtern islands? Of the 29 extinct mammalian and herpetofaunal species found in the La Brea pits, why is only one, the water-loving elephant, found on the Channel Islands? Were many of these animals originally present on the super-island Santarosae but unable to exist on the 194 square miles of land which remained after the post-glacial sea-level rise? If elephants managed it, why not others? While it is true that islands in general invariably have an impoverished fauna compared to adjacent mainlands, in consideration of the large size of the Northern Channel Islands and their former much greater extent, the present level of faunal impoverishment seems anomalous. Santa Cruz and Santa Rosa Islands are big islands with diverse habitats and many open niches, especially for small animals like moles, shrews, rabbits, squirrels, chipmunks and gophers. It is difficult to explain their absence (plus the fact that no fossils of living mainland forms have been found) in light of the great number of unfilled niches on the Northern Channel Islands in any reasonable way except that no mainland link existed. Anyway, why infer a mainland link that is not even required to explain the island fauna?

The land bridge reconstructions shown in Figure 31 were generated primarily because elephant remains occur on Santa Cruz, Santa Rosa, and

San Miguel Islands.* The fox and skunk conceivably could be explained by accidental rafting or by Indians, but not elephants. Indeed, the presence of pygmy elephant remains has generated speculations on the history of the islands, on how and when the elephants arrived, on whether the elephant arrived in pygmy form or evolved in insular isolation, on why and when the elephants became extinct, and when the islands of the northern group became separated from the mainland and from one another. In fact, if elephant remains had never been found, then altogether different views on the Quaternary geologic history of the northern islands would have been shaped. Perhaps even the chronology and history of man on the islands would have been interpreted rather differently. All of the extant and extinct fauna of the California Channel Islands, including elephants, could have arrived by swimming, by accidental rafting or waif dispersal, or by Indian watercraft.

The Swimming Capabilities of Elephants

A land bridge is not a <u>sine qua non</u> for explaining elephants on the Northern Channel Islands. Research for this thesis shows that modern elephants are excellent distance swimmers, among the best of all land mammals, and as Stock (1943) intoned, there is no reason for assuming the California elephants possessed habits different from modern ones. The problem is that there are so few documented references of modern elephants swimming that most casual observers scoff at the notion, as some of my

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*A tooth from a normal-sized mammoth was reportedly found on San Nicolas Island. However, Vedder and Norris (1963) offer evidence that the tooth was brought in by Indians and is out of provenance.

colleagues did initially. But, the opinions and experiences solicited from many elephant experts in Africa and Asia proves otherwise. The idea, however, that elephants conceivably could swim to the islands, perhaps during a time of glacio-eustatically low sea-level, is so novel and iconoclastic that I think it is absolutely necessary to present the evidence that I have accumulated. Also, since most of this information is not in print, and as no survey of the swimming capabilities of elephants has ever been made to my knowledge, to simply cite the few existing published references would probably not be adequate in light of anticipated criticism. The evidence which proves the swimming powers of elephants is found in Appendix C. It should be noted that the evidence is not comprehensive, being based only on a moderate sampling of the elephant literature (which is enormous) and personal correspondence.*

Discussion

The quotes, descriptions and discussions in Appendix C show, I think, conclusively that elephants are distance swimmers par excellence (in either fresh or salt water) and apparently they swim with a purpose in mind. Elephants definitely are water-loving animals and in some areas where conditions dictate they actually follow a semi-aquatic way of life (Sikes, 1971, p. 244; Blond, 1962, pp. 32, 140) which probably reflects the semi-aquatic habits of their ancestors as suggested by several of my correspondents (in Appendix C see Sanderson; Tors; Deraniyagala, 1955;

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*The idea that elephants could conceivably swim to the Northern Channel Islands developed out of casual discussion of the subject with P. V. Wells in 1967.

Sikes, 1971, p. 244; and Sprague de Camp, 1964, p. 61; interestingly, manatees and sea cows are among the closest living relatives of the elephant). The evolution of the trunk and the absence of a pleural cavity in elephant reflects the semi-aquatic habits of its ancestors (Short, 1962). Also, upon reviewing the elephant literature one is struck by the widely-held opinion that elephants need to bathe frequently to maintain their physiological well being. For example, Sikes (1971, p. 247) states that water is used ". . . for skin hygiene, and elephants suffer acutely from prolonged periods without the opportunity to bathe and wallow." They particularly suffer where droughts are common and at such times will seek water of any quality, salt, alkaline, muddy or foul.

Elephants swim in a porpoise-like, lunging fashion that appears to be a process in three movements. This process was described by C. R. S. Pitman* in 1934 as follows:

> In the course of the visit of the Parliamentary Delegation to the Murchison Falls, during the upstream trip a large bull elephant was seen apparently swimming the Nile ahead of the steamer. The river at this place is about four hundred yards broad: unfortunately everyone was so interested in the unusual spectacle that no soundings were taken to ascertain the actual depth.
>
> There were three different phases in the mode of progression repeated mechanically and precisely which do suggest that the creature was not merely walking along the bottom.
>
> From the three separate exposures of parts of the body made in regular sequence it seemed that while completely submerged, and presumably swimming, the elephant feeling the necessity for taking a breath of air heaved itself upwards towards the surface which resulted in the exposure of the top half of its head.

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*Uganda Game Department, Annual Report for 1934, Section II, paragraphs 124-127, pp. 22-23.

> Next the body again disappeared completely from view to be followed by the sight of a few feet of the trunk thrust above the water at an angle of 45°, and exposed for several seconds.
>
> The trunk in its turn disappeared, but instead of being withdrawn along its own axis, was used with a downward sweep to help propel the creature. This driving thrust was sufficient after the disappearance of the trunk tip to expose a tiny portion of the top of the head for a few moments. After this had disappeared beneath the water, the process as just described was repeated. (Pitman, 1934; see also Pitman, 1953, p. 104).

The porpoise-like lunging rhythm of swimming elephants also has been observed by others as shown in some of the quotes in Appendix C (see Williams; Trevor; and Douglas-Hamilton).

Finally, it appears as though swimming is instinctive in elephants since calves, in one case only a few days old, frequently have been observed swimming (see Oberjohann; Sikes; Sanderson; Douglas-Hamilton; Nicholson; Temple Perkins; McCabe; Kadirgamar; Norris; Williams; and Pitman in Appendix C).

There probably would be many more published accounts of the swimming capabilities of elephants were it not for three factors. One is that elephant swimming activity normally occurs at night and is therefore seldom witnessed. This was the standard case in Ceylon, on the Kenya and Tanzania coasts, and on the Zambesi River. The daytime swimming event that Admiral Rajan. Kadirgamar faithfully documented as a film sequence (Plate 74a) in Ceylon was apparently a rare episode, as he intimates.

Another reason, a very important one, is that few opportunities for documenting the swimming capabilities of elephants exist because elephants seldom _have_ to swim due to the shallow nature of many rivers and lakes in, for example, Africa. Thus, most instances where elephants were reported clearly swimming rivers came when the latter were swollen by floods. In many cases where observers were unsure whether adults were swimming, the juveniles definitely were, for long periods in some instances, because being in deep water they _had_ to swim. Expressed differently, if all of the African lakes and rivers were deep, there probably would be many more published reports of adult elephants swimming.

And thirdly, it is clear that expanding human settlements and populations have markedly restricted the range of elephants from coasts and certain water bodies in Africa and Asia where, with access to islands, swimming in former times may have been commonplace (note comments of Nicolson and Deraniyagala in Appendix C). For example, considering the great size of Lake Victoria and the number of islands in it, one would have expected many elephant-swimming reports to have come from that region. But, the Lake Victoria area now has a dense human population, as do many coastal areas of East Africa where elephant formerly were common. What once may have been commonplace swimming episodes (when elephants were common and people were few) are now rare events (because people are common and elephants are few). The point here is that under natural conditions (i.e., in absence of civilization and burgeoning human populations) and when the need arises swimming is part of the normal behavioral bag of elephants, if the circumstances require it. If elephants _need_ to swim or _want_ to swim, they swim.

If Admiral Rajan. Kadirgamar's speed data for the elephant swim to Sober Island, Ceylon, is used as a base for comparison (first swim = .6

mph; second swim = 1.3 mph; average = 1.0 mph) then the 79 elephants described by Sanderson in their Dacca to Barrackpur trip would have swum an average approximate distance of six miles non-stop, or nine miles total. If the maximum speed of Kadirgamar's elephants is used (1.3 mph) then Sanderson's 79 elephants could have swum an approximate distance of eight miles non-stop, or nearly 12 miles total. On the other hand, if Rowe's data on the elephant he timed is used (1.7 mph) then Sanderson's elephants could have swum some 10 miles non-stop, or 15 miles total. This means it may be within the limits of feasibility for modern elephants to swim the 13 miles of water which presently separates the Northern Channel Islands from the mainland at the eastern end of the Santa Barbara Channel. But Pleistocene elephants had only to swim less than half that distance during times of glacially lowered sea-level (Fig. 33). Sea-level was glacially lowered from 100 to 130 meters several times during the Wisconsin glaciation of 70,000 to 10,000 years ago. At such times, covering time increments of thousands of years, the narrowest part of the Channel was minimally four miles wide, a distance that elephants easily could have managed. Such an event involving a few individuals need only have happened once for an elephant population to become established on Santarosae. (Interestingly, the idea of Pleistocene elephants swimming water barriers is not indigenous to these pages, for Darlington (1957, p. 519) apparently without benefit of knowing how well modern elephants can swim, concluded that the elephants (now extinct) of Celebes Island, Indonesia, got there by swimming the 25 mile barrier of Makassar Strait during the Pleistocene.)

If elephants did in fact swim over, what factors would have induced them to make the crossing? To provide a reasonable answer to this question we must reconstruct aspects of the late Pleistocene environment of the Santa Barbara Channel. First, in reference to Figure 33, to any mainland elephant bathing in the surf zone (up to 10 miles seaward of the present shoreline) in the narrow eastern third of the Channel the mountainous super-island Santarosae must have loomed large indeed. Conversely, the mainland surf zone was backed by a broad low-lying flat plain so that the most conspicuous landform to any elephants bathing in the sea other than the immediate beach was mountainous Santarosae which

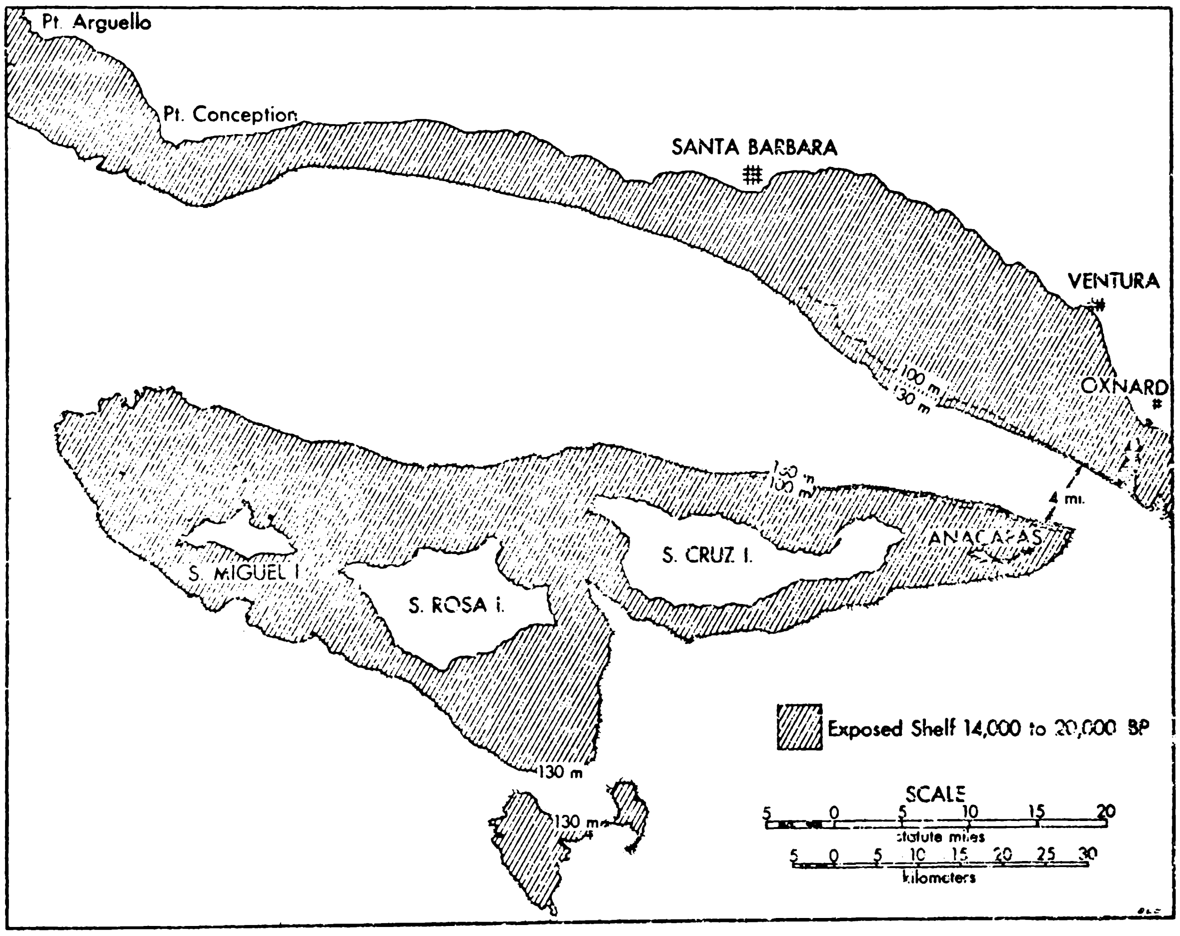

Figure 33. Approximate extent of exposed land in the Santa Barbara Channel region during the interval 14,000 to 20,000 years ago. Regardless of whether glacial seas were lowered 100 meters or 130 meters (the range of most estimates) the water gap along many miles of the eastern channel was only four to six miles

loomed seaward. Sea bathing probably was common along the California coast during the summer months and at times of drought when elephants seek water for their physiological well being. Now, most observers are of the opinion that modern elephants have poor close-up vision, but there is some evidence that they can see well at a distance (Temple Perkins, 1955, p. 24).* All elephant specialists do agree, however, that the elephant has an extraordinary sense of smell, as a review of the elephant literature will show. So acute is the elephant's sense of smell that its trunk has been likened to an environmental radar system (Blond, 1962, p. 31). An illustration of the extreme sensitivity of elephant sense of smell comes from a herd cropped in Tsavo National Park in Kenya. "In this the herd matriarch appeared normal in every way before slaughter. She was able to move with her herd, at a run, as a perfectly normal animal. On post-mortem it was found that she was totally blind and therefore had to locate herself and her herd through scent and sound alone."**

The literature also shows that elephants seek their food by smell, not sight (Napier Bax and Sheldrick, 1963). Since the Pleistocene wind direction was almost certainly predominantly on-shore as at present (Fig. 12) the elephants on the mainland beach likely could perceive the island

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*Temple Perkins believes that elephants have very good long sight, that their so-called short-sightedness is really due to indifference since they have no need to visually inspect the foreground relying instead on their trunk to sense enemies, danger, food, and water. Carl Akeley, the naturalist and taxidermist, also believed that elephants could see well at a distance (Sprague de Camp, 1964, p. 9). Blond (1962, p. 53) also claims that elephants ". . . are definitely farsighted."

**I. S. C. Parker, letter of March 28, 1972. Mr. Parker is with Wildlife Services, Ltd., Nairobi, Kenya.

vegetation by smell (and perhaps distinguish the islands by sight) as they do in Lakes Edward, George, Victoria, and Kariba in Africa, and in Ceylon and the Andaman Islands. This idea is largely attributed to I. S. C. Parker* who writes:

> [Elephants] . . . are animals of surprisingly restricted range and would have many factors operating against random aquatic expeditions. Where they do undertake a deliberate swim it seems invariably that they have fore-knowledge of their destination. Either they have been there before, are so close that they might hear other elephant at their destination, are so close they could perceive land visually across water, or most probable, they could scent an island-vegetation, etc. Their sense of smell being such it is almost analogous to our vision as a prime means of orientation. What would be the prevailing wind direction in relation to your islands?** If it was from island to mainland then it would almost certainly permit elephant on the latter (if these had a sense of smell similar to L. Africana) to perceive the islands. It also crosses my mind that constant wind of this nature might prevent them from relocating the mainland.

If the mountainous super-island Santarosae were anchored four miles off the coast of East Africa today in an area where many elephants and few humans live (like the Lamu area) and which had prevailing winds from island to mainland it probably would not be long before a resident population of insular elephants became established.

Finally, we will never ascertain conclusively whether elephants on the Channel Islands got there by walking or swimming, and I am not absolutely convinced that they did swim out. However, the picture presented

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*Letter of November 2, 1971.

**See Figure 12. Evidence presented in the next chapter shows that prevailing Pleistocene paleowind directions were essentially the same as shown in Figure 12.

here shows that they could have; and if they did the problem of why many extant and extinct mainland animals are absent on the island is relieved.

Time Required for Elephant Dwarfing

Having arrived on the northern islands the time required for development of small size probably was not excessive. In the absence of predators there is no apparent need for elephants anywhere to continue to select for large size. This fact, coupled with the observation that tremendous size variation exists among individual living elephants (Deraniyagala, 1955, p. 38, 55; Sprague de Camp, 1964; Sikes, 1971, pp. 12-15) probably provided the main ingredients conducive to rapid dwarfing of elephants. Reduced forage area and limited water supply may have been a third force operating. Certainly on islands ". . . smaller animals can live on less and are more likely to survive and to breed in times of shortage." (Simpson, 1951, p. 41-48). Another factor likely involved is the "founder" effect which is based on the principle that a colonizing individual carries only a small representation of genes in comparison to the entire mainland parent population (Mayr, 1942, 1954, 1963). As a result the genetic composition and variability of a population which derives from a small founding group will vary greatly (see Mac Arthur and Wilson, 1967, p. 154 for discussion). Moreover, the smaller the island population the greater the chance for genetic drift to occur (Wright, 1931). By the same token, great fluctuations in numbers through time would also tend to intensify divergent evolution (Huxley, 1942; Ford, 1954, 1955). Considering the frequent droughts and periodic fires that likely affected the water and food supply of elephants on Santarosae it is possible that there were considerable fluctuations in their total numbers through time.

While some authors have stated that dwarfism is a pecularity of island fauna (Hesse, et al., 1951, p. 630; Banfield, 1963; Simpson, 1953; Hantzsch, 1905), Foster recently has shown that only certain orders of the class Mammalia become small on islands (Foster, 1963, 1965). After studying the Queen Charlotte Islands fauna, and reviewing insular faunal records from many other areas of the world, Foster concluded that ". . . mammals smaller than rabbits tend to be larger on islands, while mammals of rabbit-size and larger tend to be smaller" (Foster, 1965, p. 110). More specifically he found that artiodactyls, lagomorphs, and carnivores tend to be smaller on islands. To this list we can add proboscideans*, for in every instance where elephants have lived on islands they have attained pygmy size (Malta, Sicily, Sardinia, Cyprus, Crete, Java, Celebes, Flores, Timor--see Hooijer, 1970; Vaufrey, 1929; Leonardi, 1954; on Malta full-grown adult elephants were pig sized).

The rapidity with which large mammals can attain small size on islands is shown by deer introduced to the Queen Charlotte Islands at the turn of the century ". . . and are now dwarf in size on some parts of their range." (Foster, 1965, p. 35.) Another "pygmy" ungulate, the Dawson caribou, also occurs on the Queen Charlotte Islands and Foster (1965) concluded that ". . . the characteristic features shown by the

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*Also perissodactyls, as will be discussed.

Dawson caribou could have appeared in as short a period as the 10,000 years since glaciation."

The Key deer of the Florida Keys, which stands about 26 inches at shoulder height, is a small race of white-tailed deer (Barbour and Allen, 1922; Dickson, 1955) whose size reflects the recency of post-glacial insular semi-isolation* (Allen, 1951, 1952). Small races of white-tailed deer also occur on the islands off South Carolina and Georgia (Goldman and Kellogg, 1940).

The pygmy Shetland pony, only 40 inches at shoulder height, may be another example whereby a large mammal isolated in an insular environment has evolved to small size in a comparatively short time. The history of the Shetland pony is unknown but the horse is inferred to have been on the islands prior to the Scandinavian invasions of the ninth and later centuries (Douglas and Douglas, 1913; Barton, 1911, p. 207). Whatever the origin of the horse, whether native or brought by man, its ancestors--presumably normal sized--cannot have been isolated earlier than the last glacial maximum of 18,000 years ago because the Shetlands are connected to Scotland by a shallow submarine bank.** G. G. Simpson (letter of

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*Prior to extensive European settlement there likely was some overlap between the northern range limits of the Key deer and the mainland population, but gene flow was apparently not great. The Florida Keys became separated from the mainland and each other during post-glacial sea-level rise. Interestingly, the deer regularly swim from island to island, sometimes across as much as a mile of ocean (Dickson, 1955).

**British Hydrographic Survey Chart No. 4442 (1923). The bank is everywhere shallower than 100 meters so that the Shetlands were part of the mainland during the maximum Wisconsin low sea-level.

February 2, 1972) however is of the opinion that the small size of the ponies may reflect some degree of artificial selection by the ancients, but how much (if any) is not known.

In summary, the small size of the Queen Charlotte Islands deer and caribou, the Key deer and the insular deer of Georgia and South Carolina, and the Shetland pony* show that certain large mammals may attain small size in a comparatively short time. Normal-sized elephants could have reached the Northern Channel Islands as late as early Wisconsin and evolved to small size before they were extincted in late-Pleistocene or early post-glacial times. This is a view shared by Weaver and Doerner (1967, 1969) but not by Orr (1967, 1968, pp. 16-24) who believes the elephants arrived on the Channel Islands by Illinoisan times or earlier. Unfortunately, at present we have insufficient information to resolve this matter, if indeed it is resolvable at all.

What about the origin of foxes, skunks and mice on the Northern Channel Islands? Is it necessary to invoke a Pleistocene land bridge to explain their origin, or does it seem more reasonable that they arrived either by chance rafting or by aboriginal watercraft?

Channel Islands Fox (Urocyon littoralis)

As mentioned in Section 9 of Chapter 2, the fox occurs on San Miguel, Santa Rosa, Santa Cruz, San Nicolas, San Clemente and Santa Catalina Islands. Since there is no geologic, structural, bathymetric, topographic

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*Hesse, et al. (1951, pp. 630-631), gives many other examples of mammalian dwarfism on islands round the world. Many of the islands that they list were connected to their respective continents during Wisconsin low sea-levels so that dwarfing occurred within the last 14,000 to 18,000 years.

or eustatic evidence that the Northern Channel Islands were connected to any of the southern islands, or that the latter were ever connected with one another, the insular distribution of the fox can be most reasonably explained by over water dispersal.

The morphological and skeletal characters of the island fox have been discussed by Grinnell and others (1937), Dickey (in Rogers, 1929, p. 445), and von Bloeker (1967). The fact that the fox populations on the six largest islands show relatively little divergence from each other but collectively show marked divergence from the mainland gray fox suggests that the island fox was initially isolated on one island for an indefinite time. This single island presumably provided the parent stock for the other island populations which became established only recently. In this regard Norris (1951, p. 74) concluded that the fox on San Nicolas Island was brought by the Canalino Indians, and Vedder and Norris (1963) suggested that in pre-human times the fox was endemic only to the Northern Channel Islands (Santarosae). If the fox was in fact present on only one of the Channel Islands in pre-human times, the likeliest candidate-island is either Catalina or Santarosae since both were large and closer to the mainland than other islands. Since the latter was much closer to the mainland than Catalina, the chances of animals reaching it, other things being equal, would be far greater. Moreover, there is evidence that the fox has been on the Northern Channel Islands for a long time. Orr (1968, p. 42) tells of a fossil fox skull taken from the upper part of the Tecolote member of the Santa Rosa Island Formation. The age of the uppermost Tecolote is reportedly 10,400 radiocarbon years before present. Although the skull was reportedly lost in the sea during transfer to the mainland there is no obvious reason to doubt the claimed provenance of the fox skull, which shows that the fox has been on the Northern Channel Islands for a long time. More recent subfossil fox remains have been found in middens on Santa Cruz Island ". . . throughout the time of Indian occupancy." (Rogers, 1929, p. 445).

If Santarosae was the original home of the island fox it is not surprising that the fox later turned up on San Nicolas, San Clemente and Catalina Islands. The Canalino and their ancient predecessors have traveled about the Channel Islands for a very long time. Man has been on both San Nicolas and Catalina Islands at least 4,000 years (Rozaire, 1967; Crane and Griffin, 1958), and Catalina soapstone artifacts occur on San Miguel, Santa Rosa and Santa Cruz Islands. If the Northern Channel Islands were acquiring items from the southern islands, why not vice-versa? It seems unreasonable to think that it would be a one-way trade relationship. Those who chance to live on the islands, or visit them for extended periods as this writer has, find the fox an excellent pet, easily tamed and, for a hunting and gathering people, perhaps a dependable or emergency source of food (e.g., fox remains in middens on Santa Cruz, Santa Rosa, San Nicolas, and Catalina Islands--see Rogers, 1929, p. 445; Grinnel, _et al._, 1937, p. 459; Orr, 1968, p. 143-144; Vedder and Norris, 1963; Meighan, 1959).

Certainly the gray fox was a valued source of food and pelts to certain aboriginal groups (Landberg, 1965, p. 50; Parmalee, 1965;

Grinnel, 1962, I, p. 298; Munson, et al., 1971; Baegert, in Rau, 1865; White, 1953*; Owen, et al., 1964). Some aboriginal groups used the fox for ceremonial practices (Grinnell, 1962, II, p. 301, 323, 334). Others have testified to the adaptability of foxes in general as pets ". . . on account of their gentleness, their intelligence and affectionate behavior, and their ready confidence and alertness" (Allen, 1942, p. 199). The association of man and canids in California is traced back at least 4,000 years (Haag and Heizer, 1953) and in North America at least 7,500 years and perhaps considerably earlier (McMillan, 1970; Lawrence, 1967, 1968). The Canalino Indians ate dogs (Kroeber, 1941) and transported them in their watercraft (Bowers, 1889, 1890; Schumacher, 1877; Ellison, 1937; Hardacre, 1880; see also McKusick and Warren, 1959, p. 135), and there is no reason to think that related (pet?) canines—and perhaps other animals—would not be extended the same honor. In fact, considering how well boat-traveled the Canalino Indians were it would be surprising had other animals not been introduced (it is probable that several of the herpetofauna were introduced in this way, a matter taken up later in this chapter).

There is evidence that humans, in this case of European ancestry, at least considered taking foxes from one island to another, and perhaps did as shown by the following quote:

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*In North America there was tremendous variation in food animals used from one aboriginal group to another. Some groups ate anything that moved whereas others subsisted almost solely on one species of animal. For a brief informative review of this subject see White (1953).

> As a young man, Salvador Ramirez, a Spaniard of the old school, came to San Clemente Island in 1875 to tend sheep. For many years he lived most of the time on this island. In 1920 he gave one of us [J. S. Dixon] the following story about the introduction of foxes to the island. There were, he thought, no foxes there before 1875. He, being naturally interested in birds and animals, asked and received permission from his employers on Catalina Island to catch and bring over to San Clemente some foxes and goats. One pair of foxes, male and female, were caught on Santa Catalina Island by Ramirez and turned loose near Wilson's Cove, San Clemente Island. From this pair, he believed, had sprung the entire present population of foxes on San Clemente. Ramirez said that the foxes varied a great deal in color on Santa Catalina, some being brighter (redder) than others, and he picked out "good" ones; hence the brightly colored foxes on San Clemente. Other persons on the Santa Barbara Islands have confirmed his account.
>
> Without casting doubt on the reliability of his statements, we may point out: (1) that the foxes on San Clemente at present are markedly different from those now inhabiting Santa Catalina Island; (2) that it seems possible San Clemente may have been inhabited by foxes before Ramirez' "introduction" and that this original stock has persisted while the introduced stock has completely died out, either being killed by the native animals or disappearing from some recurrent cause more fatal to the newcomers than the old-timers; and (3) that the present-day foxes of San Clemente may be descendents of Catalina Island foxes but of a strain or stock which is no longer represented on that island. (Grinnell, *et al.*, 1937, p. 464.)

Light was shed on the matter during research for this study when a letter written by Coast Survey Assistant W. E. Greenwell in 1860, 15 years *prior* to 1875, was discovered wherein he stated that no animals lived on San Clemente ". . . with exception of a small island fox."* Even though Greenwell's letter resolves the matter, and irrespective of whether Ramirez did or did not transfer a pair of foxes from Catalina to San Clemente where they already existed, the point is that Ramirez (being a

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*Hand-written letter by W. E. Greenwell to A. D. Bache, Superintendent of the Coast Survey aboard the Survey schooner *Humboldt* anchored at Santa Barbara dated September 2, 1860 (courtesy National Archives).

human) had given the idea some thought. Ramirez was no more a human than his aboriginal predecessors. As it stands the evidence strongly suggests Catalina, San Clemente, San Nicolas and the northern island group have shared no common land bridges and the fox distributions cannot be reasonably explained without invoking human agency.

The origin of the fox on the Northern Channel Islands is more difficult to explain than its presence on the southern islands. While it was clearly within the capability of an elephant to make the swim to Santarosae, it would have been difficult, if not impossible, for the gray fox to do so—even when the channel width was greatly reduced in distance. Moreover, the fox is not hydrophilous like the elephant and would have no reason to enter the ocean.

It is possible that accidental rafting may have initially brought the fox to Santarosae. Periodic flash floods, prolonged rainy periods and swollen coastal rivers are as Californian as burned chaparral, and floods may have been more frequent and intense during glacial periods. It is not difficult to conceive of a fox, perhaps a gravid female, being carried on a debris raft down the frequently swollen Santa Clara River into the Santa Barbara Channel, although the probability of this happening with successful dispersal must be low. But, since the top-most parts of Santa Rosa and Santa Cruz Islands may have been land-positive during much or all the Plio-Pleistocene there apparently were no time constraints limiting such an event, which need only have happened once for a fox population to become established. The fact that the Santa Clara River, one of the largest rivers in southern California, empties into the eastern Santa Barbara Channel increases the probability of such an event. This may in part explain how some of the herpetofauna originated on the Northern Channel Islands. The semipermanent counterclockwise current gyre present in the Santa Barbara Channel (Fig. 10, Chap. 2) would tend to increase the probability of success of such an event.

It is also possible that the early aborigines initially brought the fox to the Northern Channel Islands like they later brought them to the southern islands. We do not know when the earliest people arrived but it was certainly before 8,000 years ago, and if Orr's views prove out it may have been far earlier. While the island fox differs distinctively in size, and to some extent in dentition, from the mainland form these characters and others less well distinguished (color, muscular development, fecundity--see Dickey, in Rogers, 1929, p. 445) conceivably could have developed in 10,000 to 20,000 years. Foster (1963, 1965) provides a reasonably persuasive argument that the distinctive characters of the Dawson caribou (color, small size, imperfectly developed antlers, mane) could have appeared in the past 10,000 years since glaciation of the Queen Charlotte Islands. As indicated earlier the time it takes given characters, especially size, to develop in certain mammals (e.g., carnivores) may be very short and sometimes can be measured in several human lifetimes (normal-size deer introduced on Cuba and the Queer Charlotte Islands are now dwarfed--see Hesse, et al., 1951, p. 631; Foster, 1963, p. 68, 1965).

That character differentiation may occur rapidly in the fox is suggested by two lines of evidence: (1) obvious though slight size and color divergence from the parent stock in the recently established fox populations on the six largest Channel Islands; and (2) the fact that subfossil fox skulls in the middens on Santa Cruz Island show a change from the lower through the upper levels. Grinnell and his colleagues (1937, p. 459) had this to say about the skulls:

> The shell-mound animals show a greater range of variation than is evident in our larger series of the present population. Furthermore, these skulls (from the lower strata) are less like those of present-day foxes than are skulls from more recently deposited strata. The characters shown in this material are shape of the nasals, and shapes of auditory bullae and basioccipital. Although these old skulls do not look exactly like those of any recently killed animals, they are nearer to [Urocyon littoralis] santacruzae than to any other present island race. Finally, this material shows: (1) that foxes have been on Santa Cruz Island for many hundreds of years at least; and (2) that there has been a change, though a small one, in the appearance of fox skulls from the earliest time level represented by the shell-mound specimens.

The skulls were taken from the lower levels of a shell midden that were reportedly at least eight feet deep.

It is not necessary to invoke a land bridge to the northern islands to explain the origin of the Channel Islands fox. The fox could have arrived either by natural debris rafting or by agency of early man.

Channel Islands Skunk (Spilogale putorius amphiala)

The spotted skunk occurs only on Santa Cruz and Santa Rosa Islands but it also may have been on San Miguel until about the turn of this century (see footnote on page 92). The morphological and skeletal characters of the island skunk have been described by Dickey (1929, and in Rogers, 1929, p. 446), Grinnell, et al. (1937), and Van Gelder (1965), with comments by von Bloeker (1967). According to Van Gelder the island skunk _S. putorius amphiala_ differs from _S. putorius phenax_ on the adjacent mainland primarily by its broader face (2 mm. average) and a shorter tail (30 mm. average), with lesser variations in tail coloration and body length. The skunks on Santa Cruz and Santa Rosa Island differ from one another primarily by total length (412 and 426 mm. respectively), but show inconsistent variations in other characters. None of these differences are great. And, if they are statistically valid,* all of them could have developed during post-glacial time based on reasons cited earlier.

Dickey (1929, and _in_ Rogers, 1929, p. 446) and Van Gelder (1965) point out that the Channel Islands skunk resembles more _S. putorius latifrons_ of western Oregon and Washington than _S. putorius_ on the adjacent mainland. It is possible that _amphiala_ is a relict from a _latifrons_ population which may have ranged further south during the Wisconsin when the climate was cooler and more moist. Because Van Gelder has discussed various possibilities for the origin of the Channel Islands skunk it is not necessary to repeat them here. However, certain points made by Van Gelder should be clarified and expanded. For example, he thought that the

> . . . burden of evidence . . . fits the idea that they [skunks] occupied the islands when there was a connection to the mainland; it is suited to the existing data, and does not require an accidental rafting or intentional or chance introduction by man. (Van Gelder, 1965, p. 35).

The burden of evidence cited by Van Gelder is primarily his acceptance as fact of an early Pleistocene land bridge proposed by others. Van Gelder also thought it improbable that Indians brought the skunk since they presumably did not make pets of them, and their smell would have discouraged efforts to transport them to the islands in watercraft. Van Gelder does, however, admit the possibility that the skunk may have been naturally introduced by debris rafting.

A sampling of the literature shows that many aboriginal groups in North America ate skunks (Swanton, 1946, p. 250; Parmalee, 1965, p. 18; Munson, _et al._, 1971; Rau, 1865; White, 1953). R. Bruce McMillan* has noted that skunk formed a minor element in the diet of many aboriginal groups in the Great Plains region. Parmalee (1965) showed that the skunk (in this case the striped skunk _Mephitis_) ranked third in importance in food use by peoples living in Tick Creek Cave, Missouri.

Grinnell (1962) describes how important skunks were to the Cheyenne as meat animals:

> . . . flesh food consisted largely of small animals--skunks are particularly mentioned . . . [Vol. I, p. 6] . . . . geese, ducks, cranes, coons, and skunks constituted a large part of their summer food. . . . Each fall when the skunks were fat, all the people in the camp moved out to the hills and hunted skunks. At the end of the hunt all the skunks were brought in and laid out in rows and then divided--a certain number to each family [Vol. I, p. 51]. In autumn [the Cheyenne moved] to certain hills where these animals [skunks] abounded, and they secured great numbers of them. Such places were visited time after time, and much food secured [Vol. I, p. 248]. . . . skunks are good to eat . . . [Vol. I, p. 256].

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*Personal communication, February, 1972. Dr. McMillan is an archaeologist at the Illinois State Museum, Springfield.

In California skunk occurs as a minor element in the faunal remains of a number of coastal archaeological sites, for example in the Santa Monica Mountains (Landberg, 1965, p. 50) in Newport Bay in Orange County and at Diablo Canyon north of Morro Bay (Margaret Weide and Roberta Greenwood in personal communication with Charles Rozaire, April, 1972). Active research would probably turn up many more such examples.

Skunks were also thought to possess great spiritual powers and were used by some aboriginal groups for medicine, war, and various other purposes (Grinnell, 1962, Vol. II, p. 104, 146; Feer, 1972). For example, ". . . the skunk in almost all Indian groups is endowed with truly phenomenal powers due essentially to the overpowering presence of its scent. The skunk can move mountains and kill people simply by releasing its odors . . . " (Feer, 1972; Boas, 1918). While we have no way of knowing whether the Canalino or their predecessors used skunk in similar ways or if they used them at all, the fact remains that many recent North American aborigines did. Van Gelder commented that it was unlikely that the aborigines knew how to de-scent skunks, yet the literature shows that the Cherokee used skunk scent bags hung inside their lodges to prevent diseases (Feer, 1972; Mooney, 1900). This practice also suggests that some aborigines were not as repelled by skunk odor as we might casually think. Moreover, it is possible that very young skunks, which had not yet developed a sense of fear of humans, were transported about in watercraft. Thus the idea of humans transporting skunk in their watercraft cannot be casually dismissed.

If this mode of origin of skunk (and the fox) is admitted as a serious possibility, one puzzling question lingers. Why were not other animals purposely brought out to the islands? One answer is that perhaps they were brought out but unlike the fox and skunk either failed to escape or for some reason were not released. On the other hand, perhaps certain other animals were brought out and did escape or were released. For example the California ground squirrel which occurs only on Catalina Island may have originated in this way. Also, the species composition of the herpetofauna on the Northern Channel Islands described by Savage (1967) strongly supports the idea that several of the forms arrived during the time of human occupancy of the islands, after the post-glacial breakup of Santarosae. For example, three kinds of snakes (three species) occur only on Santa Cruz Island; if they are viewed as remnants of three populations that were present on contiguous Santarosae then why were not residual populations of them left on Santa Rosa, San Miguel and the Anacapas? To suggest that the three populations died out on the other islands in recent post-glacial times seems the least satisfying explanation. It seems more reasonable that the snakes became resident on Santa Cruz after post-glacial rising sea-levels created the four Northern Channel Islands. Thus they would have originated on Santa Cruz Island during the period when humans traveled about the Santa Barbara Channel.

It is not necessary to invoke a land bridge to the Northern Channel Islands to explain the origin of the insular spotted skunk. The skunk, like the fox, may have arrived either by debris rafting or by aboriginal watercraft. Both dispersal mechanisms were clearly feasible.

Deer Mouse (_Peromyscus maniculatus_)

The deer mouse, or white-footed mouse occurs on twelve islands and islets off southern California, including Prince Island adjacent to San Miguel. According to von Bloeker (1967) the deer mouse is the most abundant of the insular rodents. Eight subspecies of _P. maniculatus_ have been recognized by von Bloeker (1967) based on a study of 840 specimens. The island-species data are given in Table 20.

TABLE 20

Subspecies of _Peromyscus maniculatus_ on the Channel Islands*

Island	Subspecies
San Miguel	_P. m. streatoris_
Prince (islet)	_P. m. streatoris_
Santa Rosa	_P. m. santarosae_
Santa Cruz	_P. m. santacruzae_
West Anacapa	_P. m. anacapae_
Middle Anacapa	_P. m. anacapae_
East Anacapa	_P. m. anacapae_
Santa Barbara	_P. m. elusus_
Sutil (islet)	_P. m. elusus_
San Nicolas	_P. m. exterus_
Santa Catalina	_P. m. catalinae_
San Clemente	_P. m. clementis_

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*From von Bloeker (1967)

The presence of deer mice on so many islands and islets can only be reasonably explained by human dispersal, either through advertence or, more probably, inadvertence. The Canalinos and their predecessors had watercraft, and rodents are known to be frequent inadvertent passengers in boats. It is also known that the Canalinos carried ollas to the mainland in canoes in exchange for grass seeds, furs, skins, acorns and roots (Yarrow, 1879, p. 118). Canoes or other watercraft hauled up on the back beaches on the mainland and islands must invariably have been inspected by the ever-curious deer mouse. Personal experience supports this conclusion. During the summer of 1969 I established my field camp on the back beach in Cuyler Harbor, San Miguel Island. Beginning on the first night the camp was overrun with curious _Peromyscus_. They got into everything. They even climbed the guy lines that secured the tent and repeatedly clambered over the tent tops. If a canoe had been nearby they would have been in and out of it all night every night. The frequency of mice being inadvertently transported about the Channel Islands in this way must have been high indeed. That the mice may have been naturally rafted out also must be considered a distinct possibility, and rafting may have occurred, but because aborigines possessed watercraft the distribution of _Peromyscus_ on so many islands is best explained by the agency of man. In this regard Foster (1963, 1965) concluded that the presence of _Peromyscus_ on so many of the Queen Charlotte Islands and islets was almost certainly due to the Haida Indians, who used watercraft.

15. Summary

While we will probably never know for certain how the elephant, fox, skunk and mice got to San Miguel and the other Northern Channel Islands, whether by walking, swimming, rafting or by aboriginal watercraft, of the various possible permutations the following is offered as the most plausible model in light of available information.

Sometime after the mid- or late-Pleistocene Island Submergent Period, and during a time of glacially lowered seas, elephants perceived Santarosae by smell (vegetation) and sight (mountainous landmass) while bathing in the sea, probably during the dry summer months. The sight and smell of the island served as an inducement to reach the island by swimming. It is also possible that a swim may have been initiated by a rip tide which forced the elephant to sea. In any event they consequently swam the then-narrow channel. Probably this occurred more than once during the Illinoisan or, perhaps more likely, the early Wisconsinan. After several tens of millenia a pygmy population of elephants developed.

When Pleistocene man arrived on the Northern Channel Islands some 10,000 to 20,000 years ago he found pygmy elephants and perhaps a few herpetofaunal forms. During later trips to Santarosae, perhaps after the elephants became extinct, various live animals indigenous to the adjacent mainland occasionally were brought out as pets or for pelts, ceremony, medicine, and or food. At least one animal, the fox, early escaped and became established on Santarosae. Thousands of years passed during which size, color and dentition divergence occurred in Urocyon. A skunk (Spilogale) population also became established in the same manner, perhaps before the post-Pleistocene breakup of Santarosae.

One possible, indeed very plausible alternate to the above model is that prior to the advent of Pleistocene man the fox, skunk and mice were already present on Santarosae, having arrived by chance over water dispersal during the Wisconsinan or earlier times. In later Holocene time when aboriginal trade and contact with the southern islands became more frequent the now-distinctive island fox, perhaps favored over the skunk as a pet and food animal or for ceremony, spread to San Nicolas, Catalina and San Clemente Islands, perhaps at a time when soapstone artifacts from Catalina were accumulating on the northern islands. Once fox populations became established on the southern islands there would have been no strong need to continue bringing them to where they already existed, unless they were pets of canoeists. Hence slight size and color divergence subsequently occurred in the six isolated populations.

During many of the aboriginal voyages, probably covering many thousands of trips over thousands of years, Peromyscus maniculatus inadvertently was frequently carried along resulting in P. maniculatus populations on all of Channel Islands and various islets.

Finally, the evidence collectively shows that no mainland connections need be invoked to reasonably explain the presence of extinct and extant animals on any of the Channel Islands of California. And, with the exception of the northern four islands (Santarosae), none of the islands appear ever to have been interconnected with one another.

CHAPTER V

EOLIANITES

Aside from lack of arboreal vegetation, the landscape element that most forcefully impresses visitors to San Miguel is sand. Sand in sheets and dunes is almost ubiquitous over the island. Only the summit area of Green Mountain and the Gangplank region have more or less been spared its presence. Interestingly, most of the sand which has been actively blowing across the island during the past century is reworked eolianite mainly Pleistocene in age. It is thus fossil sand, not modern sand. The only modern beach sand presently blowing onto the island comes from North Simonton Cove (SMI-237) from Otter Harbor (SMI-82, 215), from Point Bennett and from Active Point (SMI-40). In each case the amount of sand involved appears not to be large but over a long period much sand could accumulate. Sand also presently derives from the east end of Cuyler Harbor (SMI-140, 141) in noteworthy quantities, but this is primarily reworked eolianite that was blown off Hurricane Deck into Cuyler Harbor in historic time (Plates 68 and 69). Because sand is nearly everywhere present on San Miguel Island and is one of the most important landscape elements, a detailed analysis of its character is given here.

In this chapter, after a brief introduction there follows a review of eolianite occurrences in southern California, including the mainland and other Channel Islands. The review is necessary because collectively the eolianites show mesoscale wind directions which prevailed over the Channel Islands during late Pleistocene times. Such information is pertinent to this thesis because paleowind evidence further illuminates an aspect of the character of the past climate of San Miguel Island. Moreover, it is probable that certain eolianite sheets were time-contemporaneous in their emplacement, and a regional review allows a better regional perspective for purposes of correlation.

16. Eolianites

In the way of a preliminary description eolianite may be thought of as an ancient coastal dune complex which has experienced weak to intense cementation by calcium carbonate derived from its sand-sized shell constituent grains. Because they occur on coasts probably such dunes should be called coastal eolianites. It is believed by many that coastal eolianites formed largely during periods of glacio-eustatically fluctuating sea-levels and consequently are indirectly genetically related to continental glaciers. In contrast, however, to such glacial indicators as tills, tillites and glacial striae which were geographically associated with middle and high latitude continental glaciers, eolianites are low latitude in occurrence.

In Quaternary research a growing number of interdisciplinary investigators have recognized the paleoecologic significance of eolianites in reconstructing Pleistocene environments. R. W. Sayles early recognized the paleoecologic use to which eolianites may be put and in 1931 wrote a now classical paper on the origin and significance of Bermuda eolianites and paleosols. Subsequent to Sayles the focus of eolianite attention turned to Australia where broad paleoclimatic interpretations based on eolianite were made by a number of investigators. In the Mediterranean area some attention was directed to eolianite during the 1930's and 1940's, but it remained until the decade 1955-65 before the paleoecological importance of eolianite gradually began to be recognized.

In the United States, aside from Sayles, only a handful of investigators have worked with eolianites, most being either coastal morphologists or environmental archaeologists and related workers. References to eolianites on the Channel Islands of California have been made by Orr (1960a), Merselis (1962), Johnson (1967, 1969, 1971) and Weaver and Meyer (1969).

Description, Morphology and Characteristics

Because eolianites vary somewhat in internal and external characters, no general description will hold for all individual units. However in order to provide a mental reference picture, the following composite general description will give a fair idea of their nature.

The most universally distinct feature of eolianite, one that reflects its eolian origin, is strong cross-stratification (Plates 34a, c, 43a, 51a, 78-80). An exception, according to Butzer (1964), is when the original calcareous sands were deposited under vegetation in which case eolianite may be preserved unbedded. Recent studies of Bermudan eolianites have shown that early surface cementation of dunes by moisture results in foreset beds that are convex upward, a distinctive feature apparently not found in other eolian sediments (Mackenzie, 1964b). The Bermudan eolianites are lobate-shaped bodies composed internally of leeward foreset strata which dip landward at 30 to 35 degrees and windward strata which dip at 10 to 15 degrees in opposite direction.

Much recent attention has also been given to eolianites by Butzer (1963) who recognized their paleoclimatic and archaeological importance. Butzer differentiated Mallorcan eolianites into: (1) a coastal (coarse-grained) facies with typical seaward dip values of 22 to 31 degrees and landward dips of 31 to 38 degrees; (2) an interior (finer-grained) facies landward on the coastal plain with free longitudinal dunes of subdued morphology which often form littoral cordons; and (3) undulating sand sheets with longitudinal affinities which are found beyond coastal cliffs and well inland on coastal plains or level uplands.

Grain constituents of eolianite commonly are coarse to fine lime-sands ranging up to 99 per cent calcium carbonate derived almost wholly from calcareous marine organisms such as mollusks, foraminifera, corals, bryozoans, and algae (Plates 73-75). A noteworthy exception is the Bahaman oolitic eolianite which is formed largely of non-organic chemically precipitated ooids. In some instances, however, the non-carbonate fraction may range as high as 90 per cent; but calcite invariably is the cementing agent. There is a tendency toward diminishing grain size landward from the coast. Constituent grains of eolianite often exhibit water-worn characters which probably reflects the short distance of eolian transport from the sea.

Field relations and a literature perusal reveal that six features tend to characterize coastal eolianite. They are (1) beachrock, (2) intercalated paleosols, often with caliche pans; (3) solution pipes, frequently filled with soil materials, (4) fossil calcified vegetation, or rhizoconcretions, (5) high angle foreset cross-strata, and (6) terrestrial fossils. These features are common to San Miguel eolianites and with the exception of beachrock which has already been discussed, are treated later in this and subsequent chapters.

Occurrence

Sites of eolianite occurrence tend to fall roughly between latitudes 45 degrees N and S along tropical and subtropical seacoasts (Johnson, 1968), generally in subhumid to arid areas (Fig. 34). They occur interruptedly along coasts of nearly every country bordering the Mediterranean

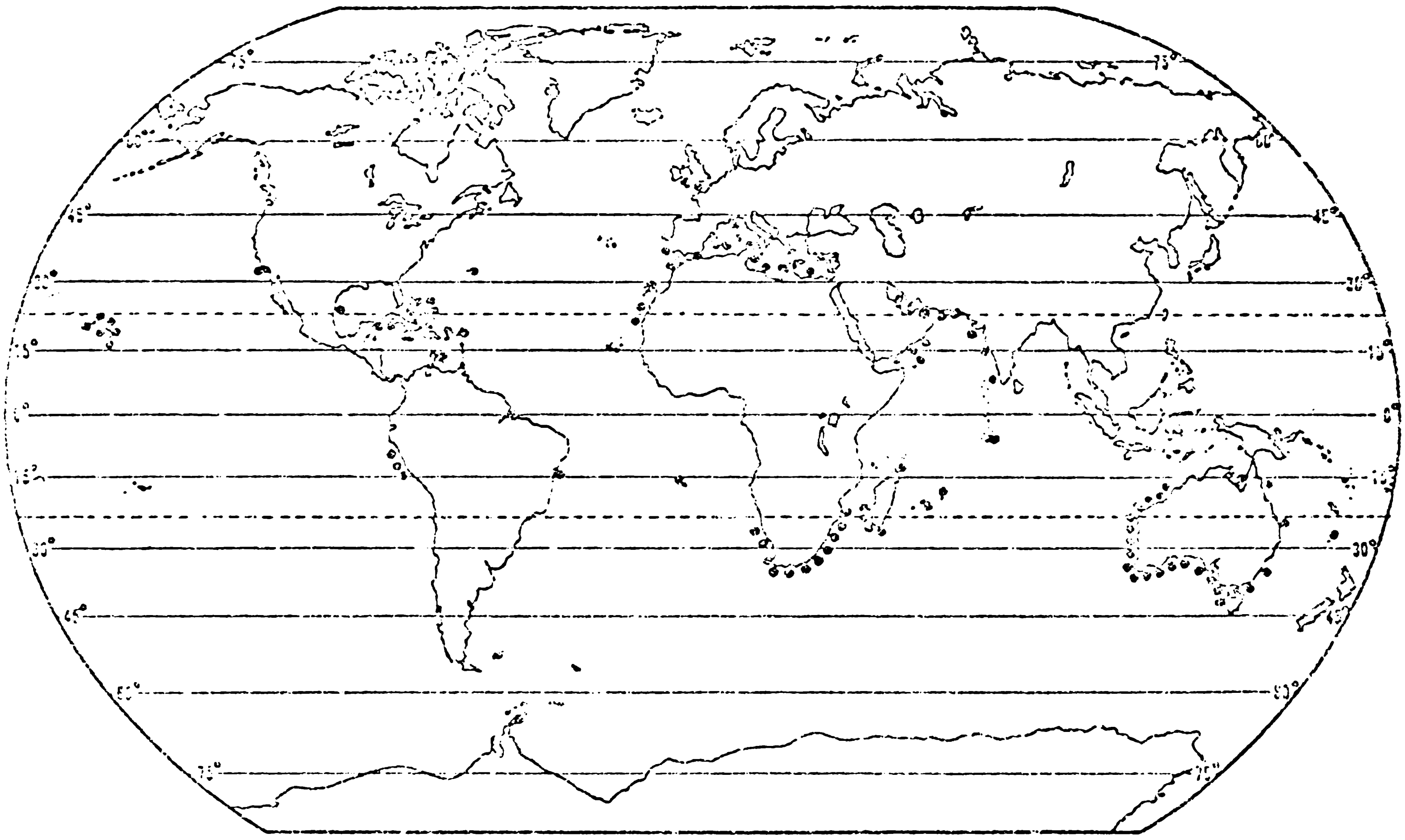

Figure 34. World distribution of eolianites. Dots indicate regions in which eolianite occurs. Note concentration of eolianite between latitudes 15° and 45° N and S.

as well as many of the islands in the Atlantic, Caribbean, and Gulf of Mexico. They also are found along the littorals of northwest Africa, South Africa, Madagascar, countries bordering the Red Sea, Persian Gulf and Gulf of Arabia, including India and West Pakistan, as well as on many of the Indian Ocean islands. In the Pacific, eolianite occurs on the Hawaiian Islands, the California Channel Islands, probably many of the South Pacific islands (although not yet verified), Norfolk Island, New Zealand, Tasmania, the Bass Strait Islands and on many other islands off the southeastern, southern, western, and northern coasts of Australia, as well as along nearly several thousand miles of the Australian coast proper. Indeed, nowhere in the world does eolianite occur in such spectacular abundance as in Australia.

Origin of Eolianite

There seems to be common agreement among Pleistocene researchers that eolianites are in some manner genetically related to glacio-eustatic fluctuations of sea-level. Aside from this point, however, there is much disagreement as to the specific duration of time in which eolianite formed during Pleistocene shoreline migrations. There are currently four lines of thought relating to the glacio-eustatic interpretations of eolianite. A view advanced by Kaiser (*in* Butzer, 1963) considers the presence of eolianite as indicative of marine transgressions.

A second point of view is that taken by Bretz (1960) and Mackenzie (1964a). According to Bretz, who limited his study to Bermuda, the eolianites on that island were coastal dunes which did not migrate from their "feeding grounds," the shorelines. To account for the presence of eolianite over the upper parts of Bermuda eolian accretion must then have occurred only during times of high sea-levels. During times of marine regression, the coastal dunes followed the progressively lowered shorelines while soils developed from materials left behind. When marine transgressions subsequently took place these soils were covered over with eolianite, and eventually became paleosols. Thus, on Bermuda, paleosols are said to record continental glaciations whereas eolianites are said to record interglacial marine transgressions. A few years later Mackenzie reached the same conclusions as Bretz.

A third and more commonly accepted explanation accounts for the accumulation of eolianite sand as a natural consequence of low level seas or marine regressions (Butzer, 1963, 1964; Bauer, 1961; Crocker, 1946; McBurney and Hey, 1955; Sayles, 1931; Kaye, 1951; Wright, 1961, 1962; Johnson, 1967; Newell, 1961; among many others). According to the adherents of this view, an abundant source of calcareous sand and marine debris was exposed to deflation by an actively retreating sea, since it took some time for vegetation to move onto and thus stabilize the newly exposed shore zone. Butzer refers to eolianites which have formed during sea-level regressions as regressional dunes. Two major arguments have been advanced in support of this view: (1) eolianites are very often found submerged in part well below modern sea-level and are thought to be best explained by regressional conditions; and (2) they frequently occur along coasts that have no exposed calcareous beach sands today (as on San Miguel) indicating that the sand presumably had to come from exposed continental or littoral shelves (Bauer, 1961). Although such evidence does suggest low sea-levels during eolianite formation, it is difficult to see how either idea constitutes a major argument for eolianites being exclusively regressional dunes. Evidence will be presented later to show that eolianite on San Miguel Island formed during regressions, transgressions, and is forming at present, which is considered to be a stillstand.

A fourth school of thought, following Fairbridge and Teichert (1953), takes a middle position: eolianite may form either during regression or transgression. In the former case dunes would tend to be left behind with every temporary pause during regression; in the latter case they would tend to be driven forward to the maximum limit of transgression. If one accepts this view, it would not be necessary to require a wide zone of exposed continental shelf in order to account for calcareous source material, but merely a normal width of beach under conditions of regression or transgression. Figure 35 shows an approximation of the sequence of events suspected in this explanation. The most important point of the diagram is that dune formation may occur at any stage of the sequence, as long as sea-level is fluctuating.

A review of the world literature shows that most authors are of the opinion that most eolianites are genetically related to marine regression or at least to periods of low sea-level. There seems to be no question that in many areas of the world, such as the Mediterranean, South Africa, the Bahamas, and Burmuda, Puerto Rico, Cuba, San Miguel and other California Channel Islands, and Australia, the presence of some eolianites

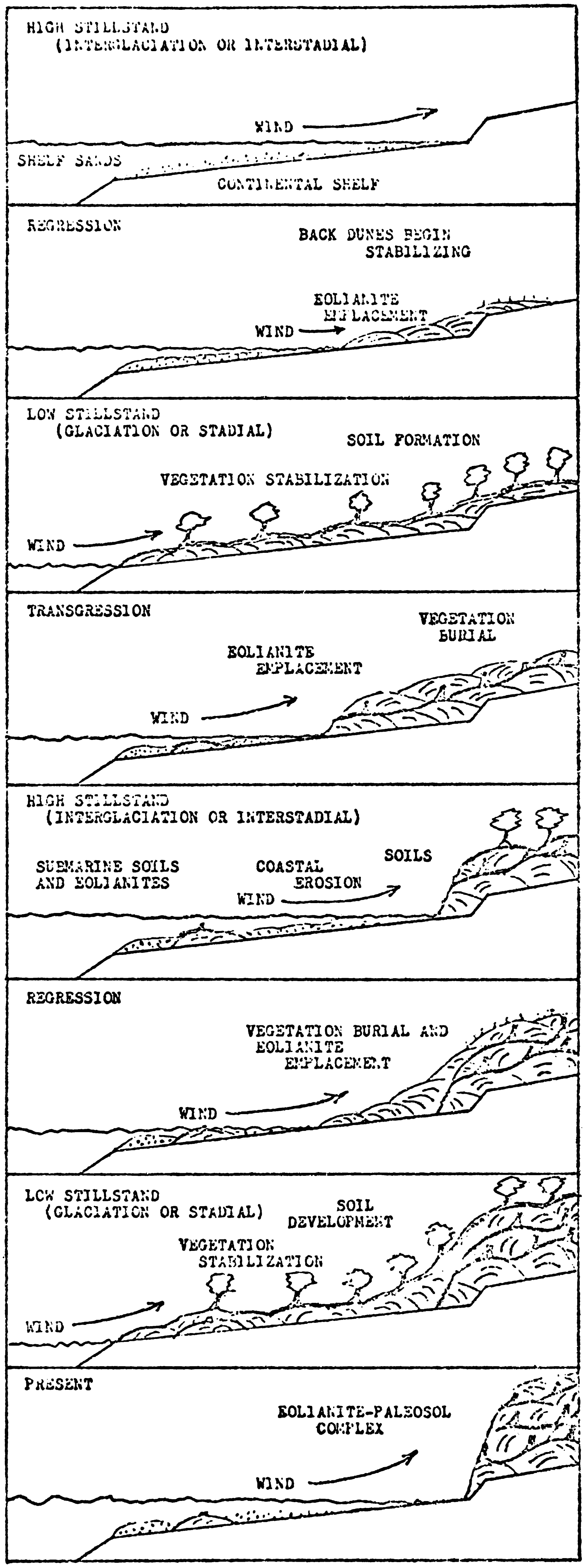

Figure 35. Suggested hypothetical sequence of events in the emplacement of eolianites and the development of intercalated paleosols. This sequence may be lacking in details, and some eolianite-paleosol complexes likely have more or less complex histories, but it provides a general picture that approximates many sequences.

which occur, or did occur, below present sea-level can only be explained by low sea-level conditions. On the other hand, radiocarbon dates on paleosols intercalated in eolianites on San Miguel show that at least one eolianite unit is of post-glacial age, younger than about 7,000 years old. Since sea-level is believed to have reached its approximate present level about 6,000 years ago (Fig. 36) the eolianite unit is related

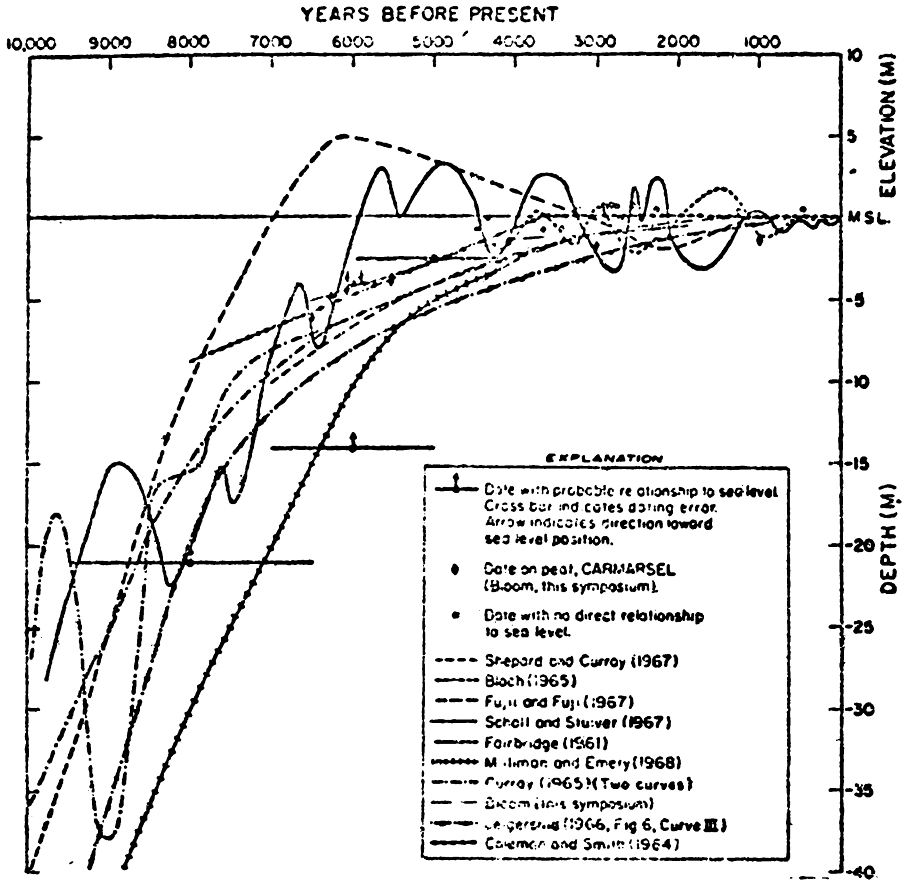

Figure 36. Dates from samples obtained on CARMARSEL Expedition compared to sea-level curves for the past 10,000 years from various authorities. Note that the dates shown by the open circles do not have direct relationship to sea-level curves (after Curray, et al., 1970).

to either very late transgressional or stillstand conditions. In addition, because of disturbance reworked eolianite dunes are forming today on San Miguel. Thus it is possible that eolianite dunes may form at any time, because disturbance may result from a variety of causes, e.g., fire, stripping of vegetation by animals, tsunamis, and violent winds.

And, although seemingly minor in amount, eolianite dunes appear to be forming presently from beach sand on San Miguel Island. The data from San Miguel Island show that simplistic explanations of the relation of eolianite to sea level position may reflect more our propensity to seek simplistic explanations than of nature to provide them. Probably most eolianites formed during glacio-eustatically lowered sea-level, perhaps mainly during regressions, but some also formed during transgressions and stillstands, determined in part by local conditions.

Paleoecological Considerations

Eolianite can supply clues leading to the recognition and interpretation of past climates and paleowind directions. Indeed, because eolianites are so widespread, they serve as the best possible means available of determining paleowind directions in tropical and subtropical latitudes during Pleistocene glaciations. Such information would contribute significantly to the reconstruction of broad-scale middle and late-Pleistocene climatic patterns. To my knowledge five such studies have been initiated thus far. McBurney and Hey (1955) have inferred from a study of eolianite distributions in Cyrenaican Libya that prevailing paleowinds were from the northwest. This conclusion was reinforced by Moseley (1965) who inferred a NNW prevailing wind direction based on a determination of bedding orientations and dip azimuths. Moseley was also able to infer the original longitudinal form of the Libyan eolianites (Moseley, 1965). Butzer (1960) was also able to determine paleowind directions on the basis of bedding characteristics of Mallorcan eolianites and thus infer the ice-mass modification of cyclonic storm tracts in the western Mediterranean region.

Mackenzie recently completed an excellent study of Bermudan paleowinds by collecting azimuths and dips of more than 800 eolianite cross-strata. He concluded, among other things, that prevailing Bermudan paleowind directions were concomitant with modern wind directions (Mackenzie, 1964a). He was also able to infer the parabolic or u-shaped form of the original calcareous dunes (Mackenzie, 1964b).

The intercalated paleosols of eolianites often contain information which can shed critical light on past pedogenic and geomorphic processes and environments. Such information may be in the form of particle size distribution of the mineral soil, clay skins, soil structural features, concretions or other features, the chemical character of the soil, organic matter, paleontological and archaeological features and so on. If charcoal is present then the paleosol, and sometimes the eolianite parent material, may be dated by the radiocarbon method. An understanding of the age of the soil-geomorphic features, the processes which formed them, and the character of the past environments in which they evolved are critical to a proper understanding of the landscape of San Miguel Island.

17. Southern California Eolianites

It was earlier thought that eolianite in California was limited to the four outermost islands of San Miguel, Santa Rosa, San Nicolas, and

San Clemente Islands (Johnson, 1967), but its presence on Santa Cruz Island recently has been documented (Weaver and Meyer, 1969; and personal observation, 1970). None however has been reported from the Anacapas, Santa Barbara or Santa Catalina Islands.

Mainland

Although no eolianite has yet been described on the California mainland evidence suggests that ancient calcareous sands of some type perhaps once existed. The evidence consists of ancient dune-capped transverse beach ridges and sands which rest upon marine terraces along parts of the mainland coast. The ancient transverse sand units parallel the coast and are best displayed from San Diego to Oceanside, from Redondo Beach to El Segundo, and from Cambria to San Simeon, although they probably are present along other parts of the coast as well. They occur at elevations ranging principally from 300 to 450 feet, an exception being the Redondo-El Segundo sands which vary from near sea-level to about 200 feet. In San Diego and Cambria the ancient sand deposits are anchored by a distinctive ironstone pisolitic soil* that is similar in profile characteristics to the Green Mountain Soil on San Miguel Island. The major apparent difference between the pisolitic soils of San Diego, Cambria, and San Miguel Island is parent material and, perhaps, age. On San Miguel the parent material is highly calcareous whereas at

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*In San Diego, the Carlsbad loamy fine sand, and in Cambria, the Arnold Sandy loam, reddish brown phase (Storie and Carpenter, 1929, 1930; Carpenter and Storie, 1928). The San Diego sand units, however, are ancient beach ridges and except for the upper few feet are not dunes.

San Diego and Cambria* it presently is not. However, since the ancient mainland sand units are of littoral origin they probably had constituent grain compositions similar to modern mainland beach sand, which is calcareous.** Presumably the carbonate constituent grains of the sand deposits have long since been leached away. Interestingly, the pisolitic soils of San Diego and San Luis Obispo Counties presently carry as part of their cover a closed-cone pine forest. A closed cone-pine forest formerly grew on San Miguel Island and is present today on Santa Rosa and Santa Cruz Islands. The mutual presence of pines and calcareous sands on elevated Pleistocene terraces under a mutual Mediterranean climate and environment that experiences frequent air-borne salt, fog and fires tempts one to speculate on a mutual genesis for the distinctive pisolitic soils. More discussion will be given to the matter when the origin of the Green Mountain Soil on San Miguel Island is treated in Chapter 6.

Channel Islands

The distribution pattern of eolianites on the Channel Islands and ancient dunes on the mainland bears an interesting relationship to present and past wind direction. This relationship becomes most apparent by considering the location of eolianite on each island and the old dunes

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*Chemical analyses of grab samples of Cambria pisolites showed them to be compositionally the same as the Green Mountain Soil pisolites (Table 22, Chapter 6).

**Thirty sediment samples from modern mainland beaches in southern California contained 6.3 per cent calcium carbonate (Emery, 1960, p. 181).

on the mainland in relation to present prevailing wind streamlines shown in Figure 12. It is noteworthy that land snails occur abundantly in many of the eolianites on the Channel Islands and prove beyond question the eolian origin of the sand units.

San Clemente Island

Eolianites on this island occur primarily on the northwest coast (Omstead, 1958; Johnson, 1967). Olmstead recognized two generations of dunes and eolianite, a younger and an older phase. The older dunes occur at elevations up to 1,100 feet and are situated mainly along the crest of the northern third of the island. They probably were derived from somewhere on the northwest coast where the younger dunes presently occur. Olmstead observed strong cross-stratification in the older dunes with foreset beds dipping strongly (30-35°) eastward. The younger eolianites are thickest adjacent to the present shoreline and together with their intercalated paleosols are being actively eroded by the sea. In places the modern platform seems to coincide with the Pleistocene platform so that the younger eolianites and paleosols appear to rest upon a landward extension of the modern platform. The eolianites almost certainly extended an unknown distance below present sea-level prior to post-glacial sea-level rise. The source area of the sands was on the submerged shelf to the west and northwest and they were transported by winds which prevailed from that direction. The present prevailing wind direction is from the west to northwest. Although the younger eolianites and paleosols are not radiometrically dated, their position at (and formerly below) sea-level suggests they are late Quaternary in age, probably mainly middle to late Wisconsin. They are tentatively correlated with the sequence of eolianites and paleosols in Simonton Cove on San Miguel Island.

San Nicolas Island

Eolianites are thickest and most extensive on the wind-struck northwest coast of this island (Burnham, et al., 1963; Vedder and Norris, 1963; Johnson, 1967). Eolianites are weak to strongly indurated and some are intercalated by caliche horizons which are mainly pedogenic in origin. The eolianites and soils formerly extended an indeterminant distance seaward of the present coast but, as on San Clemente, were destroyed by post-glacial sea-level rise. The source area was on the submerged shelf to the northwest. The present prevailing wind direction is from the northwest (de Violini, 1967; DeMarrais, et al., 1965; and Figure 12).

Ironstone concretions that presumably reflect a lag deposit from a stripped soil that probably was partly correlative in genesis and perhaps age to the Green Mountain Soil on San Miguel Island occur on the surfaces of the older eolianites of San Nicolas (Vedder and Norris, 1963, p. 32; and personal observation).

Santa Cruz Island

A small amount of calcareous eolianite and associated caliche at an elevation mainly between 50 and 100 feet was observed at Near Point in spring of 1970 in company of Mike Benedict, who called them to the writer's attention. A modicum of concretionary ironstone lag occurs on the wind-stripped dune surfaces and reflects the former presence of a soil similar to the Green Mountain Soil. However, if such a soil did once exist on Santa Cruz its lateral extent was insignificant as the present area of the eolianite is very limited. The eolianite remnants exhibit linearity with a northwest-southeast trend showing that the paleowind which emplaced the dunes was from the northwest. The present wind is predominantly from the northwest (Figure 12). The age of the Near Point eolianite is not known but is presumed to be roughly time equivalent to the late Quaternary eolianites in Simonton Cove on San Miguel Island, with which they are provisionally correlated.

On the other hand, two additional dune deposits are present on Santa Cruz that may be considerably older than the Near Point deposits. One dune deposit is calcareous, the other presently is not but originally may have been. The calcareous dunes are cemented and apparently are true eolianites as indicated by the presence of terrestrial snails, rhizoconcretions, the absence of large fossils, and laminated steeply dipping cross-strata (Weaver and Meyer, 1969) that are characteristic of eolian sand deposits. They range up to 85 feet thick and occur on the northwest coast of the eastern end of the island at elevations ranging from 250 to 800 feet. The eolianite and associated underlying marine deposits comprise the Potato Harbor Formation of Weaver and Meyer (1969). Weaver and Meyer believe the unit was emplaced during a sea-level regression and suggest a late Pliocene-early Pleistocene age for it based on the presence in the basal beds of _Pectin healeyi_, which is not known to range above the Pliocene. If this suggested age proves correct, then the Potato Harbor eolianites are probably the oldest eolianites on the Channel Islands. The presence of patches of Potato Harbor Formation lying at elevations up to 800 feet on an extensive inclined erosional surface suggested to Weaver and Meyer large scale post-eolianite Quaternary tectonism and warping, possibly by as much as 300 feet. Although this suggestion may prove correct, it is worth noting that eolian sands may occur at any elevation independent of tectonism as shown by re-worked eolianites on San Miguel which have traveled during historic times from near sea-level to the summit, a vertical distance of over 800 feet. Eolianites have also traveled over the crests of San Clemente and San Nicolas Islands, and have been blown to over a thousand feet elevation on the west end of Santa Rosa Island. And eolian sand can be blown up and over steep precipitous cliffs, as such is the case at Active Point on San Miguel Island today.

Because the Potato Harbor eolianites are perched atop north and northwest facing sea cliffs, and because the deposit has a general northwest to southeast linearity, a northwest paleowind is inferred. The present prevailing wind direction is from the northwest.

The non-calcareous sands referred to earlier are found between Christy Ranch and Canada de los Sauces on eroded terraces overlooking the sea. For convenience they are referred to as the Christy sands. Their elevation was not field recorded but is estimated from topographic maps to be from 100 to 250 feet. The Christy sands exhibit little stratification and contain opaline rhizoconcretions. A similar sand unit with abundant pencil-like opalized rhizoconcretions occurs at Punta Arena (Johnson, 1967).

The Christy Sands are similar to the sands which underlie the pisolitic Carlsbad Soil as seen at the gate to the military reservation on Point Loma in San Diego County. At point Loma the Carlsbad Soil contains abundant opaline rhizoconcretions. In general the Carlsbad Soil is very acid in reaction (pH 6 to 4.5 common), has been leached to depths as much as 30 feet, and is suggested as being perhaps early Pleistocene in age (Carter, 1957, pp. 167-173). Although no strong pedologic or geomorphic evidence suggests that the Christy sands are of equivalent age, their resemblance to the Carlsbad soil suggests they perhaps are older than the late Pleistocene Near Point eolianites which are calcareous. If the suggested early Pleistocene age for the Potato Harbor eolianites is correct, then the Christy sands probably are intermediate in age between the Potato Harbor and Near Point eolianites. A detailed field and laboratory study of these sands and their pedologic and geomorphic relations should dissipate some of the uncertainty which presently surrounds them.

It is not known whether the Christy sands are eolian or not. If they are, their location, perched above the exposed west coast of Santa Cruz, shows that the paleowinds which emplaced them came from the northwest quadrant. The present wind is from the same general direction (Fig. 12).

Santa Rosa Island

The eolianite picture on this island presently is blurred. Other than several brief references by Orr (1960) little has been written about them. Radiometric analysis of eolianites along a part of the northwest coast yielded dates of 135,000 to 120,000 years before the present, around 7,000 years ago, and again about 3,500 years ago (Orr, personal communication, 1967; Orr, 1960; 1967; 1968, p. 23, 97). Because permission to visit Santa Rosa Island was not granted during the course of field research little was learned about the age and extent of eolianites in other parts of the island. However, eolianites and intercalated paleosols are clearly visible along the north, northwest and west coasts as seen from low-flying aircraft. A recent air survey by the writer suggests that there may be more extensive eolianites on Santa Rosa, especially the northwest and west coast, than any of the other islands. Topographic maps, airphotos, and overflights also show extensive dune fields on the peninsula south of Carrington Point, and across Skunk Point. Some of these deposits are modern sands, but some or much of the sand may also be reworked eolianite, as on San Miguel and San Nicolas Islands. Field work of course can resolve the matter. In any event the sand units show clear northwest-southeast topographic linearity and their location on present wind-struck coasts shows they were emplaced by winds which prevailed from the northwest.

Discussion

The above discussions on eolianites of San Clemente, San Nicolas, Santa Cruz, Santa Rosa and, as will be shown San Miguel Islands reveal two facts, both important to this study. First, eolianites have been deposited in short episodes as shown by soils which alternate with eolianites. Secondly, the eolianites were deposited by winds that blew from the same direction from which they now blow, the northwest.

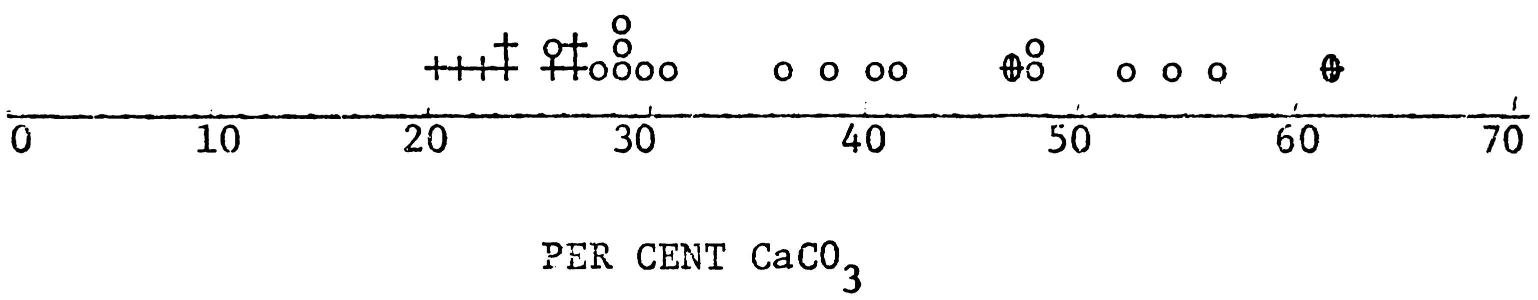
18. San Miguel Eolianites

Eolianite is strongly reflected in all aspects of the landscape on San Miguel Island. It has influenced the genesis and development of the island's soils, it has contributed practically all of the calcium carbonate for the near ubiquitous caliche, and it gives an undulating expression to much of the geomorphic landscape. Moreover it is the source for almost all the sand on the island, both active and recently stabilized. Any characterization of the soil-geomorphological landscape would be incomplete without a detailed discussion of the nature, origin and age of eolianite.

Nature and Character

Eolianite on San Miguel is comprised predominantly of quartzose and skeletal sand, but with a small amount of iron bearing minerals. Petrographic analysis of thin sections of eolianite cut for this study shows that the skeletal grains are mainly of Foraminifers and Mollusks, and to a much lesser extent Echinoderms (Plates 73-75). The skeletal debris presumably was initially comminuted to a sand size by wave-action within the surf-zone prior to pick up and emplacement by wind.

Particle size and gasometric carbonate analyses of both beach and eolian sands from San Miguel suggest that eolianite constituent grains were initially wind-winnowed by size from the backbeach of paleo-shorelines by prevailing northwest winds. Figure 37 shows the per cent of calcium carbonate of 26 sand samples taken from the island. Of these 10 are modern beach sands and 16 are eolian sands from eolianite.



\+ Beach Sands (25 per cent average)

o Eolian Sands (40 per cent average)

⊕ Pt. Bennett Beach Sands (54 per cent average)

Total $CaCO_3$ of all beach sands is 31 per cent average

Figure 37. Percentage calcium carbonate of 26 sand samples, San Miguel Island.

Figure 37 shows several important pieces of information. One is that apart from three exceptions the eolian sands contain more carbonate than do the beach sands. Two conspicuous exceptions are both samples from Point Bennett where Pleistocene calcareous eolianites are everywhere undergoing truncation by present wave action. The ancient eolian calcarenites are apparently contributing a major share of the carbonate fraction to the modern beach sand at Point Bennett which accounts for the disproportionately high amount of calcium carbonate in the Point Bennett sands compared to the other beach sands.

Figure 38 shows in histogram form the particle size distribution of the same 26 samples. Each column represents the percentage of sand held on the sieve whose size is shown below the column. It is clear that eolianite has a greater proportion of finer grains than does beach sand. The particle size analysis data was plotted in a different way in

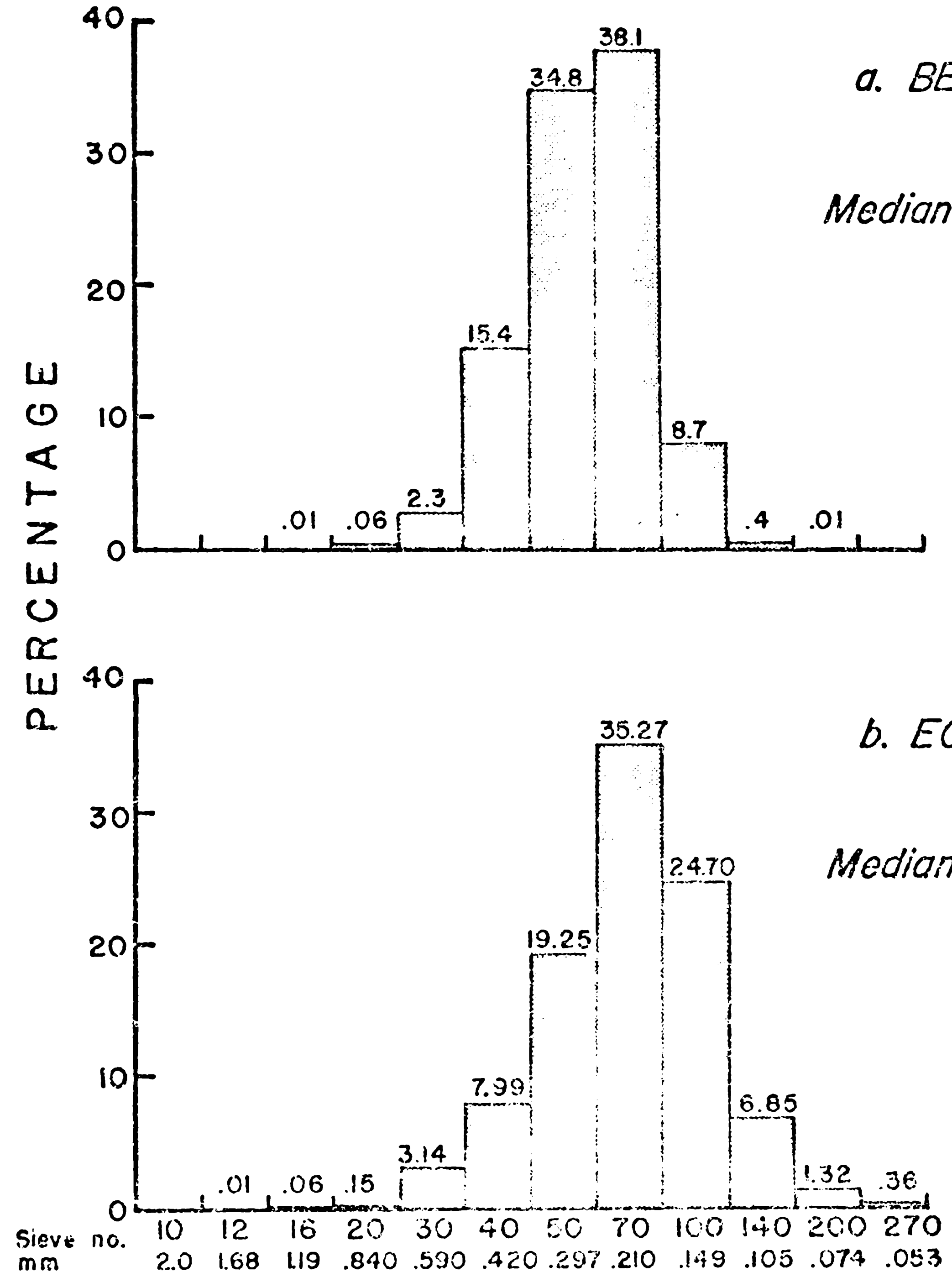


Figure 38. Particle size distribution of 26 sediment samples from San Miguel Island.

Figure 39a which shows each of the ten beach sand samples as cumulative percentages by phi class. Figure 39b shows the sixteen eolian sand samples as cumulative percentages by phi class. Five samples which show range limits are labelled. Samples SMI-152a and 152c are from different places within the same eolianite unit, which shows the great range of particle size in any given eolianite unit. An attempt has been made to simplify these data in Figure 39c which shows the maximum and minimum size limits of both beach and eolian sands. Additionally it shows one coarse grained eolianite, SMI-152c, which varies considerably in grain size distribution from the other fifteen eolianite samples and so is plotted separately. Also plotted separately are SMI-176 and Willow Creek sand, because the grains of the latter, while originally eolian, have been fluvially modified; it is not known whether SMI-176, taken 12 feet in depth, is eolian or fluvial in origin.

In Figure 39d an attempt is made to further simplify the particle size distribution data. Figure 39d shows only the maximum and minimum size limits of the true beach and eolian sands. Sample SMI-152c, an eolianite, is again plotted separately for comparative purposes because of its coarse grain size. In this figure the two Point Bennett beach sands are omitted because, as mentioned earlier, they are believed to consist largely of reworked eolianite. The curves of Figure 39d reflect two points of interest. One is that the eolianites show a wider range of size distribution than do the beach sands, and two, they are, as a whole, relatively finer grained, which these curves show even better than the histogram of Figure 38. However, certain eolianites can be

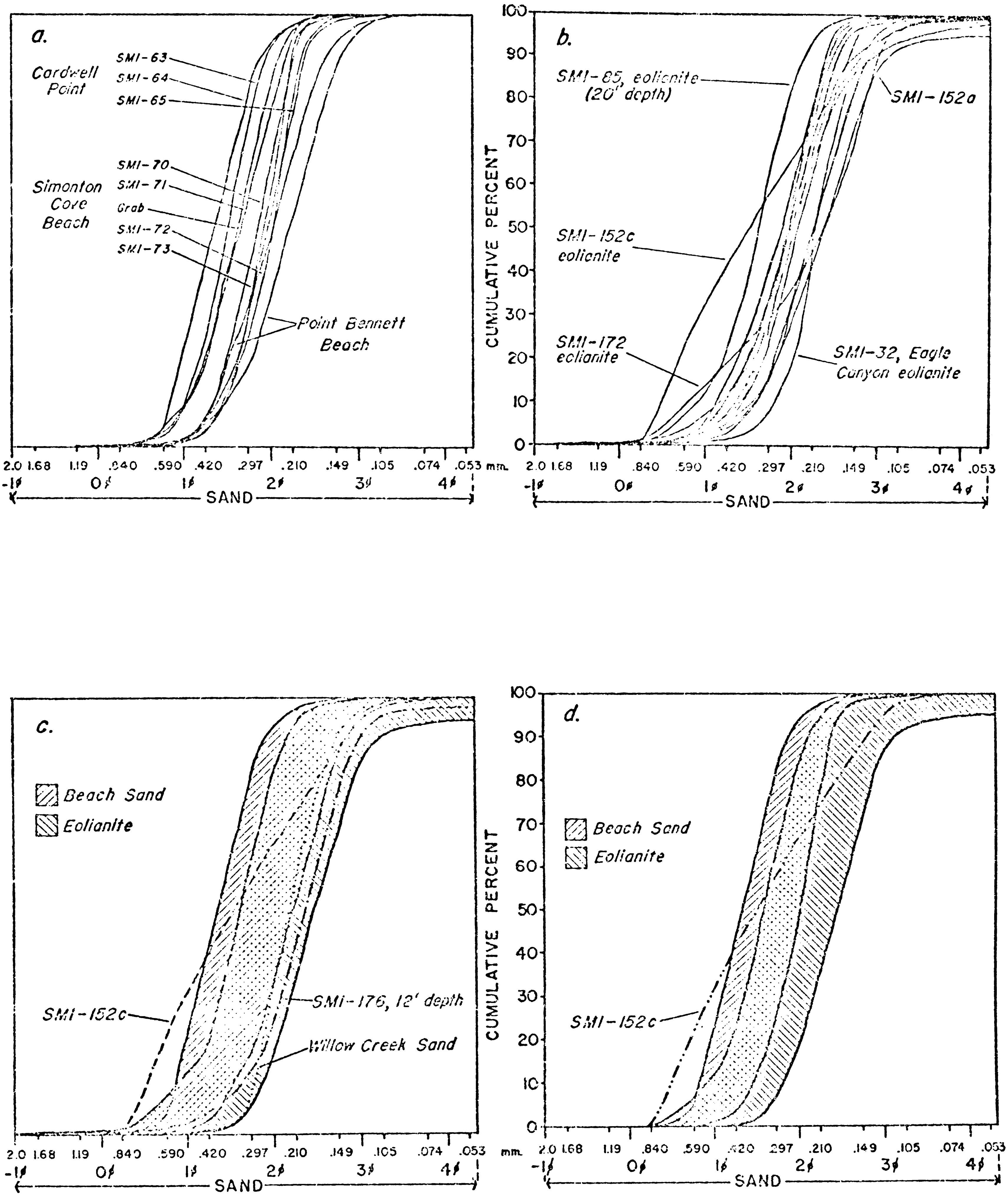


Figure 39. Cumulative percentages by phi class of 26 sediment samples from San Miguel Island.

relatively coarse grained as shown by the curves of SMI-152c and, to a lesser extent, SMI-172 (Figure 39b).

The beaches which ultimately supplied the sand for eolianites must have been far more extensive in the past than at present. The submerged shelf off the north and west coast is wide and shallow, the 100 meter isobath being five miles distant due north of Harris Point and 12 miles distant northwest of Point Bennett. This area constitutes some 50 square miles of shallow water shelf that was exposed repeatedly during glacio-eustatic sea level oscillations. The shelf area presently provides rocky and sandy habitats for abundant mollusks, red coralline algae, and other benthonic forms whose shells and skeletons contribute a continuous supply of calcareous debris to the shelf floor. Moreover, the nutrient-rich upwelled waters which bathe the shelf support a variety of pelagic microscopic organisms whose shells augment the calcareous benthonic debris. This calcareous debris is not diluted by detrital stream sand as it is on mainland shelves and beaches. The result is that island beach sand is considerably more calcareous than mainland beach sand. This fact is demonstrated by Table 21 which shows comparative grain size and carbonate percentages of sediment from San Miguel Island, the Channel Island region in general, and the mainland.

The data of Table 21 show a much higher calcium carbonate content for San Miguel beach sand than do the comparative data given by Emery for island beaches in general. This apparent anomaly may be explained in large part by the fact that wave erosion about the perimeter of San Miguel contributes abundant reworked eolianite to the beach sand. The

TABLE 21

Characteristics of Sediments from Channel Islands Region and Mainland

Environment	$CaCO_3$%[1]	Grain size, Median Diameter[2]
San Miguel Eolianites	40 (16)[3]	249 (16)
San Miguel Sand Beaches	31 (10)	293 (10)
Island Sand Beaches[4]	12 (77)	290 (99)
Island Shelves[4]	27 (256)	260 (298)
Bank Tops[4]	56 (166)	270 (248)
Mainland Sand Beaches[4]	6.3 (30)	240 (57)
Mainland Shelves[4]	9.2 (591)	130 (1773)

[1] Gasometric analyses

[2] In microns

[3] Number of samples

[4] From Emery, 1960, p. 181

reader should note that the 31 per cent calcium carbonate shown for San Miguel Island in Table 21 includes the two Point Bennett beach sand samples mentioned earlier that are mainly reworked eolianite, and if they are omitted the per cent carbonate would drop to 25. Wind has also eroded and blown much eolianite into the sea about San Miguel Island over the past 100 years. But even in the absence of carbonate enrichment of beach sand by reworked eolianite the island beaches still have twice as much carbonate than the detritally diluted sands of mainland beaches.

Origin

In retrospect the eolianites on San Miguel Island contain 15 per cent more calcium carbonate and average 44 microns smaller size than the beach sands. As mentioned, this difference is presumed to reflect wind winnowing by size from back beaches. Without experimental data one might suppose that the factors most important in the differential wind-winnowing of beach sands would be density, shape, and size of the grains. However, according to Bagnold:

> . . . neither the composition of the grains, nor their shape, are found to have any considerable effect on the character of the [sand] accumulations produced. Grain size is far more important: for though the weight of a grain of a given size may vary with the material in a ratio of two to one, this variation in weight will be offset by a change of only the cube root of two, or 1.26, in the size. (Bagnold, 1941, p. 7).

Because of their relative softness (3 on Moh's scale of mineral hardness) the carbonate grains of beach sand would have a natural tendency to be wave-abraded towards a smaller size than quartz grains (7, Moh's scale) and thus more easily picked up by the wind.

A reasonable model of differential wind winnowing might be as follows: as wind carries sand from the back beaches onto the island, the tendency is for the smallest grains to be carried farthest downwind. Abrasion during wind transport should cause an even further size reduction of those grains that are carbonate. We would expect those dunes most distant in a downwind direction from the beach source area to have the smallest particle size distribution and a higher percentage of calcium carbonate (Crocker, 1946). Unfortunately this model was conceived after the author's last field season in 1969 and cannot be tested for this study. However, the model will be tested in the field at a future time at the north end of Simonton Cove where eolian sand is presently being blown from the back-beach some distance inland (see Plate 82a). If the model is sound, a series of samples taken at the beach and at progressively distant points downwind should reveal a gradual particle size decrease and a carbonate increase.

In an earlier paper the writer (Johnson, 1967) offered the following general model for the origin of primary* eolianite on the Channel Islands of California:

> [Evidence] . . . strongly suggests that at the climax of the Wisconsin glaciation, sea level dropped more than 400 feet below its present position. It is probable that calcareous debris derived from [marine invertebrate] skeletal material exposed at the shoreline by retreat of Wisconsin seas was then gradually picked up by persistent and strong on-shore winds and blown inland a short distance in small but continuous increments. Vegetation would prevent the calcareous sand from travelling great distances inland, so that it would accumulate relatively near the sea shore. In such a site time would see the sand become slightly cemented, partly by moisture supplied by sea spray, winter rain, summer fog [leaf drip], and partly by the effects of dune vegetation, enabling an indurated calcareous "fossil" dune complex or dune rock . . . to be formed.

On the basis of five years' more experience and field work on the islands, I would qualify this model in three ways. First, although the bulk of primary eolianites is probably deposited near the shoreline, the sand can travel far inland if the wind is persistent (if a continuous source of sand is available, and if the sand does not become stabilized by vegetation). Secondly, I would omit sea spray as a moisture

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*Primary eolianite is defined here as that which forms directly by wind-winnowing on back beaches whereas secondary eolianite forms when primary eolianite is unstabilized by disturbance, for example by fire and faunal disturbance.

source for dune cementation because surface sea water is normally supersaturated with calcium carbonate (Emery, 1960, p. 239). Third, while it is probable that most of the eolianites are late Quaternary, perhaps mainly Wisconsin in age, certain eolianite units date from pre-Wisconsin time. Orr has described eolianites which date from the Fox period of 135,000 years ago (Orr, 1967). Moreover it is also possible that eolianites date from the middle or early Pleistocene as Weaver and Meyer suggest (Weaver and Meyer, 1969). Besides the Wisconsin Glaciation there were, of course, at least three other major Pleistocene glaciations with attendant fluctuating sea levels which presented conditions highly conducive for eolianite formation. An approximation of the hypothesized sequence of events, as mentioned earlier, is shown in Figure 35.

Stratification

In general the eolianites on San Miguel show good cross-stratification. Steeply dipping eolianite may be seen at many places on the island, but four places show it particularly well. They are on Harris Point above Cuyler Harbor (Plates 34a, c, 43a, 51a, 78-80), at Yardang Canyon, in lower Harford Canyon at Otter Harbor (Plate 51), and at North Green Mountain (Plates 78 and 80). The eolianites almost invariably dip to the southeast at high angles that commonly range from 30 to 40 degrees. In fact the dips of the eolianites on San Miguel rank among the highest recorded for dunes anywhere. North Green Mountain Canyon in particular contains magnificent exposures of high angle cross-stratified eolianites which blanket the Eagles Nest Cliffs section of Simonton Cove. The exceptional high angles of repose that eolianites frequently display are believed to reflect a stickiness of the eolian grains during deposition. The stickiness presumably is caused by sea spray and moisture-saturated air that characterize coastal environments.

I had originally planned as part of this study an analysis of the direction dips of eolianites in order to quantify paleowind directions as MacKenzie did on Bermuda (MacKenzie, 1964a). However, upon commencement of field work it became apparent that such a task would require much more time than could be spared from other higher priority tasks. Such a quantitative study, however, is planned upon completion of this thesis.

While quantitative data are presently not available to support inferred paleowind directions from eolianite cross-strata, field observations and intuitive reasoning are. In practically every eolianite exposure that the writer has seen, the high angle dips are to the southeast which shows a prevailing northwest wind direction. The consistency of the dips to the southeast is one of the striking sedimentological features on the island, regardless whether the eolianite is ancient or relatively young. This fact together with the observation that the bulk of the eolianites on the Channel Islands occur on the northwest sides of the islands is conclusive that the past wind directions, at least during times of eolian sand emplacements, were from the northwest.

Age

The oldest eolianites on San Miguel Island may be seen in the slide headwalls bordering Cuyler Harbor (Plates 59c and 79, and Fig. 12, Appendix B) just above the bedrock contact. Ancient marine and beach deposits grade upward into an extensive eolianite-paleosol complex. The east side of Nidever Canyon also shows these relationships well. As the ancient sea withdrew to a lower level, sand blew over and covered the exposed beach deposits. This event was followed by a period of soil formation, then more sand, another soil, and so on. The sea presumably never readvanced to its former level because no marine deposits cover any of the eolian units on the islands. The series of eolian-soil forming episodes ended temporarily with the emplacement of the last eolianite unit associated with the temporally important Green Mountain Sedimentary Event reviewed in detail in later pages. The ensuing soil-forming period produced the morphostratigraphically important Green Mountain soil. The Green Mountain Sedimentary Event is provisionally assigned a very late Sangamon or early Wisconsin age based on evidence given later in this chapter. All the presently can be said in the way of age-estimating the earlier underlying eolianites and paleosols is that they predate this event. In the absence of radiometric dates on the underlying high marine platform, it is difficult to even arrive at a reasonable estimate of the maximum possible age of the sediments. On the basis of uranium-series dates Orr assigned a greater than 200,000 year age to the 75-foot Fox platform. The latter date was made on eolianite* and, although both platforms are assigned a Sangamon age by Orr, it seems inadvisable at

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*A radiometric date on the grains of eolianite dates only the grains, not the emplacement of the dune unit. For example, sand from modern dunes on San Miguel could conceivably date from pre-Wisconsin times. The reason is because many of the sands are reworked.

this time to make a tentative correlation between the older eolianites on the two islands.

On the other hand, the ages of some of the eolianites which postdate the Green Mountain Sedimentary Event have been determined indirectly by radiocarbon dating their intercalated paleosols. Table 15 (Chapter II) lists all the dates determined in this study. By reference to Table 15 and Plate 52, which shows the stratigraphically important part of Simonton Cove, some of the more significant eolianite units can be visually identified and age bracketed. The oldest sedimentary unit in the sequence is a member of the Simonton Sedimentary Complex which underlies the Simonton Paleosol at localities 256, 181, and at other places on the northwest coast (Plate 52). Charcoal taken two inches below the top of the paleosol gave an age of greater than 40,000 radiocarbon years. It is not known when the Beachrock Eolianite which overlies the Simonton Paleosol at locality 171 was emplaced but it was sometime before about 21,500 radiocarbon years ago. The latter date was made on charcoal collected randomly through the Beachrock Paleosol (SMI-172) which formed over the Beachrock Eolianite. When the Beachrock Paleosol first began forming and when it was buried by the younger Tablerock Eolianite is, unfortunately, not known as the Tablerock Paleosol was not dated.

Neither is the age of the Abalone Eolianite known, although a C-14 date on a red abalone midden shell taken eight inches below the soil surface gave an age of 6,450± 130 radiocarbon years. All that can be said is simply that the Abalone Eolianite was emplaced some time prior to 6,500 years ago, perhaps considerably earlier than that date.

There was one episode in the Simonton Cove eolianite-paleosol complex that can be finitely dated, and that is the time of emplacement of the Yardang Eolianite, an event which occurred approximately 20,100 radiocarbon years ago. At that time the ground cover which grew on the Simonton Paleosol was burned over, leaving behind charcoalized trunks of a subarboreal type of vegetation.* The fire also left behind an extensive veneer of charcoal approximately 1 mm thick which blanketed the surface of the Simonton Paleosol (Fig. 40). Charcoalized stumps in

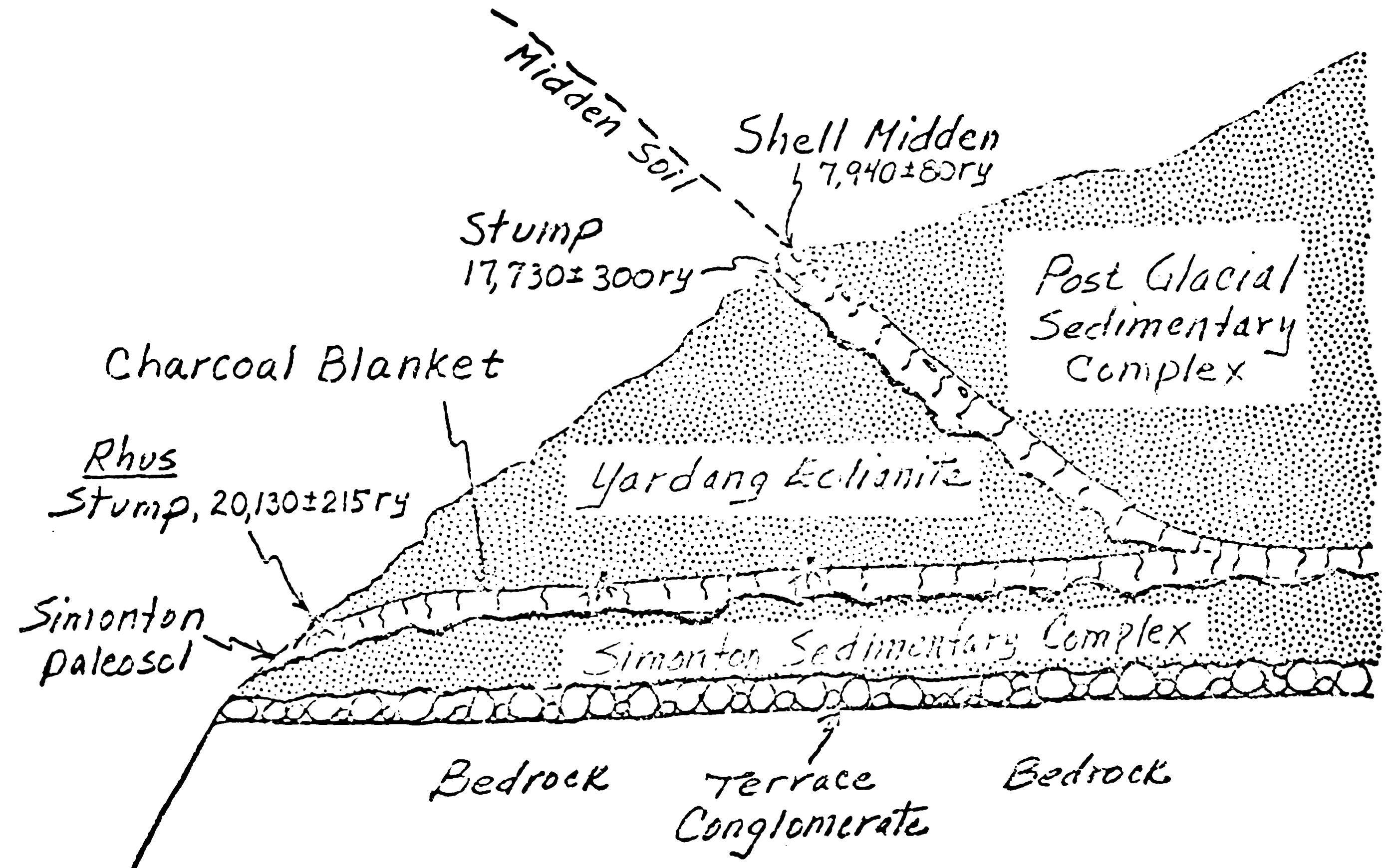

Figure 40. Vertical profile exposed in Yardang Canyon, Charcoal Cove. Not shown is a thin veneer of charcoal which markes the interface of the Simonton Paleosol and Yardang Eolianite.

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*One of the stumps gave a date of 20,130± 250 radiocarbon years. The stump was identified by R. C. Koeppen of the U.S.D.A. Forest Products Laboratory at Madison as "probably <u>Rhus</u>" (personal correspondence, 1970).

growth position and the charcoal veneer can be seen at locality 178 in Charcoal Cove; the thin charcoal blanket can also be seen in vertical section along Yardang Canyon where it defines the abrupt interface between the Simonton Paleosol and the overlying Yardang Eolianite. The Yardang sands apparently trapped the charcoal before it could be blown away, which suggests that the emplacement process was very rapid. It is here inferred that the fire which swept the vegetation of the Simonton Paleosol caused the re-activation of dune sands located some distance upwind, sands which subsequently migrated downwind and rapidly buried the Simonton Paleosol and preserved the charcoal blanket. Another line of evidence which supports a hypothesis of rapid emplacement of many eolianite units is an absence of incipient soils or zones of caliche enrichment. Here then is an example of a calcareous eolian sand emplacement event resulting from fire disturbance which took place some 21,000 radiocarbon years ago.

Three radiocarbon dates have been made on the buried paleosol which formed over the Yardang Eolianite. This paleosol is called the Midden Soil because of shell midden material which occurs abundantly in the upper 20 inches of it. The earliest date is 17,730± 30 radiocarbon years made on charcoalized wood, probably root wood, taken from the lower part of the Soil. This date lends support to the model that the Yardang Eolianite sands were emplaced rapidly, for it at least brackets the eolianite between approximately 20,100 and 17,700 years ago.

A second date of 7,940± 80 radiocarbon years was made on shell midden collected throughout the upper 20 inches of the Midden Soil. This date is significant for three reasons, one of which is that it is the earliest date for human presence on San Miguel. Also, because the material dated was so near to the soil surface the date lies close to the upper age limit of the Midden Soil. Finally, since the Midden Soil is buried by the Post-Glacial Sedimentary Complex, the date lies close to the lower age limit of the Post-Glacial Sedimentary Complex.

The third date (9,360± 200 ry) was made on charcoal collected from 30 to 40 inches below the surface of Midden Soil and has no immediate significance other than it serves as a check as it is stratigraphically and age consistent with the other two Midden Soil dates.

Another date of interest was made on early shell midden collected from the upper four inches of the Simonton Paleosol in a vertical exposure in Range Pole Canyon (Fig. 41, Plates 52, 53 and 54c). The shells

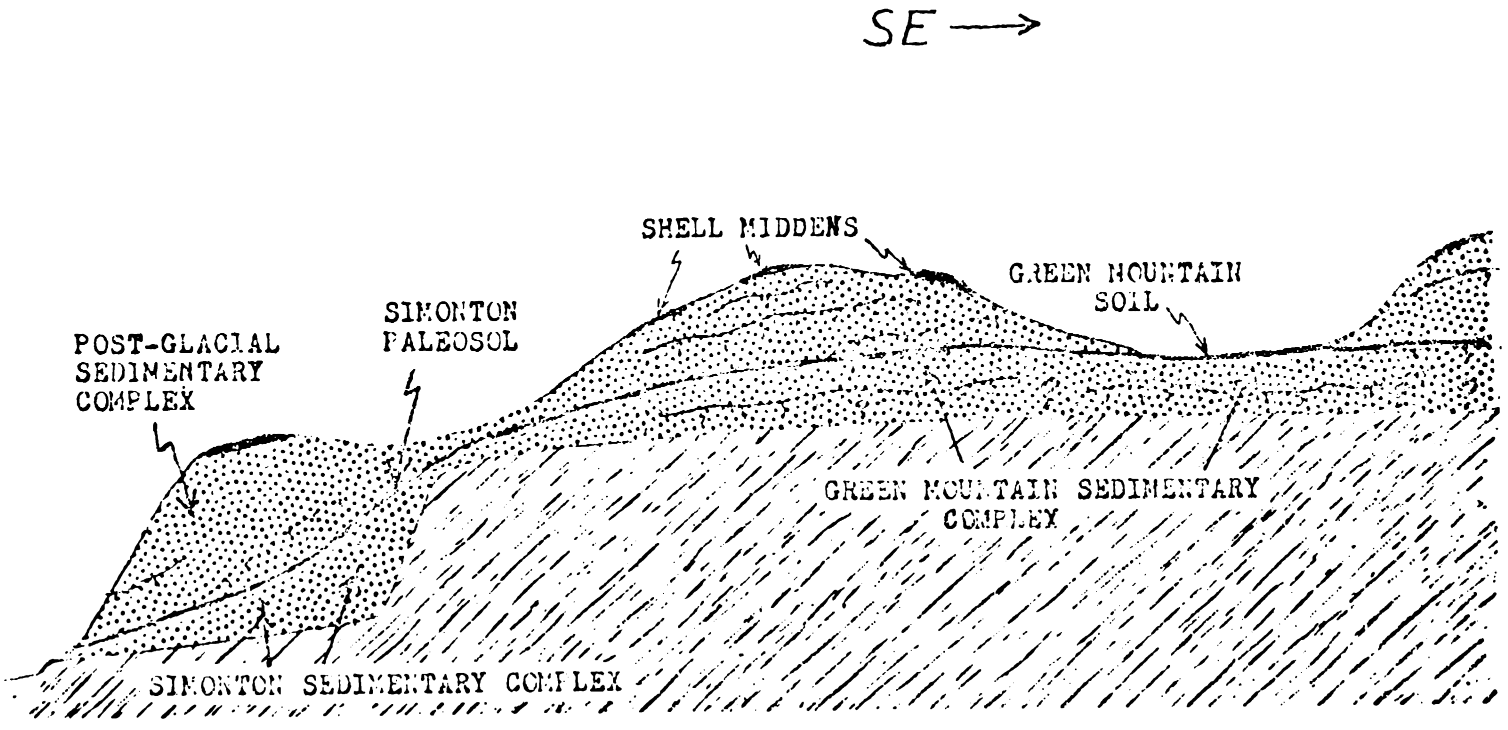

Figure 41. Diagram showing relationship between the Green Mountain and Simonton Sedimentary Complexes, and the Green Mountain and Simonton Soils. See Appendix B, Figure 10 for detail of the Simonton and Post-Glacial Sedimentary Complexes.

gave a date of 7,580± 140 radiocarbon years. Here the Simonton Paleosol is overlain by the Post-Glacial Sedimentary Complex (and locally by fluvial sediments) that range up to 140 feet in thickness. The top of this unit is capped by thick shell midden deposits, presumably left by late Canalino Indians. The significance of the date is threefold. First, it too documents the presence of man at an early time. Second, it shows that the Simonton Paleosol, which elsewhere has two dates of greater than 40,000 years (SMI-171 and 181), was here locally unburied until sometime shortly after 7,500 years ago. And third, a very thick sedimentary unit, comprised mainly of eolianite but with some alluvium-colluvium (Post-Glacial Sedimentary Complex) was deposited during Holocene time beginning shortly after about 7,500 years ago. It is noteworthy that the post-glacial episode of dune building documented here and in Yardang Canyon also has been identified on Santa Rosa Island by Orr (1967). According to Orr the dune building on Santa Rosa also began about 7,500 years ago.

It is also noteworthy that charcoal occurs very abundantly in the Simonton, Midden, Abalone, Tablerock, and Beachrock Paleosols. Fire obviously has been an important element in this insular environment for a very long time. Ancient fires are recorded by charcoalized stumps and charcoal concentrations in the eolianite-paleosol stratigraphy on other parts of San Miguel Island. Plates 21d, and 50 show a partially charcoalized stump (rhizoconcretion) in growth position in the Simonton Paleosol at Fossil Point near Otter Harbor. The stump gave a radiocarbon age of greater than 40,000 years. The rhizoconcretion is believed to have been a subarboreal or arboreal form that was partially burned, as many chaparral plants like <u>Rhus</u> and <u>Heteromeles</u> are left after fires on the mainland. The burned portion was preserved intact whereas the woody unburned parts were presumably replaced by calcium carbonate* which derived from the overlying Fossil Eolianite. It is inferred that the sands which covered the burned stump did so shortly after it was burned, otherwise it would have weathered and biodegraded in a comparatively short time.

Charcoalized stumps are also abundant in the eolianite-paleosol sequence at Point Bennett (SMI-143, 177). The paleoenvironmental situation here is similar to that described for Simonton Cove. Disturbance by fire which destroyed vegetation and exposed the soil to wind erosion apparently reactivated previously emplaced eolian units whose sands rapidly migrated downwind and buried what remained of the burned vegetation and underlying soils. Since this happened repeatedly the result was a sequence of eolianites which represent short periods of time, and paleosols which represent relatively long periods of time.

Green Mountain and Other Sedimentary Complexes

A number of other eolianite-alluvial-colluvial units were emplaced during late Quaternary time whose ages may only be guessed or inferred. One of the most important of these from a geomorphic and paleoecologic standpoint is the Green Mountain Sedimentary Complex whose lateral ex-

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*The replacement was not cell by cell replacement, as thin sections of the rhizoconcretions show, but was probably a process whereby calcium carbonate precipitated in voids left by decomposed wood.

tent is incompletely known, but which probably blankets much of the western, northern, and central parts of the island. This early eolianite-alluvial-colluvial unit (or units??) is well exposed in North Green Mountain Canyon, in the gullies which drain north from the northeast side of Green Mountain (SMI-152), in the cliffs about Cuyler Harbor (SMI-85), in the tributaries to Willow Creek, on the flanks of San Miguel Hill, and in several gullies near the Dry Lake on the west end of the island. The time interval of deposition is herewith called the Green Mountain Sedimentary Event which is partially time equivalent with the Simonton Sedimentary Event (see Fig. 10, Appendix B). One of the most distinctive features of the Green Mountain Sedimentary Complex is the paleosol which formed upon it, the Green Mountain Soil. This soil has a distinctive ironstone concretionary A horizon and is the major marker horizon on the Channel Islands, where eroded remnants of it occur on San Nicolas, Santa Cruz, and probably Santa Rosa Islands. The surface of the Green Mountain Soil which defines the upper boundary of the Green Mountain Sedimentary Event is referred to hereafter as the Green Mountain Surface.

The ultimate topographic and geomorphic effects of the Green Mountain Sedimentary Event were profound. Part of the rounded smooth appearance of the upper part of San Miguel Island is owed to the blanketing effect of this sedimentary unit (Plates 5, 51c, and 62c). What effect this sedimentation episode had on the pre-existing drainage pattern is incompletely known, but on the western third of the island where most of the sediments are of eolian origin it probably was considerable. It is provisionally interpreted that the general pre-eolianite drainage was almost due west to the Running Springs area then northwest towards Castle Rock. This drainage was dammed by the encroaching eolian sands associated with the Green Mountain Sedimentary Event, which simultaneously created both the Dry Lake and Running Springs. This interpretation is based on three factors, one of which is that the lowest elevations of the high marine terrace fore edge on the west end of the island occurs at and near Running Springs (see Figs. 4-9 and 16 in Appendix B). Second a comparison of cross-sections A, B and C on the topographic map (Maps 2 and 3) also strongly suggests that the drainage was towards Running Springs. And third, the large volume of water which issues at Running Springs plus the relative lack of significant spring activity elsewhere in the vicinity shows that much of the subsurface water on the western third of the island must drain to Running Springs. There is no other reasonable explanation for so much subsurface water that is concentrated in one place. The winter rainfall runoff which flows into the Dry Lake and smaller basins to the west presumably percolates to the bedrock aquiclude and follows the pre-eolianite ancestral drainage to Running Springs.

During percolation through the calcareous eolianite the ground water becomes enriched with calcium carbonate which precipitates as tufa around the springs upon evaporation or loss of carbon dioxide. Extensive tufa deposits up to 20 feet in thickness have accumulated about the springs and have trapped abundant plant, land snail and pygmy elephant remains. The abundance of pygmy elephant remains suggests that the springs were a regular watering place of elephants. Likewise it is reasonable to suspect that seasonal sedimentation in the Dry Lake has preserved a valuable biotic-limnologic record, although no cores have yet been taken.

The eolianite has also been the ultimate source for the soil caliche which so characterizes the western end of the island, as at Caliche Flats.

In summary the Green Mountain Sedimentary Event is an approximate correlative of the Simonton Sedimentary Event, and was directly or indirectly responsible for (1) in part, the smoothed topography of the island, (2) the source of carbonate for soil caliche and spring tufa, (3) blocking of the ancestral stream drainage on the western third of the island, (4) the creation of both the Dry Lake and Running Springs and the preserved biotic record, and (5) the corollary creation of a major watering hole which served pygmy elephants for an indefinite period in late Quaternary time.

Precisely when the Green Mountain Eolianite Event occurred is not known, but it is by inference provisionally assigned an early Wisconsin age, certainly prior to 40,000 years ago. As mentioned, this event is an approximate time equivalent of the Simonton Sedimentary Event during which the Simonton Sedimentary Complex was emplaced (Figs. 41 and 55; see also Fig. 10 in Appendix B). The assignment of an early Wisconsin age for both events is based on two lines of evidence. One is that a morphostratigraphic correlation has been made between the Green Mountain surface and the Simonton Paleosol. The latter has been twice dated at greater than 40,000 radiocarbon years. From localities 151 and 152 the pisolitic Green Mountain soil may be observed in the field to grade laterally northwest through a soil facies change to the non-pisolitic Simonton Paleosol one mile distant in Range Pole Canyon (Fig. 41). One can actually walk out the Green Mountain surface and observe this facies change. However, because the Green Mountain Soil at localities 151 and 152 is the modern soil, and the Simonton Paleosol in Range Pole Canyon is largely buried, the latter is only a partial time-equivalent of the former. The second line of evidence for assigning an early Wisconsin age to the Green Mountain Sedimentary Event is based on the observation that with the exception of the material which veneers the marine platform, all the sediments overlying the inferred 75 foot terrace in Simonton Cove are of terrestrial origin and of post-Sangamon age. Therefore the Simonton Sedimentary Complex and its high terrace correlative, the Green Mountain Sedimentary Complex, must have been emplaced after the high level Sangamon seas.

Other younger sedimentary complexes, principally comprised of eolianite, occur on San Miguel, mainly in the central and eastern part of the island. The Central and East End Dune Fields are characterized by a confusing array of eolianites and incipient paleosols many of which overlie the Green Mountain Soil and which range in age from late Pleistocene to the present. Many of the eolian units in this complex are secondary, having originated through disturbance by fire, both natural and man-caused, and by overgrazing during historic times. Many of these eolianites are capped by Indian shell middens which invariably show evidence of fire.

Summary

The eolianites on San Miguel Island were initially derived by wind-winnowing of sand from back beaches of glacially oscillating shorelines. Secondary emplacements of eolian sands occurred through disturbance, by natural and man-caused fires and, in earlier times, perhaps by elephants.

The age of the earliest eolianites is uncertain, but date from pre-Wisconsin, probably Sangamon but perhaps earlier, times. Withdrawal of Sangamon high seas was followed by episodes of sedimentation, largely eolian, in very late Sangamon or early Wisconsin time. These episodes, referred to as the Simonton and Green Mountain Sedimentation Events, had a profound effect on the island landscape. Drainage was blocked, lakes and springs were formed, tufa was deposited, and the island took on a smoothed appearance. The very short episodes of sedimentation were followed by long periods of soil formation which are reflected by the Simonton and Green Mountain Soils, and by partial-time equivalent soils elsewhere on the island. During middle and late Wisconsin and in post-glacial times eolian sands were variously emplaced over the Green Mountain and Simonton Soils. This process quickened in late prehistoric and historic times, especially after introduction of sheep and when cultivation was attempted.

CHAPTER VI

SOILS AND PALEOSOLS

Perhaps the most interesting element of the island landscape are the soils and their associated features, both modern and ancient. Even casual observers would be struck by the unusual array and character of the island soils. For example one can find a soil material which looks like tropical laterite (Plates 16-20, 22-26), a cobble and boulder-covered soil that is slowly homogenizing itself (Plate 6), ubiquitous soil material (caliche) that looks like slabs of plaster of Paris (Plates 1-2), soil features that resemble fossil forests (Plates 3, 16b, 18e, 50), buried soils, exhumed soils, relict soils, a soil that is partly buried, partly exhumed and partly relict, and so on. It is difficult to conceive of a similar array of unusual soils elsewhere in an equivalent small area.

Two soils and their features are given an in-depth analysis in this chapter. Together these two soils cover extensive areas of the island (Lithomap E), and are among the most striking soils present. One is the Gangplank Soil which seasonally cracks and has a cobble-boulder pavement upon it. The other is the Green Mountain Soil which has a strong profile development expressed as laterite-like material, giant A_2 horizons, and deep solution pipes developed in eolianite parent material (Plates 1b, c, and 80). The Gangplank and Green Mountain soils are given a detailed treatment in this thesis for two reasons. One is that the two soils and their associated features make up such a striking and important part of the island landscape. The other is that the two soils provide clues to the nature of the late Pleistocene and Holocene environment, in particular climate and vegetation, which allow insights to the nuances of landscape evolution on San Miguel Island.

The first section of the chapter describes the Gangplank and Green Mountain soils and presents a detailed analysis of their origin plus the origins of certain soil features. This is followed by a discussion of the paleoecologic evidence provided by the Gangplank and Green Mountain soils. Other paleoecologic evidence, from mainland California and elsewhere, is reviewed because it also helps illuminate the past environment of San Miguel Island. The next section reviews the origin and expression of caliche and rhizoconcretions on the island and their paleoecological implications. The reader is cautioned that although certain problems treated in this chapter appear solved, others remain unsolved in spite of light shed upon them. For example, the origin of stone pavements seems reasonably explained, whereas factors involved in the origin of ironstone pisolites are still unclear. On the other hand, as of this writing, ironstone concretions in general have never yet been satisfactorily explained genetically (Roy Brewer, personal correspondence, 1972). So, even though the origin of the pisolites, which comprise one of the most distinctive landscape elements on San Miguel, remains unsolved enough about them has been learned from the effort to stimulate further study beyond this thesis.

The essence of the principal conclusions of the chapter are that (1) the cobble-boulder pavements owe their origin to the churning action of the Gangplank Vertisol, where churning is both a function of California's seasonal wet-dry climate and expandable clays in the soil, (2) the ironstone pisolites of the A horizon of the Green Mountain Soil are hypothesized to owe their origin to either in situ development, or as pieces of clay-rich B horizon material generated at the A_2/B interface, or both; (3) it is not necessary to invoke Pleistocene climatic change to account for either the Gangplank Vertisol or the distinctive profile development of the Green Mountain Soil; and (4) the presence of abundant caliche in almost all the soils, ancient and modern, suggests that precipitation in the past has never been great enough to allow through-leaching of the carbonates such as would be expected in a perhumid climate; the late Quaternary climate was similar to the present.

19. Cobble Pavements and Self-Swallowing Soils

Background

On various parts of the eastern third of San Miguel Island, particularly on the Gangplank Surface, a cobble "pavement" may be found consisting mainly of pebbles and cobbles with occasional boulders (Johnson and Hester, 1972). The pavement overlies a dense clay loam soil, the Gangplank Soil, that typifies the well-known adobe soils on marine terraces along the California coast.

The unusual concentration of rock on the surface of well-developed soils aroused my curiosity and led to an investigation of the factors responsible for their origin. The boulders, cobbles, and pebbles were either 1) allochthonous or 2) autochthonous in origin. Among the allochthonous processes which may have been involved are soil creep, slope wash, colluviation, or mud-flows. However, the terraces on which the pavement occurs have slopes of less than four per cent. Thus soil creep, slope wash, and colluviation probably played no important role in pavement origin. Furthermore there is no evidence of mudflows on the terrace surfaces.

The autochthonous processes which were involved in formation of the pavement probably were not slope wash or deflation removal of fines because the stones occur primarily on the soil surface and not throughout the sola. Two processes which may result in stone pavements on a soil originally devoid of rocks are freeze-thaw and shrink-swell activities in the soil and regolith. Freeze-thaw action may be omitted as a mechanism because temperatures rarely drop to freeze levels on the Channel Islands. On the other hand, shrink-swell activity is evidenced by deep cracking of the soils during dry months. The dry season cracking of the terrace soils, combined with other field and laboratory data, indicate that the soils are of the "self-swallowing" type known as Vertisols (Grumusols). In the following discussion evidence is assembled to show that a genetic relationship exists between the stone pavements and the self-churning action of the Vertisols. To this end it is necessary to review research done on San Clemente Island, where cobble pavements also occur, as it sheds light on the genesis of the San Miguel Island pavement.

Pavements on San Clemente Island

In May 1969 a soil-geomorphology reconnaissance was made of the terraces on San Clemente Island where an attempt was made to determine the effect of time on local soil formation. Two observation pits were dug, one on the lowest terrace (about 25 feet elevation) and another on a higher terrace (about 615 feet elevation) in order to see the effects of time on soil formation on terrace platforms of different ages but with the same parent material.

The vertical profile on the lower terrace is uniformly brown in color (7.5YR 4/2 dry, 10YR 2/2 wet), essentially horizonless, and has no significant change in structure. Pieces of weathered bedrock and coarse terrace gravel are present throughout the solum. No slickensides, gilgai, or sphenoidal structural aggregates are apparent in the profile. Thus, it probably is not a Vertisol*. However, because of the high content of expanding lattice clay (greater than 40 per cent) cracks probably do form during the peak dry season. Hence, though not technically a Vertisol, the soil has vertisolic characteristics and probably is beginning to churn.

The soil on the upper, older terrace, although very similar to the lower terrace soil, shows several important differences. Most notable is an intermittent stone pavement of cobbles and boulders, a feature not present on the lower terrace soil. Moreover, the cobbles and boulders occur predominantly on the surface and not through the solum as on the lower terrace. Dessication cracks and slickensides also distinguish the upper terrace soil.

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*According to J. Thorp (personal communication, 1971) slickensides and sphenoidal structure are most apparent in Vertisols when the solum is wet, and often indistinct or not apparent when dry. Because the San Clemente soils were relatively dry when examined, it is possible that weak sphenoidal structure and slickensides are apparent in the lower terrace soil when wet.

It is proposed that the upper terrace soil is a well-developed Vertisol whereas the lower terrace soil is developing towards a Vertisol. Vertisols are soils characterized by: 1) moderate to warm annual temperature regimes, 2) profiles that are at least 50 cm. deep and have no carbonate or silica pans within this depth, 3) at least 30 per cent clay (less than 0.002 mm.) down to 50 cm. depth or more, 4) seasonal cracks which are at least 1 cm. wide at 50 cm. depth, and 5) slickensides, gilgai, or sphenoidal structural aggregates (Soil Survey Staff, 1970). Field observations and laboratory analyses have established that these criteria are met for the upper terrace soil on San Clemente Island, except possibly for criterion four. Regarding the latter, small cracks were present when field work was carried out in May 1969, but this was shortly after the end of the rainy season. The cracks of Vertisols, however, are presumably widest at the end of the dry season when no measurements were made. But, the high content of expanding lattice clays present in the upper terrace soil (greater than 50 per cent) suggests that deep and wide cracking probably does occur during the peak dry season so that criterion four probably is met.

How the stones came to lie on top of the upper terrace soil is a matter of geomorphic and pedologic interest. The stones are essentially the same in appearance to those found on the nearby modern marine terrace. They are rounded, wave and water worn, and some show evidence of boring by marine mollusks. It is proposed that the stones comprised the original Pleistocene terrace debris and were somehow translocated upward through the solum after the soil formed.

Pavements on San Miguel Island

The Gangplank Soil on San Miguel Island has striking similarities to the upper terrace soil on San Clemente. The surface of the Gangplank Soil, as mentioned, is marked by an intermittent stone pavement of pebbles, cobbles, and boulders. The soil profile is uniformly dark gray in color (7.5YR 4/0 dry, 7.5YR 2/0 wet), develops deep dessication cracks, has no distinct horizons, has no significant change in structure, and displays slickensides. Since it meets the criteria given earlier, the soil is classed as a Vertisol.

The modern marine terrace on the island is presently veneered with pebbles, cobbles, and boulders of marine origin. If this terrace were uplifted, soil would eventually develop over the residual marine debris, just as soil would form on any geomorphic surface exposed to subaerial weathering and pedogenesis. However, the marine cobbles and boulders should be at the bottom of the soil which forms, not at the top. Again, it is difficult to see how the stones on the Gangplank Soil on San Miguel could have been emplaced by downslope gravitative processes since the terrace is gently sloping (less than four per cent) to nearly level. This is a second case where stones seem to have migrated vertically through the soil to the surface.

In order to make a critical appraisal of the origin of the stone pavements, an observation pit was dug in the San Miguel Gangplank Vertisol (SMI-100), but this time in six-inch depth increments, in the manner of an archaeological excavation. The size and number of all the pebbles, cobbles, and boulders were recorded for each six-inch increment down to 18 inches (beyond which few pebbles occurred). The results show that all the boulders, most of the cobbles, and a sizeable portion of the pebbles occur in the upper six inches of the soil (Fig. 42; Plate 6b). Laboratory analyses of the soils support the hypothesis that the pavement is produced by vertical translocation of stones through the solum to the soil surface.

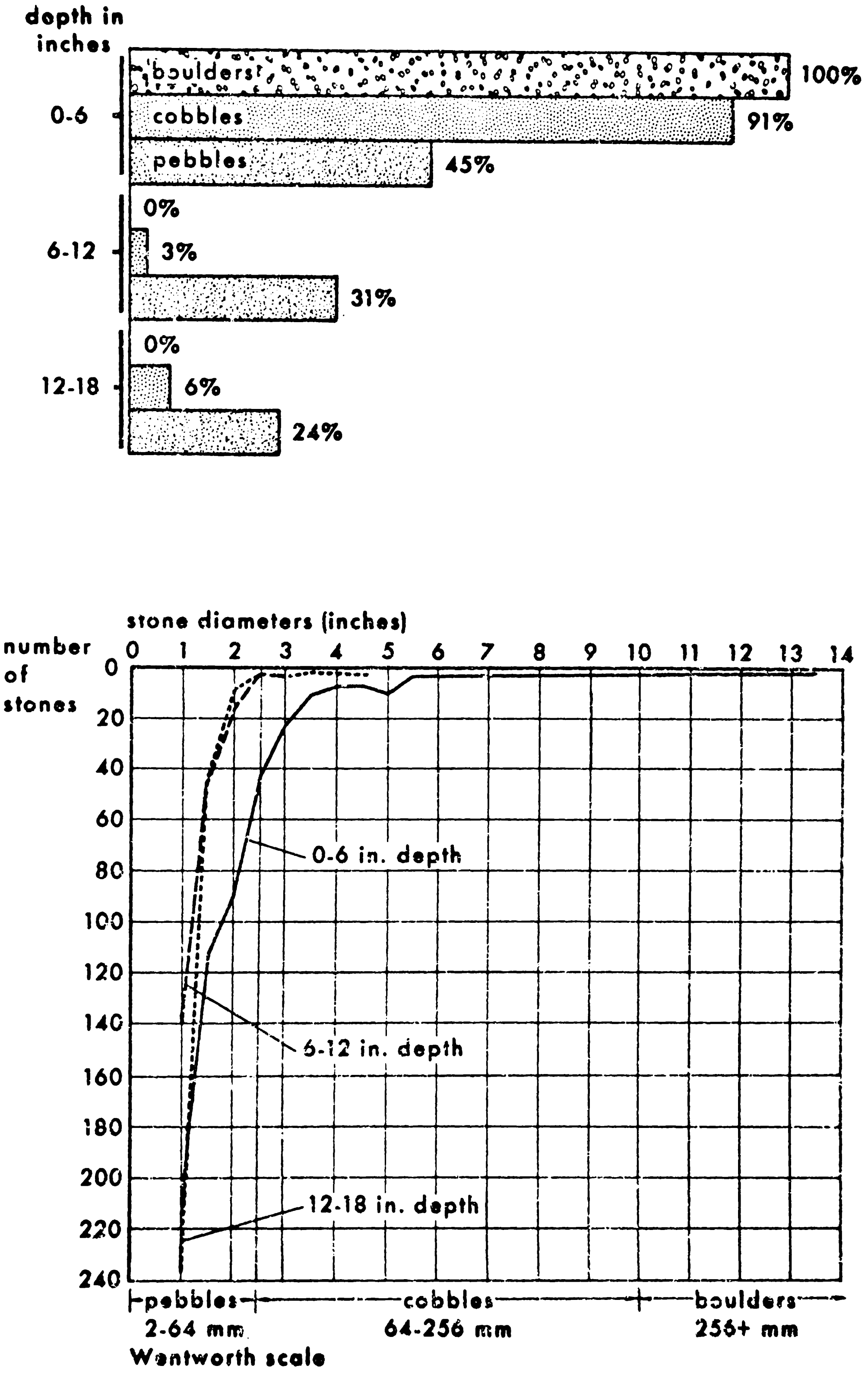


Figure 42. Relationships among depth, number and size of stones taken from the Gangplank soil pit on San Miguel Island.

Laboratory Analyses

Organic carbon, particle size, and clay mineralogical analyses were made on the Gangplank Soil as well as on the two San Clemente terrace soils (Fig. 43). The results demonstrate conclusively the homogeneous character of Vertisols. For example, organic carbon analyses convey two interesting pieces of information (Fig. 43a). First and most important is the relative uniformity of organic carbon in the profile, which supports the interpretation that the soil homogenizes itself with time.

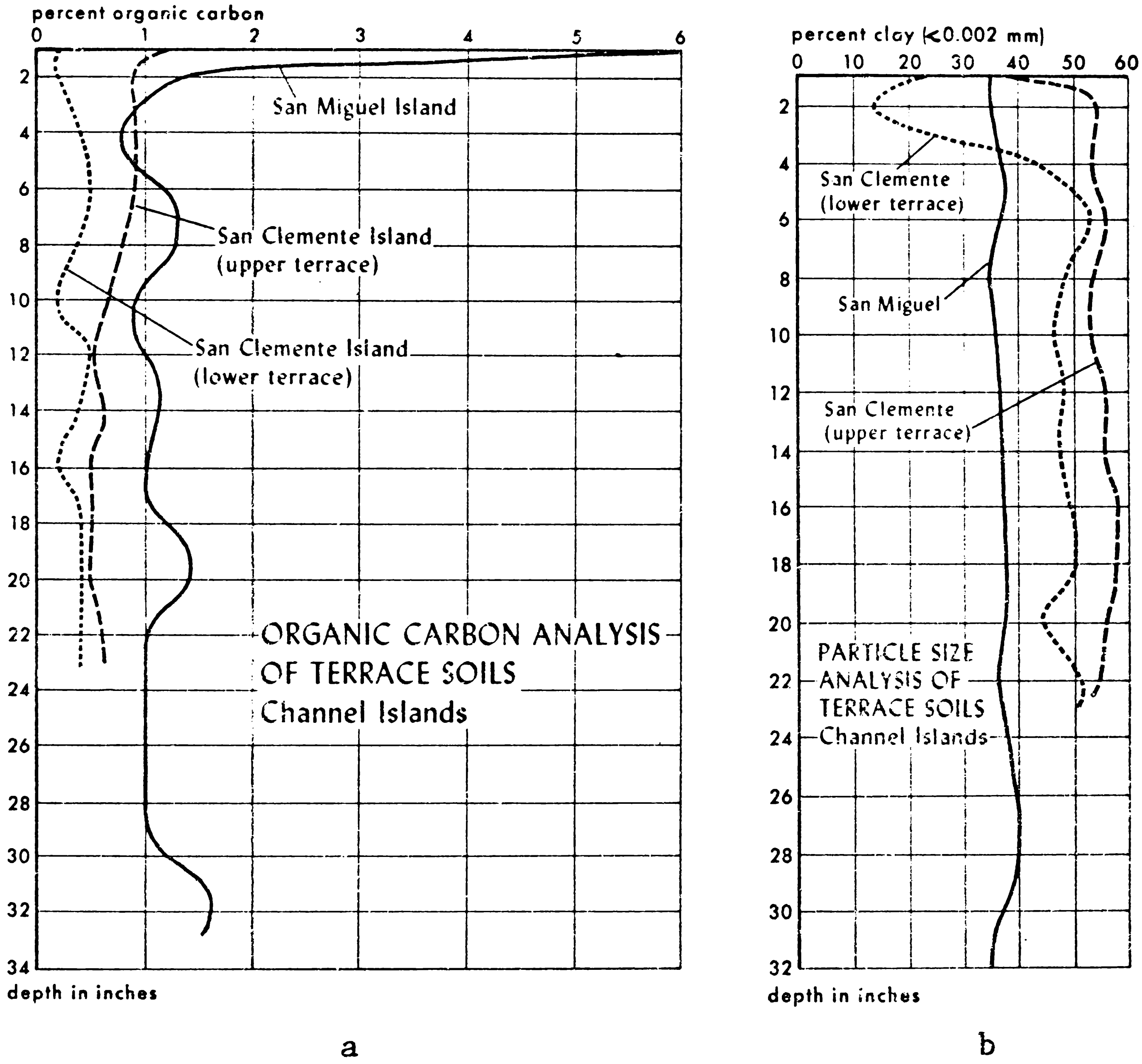


Figure 43. Organic carbon analyses (a) and clay fraction analysis (b) of three terrace soils, two on San Clemente Island and one on San Miguel Island. (Fig. 43 continued on next page.)

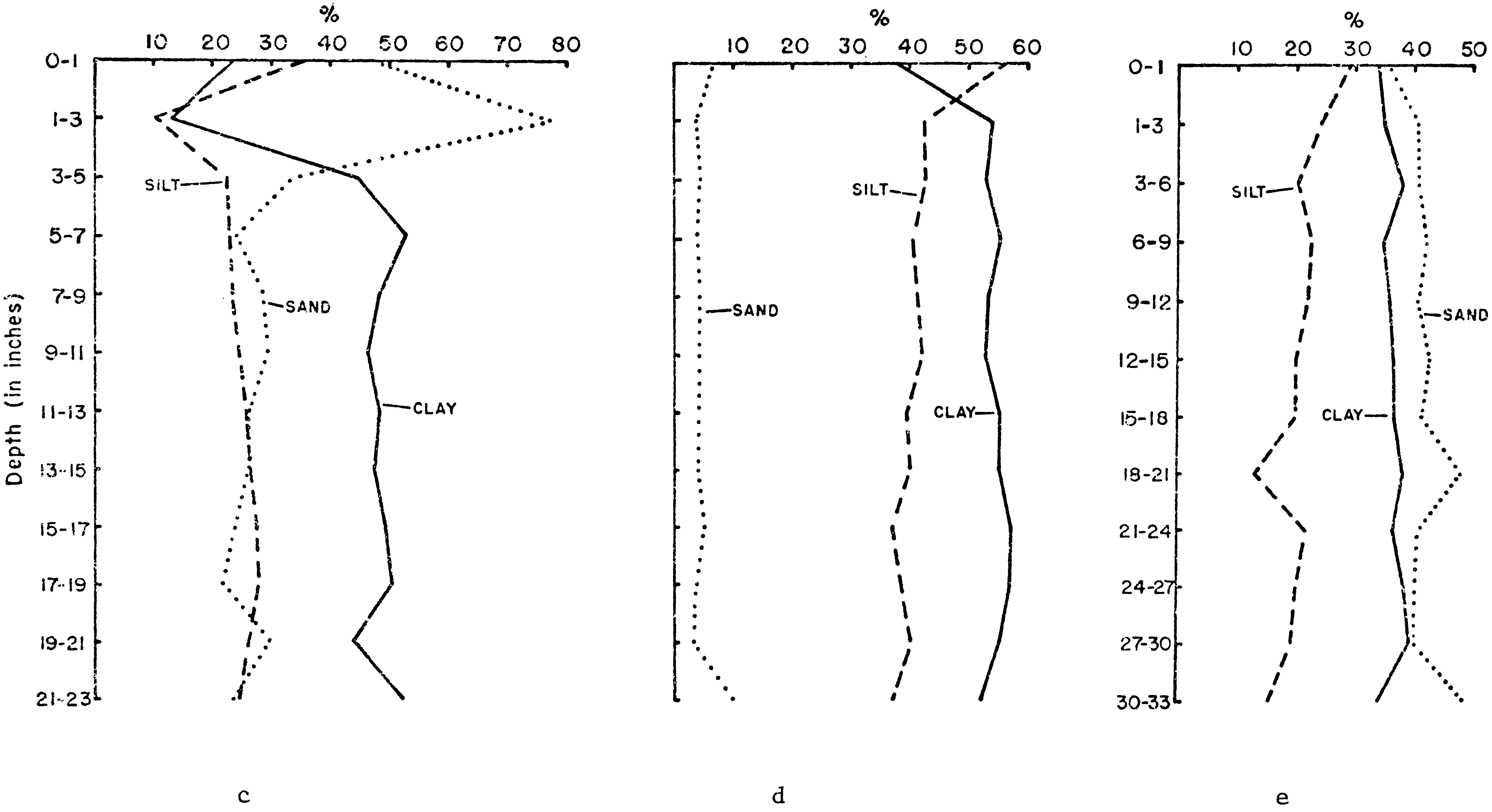
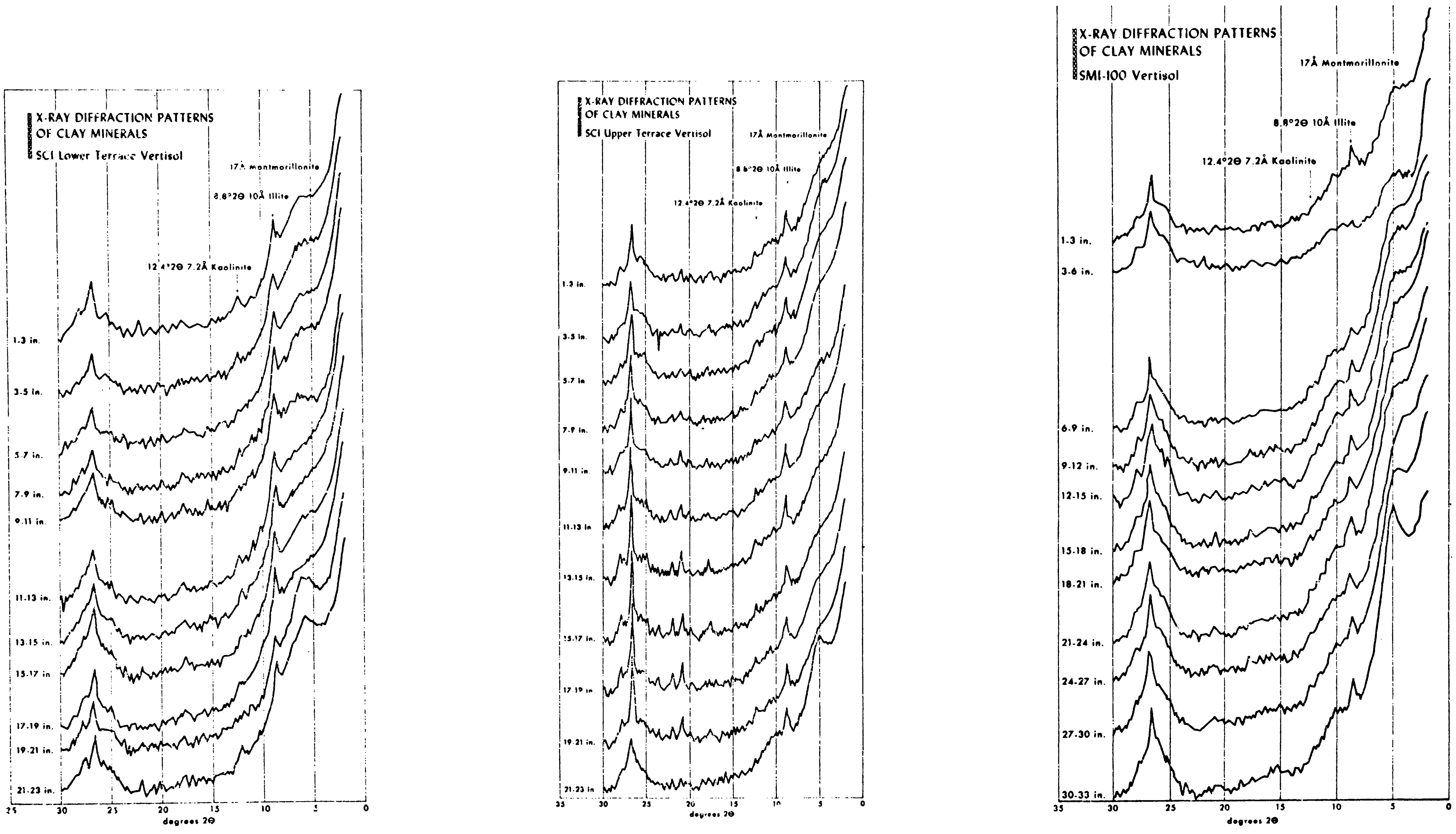


Figure 43 (continued). Particle size distribution of lower terrace soil (c) and upper terrace soil (d) on San Clemente Island, and the Gangplank Soil (e) on San Miguel Island, California.

Second is the presence of slight concentrations of organic carbon at several places within the profiles. The concentrations are best displayed by the San Miguel Island organic carbon curve where they occur between six and nine inches, 18 and 21 inches, and at 30 and 33 inches. These bulges of organic carbon may be due to either variations in the analyses, or more likely, in the sample. In regard to the latter one would expect variations within the sample because tufts of vegetation (e.g., grass, leaves, and so on) commonly fall into the cracks which form during the dessication season (see Plate 29b.).

The clay fraction totals of all three terrace soils is shown in Figure 43b. The most significant aspect of the data is the relative uniformity of the clay fraction throughout. The clay content of all three profiles is greater than the 35 per cent minimum requirement for Vertisols (the marked drop off in the upper two inches of the lower terrace soil of San Clemente Island merely reflects the presence of a thin sandy slopewash deposit and has little bearing on the general incipient vertisolic character of the soil).

Clay mineralogical information gained from x-ray analysis also shows profile uniformity in each of the three soils (Fig. 44). Illite is present in each profile and exhibits vertical constancy. Montmorillonite and other expanding lattice clays are represented by the broad shoulder on either side of the 17 Angstrom peak which also reflects a vertical constancy. According to H. Glass (personal communication, 1971) the presence of a broad shoulder in place of a sharp peak at 17 angstroms indicates a deterioration of the atomic lattice of the clay. The lattice



a

b

c

Figure 44. X-ray analyses of clay minerals of three terrace soils, two on San Clemente Island (a and b) and one on San Miguel Island (c).

deterioration is thought to reflect a long period of weathering and suggests a relatively ancient age for the soils. As indicated in Chapter 3, probably all the island terraces are pre-Wisconsin in age, probably greater than 70,000 years.

These data support the hypothesis that the stones were translocated vertically through the solum by a process that results in preferential concentration of the large particle sizes at the surface. The process is probably related to the seasonal shrinking and swelling of the 2:1 lattice clays that dominate the less than 0.002 mm. size fraction of the Vertisols. Shrinking and swelling coincides with the alternating dry and wet seasons that characterize California and other regions where Vertisols occur (Dudal, 1963, 1965). Vertisols are thus dynamic in character and tend to homogenize themselves through time.

Soil Churning and Pavement Formation

How can seasonal shrink-swell action result in the formation of surface stone pavements, and how does the homogenizing process operate? The most plausible explanation has been reported by others (Hallsworth, _et al._, 1955, with references) and is as follows: When a Vertisol cracks, surface soil material falls or is blown or washed into the cracks. The smallest particle sizes will reach to the bottom of the cracks, whereas larger sizes will come to rest higher in the solum. The solum, dominated by expandable lattice clays, will swell when wetted during the wet season. But, because new material has been added at the bottom of the crack there will be a mass and volume increase at depth. Pressure will be exerted when the cracks swell shut and soil movement will result in the direction of least resistance, which is up. Thus, movement will be essentially vertical or will have a vertical component. Also, because of the cracks Vertisols wet first at depth and expand from the bottom up. Because this process operates every wet-dry cycle, after several hundreds or thousands of years a great amount of vertical movement and churning may occur. Such self-churning soils, some with stone pavements, occur widely in subtropical and tropical regions (Thorp, 1957; Oakes and Thorp, 1951; Dudal, 1963, 1965; Soil Survey Staff, 1960; Mabbutt, 1965, with references) and to some extent in the mid-latitudes (Springer, 1958).

Once the larger soil particles (pebbles, cobbles and boulders) reach the solum surface they cannot move down again unless they are smaller than the cracks which develop during the dry season. Observation of crack widths on San Miguel suggests that only pebbles and small cobbles can re-enter the solum whereas all larger particles, like large cobbles and boulders, will remain on the surface (this process is reflected by the graph in Figure 42, bottom). A hypothetical sequence of Vertisol churning and pavement formation beginning at time zero is shown in Figure 45. Figure 46 shows how pebbles may be re-incorporated at depth once they have arrived at the soil surface. (Interestingly, in the Gangplank Vertisol on San Miguel Island artifacts were encountered in the 12-18 inch depth increment.) In reference to Figure 45, the Gangplank Vertisol on San Miguel Island and the upper terrace Vertisol on San Clemente Island are at Stage 4 in pavement formation whereas the lower terrace soil is at Stage 3.

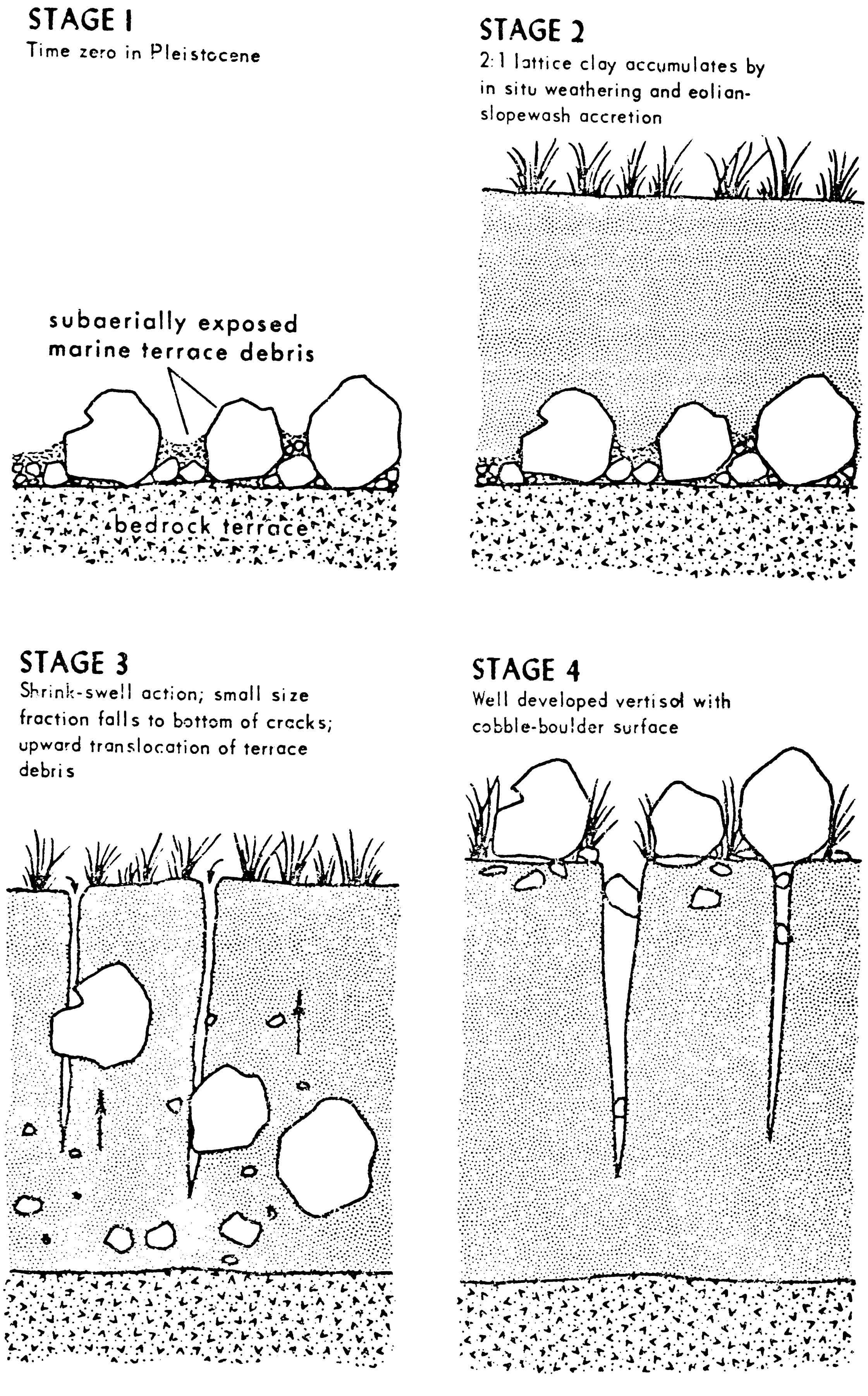


Figure 45. Hypothetical sequence of Vertisol churning and pavement formation beginning at time zero in the Pleistocene. (The orientation of the cobbles and boulders are shown unchanged through the four stages so that each may be identified; in actuality the orientations almost certainly change with each shrink-swell cycle.)

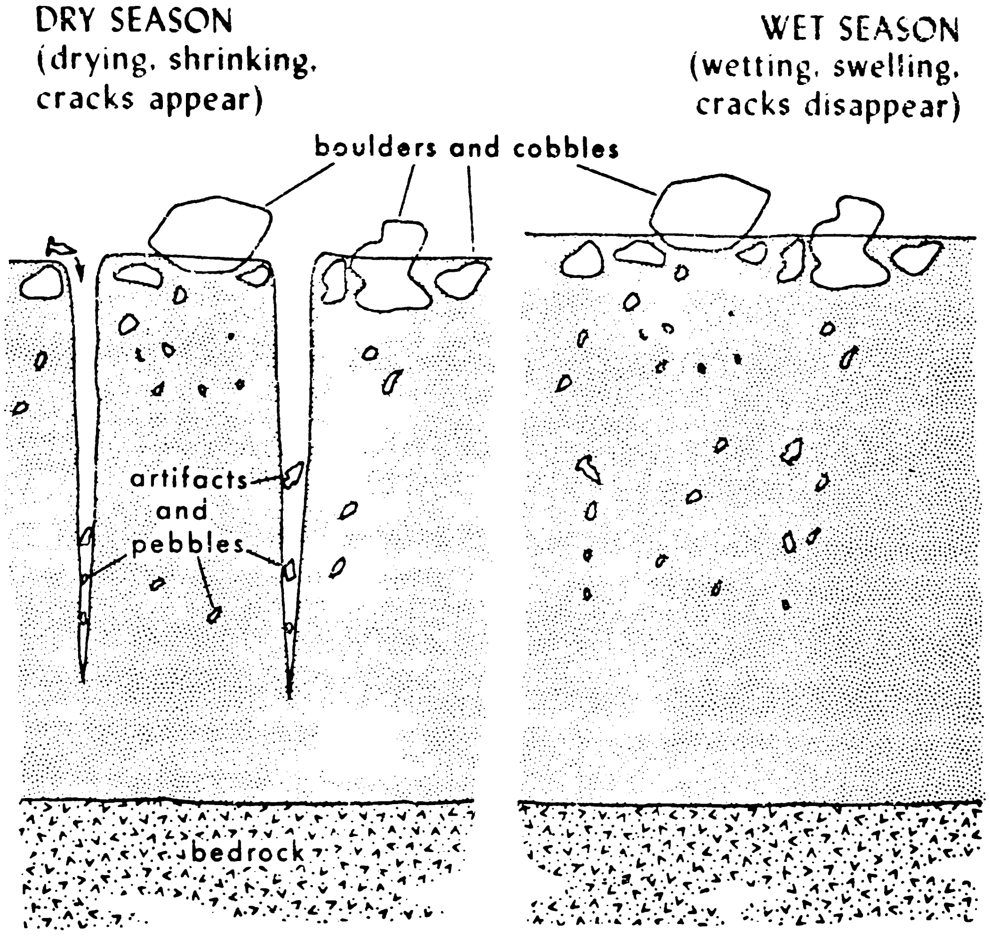


Figure 46. Diagram showing how pebbles, aboriginal artifacts and other surface materials may be incorporated at depth during dry season while large particles remain at surface. Note that during the wet season the soil increases slightly in volume.

One aspect of the process that is not shown, but what should be again stressed is that because the smallest particles (sand, silt, clay) fall to the bottom of the cracks, the result is a mass increase deep within the profile which, when wetted, causes vertical movements at depth. The deep vertical movements are necessary to initiate vertical translocation of the stones. Thus the 2:1 lattice clays, the dessication cracks and the small particles which fall into them, the deep displacements and vertical movements upon wetting are all genetically related to vertical stone translocations, pavement formation, and soil homogenizing processes. How much time is involved from time zero (Stage 1) to the point where the soil begins cracking--and churning (Stage 3)--

is not known. Future research hopefully will shed light on this question.

Paleoecologic Significance of the Gangplank Vertisol

The churning of the Gangplank Vertisol has important ecologic implications. For example, Vertisols are not favorable for tree growth because

> . . . argilliturbation, or soil movement, damages the tree roots. As a result, the predominant native vegetation type is . . . grassland. Some deciduous forests are found on [certain Vertisols of the world], but they show very slow growth, and if uncontrolled burning takes place, the area is rapidly taken over by savannah conditions. (Duffield, 1970; see also Dudal, 1963, 1965).

The fact that the Gangplank Vertisol churns through time, and the fact that fire is and has been a natural, periodically occurring phenomena on the Channel Islands strongly suggests that during late Quaternary times grass has been the predominant vegetation type on the eastern third of San Miguel Island where the Vertisols occur. Why the Vertisols are restricted to only the eastern third of the island is unclear.

20. The Green Mountain Soil

The Green Mountain Soil is one of the most unusual soils in California. The soils which are here included under the name Green Mountain Soil may vary slightly in their profile expression from place to place, but all have the following distinctive characters: an A horizon that contains reddish ironstone concretions; a leached A_2 (albic) horizon whitish in color, sandy in texture; a B_2 (argillic) horizon that commonly tongues deeply into calcareous parent material and which exhibits a reticulate polygonal structure in plan view at the A_2/B_2 interface (Plates 32-33, 35); a continuous or patchy Cca (petrocalcic) horizon of caliche. The Green Mountain Concretionary Soil has both a pisolitic and a massive phase; the pisolitic phase was studied for this thesis. The full range of expression of both phases is shown in Plates 1d; 2; 16a, d-e; 17a-b, d-e; 18a-c; 19; 20b-d; 21a-b; 22-35. The profile descriptions of the Green Mountain Soil at five pisolitic phase localities (SMI-151, 152, 85, 162 and 163) are given in Appendix D, whereas the profile characteristics are shown in Figures 47 through 51 and Plates 2, 16-35, 80, 88. The areal limits of the soil is shown in Lithomap E.

The significance of the Green Mountain Soil is many-fold. For one, as indicated in Chapter 5, the Green Mountain Soil is one of the most important marker horizons on the island. It is distinctive in its profile characteristics and defines the underlying Green Mountain Sedimentary Complex. The maximum age of the soil is unknown but time zero is marked by the termination of the Green Mountain Sedimentary Event provisionally assigned a late Sangamon or early Wisconsin age. Pedogenesis ceased in those places where, subsequent to time zero, the Green Mountain Soil was covered by encroaching dunes. For example, in the north-central part of the island the Green Mountain Soil is in places buried, as at SMI-85 (Fig. 49; Plate 18c) where it is exposed in a sea cliff at Cuyler Harbor intercalated between eolianite. The soil also underlies the Central Dune Fields and outcrops at Fossil Forest 1, and in fact served as the host soil for the pre-existant subarboreal vegetation now preserved as rhizoconcretions (Plates 16b, 18e).

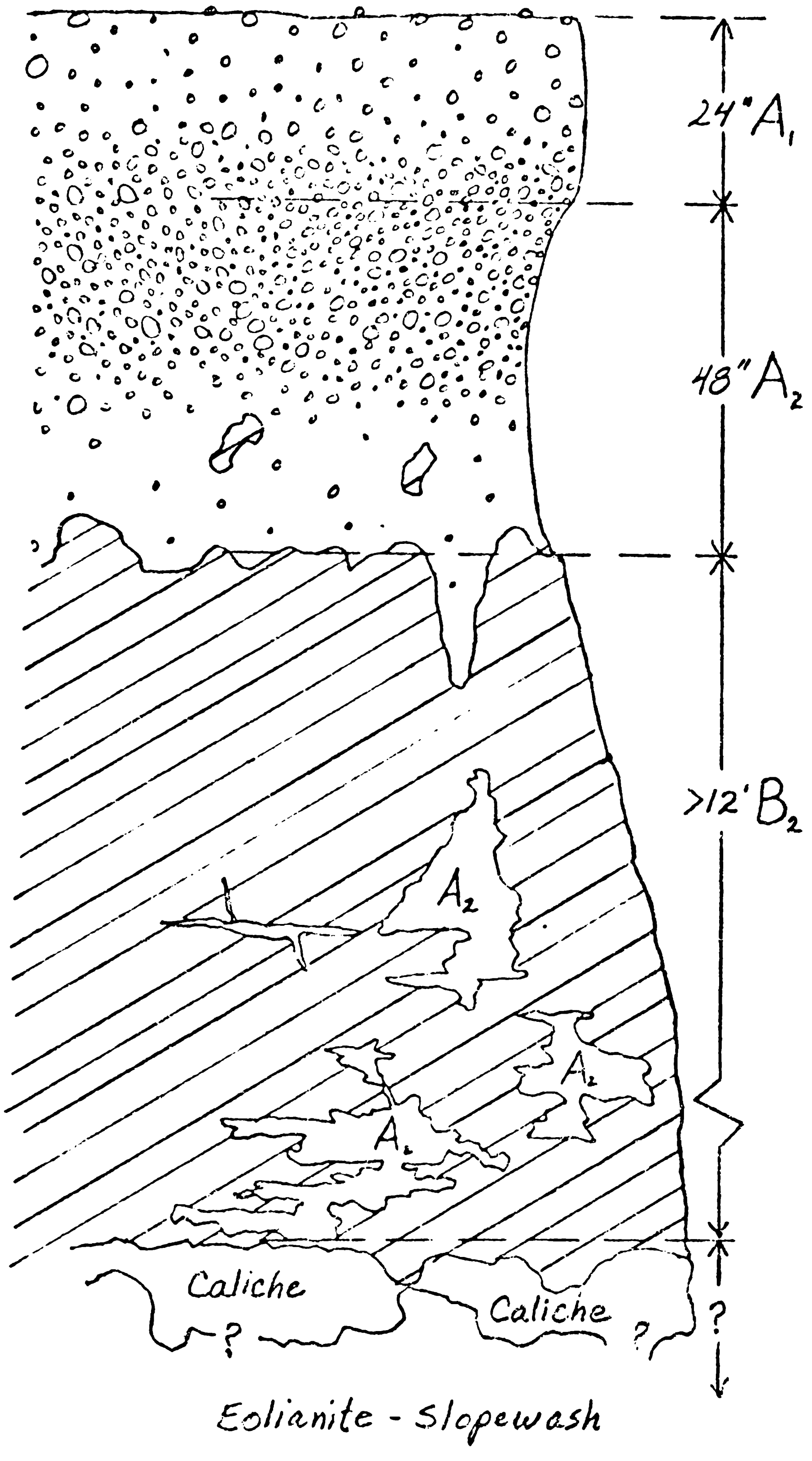


Figure 47. Profile characteristics of the Green Mountain Soil at SMI-151. Note concentration of pisolites in the lower A, and upper A_2 horizons. Note also pieces of argillic B horizon material (diagonal hatching) in the lower A_2 horizon. Channelways of sandy A_2 material extend deep into the B horizon and are interconnected three dimensionally. The B horizon should be viewed as a vesicular horizon where the vesicules are filled with loose sandy material from the A_2 horizon.

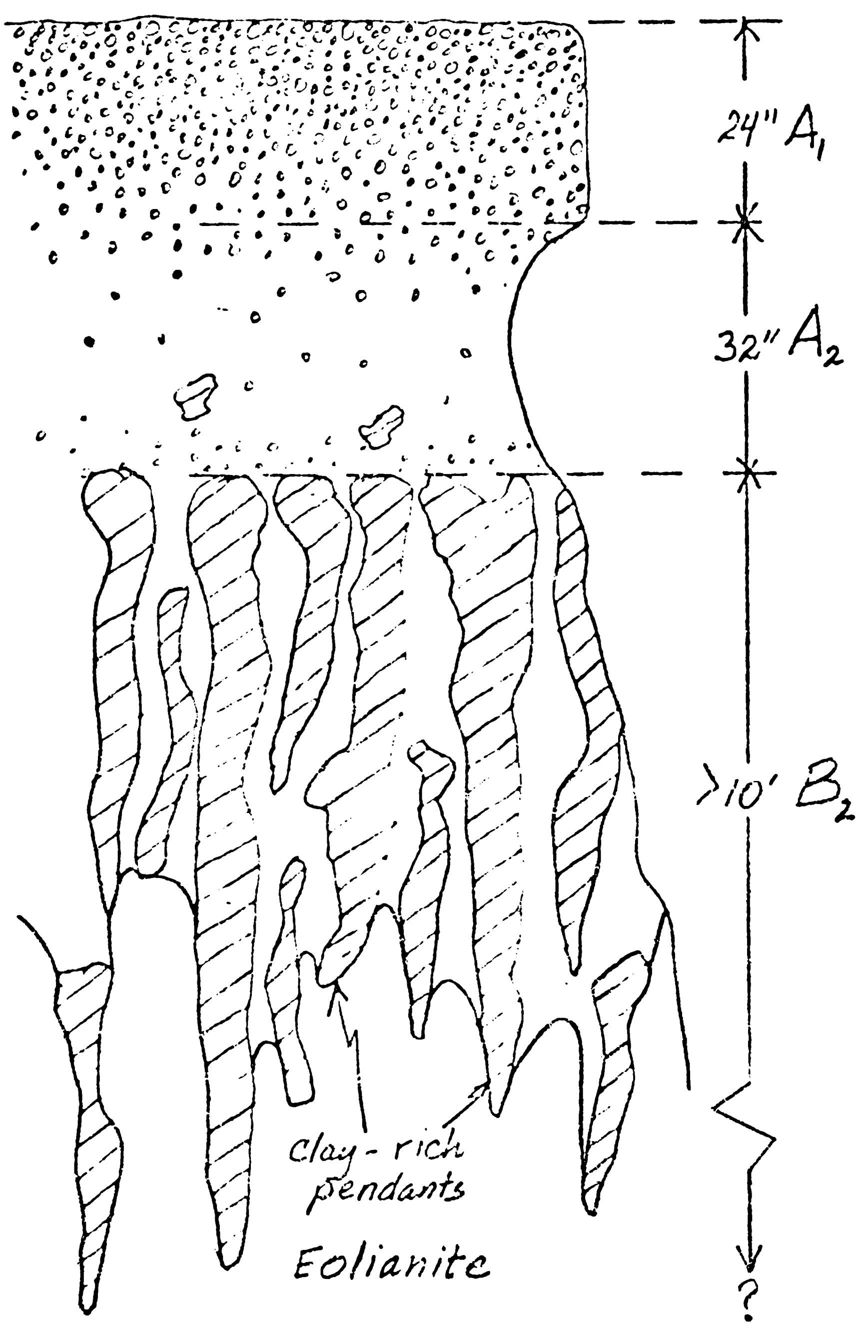


Figure 48. Profile characteristics of the Green Mountain Soil at SMI-152. Note concentration of pisolites in the A_1 horizon, and pieces of argillic B_2 material in the A_2 horizon. The latter suggests that pisolites may originate at the A_2/B_2 interface as pieces of argillic B_2 horizon material.

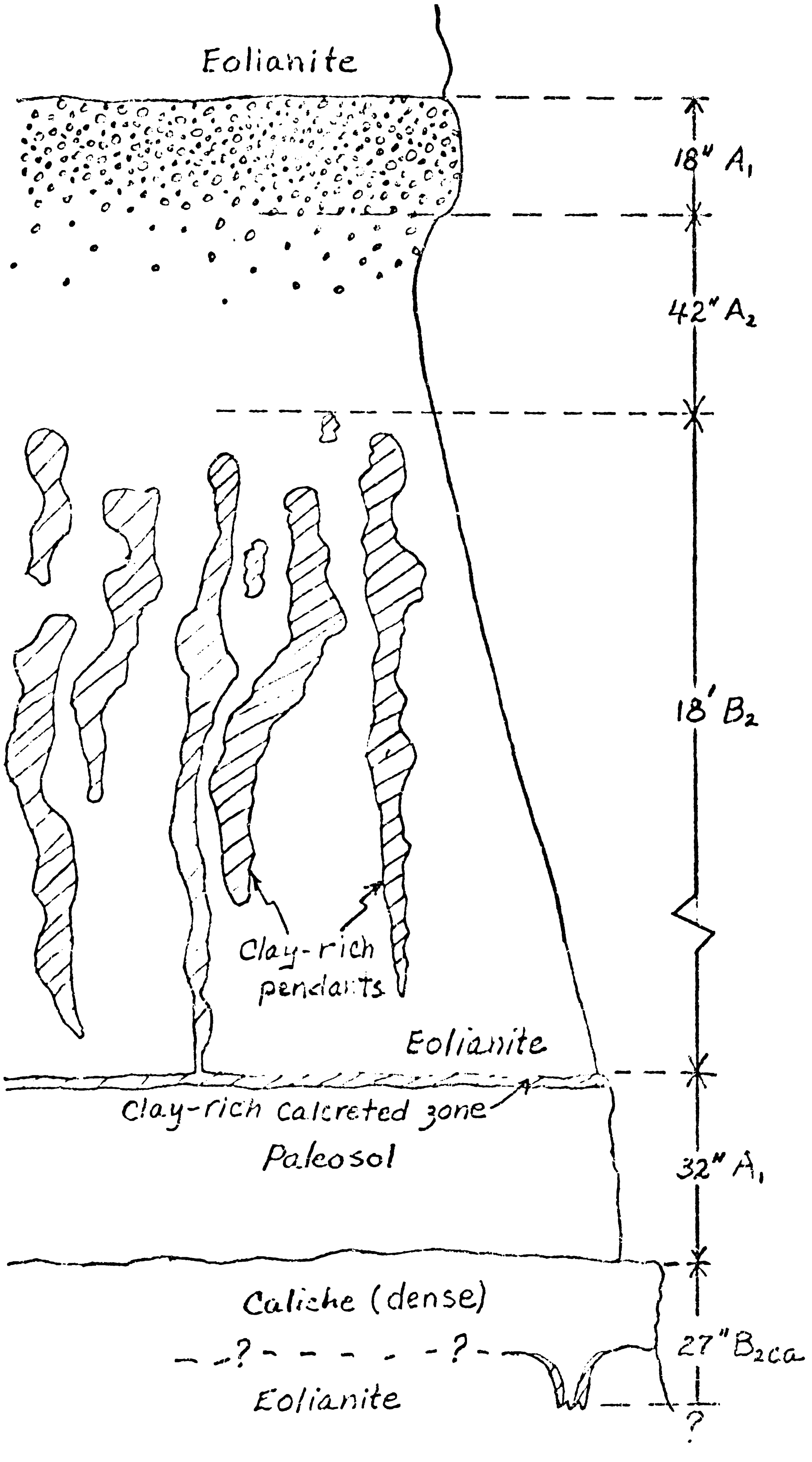


Figure 49. Profile characteristics of the buried Green Mountain Soil at SMI-85. Note paleosol underlying the Green Mountain Soil. Clay and carbonate deposition along the upper two inches of the lowermost soil has derived from the clay pendants of the superposed Green Mountain Soil. One fundamentally important question that is presently unanswerable is, Why is the lowermost paleosol non-pisolitic whereas the overlying Green Mountain Soil is? And what do the differences in profile characteristics of the two soils mean in terms of time, vegetation, or other factors of soil formation?

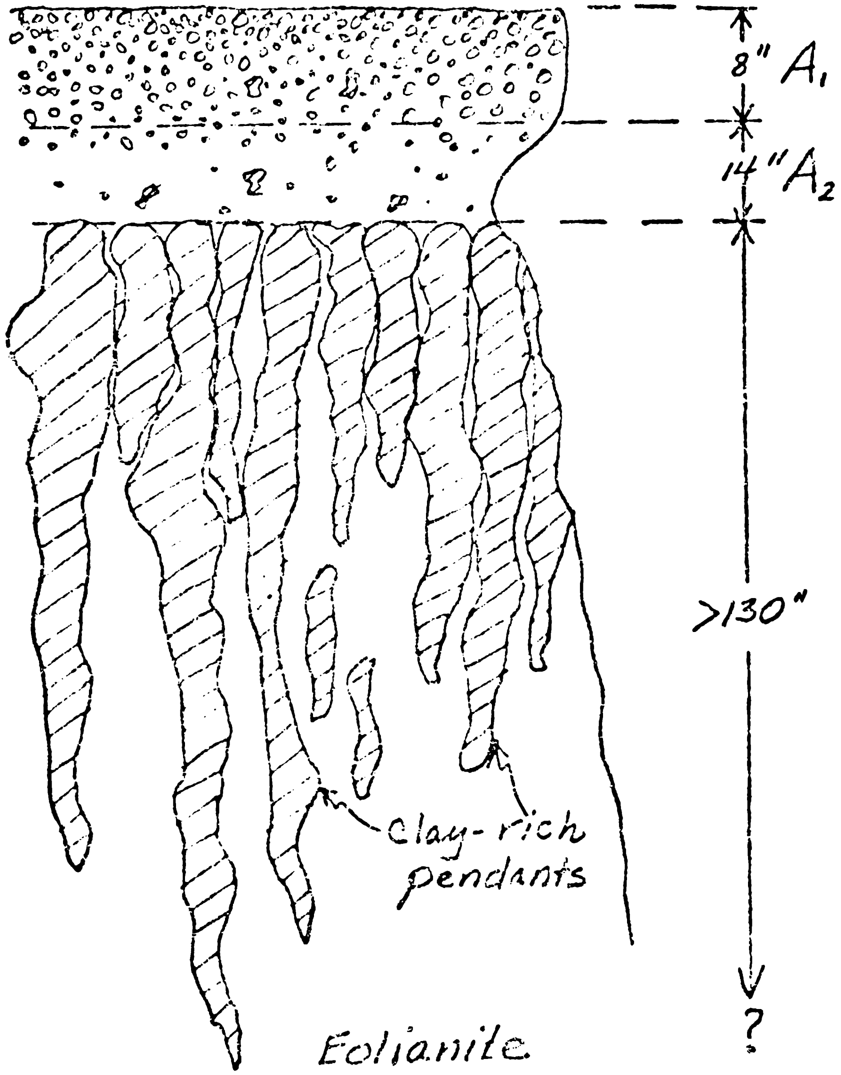


Figure 50. Profile characteristics of the Green Mountain Soil at SMI-162. Note pieces of argillic B horizon material in the A_2 horizon.

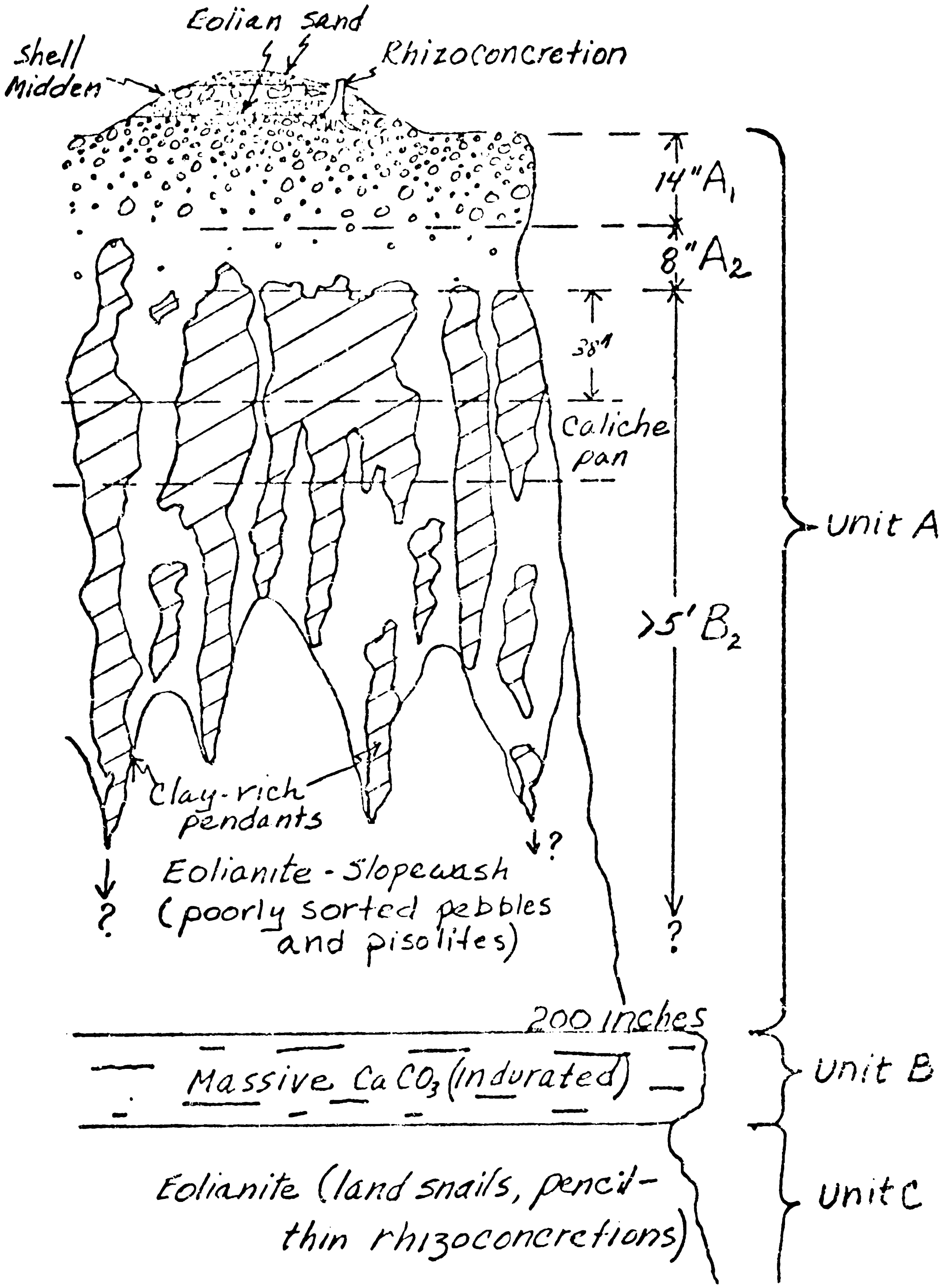


Figure 51. Profile characteristics of the Green Mountain Soil and stratigraphic relationships at SMI-163.

Another significant aspect of the Green Mountain Soil is its distinctive morphology and what it may suggest about past environments. More specifically, What in the environment led to the development of the distinctive profile of the Green Mountain Soil, in particular the ironstone concretions, as compared to other fundamentally different soils on the island formed in similar parent materials? For example, at SMI-85 at Cuyler Harbor the Green Mountain Soil is underlain by a non-pisolitic paleosol that has a dense caliche (petrocalcic) horizon and which also has formed on eolianite parent material (Fig. 49). Why? Was the climate different, or the vegetation, or both? Or does the pisolitic profile of the Green Mountain Soil simply reflect a long time period of pedogenesis whereas the subjacent soil does not? These are fundamental questions that relate to the genesis of the Green Mountain Soil and, because similar soils occur on mainland marine terraces in San Diego and San Luis Obispo County, light shed on these questions would also illuminate aspects of the pedology, geomorphology, paleoecology and geochronology of coastal California.

Particle Size Distribution

Particle size analyses were made on the clay, silt, sand and pisolite fractions of the Green Mountain Soil at localities SMI-151, 152, 85, 163, and 163. Sand, silt and clay analyses were done by the pipet method* and the pisolitic fraction was determined as a percentage weight

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*Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples, Soil Survey Investigations Report No. 1, Soil Conservation Service, U.S.D.A., 1967.

of the whole soil. The results are shown in Figures 52 and 53, respectively.

Particle size analyses show clearly the A_1-A_2 and the A_2-B_2 boundaries in each of the five profiles. The thickness of the A horizon ranges from less than two feet to six feet, whereas the A_2 subhorizon ranges from less than one foot to four feet in thickness. However, at SMI-151 islands and stringers of A_2 extend well down into the B horizon resulting in an extremely irregular A-B boundary in three dimensional space (Plates 18a and 20).

Eluviation of clay from the A_2 into the B horizon is clearly documented by Figure 54. It is the vertical distribution of pisolites that seems perplexing.

Soil pH

Soil pH determinations were run on five Green Mountain Soil profiles at SMI-151, 152, 85, 162 and 163. The samples were taken at six inch depth increments and consisted of the whole soil minus the pisolites. The results are given in Table 22 and show that, except for the 18 to 48 inch depth of SMI-151, all the samples were alkaline in reaction, with SMI-85 in particular being very strongly alkaline. The alkaline character of the Green Mountain concretionary soils on San Miguel contrast sharply with the acid concretionary soils of San Diego (Carter, 1957; Crocker, 1956) though these soils are otherwise similar in their morphology and profile characteristics. The alkalinity of the Green Mountain Soil is probably due to two factors, one being the

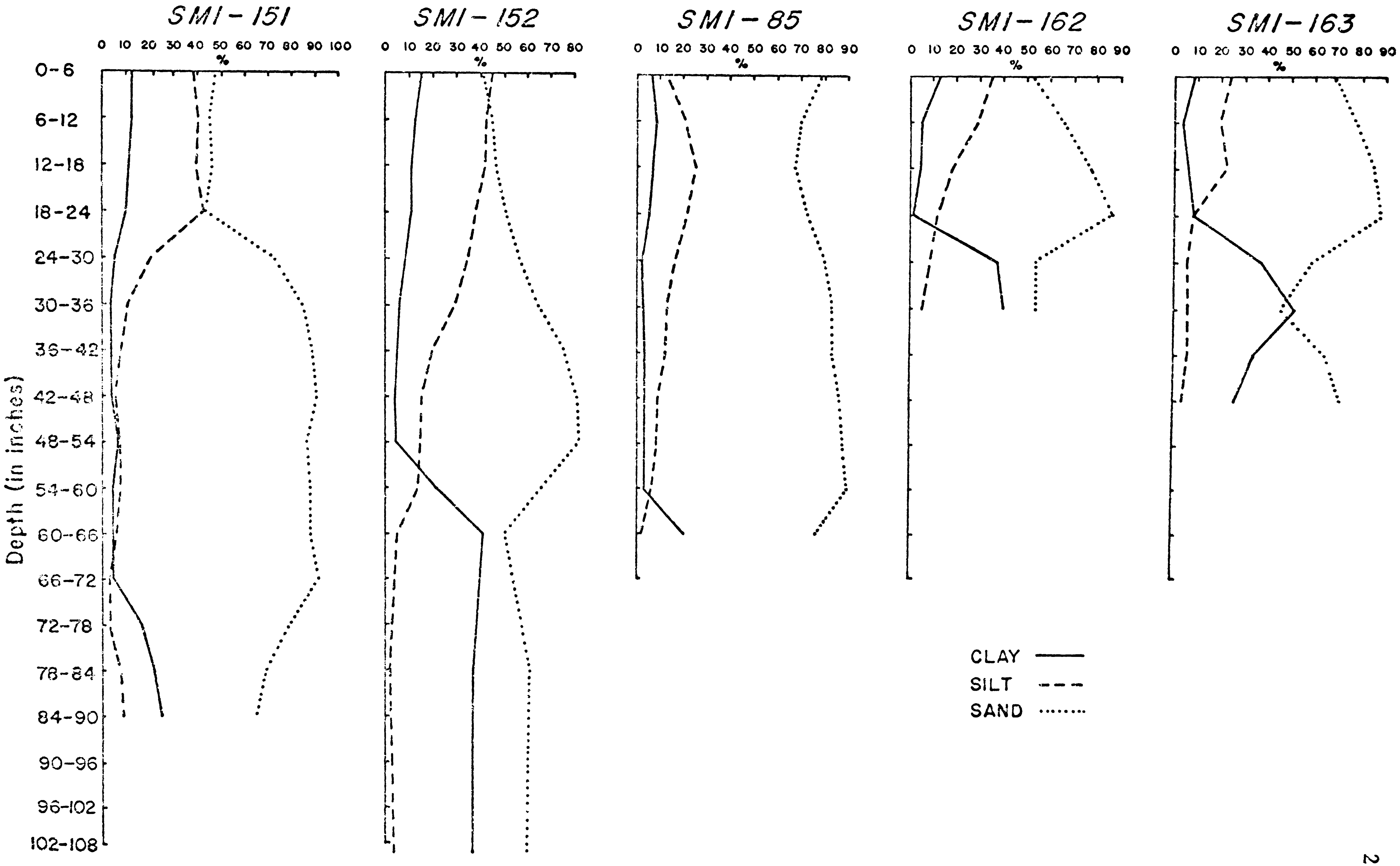

Figure 52. Particle size analysis of five Green Mountain Soil profiles.

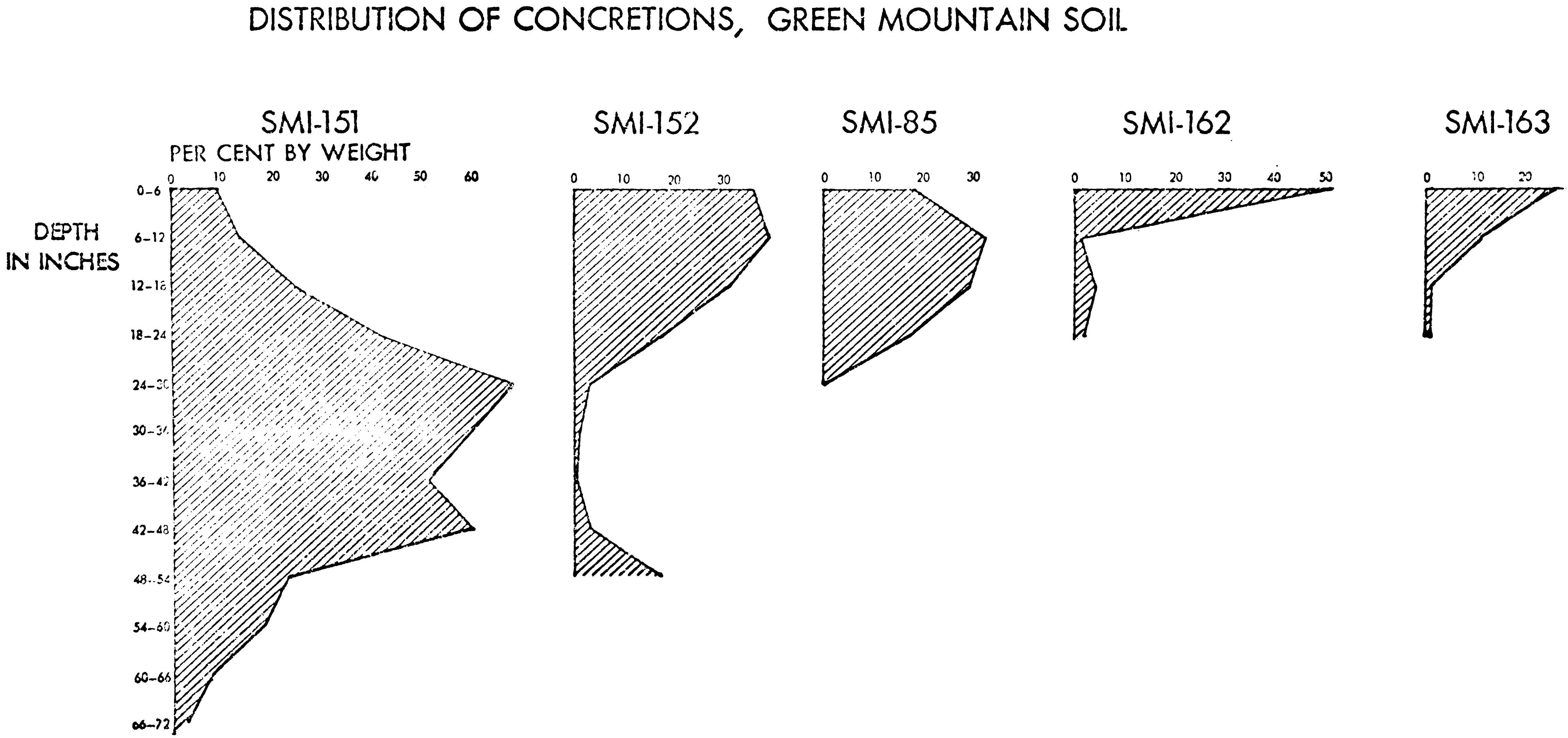

Figure 53. Distribution of pisolites as percent by weight in five Green Mountain Soil profiles, San Miguel Island.

TABLE 22

pH of Five Green Mountain Soil Profiles

Depth	SMI 151	SMI 152	SMI 85	SMI 162	SMI 163
0-6	7.5	7.3	9.3	8.1	8.6
6-12	7.5	7.0	9.3	8.4	8.6
12-18	7.4	7.6	9.2	8.6	8.6
18-24	6.8	7.9	9.2	8.7	8.6
24-30	6.1	8.0	9.3	8.6	8.4
30-36	6.0	8.0	9.2	8.1	8.4
36-42	6.1	7.9	8.6	8.4	8.3
42-48	6.4	7.9	8.5		8.3
48-54	7.2	7.8	9.1		
54-60	7.2	7.7	9.2		
60-66	7.2		9.0		
66-72	7.3				
72-78	7.5				
78-84	7.7				
84-90	7.4				
Parent Material		8.7	8.9		

presence of abundant air-borne sodium and other sea salts carried by the wind. The presence of salt grass (Distichlis) in many places and the fact that sodium chloride commonly coats the vegetation (salty to the taste) demonstrates this fact. Perhaps more important is the fact that blowing calcareous sand has effectively covered all the soils in question except SMI-151. It is noteworthy that the profiles of SMI-151 and 152 reacted considerably less with dilute HCl than did profiles SMI-85, 162 or 163. Moreover, the latter three profiles showed visible white carbonate coatings in the A and B horizons whereas SMI-151 and 152 did not. Both SMI-151 and 152 are located on the northeast slope of Green Mountain in an area that has experienced comparatively little blowing calcareous sand (Plate 2). This fact accounts for the weak effervescence of profile 152, and even weaker reaction of 151. The latter locality has probably had less carbonate contamination from above than any other Green Mountain Soil locality on the island. The fact that SMI-151 is slightly to medium acid at 18 to 48 inches suggests that under natural conditions (under conditions of landscape stability) the Green Mountain Soil would be dominantly acid in reaction.

Ironstone Concretions (Pisolites)

Two working hypotheses for the origin of the ironstone pisolites are proposed. The first is that the pisolites originally form in the upper part of the A horizon as sesquioxide coatings around sand grain nuclei, which then coalesce as more sesquioxide is precipitated around them. The second is that the pisolites originate at the A/B horizon interface as clay-rich pieces of B horizon material which somehow move upwards into the A horizon and become "lateritized." Evidence from certain of the profiles support both hypotheses.

Figures 47 through 53 show that the pisolites are concentrated in the A horizon and, with the exception of SMI-151, occur largely in the upper part of the A horizon. This tends to support the hypothesis that pisolites initially form towards the top of the profile. In addition, profile SMI-85 shows that <u>all</u> the pisolites occur in the upper 30 inches of the soil (most within the top 18 inches): none were observed in the lower part of the A horizon. The importance of profile SMI-85 over the others is reflected in the fact that the Green Mountain Soil at this locality has been buried for many thousands of years, has experienced no stripping or truncation associated with human activities, and thus presumably is pristine.

On the other hand, the four other profiles, unlike SMI-85, have pisolites distributed down to the A/B horizon interface (though there are comparatively few in number at the interface). Interestingly, in SMI-152 the percentage of pisolites gradually falls with depth to less than one per cent at 36-42 inches, but increases as the A/B horizon interface is reached (Figs. 48 and 53). This evidence, plus the pisolite distributions in SMI-151, 162 and 163 support the notion that the pisolites originally were clay-rich pieces of B horizon material. Moreover, visual inspection of pisolites at SMI-151 show a gradual change up through the profile from actual clay-rich chunks of B material to more lateritized, less clayey pisolites as the soil surface is approached.* What is more, definite large pieces of argillic B horizon material were observed in the A_2 horizon of SMI-151, 152 and 162 (see Figs. 47-48, and 50). X-ray analyses of the pisolites in the A horizon, and of the argillic B horizon further suggests that the pisolites originate as chunks of clay-rich material at the A/B horizon interface.

X-Ray Analyses of Pisolites

Figure 54 shows 15 x-ray diffractograms of the clay fraction of pisolites and argillic B horizon material from 0 to 90 inches depth at SMI-151. The diffractograms convey three interesting pieces of information that suggest pisolites do form initially as pieces of argillic B horizon material. First, the 17 angstrom montmorillonite shoulder-peak

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*Unfortunately, due to time constraints no particle size analyses of the pisolites at six-inch depth increments were made, which would have shed light on the matter. Such analyses, however, are planned for future publications that arise from this research.

(at 5° 2θ) begins developing at about 54 inches depth, well within the A_2 horizon (compare with Figs. 47, 52-53). This data supports the visual observations noted above, that the clay content of pisolites diminishes upward from the A/B horizon interface (expected if the pisolites originate as pieces of B material). Secondly, there is a gradual upward decrease in height of the kaolinite and illite peaks from the A/B interface at 72 inches. Thirdly, and most importantly, chlorite (6.5° 2θ) tends to deteriorate (weather) faster than illite (hydrous mica) and this is shown by comparing the peak heights of these two minerals through the 54 to 90 inch level. Both the chlorite and illite peaks are reduced in intensity as the A_2 horizon is reached (going from bottom to top) but the chlorite shows greater deterioration. As the chlorite weathers the products of weathering have an atomic lattice that can accept new ions (Fe^{++} and Al^{+++}). The acception of Fe and Al into the lattice is reflected by peaks that begin forming at about 54 inches in the 6.5° 2θ position. These peaks are believed to be vermiculite which is the new clay mineral formed from the acception of Fe and Al ions into the weathered chlorite lattice.*

The x-ray data thus provide strong evidence that the pisolites originate at the A_2/B horizon interface as pieces of clay-rich material which undergo intense weathering in the A_2 (albic) horizon, and which accept Fe and Al sequioxides higher in the profile where conditions are favorable.

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*This interpretation developed after a lengthy discussion of the data with W. Bradley on July 22, 1971 at the Illinois State Geological Survey. Bradley is an authority on clay mineralogy.

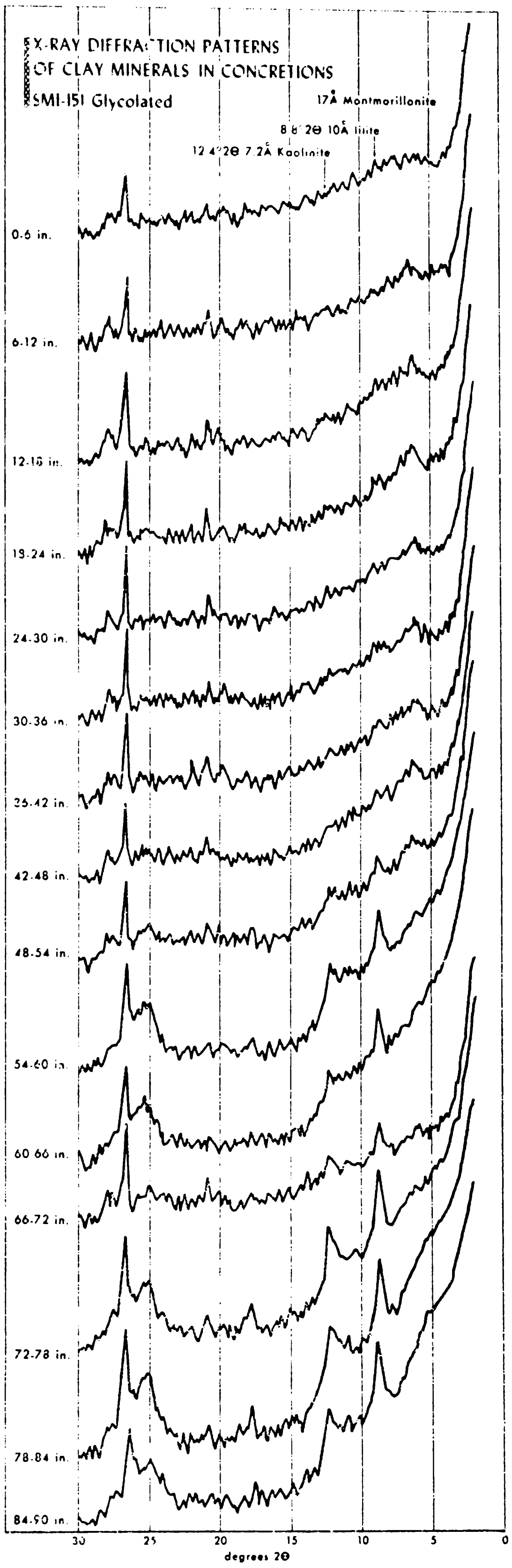

Figure 54. X-ray analysis of the Green Mountain Soil pisolites (SMI-151) at six-inch depth increments.

Figure 55 shows diffractograms of various soils from San Miguel Island. The Green Mountain Soil clay diffractograms are those which show montmorillonite shoulder-peaks in the B horizon at SMI-85, 152, 162 and 163.

It was noted in the field (Plates 32-33, 35) that where the A horizon of the Green Mountain Soil is missing, and the A_2/B_2 interface

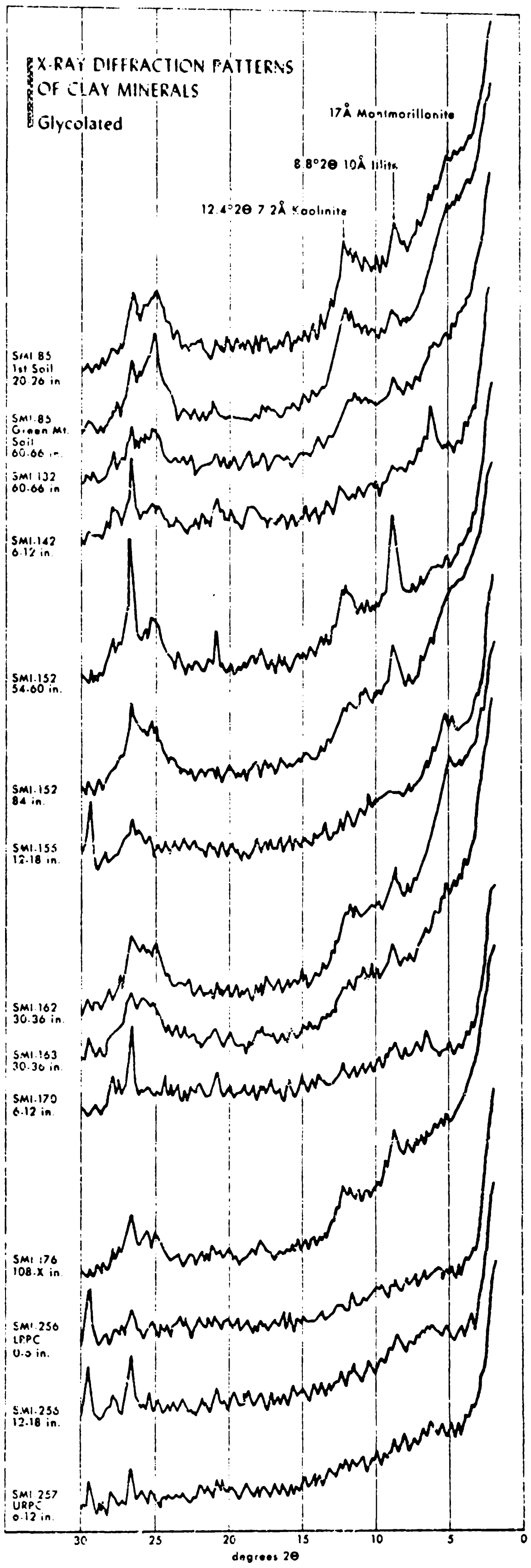

Figure 55. X-ray diffractograms of various soils and paleosols on San Miguel Island.

exposed, the B horizon in plan view is structured into reticulated polygons separated by cracks filled with sandy A_2 horizon material. The origin of the polygonal pattern is probably due to the seasonal shrink-swell characteristic of the montmorillonite-dominated B horizon. During wet periods the argillic horizon expands, whereas during dry months the clay contracts and separates into polygons whose lateral cracks fill with loose sand from the overlying A_2 horizon.

Thin Sections and Photomicrography

Thin sections of over 30 plastic impregnated soil samples provide further insight on pisolite origins. Included were 14 thin sections of pisolites and argillic clay at six inch intervals from 0 to 90 inches at SMI-151. The thin sections show a gradual upward change in color (from brownish to reddish), shape (from subangular peds to spherical pisolites), and concentricity of the sesquioxide envelopes (from little to moderate concentricity). Again, such upward changes fit the hypothesis that the pisolites originate as argillic pieces of B horizon material.

One important outcome of thin-section analysis was the discovery that incipient pisolites occur in modern soils that overlie (and are younger than) the Green Mountain Soil. For example, the Forest Soil (SMI-131-33) is a well developed soil which covers an eolianite unit which buried the Green Mountain Soil near SMI-151. Incipient pisolites occur throughout the upper 60 inches of this modern soil (Plate 88, a and e). Charcoal collected at various levels through the Forest Soil gave a C_{14} date of 14,430 ± 200 radiocarbon years, a mean age for this soil (time zero of pedogenesis presumably was much earlier). The date suggests that considerable time may be required for mature pisolite development.

Incipient to well developed pisolites also occur in the modern soil at SMI-164 on the northeast slope of Green Mountain where they are mixed with pieces of colluvial bedrock from Green Mountain.

Incipient to moderately developed pisolites occur abundantly in the barranca walls and surface soil at SMI-135. This modern surface, however, is a morphostratigraphic equivalent of the Green Mountain Soil at localities 151-152 and the Simonton Soil in Range Pole Canyon (SMI-256, 257) and may reflect considerable age, even though it is also the modern soil.

The presences of incipient pisolites in the modern soil suggests that time, not climatic change or vegetation, may be the most important factor governing the development of pisolites. This is a very important point in any consideration of the paleoecology of the island.

The incipient pisolites in the upper parts of the profiles shown in Plate 88a and b strongly suggest that they may originate there rather than at the A_2/B horizon interface. This, plus the evidence presented earlier, argues solidly that both hypotheses bear further testing.

Chemical Analyses of Pisolites

Full chemical analyses of six pisolitic and one massive phase samples from San Miguel Island, and of one sample from a mainland (Cambria) site were provided by the Kansas Geological Survey. The results are shown in Table 23. The data convey several interesting pieces of information. First, the silicon dioxide (quartz sand) content of all eight samples is high and roughly the same in proportion, ranging between 64 and 69 per cent. Secondly, the aluminum sesquioxide of the eight samples is also proportionately the same, ranging between 11 and 15 per cent. Thirdly, the iron sesquioxide content is also roughly the same, ranging from less than four to about eight per cent. The concretions are thus comprised dominantly of quartz and iron-aluminum sesquioxides. Emery (1950) found that concretions at 8-12 inches in the Carlsbad Soil pisolitic soil in San Diego contained 15 per cent Fe_2O_3.

TABLE 23

Chemical Analyses of Pisolites

	Pisolitic Phase							Massive Phase
K.G.S. No.* Samp. Ident.	70060 SMI-152 0.6"	70061 SMI-152 6-12"	70062 SMI-152 12-18"	70063 SMI-152 18-24"	70064 SMI-152 24-30"	70059 Grab Sample Cambria	SMI Grab Sample	SMI Grab Sample
SiO_2	63.95**	64.16	64.50	64.74	64.73	73.99	69.07	68.33
Al_2O_3	14.98	14.78	14.38	14.28	14.21	11.19	11.41	15.07
Fe_2O_3	5.98	5.49	6.39	5.90	6.24	6.12	8.32	3.49
TiO_2	0.88	1.08	0.85	0.97	0.93	0.72	0.10	0.27
MnO	0.13	0.13	0.13	0.10	0.12	0.03	-	-
CaO	1.69	1.66	1.90	2.21	2.30	0.40	1.34	1.29
MgO	0.50	0.66	0.66	0.68	0.63	0.30	0.25	0.25
K_2O	2.32	2.40	2.40	2.35	2.36	1.00	2.70	2.81
Na_2O	2.20	2.57	2.62	2.55	2.47	1.54	2.25	3.01
SO_3	Trace	Trace	Trace	Trace	Trace	Trace	Trace	0.01
P_2O_5	1.72	1.62	0.67	0.58	0.30	0.14	1.36	1.23
L.O.I. (1000°C)	4.86	5.06	5.38	5.70	6.06	4.73	3.33	3.82
TOTAL	99.21	99.61	99.88	100.06	99.85	100.16	100.03	99.57
Total Samp. Wt. (gms.)	44.7028	58.8266	53.9618	27.5248	17.3513	15.0050	-	-

*Kansas State Geological Survey Sample Number.
**Percent by weight.

The relative compositional consistency of the mainland and island concretions suggests similar genetic processes were involved in the formation of the concretions.

The first five samples in Table 23 were taken at six inch intervals from the Green Mountain Soil at SMI-152. Unfortunately, due to cost constraints chemical analyses could not be made on the complete profile below 30 inches depth. Such analyses, however, are planned in future research and should shed further light on the origins of the sesquioxide concretions. While the precise origins of the concretions are somewhat unclear, if the hypothesis is correct that the pisolites originate at the A/B boundary interface then the most reasonable model is that presented earlier where the atomic lattice of chlorite, upon deterioration in the A_2 horizon, accepts Fe and Al ions. If this model is valid, the key to the process lies in the intense weathering which takes place in the A_2 horizon of the Green Mountain Soil. Although an investigation into the genetic processes of A_2 horizon development is beyond the scope of this study, it is worth noting that the thickness (degree) of A_2 horizon development may be a function of leaching intensity and organic matter production (Smeck, 1969; Range, 1970; Runge and Fehrenbacher, 1972). In this regard, with one exception (SMI-151) there seems to be a relationship between thickness of A_2 horizon development and the number of pisolites as shown by Figures 47-51, 53. This apparent relationship will be more fully explored in future research.

Origin of the Sesquioxides

Since about 20 per cent of the pisolites by weight are comprised of sesquioxides it is instructive to trace the origins of the iron and aluminum. Light was shed on the matter through analysis of the eolianite parent material of the Green Mountain Soil at SMI-152. Analyses were done by the combined use of a Franz magnetic separator and x-ray diffractometer, and by optical methods.* The results show that the iron-bearing minerals ilmenite ($Fe\ TiO_3$), aphrosiderite (a chlorite - $Mg_{1.0}\ Fe^{2}_{3.2}\ Fe^{3}_{0.4}\ [Al_{1.5}\ Si_{2.5}]\ O_{10}\ [OH_8]$, and illite ($K_{1-1.5}Al_4\ [Si_{726.5}Al_{1-1.5}\ O_{20}]\ OH_4$) are present in the eolianite parent material of the Green Mountain Soil at SMI-152.

With regard to aluminum, the most likely source, in addition to aphrosiderite and illite, is albite ($NaAlSi_3O_8$ - $Ab_{90}\ An_{10}$) which is abundant in the eolianite as determined by both x-ray and petrographic analyses.

Paleoecologic Significance of the Green Mountain Soil

When the unusual profile characteristics of the Green Mountain Soil were first noted in the field, especially the laterite-like character of the sesquioxide concretions, it appeared as though the soil reflected a major change in the past environment--presumably a climatic and vegetation change. The similar laterite-like character of the Carlsbad Series soils in San Diego County has been interpreted by Carter (1957) and Pendleton (in Carter, 1957, p. 172) as reflecting great age, and a climate far more humid than the semiarid one which presently exists. Some

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*Methods and procedures are detailed in Appendix D.

soil scientists also have speculated that the pisolitic Carlsbad soil ". . . is a relic feature relating to a considerably more humid past climate" (see Crocker, 1956, p. 247). However, upon assessing the soil-geomorphology and profile characteristics of the acid Carlsbad soils, Crocker (1956) concluded that acid soils in semiarid environments cannot, in themselves, be considered as indicative of climatic change. The present study on the Green Mountain Concretionary Soil plus the paleoecologic evidence tends to support Crocker's conclusions, that no major climatic change need be involved to explain the profile characteristics. The evidence is as follows:

First, the fact that incipient pisolites occur in the upper parts of modern soils on San Miguel Island suggests that given enough time, in the absence of disturbance, the modern soil might eventually develop profile characteristics similar to those displayed by the Green Mountain Concretionary Soil. In other words time may well have been the principal factor involved in the development of the Green Mountain Soil, not a humid, tropical climate. Moreover, nothing in the paleoecologic and soil record gained from this and other studies suggests a major change from a perhumid to semiarid climate in the Pleistocene as others have proposed.

One piece of evidence cited most often for major climatic change is the character of the Willow Creek Flora on Santa Cruz Island (Chaney and Mason, 1930). The presence of fossil Douglas fir, cypress and other more mesic species has been cited by various authors as firm evidence that vegetation (and climate) which now characterizes the Fort Bragg area 440 miles north of the Northern Channel Islands prevailed on the latter during late Pleistocene time.* However, Axelrod (1967) has re-evaluated the fossil evidence and concluded that present temperature conditions at Monterey, some 200 miles north, are more representative, though rainfall at Willow Creek was higher than at Monterey. In this regard it should be noted that the _present_ flora of Santa Cruz Island already has many northerly components, for example _Arbutus Menziesii_, _Vaccinum ovatum_ and _Ribes malvaceum_ as well as various herbs (Axelrod, 1967, p. 296). These are thought to be relicts of the last glacial. Axelrod infers and implies that had the post-Pleistocene Xerothermic Period not greatly affected the forests which grew along the southern California coast during full glacial times the character of the present coastal flora would have a more northerly cast, especially on the Northern Channel Islands which, due to their maritime environment, are more mesic than the opposite mainland (see Figs. 17 and 20). What this suggests is that the present climate may not be too unlike full glacial conditions.

Higher rainfall during full glacial times does not spell major climatic change. Possibly the winter rainy season began earlier in the fall and lasted later in the spring. The vast amount of fossil plant evidence from California reviewed by Axelrod (1967) argues strongly that a climate basically Mediterranean in character with cool moist winters

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*Redwood logs were reportedly found ". . . buried 80 feet deep on the old Abbey farm where the Southern Pacific R.R. is making excavations for placing piers" (L.A. _Times_, June 18, 1895, p. 11). This report has never been verified.

and warm dry summers prevailed along the southern and central California coast during all of middle and late Pleistocene time. In addition, a major change in temperature on the Channel Islands would require a notable change in the surface temperature of the California Current. Evidence for such change is at present lacking. The evidence suggests that the temperature and precipitation regime which presently occurs in central coastal California was shifted south during full glacial times. If such a slight change occurred today it would hardly impress people now living along the coast. Certainly a slight latitudinal shift in climate in coastal California stands in stark contrast to the dramatic shifts that most of the rest of North America experienced. Again, no evidence suggests a humid climate like that proposed to explain the lateritic character of the Carlsbad soils in San Diego County, nor the Green Mountain Soil of San Miguel or the Arnold sandy loam in San Luis Obispo County.

It is worth noting that as mentioned in Section 16 of Chapter 5, the three known areas in coastal California where soils contain pisolitic sesquioxide concretions, the Channel Islands, San Diego County and Cambria, also carry (or did carry) as part of their vegetative cover a closed-cone pine forest. In this regard it has been shown that certain species, notably pines, give rise to highly acid litter which intensifies leaching and contributes to A_2 horizon development and the mobilization and translocation of iron and aluminum sesquioxides (Bloomfield, 1953a, 1953b, 1954a, 1954b, 1954c). In addition to time, the pisolitic soil of Cambria and San Diego, like the Green Mountain Soil of San

Miguel Island, may also owe their distinctive A_2 horizons and pisolitic character to coniferous vegetation and sandy parent material. The rhizoconcretions at Fossil Forest I (SMI-131-33) mark former arboreal or subarboreal forms that were clearly growing as a stand in the Green Mountain Soil (Plate 18e); some of these forms may have been closed-cone pine, such as Monterey pine which formerly grew on the island (Plate 87). Closed-cone pine stands occur extensively and tend to be concentrated today on the pisolitic Arnold sandy loam and Carlsbad loamy fine sand in San Luis Obispo and San Diego Counties. Further support for this idea is found in the fact that there are great expanses of dunes in southern California, for example the El Segundo-Redondo dunes, where no pisolitic soil occurs (Merriam, 1949), and where closed-cone pine stands are absent. A worthwhile study would be to map in detail the mainland occurrences of pisolitic soils and closed-cone pine stands, and see if there exist areas where the pines occur on sand but without pisolitic soil development.

21. Other Soils

Besides the Gangplank and Green Mountain Soils, the only other soils of significance on the island are the sand dune soils. These soils are most conspicuous and numerous along Simonton Cove and at the west end of the island. The sand dune soils were not studied as intensively as the Gangplank and Green Mountain Soils because they contain less decipherable environmental information and are less important areally on the landscape. However, they have contributed significantly to the geochronologic framework established for the island (see Table 15 in Chapter

2, and discussion in Chapter 5). For example, they have yielded charcoal for C-14 dating and midden material for archaeological control and have preserved rhizoconcretions that have been dated. However, a search for pollen grains to aid in paleoecological reconstructions proved fruitless. Beyond this, no further analyses were made since information that sand dune soils yield is disproportionately small in comparison to the required investment of research time and money.

22. Caliche

The origin and character of caliche on San Miguel, and on the other Channel Islands, has already been treated by the writer in an earlier study (Johnson, 1967). It seems appropriate, however, that because caliche is such a dominant landscape element on San Miguel a brief review of this earlier study would be worthwhile. The following is similar to that already published (Johnson, 1967, pp. 154-155) but with modifications.

Caliche is found in an almost endless profusion and variety of forms on San Miguel which may be grouped into two main types--soil caliche, and eolianite caliche. The eolianite caliche may be further divided into surface case-hardened caliche and rhizoconcretions, and the rhizoconcretions into hollow root sheaths and filled root, trunk, and stem casts. Each of these types is formed by somewhat different genetic processes.

Soil Caliche

In areas with subhumid to arid climates, particularly where distinctly seasonal rainfall occurs in amounts less than about 30 inches, calcium carbonate, if present, is leached from the topsoil and deposited in the subsoil or substrate as caliche. In areas of high rainfall, as in the eastern United States, carbonates are, of course, leached out of the soil and into drainage systems. The mechanisms involved in rendering calcium carbonate soluble and leading subsequently to precipitation are well known. Rain picks up CO_2 in falling, thus forming small amounts of carbonic acid. Much more carbonic acid is formed when rain water joins with carbon dioxide given off by plant decay in the soil. Calcium carbonate present at or near the soil surface is then taken into solution as a bicarbonate $[CaCO_3 + H_2O + CO_2 \longrightarrow Ca(HCO_3)_2]$ by the carbonic acid, and is carried downward; and, upon evaporation or loss of carbon dioxide, is subsequently precipitated at the general level to which rain water may penetrate. When the soil parent material is calcareous eolianite, as on the Channel Islands, unusually thick caliche accumulations may result.

Eolianite Caliche

In certain areas on the northwest coast of San Clemente Island and the northern part of San Miguel Island, initial observation suggests that caliche formed directly upon the undulating surfaces of former dunes. Closer inspection, however, reveals that the caliche horizon represents a relict soil hardpan which became case-hardened after the surface soil was stripped away during an unstable episode. Winter rain and summer fog aided case-hardening through solution and redeposition. After the initiation of such case-hardened topography, each succeeding rainfall or moist period served to further the lithification of the former dune surfaces. Sufficient time elapsed to allow thorough case-hardening of the eolianite surfaces before they were buried by new dunes. Such relict case-hardened surfaces now appear as caliche bands interbedded with calcareous eolianite (as on Harris Point) and serve to outline the former dune topography. Caliche case-hardening locally is still active today on San Miguel Island.

Fossil forests, which presently are being exhumed by wind erosion, are believed to have originated from two dissimilar processes. Both the hollow and solid caliche rhizoconcretions are referred to as "root casts." Though root casts are present, the hollow forms are not really casts at all, but are more correctly called "root sheaths." Root sheaths apparently form in one or more of five biochemical ways, dependent upon (1) the presence of organic acids exuded by living plant roots; (2) symbiotic relations between roots and certain soil bacteria; (3) symbiotic relations between roots and certain fungi; (4) the presence of some blue-green soil algae which have calcium carbonate-precipitating bacteria housed in their slime sheaths; (5) calcium exclusion properties of some plants which promote the precipitation of calcium carbonate outside the root. Although the possibility exists that any one of a combination of the above processes may result in the formation of caliche root sheaths, recent conversations with several plant physiologists lead me to the tentative conclusion that the first is probably responsible.

As the roots of some plants penetrate the soil, or eolianite, they exude organic acids. Moreover, soil moisture is normally drawn by capillarity toward the roots in response to evapo-transpiration from the leaves. When exuded root acids come into contact with soil water adjacent to roots, ionic exchange takes place, carbonic acid is formed, the carbonate fraction of eolianite goes into solution, and, with subsequent evaporation or loss of carbon dioxide caliche is precipitated. Given sufficient time, caliche sheaths can form even around the living roots of some plants. On San Nicolas Island, the roots of some still living Bur-weed plants (Franseria chamissonis subsp. bipinnatisecta), (identified by Ralph N. Philbrick of the Santa Barbara Botanical Gardens) were in some instances found to exhibit caliche sheaths in various stages of induration. But the variety of sizes of root sheaths in the fossil forests certainly indicates many other as yet undetermined species were involved. A complicating factor in the study of root sheath origins is the numerous living juvenile plant roots growing in obviously ancient root sheaths. Apparently the sheaths, many of which still contain recognizable organic matter, provide an easy and nutritious avenue of penetration by modern roots into eolianite or caliche.

On the other hand, root and trunk casts, as opposed to root sheaths, are apparently actual casts in the geologic sense and are formed differently. One could conceivably call them caliche pseudomorphs after trunks and roots. Of the comparatively few examples of trunk casts found on the islands, the most unusual was a hugh caliche log some 2 1/2 feet in diameter and about 30 feet long near SMI-47. Some of the caliche forms are believed to be replicated stumps of ancient trees. Most of the structures, however, that are casts per se are root casts. The mode of genesis is believed to be slow caliche-filling of molds left in incipient or weakly cemented eolianite by roots, trunks, and stems of vegetation long since decayed. This is probably the same process which permits the hollow interiors of some root sheaths to become filled with concentric bands of almost pure calcium carbonate. Blowing calcareous sand apparently overwhelmed and buried the old trees, either in upright or fallen positions; this sand later became slightly cemented to form eolianite.

Charcoalized Rhizoconcretions

Many of the rhizoconcretions are partially charcoalized which shows that fire periodically swept the vegetation. Four charcoalized rhizoconcretions have been radiocarbon dated at 17,370 ± 290 ry, 17,730 ± 300 ry, 20,130 ± 215 ry, and >40,000 ry (Table 15, p. 83). The significance of these dates in the development of a geochronologic framework is discussed in Chapter 5.

Paleoecologic Significance of Caliche and Rhizoconcretions

The paleoecologic significance of caliche on San Miguel Island is fourfold. First, the presence of abundant rhizoconcretions shows that sizeable stands subarboreal or arboreal vegetation formerly grew on the island. Secondly, the fact that so many of the rhizoconcretions are charcoalized shows that fire has been an important landscape element throughout late Pleistocene time. Third, the charcoalized rhizoconcretions are datable by the C-14 method and have contributed to a geochronologic framework for late Pleistocene soils and sediments on the island. And fourth, the presence of abundant caliche in nearly all the soils on the island, buried and modern, shows that precipitation in the past has not been enough to through-leach the carbonates such as occurs in perhumid climates. Thus the climate is inferred to have been always subhumid or semiarid, although some variations in rainfall undoubtedly occurred from time to time.

CHAPTER VII

LATE QUATERNARY LANDSCAPE MODIFICATIONS

It has been intimated in several earlier sections of this thesis that profound and irreversible landscape changes have occurred on San Miguel Island during late Pleistocene and Holocene times. The surface of San Miguel epitomizes wind and water erosion induced by the combined effects of climate (drought and wind), fire, and biota (elephant and man). Fire, climate and elephant, however, formed an erosional triumvirate long before man appeared on the scene as will be shown.

The purpose of this chapter is to pull together disparate pieces of evidence to paint a picture of late Pleistocene-to-present landscape stripping and its present manifestation in the island landscape. Fire and climate are first considered as both have played a definite role in insular landscape evolution. Elephant ecology is next reviewed in order to show how fluctuating numbers of pygmy elephants on San Miguel likely affected vegetation and surface stripping during times of drought. Then follows a discussion on the possible contemporaneity of elephant and man, as it seems clear that aboriginal man replaced the elephant in late Quaternary time as a major modifier of the landscape. The next section documents the presence of aboriginal man on San Miguel during practically all of post-Pleistocene time and shows how various aspects of his activities are manifested in the landscape. The section which follows deals with the historic period, a time when great episodes of ground stripping occurred.

Also included in this chapter is a discussion of the description, origin and landscape expression of landslides and slumping about Cuyler Harbor. The last section deals with stream erosion on San Miguel Island. Finally, this chapter in particular brings to the reader the full range of environmental events and episodes which have played interrelated roles in shaping the landscape of San Miguel Island.

23. Fire and Climate

It was demonstrated in Chapters 2, 5 and 6 that fire has been a persistent major force in the ecology of the Northern Channel Islands during late Quaternary Time. Abundant charcoal occurs in all the paleosols on the island which are of widely varying ages. The Pleistocene fires which produced the charcoal probably occurred under the same conditions that prevail now when natural chaparral fires occur, during summer droughts when lightning centers are present. There is no reason to suppose that the climatic controls which govern the present Mediterranean type of climate were not operative in earlier times (e.g., the Hawaiian High, the Aleutian low, and the cool upwelled waters of the California Current). The occurrence of chaparral elements in Pleistocene floras in California (Axelrod, 1967, with references) provides further evidence that a Mediterranean climate characterized the region. We may thus conclude that droughts, wind, and periodic fires effected the insular landscapes in the Pleistocene, and differed from the present only in degree rather than kind.

24. Pygmy Elephant Ecology

General Review

If elephants are set into an insular environmental context of droughts, high winds, and periodic fires, what resulting landscape modifications might we expect to have occurred on San Miguel and the other northern islands? This is an important question because if fire or drought (or both) reduced food and water supplies, elephants probably had profound effects on the insular landscape. While we have no direct information on the effect of too many elephants on the Channel Islands we know what happened on San Miguel when the carrying capacity for sheep was surpassed in the 19th century. The result was complete landscape stripping, excessive erosion, and wholesale deaths of sheep and other animals (these episodes are documented in detail later in this chapter). Now, sheep are voracious eaters but no land animal comes close to matching elephants in the amount of food consumed per diem. They are vegetation consumers and modifiers of the first order, and when their numbers surpass the carrying capacity of an area drastic tree and shrub destruction occurs (Napier Bax and Sheldrick, 1963; Buechner and Dawkins, 1961; Glover, 1963). Several of the African national parks which effectively function as islands have suffered catastrophic vegetation destruction due to the combined effects of too many elephants, drought conditions, and fire (Frame and Goddard, 1972). Full grown African elephants eat from 500 to 600-plus pounds of plant food daily and they normally damage more vegetation than they eat (Glover, 1963).

In recent years, for example, the numbers of elephant at Tsavo National Park in Kenya have exceeded the carrying capacity of the park. The result is that during droughts wholesale deaths of elephant and great destruction of the woody vegetation occurs. Over the years the water holes become

> . . . surrounded by nearly treeless, desert-like wastes up to 10 to 20 miles in radius. Every day the elephants were compelled to trek across these barrens in order to obtain water before returning to the ever more distant feeding grounds (Frame and Goddard, 1972).

On this matter W. Leuthold recently wrote:

> The last two years have been exceptionally dry here and the resultant dearth of green vegetation has caused the death of probably several thousand elephants within the Tsavo Park. All available evidence points to malnutrition as being the actual cause of death.*

Before the creation of the Tsavo Park in 1948, whenever droughts occurred elephant migrated out of the area. This permitted the vegetation to recover before the elephants returned. Now, however, due to creation of artificial water holes and frustration of the migratory habit, as well as poaching outside the park, elephants no longer migrate but stay permanently at Tsavo. When droughts occur the elephant simply begin dying when their food is consumed. Thus with respect to the elephants the park now functions as an <u>island</u> in a semiarid climate characterized by periodic droughts like California (rainfall at Tsavo is 10 to 20 inches per year, with drought years as low as 2 1/2 inches). The Tsavo elephant are at the mercy of their "insular" environment just as the Tsavo environment is at the mercy of the elephant.

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*Letter of March 22, 1972. Mr. Leuthold is Research Zoologist, Tsavo Research Project, Tsavo National Park (East), Voi, Kenya.

We are now witnessing at Tsavo what may well have occurred repeatedly on San Miguel and the other northern islands (Santarosae) during late Quaternary time. That is, wholesale destruction of vegetation and landscape stripping. While we have no window to the past it takes little imagination to trace what must have been a recurrent history on the Northern Channel Islands of too many elephants, too little food due to periodic drought and fires, and subsequent landscape stripping. For example, what would have been the ecological effects of too many elephants on San Miguel during the major dry cycle which began about 1570 and ended about 1595? (Fig. 15) or in the dry cycle which followed, beginning about 1623? Although we will never be able to document their full effects, elephants must have been a most important factor in Quaternary landscape modification. How those modifications are expressed in the present landscape is unknown, but possibly elephants (along with fire) were a disturbance factor in the dune unstabilization-reemplacement episodes described in Chapter 5.

Was Man Contemporaneous With Elephant?

It is not known when man first arrived on San Miguel Island except that it was prior to 8,000 years ago. Claims by Orr (1968) and others (Carter, 1956) that man was on the islands as early as 30,000 years ago are not widely accepted by critics (Meighan, 1965)*. However, evidence

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*It is no secret that Orr's work has been widely criticized privately and in print by archaeologists and geologists. The primary reason is due to the intolerable circumstance wherein highly important claims have been made by one person (Orr) on Santa Rosa in the almost total absence of opportunities for critics to view the field relations for themselves at their own leisure, without proctoring by the principal investigator. The level of criticism will probably not subside, nor will Orr's work be uncritically accepted by the scientific community, until free access to the island is available so people can see things for themselves.

that man has been on the islands for at least 10,000 years is supported by human bones (Arlington Springs Man) from Santa Rosa Island that indicate comparable antiquity (Orr, 1962a, 1962b, 1964, 1968; Oakley, 1963). The early shell midden dates (Table 15) from San Miguel also supports a terminal Pleistocene or early Holocene age for man on the islands. It is here tentatively assumed that humans arrived on Santarosae sometime during the period 8,000 to 20,000 years ago.

What immediate effect man had on the landscape upon his arrival is not known, but possibly it was the extinction of the pygmy elephant. Orr has long made such a claim and evidence on San Miguel Island suggests that elephant persisted into either terminal Pleistocene or early Holocene times. Some of the elephant remains on San Miguel occur in the upper part of the modern soil, and the only radiocarbon date on elephant (bone collagen) gave an age of 5,070± 105 radiocarbon years (Table 15). However the age of the bone seems too recent in light of the documented presence of man on San Miguel at least 8,000 years ago. That is, it does not seem reasonable that man and the pygmy elephants co-existed for several thousands of years (unless the elephants were maintained by man). Since no natural predators were present on the islands the elephant, like the dodo bird, probably had no fear of any animal, including man when he first arrived. Under such conditions the elephant likely would have been extincted in a very short time.

There is suggestive (not conclusive) evidence that man and pygmy elephant were contemporaneous for a short time on San Miguel Island (Plate 84). Field work during and since 1966 turned up abundant pygmy elephant remains, mainly on the northwest coast of the island. The remains were found to occur in some of the oldest as well as very recent Quaternary colluvium and in the modern soil (Plates 84-86). During 1967 sizable concentrations of elephant bones were found around the spring complex at Running Springs. Thick banks and cliffs of tufa exposed downslope from the springs indicate spring activity over a long period of time; elephant remains, land snails and plant remains of Monterey pine and Ribes occur in the tufa. Elephant remains are also found in the colluvium in almost every gully west of Running Springs (Bone Gully, Tusk Wash). On the surface of the tufa and colluvium, there occurs patches of a badly truncated soil in which burned and calcined mammoth bones occur (Plate 84). For example at SMI-182 a partial skeleton of a pygmy mammoth was found in a semi-disarticulated condition in which many of the bones were burned or calcined (Plate 84a-b). The skeleton was in situ within the A horizon of the truncated soil. Canalino shell midden occurred several inches above the elephant remains but is probably much younger than the elephant remains. It is presumed that the truncated soil was formerly much more extensive over the area and is the side-slope equivalent of the extremely truncated soil on Caliche Flats (Plate 1f). Truncation of this extensive, essentially modern soil may have in part occurred during the 1850-1950 sheep ranching period. However, much truncation may have occurred in prehistoric times as shown by extensive patches of burned caliche on Caliche Flats, suggesting that the topsoil was not present when the burning occurred (probably aboriginal campfires). It is, however, also possible that Indians dug fire pits in the pre-existent A horizon down to the depth of caliche, allowing the latter to be burned in patches prior to wind stripping of the A horizon. If this is the case, then stripping on Caliche Flats was almost certainly due to over-grazing in historic times.

Proboscidean remains also occur in the A horizon of the soil developed on the colluvium along the footslopes of Eagles Nest Cliffs in western Simonton Cove (SMI-248). It was this elephant that gave the unexpectedly young collagen date of 5,000 plus radiocarbon years mentioned above (see Table 15). Thus there are two instances of pygmy elephant remains contained <u>in situ</u> in the A horizon of the modern soil on San Miguel Island , which suggests a relatively young age for both elephants.

Finally, a calcined pygmy mammoth tusk occurs at SMI-150, and evidence of considerable burning, heat oxidation, and heat shattered rock is widespread at many places in the immediate vicinity of Running Springs. Taken together this evidence is remarkably like that which Orr has described on Santa Rosa Island (see Plate 84). However, until detailed archaeological excavations are carried out all we may say is that the evidence tantalizingly suggests, but does not prove, late Quaternary man-mammoth contemporaneity on San Miguel Island.

Extinction of the Pygmy Mammoths

With reference to the above, the two most obvious factors that may have led to the extinction of the pygmy elephants on the Northern Channel Islands are: (1) disappearance of food and water supplies of the elephant due to a prolonged drought, perhaps aided by fire. Extinction in this manner would seem to be feasible if the drought and fires followed a prolonged wet cycle during which elephant numbers far exceeded the carrying capacity that a subsequent drought period could sustain. And (2) the late Quaternary appearance of the first insular elephant predator, man.

Interestingly, one line of evidence suggests that drought and fire perhaps did not play a role in the extinction of the elephants. That is the fact that the elephant were pygmy, had been on the islands long enough to become reduced in size, and so must have suffered through innumerable droughts and fire episodes for many millenia prior to extinction. After becoming "adapted" to a droughty insular environment did the elephant experience a super-drought that they could not withstand? It is noteworthy that at Tsavo Park during droughts when thousands of elephant die thousands also survive. On the other hand the only new element in the insular environment, one which arrives abruptly and has profoundly altered the faunal balance on most other islands of the world, was cultural man.

25. Man-Caused Modifications of the Landscape

Aboriginal Period

For thousands of years following the extinction of the pygmy mammoth man lived on the island and left evidence of his early tenure in the form of ancient kitchen middens, occasional abalone shells in paleosols, and abundant charcoal. If we assume that human occupance of the island has been at least intermittent for the last 8,000 years then man must have had a noticeable, if not at times profound, effect on the environment. Kitchen middens, many of them fire darkened, cover extensive portions of San Miguel's northeastern and northwestern coasts, indicating the former use of some type of fuel, probably wood. Doubtlessly some of the fuel was driftwood (drift redwood was reportedly used as grave partitions--Schumacher, 1875) but one suspects that a dependable indigenous source was also used.

Historical Period

Geologic and historic evidence suggests that in the relatively recent past the vegetative pattern of San Miguel was quite different from the present pattern. It is fairly certain that the former community had plentiful arborescent representatives. As mentioned, a number of areas of the island are characterized by calcium carbonate replicas of roots and trunks of pre-existent vegetation (rhizoconcretions) killed by encroaching dunes. Earlier writers believed this former vegetation to be extensive and composed predominantly of one or more of three types: tree mallow, toyon, and lemonadeberry, a type of sumac.

Greene (1887) believed some of these "casts" to be of tree mallow (_Lavatera assurgentiflora_). Several of these "casts" he found to be nearly a foot in diameter and associated with still living specimens on the land-tied island at Point Bennett. Moreover, he found 30 small trees growing in an "open grassy valley" also near the western end of the island. Dall (1874), while visiting the island in 1874, noted a small grove of "malva-trees" near the middens at Harris Point, although it is possible he really meant Point Bennett. Greene also observed several stunted toyons or christmasberry (_Heteromeles arbutifolia_) along with lemonadeberry (Rhus integrifolia), in a sheltered spot at the eastern end of the island. He believed, as I do, that all the higher middle portions, especially on the north side once were covered with Rhus ". . . in a low spreading form, such as it is wont to take on when growing in exposed situations along the mainland coast." Furthermore, he found wood good enough for fuel consisting of gnarled Rhus branches 30 feet long. During the field season 1964-1969 the writer found Rhus rootwood* in many places on the island lying in some cases on dunes, in others on bare rocks. There seems to be a concentration of this "fossil" wood along the northwest coast, especially the grassy areas above Running Springs, along the cliffs facing Bone Bight, and on the post-glacial dunes in Simonton Cove. Cockerell in 1938 also found Rhus wood in such abundance that "the wood is even now used for fuel" (Cockerell, 1938a). Hoffman (in Cockerell, 1938a) is said to have found one live Rhus shrub on an ocean bluff in 1930. Cockerell (1938a) found several specimens on Prince Island eight years later. He also believed that Rhus composed the pre-existent vegetation now represented by the rhizoconcretions. Dunkle (1939) while visiting San Miguel with the Los Angeles Museum Biological Survey, contended that:

> Extensive groves of large shrubs and small trees have been exterminated, as is evidenced by large numbers of dead trunks, branches and root crowns still existing in several areas despite the fact that these have been utilized for many years as fuel.

Rhus is presently common about the mouth of Willow Canyon and occurs sparingly on some of the north-facing ocean bluffs. Rogers (1929) stated

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*Identified by R. Koeppen, Forest Products Laboratory, Madison, Wisconsin. One piece, at SMI-121, was 25 feet long.

that as of 1929 there were still people living who recalled lush vegetation covering San Miguel. Such impressions, however, may be misleading and more reflective of season rather than true character of the vegetation. For example, if one visits the island during the spring, one is impressed with verdancy, with lush knee-high grass, shrubs and flowers, whereas fall presents an opposite picture of brown dessication. Also important is whether a given visit occurred during a wet or dry trend or year. If a summer visit is made during a low-rainfall year of a dry cycle the vegetation probably would look fairly desolate.

There is evidence which suggests that destruction of the dominant vegetation was initiated during the drought years which accompanied the dry cycle of 1856-1864 especially during 1863-1864. Prior to 1863 San Miguel apparently had a somewhat more luxuriant ground cover. Before this date there is a notable absence of pessimistic statements about blowing sand and barrenness so frequently alluded to by subsequent writers. Alden (1852) in a terse but optimistic description of Cuyler Harbor made no mention of erosion, blowing sand, or lack of vegetation. Six years later Davidson (1858) described San Miguel as being covered with grass and bushes; the same year Greenwell (1858) made a prolonged visit to the island as surveyor for the Coast Survey and made no allusion to extensive erosion, widespread sand dunes, or lack of vegetation in his reports to the Superintendent, although he did mention several times that the island was destitute entirely of wood* (Greenwell, 1858a, 1858b,

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*The use of the word "wood" in the context of the 19th century probably meant lack of timber or trees usable for fire wood. In this sense, whether shrubs like _Rhus_ or _Heteromeles_ were considered as 'wood' is not known.

1858c). Greenwell's original field notes (Greenwell, 1858d)* contain only four passages alluding to the character of ground cover at specific localities on San Miguel. San Miguel Hill he described as being "covered with low sage bushes and cactus," whereas now it is characterized primarily by bare, wind-stripped ground, a little grass and an occasional shrub. At Black Point (Map 3) between Voy and Greenwell Canyons, he found "dark looking bushes," where presently no bushes exist. Devil's Knoll on Harris Point he described as being "covered with low black sage bushes and cactus," where presently no bushes exist.** His only allusion to uncovered ground was at Big Dune (Brockway) on Caliche Flats which he described as ". . . a strip of white sand drift," as it essentially is today, although now partly stabilized by a few herbaceous plants. Besides the brief descriptions of Alden and Davidson, to my knowledge these by Greenwell are the only pre-1863 vegetation descriptions of San Miguel that are available.

If the severe drought of 1863-1864 did not initiate the erosive conditions invariably referred to by subsequent writers, it must certainly have been a significant contributing factor. It was during this drought that Nidever lost 83 per cent of his sheep, 90 per cent of his cattle, and 94 per cent of his horses, over 5,200 plus animals (Ellison, 1937). The animals perished mainly due to lack of food, which means that they must have consumed every edible thing on the island. Such a stripping

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*Courtesy National Archives.

**Cactus conceivably may be sparingly present on the precipitous, inaccessible north face of Devil's Knoll beyond the reach of sheep, but the main part of the Knoll has no vegetation like that described by Greenwell.

episode in a persistently windy environment like San Miguel would have unstabilized the dunes, the eolianites, the soil, indeed the whole surface of the island. Nidever's misfortune may or may not be the origin of a description given by unidentified sources in Roger's book (1929) who recalled lush vegetation that once covered the island. It was described how this pasturage encouraged sheep grazing which thrived for a while but then several drought seasons were experienced which reduced the growth. This forced the sheep to strip the shrubs and trees of first their lower branches, then the bark and finally "the poor beasts even pawed into the earth and consumed the roots." Afterwards the entire island was said to be devoid of trees and shrubs. Interestingly, an almost identical account on San Nicolas Island in reference to the drought of 1870 was given to Phillips (1927) by Mrs. Jane Kimberly, wife of an early resident of that island. Phillips writes that after Kimberly arrived on San Nicolas (ca. 1857-58) he stocked the island

> . . . with sheep which increased so rapidly that soon he had a flock of 15,000, and his income was $10,000 a year. Wool was very high, and he rode the top wave until the dry year of 1864 when many sheep died.
>
> Another dry season--'69 or '70--turned San Nicolas into a desert and drove Captain Kimberley out of the sheep business with a heavy loss. In those days the island was covered with wild carrot and other vegetation. In their frantic efforts to get moisture [and food] the sheep dug two and three feet into the soil after the roots.
>
> Strong winds blew the sand completely over the island, burying the seeds so deeply, as well as the remaining roots, that everything was killed. And a waste of blowing sand it remains today.

The similarities of this description to that given later in Roger's (1929) book suggests that Roger's source was perhaps referring to San Nicolas rather than San Miguel, or at least drew inspiration from the earlier writings of Phillips. Regardless, during the years 1863-1864 and 1870 both islands experienced essentially parallel histories of drought, overgrazing and consequent profound vegetation and soil stripping.

After the great droughts of 1863-1864 and 1870 Stehman Forney of the Coast Survey wrote a letter to his superior on October 31, 1871, stating that San Miguel ". . . is entirely destitute of wood, not a tree upon it . . . is covered with coarse grasses . . . being destitute or under brush of any kind" (courtesy National Archives). Forney arrived at San Miguel on April 12 and so had seven months during spring, summer and fall to gain his impressions. In 1874 Dall commented with disdain on the barren wastes, drifting blowing sand and the blighted condition of the vegetation (Dall, 1874). Dall wrote:

> Near the shell heaps is a small grove of malva-trees, whose green leaves & penciled blossoms refresh the eyes. There are no young trees, however, as the omnipresent sheep crop every green thing within their reach close to the ground.

Dall did not indicate the season or year of his visit, but it was after the onset of the dry cycle of 1870-1883, probably in 1873. During May of 1875 Schumacher visited San Miguel and disparagingly referred to it as a "barren lump of sand" and described the sheep as being in a starved condition (Schumacher, 1875). While writing about the same trip in a later publication (1877) he recalled the vegetation as consisting of "low bushes, cactus and grass, but no trees." In 1878 George Nidever stated that "I have not been to the Island for several years, but I am told that it is almost covered with sand." (Ellison, 1937.) Thus his statement indicates a changed condition on the island over that which prevailed in prior years. In 1879 the island was pictured by Wheeler (1879) as being barren and extremely desolate as a result of drifting sand. Seven years later during a late June-July, 1886* visit of 25 days, Streator gave his impressions of the surface character of the island:

> On approaching the Island the view is not very inviting, the cliffs rising two or three hundred feet, between which descend ever shifting banks of sand. By following a steep trail to the mesa we observe a fine pasture almost as far as the eye extends, but on reaching other parts of the island I found it barren, and half of the area drifting sand. It . . . is stocked with the choicest horses, cattle and sheep (Streator, 1887).

During late August and early September of the same summer the resident occupants of the island, Mr. and Mrs. Crawford, informed the botanist Greene that the sand was fast encroaching upon and burying yearly more and more of the fertile grassy acres of the eastern portion. Impressed with the extent and richness of the grassland at the time, Greene concluded:

> I judge that remarkably good and truly perennial pasturage [covers] the eastern third of the island. . . . These many acres of such pasturage have been the pride of the owner of San Miguel, whose horses, cows and sheep fare better on this cold bleak and desolate marine table-land and are much better secured against the perils of starvation** than are the flocks and herds on any of the larger and more fertile members of the archipelago where, as on the mainland, the grass species are annual and the crop yearly good or poor according to the winter rain fall (Greene, 1887).

Some time after 1886 but before 1895 and probably within the 1883-1893 wet cycle Voy (ca. 1893) had this to say about the vegetation of San Miguel:

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*A wet cycle year.

**Greene apparently was ignorant of the 1863-64 disaster experienced by Nidever.

> The greatest portion of this island, appears to be good soil, and is good grazing land, the year round, and is abundantly supplied with nutritious native grasses. . . .
>
> At the present time the island is entirely destitute of timber, but from the general appearance it has not always been so. In some of the isolated canyons and hills, in sheltered spots, are a great many varieties and species of handsome shrubs and bushes. . . .

One of Voy's photographs (published later, incidentally, without acknowledgment by Yates, 1902) shows the hugh dunes mentioned by Streator that were spilling into Cuyler Harbor during the 1880's and 1890's (Plate 48). Four Coast Survey sketches made in November, 1895, also show these monster dunes spilling into the harbor and into the open ocean off the north side of Harris Point (Plates 69-70). A note which accompanied the large original sketches is reproduced below:

> *The shore-line, bluff-lines, rocks and Δ^{n} points marked in black have been copied from a topog. tracing of San Miguel Island made by Asst. Forney in 1871. The additions in blue ink of stations, marked thus ⊙, the shore-line and areas of sand, etc. have been made to determine an encroachment of the shore upon the harbor which was first discovered on March 10th 1895. The areas of drifting sand are sketched in approximately. The dotted lines shown in the harbor enclose areas over which the sea was observed to break in heavy swell and could only be approximately delineated. Sketches Nos. 1 and 2 were made to exhibit the present appearance of the changes in the shore-line; and the extended sketch of San Miguel Island was made from the vessel, under way when leaving the island, to illustrate the fact of the great amount of drifting sand which is being constantly deposited in Cuyler's Harbor. The names of rocks in the harbor have been copied from a hydrographic tracing. The kelp-field shown on topog. tracing of Cuylers Harbor no longer exists except in small, scattered bunches.*

The topographic tracing referred to in the note above is that executed by S. Forney in 1871 (see Map 6). It is noteworthy that whereas the island vegetation was directly destroyed by sheep the extensive submarine vegetation (kelp) shown on Map 6, which requires a rocky bottom on which to attach its holdfasts, was destroyed by submarine sedimentation of reworked eolianite unstabilized by sheep. Thus both the subaerial and the submarine vegetation was largely destroyed due to the direct and indirect effects of sheep.

Willett (1910) visiting the island in June 1910 commented that San Miguel:

> . . . is mostly composed of rocks and sand hills, altho there is considerable grass on the more elevated portions. This, however, is being gradually covered up by sand which is drifting slowly but surely across the island, carried by the prevailing northwesterly winds. There are several varieties of shrubs on San Miguel but no trees worthy of name.

Holder (1910), Wright and Snyder (1913) and Heye (1921), among others, gave similar descriptions of the plant cover on San Miguel Island. Wright and Snyder, for example, concluded that the island ". . . is nothing but a vast pile of continually drifting sand." In 1924 lack of rain again reduced forage to such a degree that Robert Brooks, lessee at the time, had to remove all the sheep to the mainland (Brooks, personal communication, 1965). During a late September 1927 visit to San Miguel Island, two mammalogists, C. C. Lamb and J. E. Green observed that bushes were practically non-existent. Most of the island was said to be sandy and "free of trees or even of brushy vegetation" (Grinnell, _et al._, 1937).

Probably some of the many impressions quoted above were laced with a degree of personal bias or, as indicated earlier, reflected the season of visit. Dunkle concluded as much about the impressions of certain early observers regarding the character of the early vegetation of Santa Cruz Island (Dunkle, 1950). The assessment of landscapes, like beauty, lies in the eye of the beholder, and some beholders apparently have far more critical eyes than others. Even so, the above descriptions are about all we have during the early historic period.

Toward the end of the last century cultivation was practiced which resulted in accelerated wind and water erosion, and probably concomitant vegetation destruction. While searching through ownership records of San Miguel Island a sale statement was discovered by the writer and Bernard Neitschmann which contained an inventory of all the equipment and personal property on the island as of December 20, 1890. At that time there were approximately 3,000 head of sheep and 150 head of cattle, 10 horses and mules, hogs, poultry, goats and ". . . farming and agricultural implements . . . consisting of wagons, cart, plows, harrows, mowing machines. . . ." Another sale statement dated December 19, 1889, mentioned the presense of "hay farming implements." Another statement, dated March 6, 1897, mentions the presence of a mowing machine and a hay rake. The documents show that farming was carried out on the island in the 1880's and 1890's at least. These activities are further documented by a map in Voy's manuscript dated circa 1893 which locates the cultivated fields (Plate 72). The plowed area on the map is referred to as the "Old Cultivated Area" on the place name map (Map 1). Today the area is one of the most severely eroded tracts on the island and is being actively dissected by huge ravines (Plates 28 and 31). The topsoil in this region has been largely stripped away leaving behind an essentially sterile surface. Robert L. Brooks, former lessee of the island, is of the opinion that cultivation, not sheep grazing, was the primary cause of 19th and early twentieth century vegetation stripping and soil erosion, whereby the wind removed all that the plow turned up (personal communication, 1965). However, Mr. Brooks obviously had not read Nidever's account of the results of the 1863-64 drought. Overgrazing by sheep _and_ cultivation in a windswept environment combined to cause the demise of significant portions of the insular vegetation and soil.

Photographs taken since 1929 allow us to see what the character of the vegetation was like for the past 40 years. Photographs taken about the ranch house during the early 1930's show only bare ground (Plate 10; compare Plate 4b). Photographs in Bremner (1933, p. 12, 20) show extensive dune blankets on Crook Flats and the Wind Tunnel in the early 1930's. Airphotos taken in 1929, 1940, 1954, 1960, 1961, 1965, 1968 and 1969 give a general impression of the extent and cover of vegetation during that time span (Photomaps 1, 2, 3, and 4 in map pocket, and Plates 11, 12, 13, 14, and Frontispieces). The photographs show that vegetation has been gradually expanding at the expense of dune terranes since 1929.

Nineteenth century stripping of vegetation and soils resulted in marked shoreline changes about San Miguel Island. Reference again to Plate 11 shows, in stages, how the perimeter of the island has been modified through time. In 1871 the shoreline of the island was primarily rocky. Sandy beaches were limited to only the windstruck northwest coast, eastern Cuyler Harbor, and a small area immediately north of Cardwell Point. The spit at Cardwell Point had not yet formed, nor had the escalloped southern coast been filled with sand. The year 1870 was one of severe drought and was only six years removed from the ecological disaster of 1863-64. At this time the stripping episode had not yet manifested itself as modifications in the shoreline. By circa 1893, however, sand had encroached on many of the beaches (Plates 68 and 72). As mentioned earlier, Plates 68 and 69 in particular show clearly how Cuyler Harbor was being invaded by extensive sand dunes cascading from Harris Point into the bay. A comparison of bathemetry data collected in 1852, 1875-76, and again in 1940 show marked shallowing of the bay due to blowing sand from Harris Point (Fig. 56). Most of the shallowing of the bay and wind erosion of the island occurred in only 12 years, from 1863-64 to 1875-76. By 1910 significant changes had occurred with extensive sand beaches all about the island (Plate 11). The first airphotos taken in 1929 document the presence of the well-developed sand spit at Cardwell Point and show the smoothed shoreline perimeter which so contrasts with its escalloped character in 1871 (Plate 11). Airphotos taken since show only that the sand spit at Cardwell Point has diminished in size from its maximum development in 1940. If this trend continues we may expect the spit to be washed away eventually.

Since the cessation of cultural activity on the island in the 1940's, and the removal of most of the sheep in 1950, erosion has been markedly reduced, and many plant species have actively re-established their

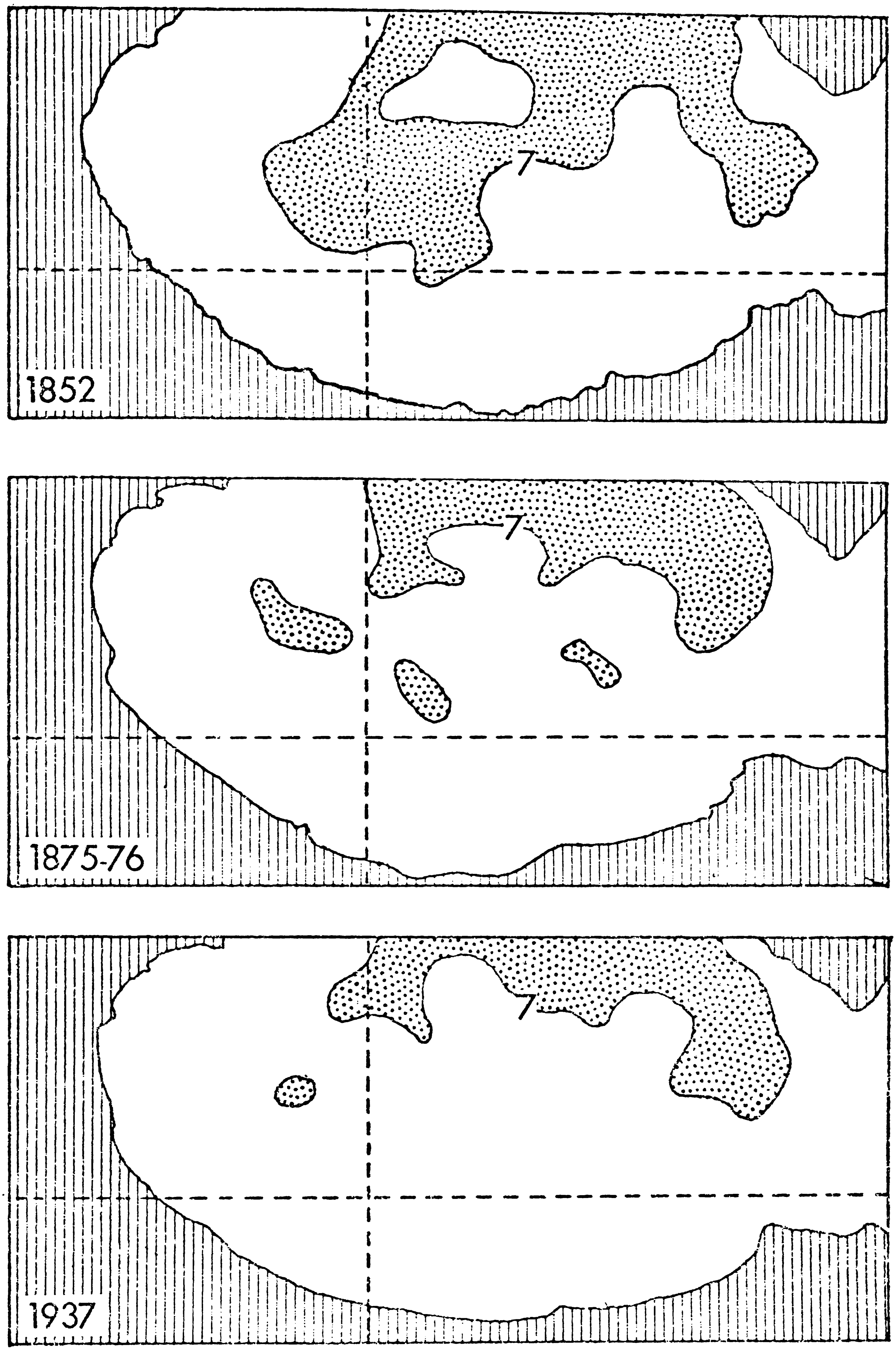

Figure 56. The diagram shows three stages of shallowing in Cuyler Harbor based on bottom bathymetry obtained in 1852 (Chart 607), 1875-76 (issued 1883) and in 1937 (Chart 5116). The stippled pattern shows depths greater than 7 fathoms (42 feet). Actually, since erosion began actively during the 1863-64 drought the marked shallowing which had taken place by 1875-76 occurred in only 12 years.

numbers, probably to a greater degree than at any time during the past 120 years. It can be reasonably argued, however, that cessation of erosion is in one sense an unfortunate circumstance because the unique physical character of the island is almost exclusively a result of erosion and deposition of the products of erosion.

Summary

In summary, the various lines of evidence presented above show that the following may be concluded about the post-human landscape of San Miguel Island: (1) in prehistoric times man burned and otherwise modified the vegetation of the island, was thus an agent of landscape disturbance, and left many middens variously about the island; (2) within historic time the ground cover, where it existed, largely consisted of grass and shrubs, with bushes and some trees in sheltered areas; (3) beginning in 1863-64 overgrazing during times of drought has periodically resulted in destruction of much of the ground cover, thereby unstabilizing the dune landscape and promoting wind erosion;* (4) few trees have grown on the island since the drought of 1863-64 and apparently were few in number before the drought; (5) cultivation in the late 19th century also contributed to a reduced ground cover with attendant wind and water erosion; (6) the ground cover has periodically recovered in varying degrees from the effects of overgrazing; and (7) sand blown off the island has shallowed Cuyler Harbor, has contributed to the formation of

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*Actually, since droughts and dry cycles are a normal part of the environment, the surface stripping of the island was due _in sensu stricto_ to overgrazing. To express it another way, the droughts of 1863-64 and 1870 did not strip the island, animals did. Had too many animals not been on the island no stripping would have occurred.

the spit at Cardwell Point, and has resulted in coastline progradations on the south and east sides of the island.

26. Landslides

The 1895 Slide

Significant landsliding and earth slumping has occurred repeatedly on San Miguel Island. Most of the slumping has taken place around Cuyler Harbor, although slumping has occurred elsewhere on the island (SMI-166). It is probable that the evolution of Cuyler Harbor is in part related to intermittent earth slumping over a long period of time.

One of the most celebrated landslides that ever occurred in California took place on San Miguel Island on either March 8 or 9, 1895. The event received a great deal of news coverage in Los Angeles and San Francisco newspapers. In fact, so great a fuss was made that the Coast Survey sent a party out to the island the following November to re-survey Cuyler Harbor. Plate 69 consists of sketches made by Coast Survey personnel showing the extent of the resultant coastline modifications (see Plate 70 for plan lay-out). The slide was given the name "The Upheaval," which appears on Map 1 in this thesis. The three views of Plate 69 show not only the character of the slide but also the tremendous sand deposits which at the time were spilling into the harbor and into the sea north of Harris Point (see also Plates 70 and 71). Plate 68 is a photograph of the same area shown by sketch no. 2 in Plate 69 but taken sometime prior to the slumping event (circa 1893).

Plate 71 shows various drawings of the landslide made from photographs taken by press observer-authoress Flora Haines Loughead who was on the island from March 27 to April 6 (inaccurate sketches of Cuyler Harbor and the slide were published in the San Francisco _Examiner_, March 24, 1895). Loughead wrote two full page articles on the incident, one for the San Francisco _Call_ and another unsigned version which appeared in the Los Angeles _Times_, both dated April 14, 1895. These were but two of a long series of articles which appeared in the San Francisco _Call_ (March 24; April 7, 14), the San Francisco _Examiner_ (March 17, 23, 24; April 2, 7), and the Los Angeles _Times_ (March 17; April 3, 9, 14, 22).

The entire episode was treated by the press as a mysterious weird act, a "convulsion of nature" that defied natural explanation. This attitude was strengthened by the wrecking of the sloop _Liberty_ in Cuyler Harbor some 20 days later on the night of March 29. The wrecking of the sloop (owned by the resident proprietor W. G. Waters) was attributed to the same mysterious forces which caused The Upheaval to be "torn from the harbor's bed and flung shoreward." High seas which were running during late March were also implicated as a manifestation of the unnatural convulsions (actually, the demise of the _Liberty_ was more likely due to carelessness on the part of the skipper, Captain Dally). As a matter of mainly historical interest, but also because they provide details of the landslide incident, a letter written by Captain W. G. Waters to E. W. Gaty, then proprietor of the Arlington Hotel in Santa Barbara and general manager of the island ranch, is reproduced below followed by another description which Waters gave to Loughead:

> There has been quite a commotion over here. The land that formed those high bluffs back of the boathouse has sunk more than sixty feet perpendicularly and forced itself into the harbor,

> raising the beach and rocks which have lain at the water's edge for thirty years some thirty feet above. This upheaval extends up and down the beach more than 1,000 feet. The boathouse is in a depression, and the sand and stones in front of it are over thirty feet high. This must have happened Saturday, March 8th. I felt a shock, but as the wind was blowing strong thought nothing of it. It must have come very suddenly, as lots of fish and small crabs were caught in the upheaval and left high and dry out of water.
>
> The extent of this upheaval covers over twenty acres, and as it is continually on the move I cannot tell what the next change will be. Whether this extends far under the water in the harbor I do not know. It will leave huge stones on the west side of the harbor and change the landing. My boats and those of Captain Ellis are all right. The land was raised in the boathouse, while the posts remained as they were.
>
> It is a strange and peculiar upheaval. Some scientific man should see it. I give it up. I shall be obliged to remove my corral to the other side of the spring and rocks. The boathouse is now about 300 feet inland. Captain Dally will tell you all about it. I went all over it, but as it was on the move I thought I had better return to solid land and await events. (Quoted in San Francisco Examiner, March 17, 1875, p. 29.)

The quote from Loughead reads:

> On the morning of the 10th of March I went up to the flagstaff to ascertain if my boat, the Liberty, which had gone over to the mainland with a load of sheep, under command of Captain Dally, on Wednesday, the 6th of March, was in sight. There was no sail to be seen, and after I had swept the sea I turned the glass on the harbor, 500 feet below. By the nearest chance, as I was about to put up the glass, I turned it on the shore in the vicinity of the boathouse, which had always stood on the brink of a sloping bank about eight feet above the harbor at high water.
>
> Heaven! What's the matter with the boathouse? I said to myself.
>
> I took the glass and rubbed it, then examined it to make sure it was clean. There was the boathouse, to be sure, but instead of facing to the east it was pointing north-northeast by south-southwest and presented its broadside instead of its front to me, while between it and the water rose an abrupt bluff a hundred yards wide and some sixty or seventy feet high. I didn't know what to think of it, I'll acknowledge. I tried to persuade myself that something ailed my eyes or that some low bank of fog or mist, with the sun shining through it, had created a queer optical illusion.

> There are just two souls live on the island besides myself, this man, Harland, who acted as general ranch-hand, and his wife, who went over to the mainland last week. I went back to the house and found him there.
>
> "Harland," I said, "just go up to the big bluff and take a look at the boathouse. It looks to me as if there'd been a tremendous upheaval down there. It may be it's the reflection in the water, or that my eyes deceive me, but I wish you'd see for yourself."
>
> It wasn't long before Harland was back.
>
> "Why, there's been a big landslide down there. Let's go down and look at it," he said.
>
> The beds of sand on San Miguel Island are of vast extent and often of immeasurable depth. They are constantly shifting and changing, and the explanation of the queer changes that had occurred seemed at first the most reasonable.
>
> It was only when a close observation had been made it became apparent that this bast body of earth and gravel and rock had been lifted up from the bed of the harbor.
>
> This was the beginning of the strange disturbances which are making Cuylers Harbor famous. The ground is still in motion. Every day sees new changes along the shore, and rocks are constantly rising from beneath the water along the harbor's southwest shore, where they have never been seen before. (Los Angeles Times, April 14, 1895).

Upon critically reviewing all of the written commentary on the incident it is clear that "The Great Upheaval" was simply a large rotational slump-landslide, being one among many such slides which have occurred earlier and since on San Miguel Island. Traces of the 1895 slide can still be seen on the Photomaps accompanying this thesis. It has been suggested (Townley and Allen, 1939) that the slide was not triggered by an earthquake as implied by Waters in his letter to Gaty and as several newspapers subsequently reported. The basis for this suggestion is that the shock described by Waters was not felt anywhere else in California (Townley and Allen, 1939). However, other earthquakes have been reported on San Miguel which have not been felt elsewhere (see Townley and

Allen, 1939, p. 98). It is conceivable that the shock that Waters felt was the result of the slide rather than the cause of it. However, one newspaper reported that the shock was also felt on one other island either Santa Rosa or Santa Cruz Island (San Francisco Examiner, March 24, 1895). In addition, some weeks later at midnight on April 3, 1895 the crew of the schooner Arcadia which was anchored in Cuyler Harbor reportedly experienced "a sudden severe shock [which] sent the ship reeling and tossing, and brought the crew on deck." Immediately afterwards the water reportedly began churning and the ship started dragging anchor whereupon the crew quickly slipped the anchor off and ran from the harbor (San Francisco Call, April 7, 1895; Los Angeles Times, April 9, 14, 1895). The incident may have been caused by an earthquake, or by slide-related adjustments of submarine debris. On April 17, 1895, a shock again was felt on San Miguel Island (Los Angeles Times, April 22, 1895) which appears definitely to have been an earthquake as a very sharp earthquake rocked central California on this date (Townley and Allen, 1939). Thus the sequence of events which followed the shock initially reported by Waters suggests that a period of tectonic instability existed on the island. It is worth noting that at least one major fault passes through Cuyler Harbor (Bremner, 1933; Weaver, 1969) so that local earthquakes are not altogether unexpected. Indeed, the genesis of Cuyler Harbor is difficult to explain in a non-tectonic context.

Besides the slide mass per se, one other important change in the geomorphology of Cuyler Harbor resulted from the episode. Previous to the slide a series of tide-level caves were reportedly present in the

the southwest section of the harbor where the slide occurred. No caves presently exist in that part of the harbor. A description of the caves, presumably given to authoress Loughead by W. G. Waters, is given below:

> Previous to this occurrence, as old photographs and the testimony of dozens of reliable witnesses prove, the southwest curve of the harbor was a perfect crescent in form, with a narrow strip of sandy beach lapped by a light surf, where boats were accustomed to land. At its southwestern extremity the heights above drop in almost precipitous ledges to the water's edge and here the old sedimentary strata has in some bygone period been pitched in almost vertical lines meeting in sharp angles and forming a series of deep caverns at the water's edge. Adjoining this cavern-ledge on the south was a sand hill five hundred feet high, falling off sharply to the beach and constantly raining sand below, so that the mouths of these caverns were alternately blocked with dry sand, and washed out again by the tide. Notwithstanding the steady and enormous precipitation of sand constantly descending from the west and southwest shores, the strong sweep of the current, setting in and out of the north entrance and the eastern passage between Prince's Island and the shore, kept the harbor bed clean swept. . . . (Los Angeles Times, April 14, 1895).

San Miguel Island captured press coverage one more time in 1895. On July 14 an article appeared in the San Francisco Call titled "Earths giant forces, again playing havoc around San Miguel Island." The article, based on reports given by two otter hunters, described how one portion of Castle Rock was shattered on June 8 by some force which sounded like "an artillery report." It was reportedly heard by five persons on the island.* Also, a shoal area south of Richardson Rock reportedly became more prominent at the time, although the commentary hints that this observation may have been more imagined than real. What actually happened is not known but probably, if the account is correct, a large rockfall

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*Two otter hunters, Jake Nidever (son of George Nidever the former owner of the island) and Antonio Cabellero, and Water's housekeeper Mrs. Devine and her two sons, Will and Francis.

or slide occurred on Castle Rock. The islet was not visited during the period of field work.

Other Slides

As indicated, other slump slides have occurred about Cuyler Harbor before and since the 1895 slide. Prior to this slide, for example, the 1896 Chart of Cuyler's Harbor (Figure 57) shows that three sizable

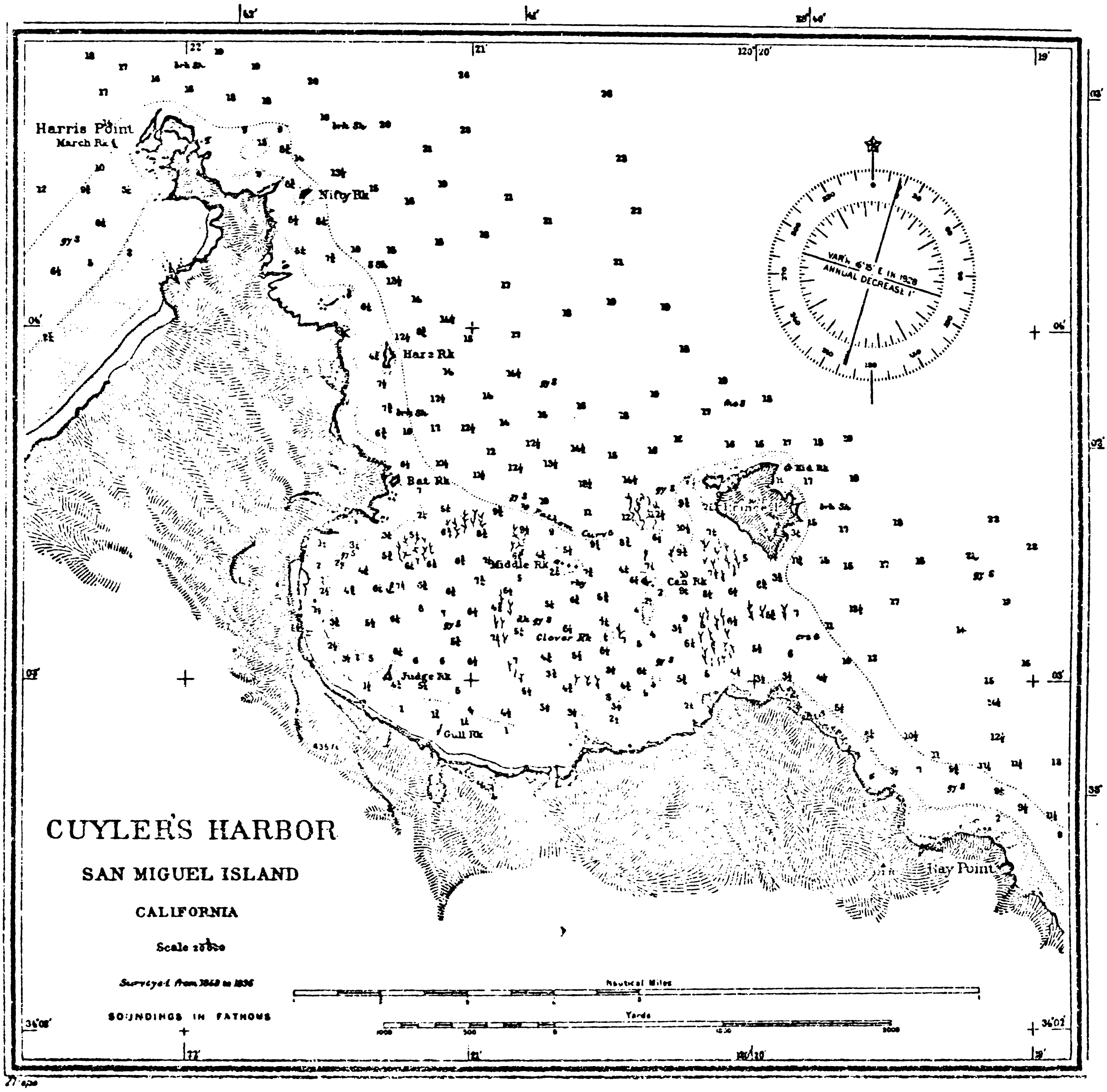

Figure 57. Chart of Cuyler Harbor showing large cracks around the west and south sides of the bay which existed in 1871. The surveying was executed by W. E. Greenwell in 1858, the topography by S. Forney in 1871, the hydrography by C. Taylor in 1875-76, and the Upheaval defined and surveyed by A. F. Rodgers in 1895.

headwall-cracks were present about the harbor as early as 1871 when the topography was executed by S. Forney. Below these cracks are presently found the three most conspicuous landslide-slumps in the habor, which includes the slide of March 1895.

A careful study of Plates 11, 68, 69, Figure 57, and Photomap 1 shows that at least one major slide occurred prior to 1895 and at least one minor one between the period 1895-1929. Sometime after 1940 another monster slide occurred at the northern part of Cuyler Harbor. This slide was photographed several weeks ex post facto by Mr. U. F. Stevens of Santa Barbara who regularly delivered supplies to the island from the late 1920's to 1942 and is shown in Plate 67a. However Stevens was of the opinion that the slide occurred in 1929 (personal correspondence, 1965), but it is not shown on either the 1929 or 1940 airphotos (Photomaps 1 and 2; Plate 11), nor is it shown on Bremner's 1933 geologic map, but is shown on the 1954 airphotos (Photomap 3). Since the slide occurred during the period when Stevens delivered supplies to the island (to 1942) it is here presumed that this slide, which is still so strikingly conspicuous today, occurred sometime during 1940-42. Careful comparison of the two photographs on Plate 67 shows that little change has taken place other than the development of a shingle beach and vegetation. The large boulders shown in the 1967 photo are in essentially the same positions as they were when the slide occurred.

Bremner photographed the southern part of Cuyler Harbor (East Cuyler Slumps) in the early 1930's which showed only one slide (Bremner, 1933, p. 11) but three slides were present in 1969. Other slump-slides are shown in Plate 60a. During the 1969 field season at least two small slump-slides occurred about 300 yards west of the mouth of Nidever Canyon (SMI-11). One of these occurred just as I was passing by on the evening of August 9, a most startling experience. Several days later, the other slide noted occurred next to the first. It is probable that in this particular area (SMI-11), which appears to be water-saturated most of the time, slump-slides are a regular occurrence. In fact, in view of the widespread spring seepage about Cuyler Harbor, most of its cliffed perimeter is highly unstable and subject to slump-sliding at any time.

Cause of the Slides

Although slump-sliding is a common phenomenon along the ocean bluffs of southern California, and has been quite active on most of the other Channel Islands (Weaver, 1969; Slosson and Cilwek, 1966; Vedder and Norris, 1963), few areas as small as Cuyler Harbor have experienced so much mass movement by slump-slides.

The factors responsible for the slumps and slides, and for the origin of Cuyler Harbor, appear to be several. First, occasional strong currents tend to "sweep out" loose sediments in the bay with time. This must be the case as otherwise Cuyler Harbor could not have formed, for the material which formerly occurred in the area defined by the bay is, of course, gone. Moreover, the debris injected into the harbor by the March 1895 slide has been almost completely removed by wave action and currents. It is probable that the sand blown into the bay since 1863 will eventually be carried to deeper water towards San Miguel Passage. Some sand is also being regularly removed by eolian deflation in the southeast part of the bay. Wave action during summer months concentrate the sand in this part of the bay and the wind transports it back up upon the island and eastward down the Wind Tunnel. Sediment removal from the bay by water and air currents combined with winter storms that occasionally send erosive waves into Cuyler Harbor bring about oversteepening of the bluffs. Oversteepening combined with other factors discussed below eventually results in bluff failure and slump-sliding.

Another factor that likely plays a role in slump-sliding is the concentration of subsurface water along the bedrock-Quaternary sediment interface around Cuyler Harbor. There are several reasons why subsurface water tends to concentrate in the area. One is that the 300+ foot marine platform that marks the bedrock-sediment interface decreases in elevation from the base of San Miguel Hill towards Cuyler Harbor. Thus groundwater moves north downslope along this incline and issues as a series of springs around the bay. The thick blanket of eolianite and other sediments which overlie the platform serves as an effective aquifer for rainwater falling on the north side of the island. Also, until the development of gullies and barrancas in the Old Cultivated Area in the early part of this century no surface drainage network existed for the north-central part of San Miguel including Harris Point (Nidever Canyon drained only a very limited area prior to this century). Therefore, almost all the rainfall that falls on this part of the island which is not evapotranspired becomes groundwater and ultimately issues as springs around Cuyler Harbor.

A third factor that likely is involved in slump-sliding is montmorillonite clay, which occurs in the bedrock along the south side of Cuyler Harbor. For example, at SMI-210, there occur a series of intermittent ponds formed when longitudinal dunes developed parallel to the cliff front and blocked drainage to the sea. The ponds are catchments for water which percolates through the slump area east of Nidever Canyon. During the summer when the ponds dry up the bottom sediments crack and curl extensively, showing the presence of expanding lattice clays (Plate 83). X-ray analyses of several grab samples of the sediment verify the clay as montmorillonite. It is known that montmorillonite family clays are associated with other slide areas which reflects their superb lubricative qualities (Anderson, et al., 1969).

A fourth factor, almost certainly responsible in the main for the slide shown in Plate 67, as well as the slide immediately to the west (SMI-2), is the presence of highly shattered, unstable bedrock. Plate 59 shows how incredibly fractured the bedrock is at SMI-2 and SMI-4. The rock in question is a foraminiferal silt or claystone that has been partly silicified by low temperature silica (cristobalite)*, presumably associated with a fault that occurs just to the north of the slide headwall at SMI-4. The lithologic unit is probably the upper member of the Rincon Formation of Oligocene Age, although not mapped as such by Weaver and Doerner (1969). The fracturing may be related to stresses associated with the nearby faults.

Tectonic activity, a fifth factor has probably served as a triggering mechanism for the slump-slides. Although Weaver and Doerner (1969) show no faults to the north of the slide headwall at SMI-4, there is clearly at least one major fault present, and Bremner shows two faults meeting at this point (Fig. 58).

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*Identified by X-ray analysis.

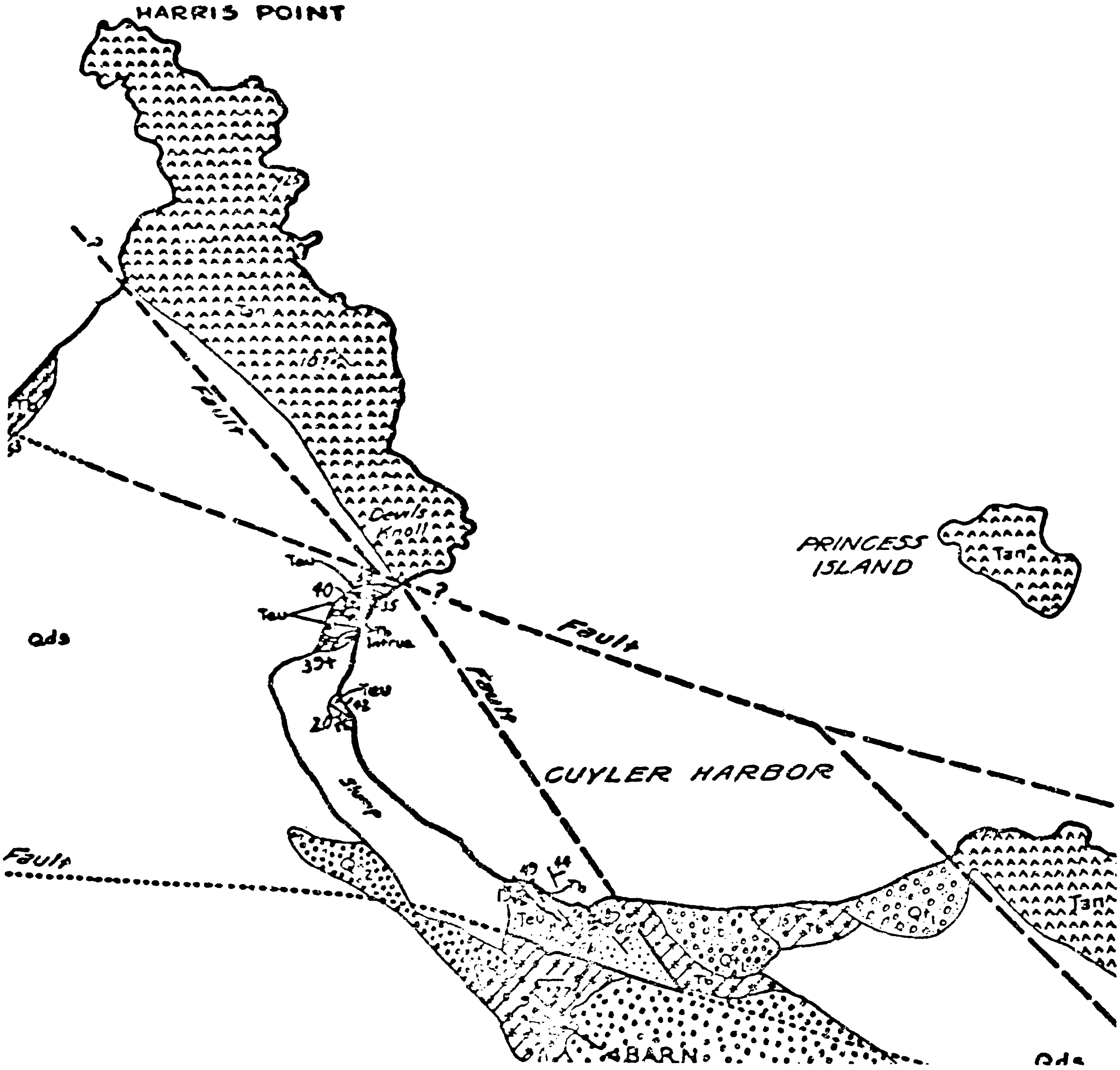

Figure 58. Portion of geologic map of Bremner (1933) showing faults which transect Cuyler Harbor. At the time Bremner's study was made the large landslide at SMI-4 had not occurred.

Although the five factors listed above are considered responsible for slump-sliding on San Miguel Island, mention should be made of the Ghyben-Herzberg effect because it was invoked as a partial explanation of the Parson's Landing landslide on Catalina Island by Slosson and Cilwek (1966). The principle involved is that as sea-level rises, in this case during Wisconsin deglaciation, the zone of ground-water saturation rises commensurately on adjacent land areas. Ground-water saturation of the modern bluffs presumably would increase the probability of slope failure. However, because the ground-water around Cuyler Harbor is largely perched upon a high marine platform the Ghyben-

Herzberg principle would have no great influence on mass-wasting rates. One exception might be on Harris Point where the bedrock, being highly fractured, probably is saturated with groundwater. However, the presence of an overlying eolianite aquifer would probably keep the shattered bedrock saturated regardless of the level of the sea.

Origin of Cuyler Harbor

Bremner (1933) believed that an inferred offset in the Cardwell fault (Fig. 58) was responsible for the development of Cuyler Harbor. "The embayment of Cuyler Harbor has been formed where a fault offset the hard ridge of volcanic rocks that forms the northeast coast, and allowed the waves to attack the softer rocks behind." If this is the case, as it appears to be, once the breach in the resistant volcanics was made, the development of Cuyler Harbor proceeded rapidly through erosion and mass-wasting.

If the amount of slump-sliding recorded during the historic period is a representation of pre-historic times then geologically Cuyler Harbor must be very young indeed. Probably it was formed during Holocene times. It is now well established that world sea-level reached its approximate present level around 6,000 years ago (Fig. 36). Before that time the shoreline lay to the north of San Miguel, being some 10 miles distant 18,000 years ago and some 400 feet lower than at present. It seems reasonable that the pre-Cuyler Harbor cliffs inferred for the north side of the island were not actively mass-wasted until sea level approached its present level, and that Cuyler Harbor has evolved since that time, or roughly over the past 6,000 years (Fig. 36).

27. Stream Development

On the whole there has been remarkably little stream erosion since the island was initially shaped by marine planation in the late Pleistocene. The lack of stream erosion may in the main reflect the fact that the island has been periodically inundated by eolian sand. Porous sand tends to absorb rainfall like a sponge and inhibits both surface erosion and the development of integrated drainage systems. The only stream system of any consequence is Willow Creek which drains the eastern third of the island. The creek has cut only a very shallow trench due to several resistant rock ledges, one near the mouth, which act as temporary base levels to erosion. Also, in the historic past, and presumably during late Quaternary times, Willow Creek has been periodically blocked by dune sand which creates small ponds and restricts rapid runoff. The writer saw this happening on Willow Creek in 1967, and the location of ancient eolianite units suggests this happened many times in the past. Stream piracy, caused by blocking sand dunes, may also have changed the course of several western tributaries of Willow Creek from north flowing (into Cuyler Harbor) to southeast flowing streams (SMI-116).

As mentioned in Chapter 5, the streams that head on Green Mountain and flow west meet a base level at the dry lake which was created by a Pleistocene eolianite emplacement. Formerly this drainage continued west to Running Springs and beyond but was only incipiently developed when dune emplacement occurred. Consequently there has been little stream erosion on the western third of the island.

South Green Mountain Canyon is the deepest and most precipitous valley on the island, but it too is quite young and has been blocked at least once by migrating dune sands as huge slabs of pedologic caliche testify to their former location (SMI-118). A similar history characterizes North Green Mountain Canyon which has only recently cut through a magnificent eolianite unit (Plates 78, 80) which blankets the bluffs north and west of Green Mountain above Simonton Cove.

One of the youngest of the deep canyons is Nidever Canyon which drains north into Cuyler Harbor. Only in recent geologic times, mainly during the Holocene, has it managed to cut through the thick eolianite-paleosol sequences which formerly stretched in an unbroken rampart east to west across the Canyon from SMI-1 to SMI-85.

The remainder of the streams occur along the south bluffs of the island and along Simonton Cove. They are numerous, very young and most may have developed during the historic period, possibly as a consequence of overgrazing and vegetation stripping.

In summary, stream erosion on the island has been on the whole negligible. Ubiquitous porous sand has served as a sponge to rainfall and surface runoff has been consequently light. Sand has also periodically blocked, and retarded development of,surface drainage networks. Numerous small streams which occur on the south and northwest sides of the island may date from the early historic period.

28. Chapter Summary

Profound changes have occurred on San Miguel Island in late Quaternary time. The erosional triumvirate of fire, climate (drought and wind) and elephant must be markedly expressed in the present landscape, although the detailed effects of each may never be completely deciphered.

The extinction of elephant seems to have coincided with the arrival of man, and the disappearance of elephant as a major ecological force may well have been the first important stamp of human activity on the island.

Man's subsequent effects on the insular landscape have been equally profound. Extensive accumulations of shell midden created anthropic landforms about the island. Fire, which the island vegetation experienced occasionally prior to man, became more common after his arrival. The tempo of landscape change increased drastically during and since the drought of 1863-64, reflecting overgrazing by sheep in a windswept insular environment. Vegetation destruction and windstripping caused the formation of great dunes which periodically expanded over much of the island. Cultivation also left an imprint on the insular landscape, now indelibly expressed by deep ravines and gullies in the old cultivated area.

Tectonic and slump-slide activity have, in late Quaternary time, created a major physiographic form in Cuyler Harbor. The combined factors of faulting, shattered and montmorillonite-bearing bedrock, concentrated subsurface waters, and ocean waves and currents which erode and sweep clean the debris of mass wasting have played important roles in the development of the bay.

Stream erosion on the whole has little effected the mesa-like character of the island. A porous sedimentary cover which served as a sponge for rainfall has inhibited erosion and the development of an integrated drainage network. Dunes have periodically blocked surface drainage and have thereby also retarded stream erosion and drainage system development.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

It was stated in the Introduction that the purpose of this thesis was to analyze the landscape of San Miguel Island and to shed light on the intricacies of its evolution. In this context, answers to the following six questions were sought: To what extent is the present geomorphic and pedologic landscape the result of the factors of climate and climatic change? Of structural or tectonic causes? Of marine processes? Of biogenic causes and events? Of pedogenic processes? What role has man played in the geomorphic evolution of the island?

In conjunction with field work carried out intermittently from 1964 to 1969, answers to the questions were sought by drawing together many disparate pieces of evidence from historical climatic records, tree rings, archaeology, radiocarbon dating, charcoal and petrographic thin-section analyses, structural geology, seismic records, marine terrace and sea-level studies, zoogeography, paleobotany, sedimentological and geochemical analyses, soil analyses, maps and airphotos, archival research, and personal correspondence and interview. The result is a broad picture of the late Pleistocene and Holocene evolution of San Miguel Island, with many detailed insights, which together illuminate the six questions initially posed.

Factors of Climate and Climatic Change

San Miguel Island experienced a climate that was basically Mediterranean in character during most of the Quaternary, wet in winter, dry in summer. Air temperatures, conditioned by the cool California

Current, are characterized by a lack of extremes and continentality. Precipitation is, and has been in the indefinite prehistoric past, characterized by wet and dry trends of variable duration. Under this temperature and precipitation regime, persistently strong northwest winds combine with episodes of drought, fire, animal, and human disturbance to produce an insular landscape characterized by multiple eolianites, intercalated paleosols, reworked eolianites, stripped soils, exposed caliche, stands of rhizoconcretions, and extensive dune sheets.

Evidence of major climatic change is lacking on San Miguel Island. Precipitation waxed during full glacial times, but may have simply begun earlier in the fall and lasted later in the spring; summers remained dry. The temperature and climatic regime of San Miguel during the maximum Wisconsin glaciation was probably similar to that which presently prevails along the Monterey coast of central California, which is slightly cooler and more moist than San Miguel today. Soil development on the island has been influenced by a semiarid seasonally wet and dry climate as evidenced principally by "self-swallowing" vertisols and abundant caliche. Soil caliche of widely varying ages serve as reminders that precipitation in the past was insufficient to completely remove the calcium carbonate through leaching, such as presently occurs in humid climates. Nothing in the landscape suggests major climatic change comparable to what most of North America experienced during the Pleistocene. Changes which did occur were slight and subtle. And fire has been an important element in the insular landscape during late Pleistocene and Holocene time, before and after the arrival of man.

Structural and Tectonic Factors

Structural evidence suggests that San Miguel and the Channel Islands Platform are allochthonous and have moved west at least 50 miles since mid-Tertiary times. There is no evidence of structural continuity with the west end of the Santa Monica Mountains as previously supposed. Thus both the Channel Islands Platform and, in part, the tableland form of San Miguel owe their origin to long-term vertical and horizontal tectonic pulsations. San Miguel seems to have been an island, or part of an island system, for most or all of the Pleistocene.

The basic mesa-like geomorphic form of San Miguel reflects the combined processes of marine erosion, glacially induced sea-level changes, and tectonic activity. Although low terraces are mainly glacio-eustatic in origin, higher terraces also reflect Pleistocene tectonic activity. If historic seismic activity of the Santa Barbara Channel is used as a guide for prehistoric time, then it is clear that the area has long been subjected to tectonic impulses and consequent geomorphic modification. Since the mid-Pleistocene Island Submergent Period, San Miguel has been tectonically rising slowly out of the sea, irrespective of glacially-caused oscillations.

On a local scale, the slump-slide origin of Cuyler Harbor is in part due to the triggering effects of tectonic activity.

Marine Processes

It should be re-emphasized that the gross form of San Miguel, in addition to tectonism, reflects marine erosion and relative sea-level change. Pulsations of sea-level regressions, transgressions and still-stands together with tectonics have produced a series of marine terraces that dominate the surface geomorphology of the island. Shoreline angles of ancient terraces occur at elevations of 25, 75 and 325 feet above present sea-level. Normal marine terrace abrasion operates at maximum capacity in the surf zone, particularly during episodes of high-energy waves; diurnal surf zone migrations are cyclic as the tides. Biochemical solution of intertidal surfaces follows a tidal and diurnal cycle. Intertidal and supratidal salt weathering, if it does indeed occur, follows a pattern of recurring sea water evaporation dependent intertidally upon tidal cycles and supratidally upon episodes of storm waves and upon normal, wind-carried sea spray. An unusual form of beachrock has developed on the marine terraces subsequent to their being covered with Pleistocene eolianite.

In addition to tectonism, marine erosion has played an important role in sculpturing Cuyler Harbor.

Pedologic Processes

The three most conspicuous manifestations of soil processes on San Miguel are cobble-boulder pavements, Vertisol cracks, and soil ironstone pisolites. It has been shown that cobble-boulder pavements and cracking of Vertisols are interrelated phenomena; when the soil cracks during the dry season, material falls into the cracks and causes a volume displacement at depth, which ultimately causes soil churning and pavement formation.

The origin of the ironstone pisolites which so characterize the unusual profile of the Green Mountain Soil seem to be due to one or two processes, or both; in situ development of sesquioxide envelopes about quartz grain nuclei, or the ferruginization of clay-rich aggregates which originate at the A_2/B horizon interface. Both podzolization and ferralization processes are involved in the profile development of the Green Mountain Soil.

Biogenic Factors

In addition to the erosional efficacy of intertidal organisms on marine terraces, elephants have also contributed to landscape evolution. The role of elephants as landscape conditioners is inferred by the fact of their existence on San Miguel, and by analogy with the way modern elephants destroy vegetation and modify "ecological islands" during droughts in Africa. The periodic destruction of vegetation by elephants on San Miguel Island would have the same effect as fire, or overgrazing by sheep, in that the soil would be exposed to the erosive effects of strong winds. The disturbance effects of elephants began when they arrived on the islands (probably by swimming) and ceased when they became extinct, probably at the hand of early man.

The Role of Man

A new dimension of landscape modification began with the arrival of aboriginal man in terminal Pleistocene times which coincided with the disappearance of elephant. Man brought fire with him, and we may infer from the abundant evidence of aboriginal fires that the incidence of natural fire was subsequently supplemented by man-caused fires. Thus the process of exposing bare unprotected ground to wind erosion through burning of vegetation quickened with the arrival of man.

Historic time saw widespread vegetation destruction and subsequent soil stripping brought about by grazing and cultivation activities. Indeed the entire insular landscape was unstabilized for a time following the severe drought of 1863-64 during which thousands of domesticated animals consumed all the vegetation and then died in the absence of food. Revegetation of the island has been gradually occurring, principally since 1950 when the bulk of the sheep were removed. However, by removing the sheep, the culprits of erosion, the unique and fascinating surface character of San Miguel Island will surely disappear with time because vegetation eventually conceals detail.

Future Research

One particularly fruitful result of this thesis was the definition of problems for future research. For example, how might the question of contemporaneity of man and mammoth be resolved? Probably the best way would be to conduct detailed paleoecological, archaeological and paleontological studies and excavations at Running Springs where artifacts, middens, mammoth bones, plant remains, land snail shells and charcoal occur. Moreover, if such a study were combined with biotic and limnologic analyses of sediment cores taken from the Dry Lake a much clearer picture of the past environment might emerge.

It would also be worthwhile to know the age of the vegetation represented by the Fossil Forests on San Miguel. The ages could be determined by radiocarbon dating the fossil organic residue present in the hollow interiors of many rhizoconcretions.

The problem of the 75 foot terrace on San Miguel and Santa Rosa Islands is also in need of resolution. Further field work on both islands surely would shed light on the matter.

It was hypothesized in the text (and by others) that eolianite grain size decreases and carbonate percentage increases downwind from the source area. This model could easily be tested by grain size and carbonate analyses of sand collected at an eolian source area on the beach at SMI-237 and at regular intervals downwind. Moreover, detailed C-14 and dip direction studies of eolianites on all the islands where they occur would define the paleowind direction and ages of eolianites in the offshore area of California. Such information would be very useful to island researchers.

A soil-geomorphological study of the stair-step marine terraces of San Clemente Island referred to in Chapter 6 would shed light on the origin and relative age of the terraces and the Vertisols formed on them as well as the stone pavements. Furthermore, an eolianite-paleosol complex rests upon these terraces that contain considerable charcoal, which can be radiocarbon dated.

Future research can also shed light on the question of whether a land bridge to the Northern Channel Islands ever existed. If, for example, a series of sediment cores taken from the sea floor to the depth of bedrock were collected and found to contain soil or other clearly in situ terrestrial sediments the idea of a land connection would have solid support.

Another area of fruitful research is a study of the origins of giant A_2 horizons in the Green Mountain Soil, and the continued study of ironstone concretion origins. Light shed on these two problems would illuminate the origin of like features many mainland soils. As mentioned in the text, a study delineating the range of concretionary soils and closed-cone pines on the mainland may also prove rewarding since their respective general distributions hints at a relationship.

General Conclusion

This study has shown that the esthetically and scientifically appealing landscape of San Miguel Island is the product of a multiplicity of environmental events, cycles, pulsations and episodes involving tectonics, sea-level, marine processes, precipitation, wind, fires, droughts, surface stripping, soil processes, vegetation, elephants, sheep, man, stream erosion, landslides and other geomorphic processes. Indeed, this small but fascinating insular landscape epitomizes the interplay of environmental elements in a natural system. Students of the environment are advised that erosion--and the products of erosion--can often be the esthetic and scientific friend of humankind, not our enemy. San Miguel, like many of our national parks, monuments, and places of esthetic and scientific interest, is essentially the product of erosion.

Finally, in geomorphological and geological work the present is usually viewed as providing keys to the past. This study, however, has shown that the past can provide valuable keys with which to better understand the present.

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APPENDIX A

AIRPHOTOMOSAICS AND MAPS

In order to present the information contained in this thesis in the clearest possible way I have found it necessary to call on the use of numerous diagrams, graphs, charts, photographs, and especially maps. It is to these maps that I wish to call the reader's attention.

There are six large maps, five small lithograph maps, and five airphotomosaics (photomaps) in the back pocket. Air photographs for Photomaps 1, 2, 3 and 4 were taken respectively in 1929; on May 7, 1940; on May 13, 1954; and on April 1, 1960, and are provided in order to show detailed changes in vegetation and the general surface character of the island since 1929. The four photomaps are also found on Plate 11 along with two topographic maps. All may be used in conjunction with Frontispieces A and B, and Plates 12, 13 and 14.

The fifth photomap shows numbered locations of sites referred to in the text. Most of the numbers have pointers that direct the reader to precise places of interest, or at least as close to them as the width of the line allows. The numbered location map is supplemented with a place name map, Map 1 (see also Lithomaps A and D).

Map 1 (place name map) is useful when referring to general rather than specific areas; for example, a cove or a canyon. The origin of the place names is threefold: (1) pre-existent names shown on the two U. S. Geological Survey Topographic Maps, San Miguel East and West Quadrangle, 7.5 minute series; (2) specific places like canyons, points and headlands were taken either from early maps (e.g., Otter Harbor, Lion Rocks, Offshore rock, China Harbor, Cormorant I., Cañada Casa), or were given the names of personalities or events that have contributed in some way to the colorful history of the island (hence Nidever Canyon--Nidever owned the island for many years; Anubis Point--Anubis was a German liner that went aground off Castle Rock in 1908 which generated lively newspaper accounts, and so on); (3) descriptive names given to general areas that evoke mind pictures to the reader (thus West End Dune Fields, Sandblast Pass, The Gangplank, Fossil Forest I). Some of the names are clearer on Lithomaps A and D because two colors could be used in the printing process.

Map 2 (cf. Lithomaps B and D) is a physiographic diagram of San Miguel Island surrounded by nine surface profiles. Map 4 is a physiographic diagram only. Both maps 2 and 4 show well the topographic character of the island and are referred to extensively in the text. Map 3 (cf. Lithomap C) is a regular topographic map. Map 5 is a generalized geologic map of the Santa Barbara Channel region taken from U. S. Geological Survey Professional Paper 679 (Hamilton, et al., 1969). Map 6 is a copy of the original topographic map executed in 1871 by S. Forney (courtesy U. S. National Archives).

Finally, five lithomaps are provided, four of which supplement and clarify Maps 1, 2, 3 and 4. The fifth, Lithomap E, is the Generalized Soil Map of San Miguel.

APPENDIX B

ANCIENT BEACH DEPOSITS AND MARINE TERRACE DESCRIPTIONS AND MEASUREMENTS

Please see Chapter 3, page 104 for text reference to these descriptions, and interpretations. For the locations and place names, see Photomap 5 and Map 1. The figure numbers in this appendix are independent of those in the text.

SMI-39 (Tyler Bight)	A 60 foot platform (fore edge), shell debris on surface.
SMI-38 (Tyler Bight)	A 60 foot platform with beach cobbles.
SMI-12 (Tyler Bight)	A beach deposit at 430 feet consisting of marine shells and water-worn pebbles.
SMI-35 (Tyler Bight)	Three, possibly four, marine (?) platforms present, but no beach deposits (Fig. 1, this appendix).

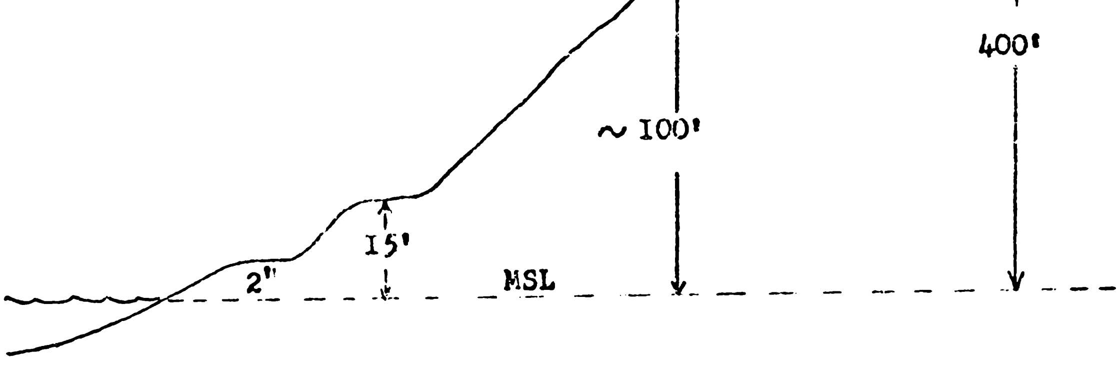


Figure 1. View to west showing "platform" elevations. Although three small platforms are present at SMI-35, only the topmost can be unequivocally interpreted as being marine in origin.

SMI-36 (Tyler Bight)	A 40 foot platform, no terrace debris.
SMI-123 (Spillway)	Fore edge of terrace 290 feet in elevation consisting primarily of caliche encrusted pismo clams (<u>Tivela stultorum</u>), with both articulated and disarticulated valves; wave-worn pebbles are also present. George Kritzman, an archaeologist who has worked extensively on the island, speculated that the shells may have been brought in by aborigines, but C-14 analysis gave an age of > 37,800 radiocarbon years (N-781). The report which accompanied the analysis indicated that the level of C-14 activity was extremely low which suggests that the sample is far older than 37,800 years.
SMI-243 (near Abalone Point)	Fore edge at 30 feet with abundant wave-worn, partially weathered cobbles and gravels (Plates 38a, 39c). A paleosol 2 feet thick overlies the terrace cobbles. Three dune units overlie the paleosol and are intercalated by two additional weakly developed paleosols, capped by a modern soil and a midden. All except the latter have been truncated, and the modern soil has developed on the truncation surface (Fig. 2, this appendix).

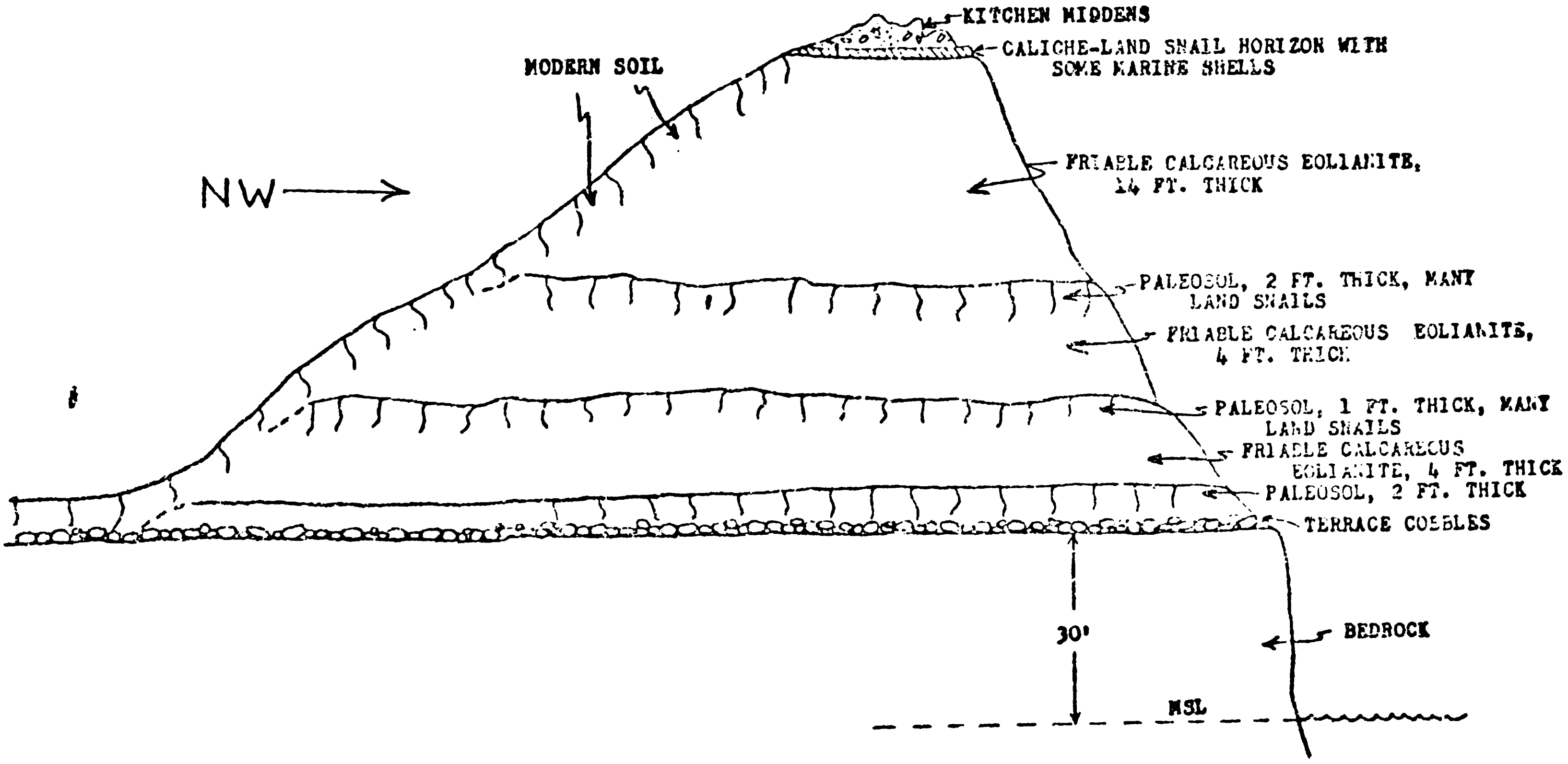


Figure 2. Observed terrace relationships at SMI-243.

SMI-22 (Busted Balls Cove)	Fore edge at 40 feet overlain by caliche and eolianite, a cobble layer, and various paleosols shose relationships are shown in Fig. 3, (this appendix).

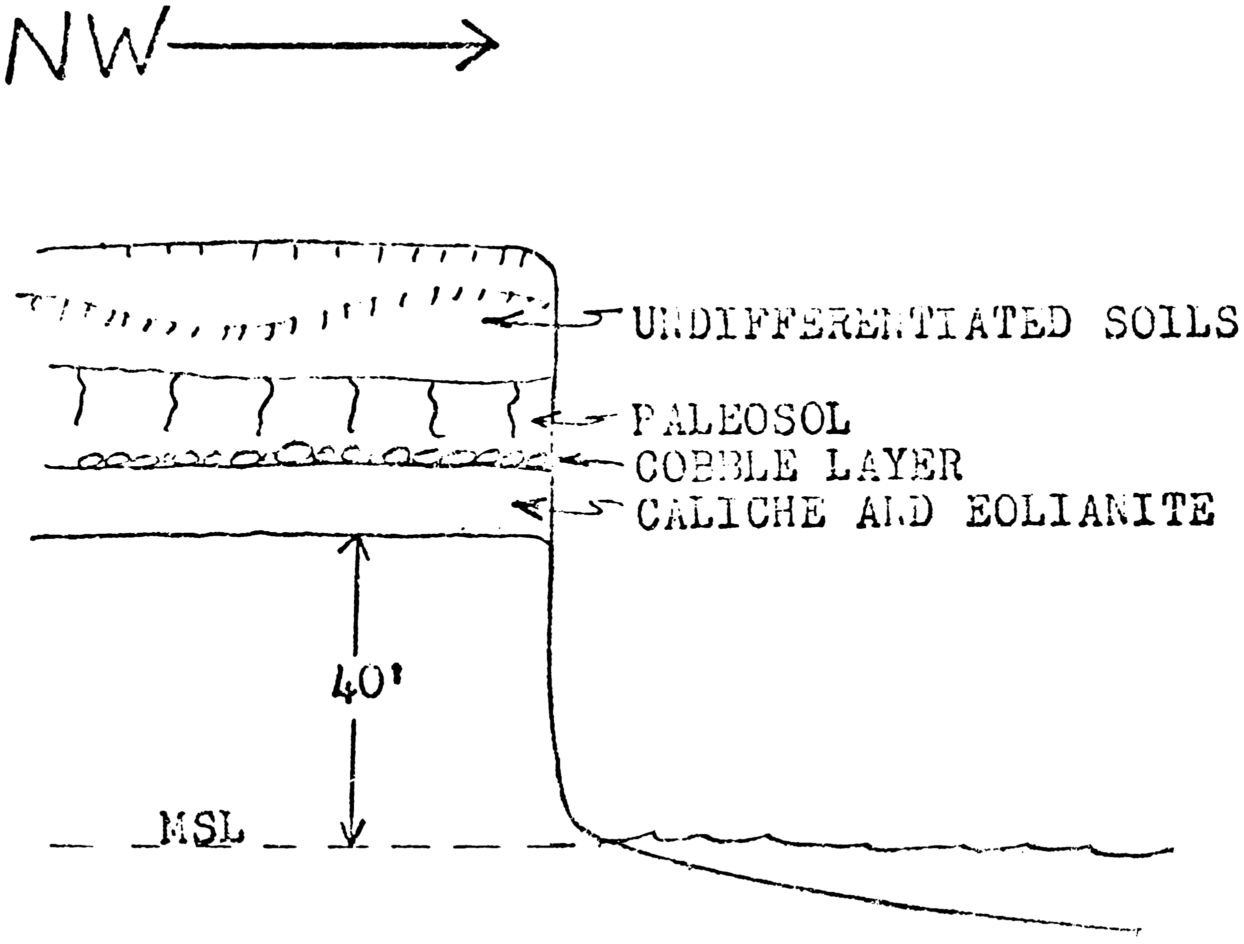


Figure 3. Observed terrace relationships at SMI-22.

SMI-23 (Busted Balls Cove)	Fore edge of platform which varies from 6 to 10 feet elevation above mean sea-level veneered at the seaward edge with 3 feet of cobbles and boulders of quartzite, shale, siltstone, and sandstone, with comminuted marine shells and land snails. The beach conglomerate pinches out landward over a distance of 25 feet and in places is lithified with calcium carbonate (beachrock). The relationships of this terrace complex are given in Figure 4 (this appendix) and to a certain extent in Plates 38c, 40, 41, 42, and 44a.

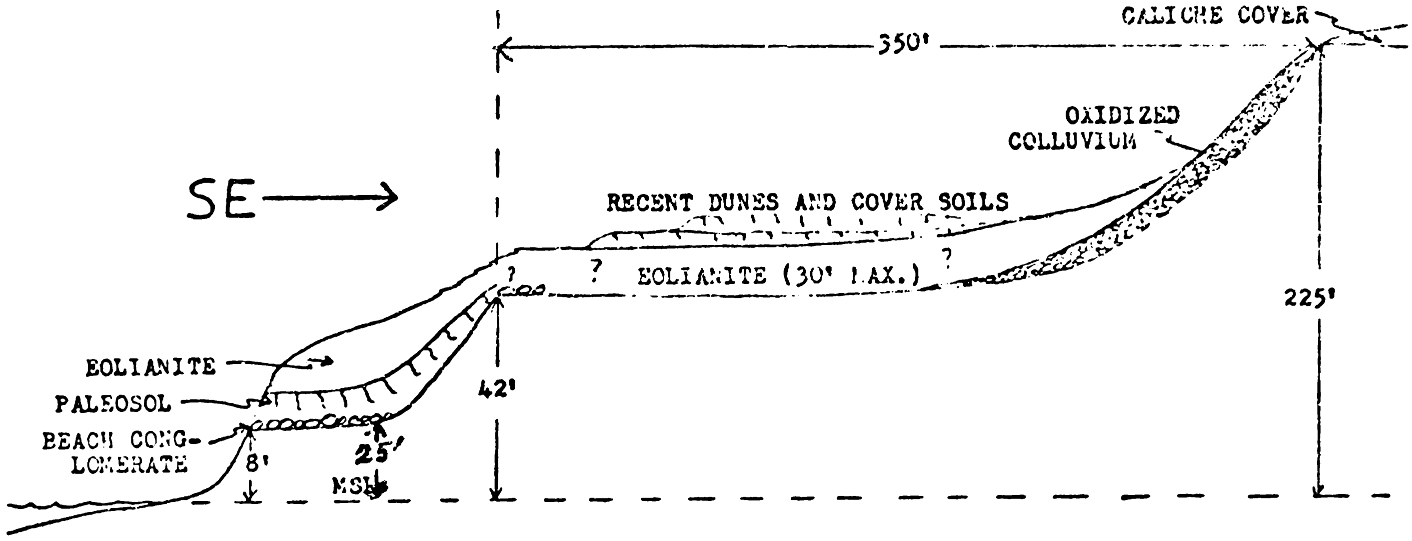


Figure 4. Terrace relationships as observed at SMI-23.

SMI-245 (Busted Balls Cove)

Three terrace platforms occur between and including SMI-147 and 245. The shoreline angle of locality 147 is about 25 feet above mean sea-level and consists of approximately 2 feet of wave-worn boulders and cobbles resting on truncated Cretaceous sandstones and shales (Plates 39a and 41b); whale bones also are present (identified by C. Repenning). The beach conglomerate is overlain by caliche and eolianite which also blankets part of the upper terraces. The relationships of this terrace complex are shown in Figure 5 (this appendix).

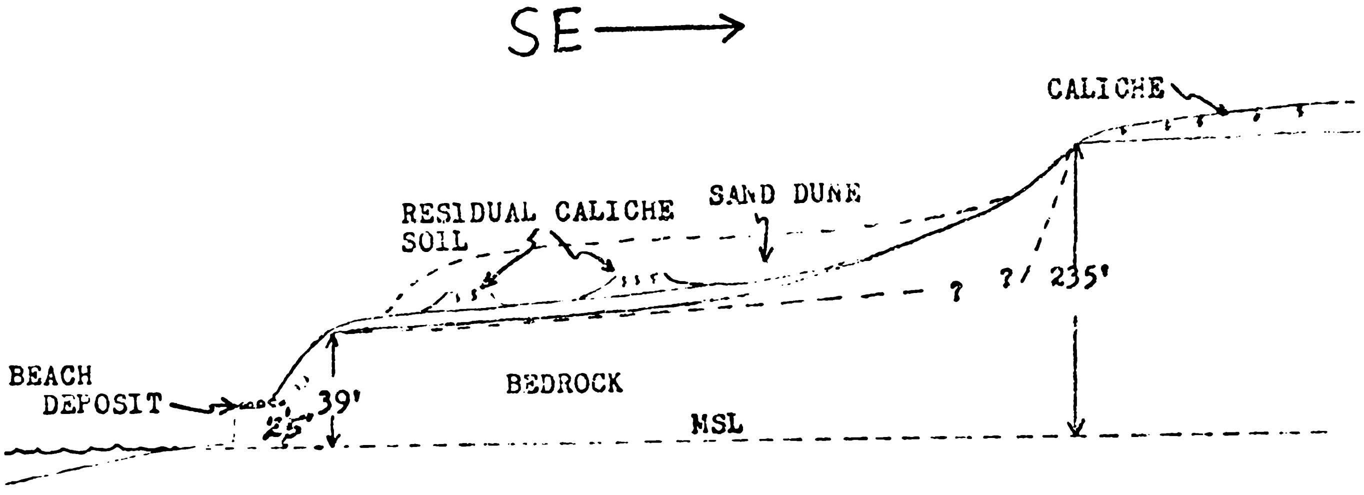


Figure 5. Marine terrace relationships at SMI-147, 245.

Plate 39b shows the beach deposit-platform interface of the upper terrace of SMI-245 at 235 feet elevation; caliche has precipitated within the beach deposit and along the bedding planes of the bedrock to a depth of 4 feet and shows as white diagonal bands in the lower part of the photo. The beach deposit ranges from essentially 0 to about 2 feet in thickness and has abundant mollusks, which are listed below (identified by W. O. Addicott, U. S. Geological Survey).

Gastropods:
Acanthina sp.
Acmaeids
Acteocina culcitella (Gould)
Amphissa sp.
Bittium eschrichti forma *montereyense* Bartsch
Bittium attenuatum Carpenter
Bittium sp.
Calicantharus fortis (Carpenter)
Colisella cf. *C. limatula* (Carpenter)
Colisella cf. *C. scabra* (Gould)
Crassispira sp.
Crepidula cf. *C. aculeata* (Gmelin)
Crepidula sp.
Elaeocyma empyrosia (Dall)?
Epitonium sp.
Homalopoma luridum (Dall)
Lacuna cf. *L. unifasciata* Carpenter
Lirularia optabilis (Carpenter)
Littorina cf. *L. scutulata* Gould
Mangelia nitens Carpenter
Margarites lacunata Carpenter
Nassarius mendicus forma *cooperi* (Forbes)
Odostomia sp.
Ocenebra cf. *O. tenuisculpta* (Carpenter)
Olivella biplicata (Sowerby)
Tegula funebralis (Adams)
Trophonopsis? sp.
Undetermined minute gastropods

Pelecypods:
Epilucina californica (Conrad)
Glans subquadrata (Carpenter)
Macoma nasuta (Conrad)
Macoma secta (Conrad)
Tellina carpenteri Dall?
Transenella tantilla (Gould)

SMI-128 (Tusk Wash)	The fore edge of SMI-128 is at the same elevation as SMI-245 and is about 150 yards northeast. The importance of this locality is the presence of a pygmy elephant tusk (Plate 43e, f), and though it appears to lie in the marine terrace debris it cannot be unequivocally demonstrated to be depositionally time-contemporaneous with the marine unit. Terrestrial calcareous tufa lies at and above the level of the tusk, but not below. The beach deposit is capped by caliche and is traceable between localities 128 and 245.
SMI-220, 221 (Bone Bight)	Photographic localities (Plate 45) showing truncated Cretaceous bedrock, beach conglomerates, and overlying eolianite-paleosol complexes. The fore edges shown vary in elevation due to different levels of the Pleistocene sea and differential erosion of cliff face.
Running Springs (Travertine Cove)	This locality includes the series of springs that issue at the bedrock-eolianite contact at elevation 200 feet. The field relations are shown in Figure 6 (this appendix).

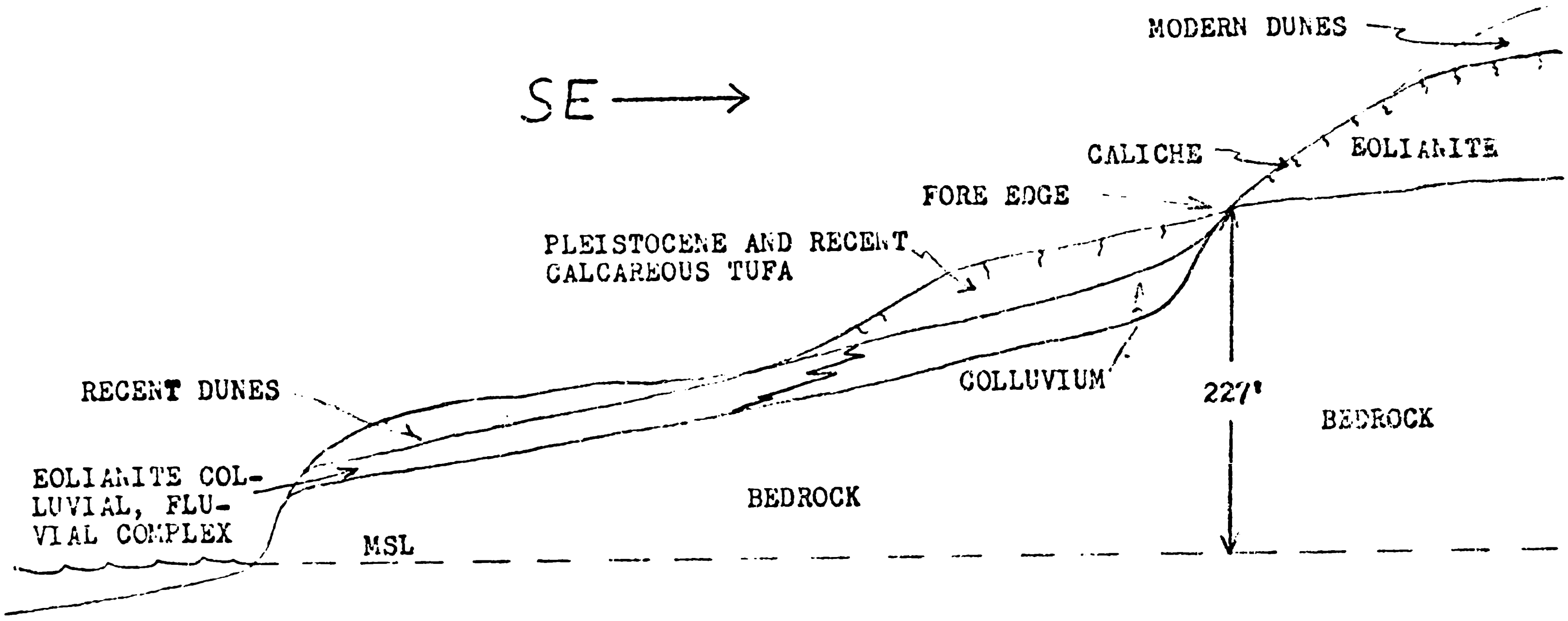


Figure 6. Running Springs terrace and cover relationships.

SMI-81 and 217 (Bowl Cove)	A low and a high terrace occurs here and an intermediate terrace occurs nearby (SMI-149). The fore edge of the low terrace varies from an indeterminable shoreline angle elevation to sea-level and actually appears to pass below sea-level (SMI-217). The low terrace consists of a marine platform overlain by a bouldery beach deposit that is in places well indurated by caliche

(Plate 47a). Many comminuted marine shell fragments occur with the boulders. At its seaward edge the beach deposit is overlain by a locally thick paleosol but landward a sand unit which varies from sea-level to more than 40 feet thick lies between the boulder beach and paleosol. Other more recent sand units overly the paleosol and are intercalated by other, less developed paleosols as shown in Plate 49.

The high terrace fore edge (SMI-81) was measured at 285-290 feet above mean sea-level and consists of an indeterminant thickness of beach cobbles and marine organic debris overlain by an eolianite-caliche complex that measures up to 150 feet thick. The relationships of the low and high terraces are shown in Figure 7 (this appendix).

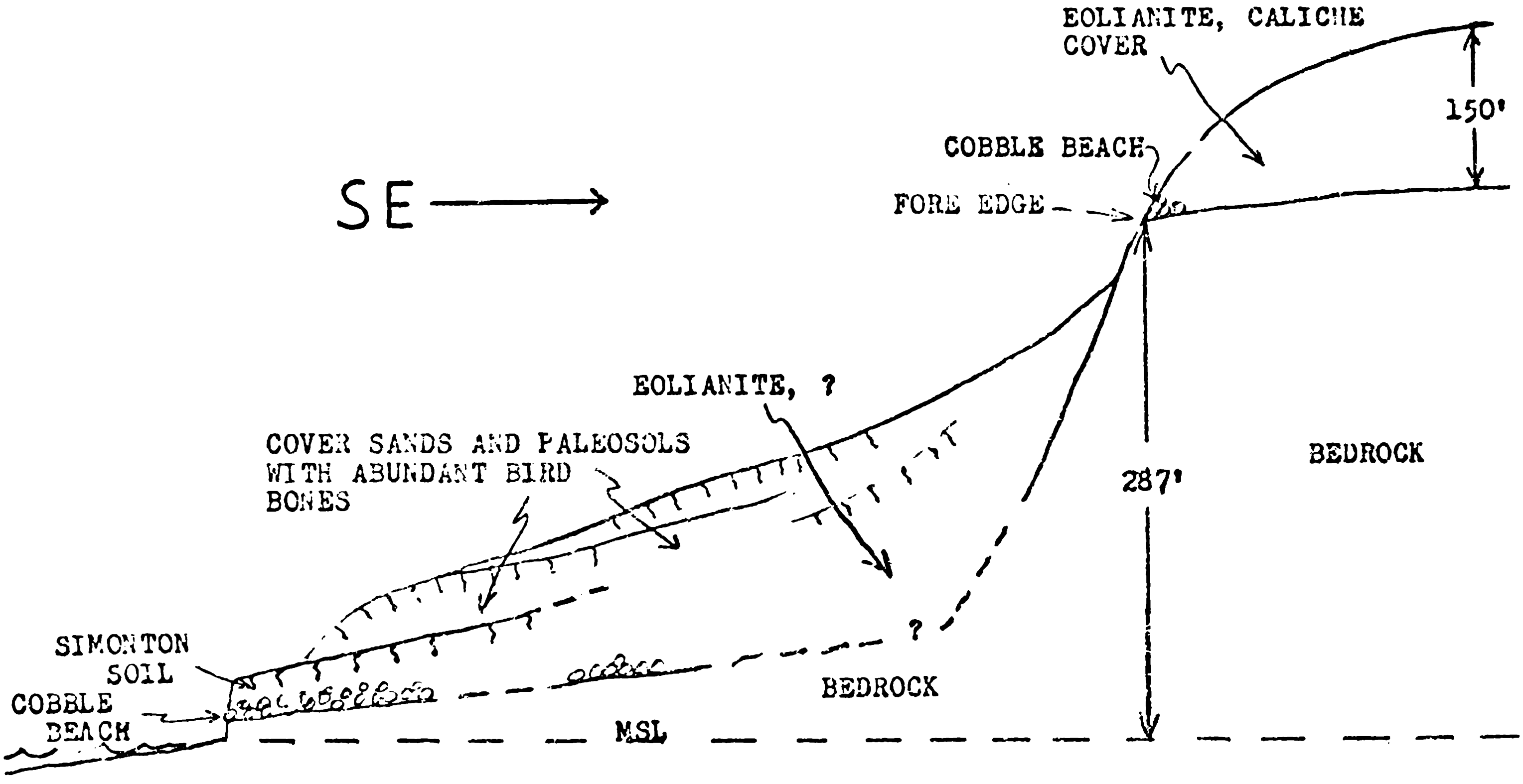


Figure 7. Terrace relationships at Bowl Cove (SMI-81, 217).

SMI-181, 214
191, 102
(Fossil Point
Oil Point)

Fossil Point (SMI-181, 214) is marked by a marine platform overlain by the Simonton Soil both of which are being actively eroded by the sea (Plate 50). The Simonton Soil has developed across the platform and soil-forming processes associated with it have indurated the upper 4 feet of bedrock with caliche (see Plate 50c). Eolianites and intercalated paleosols have formed over the Simonton Soil here which has a C-14 date of greater than 40,000 radiocarbon years.

Oil Point is characterized by a modern marine platform (SMI-191) with another platform immediately behind it (landward) that rises from sea-level to 6 feet. Upon the latter platform is a bouldery beach deposit overlain by the Simonton Soil. Eolianites and intercalated paleosols occur above the Simonton Soil (see Insert c, Photomap 5). All of the marine terraces in this part of the island from Otter Harbor to Harris Point are exposed only at their fore edge.

SMI-32, 227
(Crawford
Canyon)

Crawford Canyon has terrace relationships as shown in Figure 8 (this appendix). The back edge of the intermediate terrace is alluvium buried but is inferred to be in the neighborhood of 65 to 75 feet elevation. An interesting feature of this locality is the only observed occurrence of eolianite below the distinctive oxidized, cliff-derived talus. This oxidized talus, derived principally from the Cretaceous Jalama Formation, was observed in other places to rest directly upon the beach or other deposits of the marine terraces.

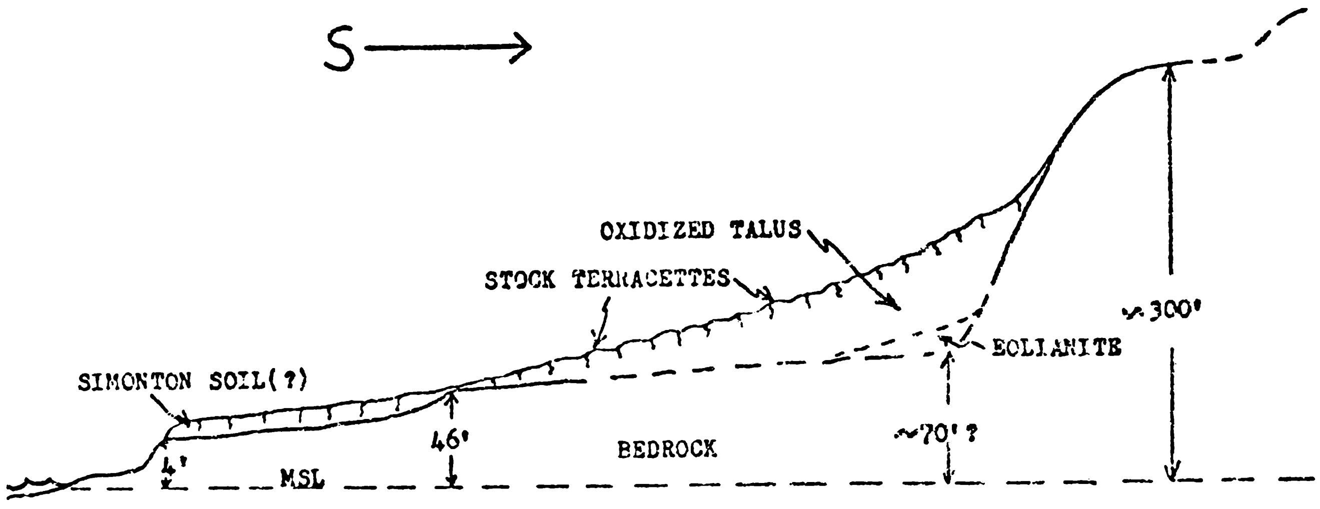


Figure 8. Crawford Canyon field relationships (SMI-32, 227).

SMI-83

The shoreline angle in Ward Wash is also unexposed but is estimated to be in the neighborhood of 65 feet. The alluvium in the floor of the Wash at its base of the ancient sea cliff measured 70 feet elevation. The terrace relationships are shown in Figure 9 (this appendix). The ∼300 foot fore edge elevation in Figures 8 and 9 (this appendix) were both estimated from topographic maps.

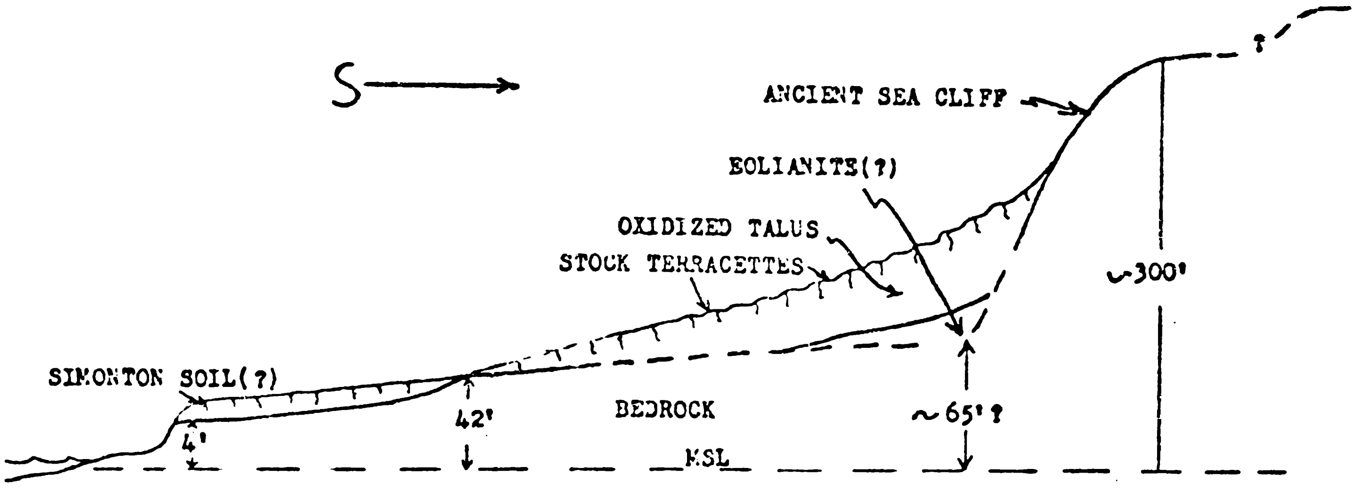
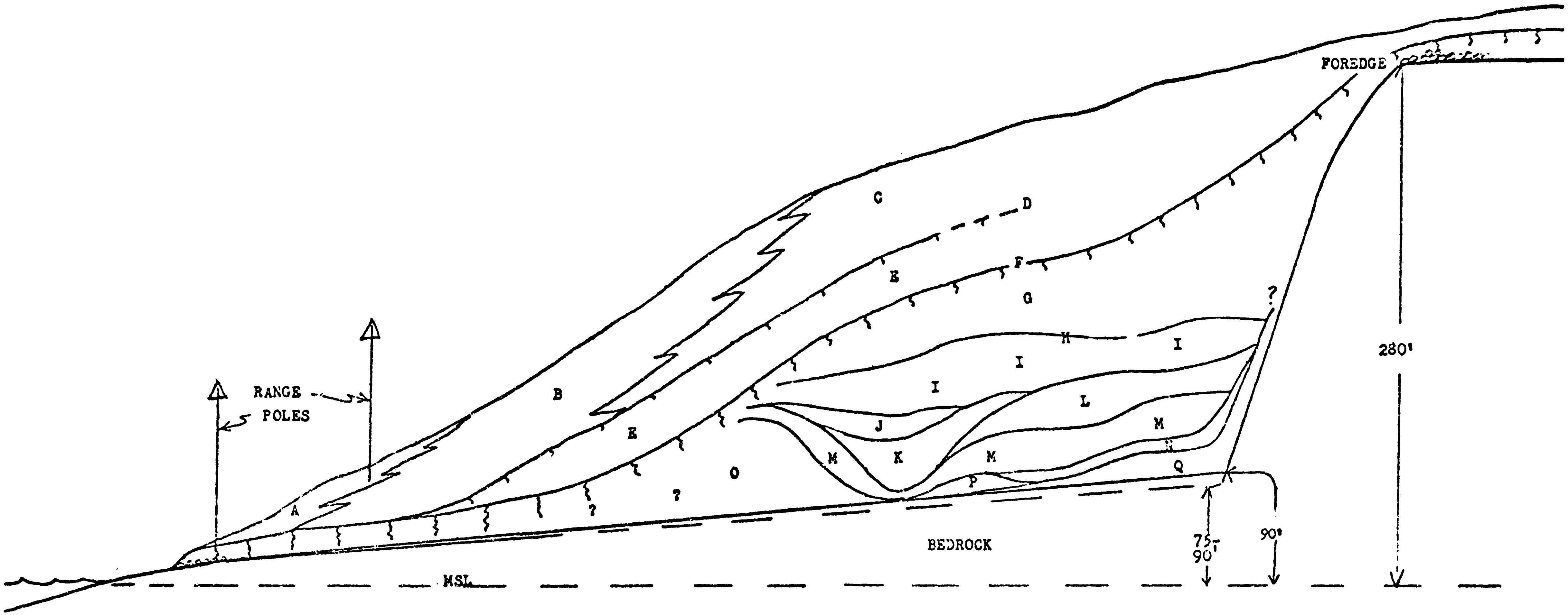


Figure 9. Ward Wash field relationships (SMI-83).

Range Pole Canyon

As indicated, the shoreline angles of all the terraces in Simonton Cove are unexposed so that only estimates of their elevations may be made. Figure 10 (this appendix) shows the marine terrace relationships on the east side of Range Pole Canyon, its complex cover deposits, and estimates of back edge elevations inferred from the contact of the stream floor and old sea cliff. The shell midden (F) occurs in the upper 4 inches of the Simonton Soil and has been radiocarbon dated at 7,580 ± 140 radiocarbon years (I-4852). As much as 140 feet of eolian (mainly) sand overlies this soil on the west side of the canyon. The sedimentary complex which underlies the Simonton Soil is referred to as the Simonton Sedimentary Event and is interpreted as being post-Sangamon in age, and probably was emplaced shortly after the sea withdrew from the immediate area.



A. EOLIANITE
B. ALLUVIUM
C. EOLIANITE, ALLUVIUM
D. INCIPIENT SOIL
E. EOLIANITE, ALLUVIUM
F. SIMONTON SOIL, SHELL MIDDEN
G. EOLIANITE, MAXIMUM THICKNESS 40 FT., RHIZOCONCRETIONS, BIRD BONES
H. INCIPIENT SOIL
I. EOLIANITE, MAXIMUM THICKNESS 20 FT., RHIZOCONCRETIONS, COLLUVIUM NEXT TO CLIFF
J. EOLIANITE, MAXIMUM THICKNESS 12 FT., RHIZOCONCRETIONS
K. EOLIANITE, DEPOSITED FROM WNW DIRECTION, RHIZOCONCRETIONS, MAXIMUM THICKNESS 15 FT.
L. ALLUVIAL UNIT, DERIVED FROM ESE DIRECTION, MAXIMUM THICKNESS 9 FT.
M. EOLIANITE, STEEPLY DIPPING LANDWARD, MAXIMUM THICKNESS 20 FT. (NEAR CLIFF), RHIZOCONCRETIONS
N. ALLUVIAL AND COLLUVIAL (AT CLIFF FACE) UNIT, CAPPED BY INCIPIENT SOIL, MAXIMUM THICKNESS 4 FT.
O. EOLIAN UNIT, INCIPIENT SOIL AT TOP, MAXIMUM THICKNESS 20 FT., MANY RHIZOCONCRETIONS
P. EOLIAN UNIT, CAPPED BY INCIPIENT SOIL
Q. COLLUVIUM, SLOPEWASH, AND TALUS, MAXIMUM THICKNESS 8FT., PINCHES OUT HORIZONTALLY, OXIDIZED ON SURFACE

Figure 10. Range Pole Canyon field relationships. The Sedimentary complex which underlies the Simonton Soil is referred to as the Simonton Sedimentary Complex, and was emplaced during the Simonton Sedimentation Event. This event is provisionally correlated with another, major sedimentation episode referred to as the Green Mountain Sedimentation Event discussed in Chapters 5 and 6.

SMI-161, 186
(Charcoal Cove
Canyon)

The stream in Charcoal Cove Canyon has exposed a high and intermediate terrace fore edge and cross-section of the Quaternary cover, as shown in Figure 11 (this appendix). See also Plates 52, 54b for reference.

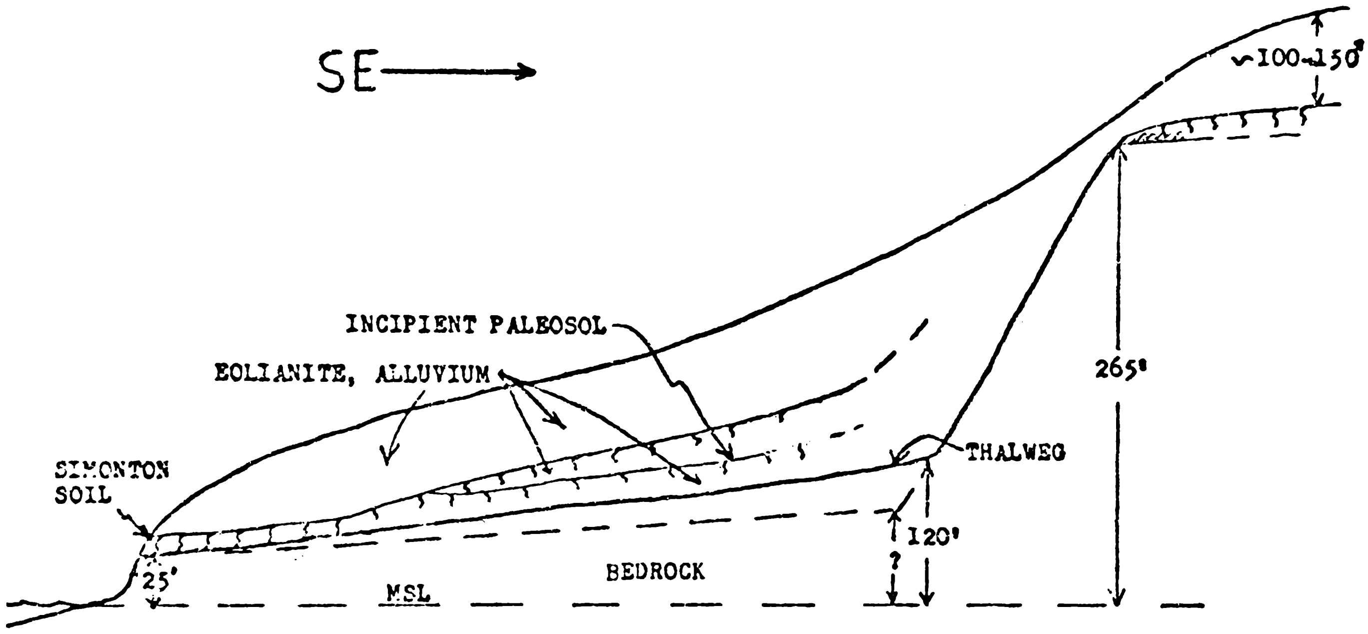


Figure 11. Charcoal Cove Canyon field relationships.

SMI-4
(Cuyler
Slide)

The massive landslide which occurred about 1940 left exposed in the headwall a marine terrace fore edge, a fossiliferous beach deposit, and a Quaternary cover consisting of numerous eolianite units and at least ten intercalated paleosols. (Plates 59c, 67, Fig. 12, this appendix). This beach deposit also outcrops at about the same elevation on the north side of Cabrillo Overlook.

As mentioned in Chapter 3, pinniped bones were found in the eolianite immediately above the beach zone at SMI-4.

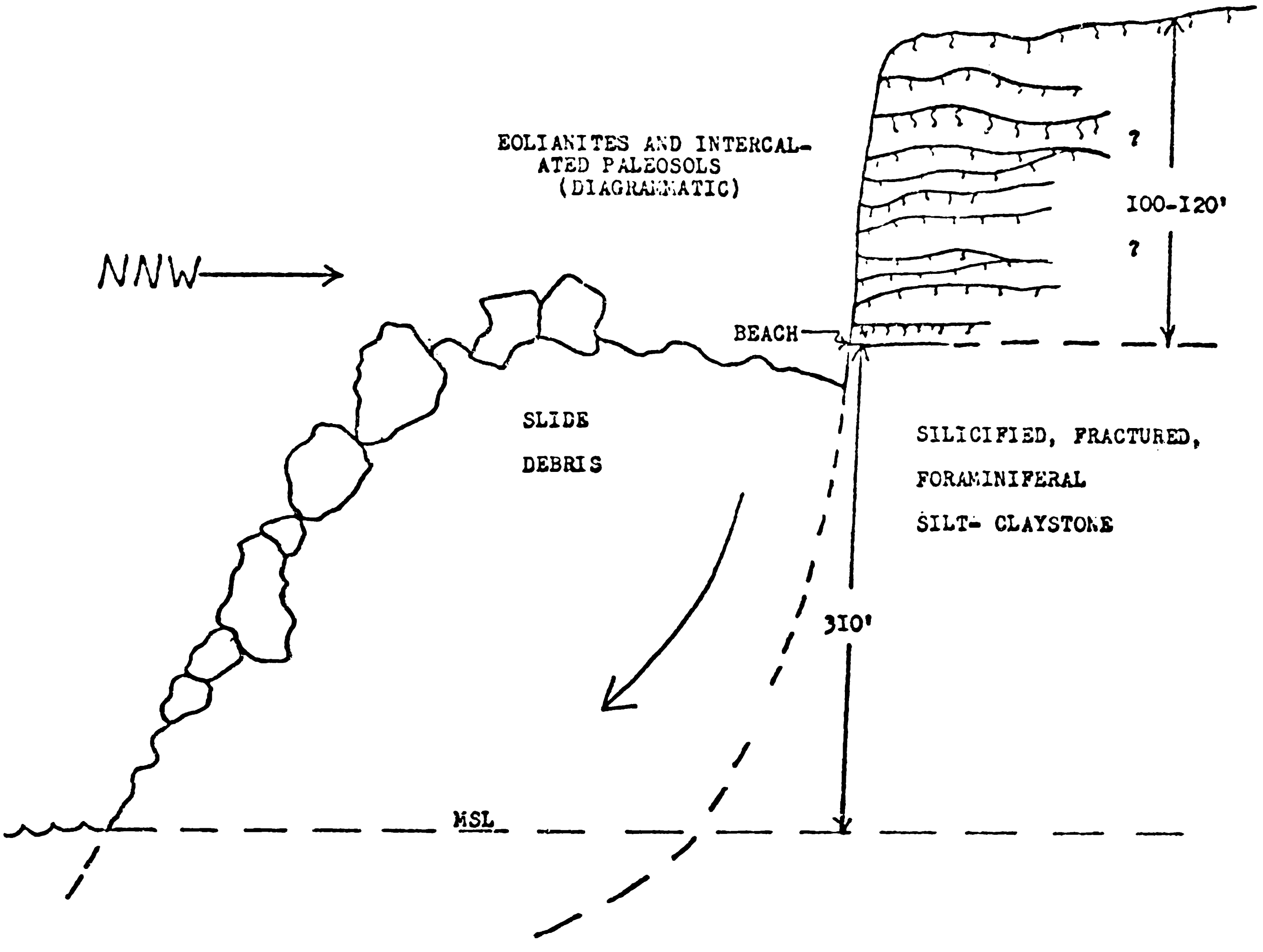


Figure 12. Cuyler slide showing terrace eolianite and paleosol relationships.

SMI-230
(The Up-
heaval)

Another big slide took place in Cuyler Harbor on March 9, 1895 and left exposed in the north headwall a Pleistocene marine deposit that consists of fossiliferous sands at 290 feet which gradually give way vertically to eolianite. This marine deposit may have been emplaced by the same seas that emplaced the beach deposit at Cuyler Slide. The actual boundary between the marine and non-marine units was not identified but occurs at an indeterminant distance above the 290 foot level. The field relations are given in Figure 13 (this appendix).

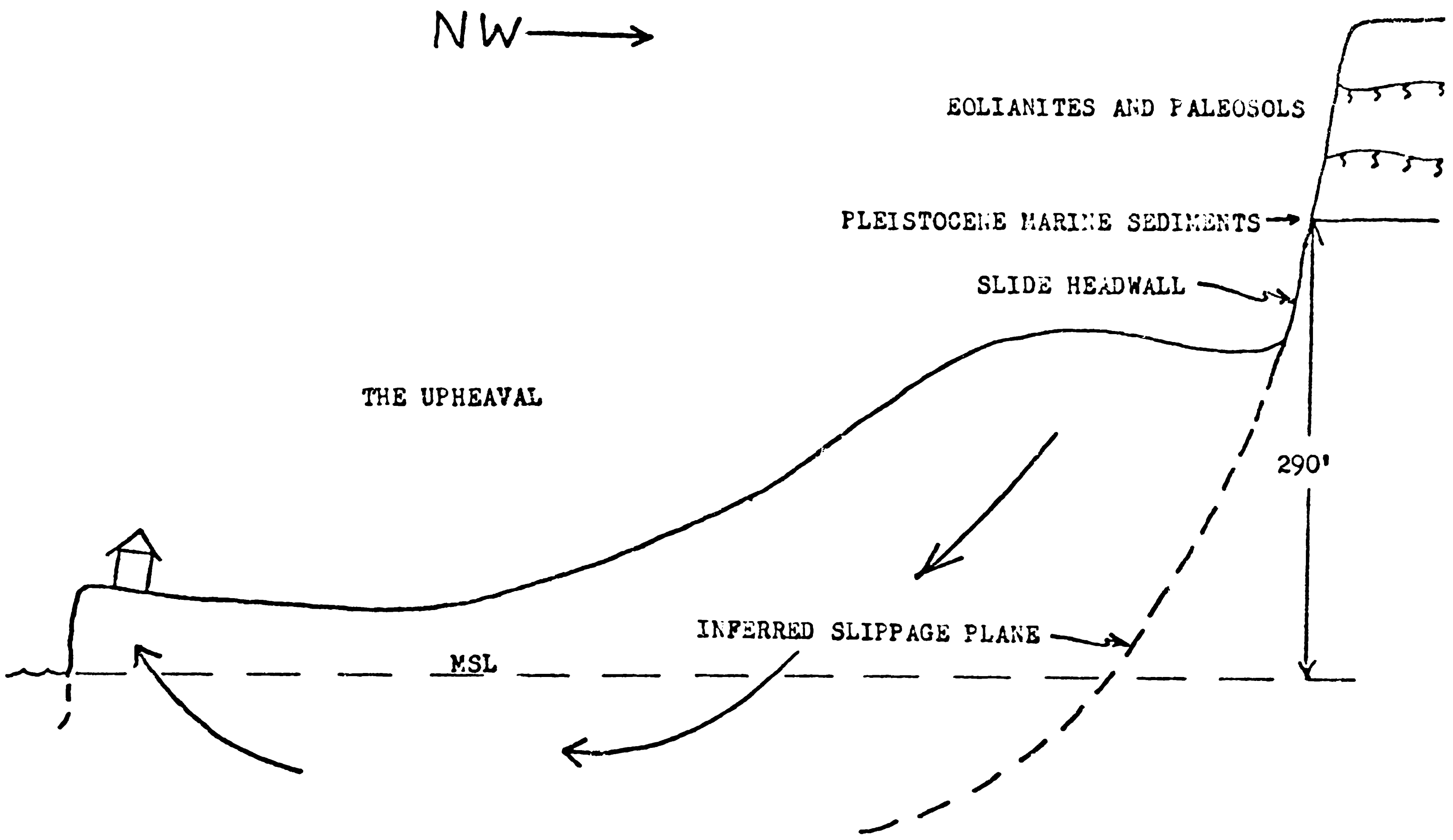


Figure 13. The Upheaval, Cuyler Harbor.

SMI-67	There is a low terrace exposed in the bedrock on the northside of the upheaval in Cuyler Harbor just above water level. The terrace platform is overlain by marine cobbles with a few shells and has a shoreline angle at an elevation about 25 feet above mean sea-level. This shoreline angle is correlated with the 25 foot shore line angles in Bone Bight described previously (Plate 41b). There is also poorly preserved and suggestive evidence of a terrace at this elevation occurring at several other places around the island.
SMI-85 (West Cuyler Slumps)	Pleistocene marine sediments, superposed eolianites, and paleosols are exposed here also as a result of extensive earth slumping. A platform-marine sediment interface occurs at 325 feet elevation (Fig. 14, this appendix, Plates 60. 62c).

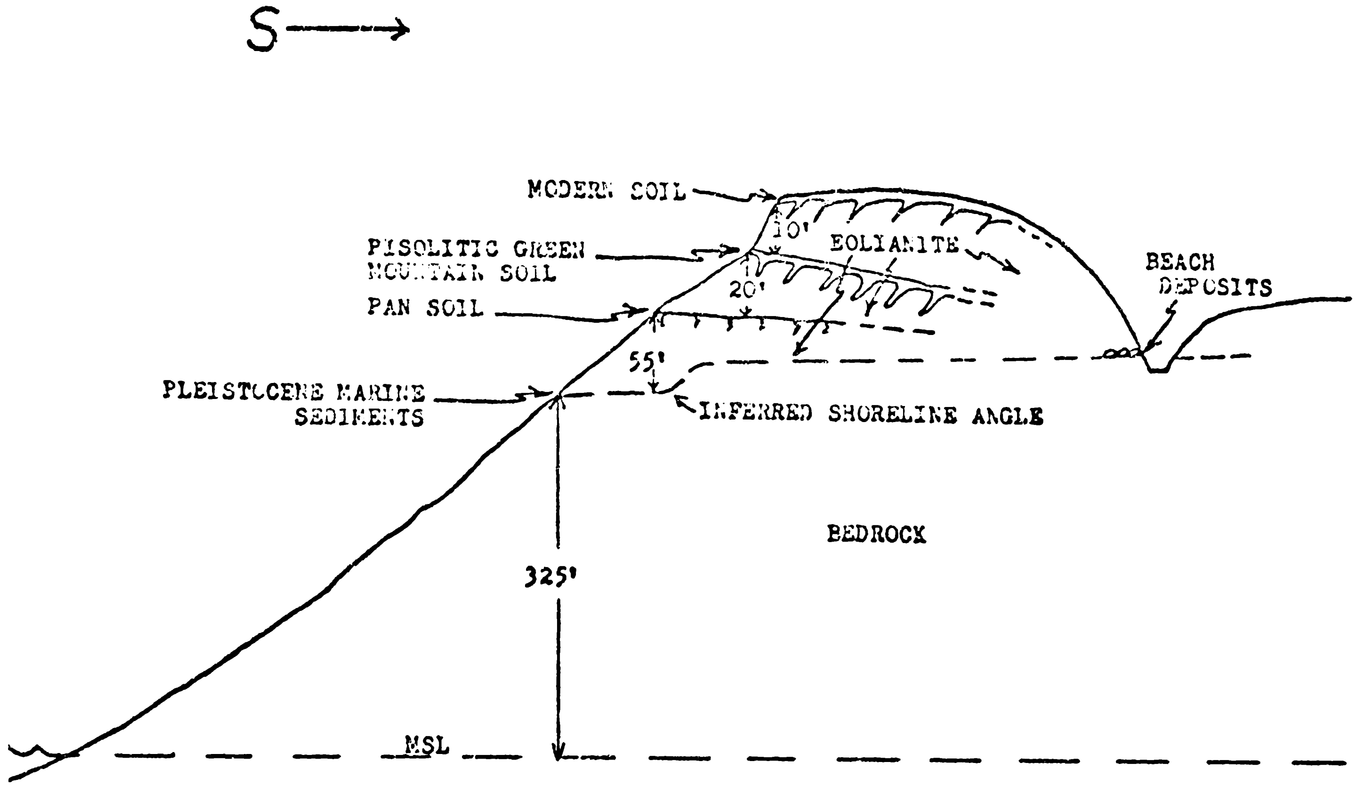


Figure 14. Field relationships at SMI-85, West Cuyler Slumps.

The marine sediments are fossiliferous and have yielded abundant pelecypods of the species Transenella tantilla (Gould) as well as a fragment of a minute gastropod ". . . that appears to be a pyramidellid." (Marine shells identified by W. O. Addicott.) Addicott (personal communication, 1971) points out that the present bathymetric range of Transenella tantilla is intertidally to depths of 120 feet off the California coast today. Because many of the T. tantilla valves were in a closed, articulated state which suggests that the enclosing sediments were not subjected to extensive reworking by wave action following deposition, Addicott reasonably suggested that the depositional environment was towards the lower part of the depth range. However, the elevation of the platform correlates with the 325 foot shoreline angle at SMI-1 in Nidever Canyon several hundred yards east (see Fig. 15, this appendix). Modern shoreline angles frequently are intertidally located, which suggests that the marine unit at SMI-85 was intertidally deposited. However, it is possible that the T. tantilla shells were deposited in deeper water when the sea stood at a higher elevation, perhaps when the next higher platform was cut, and were somehow not reworked during the next regression. If the last interpretation is correct then the 325 foot platform predates the next higher platform which, though not impossible, is improbable as such events normally are interpreted.

SMI-1 (Nidever Canyon)

The only exposed high terrace shoreline angle observed during the field study period was on the east side of Nidever Canyon near its mouth at 325 feet elevation (Fig. 15, this appendix, Plates 60, 61, 62).

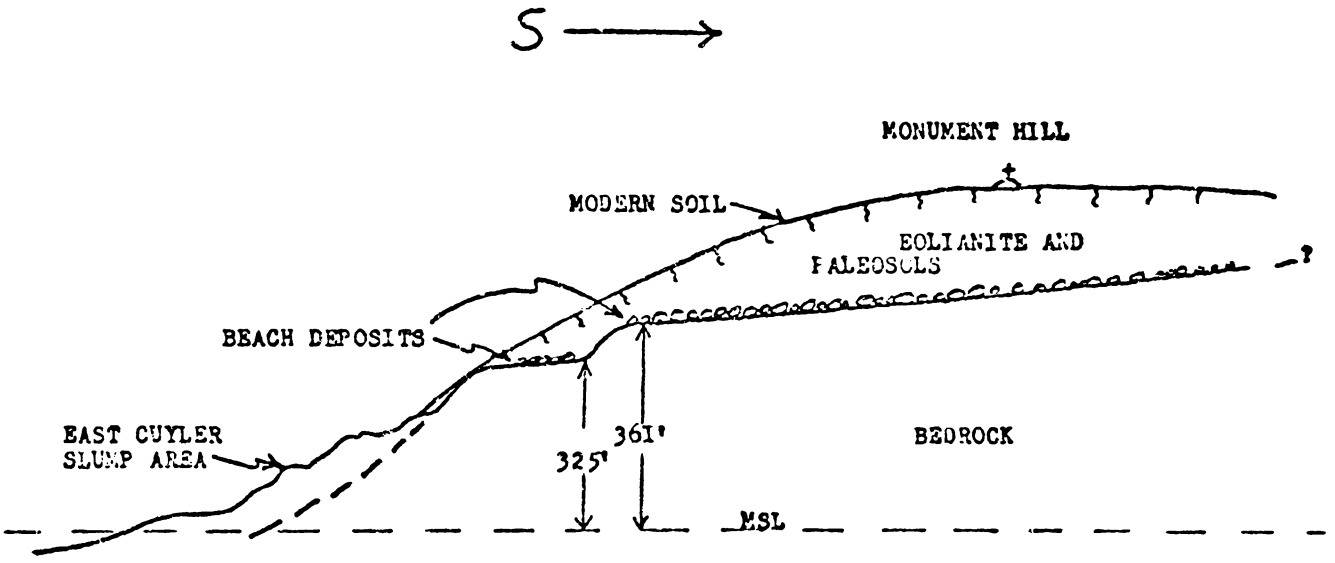


Figure 15. Field relationships at SMI-1, Nidever Canyon.

Above the shoreline angle an old sea cliff rises some 35 feet to another exposed terrace whose fore edge measures about 360 feet elevation. The upper platform slopes gently toward San Miguel Hill, but has no exposed shoreline angle. This same beach line also outcrops on the western side of Nidever Canyon (SMI-37). Fossils collected from the 360 foot fore edge include:

Gastropods:
- Acmaea mitra Rathke
- Colisella cf. C. mitchelli (Lipps)
- Crepidula princeps Conrad
- Crepidula cf. C. norrisiarum Williamson
- Diodora aspera (Rathke)
- Ocenebra?
- Olivella biplicata (Sowerby)
- Serpulorbis squamigerus (Carpenter
- Undetermined acmaeid

Pelecypods:

- *Epilucina californica* (Conrad)
- *Glycymeris* sp.
- *Hinnites multirugosus* (Gale)
- *Mytilus californianus* Conrad

(Identifications made by W. O. Addicott)

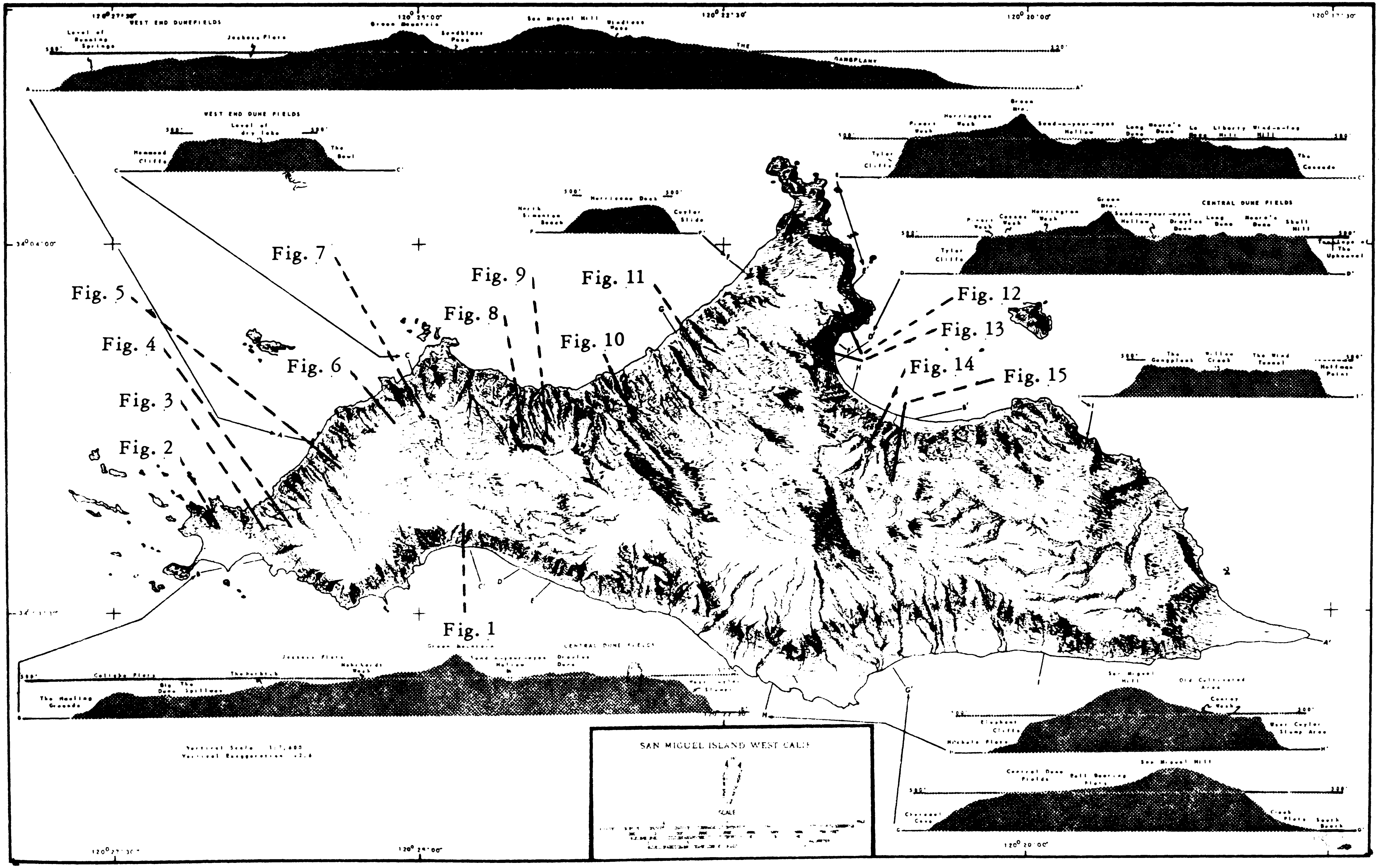


Figure 16. Locations of figures and transects listed in this appendix (Figs. 1-15).

APPENDIX C

DOCUMENTATION OF THE SWIMMING CAPABILITIES OF AFRICAN AND ASIAN ELEPHANTS

This appendix contains excerpts from a series of letters gained by personal correspondence with various elephant and wildlife specialists. There are also a number of excerpts from books on African and Asian elephants. Collectively these excerpts prove beyond question that elephants are excellent swimmers. They can and do swim long distances (several miles) and for long periods (several hours), as the following statements show.

Africa

> If necessary, they [elephants] will swim through the larger [chad] lakes, some of them as big as a thousand to three thousand square yards. It is a wonderful sight to see two hundred elephants, old and young, diving and swimming with great elegance, only the tops of their big heads showing above the water. (Oberjohann, 1952, p. 70; see also pp. 84-85).

> . . . [elephants] are very fond of water and all of them are good swimmers. In fact, it looks very much as if their ancestors may have been partially aquatic, at least to the extent that hippos are.
>
> Forest Loxodonts are very competent swimmers and spend a great deal of time in deep water, even in very swift rivers. The little ones actually dive, and all of them can regulate the depth at which they float by swallowing air or water. Normally they lower themselves till just the top of the head is above water, whereby they are still able to see. Then they curve the trunk into an 'S' so that it forms a breathing tube ahead. Forest Loxodonts make the same motions with their legs when swimming as when walking on dry land, and for some quite inexplicable reason this propels them ahead at a really astonishing rate. One would imagine that the drag against the water caused by the movement of their stubby legs forward would just about counteract any backward push, but you have to paddle hard in a native canoe to keep up with them.
>
> . . . [elephants] swim better than any other mammals regarded as being primarily terrestrial. (Sanderson, 1962, pp. 318-319).

It has not been my good fortune to see an African elephant swim, but Selous says they are good swimmers and that in his day it was a common thing for elephant to cross the Zambesi during the night between the Victoria Falls and the mouth of the Chobi. Captain Keith Caldwell, in his interesting account of the training of African elephants at Api in the Belgian Congo, says that the elephants which worked on the opposite side of the river swam over to their work and back, even when the river was in flood and deep. (Blunt, 1933, p. 38).

The author has failed to trace accounts of African elephants assisting their calves to swim, although this habit is well known in the Asiatic species. However, it is known that when swimming across a river African elephants, like the Asiatic also, place their calves on the upstream side. A singular idea that African elephants do not actually swim appeared in a recent book (Bourliere, 1954). While this may be true in zoos and in areas where there is no deep water or no necessity for swimming, or perhaps where the rivers are too turbulent, elsewhere African elephants are known to be good swimmers (Robins and Legge, 1959). They have been witnessed swimming in very deep rivers, including the lower Zambesi, Nile and its tributaries, and Ubangi-Chari and in Lake Chad--and it may be recalled that when Hannibal crossed the Rhone in Europe some of the elephant rafts overturned and, although some of the attendants were drowned, the African elephants in spite of their heavy foot chains swam ashore 'with great churning of the water.' African elephants are apparently equally happy to walk on the river or lake floor if it is sufficiently shallow, holding the trunk aloft periscope-wise, the calves swimming alongside. Calves thus learn early to swim in places where the elephants customarily bathe in deep water, but it is not certain whether they can swim instinctively or whether they learn to do so with parental assistance. It may be that the physical movements of swimming are instinctive, but that the incentive has to be provided by adult initiative, and confidence gained when the calf imitates and accompanies the adult. (Sikes, 1971, pp. 273-274).

This splendid old hunter (who wrote this just before he died in 1893 of his experiences round about 1840) also refers to the elephant's powers of swimming and how, on reaching the far bank of a river, if they fail to find a landing-place, they pound the bank with their forefeet until they get a footing, and then make steps, one by one, up the bank . . . (Melland, 1938, p. 110).

On the 7th February while proceeding by steamer up the Kagera river a small cow elephant was observed in the water struggling

> unsuccessfully to get up a steep bank. The water appeared to be several feet deep and it seemed curious that she did not move to easy exits either above or below her. The reason for her lack of enterprise was at once apparent when a diminutive calf a few days old was noticed in the water up-stream of its dam. This little fellow was treading water snuggling alongside its mother's huge body, with its head reared high out of the water which was most certainly too deep for it to stand.
>
> The wretched cow struggled for about twelve minutes before she achieved terra firma, and it was most unfortunate that at the psychological moment the boat was not close enough to see exactly when and how the youngster was lifted out. (Pitman, 1935).

Elephants have also been seen swimming to and from islands in Africa. For example, in the 1950's when Lake Kariba began filling upon completion of the Kariba Dam on the Zambesi, elephants swam from some of the islands to the mainland, and vice versa. Robins and Legge relate such instances during their attempt to rescue island-bound animals while the Kariba reservoir was filling:

> When the team returned to the island they found it deserted except for a trio of duiker. . . .
>
> Again there has been tragedy. The bull elephant calf was found dead in a clump of bushes. The ranger was unable to establish the cause of its death.
>
> It is believed that the two adult elephants had been 'called' ashore after the calf died by a herd of elephant which arrived on the mainland in the vicinity of the island between the two rescue attempts.
>
> A lone bull remained disconsolately on another island--this time on the south side--long after it had stripped the trees bare of foliage and the water was rapidly invading his desolate sanctuary. Hearing the sound of trumpeting from among the bush on the mainland a mile away, he bellowed a joyous reply and lumbered towards the mud. . . . he waded out far beyond the island. Chest-deep, the elephant took the plunge and struck out strongly, churning the water around him to a carpet of foam.
>
> During the long swim until he struggled ashore and shook himself before disappearing in the direction of the herd the bull held his trunk aloft like a periscope.

> One major scientific discovery arising out of the formation of the lake at Kariba is that all animals can swim, even if for a short distance. . . .
>
> Champion swimmers of the game on the lake are leopards, waterbuck and bushbuck which can cover up to one and a half miles. Elephant and kudu are also long-distance swimmers, both in the mile class. (Robins and Legge, 1959, pp. 129-130, 148).

On this matter Simon Trevor* also writes:

> When I worked on the Kariba Dam Operation in Rhodesia, elephants definitely swam from islands to the mainland on several occasions. As far as I can remember this was about a mile swim. They have also been seen crossing the Nile in Uganda which, although it is certainly less than half a mile wide, does have a very strong current which all goes to prove that elephants are very good swimmers.
>
> I . . . have seen them crossing rivers in Africa, and they seem to walk on the bottom until they are out of their depth completely, and then they adopt a porpoise-like action, going right under and then surfacing before disappearing again. One has only to watch baby elephants in deep rivers to get the idea of this motion.

Correspondence on January 4, 1972 from I. Miller** about this matter reads:

> I have been in touch with Mr. R. B. Fothergill [see acknowledgements page in Robins and Legge, 1950] who was in charge of the Kariba Game Rescue Operation and he informs me that he has frequently observed elephants swimming to islands in Lake Kariba over two miles from the shore and he is of the opinion that they could, if necessary, swim considerably greater distances.

Also on this subject, Mr. W. L. Astle*** writes:

> We believe that elephants swim to and from the islands in Lake Kariba and I believe that elephants would certainly be able to swim the distance you mention [four to six miles].

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*Personal correspondence, October 14, 1971; Mr. Trevor is a prominent wildlife photographer and animal expert in east-central Africa.

**Game Ranger, Regional Warden's Office (Mashonaland South), Department of National Parks and Wild Life Management, Causeway, Rhodesia.

***Personal correspondence, October 12, 1971; Mr. Astle wrote for the Director, Department of Wildlife, Fisheries and National Parks, Chilanga, Zambia.

Elephants have also been reported on all the islands in the north of Lake Edward in Uganda.

> The Queen Elizabeth National Park in southwestern Uganda which is situated around the north part of Lake Edward supported a fairly large elephant population. I was the Warden of this park for nine years and during my service in the area on two occasions an elephant moved across a part of Katwe Bay--a distance of two miles--and took up residence on an island in the middle of the bay; before my time this incident occurred at least once.
>
> Now I cannot say definitely if elephants actually swim. Katwe Bay is fairly shallow but I had no accurate information on the depths of the water. . . . . it is just possible that by using their trunks and walking or bouncing off the bottom they may be able to negotiate depths up to 15 feet.*

In regard to the depth of Katwe Bay, Mr. N. A. Din, Warden Scientific of Queen Elizabeth National Park, Uganda, in correspondence dated January 28, 1972, expressed the opinion that elephants probably are able to walk their way to the islands rather than swim. On the other hand, Mr. J. T. Makoro, writing for the Chief Fisheries Officer, Fisheries Department, Entebbe, Uganda, on February 7, 1972, stated:

> The depth of water in Katwe Bay ranges from 0-5 meters [0-16 plus ft.], between the mainland the islands which lie 2 miles out in the'bay. Apparently the depth of water is such that the elephants have to swim to the island.

Moreover, C. R. S. Pitman (personal correspondence, February 18, 1970 and October 25, 1971)** writes that:

> One [island] is not far from the shoreline and elephants wade out to it. The second is further out and necessitates a little swimming to get to it. I am not absolutely certain but I seem to recollect that the few elephants which visited it did eventually return to the mainland. The third islet is a conspicuous hillock with coarse grass and some euphorbias and bush and shrubs

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*Personal correspondence on November 24, 1971, with Frank Poppleton, College of Wildlife Management, Mweka, Moshi, Tanzania.

**Captain Pitman is a renowned former Uganda game warden and East Africa mammal expert.

> which a small group of elephants (six I believe) devastated. To get to it the elephants had to swim some distance. Having got there they never came back.

And Mr. Helmut K. Buechner* writes:

> I have seen elephants walking to the islands in Lake Edward, and I am confident that they swim where they cannot walk.
>
> Elephants swim very well using the trunk as a snorkel.

Finally, Temple Perkins (1955, p. 225; see also 1947, p. 38) writes:

> They are only a mile away from the mainland. The elephant while bathing would often wade out half-way, and then, by walking on the lake bed or swimming, could easily negotiate the rest.
>
> There is deep water close to the islands.

Elephants regularly visit the islands in Katwe Bay, negotiate the Kazinga Channel which connects Lakes Edward and George, and visit islands in the latter lake (Temple Perkins, 1935, 1947, 1955; Bere, 1966; and personal correspondence with I. Buss, November 18, 1971, and R. Bere, January 1, 1970). For example, Temple Perkins (1955, p. 48) recalled:

> I have frequently seen herds crossing the Kazinga Channel, which is a third of a mile wide and ten to fifteen feet deep. Even if the adults were able to walk on the bottom it would certainly be impossible for the calves and the adolescents to do so and keep their trunks above water. And then there is the case of a crippled cow that managed to get to an island about a mile from the mainland across water in parts 12 to 15 feet deep.
>
> When elephants swim, very little of the back is visible, and the tip of trunk is held about a foot above water. (Temple Perkins, 1955, p. 48).

In the same book Temple Perkins describes elephants on two islands in Lake George:

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*Senior Ecologist, Smithsonian Institution: personal correspondence, February 6, 1970.

> There are two large islands about six hundred yards or so off the coast, the northern one called Kankaranka and the southern Akika. Elephants often left the reserve to visit these islands, and stayed for some weeks . . . (p. 184).

The occurrence of elephants on these islands was also mentioned by Sylvester Ruhweza* in correspondence dated February 20, 1970:

> Elephants do swim across rivers such as the Nile and have been observed to swim across channels and to off-shore islands in Lake George.
>
> It is not known for certain, however, whether the elephants actually have to swim or can wade to these islands.

Finally, S. K. Eltringham, Director of the Nuffield Unit of Tropical Animal Ecology** writes:

> Elephants frequently wade across bays in Lake George . . . but I have no reliable information of their swimming in the lakes . . . although I have no doubt that they do swim on occasions.

There are also reports of elephants swimming to islands in Lake Victoria. For example, on October 21, 1971, Ivan Tors*** wrote:

> I personally cannot give you an expert opinion for although I spent a great deal of time among wild herds of elephants my studies were conducted among arid conditions when there was very little water in the water hole and riverbeds. However, having read nearly everything that was written about elephants other observers are very positive about the excellent swimming ability of the Indian and African elephant.
>
> I heard from other observers that elephants were swimming in Lake Victoria from the shore to faraway islands. They were observed in India swimming for six hours, non-stop, [in reference to Sanderson, 1879, cited on last page of this appendix] and according to many experts they fill up their stomachs with water to weight them down and then walk across the bottom with their trunks held high as snorkels.

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*Chief GameWarden, Game Department, Entebbe, Uganda.

**Personal communication, March 2, 1970.

***Ivan Tors (Ivan Tors Studios, 285 Madison Ave., N.Y.) has had considerable experience observing and photographing elephants in the wild, many of his sequences being nationally televised.

> I will return to Africa shortly and will pay more attention to the swimming ability of the elephant which I feel is inborn as they evolved from creatures that lived in riverbeds like Moeritherium.

Mr. David Sheldrick, Warden of Tsavo National Park (East) in Kenya wrote the following on November 1, 1971, to Mr. Peter Davey* regarding the swimming abilities of elephants:

> I know that elephant cross over onto some of the islands in the Chobe River in Botswana and I have heard of a case of them swimming to a small island in Lake Victoria on the Uganda side. I understand that this particular group finally died of starvation, having cleaned out all the vegetation on the island, and made no attempt to return to the mainland.**

Unfortunately, because the area around Lake Victoria has growing concentrations of humans, elephant activity is now rare. However, C. L. Nchimbi*** writes that:

> Information received from local people narrate that in the olden days there used to be elephants on the islands of Lake Victoria which swam to and from the mainland. Unfortunately no records were kept by either this division or any person; if there were any they have been lost during the moves of the office.

Elephants have also been reported crossing the Nile River near the Paraa Lodge and Chobe Lodge in Murchison Falls National Park****. Of

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*Bateleur Safaris Ltd., Nairobi, Kenya.

**It is possible that this account is the same as that described earlier at Katwe Bay, Lake Edward, and was inadvertently ascribed to Lake Victoria.

***Personal correspondence, April 25, 1972; Mr. Nchimbi is Regional Game Officer, Game Division, Ministry of Natural Resources and Tourism, Mwanza, Tanzania.

****Personal correspondence with (1) Susan Allan, Assistant Editor, East African Wildlife Journal, October 11, 1971; (2) Bernard Grzimek, Zoological Gardens, Frankfurt au Main, Germany, May 28, 1971; (3) Francis X. Katete, Director, Uganda National Parks, Kampala, March 3, 1970; and (4) J. M. Savidge, Senior Park Warden, Ruaha National Park, Iringa, Tanzania.

the Lake Manyara elephants, I. Douglas-Hamilton* writes:

> At Lake Manyara the elephants only go into the lake when there is some floating vegetation which they can eat. Although they submerge themselves completely I do not believe that they go out of their depth. The only swimming I have seen happened when small calves, sometimes younger than 6 months, went out of their depth while following their mothers across a river about 5 feet deep and 50 feet wide. The swimming calves looked like porpoises bobbing up and submerging in an apparently regular rhythm. Neither the mothers nor any other elephants in the family units made any attempt to help them. I have seen this happen many times.

Other references to elephants swimming in Africa include:

> I have observed elephants swimming distances in excess of one mile on the flooded Kilombero. I have also observed calves in water, too deep to stand in, for several hours, whilst the adults fed on vegetation in water six to eight feet deep.**
>
> Elephant can swim and I think that they could do so sufficiently well for many adults to achieve distances of up to four miles. I am not certain whether immatures could do this. Most records of which I am aware--crossing the Albert Nile and swimming out to small islands from the shore in Lake Edward, Uganda--have adult males. Both free swimming and walking along the bottom using trunks as snorkels have been recorded, though I have only seen the latter myself.***
>
> I have seen elephants apparently swimming across the Victoria Nile in Uganda and across the Great Ruaha River in Tanzania. I say 'apparently' because, the animals being largely submerged, it is difficult to tell whether they are w lking on the bottom. They rolled and pitched and appeared to use the trunk as a 'snorkel' and I think, from this motion, they were really swimming (usually bulls). I have also seen them swimming when playing in the water (mostly young animals) when they roll over on their sides and totally submerge. In the course of 15 to 30 minutes they may drift slowly downstream quite a distance when the current is strong, but this is not swimming as such . . . . As you know, Asiatic trained elephants swim

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*Lake Manyara National Park, Arusha, Tanzania; personal correspondence, February 12, 1970.

**B. D. Nicholson, Project Manager, Selous Game Reserve Project, Dar es Salaam; letter of January 29, 1972.

***I. S. C. Parker, Wildlife Services Ltd., Nairobi, Kenya; letter of November 2, 1971.

> well, so I presume that the African elephant does too, but it is often difficult, in the field, to be sure that they are out of their depth when the appear to be swimming.*

African elephants also have been observed on ocean beaches, bathing in the surf zone, and wading or swimming to offshore islands.

> I understand that they have been seen swimming in the ocean off the East African coast . . . .**

> . . . Dr. Leakey in his letter received yesterday has asked me to tell you that modern elephants certainly can swim, but he does not know how far, especially in salt water.***

> The incident you ask about happened during the [1961] drought prior to the floods when some thirst-crazed animals came onto the beach at Kipini & drank sea water. One died and fell into the sea . . . .****

> Although I have been out here over 43 years during which I have served with the Kenya Game Dept. and the Tanzania National Parks I have little information for you. My comments are based on my personal knowledge and experiences.
>
> Whilst on elephant control work on the Kenya coast 50 miles north of Mombasa I have on a few occasions come upon elephant spoor leading into the sea; they only went into the sea at night time. Whether to bathe and or drink or what I do not know. I should think to bathe and quite possibly to drink a small amount as at that time of year there was no fresh water for many many miles. Domestic goats certainly drink the sea when no other water is available--I've seen them.*****

> They come in considerable numbers out of the great Nyika, north of the Sabaki and haunt the coastal strip north and south of Malindi, although natives say they come to bathe in the sea. (Melland, 1938, p. 93).

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*J. M. Savidge, Senior Park Warden, Ruaha National Park, Tanzania; letter of October 21, 1971.

**W. L. Astle, letter of October 12, 1971.

***Secretary to L. S. B. Leakey; letter of November 2, 1971.

****M. Brown, Safaris, P. O. Box 182, Malindi, Kenya; letter of November 10, 1971 to Peter Davey. Mr. Brown is head of Monty Brown, Safaris and is well-versed in East Africa wildlife matters.

*****G. Harvey, Karl Pollman & Gordon Harvey Wildlife Safaris, Nairobi, Kenya; letter of June 1, 1971.

> There have been reports of elephants entering the sea on the Kenya coast near the island of Lamu. . . . This necessitates the elephants having to swim about 1-2 miles across the inlet to reach off-shore islands. They regularly appear on the beaches in this same area, and in an area around the Tana river-mouth, but I do not believe they actually bathe in the sea. (Simon Trevor, letter of October 14, 1971).

> In the big swamp behind Lamu [elephants] come down to the sea. I've seen elephants on the beaches. . . . I've seen them walk into the sea . . . . Far out. So the surf smacks against them.*

> During 1959 when I was game warden at Lamu an unprecedented drought caused the deaths, directly and otherwise, of a large number of elephant. There was reason to think that a number of elephant were forced to the sea as a number were found dead near the beaches. A carcase was in fact found in the sea and had been mutilated by sharks but there was no reason to assume that the mutilation had occurred other than after death. It is not known whether this elephant died in shallow water (i.e., collapsed on the beach) or whilst swimming before being washed in to where it was found in the shallows.

> There is abundant evidence that elephants can in fact swim. My own observations are however limited to those where water is wadeable except by juveniles . . . .

> For what it is worth, you might be interested to know that it is fairly common for elephant to cross from the Kenya north coast mainland to various of the offshore islands. However, many or all of these islands are isolated by water which, at low tide, could be waded by elephant. Whether elephant wait for such a tide or swim regardless of the state of the tide, I regret that I really do not know for certain. I can only offer it as an opinion that it is unlikely that the state of the tide is within the comprehension of the elephant.**

> There are numerous instances of elephant crossing to Manda Island. Within my own experience there have been occasional instances of elephants also crossing to both Kiwaiyu and Patta Islands. There was also an isolated report of a single elephant turning up on Ndau Island in 1959. These moments invariably coincide with periods of drought. So far as I know the islands mentioned are the only ones visited by elephant. . . .***

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*Written by George Plimpton of his conversation with Mr. Bunny Allen, resident elephant hunter at Lamu Island, on the north coast of Kenya. (See article on Ahmed the elephant in Life Magazine, January 28, 1972, pp. 49-57.)

**David McCabe, Game Warden, Game Department, Malindi, Kenya; letter of October 26, 1971.

***Ibid, letter of January 26, 1972.

> Elephants do regularly bathe in the sea, day and night, but in the remoter spots [in the Lamu area]. There is no evidence of elephants walking on the sea floor [to the islands] other than when it is a very low tide and with their trunks out of water. I personally have not seen elephants swimming to our islands. This they do, without a doubt, at night. I have not seen elephants on the islands but I have felt their hot droppings an hour or so behind them. I concur with David McCabe that elephants have been on all of our local islands in recent years. Lions also pay regular calls. (Bunny Allen, letter of February 16, 1972).

> . . . in the Somanga area of Kilwa District [Tanzania] elephants went into the sea frequently, when the area was still thinly populated. I believe there are records of similar behavior along the coast of Kenya.*

Finally, C. S. Alexander** has described to me instances where elephant tracks were seen entering salt lagoons along the Tanzania coast.

Asia

In south Asia there are also documented accounts of elephants swimming. In fact, though fewer in number than the African accounts, the Asian instances provide solid evidence that elephants are long distance swimmers of the first order. For example, there are repeated instances of elephants swimming to islands off the coast of Ceylon. Several such instances were documented, once in 1958 after military officers reported seeing a lone elephant scrambling out of the sea at night, and after local fishermen repeatedly reported maritime elephants (Rowe, 1958a, 1958b). A number of people in fact reported elephants periodically coming out of and entering the sea at Trincomalee. The elephants were

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*B. D. Nicholson, Project Manager, Selous Game Reserve Project, Ministry of Natural Resources and Tourism, Dar es Salaam, Tanzania; letter of January 29, 1972.

**Professor, Department of Geography, University of Illinois, Urbana; conversation, February 16, 1972.

swimming to and from Sober Island (and perhaps Elephant Island) offshore. Rowe (1958a) writes the following description of one of these incidents recorded on January 17, 1958:

> I was taking a much needed siesta (after a monumental curry with the usual preliminaries) when Cecil Hooper, who lives at Honeymoon Cottage, telephoned me at about 1500! I was all prepared to improve his education on auspicious hours for the use of the telephone, when he said, 'Come as quickly as you can, Charles, and bring your camera--the elephant is swimming over again from Sober Island.' I am unaware of the record for a standing start from bed to destination but I must have set a record which will remain for all time! On arrival at Honeymoon Cottage, I was privileged to record the unique photographs which you see reproduced here.
>
> Cecil Hooper told me that he had first spotted the elephant about half an hour previously, on the foreshore of Sober Island at Eagle Point. He said that she appeared out of the jungle and had made one or two sorties along the narrow beach before entering the water. The distance from Eagle Point to Honeymoon Point, measured on the chart, is 1,700 feet and the greatest depth of water is 33 fathoms. Allowing for the drift of current, which at that time would have been running at between one and two knots, it is estimated that the elephant must have covered a distance of some 2,500 feet and that in the time of 17 minutes [1.7 mph]. Some swimmer! During the swim the only part visible was the top of the head and a small portion of the back, as the picture shows; from time to time she took a breather by exposing the tip of the trunk. Eventually, on finding ground beneath her feet, she paused to take a look at Cecil and me and then ambled off in the direction of Nicholson Cove. We were able to watch her for a while but, as the foreshore curves, she was soon out of sight. Quickly embarking in a launch, we again saw the elephant about half way down the Cove. She must have been startled by the noise of our boat's engine because she suddenly disappeared into the jungle. . . .

In addition to the January 17, 1958, incident elephants were reported going into the sea on or about January 7, 9, 14, 15, 16, and March 31, 1958. The article by Rowe contains several of the photographs mentioned, showing the elephant swimming to shore and coming out of the sea (Plate

74b). This incident was also written up in the August 28, 1958 issue of The Field under the title "An Elephant Puts to Sea."

P. E. P. Deraniyagala* also writes of similar incidents:

> When I was conducting the Government trawling survey of the Pedro fishing bank in 1925 to 1930 we used to refuel our Trawler the S.T. "Nautilus" at Trincomalee. At that time wild elephants would swim fairly often from Ceylon on to Sober Island in the Bay there.
>
> This stretch of sea is three quarters of a mile wide and sixty fathoms deep. Only a few years ago a cow elephant had swum across and given birth upon the island, but with the spread of human settlement these visits are decreasing rapidly. Last year an elephant swam from Sober Island to the Naval dock yard and when shooed off swam back to that island.

One of the best documented instances on record of elephants swimming at sea occurred on July 15, 1960, again at Trincomalee, Ceylon. In this instance the time was also recorded when the elephants went into the sea and when they arrived at their destination. The exact route, current speed and water depth were also recorded. In addition the elephants were followed in a launch and photographed continuously during their sojourn. These photographs, reproduced on Plate 74a, were generously provided by Rear Admiral Rajan. Kadirgamar and Mr. N. de Costa, Editor of Loris**, both of Colombo, Ceylon. The following intriguing account of the incident is from a letter written by Admiral Rajan. Kadirgamar:

> I was most fortunate to very closely observe a cow elephant with its junior swim across the entrance to the harbour of Trincomalee. . . . This happened on July 15, 1960, between 0600 and 0900. Normally [a] family of three swam across the entrance after dark when all was quiet and there were no ship

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*Mr. Deraniyagala is a renowned authority on elephants, both living and fossil; he is with the Ceylon National Museum, Colombo, Ceylon.

**Journal of the Wildlife Protection Society of Ceylon.

> or boat movements. They had been regularly observed by sentries and patrols but no one before and since then has been able to record the [complete] swim on photographs. I was the only lucky one to . . . make a series of sequential shots from the moment of entry into the water until emergence after the swim. The other observers were my wife and three officers on my staff. As these elephants were regular nocturnal swimmers I was banking on the hope that one day they would make a daytime crossing and accordingly made detailed plans to record such an event. I had a lookout and warning organization set up, cameras, binoculars, stop watches and notebooks were always within easy reach either in my car or in my office or at home or in my barge. My barge and car were always at five minutes notice. July 15 dawned a bright but sultry day. At 6 a.m. I was lounging on my verandah sipping coffee and going over in my mind the main points of my day's programme when the telephone rang and the sentry in the signal tower reported sighting two elephants ambling along the shore. I was sure this was it - the moment and day I was waiting for. My plan was put into immediate operation. My barge and crew were brought to immediate notice, my staff were ordered to rendevous with me in the barge and I grabbed my gear and my wife and raced down to the harbour entrance to the signal tower. I spotted the two elephants on the shore across Nicolson's Cove. They weren't ambling--their's was a walk with a purpose. They gave me the impression that they were on their way to keep a date. Then two things happened. One the elephants waded into the water and began swimming on to my side, the other I saw a merchant ship making for the harbour entrance. My first reaction was to swear and cuss the freighter and the pilot. Then I think I must have prayed. I am a middle of the run type of Christian but God had time for me that morning! The elephants without anymore ado finished their first swim and hauled themselves up the beach and made for the harbour entrance. The freighter--The City of Bedford was, I think, its name--cleared the entrance and to me it appeared that the stage was all set. I shot down from the signal tower on the hill and into my barge, set up my camera and organized my team of observers. Shortly afterwards the elephants appeared round the corner, so to speak, and without a glance either way walked into the water and were away. The rest was fully recorded. During their swim I kept slightly astern of them and about 50 feet away. The first swim was over 433 yards and took 25 minutes and the second was 600 yards done in 16 minutes. Their first stop was at Sober Island then across Great Sober Island and that night they swam across French Pass onto the mainland and into the jungles across the airfield.

The speed of the elephants during the first swim was thus .6 miles per hour (1 km/hr) and the second 1.3 miles per hour (2.1 km/hr) for an average speed of .94 miles per hour (1.5 km/hr). The maximum depth of water during the first swim was 72 feet (22 m.) and for the second swim 198 feet (60 m.). The state of the sea was calm, no swell, and due to slack water conditions the current was negligible.

One other incident of elephants swimming in Ceylon was given by C. E. Norris* who writes:

> I have witnessed elephants in Ceylon swimming swollen rivers and being carried down by the current to land quite a way downstream from where they started. They appear to walk on the bottom for as long as they are able, raising their trunks as breathing periscopes. I, once witnessed, a cow taking a very new baby across water; the baby unfortunately was hidden by the cow's body as they crossed this piece of fairly deep water. I was able to see the baby was not supported by the cow's trunk so I can only presume it swam as the water was too deep for it to walk through.

While reading through an August 27, 1874 issue of the Santa Barbara (California) Index newspaper I came across an article titled "Elephants at Sea" written by a "Calcutta Englishman" which read:

> When they [the ship] reached port they [elephants] were hoisted out of the hold and swam on shore, thirty-five being thus safely landed without any accident whatever. When they were released from the sling it was a supreme moment for the mahout, who was always on the elephant's neck from the time of its touching the water to letting go. As the word was given to let go each of the elephants . . . plunged down deep into the water, the mahout on his neck. The anxiety on the fact of the mahout, just one second before the plunge, was a study; so, too, was it when elephant and man rose to the surface again, the former blowing water from his trunk and the latter from his nose.

Although the exact location of the point of disembarkation from the ship was not indicated, it was quite possibly the Andaman Islands in the Bay of Bengal. In former times it was common for work elephants to be shipped from Calcutta for timber work on the Andaman Islands. This practice

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*Mr. Norris is a well-known wildlife expert and safari leader in East Africa, with considerable experience in Ceylon; letter of February 23, 1970.

is documented in detail in Shebbeare (1958, pp. 15-18), a section of which reads:

> . . . as the derrick swings her over the side and lowers her into the sea. Her man [mahout] is astride her neck; as before, he is facing her tail and as the pair of them reach the water he stands on her withers, the only part of her above the surface except the top of her head, and the tip of her trunk when she breathes. He is tucking up his loincloth, and as the dripping sling dances aloft to the tune of the clanking winch, he ties her neck rope into a loop by which to steady himself as she swims ashore.

Shebbeare describes elephants as ". . . excellent swimmers . . . ." Occasionally work elephants escape from captivity on the Andamans and they or their spoor (droppings and footprints) have been observed on many islands other than the one on which they escaped. This is recorded by Lt. Col. J. H. Williams in several of his books. For example:

> . . . the elephant, as I discovered later, was one of the group which had been introduced into the South Andaman a dozen years before as a calf. He had escaped and swum the channels separating the Middle Andaman from the South and the North Andaman from the Middle.
>
> It was a rather horrifying through . . . that however well he swam from island to island, he would find no female elephant in any of the hundred and forty-eight islands in whom he could implant himself. (Williams, 1957, p. 191).

It is probably this same elephant to which he alludes in an earlier book:

> Elephants are not indigenous to the Andaman Islands, but the Forest Department had, some years previously, imported eighty into the South Islands . . . .
>
> During a trek across the largest island of the northern group, I was amazed to discover the tracks and droppings of an elephant which I could only suppose was a wild one. Judging from the impressions of the pads and the size of the droppings, I came to the conclusion that it was a young animal, about twenty years old. I got quite close to him on two occasions but, owing to the dense jungle, was unable to see him before he winded me. Thus I was left guessing until the end of our exploring trip.

> My inquiries then revealed that a seven-year-old calf elephant, one of the South Andaman Forest Department's elephants, had been missing for twelve years. It had been 'written off' in the Forest Department records as 'believed drowned,' having been seen attempting to swim from island to island. The age of this animal coincided pretty well with my estimate, and there can be no doubt it was the same. It was a remarkable swim, for it was over two hundred miles from where he was last seen to where I found him, and some of his swims from island to island must have been at least a mile in the open sea, which is seldom without a swell, and in a country where there are two monsoons a year. Of course he had twelve years in which to do it and no doubt he had a good sojourn on each island before moving to the next.
>
> He must have been a considerable surprise to any of the wild Jarawa tribesmen who saw him and he must have seemed to them like a sea monster. An elephant thoroughly enjoys swimming and will submerge entirely for brief periods when in deep water.
>
> No doubt the young elephant had just as big a surprise on emerging from the sea after swimming from a distant island on being confronted by a modern Eve as the Jarawa Eve was to see a sea monster rise up out of the sea and disappear into the jungle. (Williams, 1950).

Williams also describes in great detail the swimming powers of Burmese elephants:

> Elephants are good swimmers and extremely bouyant. When the oozie [mahout] is going to cross a large river, such as the Chindwin or the Irrawaddy, with his elephant, keeping it under control, he fits a surcingle under its belly and over the withers, kneels on the elephant's back, and grips the rope in front of him, using a small stick, instead of his feet, to signal his "aids," behind the elephant's ears. In this position he is on top of the highest point of the elephant.
>
> Once they are under way and in deep water, it is most amusing to watch. For a time the elephant will swim along gaily with a rather lunging action. Then, all of a sudden, the oozie will snatch a deep breath as the elephant goes down like a submarine into fifteen feet of water. The elephant, for pure fun, will keep submerged almost to bursting point, trying to make his rider, who goes down with him, let go.
>
> But the oozie knows that an elephant can only stay under water for the same length of time as man. So he holds on. The elephant, meanwhile, is doing a fairylike dance on tiptoe along the bottom, while the poor old oozie is wondering if she will ever surface. Suddenly both reappear, blowing tremendously and taking great gasps of breath.

> In crossing a wide river, where the elephant has to swim a thousand yards or so, he may drift as much as four hundred yards downstream. He makes no strenuous effort to make the crossing where the river is narrowest or to reach a particular point on the opposite bank. (Williams, 1950).

Reports of elephants swimming have also come out of India. For example, Mr. Harry Miller* writes:

> Elephants certainly do swim of course, there are many entirely reliable accounts of elephants swimming across the dam at Periyar, the game reserve in Kerala, South India, in order, as someone wisely pointed out, to get to the other side.

In Southeast Asia elephants occasionally swim for long periods and cover great distances during the wet season. In Cambodia, for example, elephants annually converge on Tonle Sap, or the Great Lake north of Phnom Penh, which swells enormously during August and September. This lake offers abundant marsh vegetation that elephant frequently browse. At such times the area inhabitants hunt the elephant from boats using harpoons for the purpose of capturing them for eventual use as work animals. During such episodes elephants numbering in the hundreds break for deep water, swimming ". . . wildly in every direction, their glistening black heads and bodies emerging like those of sperm whales." (Blond, 1962, p. 155). In the process of being chased and captured the elephants must swim for long periods of time, several hours or longer, and for great distances when they escape capture. Blond (1962, pp. 143-157) describes in detail how the swimming elephants are harpooned through the ears whereupon they are eventually chained to emergent tree tops projecting above the swollen lake. "The final spectacle was of elephants swimming in circles round every tree over a large area."

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*"The Frogs," Thirumullaivayal, via Avadi, Madras, India; letter of June 23, 1971; Mr. Miller is a well-known photographer of Indian wildlife.

Finally, perhaps the greatest elephant swim ever recorded occurred in November 1875, in what is now Bangladesh:

> Full grown elephants swim perhaps better than any other land animals. A batch of seventy-nine that I dispatched from Dacca to Barrackpur, near Calcutta, in November, 1875, had the Ganges and several of its large tidal branches to cross. In the longest swim they were six hours without touching the bottom; after a rest on a sand-bank, they completed the swim in three more; not one was lost. I have heard of more remarkable swims than this. (Sanderson, 1878, pp. 51-52).

APPENDIX D

This appendix lists methods and procedures of soil and sediment analyses, and the profile descriptions of five Green Mountain Soil Profiles, SMI-151, 152, 85, 162, and 163.

Sieve Analyses (see Figs. 38 and 39, Chapter 5).

Sieving was done using a Tyler Ro-Tap Shaker and sieve sizes (mm) of 2.00, 1.68, 1.19, 0.840, 0.590, 0.420, 0.297, 0.210, 0.149, 0.105, 0.074, and 0.053; shaking time was 15 minutes per sample. Reference literature was R. L. Folk, Petrology of Sedimentary Rocks (Austin, Tex.: Hemphill's), 1965.

Carbonate Analyses (see Fig. 37, Chapter 5).

Determination of carbonate was done by using a mercury manometer following procedure 6E1b detailed in Soil Survey Investigations Report No. 1 (see References Cited for full citation).

Boulder-Cobble-Pebble Analysis (see Fig. 42, Chapter 6).

The long axes of the stones were measured and their total number counted for three, six-inch depth increments.

Organic Carbon Analyses (see Fig. 43).

The organic carbon analyses were made by NU-AG Inc., Laboratories, New Rochelle, Illinois (Mr. R. Casteson, proprietor), using the Walkley-Black method.

Particle Size Analyses (see Figs. 43, 52, and 53).

Sand, silt and clay distribution was determined by the pipet method, procedure 3A1 in Soil Survey Investigations Report No. 1 (see

References Cited for full citation).

Pisolite distribution was determined by fractionating the pisolites from six-inch sampling increments of the whole soil and calculating their per cent by weight.

X-ray Analyses (Figs. 44, 54, and 55).

X-ray diffraction patterns were made using a Norelco diffractometer with nickel-filtered CuKd radiation, a 2° scatter slit, a 0.006° receiving slit, and 0.02 divergence slit; the tube was operated at 40 Kv and 15 ma, using a 2° 2 theta/minute goniometer scanning speed at 500 counts/second with a strip chart recorder speed of 1/2 inch/minute, and log scale paper. A monochrometer was attached.

All clay mineral samples were mounted on slides using the smear technique of Gibbs* and glycolated prior to x-ray analysis.

Other, non-clay mineral samples mentioned in text were ground to powder in an agate mortar and pestle and mounted on slides using Duco-cement mixed with acetone as a binder.

pH Analyses (see Table 22, Chapter 6).

The pH analyses were made from 1:1 water dilutions as outlined in procedure 8C1a of Soil Survey Investigations Report No. 1 (see References Cited for full citation).

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*R. J. Gibbs, Error due to segregation in quantitative clay mineral x-ray diffraction mounting techniques. The American Mineralogist 50:741-751 (1965).

Profile Description, Green Mountain Soil, SMI-151

Location: NW wall of NE draining gully on lower SE slopes of Green Mountain, 2,600 ft. (793 m) from summit (map distance).

Geomorphic Surface: Green Mountain Surface.

Land Form: SE sloping (8%) cumulose eolianite--slopewash complex which onlaps Green Mountain on SE slopes.

Elevation: Approximately 500 ft. (153 m) above MSL.

Parent Materials: Mixture of calcareous eolianite and colluvial--slopewash materials from SE flanks of Green Mountain.

Vegetation: A thick carpet of grasses (Distichlis) and common annual herbs.

Soil Surface: Untruncated; completely covered with grass-herbaceous vegetation, with sparse loose sand present.

Profile Characteristics:

A_{11} 0-10 in. (0-25 cm). Very dark brown (10 YR 2/2 dry) or black (5 YR 2/1 moist) loam; massive; slightly hard; slightly effervesces, no apparent carbonate films, coatings or filaments; ferruginous concretions (11% by wt.) ranging from very dark brown (7.5 YR 3/2 dry) to pale brown (10 YR 6/3 dry) or dark reddish brown (5 YR 3/4 moist) to gray brown (10 YR 5/2 moist) in color, and in diameter from 1/8 in. (3 mm) to 2 in. (52 mm); common fine roots, rootlets; common fine pores; gradual smooth boundary.

A_{12} 0-24 in. (25-61 cm). Dark brown (7.5 YR 3/2 dry) or dark reddish brown (5 YR 2/2 moist) loam; massive; slightly hard; slightly effervesces, no carbonate films, coatings or filaments;

ferruginous concretions (32% by wt.) ranging from reddish brown (5 YR 4/4 dry) to brown (10 YR 5/3 dry) or dark reddish brown (5 YR 3/4 moist) to brown (7.5 YR 5/4 moist) in color, and in diameter from 1/8 in. (3 mm) to 1 in. (25 mm); common roots, rootlets; common fine pores; common light-colored sand in cracks, sifting from above; clear very irregular boundary.

A_2 24-72 in. (61-183 cm). Gray brown (10 YR 5/2 dry) or dark yellowish brown (10 YR 3/4 moist) sand; structureless; loose; no effervescence, no carbonate films, coatings or filaments; ferruginous concretions (36% by wt.) ranging from reddish brown (5 YR 4/4 dry) to dark brown (7.5 YR 3/2 dry) or dark reddish brown (5 YR 3/4 moist) to dark reddish brown (5 YR 2/2 moist) in color, and in diameter from 1/8 in. (3 mm) to 1 1/4 in. (32 mm); argillic chunks present (see Fig. 47); common roots, rootlets; an abrupt, irregular-festoon boundary.

B_{2t} 72-144 in. (183-366 cm). Brown (10 YR 4/3 dry) or dark brown (7.5 YR 3/2 moist) sandy clay loam; massive to weakly columnar; hard; no effervescence, no carbonate films, coatings or filaments; some ferruginous concretions; clay skins up to 1/2 inch wide; common fine pores; abrupt boundary.

132- ? in. (335-? cm). Carbonate petrocalcic horizon (caliche), areally discontinuous, extending to unknown depth.

Remarks: This profile is one of the more interesting Green Mountain Soil profiles in that it has a mollic epipedon, a giant A_2 horizon (see Figs. 47 and 52) and an irregular Swiss-cheeze-like argillic horizon that has many large "vesicles" filled with whitish loose A_2 horizon sand. Plate 20c shows these features well (the rectangular form in the lower center of Plate 20 is a ledge cut into the argillic horizon and is not pedogenic). Downslope (to the east) of this sampling profile in a low-lying position on the landscape the A horizon is comprised dominantly of ironstone pisolites (Plate 19) that appear to have in part originated by downslope accretion.

Profile Description, Green Mountain Soil, SMI-152

Location: S wall of NE draining gully on lower SE slopes of Green Mountain.

Geomorphic Surface: Green Mountain Surface

Land Form: SE sloping (5%) eolionite unit which onlaps Green Mountain.

Elevation: Approximately 350 ft. (110 m) above MSL.

Parent Materials: Calcareous eolianite.

Vegetation: Grasses (Distichlis) and ice plant.

Soil Surface: Truncated somewhat; grass-herbaceous cover.

Profile Characteristics:

A_{11} 0-5 in. (0-13 cm). Dark brown (10 YR 3/3 dry) or dark reddish brown (5 YR 2/2 moist) loam; massive; slightly hard; common ferruginous concretions (36% by wt.), widely varying in color, ranging in size from 1/8 in. (3 mm) to 1 1/2 in. (38 mm); common fine roots, rootlets; common fine pores; gradual smooth boundary.

A_{12} 5-24 in. (13-61 cm). Brown (10 YR 5/3 dry) or dark brown (7.5 YR 3/2 moist) loam; massive; soft; slightly effervesces, no apparent carbonate films, coatings or filaments; common ferruginous concretions (29% by wt.), widely varying in color, ranging in size from 1/8 in. (3 mm) to 1 1/2 in. (38 mm); some roots, rootlets; common fine pores; gradual smooth boundary.

A_2 24-54 in. (61-137 cm). Gray brown (10 YR 5/2 dry) or brown (10 YR 5/2 dry) or brown (10 YR 4/3 moist) loamy sand; structureless; loose; very slightly effervescent, no apparent carbonate films or coatings; ferruginous concretions (5% by wt.); occasional fine rootlets; abrupt, irregular-festoon boundary.

B_{2t} 54-108 in.+ (137-275 cm+). Dark brown (7.5 YR 3/2 dry) or very dark brown (10 YR 2/2 moist) sandy clay; massive to very weakly columnar; hard; non-calcareous in pendant centers but slightly calcareous towards pendant outer edges; clay skins; slickensides; common fine pores; abrupt; irregular-festoon boundary.

C Variable depth of calcareous eolianite; lower limits uncertain.

Remarks: As with SMI-151, this profile has a remarkable intermingling of the A_2 and B_{2t} horizons. The argillic horizon should be viewed as containing large vugs or vesicles filled with loose albic horizon material. The A_2/B_{2t} and the B_{2t}/C horizon boundaries are extremely irregular and festooned, so that horizon thicknesses may vary several feet over a lateral distance of several inches. Plate 30d of SMI-152 shows well the tendency towards pendant formation of the Green Mountain Soil. Clay skins appear very thick at various places in the soil pendants.

Profile Description, Green Mountain Soil, SMI-85

Location: N facing cliff exposure overlooking Cuyler Harbor, several hundred yards west of Nidever Canyon.

Geomorphic Surface: Green Mountain Surface (buried).

Land Form: Eolianite unit, slope uncertain due to soil being buried, but probably to the south.

Elevation: Approximately 385 ft. (117 m) above MSL.

Parent Materials: Calcareous eolianite.

Vegetation: None.

Soil Surface: Buried.

Profile Characteristics:

A_1 0-18 in. (0-46 cm). Pale brown (10 YR 6/3 dry) or dark yellowish brown (10 YR 4/4 moist) sandy loam; massive; slightly hard; slightly effervescent; common ferruginous concretions (26% by wt.) widely varying in color, ranging in size from 1/8 in. (3 mm) to 1 1/2 in. (38 mm); gradual smooth boundary.

A_2 18-60 in. (46-152 cm). Light gray (10 YR 7/2 dry) or pale brown (10 YR 6/3 moist) loamy sand; massive to single grain; slightly hard, weakly cemented; strongly effervescent, common white carbonate coatings; common ferruginous concretions (9% by wt.), widely varying in color, ranging in size from 1/8 in. (3 mm) to 1 1/2 in. (38 mm); abrupt, irregular boundary.

B_{2t} 60-264 in. (152-671 cm) in soil pendant. Brown (10 YR 5/3 dry and moist) sandy clay loam; massive to very weakly columnar; slightly hard, weakly cemented; strongly to violently effervescent with common carbonate filaments and films, and common fine pores lined with carbonate; abrupt, irregular-festoon boundary.

C Variable depth and thickness, but not greater than 18 feet (see Fig. 49).

Remarks: This profile is distinctive in that it is buried below an eolianite unit. It may be considered one of the few profiles not modified in any way by human activity, and from that standpoint is of especial interest. Some of the soil pendants descend 18 feet to an older underlying paleosol (Fig. 49, Plate 20a). Clay and carbonate have moved down the pedants to the level of the subjacent paleosol and have indurated its surface with several inches of precipitated carbonate and illuviated clay.

Profile Description, Green Mountain Soil, SMI-162

Location: 2200 ft. SE of the ranch house on the E lower slope of San Miguel Hill.

Geomorphic Surface: Green Mountain Surface.

Land Form: Lower slope of San Miguel Hill sloping 3% to NE.

Elevation: Approximately 525 ft. above MSL.

Parent Materials: Eolianite and possibly some slopewash.

Vegetation: Very sparse cover, a few composite plants, *Astragalus*, and grass--much of surface bare.

Soil Surface: Surface soil is somewhat truncated with loose ferruginous concretions lying about on the surface.

Profile Characteristics:

A_1 0-8 in. (0-20 cm). Very dark gray brown (10 YR 3/2 dry) or very dark brown (10 YR 2/2 moist) loam; massive; slightly hard, slightly cemented; strongly to violently effervescent with common filaments and coatings of carbonate; common ferruginous concretions (51% by wt.), widely varying in color, ranging in size from 1/8 in. (3 mm) to 2 1/4 in. (57 mm); common fine pores; fine rootlets; gradual smooth boundary.

A_2 8-22 in. (20-56 cm). Light gray (2.5 YR 7/2 dry) or dark gray brown (10 YR 4/2 moist) loamy sand; structureless; soft to loose; moderate effervescence; some ferruginous concretions (3% by wt.) varying widely in color, ranging from 1/8 in. (3 mm) to 1 1/2 in. (38 mm); abrupt, irregular boundary.

B_{2t} 22-130+ in. (56-330+ cm). Brown (10 YR 5/3 dry) or dark gray brown (10 YR 4/2 moist) sandy clay loam; moderate, columnar; hard to very hard, weakly cemented; violently effervescent on ped surfaces, common filaments and coatings of carbonate, slightly effervescent in ped interiors; common clay cutans (up to 1/2 in.), slickensides; common fine poores; abrupt, irregular boundary.

C Calcareous eolianite of unknown thickness.

Remarks: This profile has a mollic epipedon, albic and argillic horizons that have been caliche-enriched, probably within historic times when calcareous dunes covered the area (Plate 11). Figure 50 shows a diagram of the profile.

Profile Description, Green Mountain Soil, SMI-163

Location: 1750 ft. (550 m) SE of San Miguel Hill summit; 760 ft. (232 m) SSE of road (map distance).

Geomorphic Surface: Green Mountain Surface.

Land Form: E face of barranca on the SE flank of San Miguel Hill sloping 10% to SE.

Elevation: Approximately 710 ft. (217 m) above MSL.

Parent Materials: A calcareous eolian-colluvial-alluvial complex terminated at 16.7 ft. (200 in., 408 cm) by an indurated carbonate (caliche?) horizon averaging 40 in. (100 cm) thick.

Vegetation: Practically none; an occasional ice plant or Astragalus.

Soil Surface: Surface of soil is truncated, with loose ferruginous concretions, artifacts and, less commonly, rhizoconcretions lying about on surface. Part of the original epipedon is preserved under occasional shell midden accumulations and dunes. Caliche coatings and veinlets developed extensively in A horizon are visible on the surface.

Profile Characteristics:

A_{12} 0-14 in. (0-36 cm). Gray (10 YR 5/1 dry) or very dark brown (10 YR 2/2 moist) sandy loam; massive; hard, weakly cemented; strongly to violently effervescent with common filaments and coatings of carbonate; common ferruginous concretions (18% by wt.) of brown (7.5 YR 4/4 dry) or dark brown (7.5 YR 3/2 moist) color, with diameters from 1/8 in. (3 mm) to 5/8 (16 mm); concretion interiors non-effervescent; common fine to large pores lined with carbonate; common fine insect (?) burrows and burrow-fillings.

A_2 14-22 in. (36-56 cm). Light brownish gray (10 YR 6/2 dry) or dark yellowish brown (10 YR 4/4 moist) loamy sand; massive to single grain; soft; very slightly effervesces, no carbonate filaments or coatings; few ferruginous concretions (2% by wt.) of brown (7.5 YR 4/4 dry) or dark brown (7.5 YR 3/2 moist) color, with diameters from 1/8 in. (3 mm) to 1/4 in. (7 mm)*; abrupt, irregular boundary.

B_{21t} 22-50 in. (56-127 cm). Dark yellowish brown (10 YR 4/4 dry) or dark brown (10 YR 3/5 moist) sandy clay; strong coarse prismatic to columnar; very hard; ped faces coated with carbonate of white (7.5 YR 8/ ; 10 YR 7/1 moist) color, violently effervescent; ped interiors slightly effervescent; common carbonate films on well developed (up to 3 mm) clay cutans; filamentous carbonate in rootlet and burrow (?) channel-ways; gradual boundary.

B_{22t} 50-? in. (127-? cm). Dark yellowish brown (10 YR 4/4 dry) or dark brown (10 YR 3/5 moist) sandy clay; strong coarse prismatic to weakly columnar; very hard, developed as pendants or pipes extending well into parent material; other characteristics as in B_{21t} above; very abrupt, broken boundary.

B_{ca} 60-? in. (152-? cm). Weakly cemented (not sampled). See Figure 51 in text for description of subjacent features.

Remarks: The Green Mountain Surface has been somewhat truncated; the upper part of the pisolitic horizon is partly preserved under

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* A single large concretion measuring 1 in. (25 cm) in diameter occurred at 18-24 in. (46-61 cm).

several aboriginal shell middens. The pre-midden soil surface also probably was truncated since no mollic epipedon is present on the Green Mountain Soil at this locality. The few middens, formerly more extensive, were deposited on reworked eolianite dune sands which formerly covered the soil.

The reconstructed soil-geomorphologic picture shows dune sand deposited on the Green Mountain Surface capped by later shell midden material which was covered by a second dune unit. The relations are shown in the upper part of diagram in Figure 51. Rhizoconcretions on the middens, in the relict dunes, and in growth position on the truncated soil surface provide indisputable evidence of a former sand cover. This second dune unit is still preserved in many places in the immediate vicinity of SMI-163 and its former extent may be seen on the 1929 airphotos (Fig. 11, Photomap 1). Even if these various lines of evidence were absent a pre-existing calcareous dune unit can still be inferred from the carbonate accumulations in the upper part of the soil. Only by the leaching of carbonates from overlying calcareous materials can such accumulations occur. This last criterion is highly important since many soils on the island have excessive carbonate accumulations in the surface horizon but lack other conclusive evidence of pre-existent dunes.

PLATES

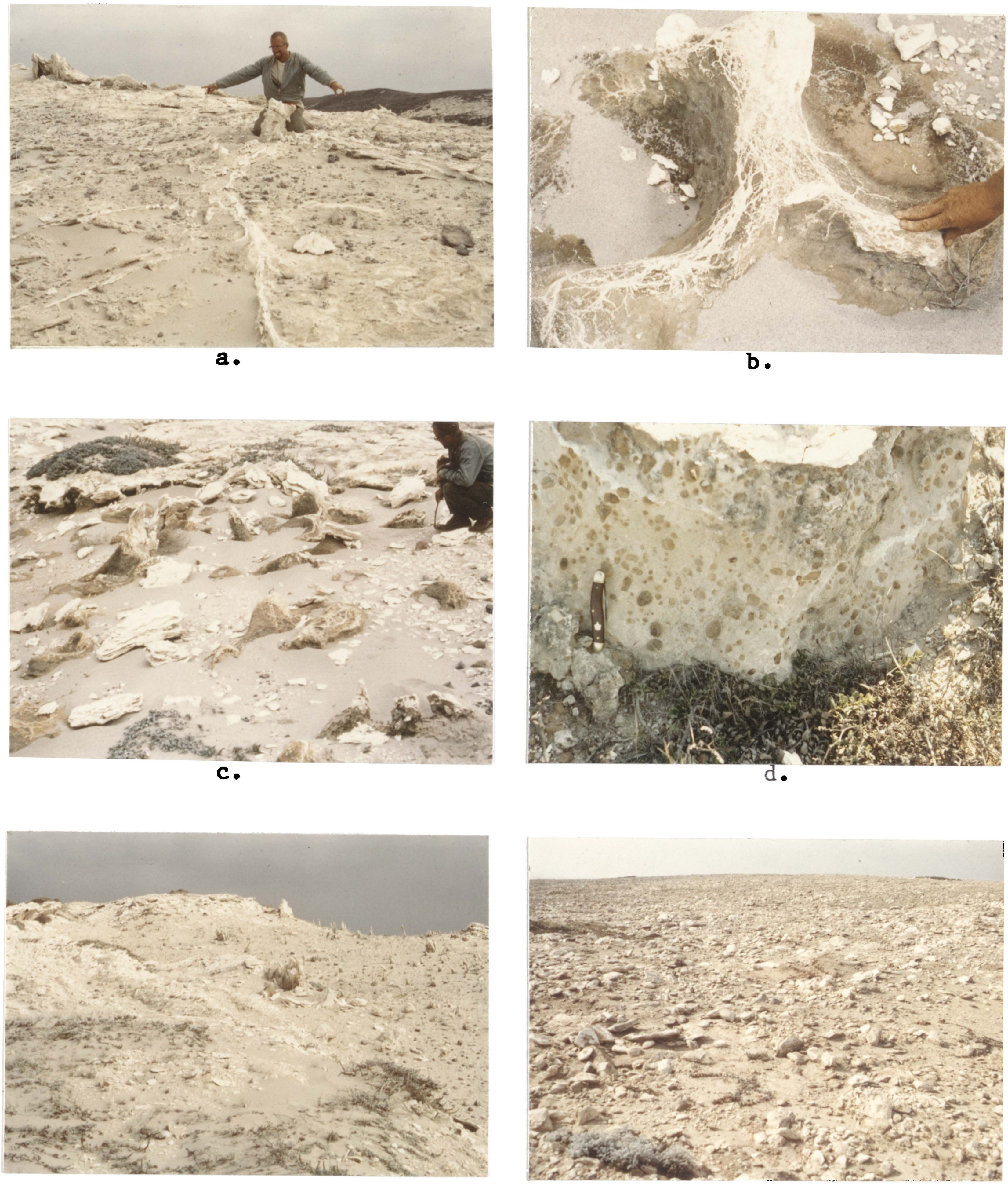
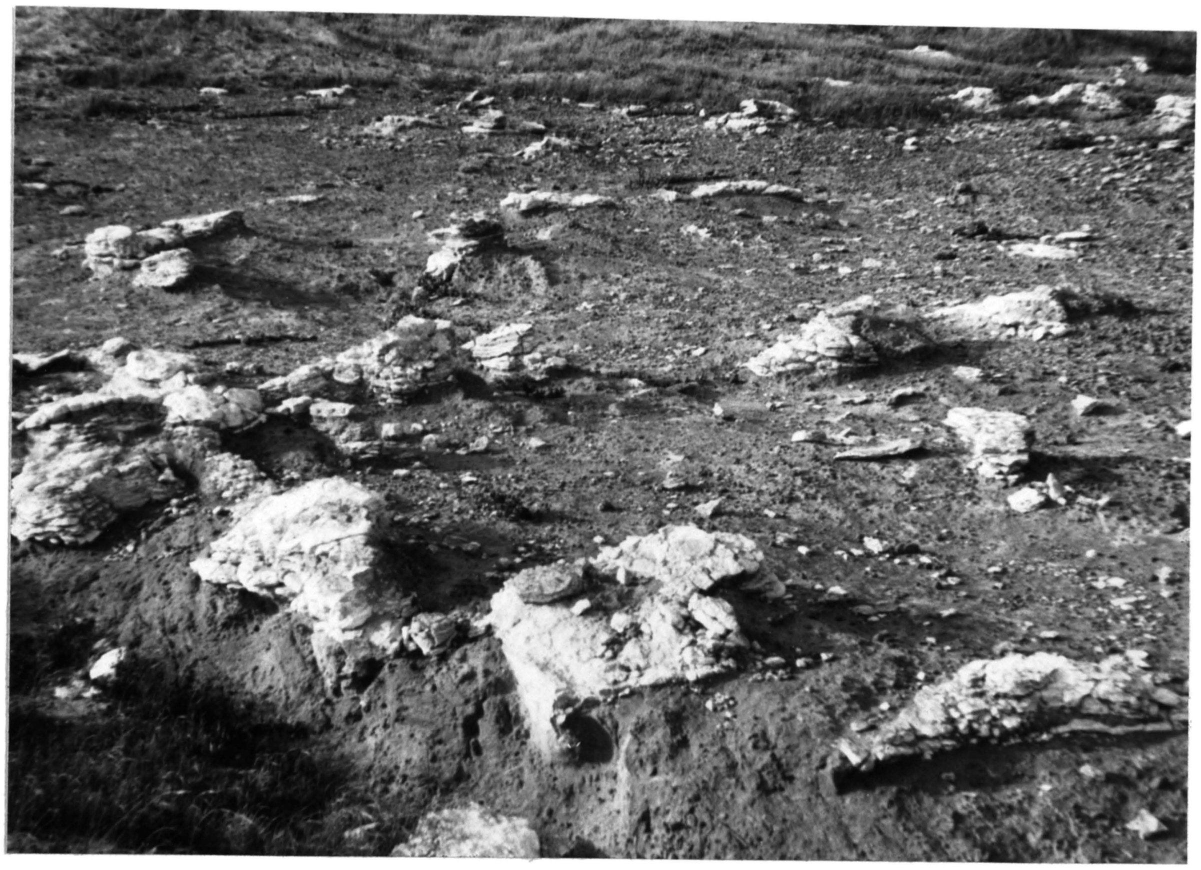


Plate 1. a. Calcified root system of former vegetation, SMI-46.
b. and c. Top plan view of solution pendants filled with soil and periferally armored with caliche (at fingers), SMI-46.
d. Calichefied A horizon of Green Mountain Soil, SMI-37.
e. Wind truncated paleosol (caliche) overlaying eolianite and rhizoconcretions, Fossil Forest III, SMI-46.
f. Caliche on Caliche Flats with *Astragalus* and *Mesembryanthemum*. All photos, August 1967.



a.

b.

Plate 2. a. Caliche overlying A_{12} horizon of Green Mountain Soil, SMI-201, July, 1969. The caliche derived from pedogenic activity in an eolianite unit which formerly covered over and buried the Green Mountain Soil and which was later removed by wind erosion, leaving caliche exposed.

b. "Yardangs" comprised of A_{12} soil horizon material of wind-eroded Green Mountain Soil, SMI-234, August, 1967.

a.

b.

c.

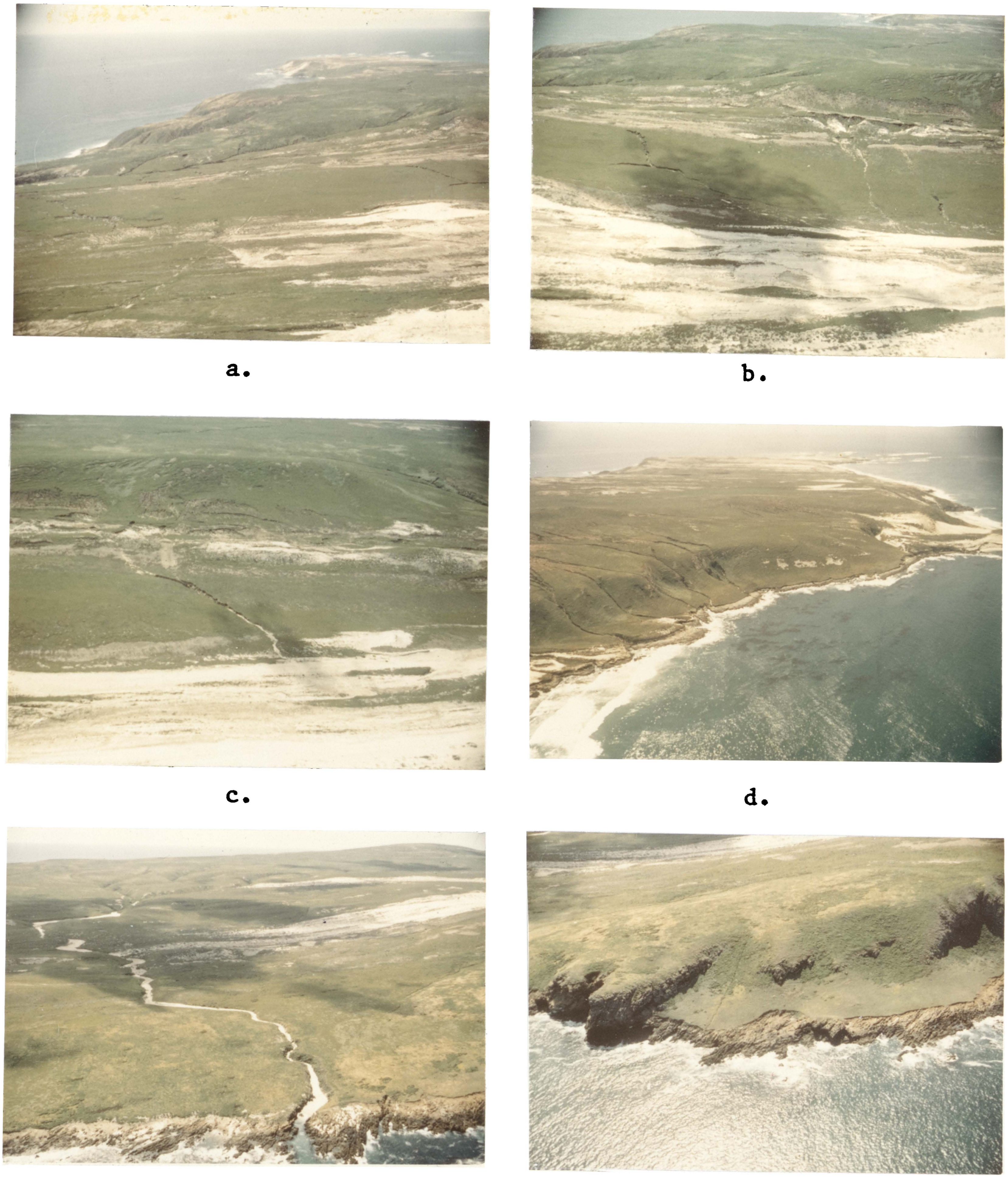
Plate 3. a., b., c. Wind stripped caliche and dune terrane with rhizoconcretions, East End Dune Fields, Fossil Forest III, SMI-46, 140, 239, April 1964.

a.

b.

Plate 4. a. View northwest from SMI-14. Stabilized historic dune on left side of photo, August, 1967. The linear boundary between dune and non-dune terrane extending from upper left to lower right is clearly apparent.

b. View east-southeast from SMI-37, summer, 1966.



a.

b.

c.

d.

e.

f.

Plate 5. a., b., c., d. Air views west from center of island.
e. and f. Air views of Willow Creek Flats and Bay Point area. *Coreopsis* shows as dark green patches. Date line all photos March, 1969.

a.

b.

Plate 6. a. View east on Gangplank surface near SMI-100 (woman as scale).

b. Soil pit, SMI-100 showing yard square (string grid) area from which cobbles and boulders in foreground came. Cobbles and boulders in pile on right came from the 0-6 inch level; those on left from 6-12 inches. Material from 12-18 inches (not shown) was about half that of 6-12 inch pile. Boulders in background are part of *in situ* cobble-boulder pavement, July, 1969.

a.

b.

Plate 7. a. View east of stabilized dune terrane; Cardwell Point and Santa Rosa Island in background.

b. View southeast down axis of dune in 7a. Photos taken 200 yards east of SMI-52, July, 1969.

a.

b.

c.

Plate 8. a. Marsh vegetation in Willow Creek near SMI-240, January 1966.
a. and c. *Coreopsis* and *Rhus* near Bay Point, December, 1965.

a.

b.

c.

Plate 9. a. Coyote brush, grass and annuals in Nidever Canyon, near SMI-246, April, 1964.
b. Wind sheared vegetation, either Toyon or Arroyo Willow, near SMI-234.
c. Coyote brush and grass, SMI-235.
Photos b. and c. taken January, 1966.

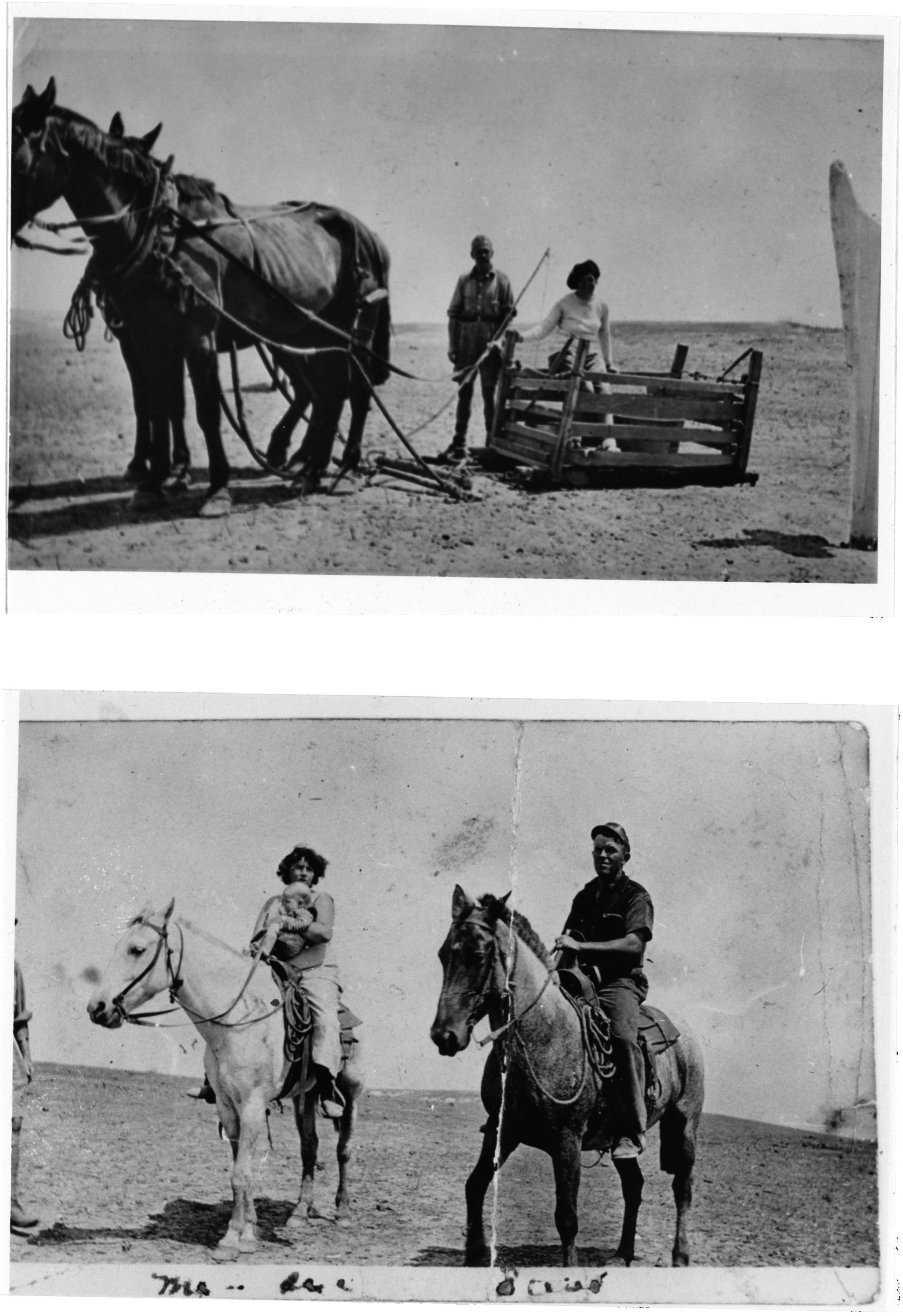


Plate 10. Upper photo, Herbert and Elizabeth Lester. Lower photo, H. Lester (left), Mr. and Mrs. U. F. Stevens. Photo taken at Rancho Rambouillet, July, 1931. Note the almost total lack of vegetation about the Ranch during this time when large numbers of sheep grazed the island. (Courtesy of U. F. Stevens.)

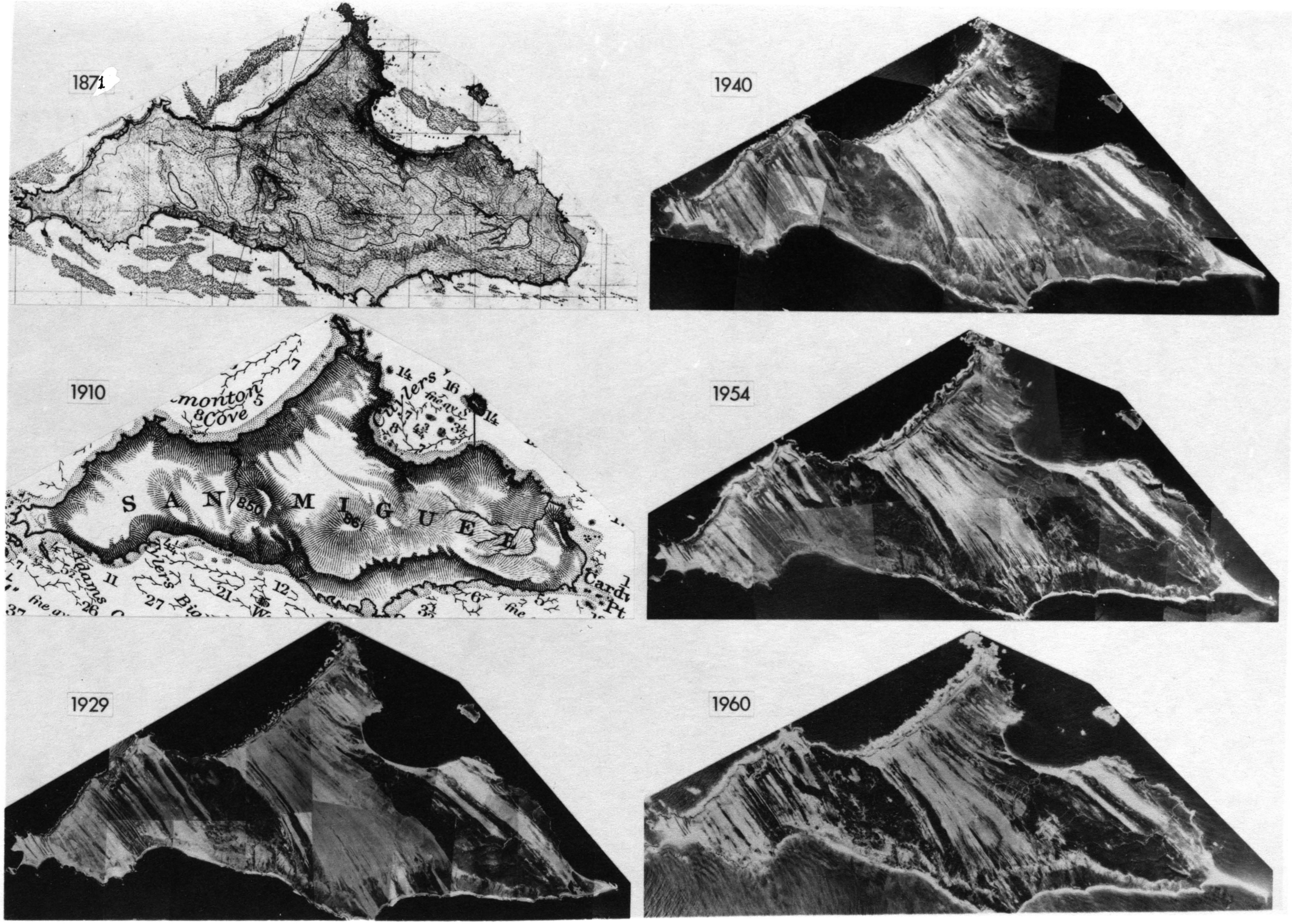


Plate 11. Topographic and photomaps of San Miguel Island showing topography and vegetation change over 90 year period. Note the changing coastline through time.

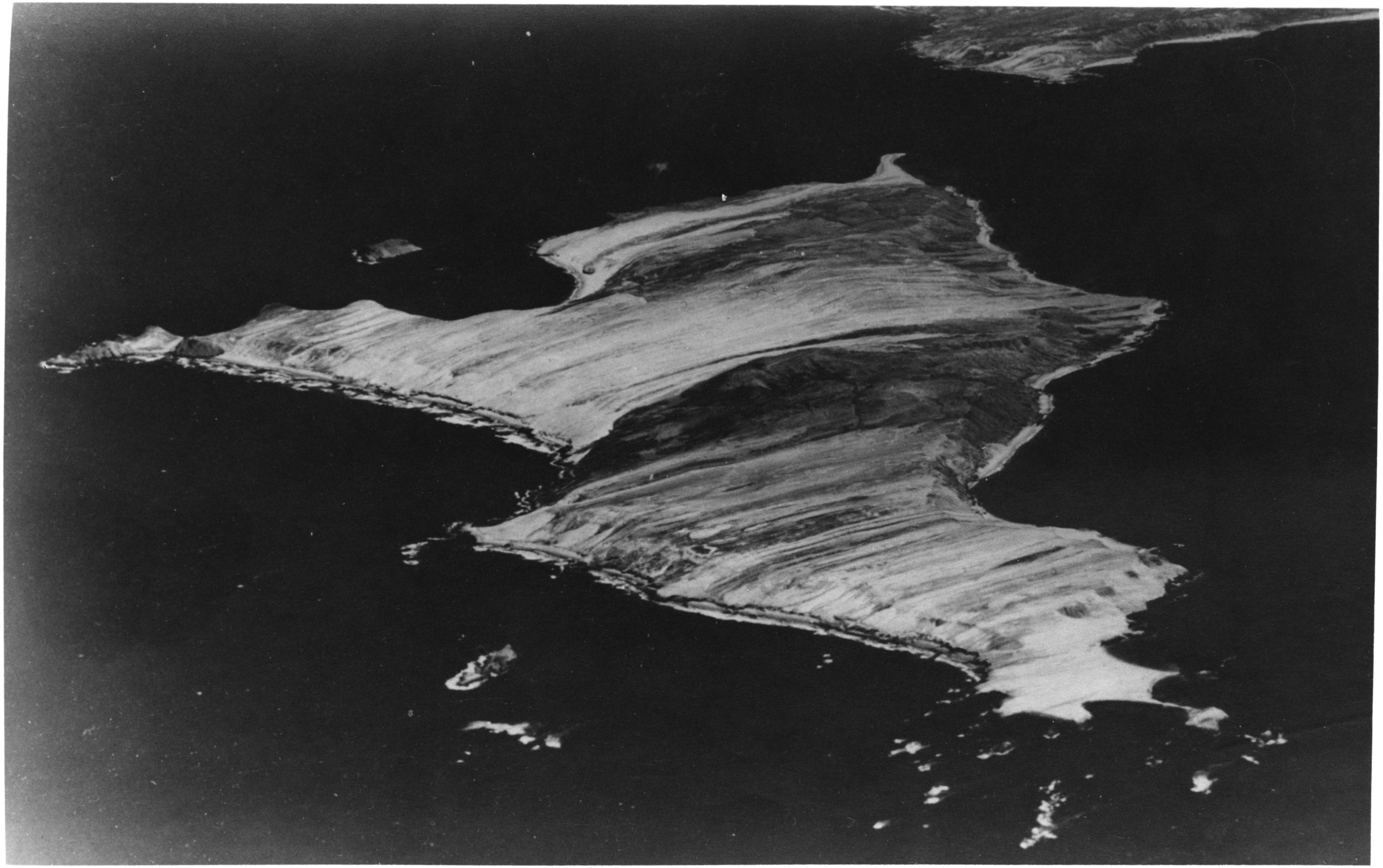
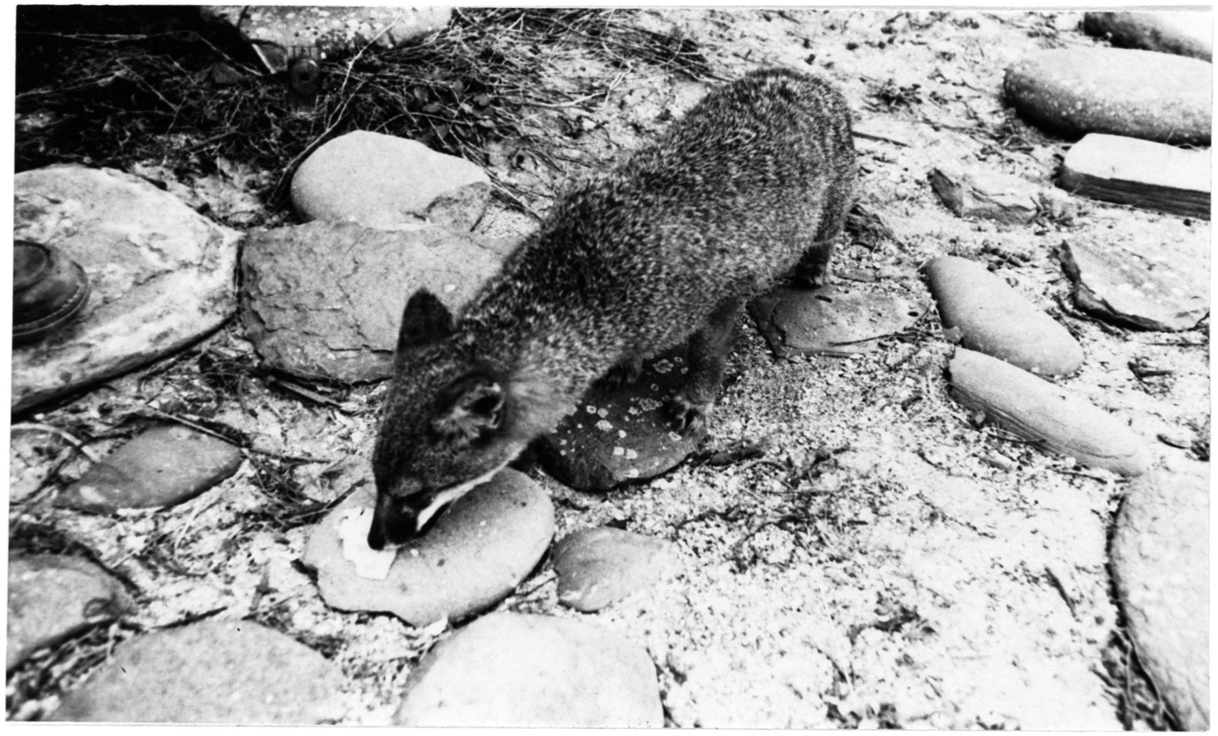


Plate 12. Airphoto, San Miguel Island, February, 1961. Note prevailing wind direction shown by dunes. (Official photograph, U. S. Navy.)

Plate 13. Airphoto, San Miguel Island, January 29, 1965 at 5000 feet altitude looking due west. The bench-like character of the island and the prevailing wind direction are clearly apparent. (Official photograph, U. S. Navy.)

Plate 14. Airphoto, San Miguel Island, December, 1968. Note 75 foot marine terrace at arrows. (Official photograph, U. S. Navy.)

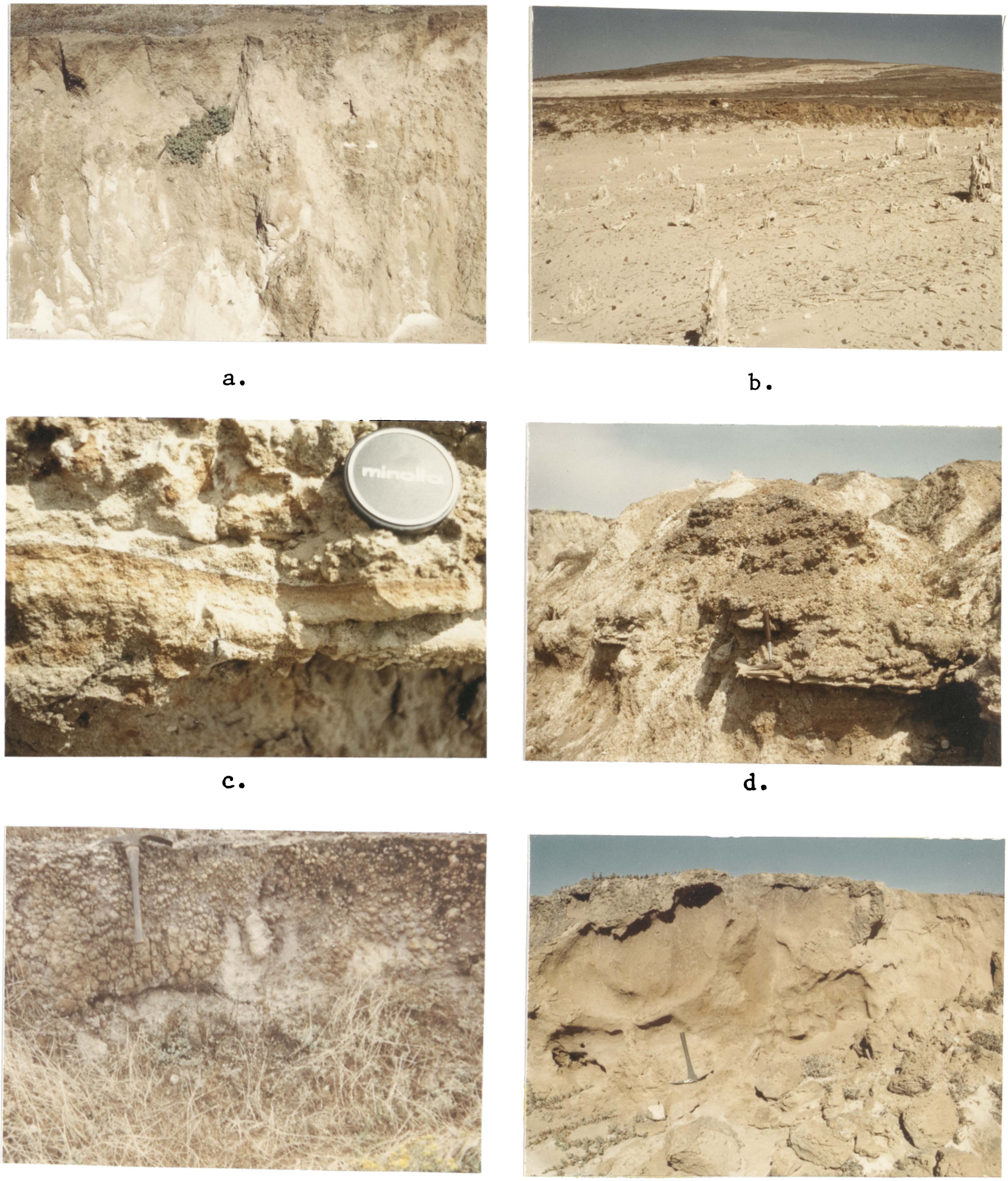


a.

b.

c.

Plate 15. a., b., c. Channel Islands fox, taken August, 1969 at R. DeLong's house, near SMI-144. Note shoe of DeLong standing at left of fox in photo 15a. which shows tameness of fox. The fox would commonly accept hand-held food.



a. b.

c. d.

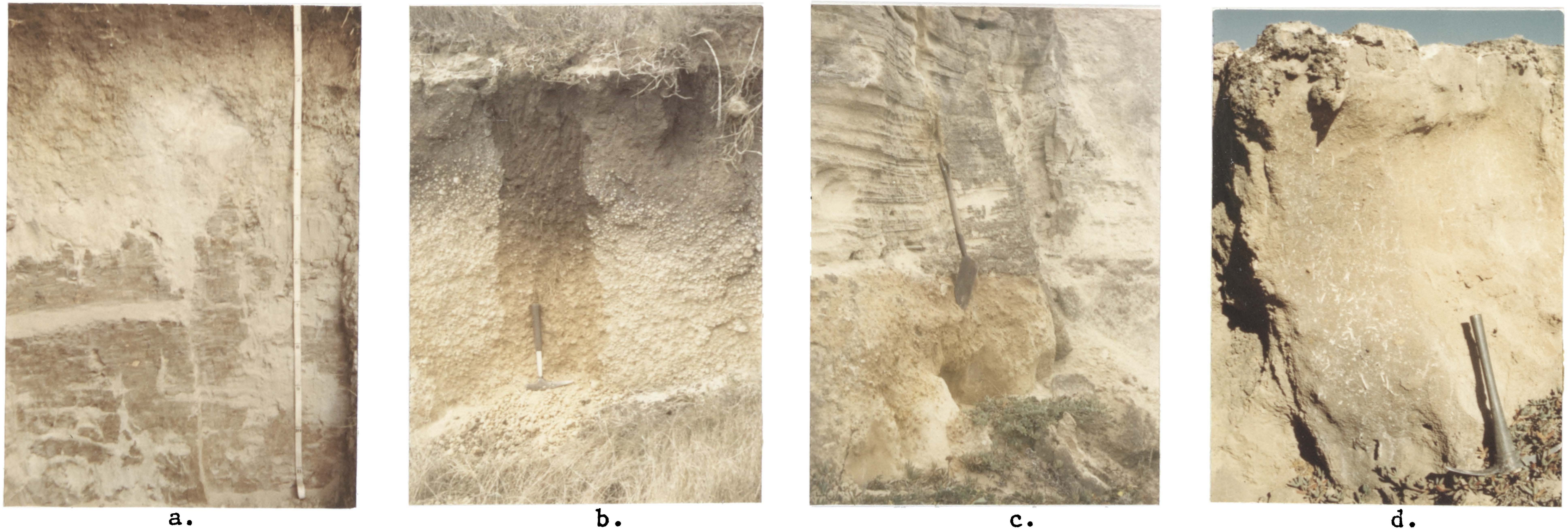
e. f.

Plate 16. a. Green Mountain Soil, SMI-152.
b. Rhizoconcretions at Fossil Forest I, view east from SMI-197 showing truncated Forest Soil in background, C-14 dated at ca.14,430 years BP I-4584 (SMI-131-133).
c. Banded iron and aluminum sesquioxides, Pinart Wash, SMI-184.
d. Massive "ironstone," Pinart Wash, SMI-184.
e. Massive "ironstone," Beckman Wash, SMI-190.
f. Close-up of truncated Forest Soil shown in 16b, SMI-132.

a. b. c. d.

e.

Plate 17. a., b., and e. Massive "ironstone" outcropping along Beckman Wash, near SMI-190.
c. Bedrock soil, Harrington Wash, upstream along SMI-189.
d. Looking up at soil-filled solution pendant in eolianite, North Green Mountain Canyon, SMI-77.
Photos a-d taken August, 1967; photo e. taken August, 1969.



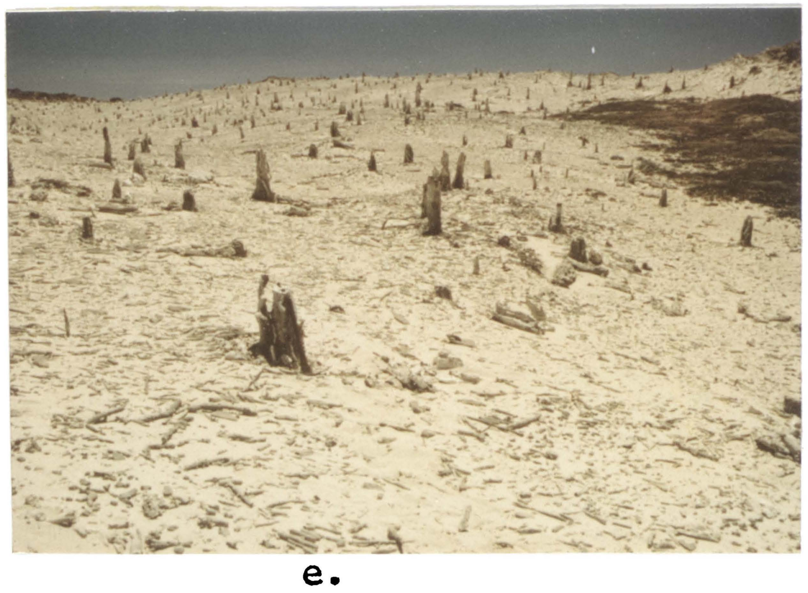


Plate 18. a. Green Mountain Soil, SMI-151.
b. Green Mountain Soil, SMI-89, inter-dune exposure.
c. Buried Green Mountain Soil overlain with Pleistocene eolianite, SMI-85.
d. Forest Soil, SMI-131.
e. Rhizoconcretions at Fossil Forest I, view southeast from near SMI-130. Rhizoconcretions "growing" out of Green Mountain Soil in view at right center.
All photos in August, 1969.

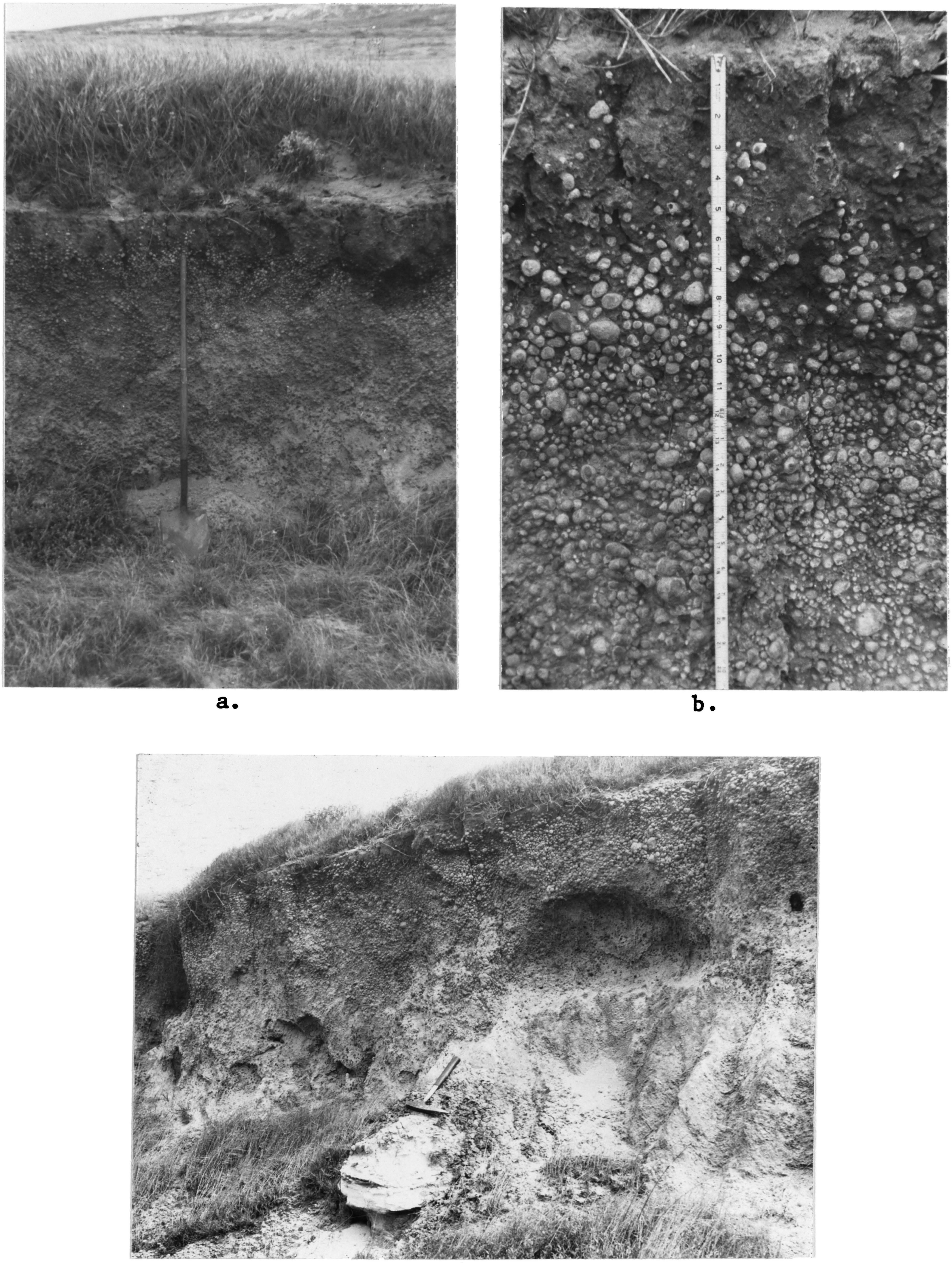


Plate 19. a. and b. Green Mountain Soil, SMI-89, inter-dune situation.
c. Green Mountain Soil, SMI-88, showing caliche and easily erodible A_2 albic horizon. Photos taken in August, 1967.

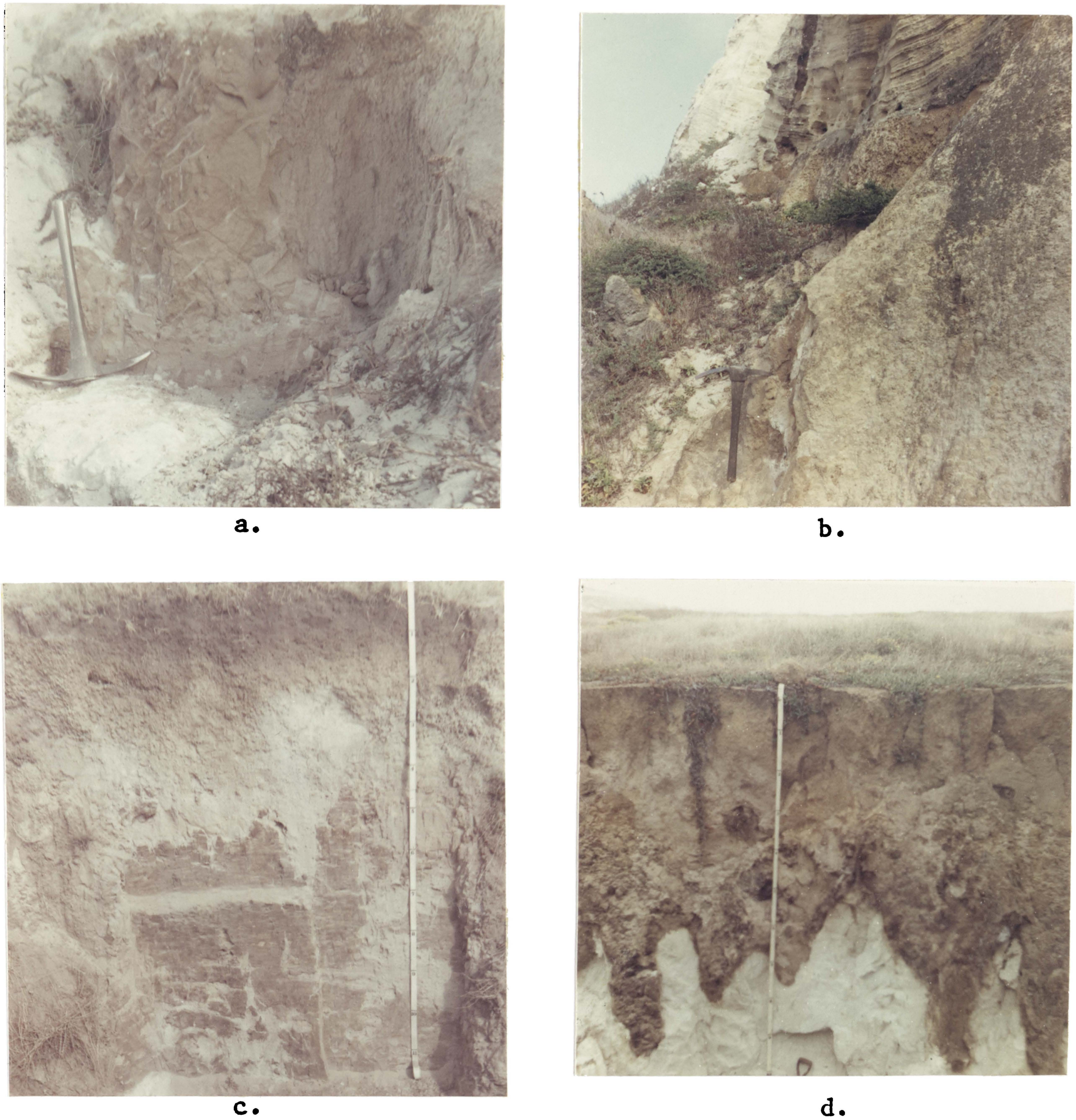


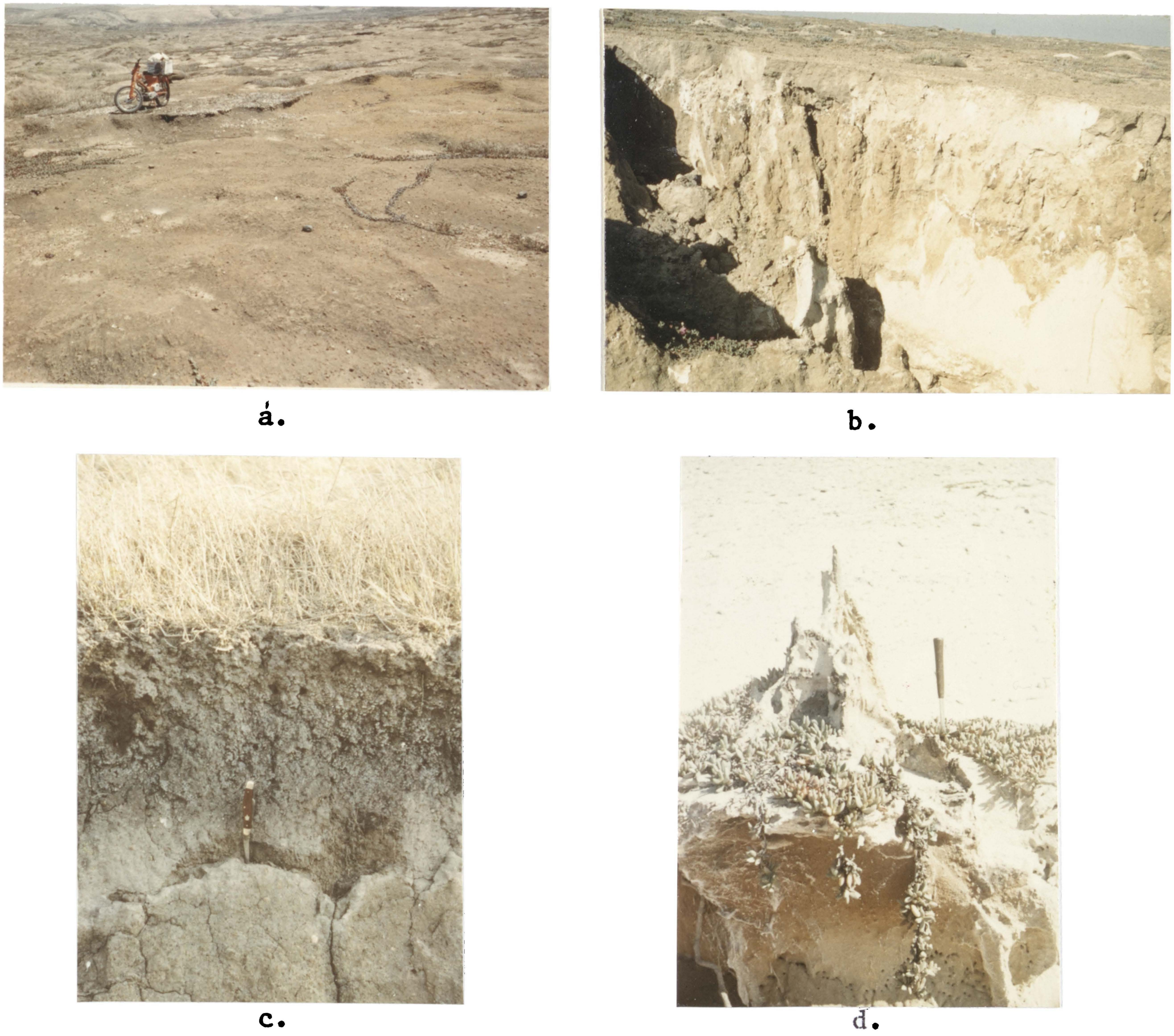
Plate 20. a. Lowest dune soil, SMI-85, showing rock-hard caliche (K horizon) at lower left.

b. B horizon of Green Mountain Soil, SMI-85; pisolitic A_{12} horizon in background, center right.

c. Green Mountain Soil, SMI-151, slope-wash and eolian parent material. Caliche visible at bottom left of photo.

d. Green Mountain Soil, SMI-152, scraped off to show solution pendants developed in calcareous eolianite parent material.

All photos taken in August, 1969.



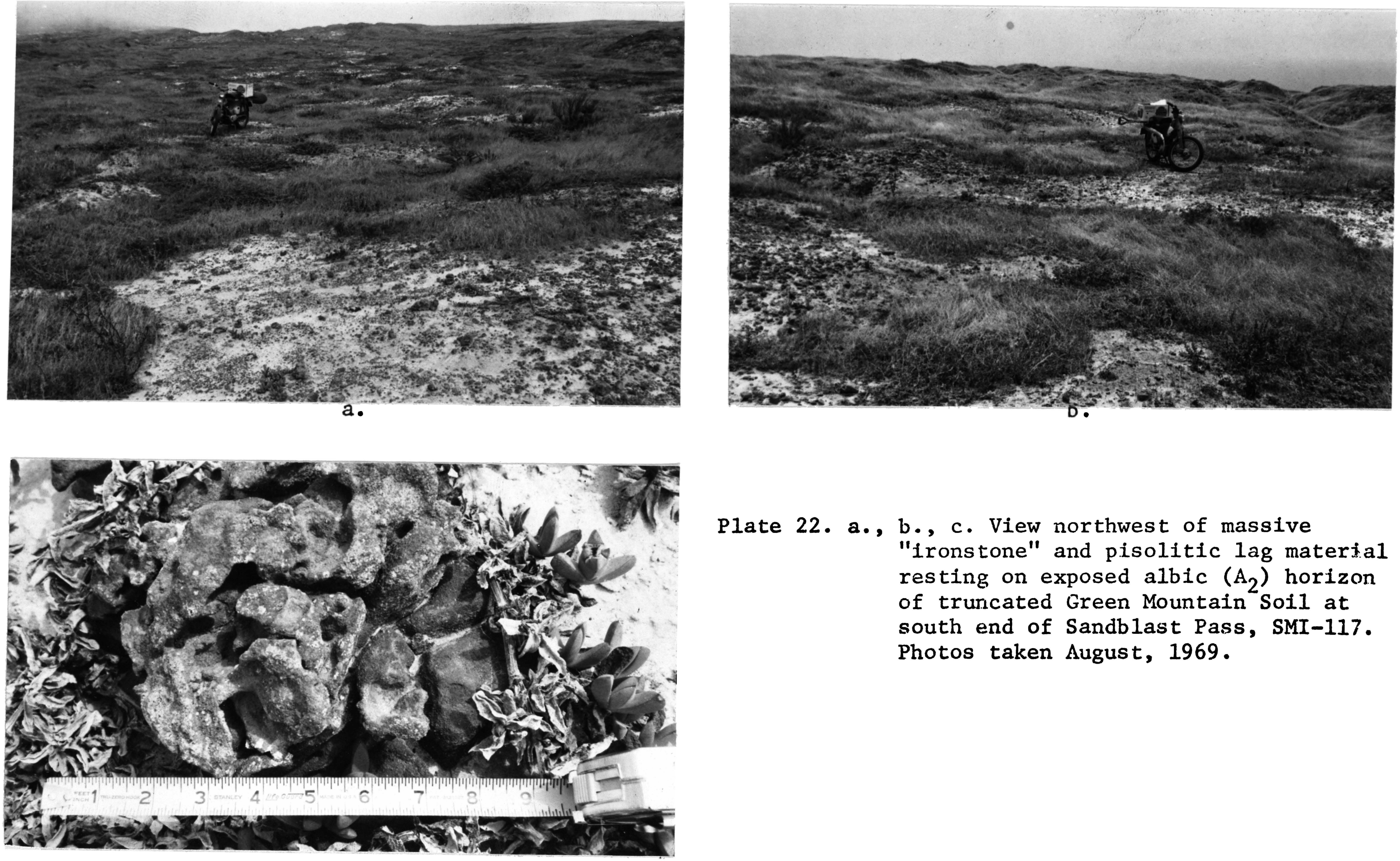
a. b. c. d.

Plate 21. a. Truncated surface of Green Mountain Soil, near SMI-126. Ancient shell midden at motorcycle retards erosion.

b. Green Mountain Soil, SMI-163; note remnant dunes on soil surface and caliche veins in argillic (B) horizon.

c. Solodized solonetz showing columnar structure at knife; note whitish salt in hand just above knife.

d. Simonton Soil at Fossil Point, SMI-215. Abundant charcoal (black area) in rhizoconcretion dated at > 40,000 years BP (UCLA-1457). Photos a., b., d., taken August, 1969: photo c. in August, 1967, by J. Thorp.

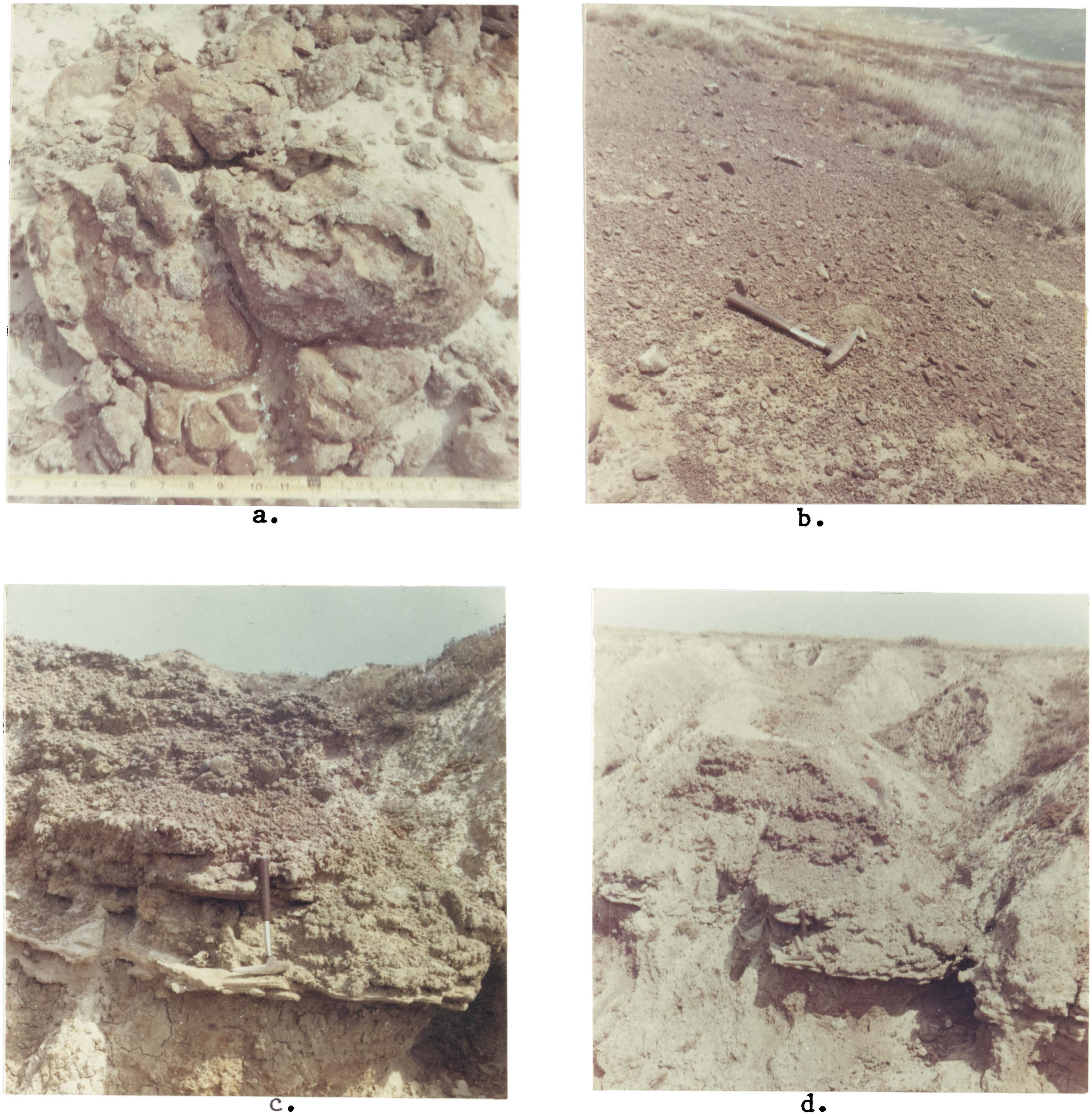


a.

b.

c.

Plate 22. a., b., c. View northwest of massive "ironstone" and pisolitic lag material resting on exposed albic (A_2) horizon of truncated Green Mountain Soil at south end of Sandblast Pass, SMI-117. Photos taken August, 1969.



a. b.

c. d.

Plate 23. a. Vertical view of massive "ironstone" lag resting on exposed albic (A_2) horizon of Green Mountain Soil at south end of Sandblast Pass, SMI-117.

b. Slopewash and lag deposit of sandstone bedrock enriched with iron sesquioxides, SMI-119.

c. and d. Massive and banded "ironstone," Pinart Wash, SMI-184. Photos taken August, 1969.

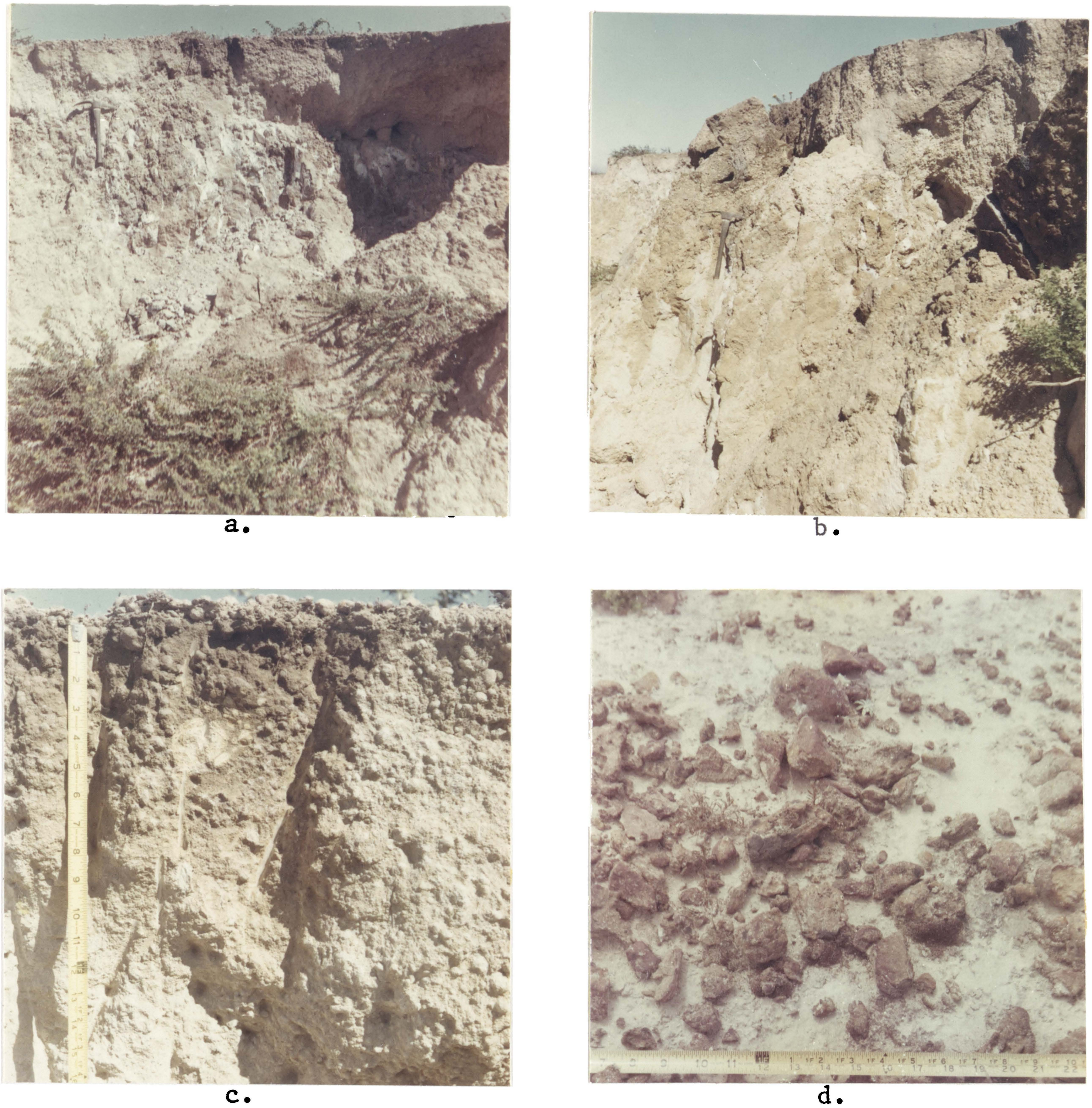


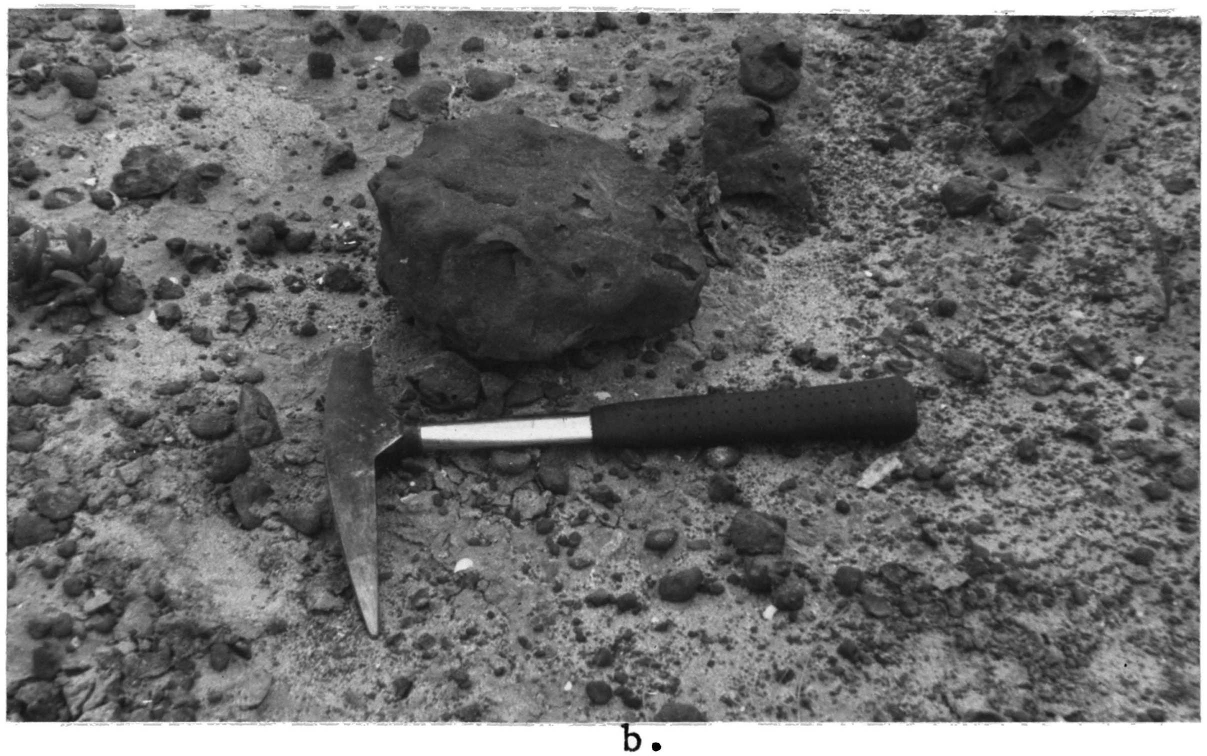
Plate 24. a. and b. Green Mountain Soil, SMI-162, showing structurally weak albic (A_2) horizon, and caliche impregnated argillic (B_2) horizon.

c. Pisolitic A_{11} horizon of slightly truncated Green Mountain Soil, SMI-152.

d. Massive "ironstone" lag, SMI-117.

All photos taken August, 1969.

a.



b.

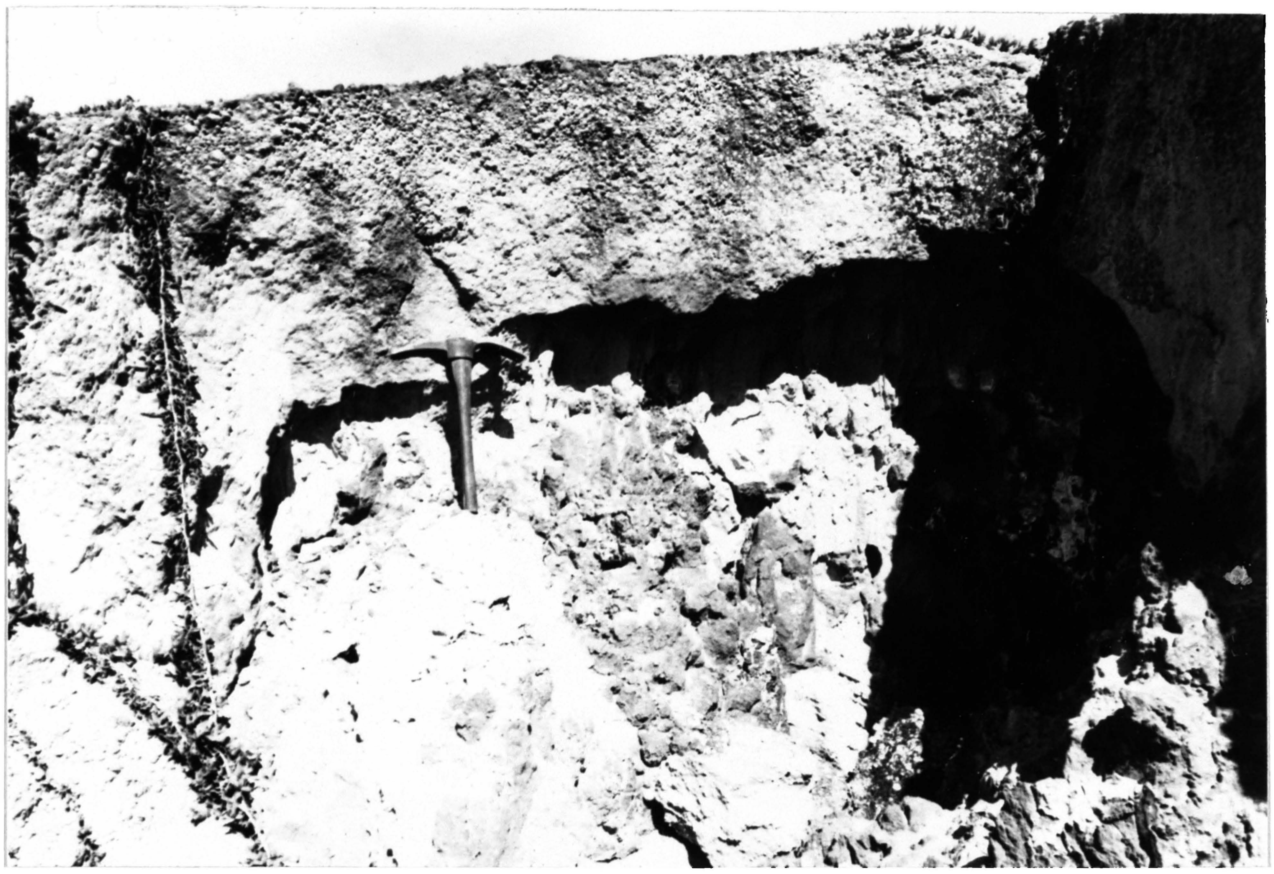
c.

Plate 25. a. and c. Rhizoconcretions "growing" in partially truncated surface of Green Mountain Soil, near SMI-163.

b. Massive and pisolitic "ironstone" lag on Ball Bearing Flats, SMI-244.

All photos taken August, 1969.

a.



b.

Plate 27. a. Green Mountain Soil, on left sloping into depression filled with alluvium of Holocene Age, Schilling Wash in Old Cultivated Area, SMI-155.

b. Close-up of Green Mountain Soil shown in left of photo 27a.

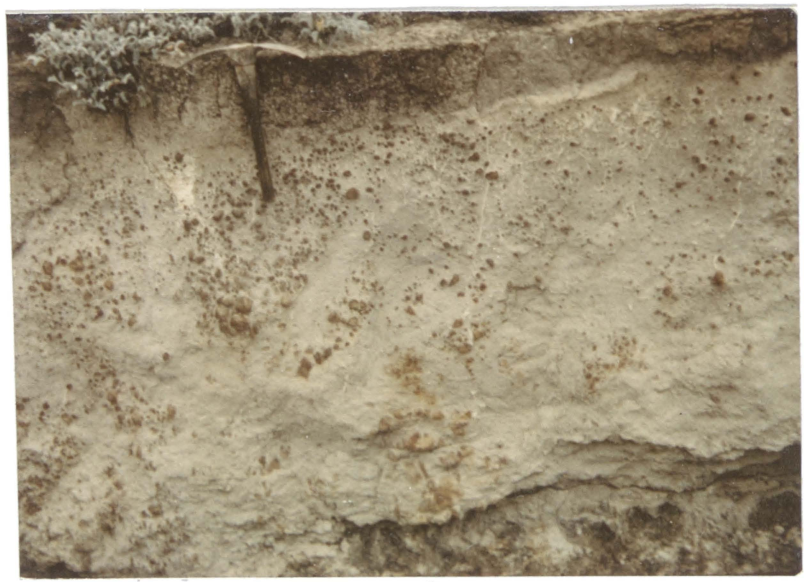
Photos taken in August, 1969.

a.

b.

c.

d.



e.

Plate 28. a., e. Complex of pisolitic and massive "ironstone" soils and paleosols at SMI-176. Note buried soil in 28a. "Ironstone" crust in 28c; d. is genetically related to spring seep which issues along crust surface at hammer. In this gully were found cutans (clay skins) over one inch thick.

Photos taken in July, 1969.

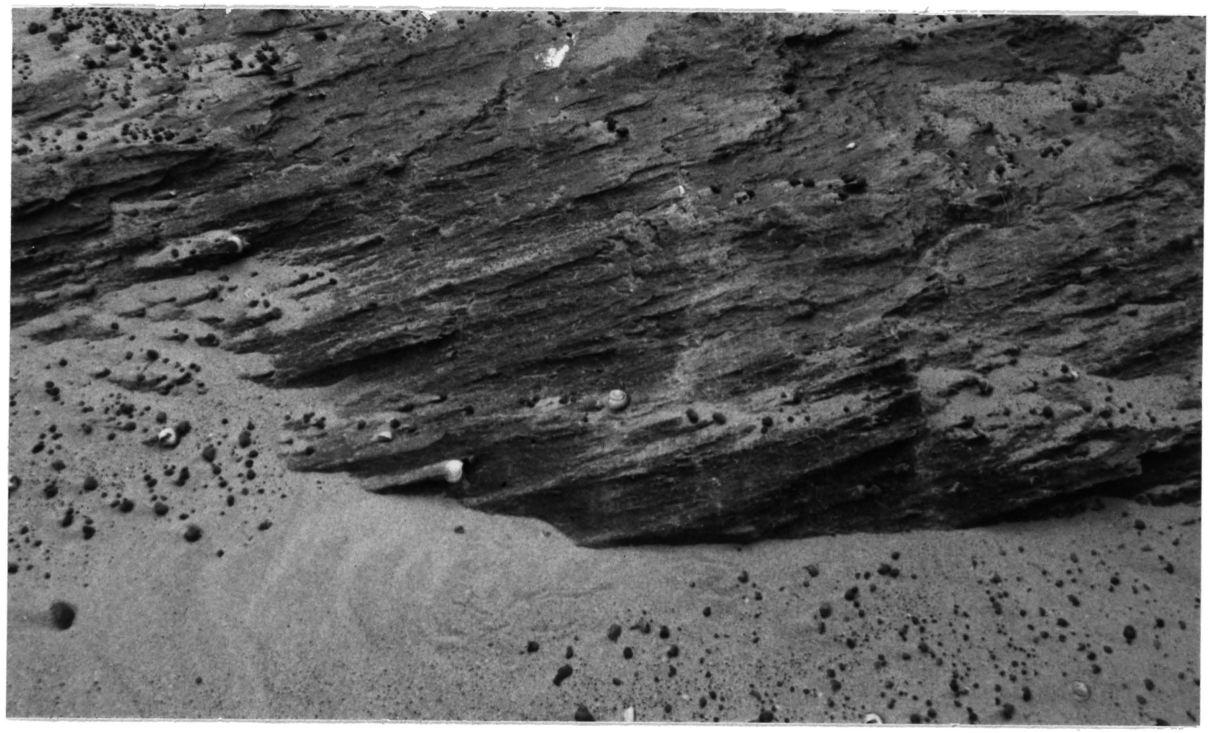
a.

b.

Plate 29. a. Green Mountain Soil, SMI-162 (photo taken in August, 1969).

b. Dessication cracks in Vertisol near Ranch House which had formed under a plywood board. Key's are for scale. Note mouse nest. (Photo taken in July, 1969.)

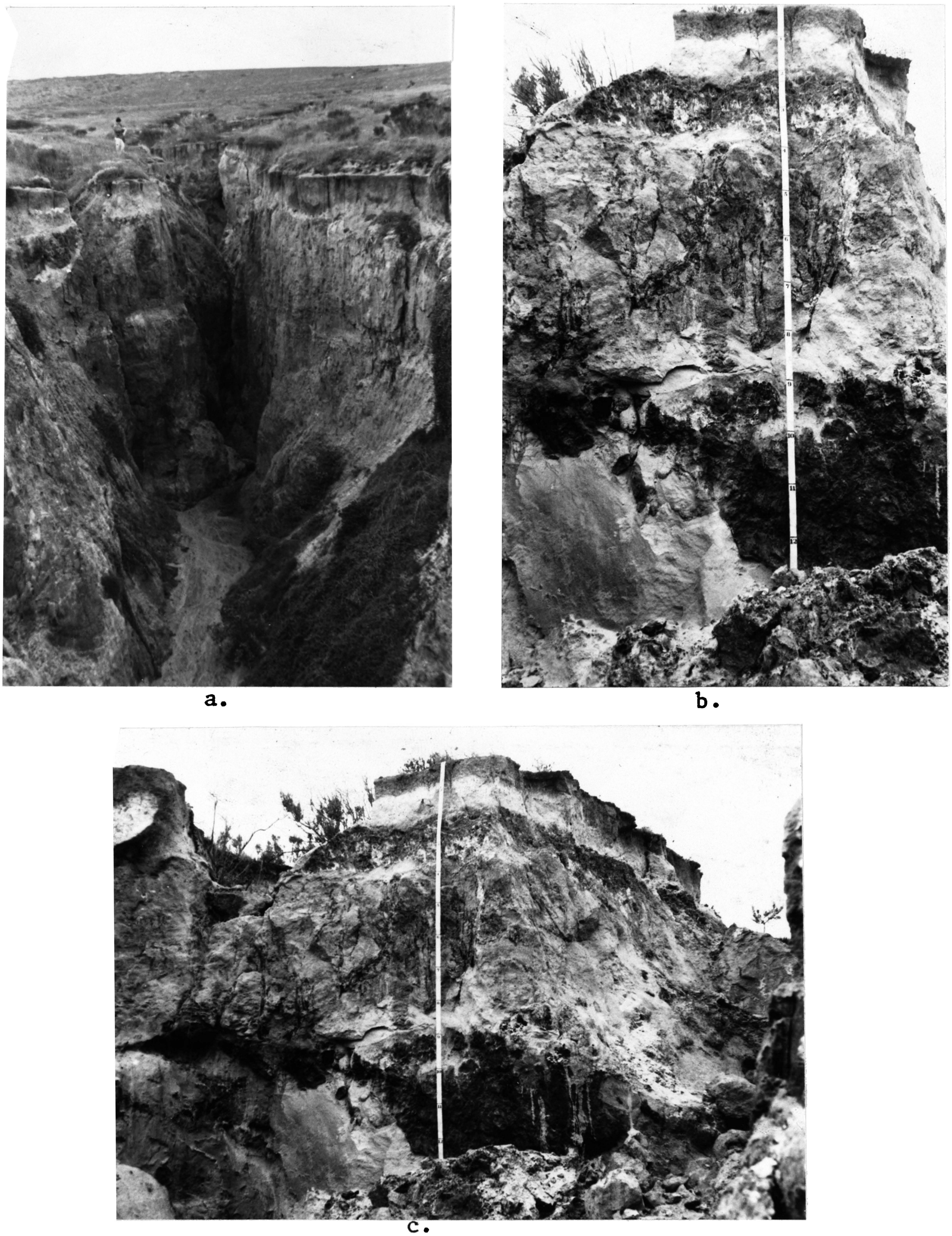
a.



b.

c.

Plate 30. a. and b. "Yardangs" comprised of A_{12} soil horizon material of wind-truncated Green Mountain Soil, SMI-212. Pisolites and fossil snail shells serve as wind pillars and retard erosion.
c. Fossil snail shells (*Helminthoglypta ayresiana*) left as lag on surface.
Photos taken August, 1969.



a.

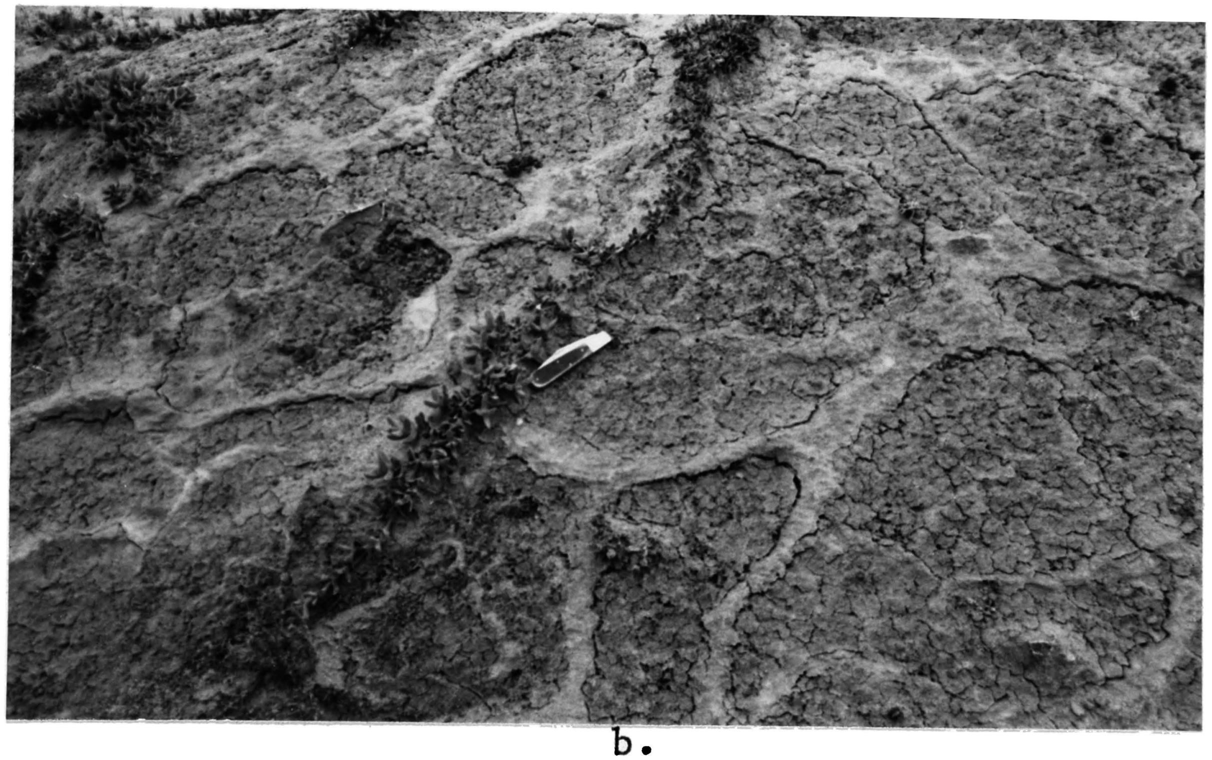
b.

c.

Plate 31. a., b., c. Locality SMI-174 in Old Cultivated Area showing advanced stream erosion and consequent exposure of buried soil (note double argillic horizons at 2-4 and 9-12 plus feet in 31b, c).

Photo a. taken in January, 1966; photos b. and c. taken in August, 1969.

a.



b.

c.

Plate 32. a. and b. Green Mountain Soil with the A horizon completely stripped off exposing argillic B_2 horizon, SMI-199. Light colored reticulate pattern is due to A_2 horizon sand which has filled shrink-cracks in argillic horizon.
c. Remnants of A horizon at SMI-199 preserved by small caliche caps.
Photos taken August, 1969.

a.

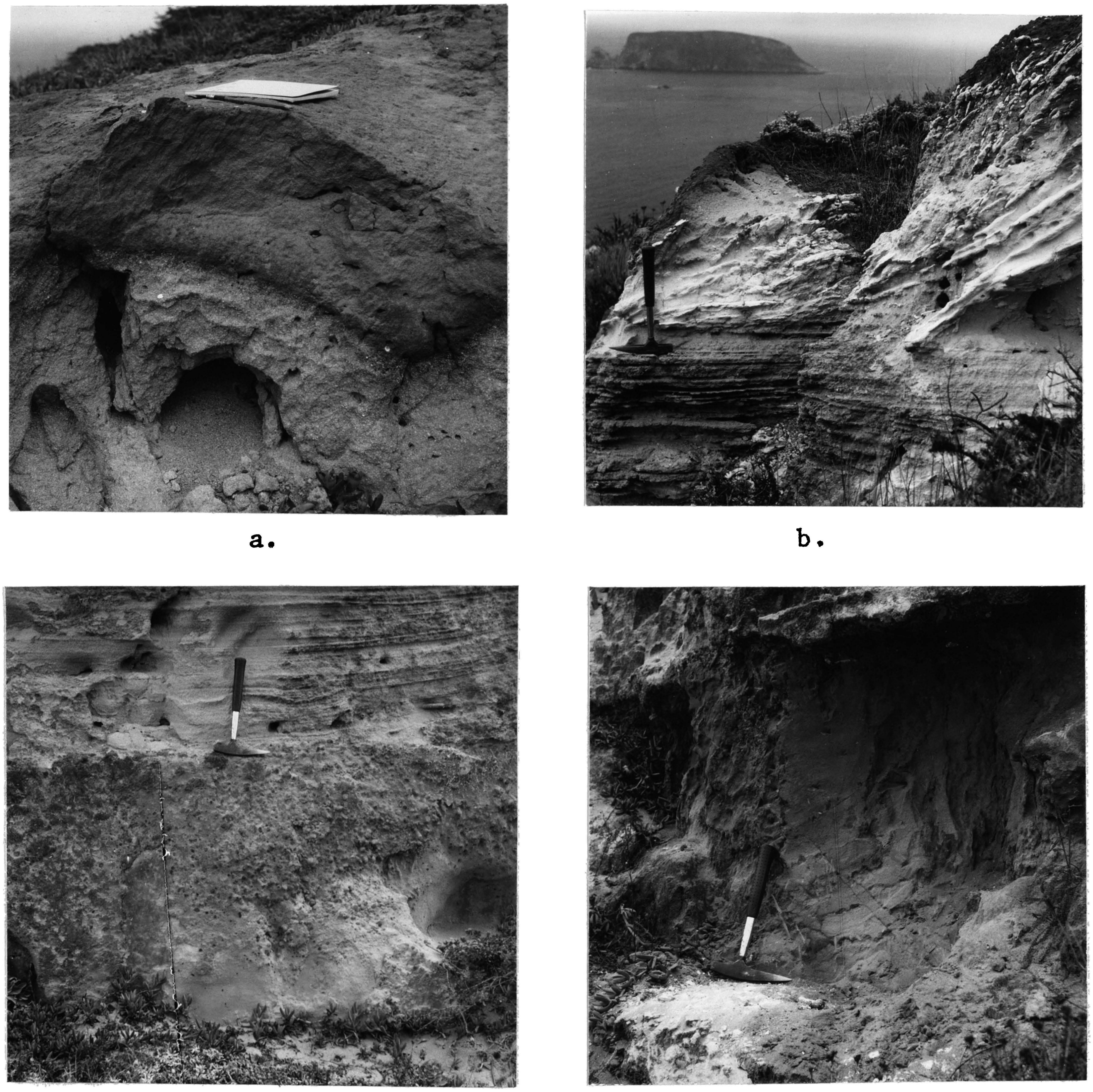
b.

c.

Plate 33. a. Green Mountain Soil, SMI-107, showing pedestalate A$_{12}$ and A$_2$ horizons surrounded by exposed reticulate argillic B horizon.

b. and c. Same soil A and argillic B horizons have been stripped leaving caliche (K) horizon exposed (b. is at SMI-110; c. is at SMI-111).

Photos taken August 1969.



a.

b.

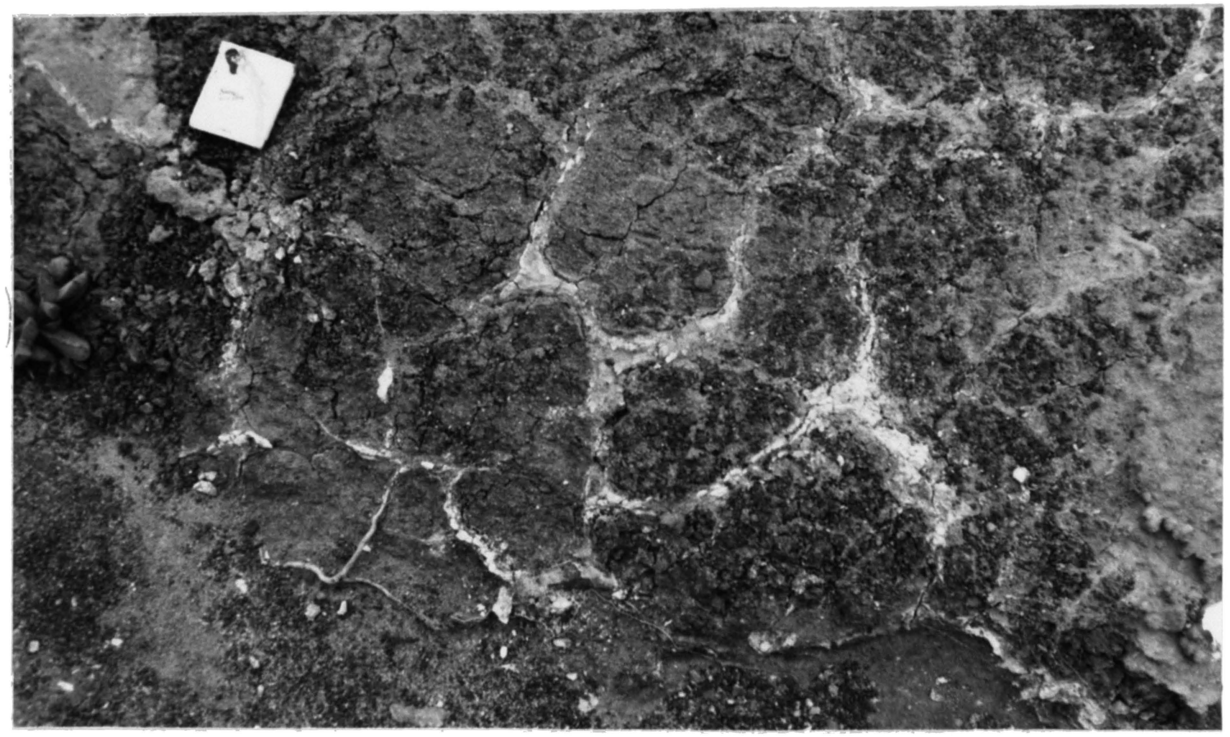
c.

d.

Plate 34. a. Modern eolianite soil, SMI-85.
b. Calichified eolianite parent material of modern soil of 34a. Note that caliche accumulates along (and preserves) the bedding planes of eolianite.
c. Buried Green Mountain Soil overlain by eolianite, SMI-85.
d. Lowest soil at SMI-85, overlain by eolianite on which Green Mountain Soil at 34c is developed.
Photos a, b, c taken August, 1967; photo d taken August, 1969.

a.

b.



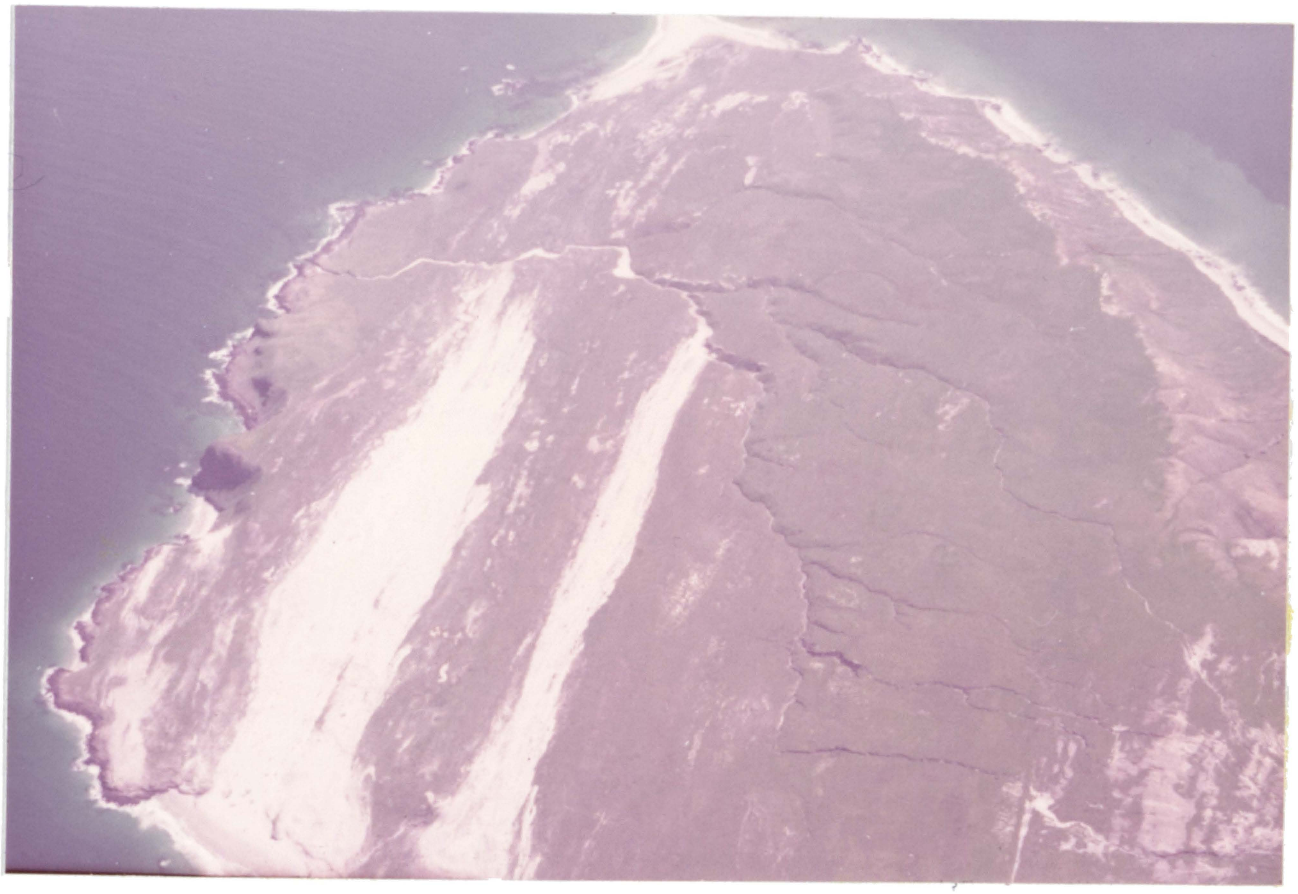
c.

Plate 35. a., b., c. Truncated Green Mountail Soil at SMI-107. Reticulated sand-filled cracks of exposed B horizon visible in all three photos. 35b shows pisolites lying loose on B horizon, weathered from A. Caliche horizon visible in background of a. and b. and in immediate foreground of b.

Photos taken August, 1969.

late 36. Airphoto of eastern half of San Miguel Island looking southeast.

a.

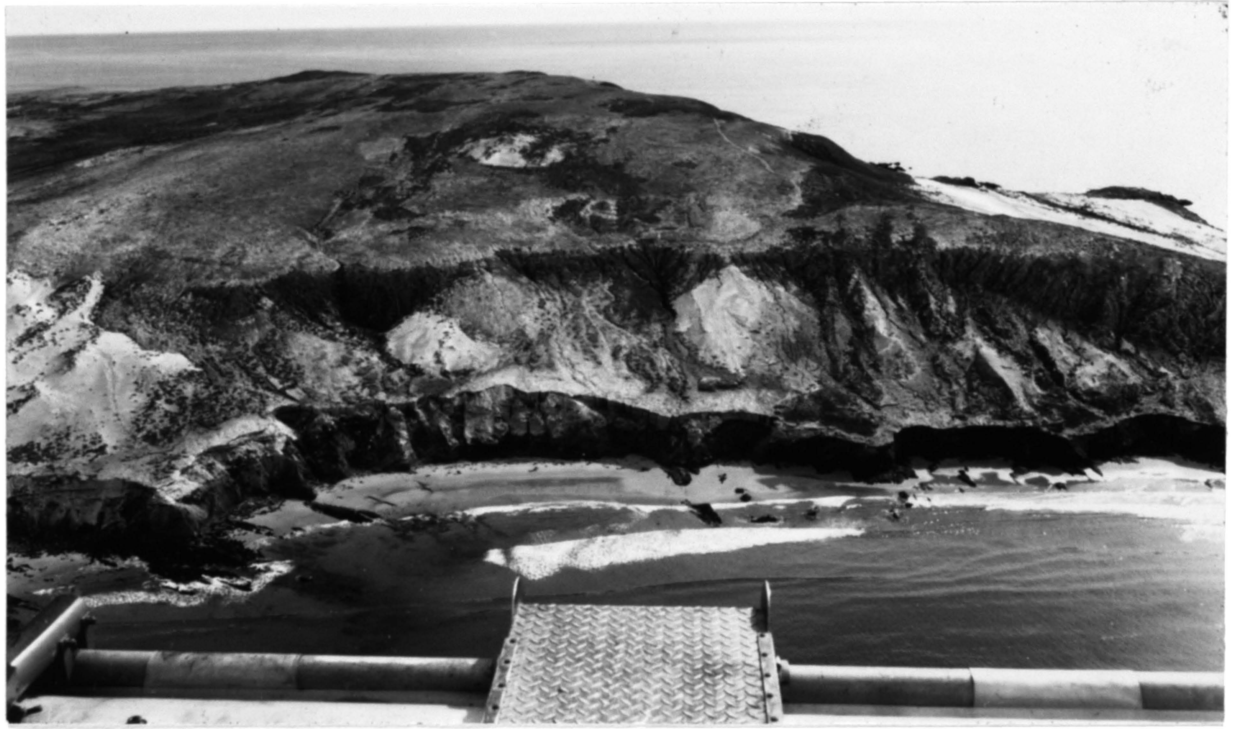


b.

Plate 37. a. and b. Airphoto of eastern third of San Miguel Island, Santa Rosa, and Santa Cruz.
Photos taken January or February, 1969.

a.

b.



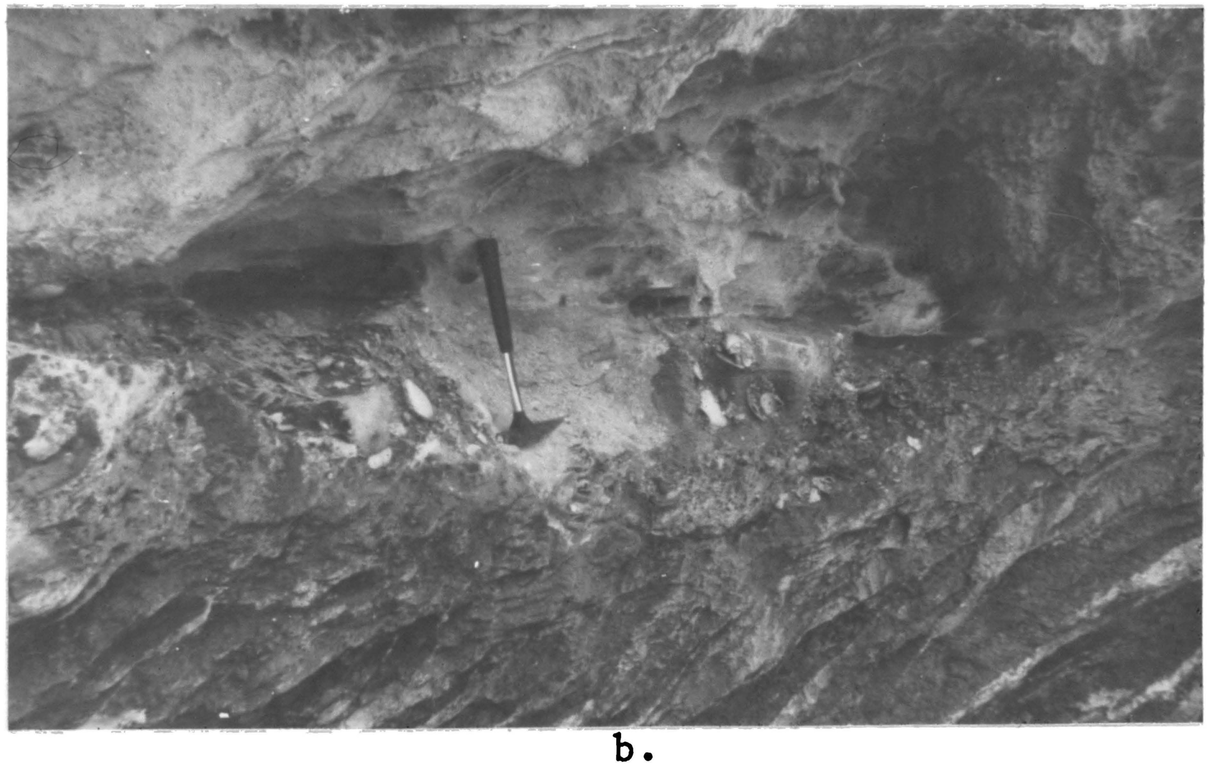
c.

Plate 38. a. Airphoto of the Hauling Grounds (top center and right) and a partial view of Busted Balls Cove (left foreground) showing Abalone Point (in center foreground) and, just to the right, the 30 foot foredge of SMI-243 (at arrow). The Hauling Grounds is a complex of eolianites, paleosols and shell middens. Photo taken in March, 1969.

b. Another view of the Hauling Grounds, Busted Balls Cove and Caliche Flats on the upper mesa.

c. Busted Balls Cove (foreground) and Caliche Flats (upper mesa). Localities 22 and 23 are in the center foreground just off the beach. Photos b. and c. taken in November, 1969.

a.



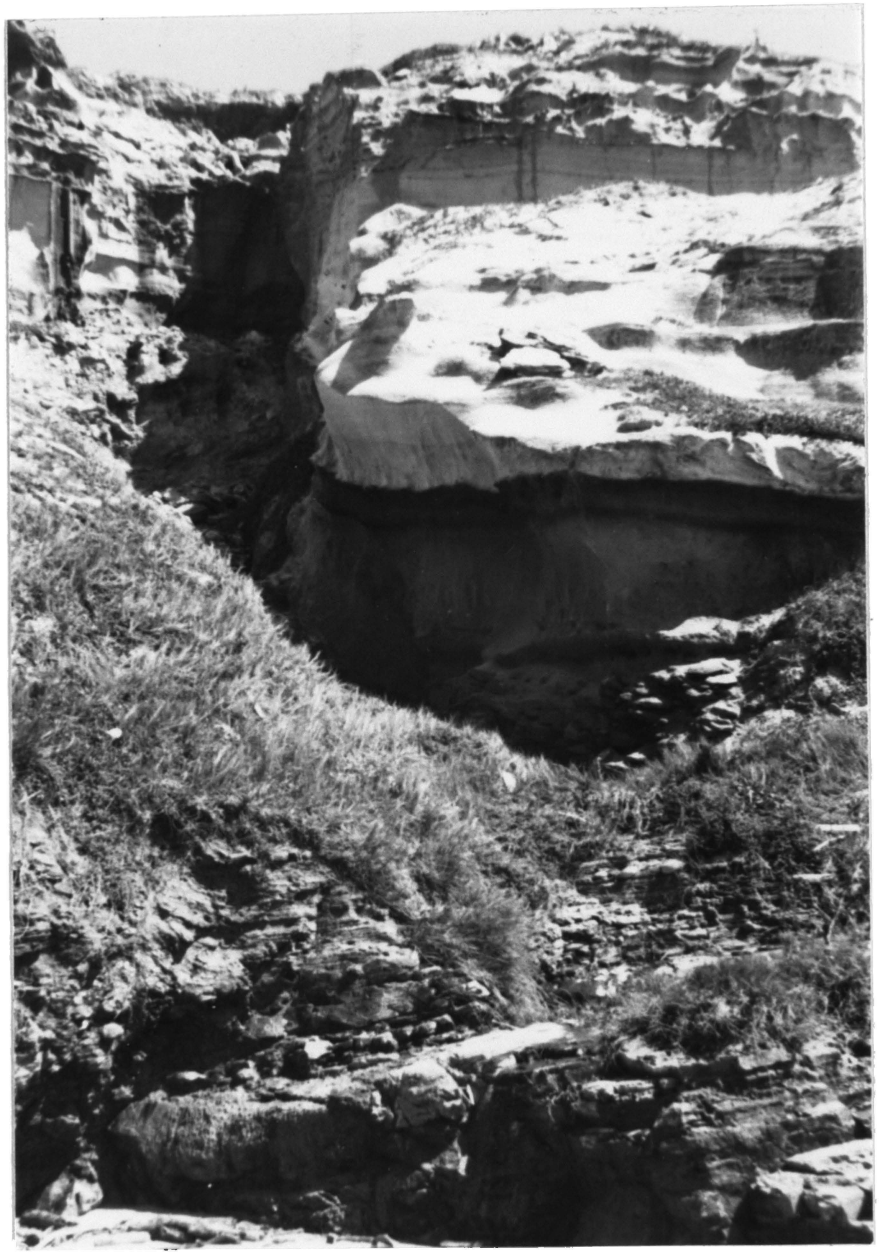
b.

c.

Plate 39. a. Raised beach deposit at SMI-147 (taken August, 1966).

b. SMI-245, showing bedrock-beach deposit interface at 235 feet elevation. The beach deposit and bedrock have been partially calichified.

c. 30 foot foredge of SMI-243 with overlying eolianites capped by shell middens and shrubs. See Fig. 2 in Appendix B for detail. Photos b. and c. taken August, 1969.



a.

b.

Plate 40. a. SMI-23 showing truncated Cretaceous sedimentaries (foreground) overlain alternately by terrace cobbles, the Simonton Soil, eolianite, and caliche. Photo taken in August, 1966.

b. Side view of a. Photos taken in August, 1969.

a.

b.

Plate 41. a. Near SMI-23, 10 foot beach deposit resting on locally truncated Cretaceous sedimentaries, Busted Balls Cove.

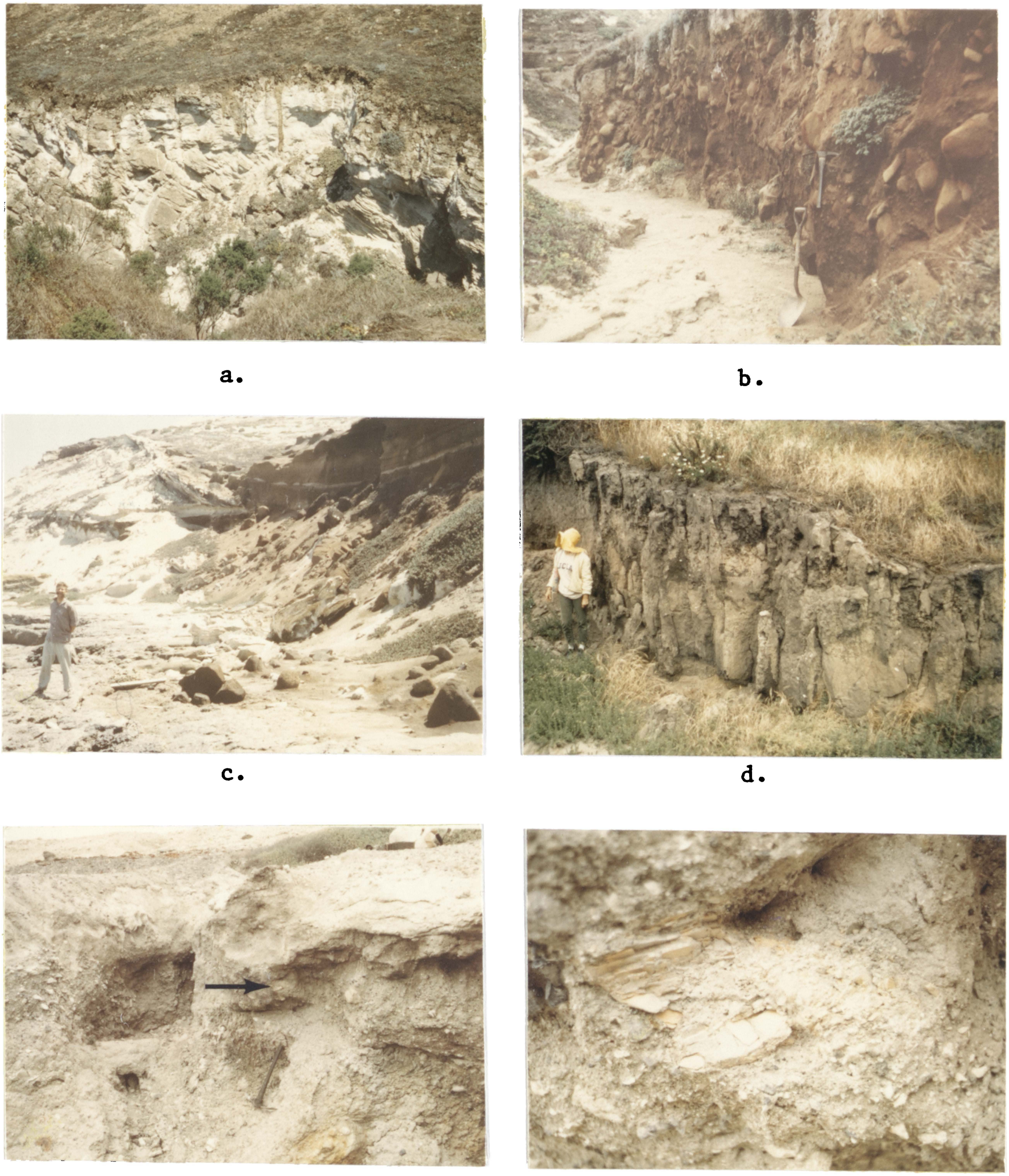
b. East end of Busted Balls Cove near SMI-23 and 147, showing shoreline angle (at end of pointer held by man) and beach conglomerate of 20 foot terrace. Both photos taken May. 1969.

a.

b.

Plate 42. a. View northeast from SMI-19 showing Busted Balls Cove. Interface of intermediate terrace platform (foredge) and overlying Quaternary cover is clearly visible.

b. View east from SMI-16 showing Judith Rock Point (right foreground), Leuzarder Point (left center) and Crook Point (upper right). Note the high terraces up from Crook Point. Both photos taken August, 1967.



a. b. c. d. e. f.

Plate 43. a. Soil pendants in eolianite, SMI-78, 79.
b. Oxidized colluvium, Greene Barranca, SMI-76.
c. Beachrock (under man) overlain by eolianite-paleosol complex, Simonton Cove, SMI-260. Photos a-c taken August 1967.
d. SMI-104, alluvial soil with vertebrate remains and abalone shells. Photo taken July 1969.
e-f. Beach deposit at SMI-128. Arrow points to elephant tusk (f shows close up of tusk). Taken August 1969.

a.

b.

Plate 44 a. View of SMI-23 looking west.

b. View of SMI-245 (upper left) from SMI-222 looking southeast. Both photos taken May, 1969.

a.

b.

Plate 45. a. View looking west from SMI-220 showing beach conglomerate and overlying eolianite-colluvium-fluvial-paleosol complex. Midden-capped dune on top of sea cliff.

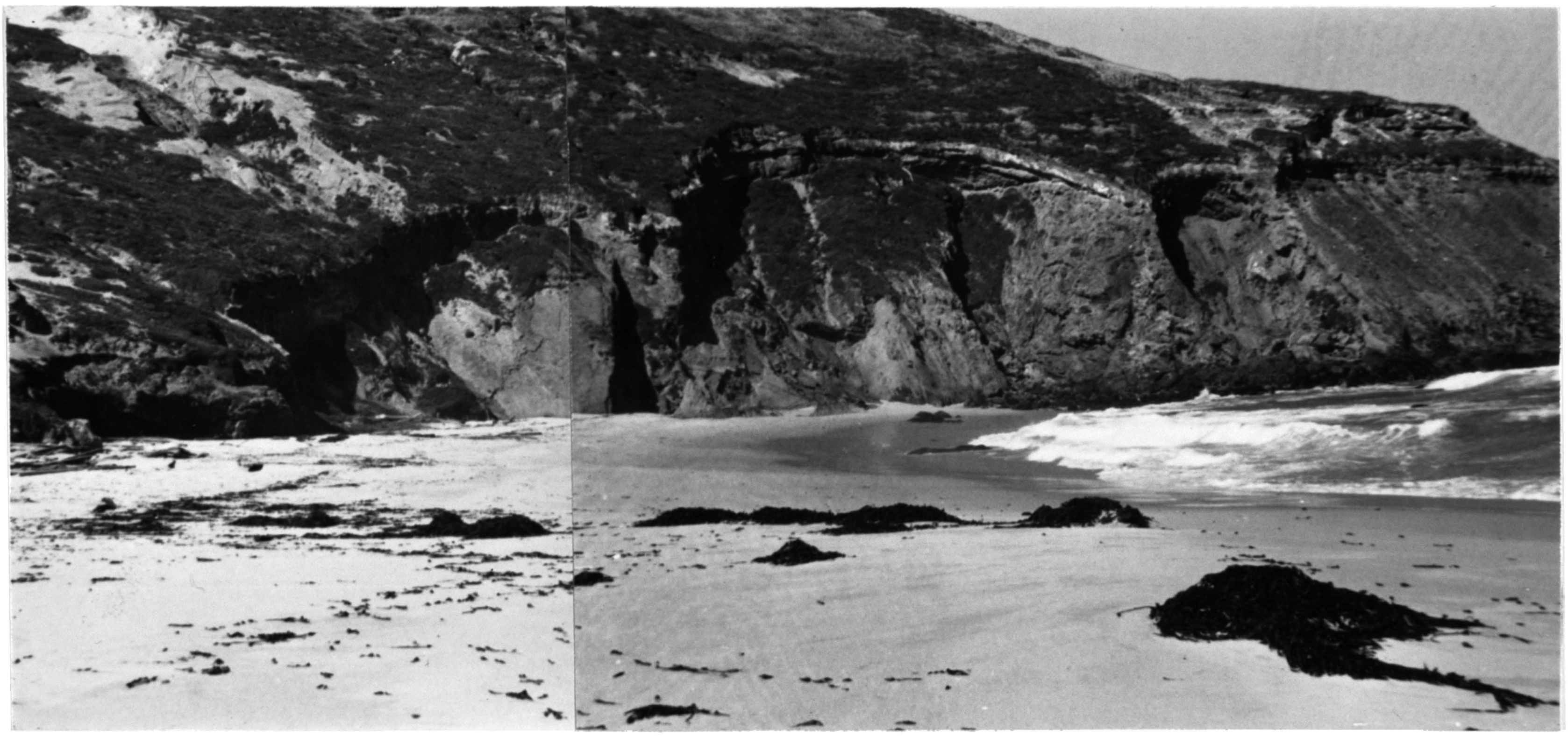
b. View east from SMI-221 showing truncated bedrock overlain by beach conglomerate and a complex body of eolianites, colluvium, fluvium, paleosols and aboriginal shell middens. Both photos taken May, 1969.

a.

Plate 46. a. View southeast from SMI-149 at Chinese Point showing angular unconformity of intermediate terrace platform and flat lying Quaternary cover.

b. Looking west to Chinese Point and SMI-149 from Bowl Cove beach. Photo a. taken August, 1969; b. taken May, 1969.

a.

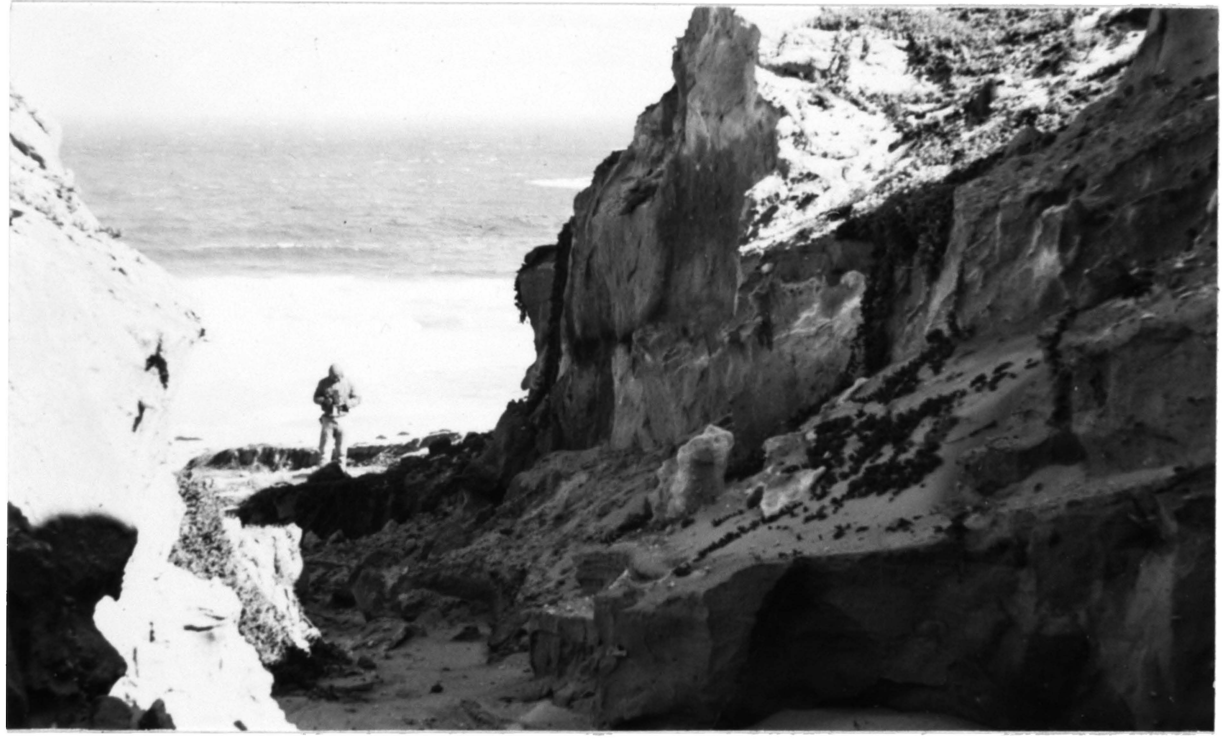


b.

Plate 47. a. View west to SMI-149 (off upper right edge of photo) and 217 (far left center) showing Pleistocene cover over Cretaceous sedimentaries. A 15-20 platform may be seen at lower left.

b. Close up ot 15-20 foot platform (SMI-217) and boulder conglomerate showing well developed dark paleosol above. The Pleistocene boulder beach is partially caliche-indurated.

Both photos taken in May, 1969.



a.

b.

c.

Plate 48. a. and c. Bird Bone Wash in Bowl Cove looking northwest (a) and southwest (c) at SMI-216. The sediments and paleosols contain abundant small bones of shore birds wind-blown from the beach below.

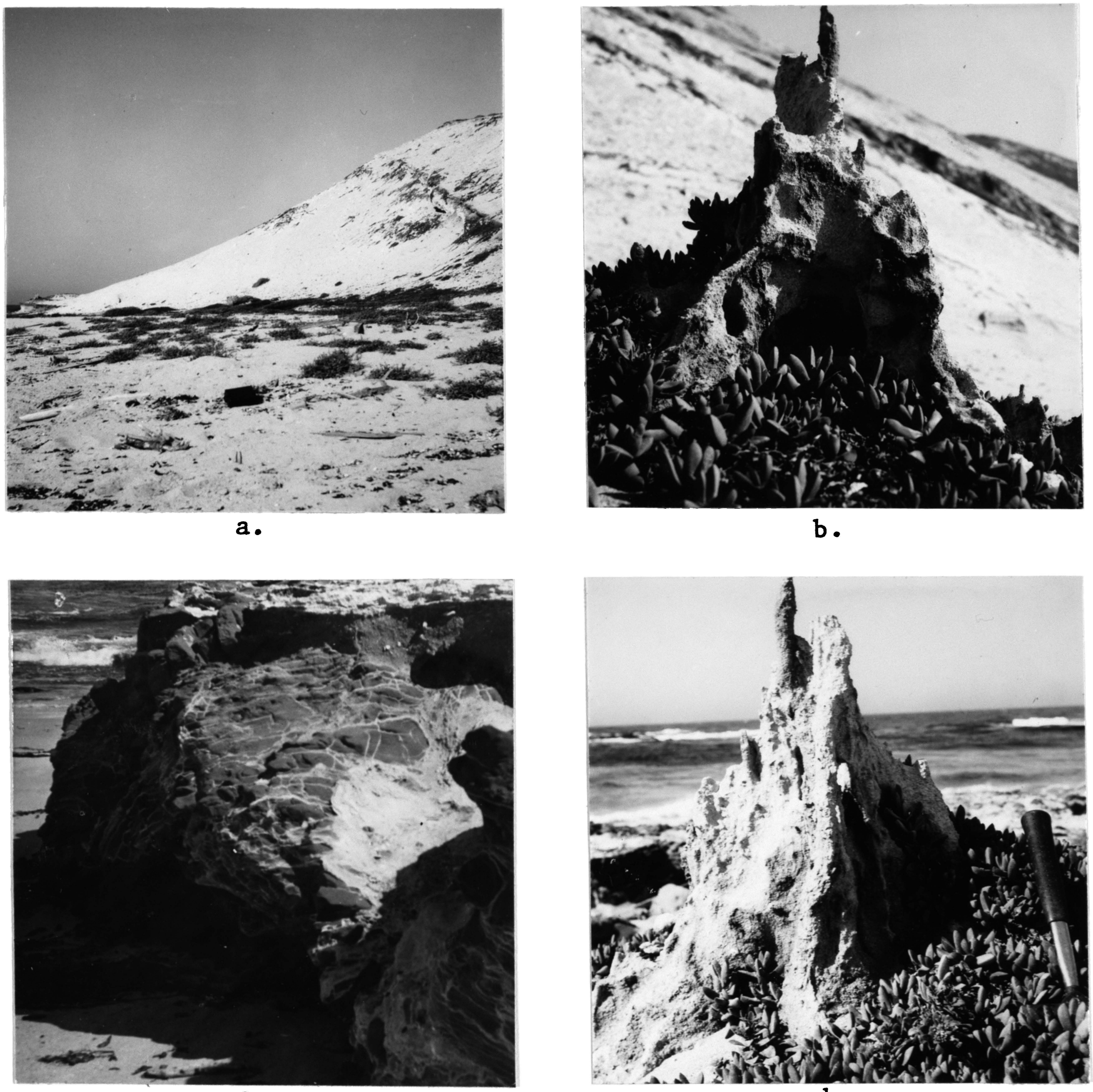
b. Air view looking southeast at Bowl Cove and localities 81, 216 and 217. The high terrace foredge-Quaternary sediment interface is clearly visible as the lowest of a series of horizontal lines along the upper third of the cliff. Photos a. and c. taken May, 1969; photo b. taken March, 1969.

a.

b.

Plate 49. a. View looking northeast taken from upper Chinese Point showing interface (dashed line) between the 285-290 foot platform and overlying Quaternary cover. The left center of the photo shows sand and eolianite complexes and intercalated paleosols.

b. Well developed paleosol (Simonton Soil) at SMI-242 showing K horizon (caliche) and solution channels (soil pendants) extending into eolianite parent material. The comparatively advanced stage of profile development probably reflects long term pedogenesis and moderate to poor drainage conditions. Photo a. taken in August, 1969; b. taken in August, 1966.



a. b. c. d.

Plate 50. a. View looking north from Bowl Cove (SMI-215) to Fossil Point, SMI-181 (far left center).

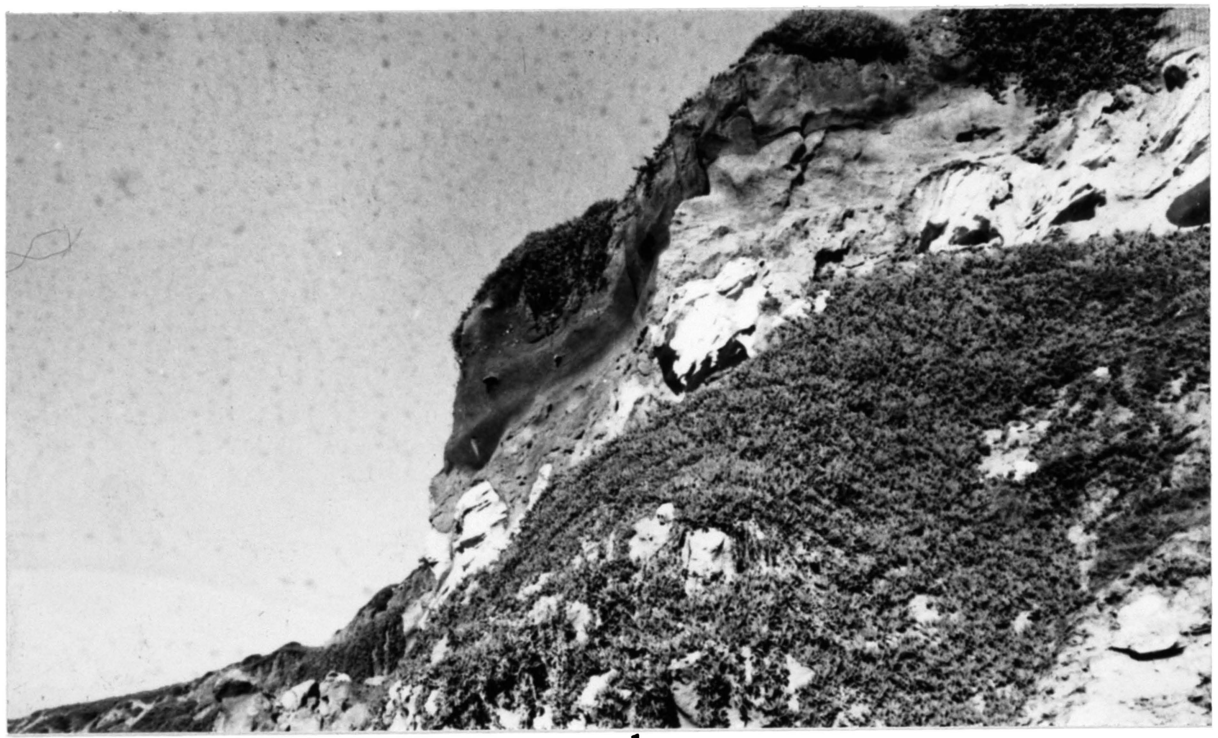
b. Southwest looking close up of partially charcoalized rhizoconcretion "growing in Simonton Soil at SMI-181. This former shrub or tree gave a C-14 date of > 40,000 radiocarbon years (see also Plate 21d).

c. Caliche-impregnated marine platform on which Simonton Soil developed, now actively eroded by the sea. This platform is visible in 50a at far left center and lies several feet seaward of rhizoconcretion in a and d.

d. Same as a, but view to north.

All photos taken in August 1967.

a.



b.

c.

Plate 51. a. North view of eolianite in Harford Canyon (SMI-209), with abundant land snails.
b. Well developed soil with abalone middens in upper half (as yet undated) SMI-253, Harford Canyon.
c. Air view looking southeast showing intermediate and high terraces with Quaternary cover along Eagles Nest Cliffs, Simonton Cove. Photo a. taken in August, 1967; b. and c. taken in November, 1969.

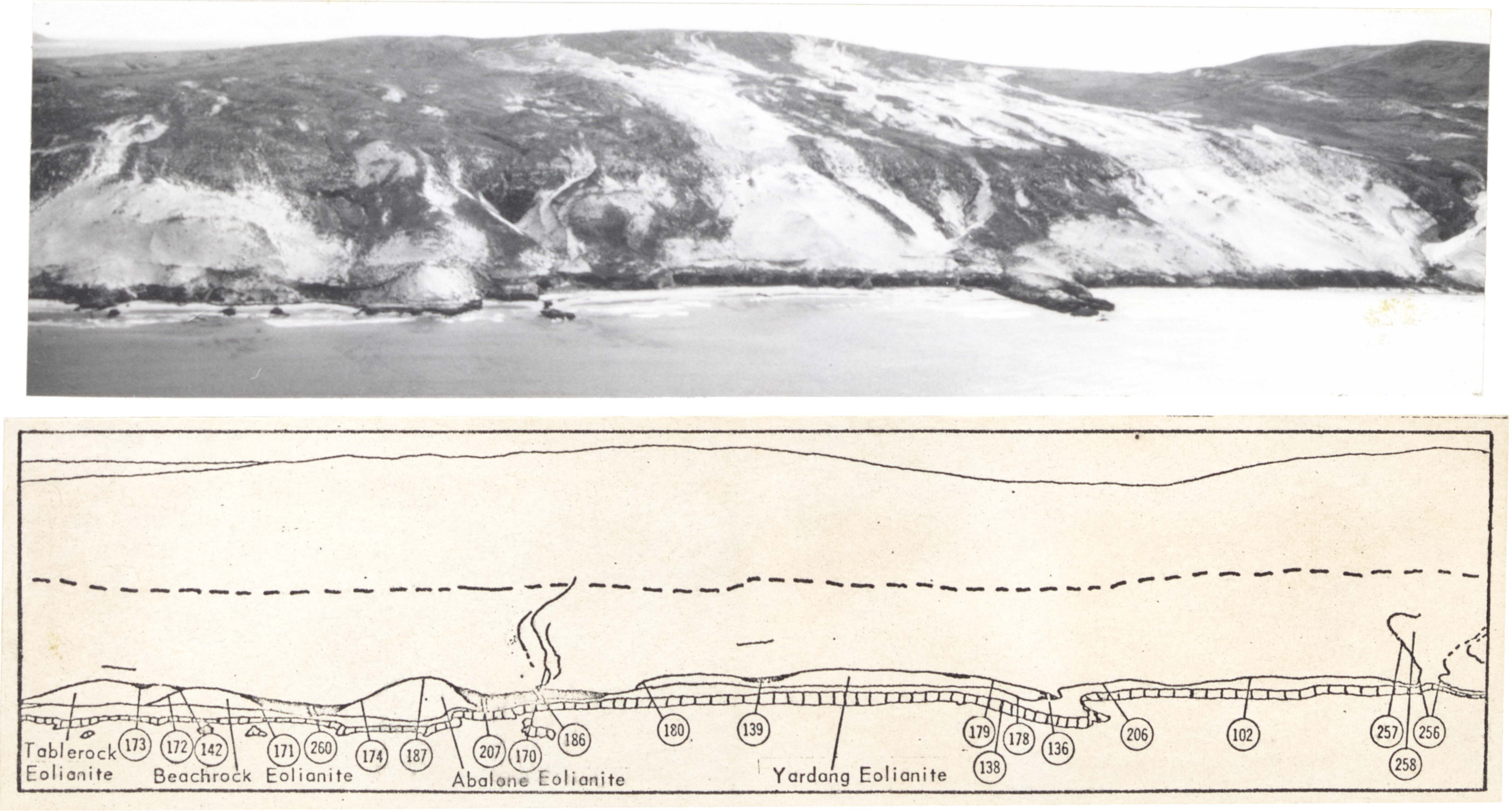


Plate 52. This view is southeast and stretches from Range Pole Canyon on the right to the beginning of North Simonton Beach on the left. The continuous lines identify paleosols; the heavy dashed line identifies the foredge of the high terrace. (See place name map, or Toponomy Map, for names of canyons and coves.)

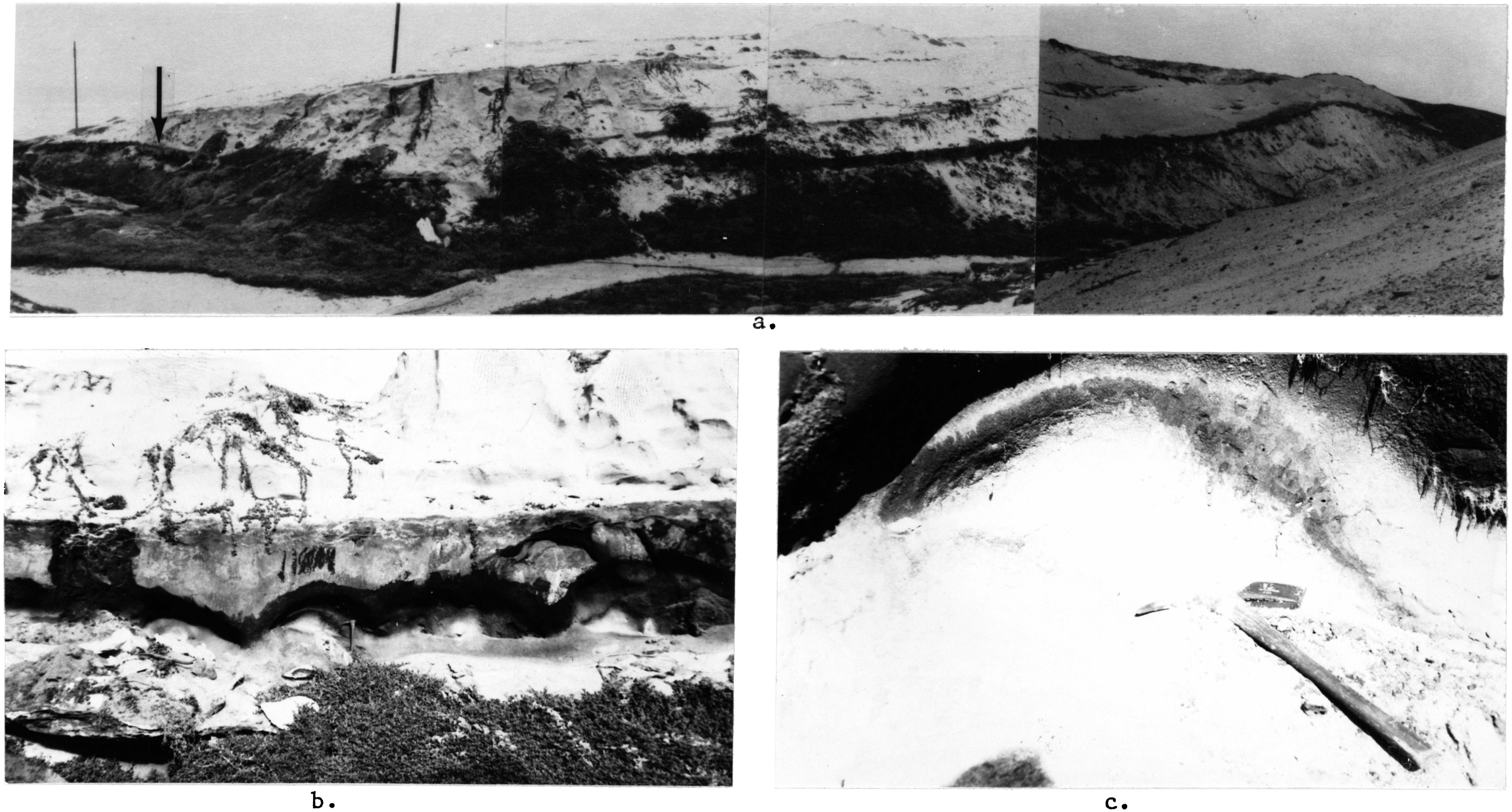
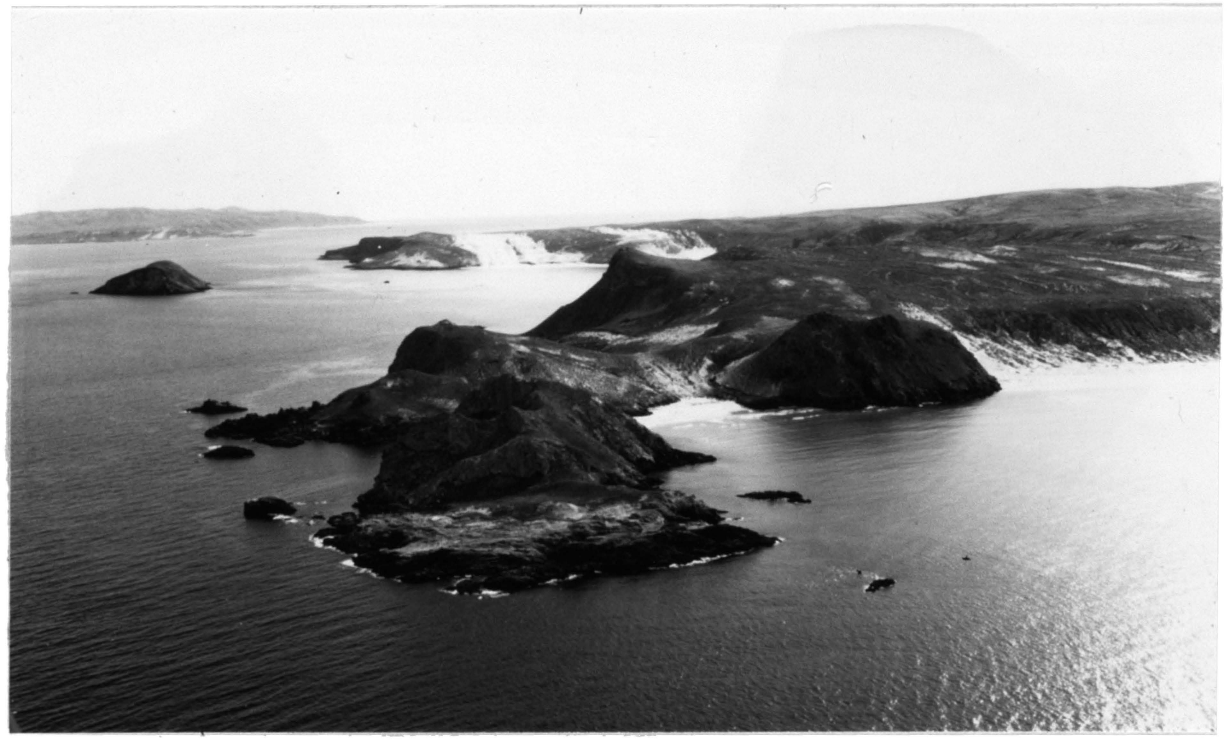


Plate 53. a. North side of Range Pole Canyon showing Simonton Soil and its relationship to underlying and overlying sands. Shell midden in upper 4 inches of Simonton Soil was 7,580 ± 140 radiocarbon years old (I-4852).

b. Close-up of Simonton Soil shown at arrow in a. Note the massive caliche horizon.

c. Close-up of area between solution channels (soil pendants).



a.

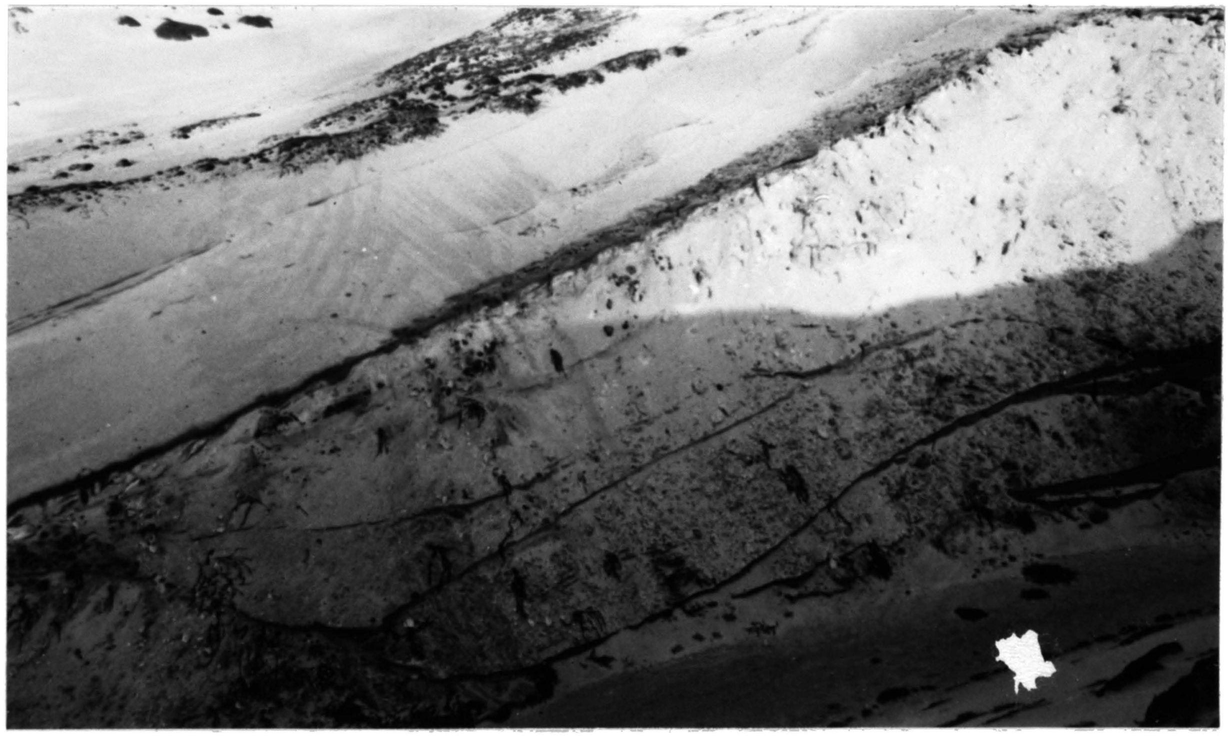
b.

c.

Plate 54. a. Air view southeast showing Harris Point, Lester Point and Devil's Knoll. Note flat marine platform at the tip of Harris Point. Photo taken November, 1969.

b. Air view of Charcoal Cove Canyon and associated eolianite and intercalated paleosols.

c. Air view of Range Pole Cove, Sand-N-Your-Eyes Hollow, and Green Mountain. Photos b.-c. taken March 1969.



a.

b.

c.

Plate 55. a. Eolian, fluviatile, colluvial complex underlying Simonton Soil in north wall of Range Pole Canyon.
b. Caliche-capped bedrock being stripped by wave action, Simonton Cove.
c. Beach zone in headwall of the upheaval, Cuyler Harbor.
All photos taken August, 1969.

a.

b.

Plate 56. a. and b. Beachrock (water-tablerock) resting unconformably upon terrace platform, Simonton Cove. Note particle size range in photo a. which varies from sand and gravels to megaclasts.

Both photos taken August, 1967.

a.

b.

c.

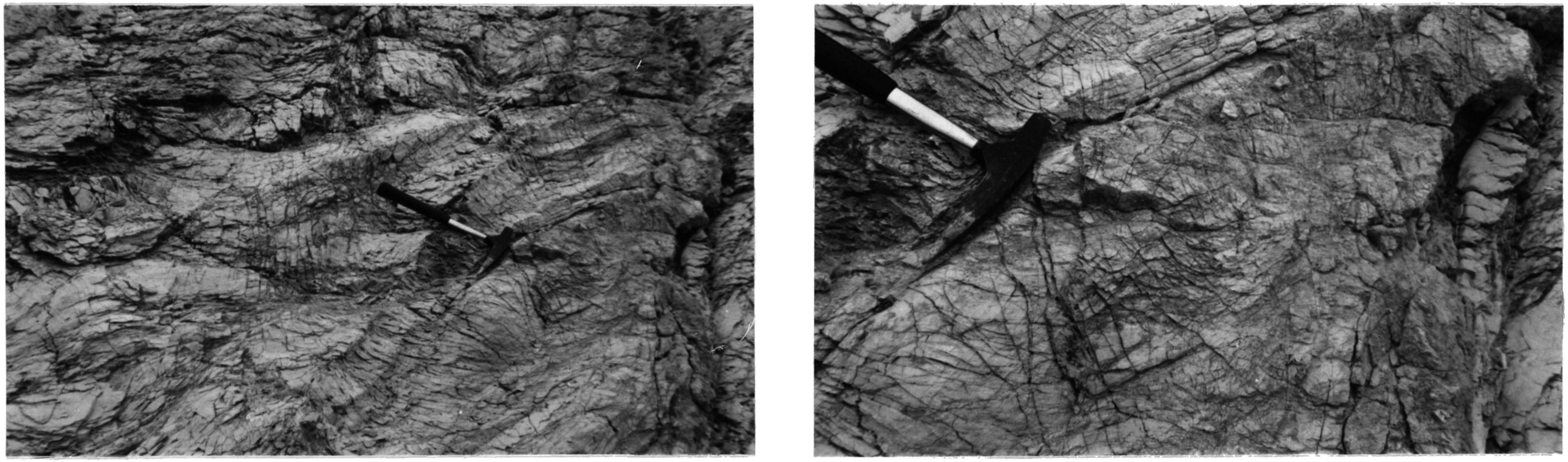
Plate 57. a., b., and c. Beachrock resting on marine platform at Beachrock Beach, Simonton Cove. Photo a. shows beachrock *in situ*; b. and c. show beachrock as shingle thrown up by storm waves.
Photos taken August, 1967.

a.

b.

Plate 58. a. Beachrock resting on terrace platform being actively eroded by the sea.

b. Beachrock showing ridge-furrow systems characteristic of tropical beachrock. Most likely the fluting is caused by sand abrasion during swash associated with spring tides and storms. Both photos taken August, 1967.



a.

b.

c.

Plate 59. a. and b. Highly fractured character of bedrock at Cuyler Slide, just north of SMI-4. The rock is a foraminiferal silt or claystone that has undergone post-fracturing silicification by low-temperature silica associated with a nearby fault. Although not shown on the geologic map of Weaver and Doerner, it probably is the upper member of the Rincon Formation of Oligocene age.

c. Headwall of Cuyler Slide showing Pleistocene eolianites alternating with paleosols. This complex is underlain by a beach deposit at the lower-left corner of the photograph.

All photos taken July, 1969.

a.

b.

Plate 60. a. View to the southeast showing West Cuyler Slumps and Pleistocene beach deposits (a=SMI-85, b. and c=SMI-1). Note rotational character of slumping. Close-up of b. and c. shown on Plate 61. See also Plate 62c. Both a. and b. are at the same elevation, but a. is closer to the camera than b. and appears lower in elevation.

b. Close-up of beach deposit at SMI-85 shown in a. Arrow points to contact of bedrock and beach debris. Both photos taken August, 1969.

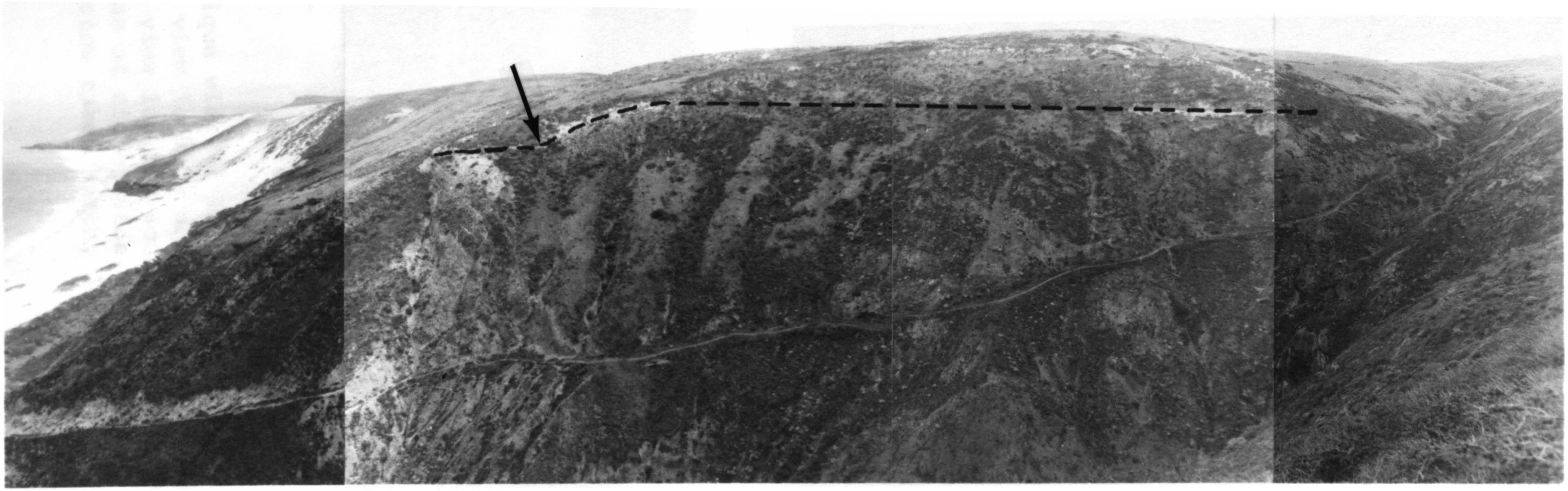


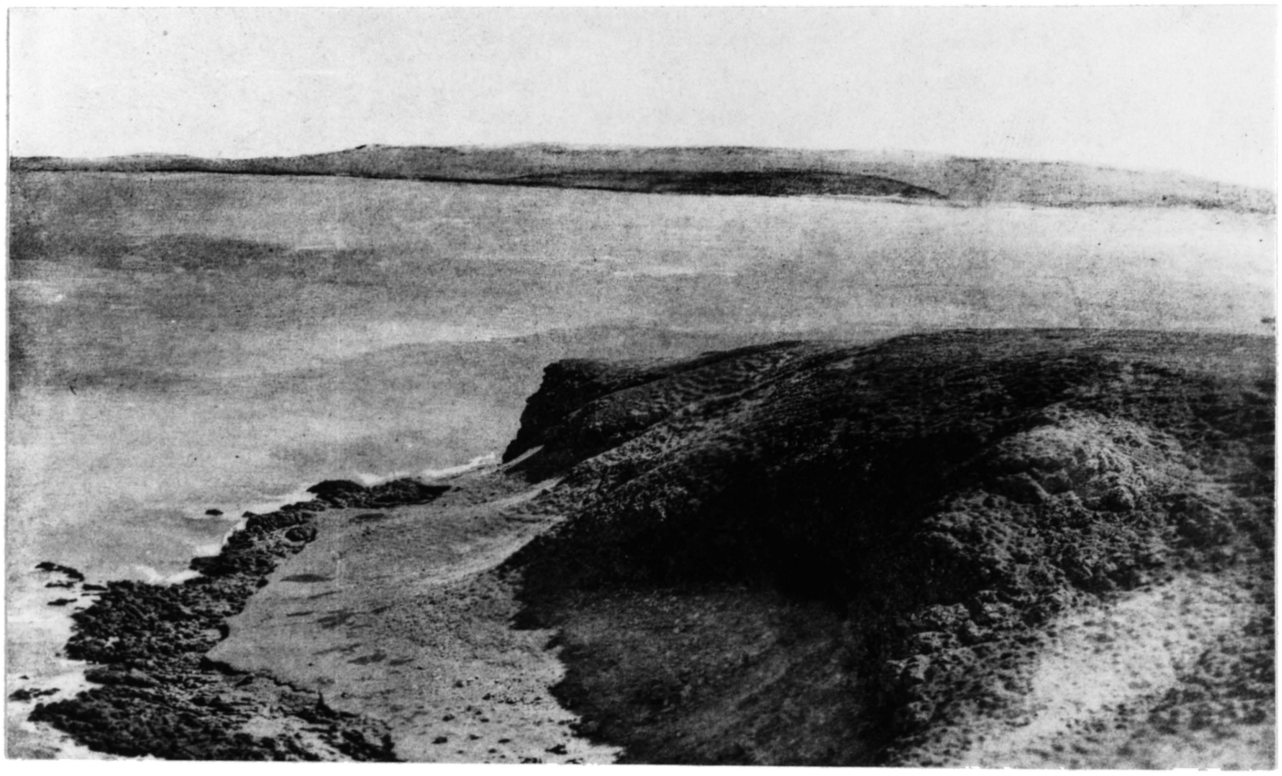
Plate 61. Composite photo of east face of Nidever Canyon showing two terrace platform and beach deposit levels (dashed line) at SMI-1. Note shoreline angle at arrow; the elevation is 325 feet. The eolianite cover above the beach deposits is interpreted as pre-dating the cutting of Nidever Canyon and was formerly continuous across to where the photograph was taken (see also Plate 62c). Photos taken July, 1969.

a.

b.

c.

Plate 62. a. Oblique view of South Green Mountain Canyon.
b. Air view looking north at eastern half of San Miguel.
c. Air view looking south to Nidever Canyon and slump areas at either side.
All photos taken March, 1969.

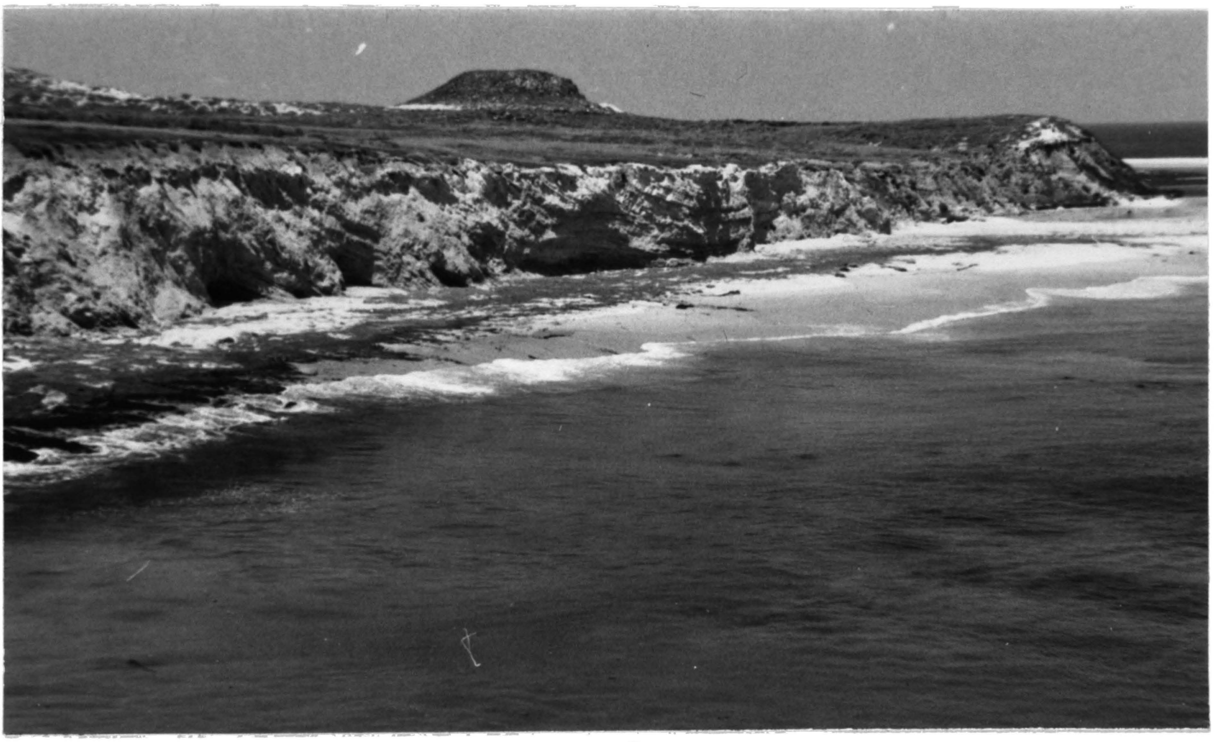


a.

b.

Plate 63. a. Photo dating from sometime around 1893 by C. D. Voy, published by Yates (1902). View is to the southeast from Hoffman Point, SMI-8 towards Bay Point (upper center). Note stock trails.

b. Photo taken December 1965. Considerable filling of old sea cave in foreground may be either apparent or real.



a.

b.

c.

Plate 64. a. Exposed foredge of intermediate terrace platform cut across Monterey Shale, SMI-66. Quaternary cover and paleosol visible at upper right.

b. Close-up of paleosol and terrace cover near SMI-66.

c. Close-up of caliche-impregnated bedrock and associated beach debris near SMI-66.

All photos taken July, 1969.

a.

b.

Plate 65. a. View looking west from SMI-40 showing intermediate and high terrace levels in distance. Note dune climbing cliff face.

b. View from SMI-43 looking east to point where photo a. was taken. Note sand traces on cliff face blown up by wind. Note also caliche outcrop at base of soil along cliff exposure. Photos taken July, 1969.

a.

b.

c.

Plate 66. a. b. and c. Marine benches being etched by biochemical and salt-weathering processes. Bench is in normal wave spray zone and is washed by spring tides. Note linear depressions and solution pits along joints in a. and selective concentrations of gastropods on topographical high spots above water in b. and c. Salt precipitate visible in c. Photos taken at SMI-18, Otter Harbor, in August, 1969.

a.

b.

Plate 67. a. Cuyler slide, which took place about 1929 according to U. F. Stevens of Santa Barbara who took this picture a short time after the slide (slide occurred in 1940-42).

b. Cuyler slide as it appeared in 1967. Note numerous fossil soils intercalated in the eolianite exposed in the slide headwall. At least 10 paleosols are present, one of which has well developed soil pendants (near top left of slide headwall in photo a). Photo b taken August, 1967.

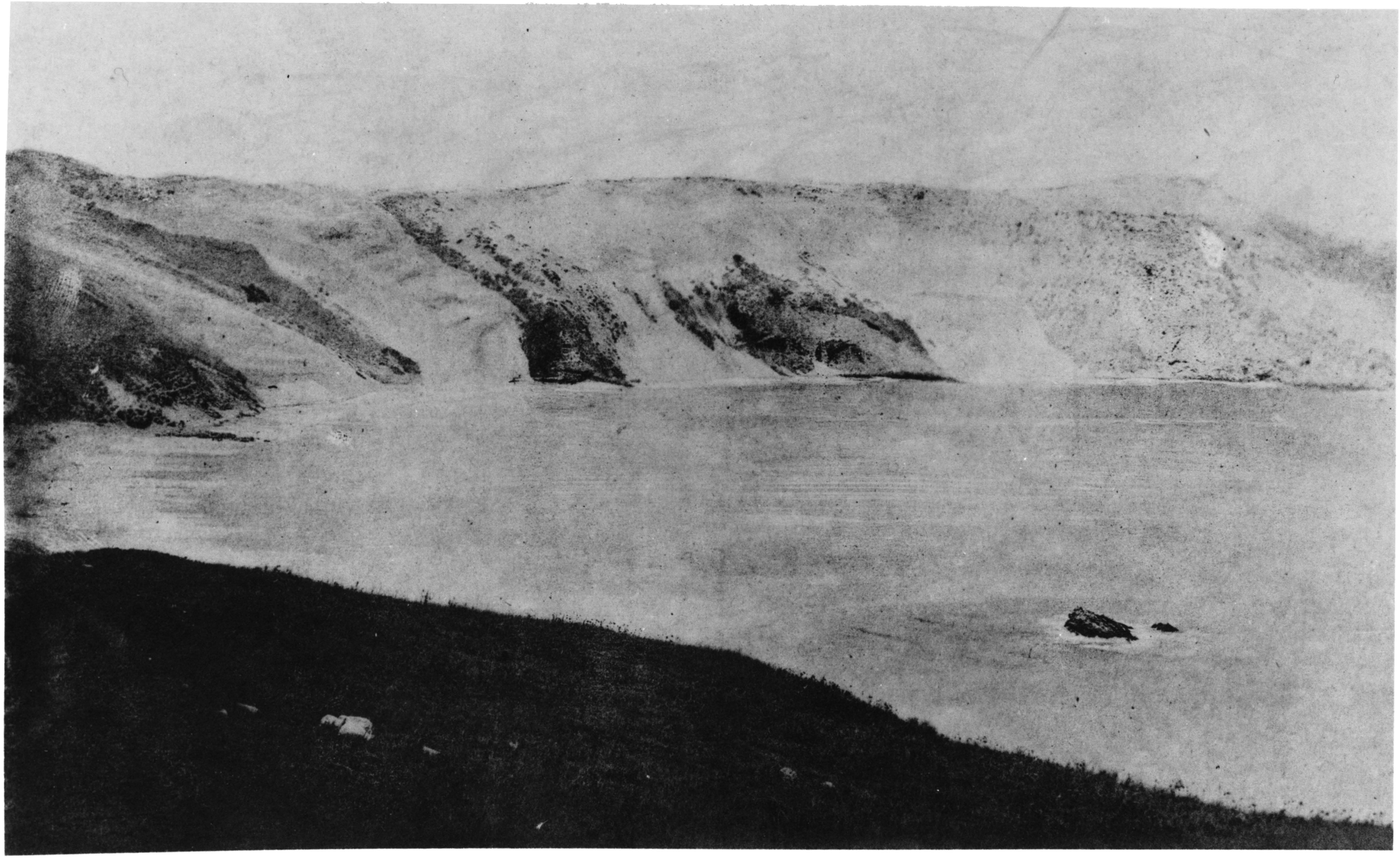
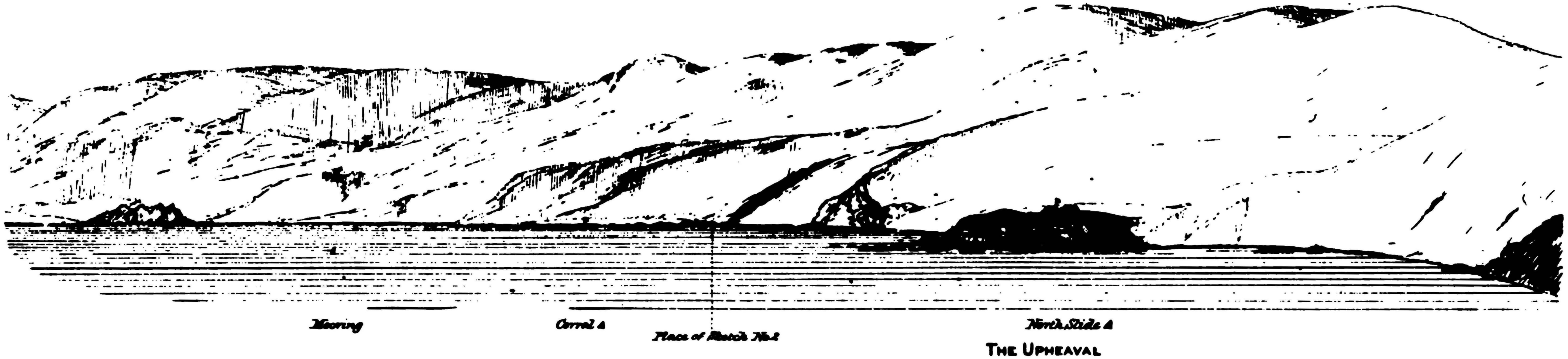
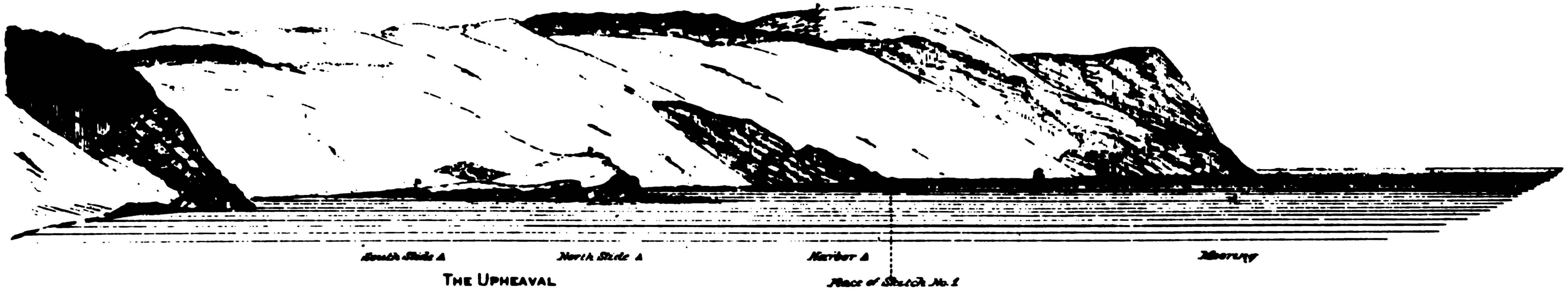


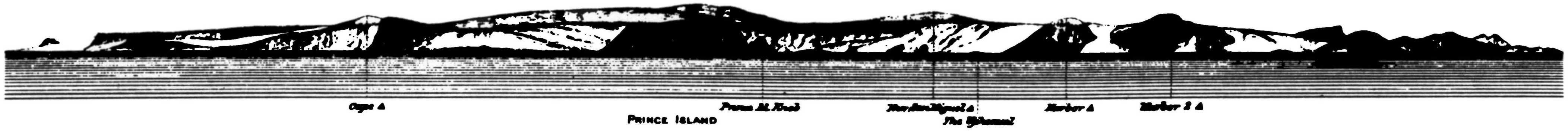
Plate 68. Photo of Cuyler Harbor prior to large landsliding events. Note huge dunes spilling into harbor from Hurricane Deck. This photo, though published by Yates (1902) was probably taken by Voy (ca. 1893).



Sketch No. 1



Sketch No. 2

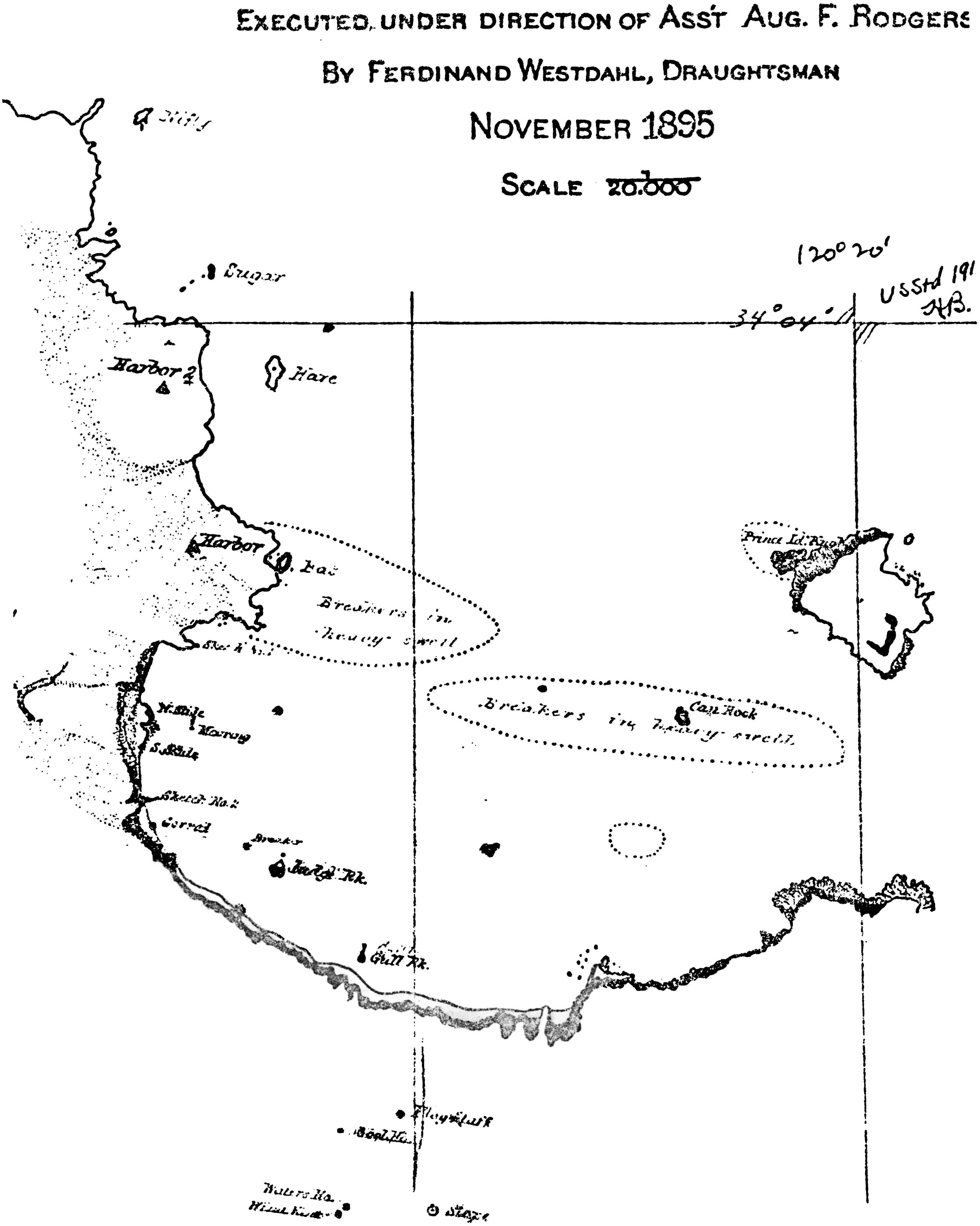


View of Cuylers Harbor, San Miguel Island, Prince Island bearing SW.¼S. distant 5 Miles

Sketch No.3

Executed under direction of Ass't Aug. F. Rodgers
By Ferdinand Westdahl, Draughtsman
November 1895

Plate 69. Three sketches of Cuyler Harbor made by Coast Survey personnel in November, 1895. These sketches were photo-reduced from large bromex originals so that some detail is lost. Even so, the extensive dune blankets which covered the island are apparent, especially in Sketch No. 3. All areas in white are dunes (courtesy National Archives).



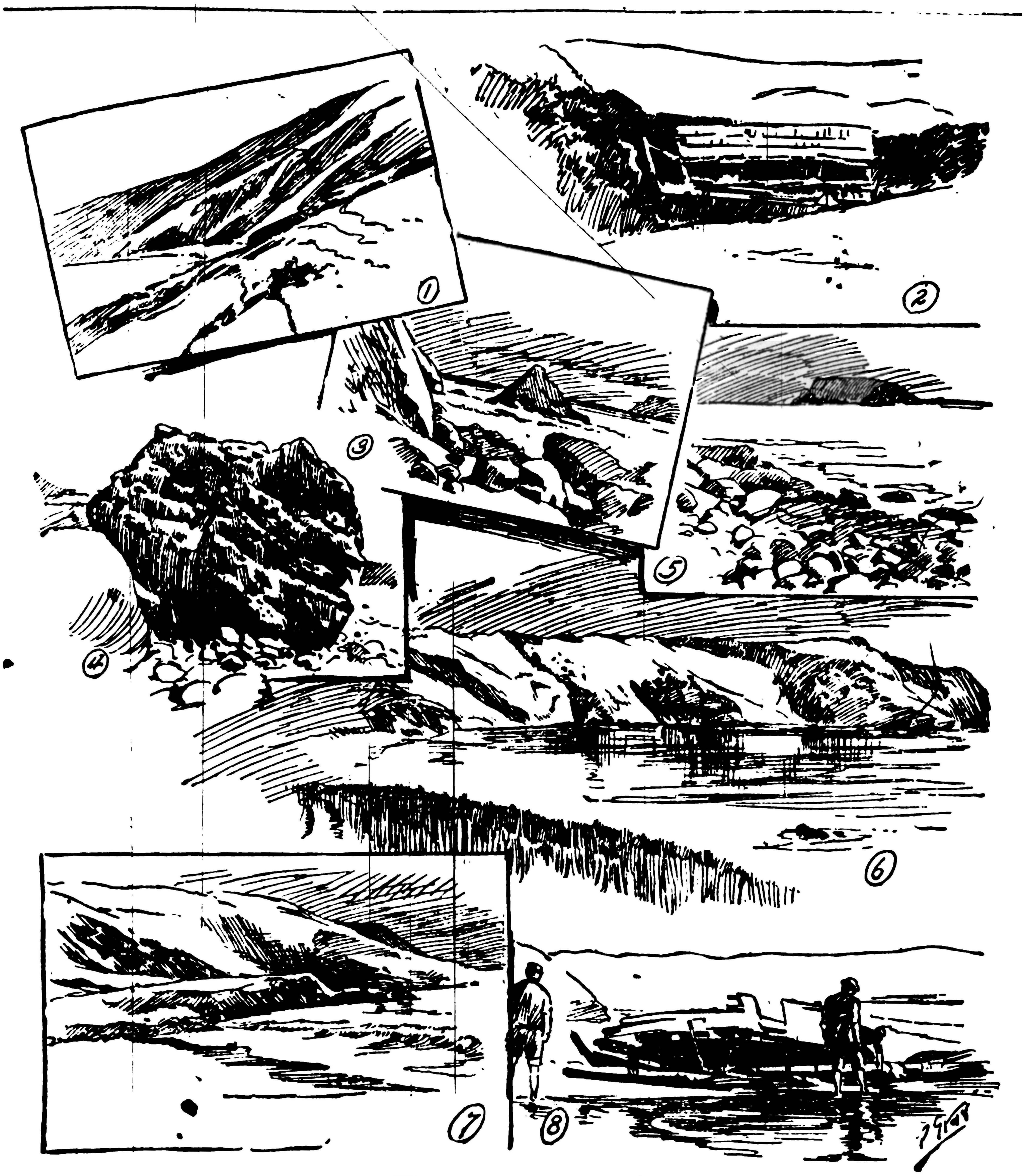
EXECUTED, UNDER DIRECTION OF ASS'T AUG. F. RODGERS

BY FERDINAND WESTDAHL, DRAUGHTSMAN

NOVEMBER 1895

SCALE 20.000

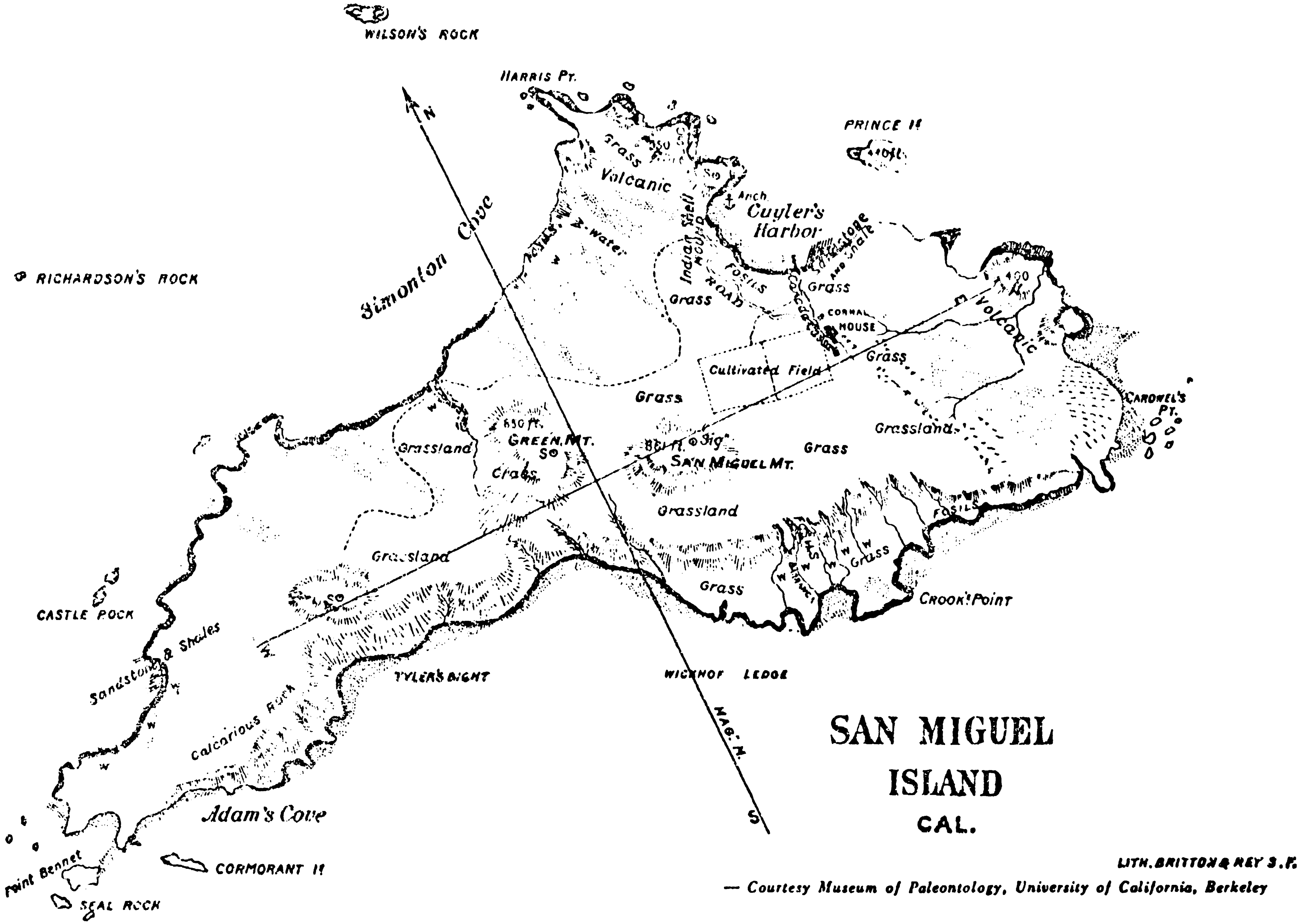
Plate 70. Plan layout of The Upheaval (slide of March 8, 1895) on west side of Cuyler Harbor drawn by Coast Survey personnel in November, 1895 (courtesy National Archives).



VIEWS AT SAN MIGUEL.

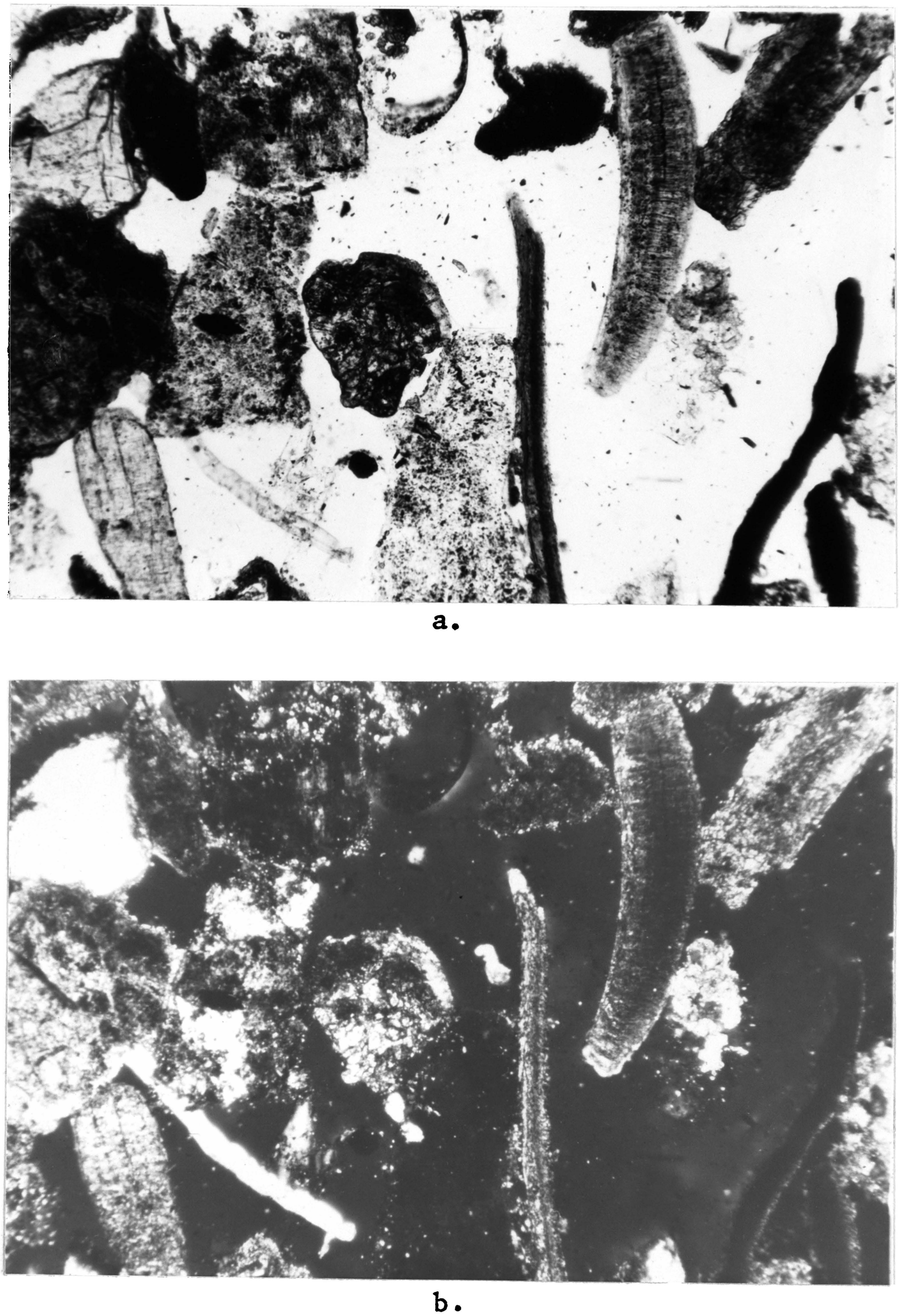
1—The hillside above the new bluff, plowed and furrowed. 2—The boathouse since the disaster. 3- Shore in front of upheaval (the h bank on the left is part of the face of the upheaved bluff, and on the middle distance appears the tall rock which marks its seaward terminu 4—The great rock formerly on the beach at the water's edge. This rock was flung to a height of seventy feet by the convulsion of March 5—Mass of rocks on newly upheaved beach. Princes Island in the distance. 6—General view of Cuyler Harbor. 7—The upheaval (bluff at the left of the picture is new ground thrown by the convulsion of March 9). 8—Wreck of the Liberty. From photographs take "Call" correspondent.

Plate 71. Views of Cuyler Harbor after the great Upheaval of March 9, 1895. Sketches from photographs taken by F. H. Loughead (San Francisco Call, April 14, 1895, p. 17).



— Courtesy Museum of Paleontology, University of California, Berkeley

Plate 72. Sketch map of San Miguel Island taken from unpublished manuscript of C. D. Voy, circa 1893 (courtesy Bancroft Library, Berkeley, California).



a.

b.

Plate 73. Photomicrograph of eolianite (SMI-4) showing detail of skeletal and detrital grains. Photo a., plain light; photo b., crossed nicols. Magnification x60.

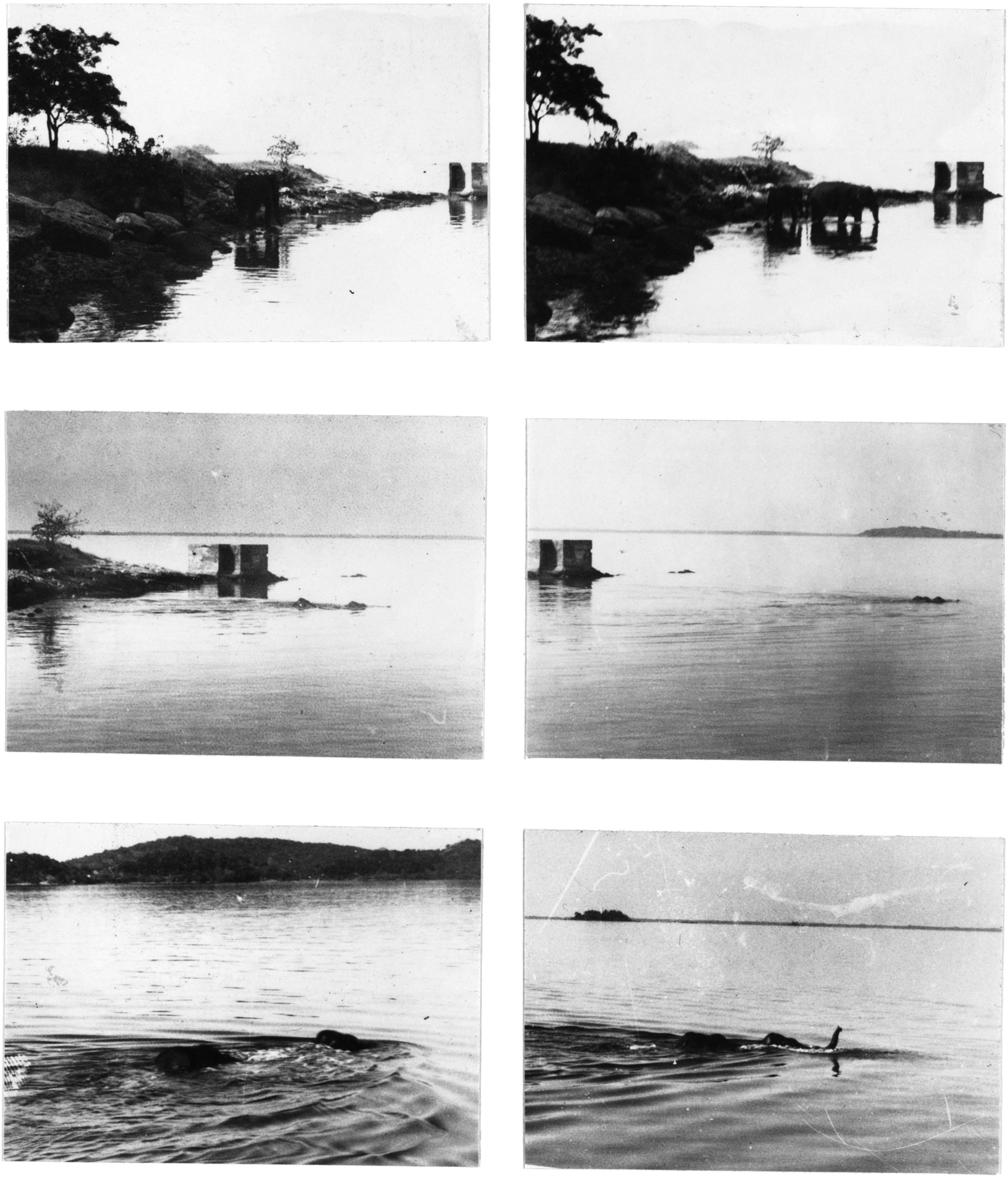


Plate 74. a. Sequence of 11 photos taken by Admiral R. Kadirgamar on July 15, 1960, showing an elephant cow and calf swimming from Ostenburg Ridge to Sober Island, Trincomalee Harbor, Ceylon. (Photo sequence continued on next page.)

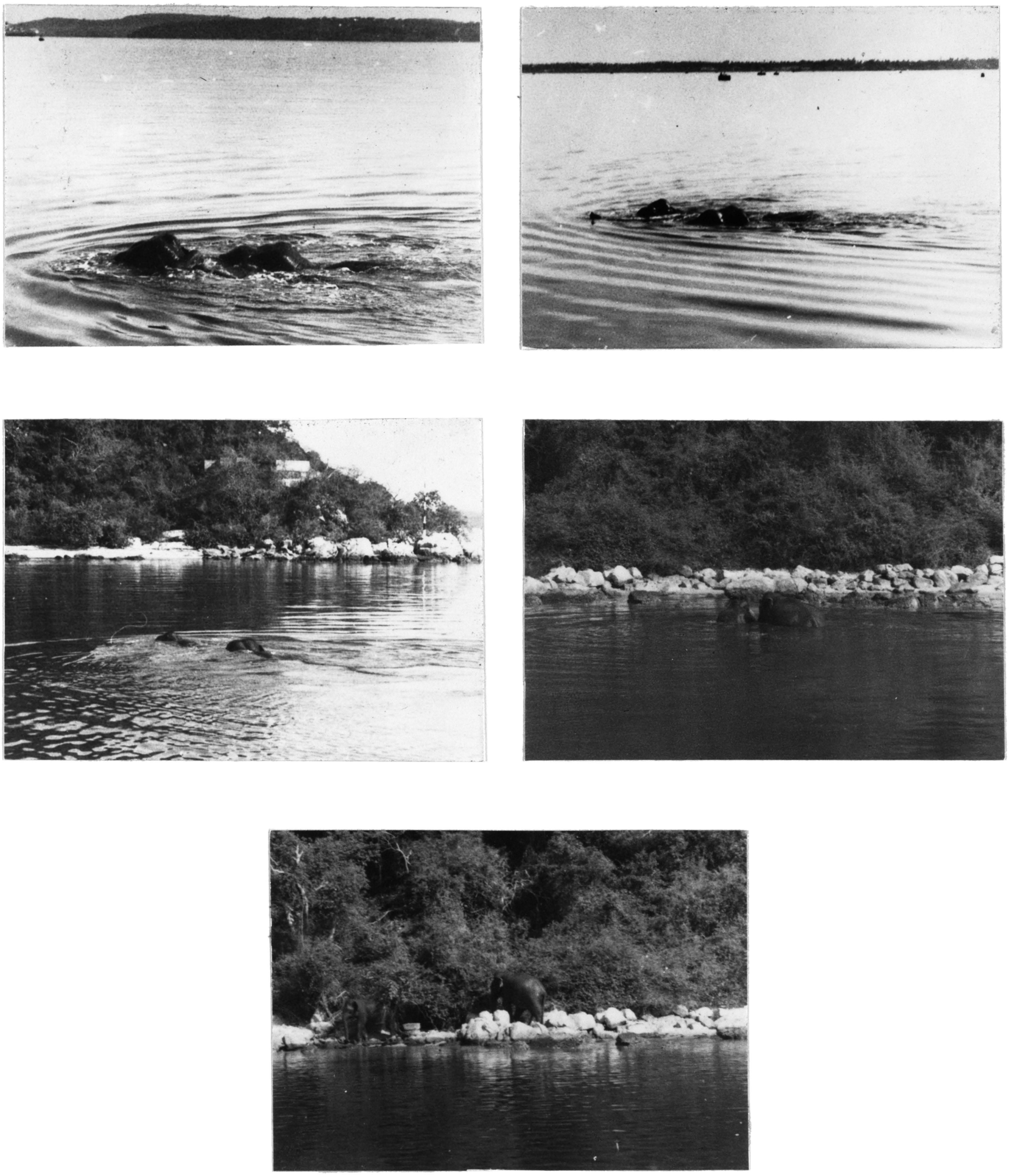


Plate 74. a. (continued)

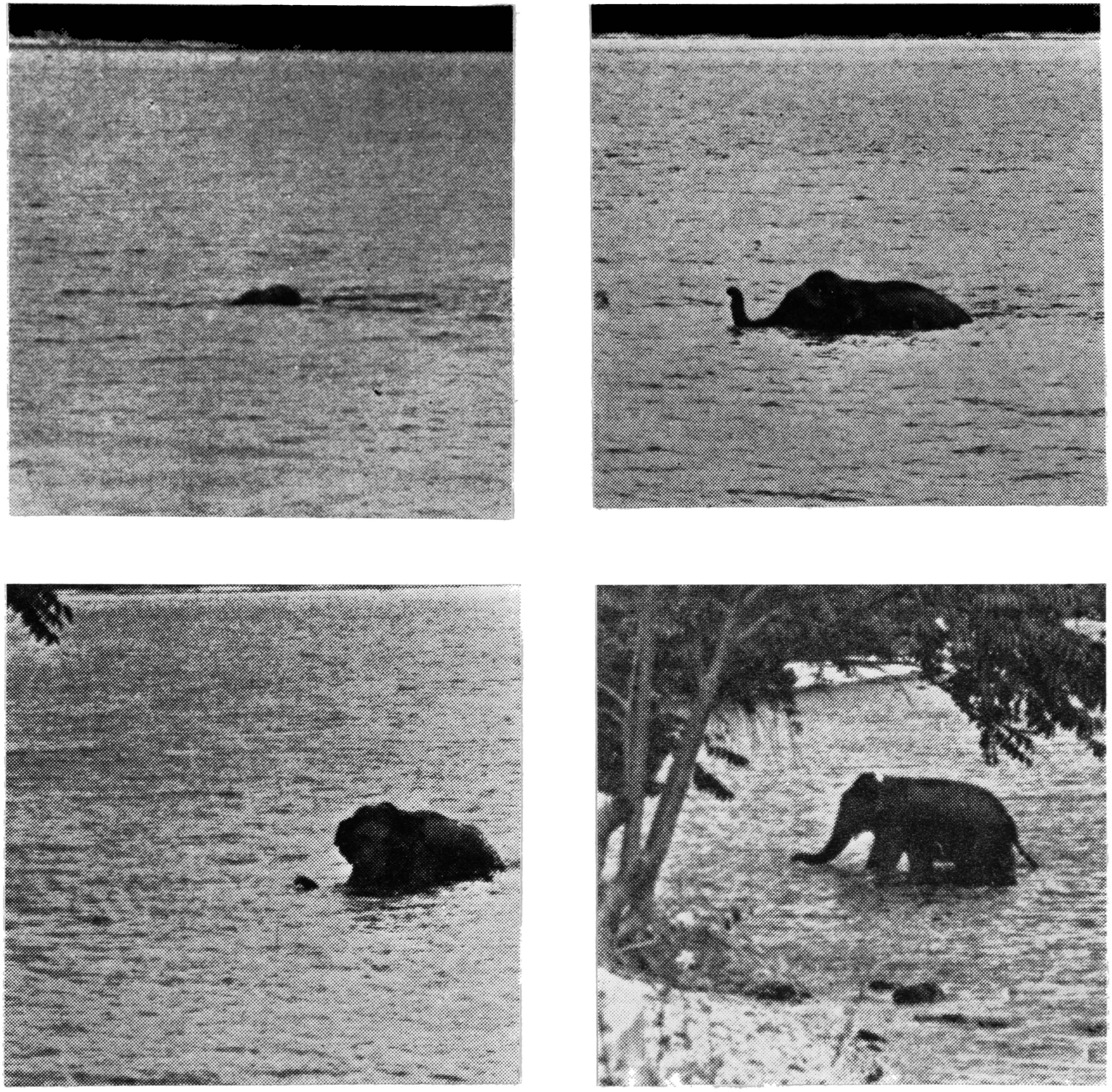
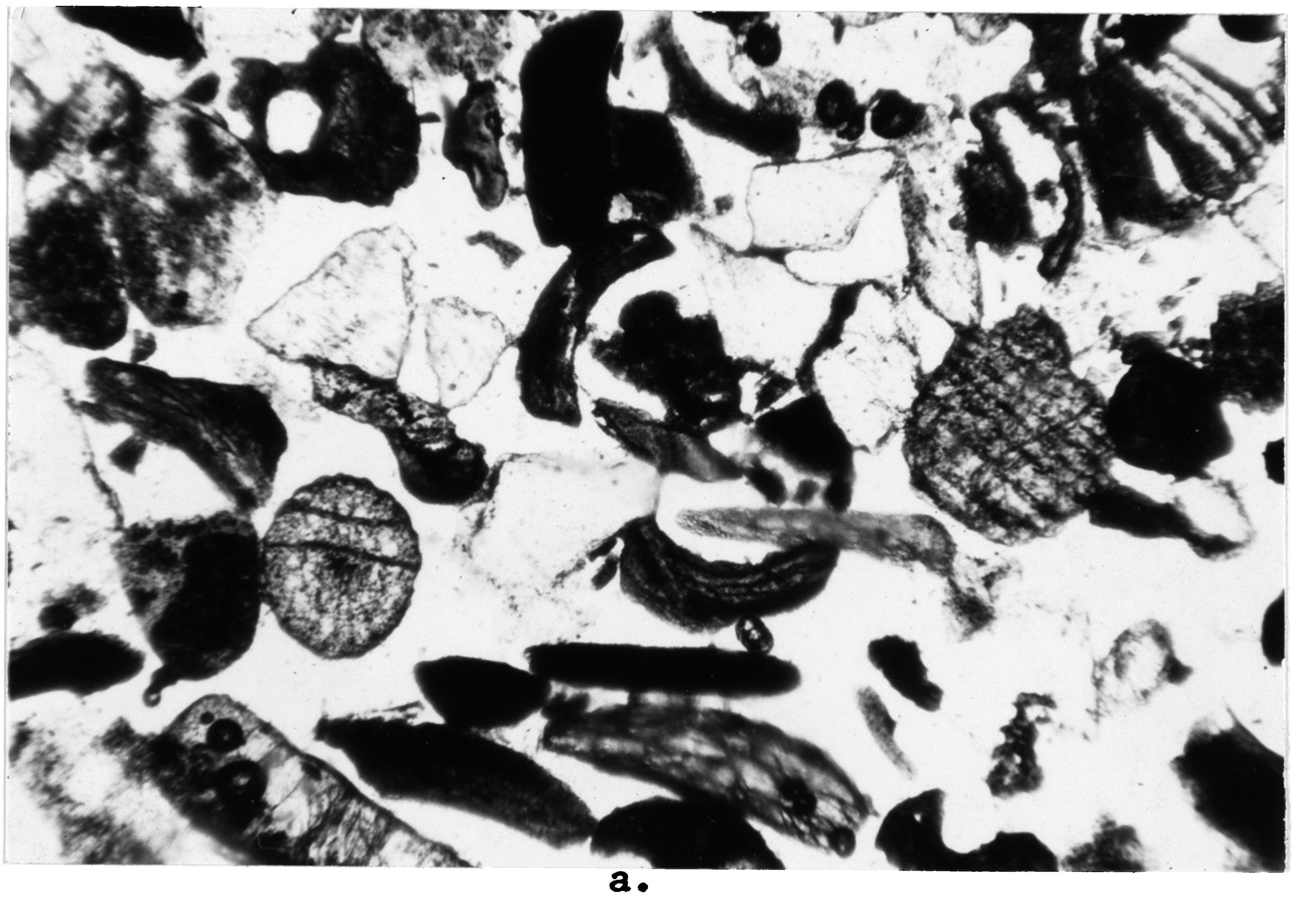
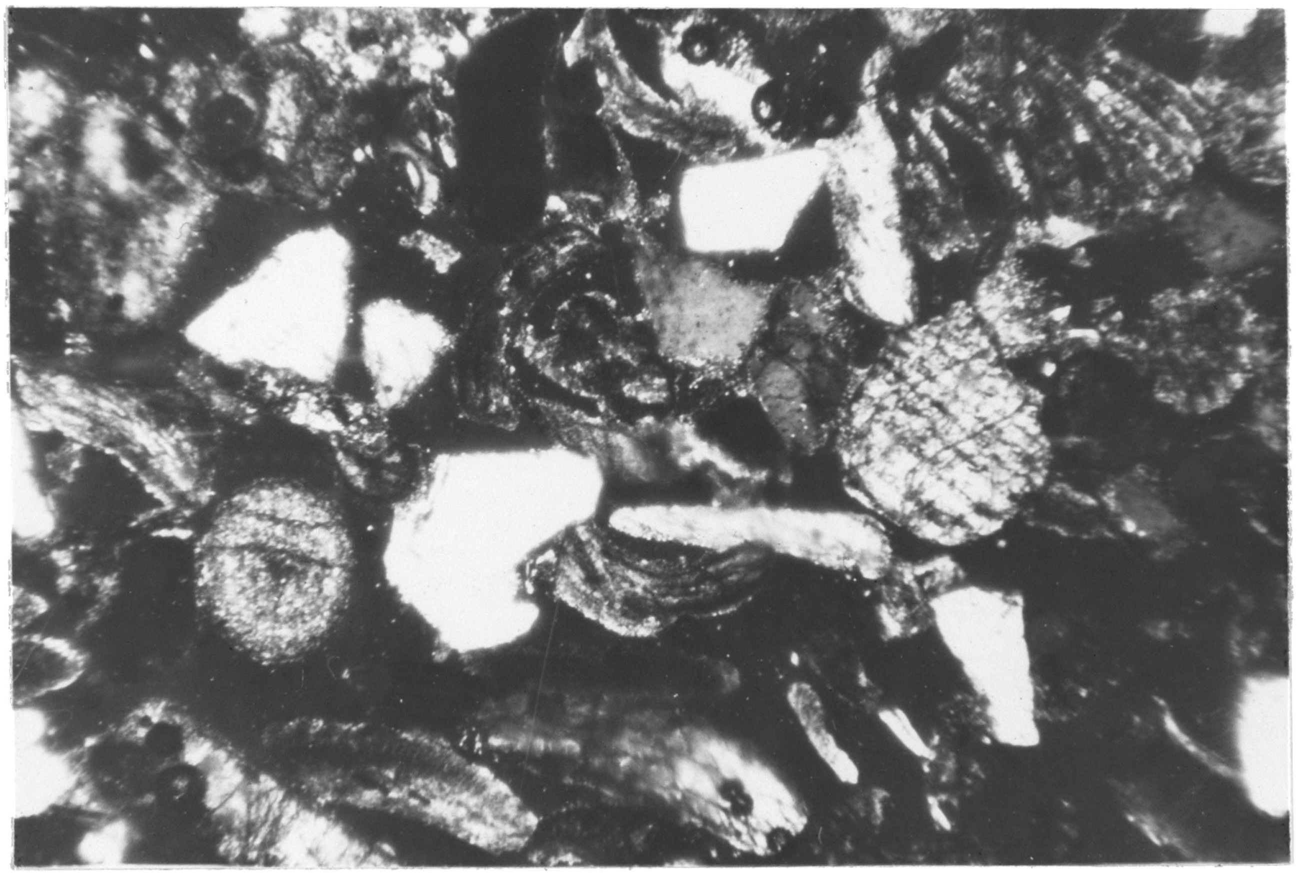


Plate 74. b. Sequence of photos taken by Rowe (1958a, 1958b) on January 17, 1958, showing a lone cow elephant coming out of the sea after swimming from Sober Island, Trincomalee Harbor (courtesy The Field Magazine).

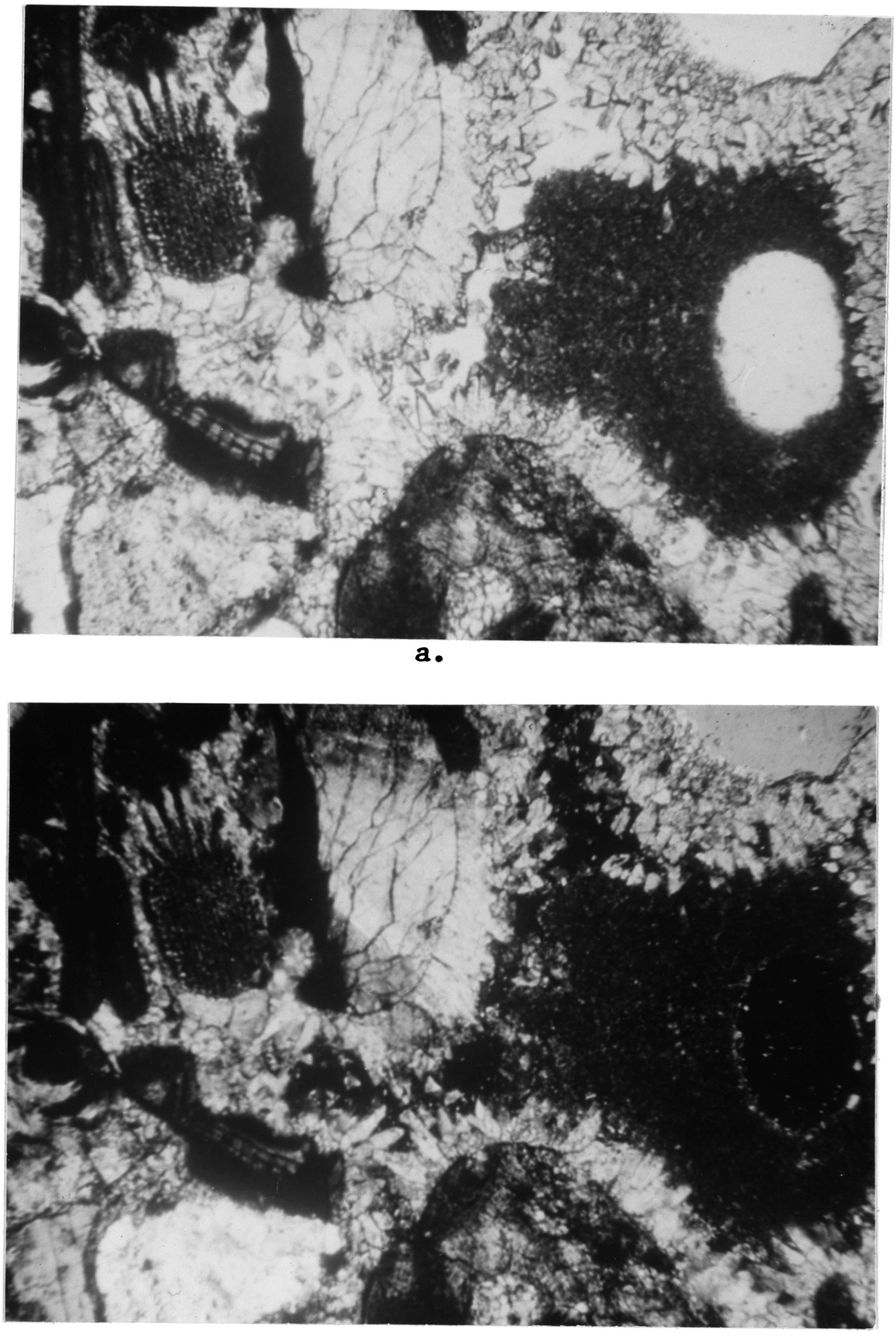


a.



b.

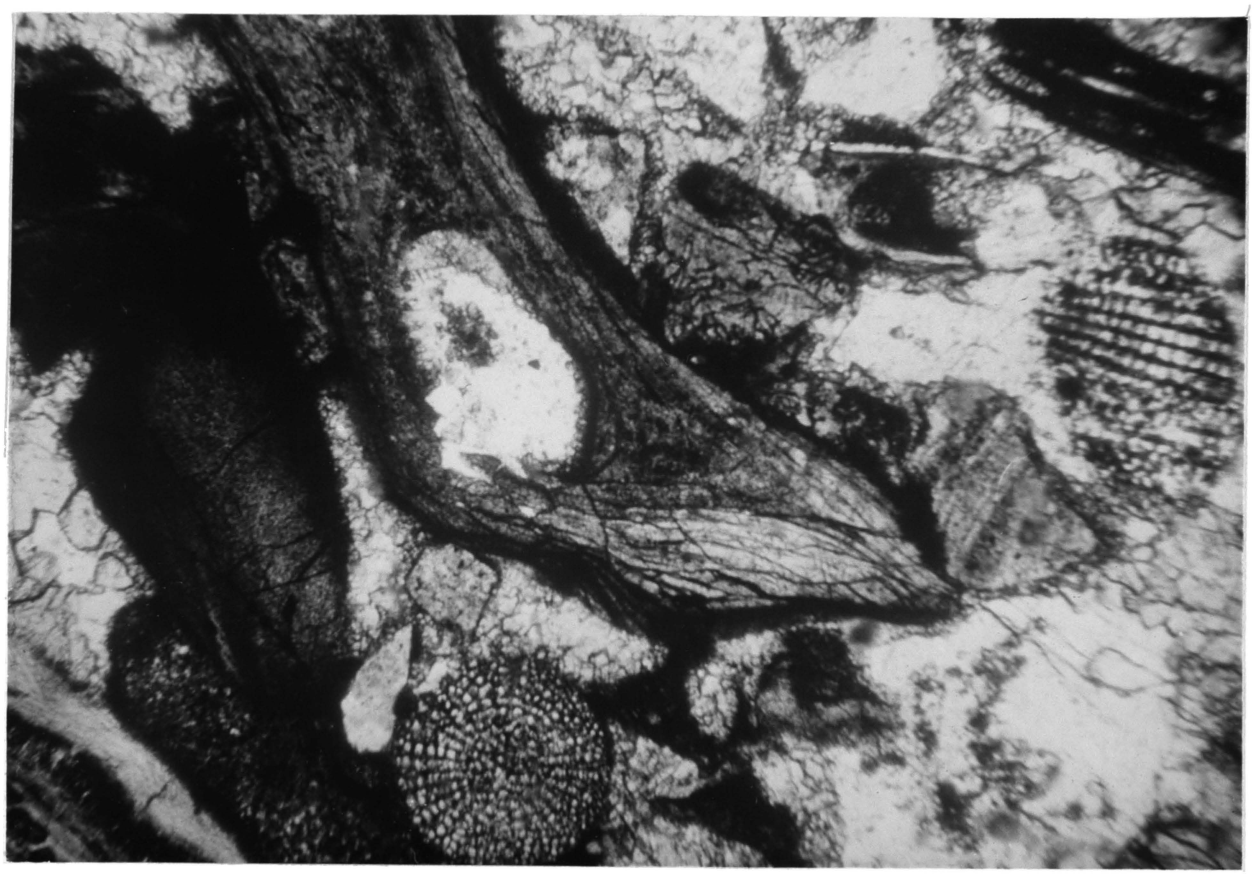
Plate 75. Photomicrographs of eolianite (SMI-4) showing high incidence of calcareous skeletal grains, mainly of foraminifers and mollusk. Photo a. was taken in plain light; photo b. shows crossed nicols. Magnification x35.



a.

b.

Plate 76. Photomicrographs of beachrock showing skeletal and mineral grains and sparry calcite cement. Photo a., plain light; photo b., crossed nicols. Magnification x35.

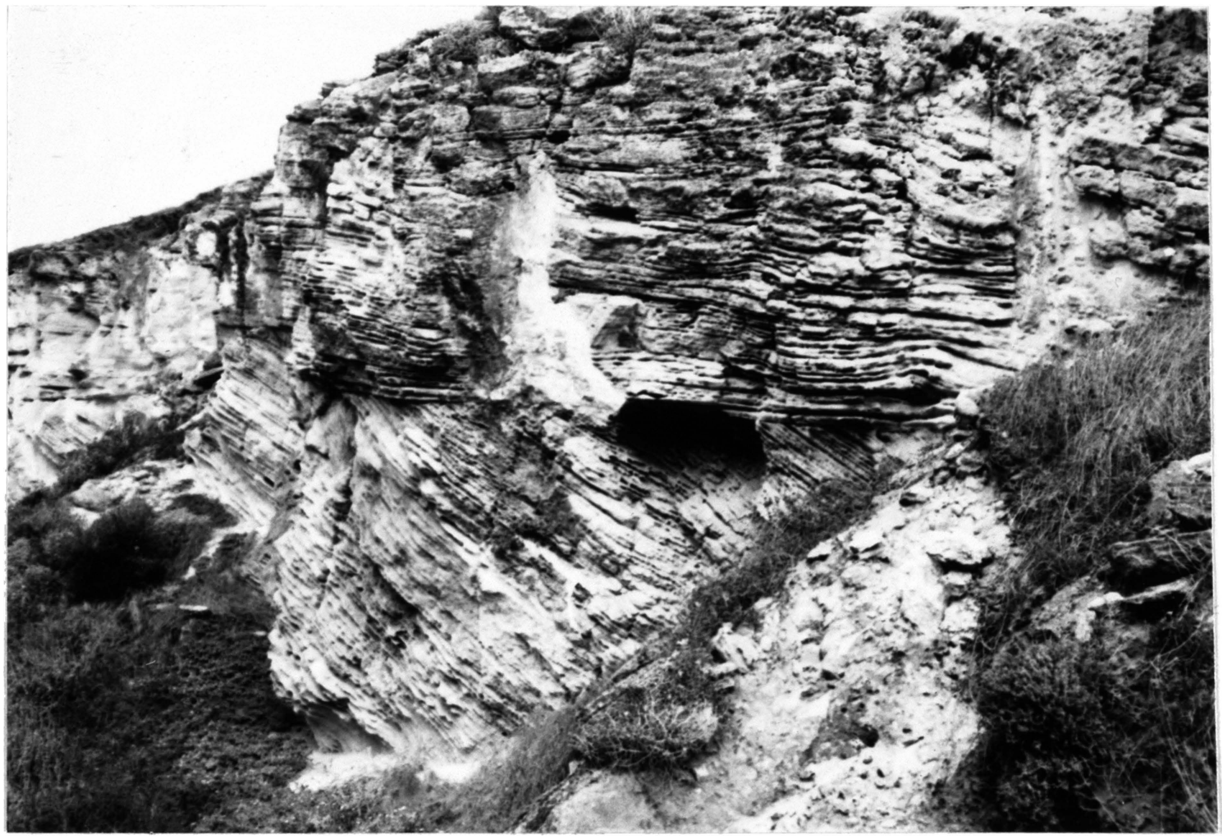


a.

b.

Plate 77. Photomicrographs of beachrock showing skeletal and mineral grains and sparry calcite cement. Photo a., plain light; photo b., crossed nicols. Magnification x35.

a.



b.

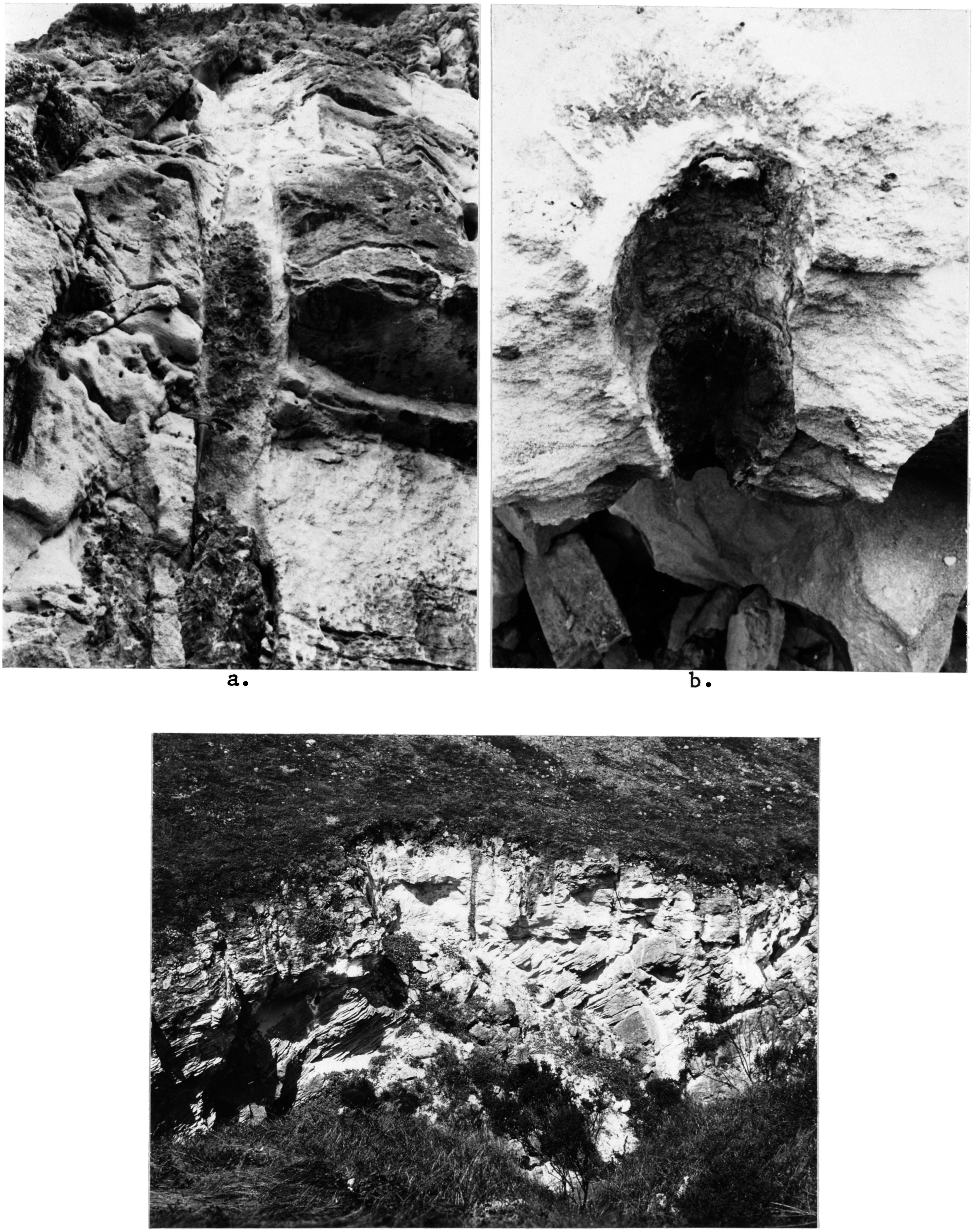
Plate 78. Steeply dipping cross-stratified Pleistocene eolianite at SMI-77. The southeast dips range as high as 41°, among the highest for any sediments.

a.

b.

c.

Plate 79. a. and b. show cross-laminated and stratified eolianite at SMI-233 on the far west side of Cuyler Harbor (note pick for scale in b.). Photo c. shows a paleosol intercalated in the ancient eolianites at this locality.

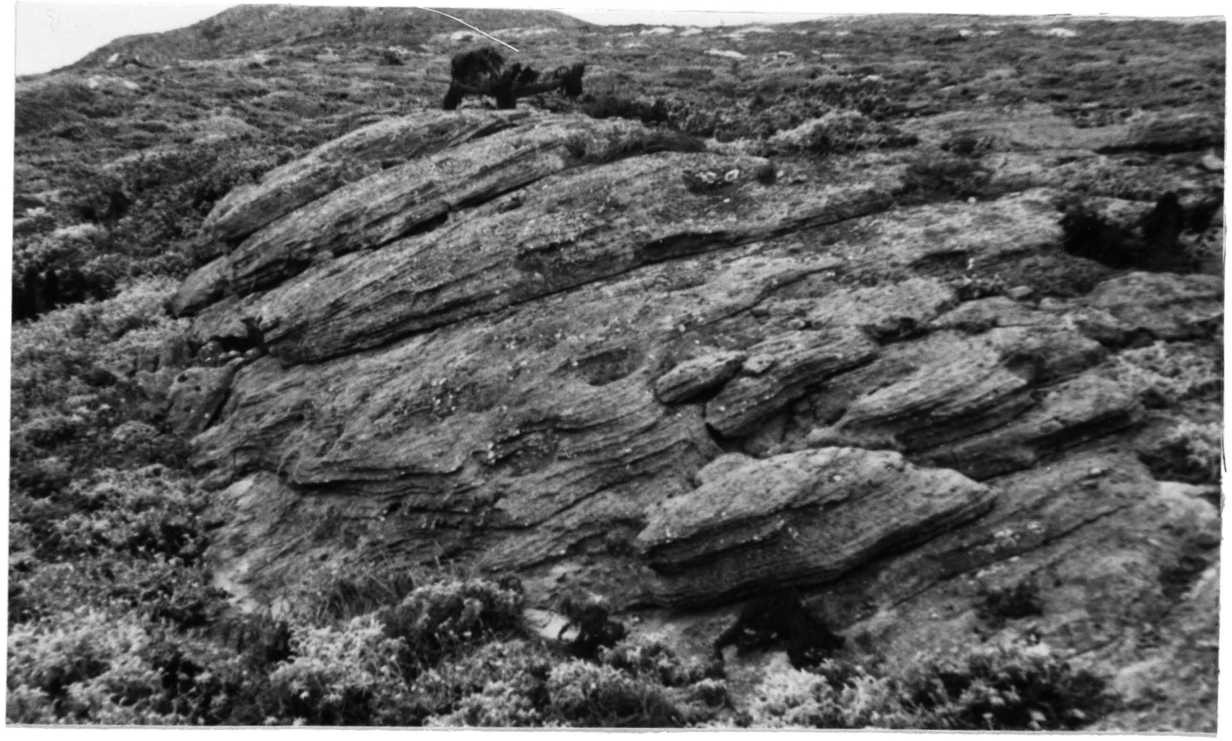


a.

b.

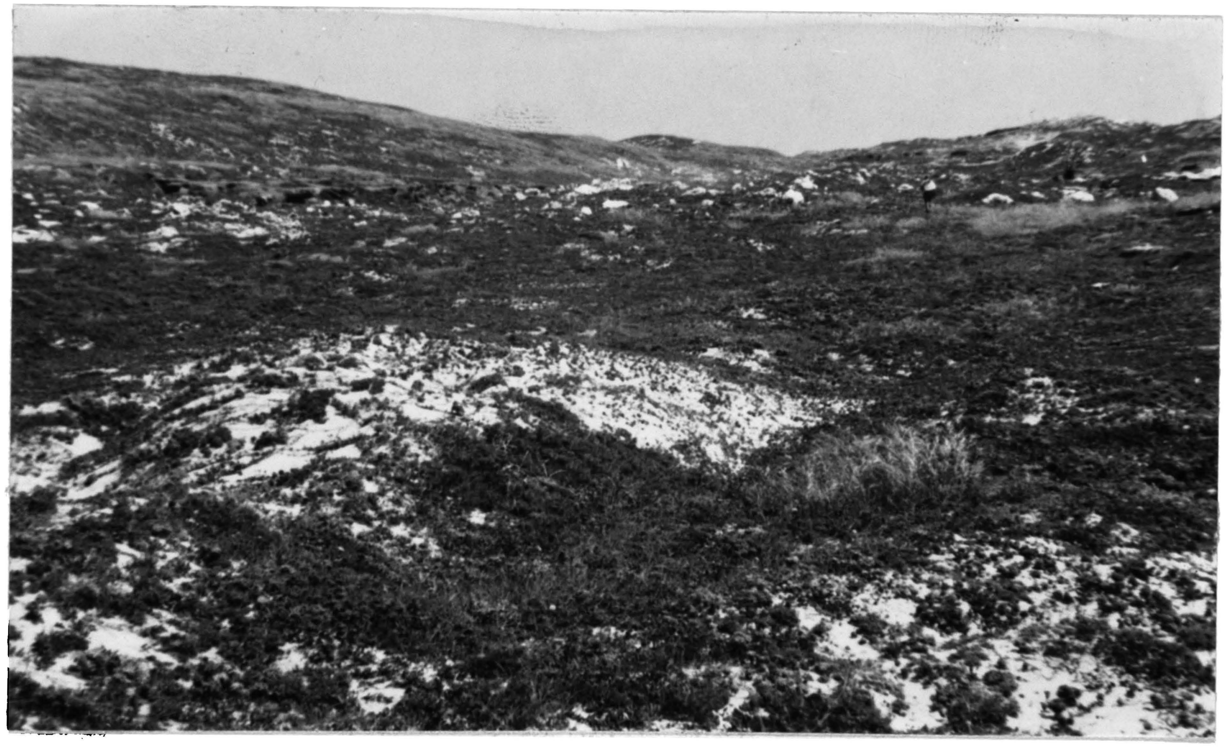
c.

Plate 80. Photos a., b., and c. show deep soil (argillic)-filled solution pendants in eolianite in North Green Mountain Canyon (SMI-77). Note pick for scale in photo a.



a.

b.



c.

Plate 81. Photo a. shows weathered eolianite outcropping on Harris Point at SMI-203. Note dipping cross-strata (to the southeast in this case). Photo b. is of a caliche shee with rounded bumps and pipes extending int underlying eolianite (photo taken at foot of Devil's Knoll,Harris Point). Photo c. shows a common scene of eroded soils and loose sand on Hurricane Deck of Harris Point.

a.

b.

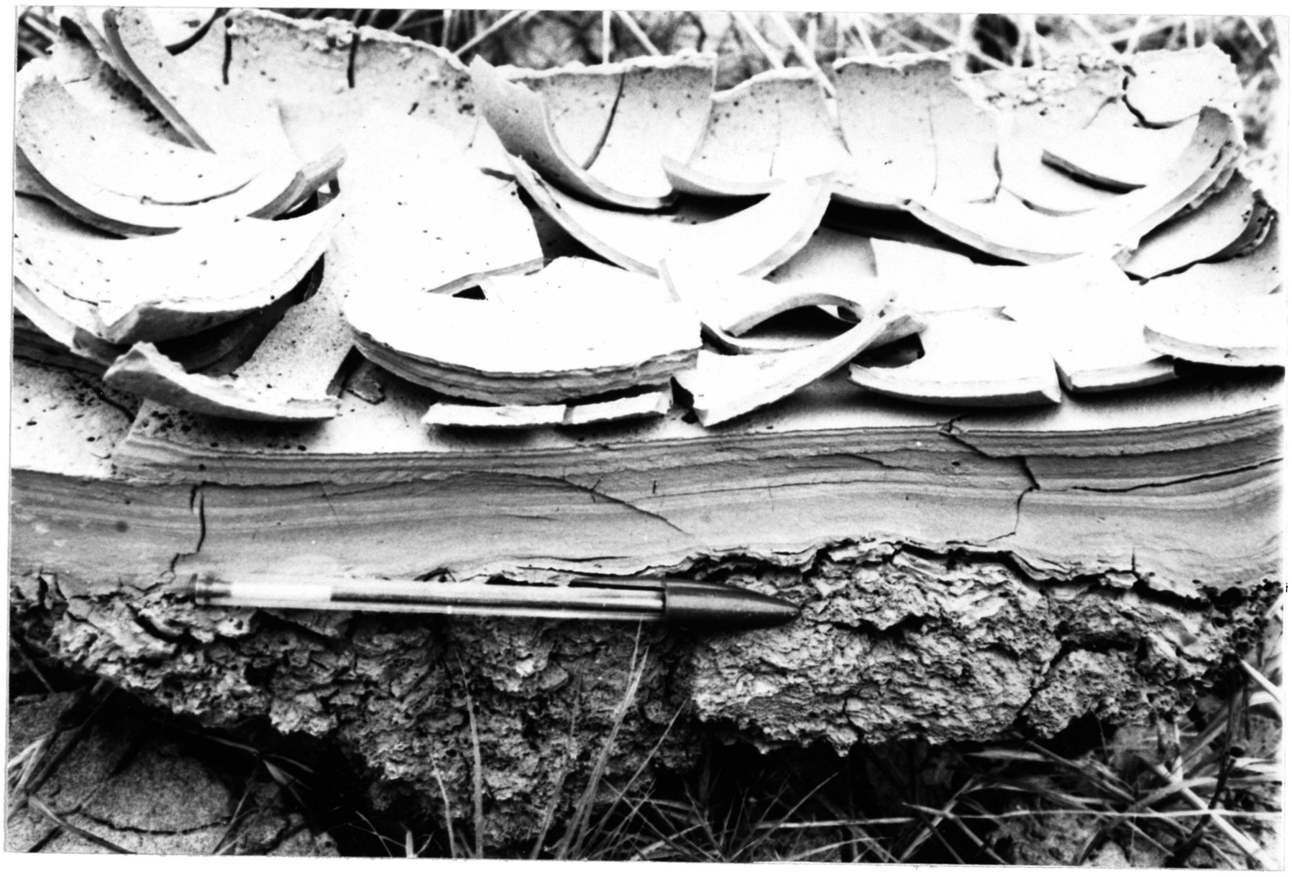
c.

Plate 82. a. Airphoto looking east showing northern end of Simonton Cove. Note sand blowing off backbeach up the old sea cliff to the high terrace of Hurricane Deck.

b. Highly jointed dacite porphyry at the northwest tip of Harris Point. Crystallized salt from sea spray is present in the joints.

c. Wave-cut notch in Cuyler Harbor at SMI-67.

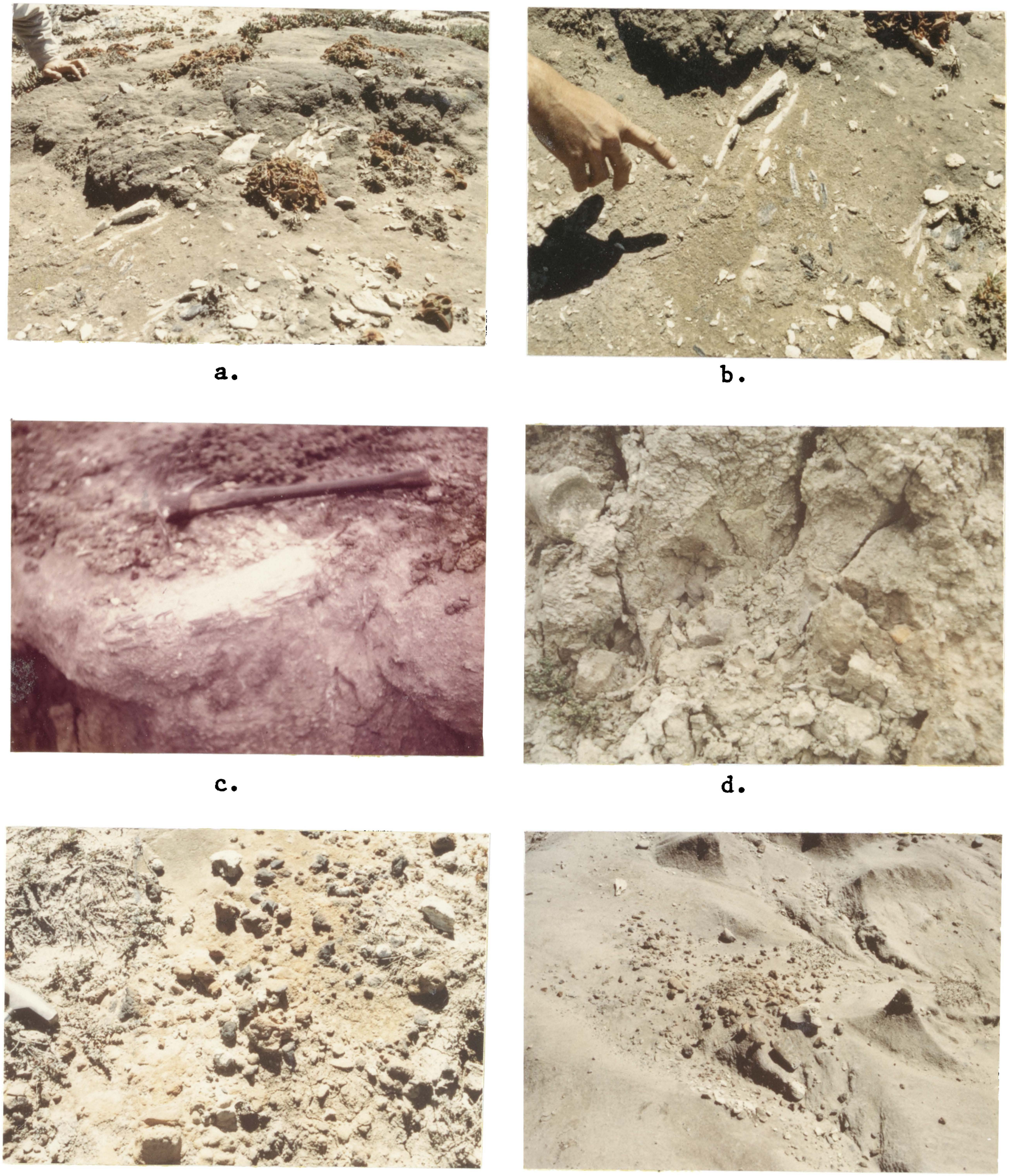
Photos taken in August, 1967.



a.

b.

Plate 83. Cracked and curled montmorillonite-rich sediments in dry pond beds at the foot of the slumps at East Cuyler Beach. The expanding-lattice clays have washed out of the superjacent slump debris and bedrock. It is thus probable that the montmorillonite serves as a lubricant for slump-slides in the area (camera case for scale in lower photo).



a. b.

c. d.

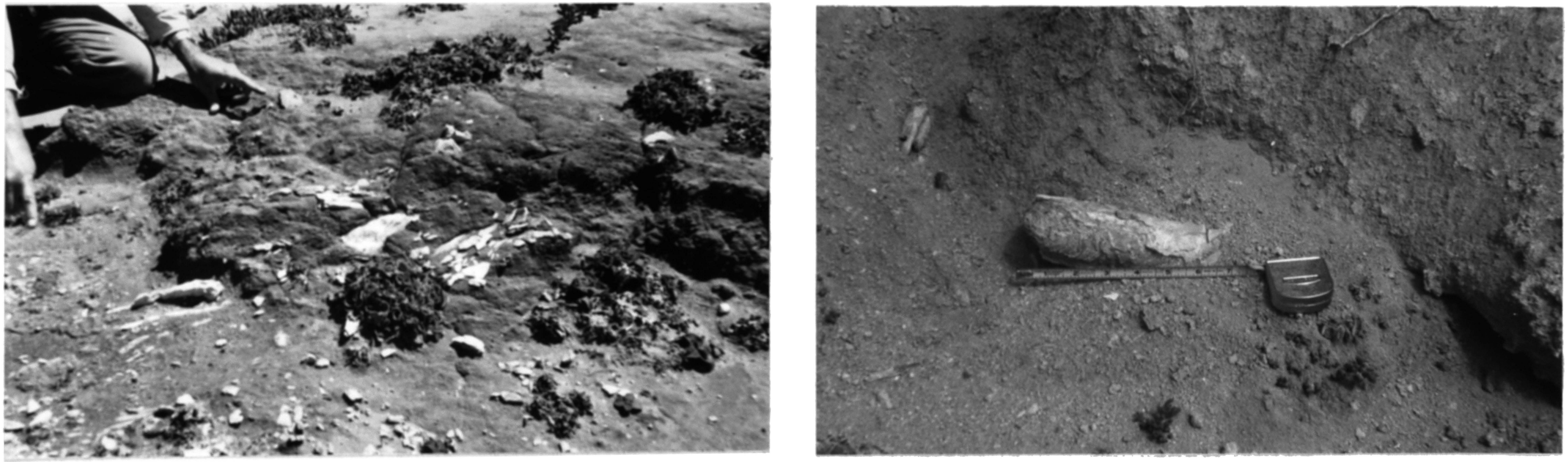
e. f.

Plate 84. This plate shows a series of photos taken at Running Springs showing strongly suggestive evidence of ancient man-caused fires. Photos a through d are burned mammoth bones at SMI-182 and 150. Photos e and f show oxidized zones with fire-shattered rocks, mammoth bones and possible artifacts.

a.

b.

Plate 85. Proboscidean remains at Running Springs tufa and fossil locality (SMI-251, 252). Photo a. shows a tooth and b. shows a tusk.

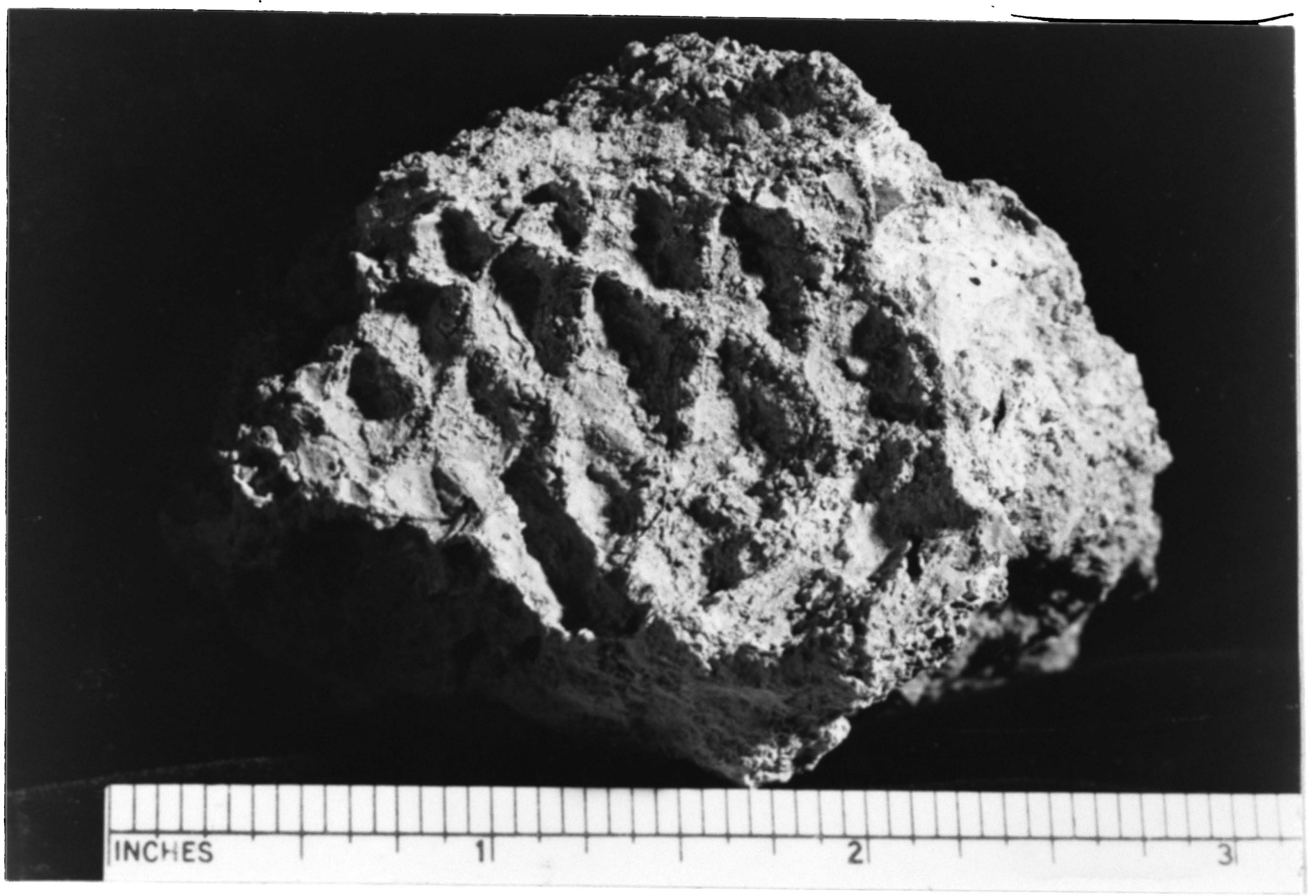


a.

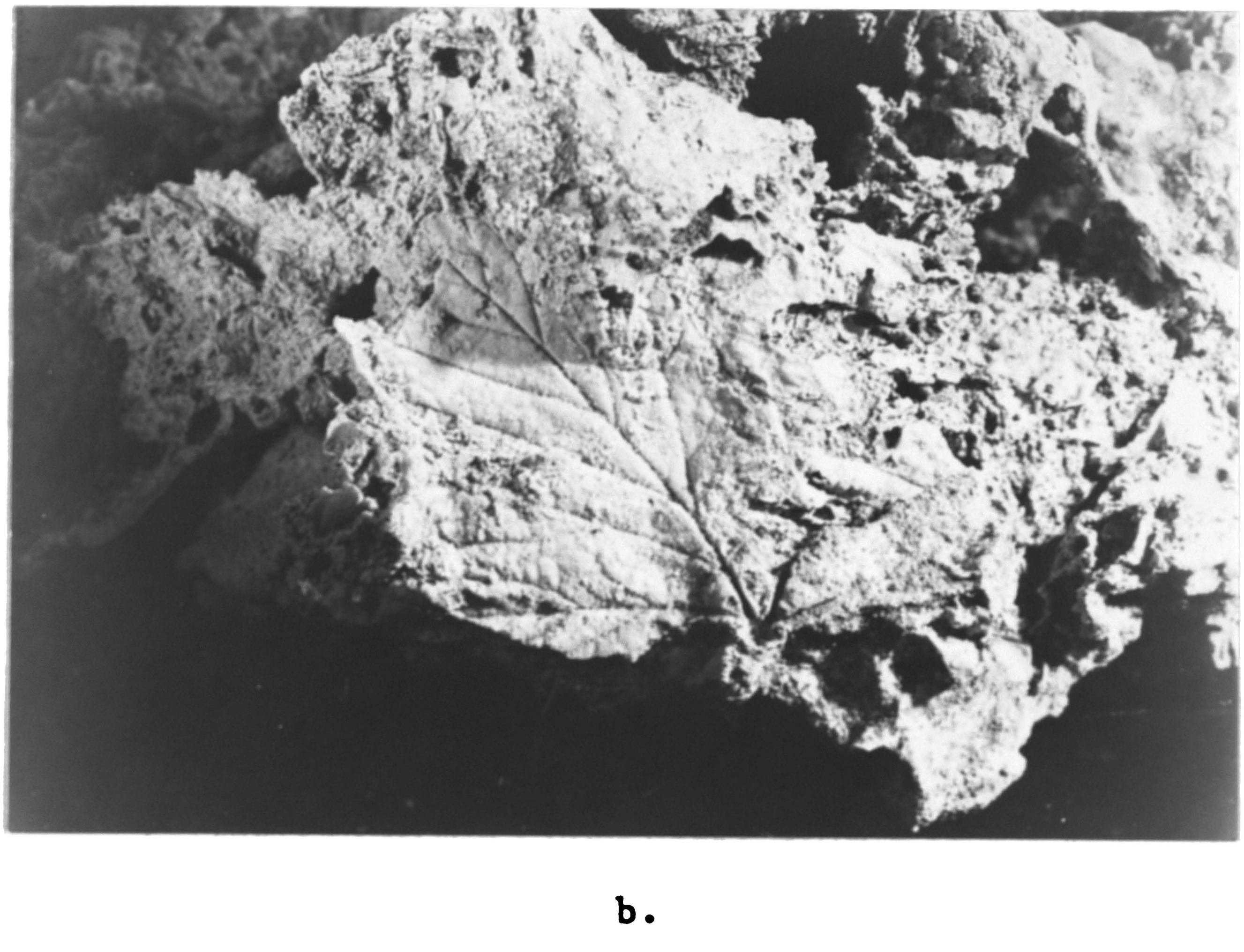
b.

c.

Plate 86. Photo a. shows burned elephant bones at SMI-182, Running Springs weathering out of modern soil; left hand of man points to possible artifact, *in situ*. Photo b. shows *in situ* elephant tusk at SMI-251, Running Springs. Photo c. shows leg bone of elephant *in situ* at SMI-80, North Green Mountain Canyon. Photos a. and b. taken in May, 1969; photo c. taken in August, 1967.



a.



b.

Plate 87. Cone of Monterey pine (Pinus radiata) in photo a., and Ribes in photo b. Scale is the same for both photos (identified by J. Wolfe, U. S. Geological Survey, Menlo Park, California).

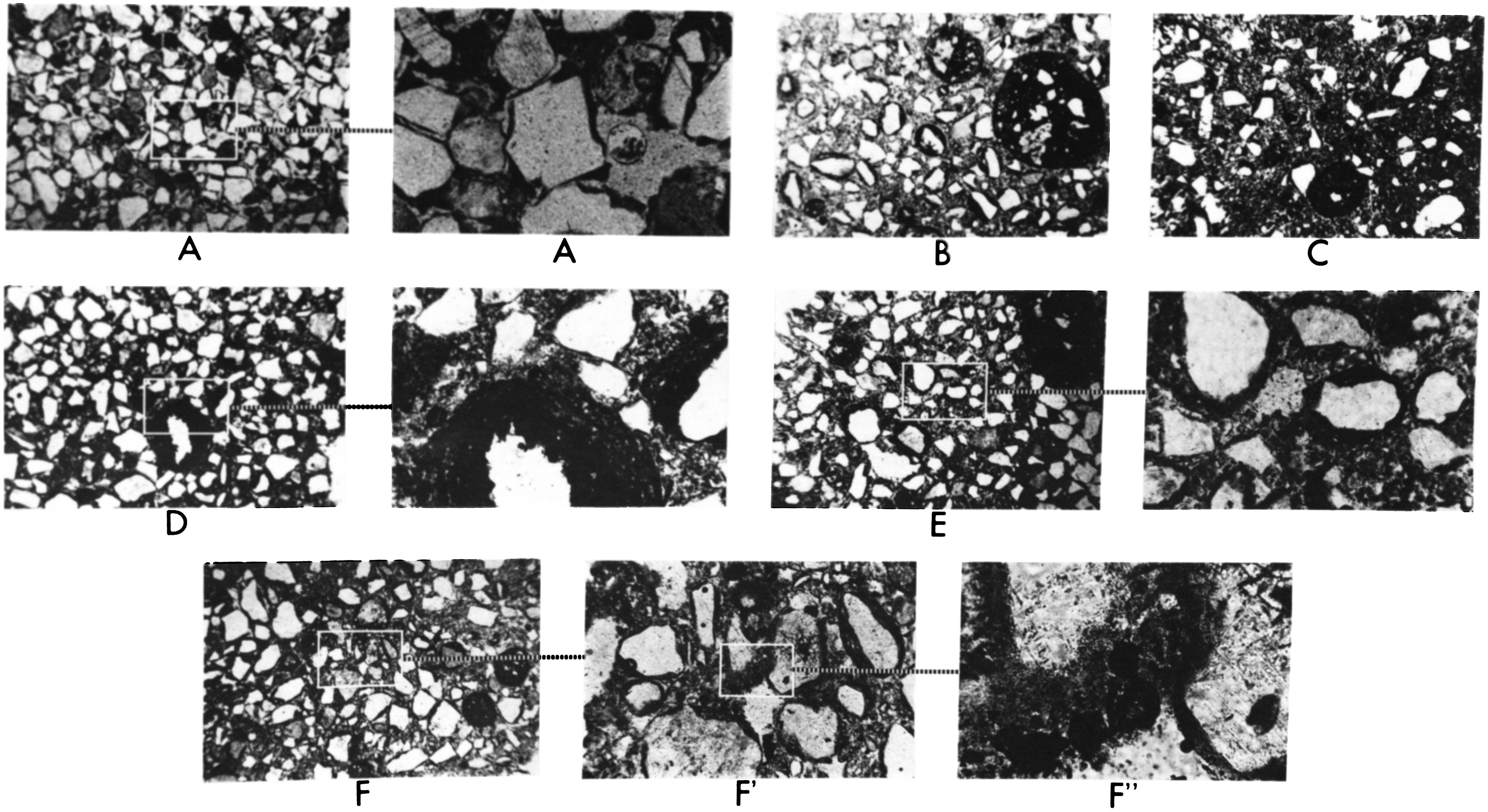


Plate 88a. Photomicrographs of soil thin-sections in plain polarized light which show the sand grain nuclei of incipient pisolites with sesquioxide envelopes. Photos B, C, and E show larger pisolites comprised of coalesced nuclei. (A, SMI-132, 54-60", Mag. X70 and X310; B, SMI-135, Mag. X70; C, SMI-164, 0-10", Mag. X70; SMI-132, 20", Mag. X70 and X310; E, SMI-132, 20", Mag. X70 and X310; SMI-135, Mag. X70, and X310, and X1370.)

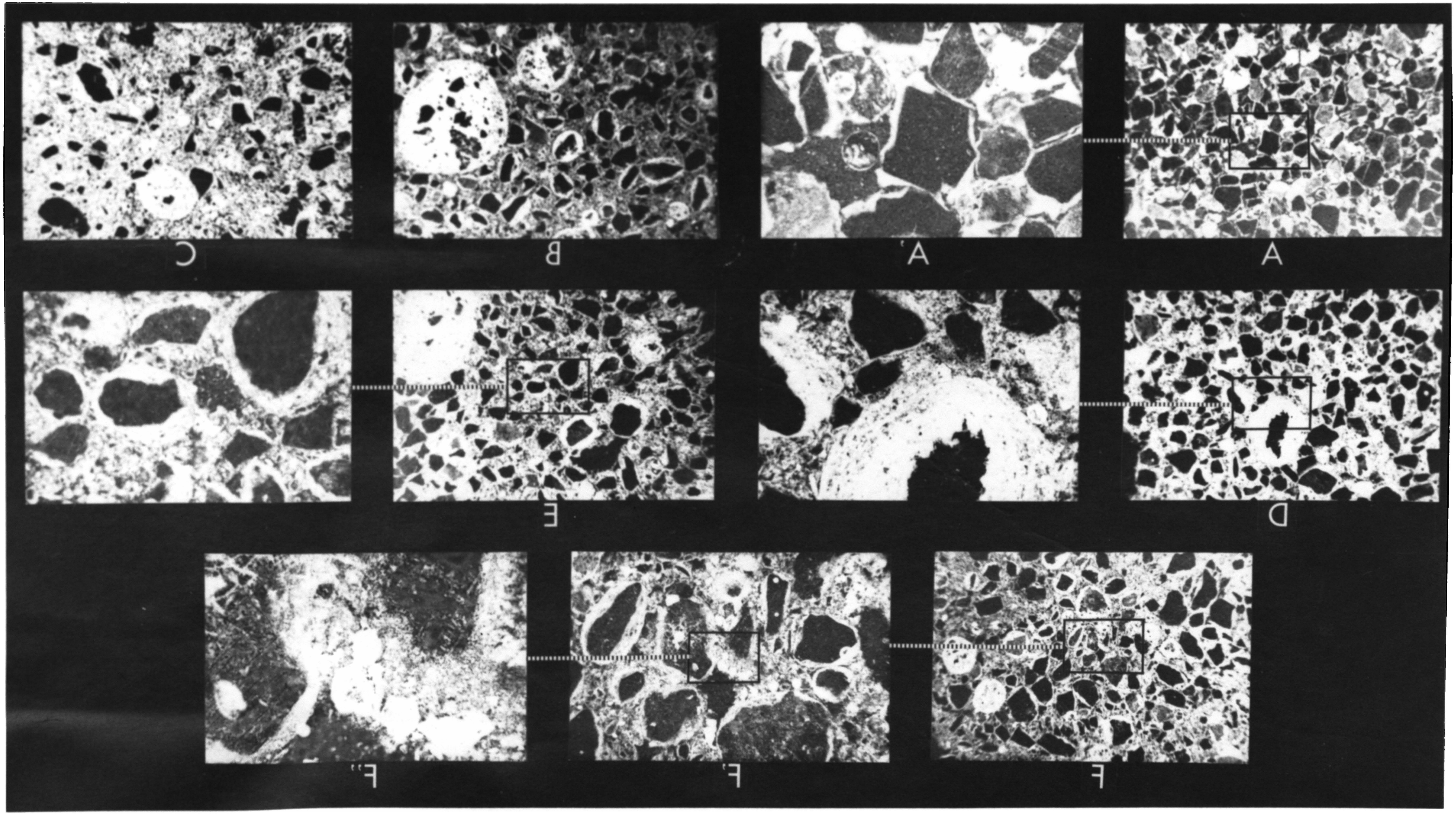


Plate 88b. Print of reversed negative of Plate 75a which shows more clearly the sesquioxide envelopes of the incipient pisolites.