MINING ENGINEER'S THESIS

UNIVERSITY OF KANSAS

LETTER OF TRANSMITTAL

THE GOVERNMENT OF THE PHILIPPINE ISLANDS

DEPARTMENT OF THE INTERIOR

BUREAU OF SCIENCE

MANILA

February 18, 1914.

To the Dean of the School of Engineering,
University of Kansas,
Lawrence, Kansas.

Through the
Chief, Division of Mines, Bureau of Science,

And the
Director, Bureau of Science.

Sir:

I respectfully submit to you "The Geology and Petroleum Resources of Bondoc Peninsula, Tayabas Province, Philippines," and request that the portion of it for which I am responsible be considered as a thesis in part fulfillment of the requirements of the University of Kansas for the degree of Mining Engineer, for which I have made application.

I am forwarding this through official channels with the request that Dr. Alvin J. Cox, Director of the Bureau of Science, make a statement showing just what part of the work I have done.

Very respectfully,

Wallace E. Pratt

1st INDORSEMENT

February 18, 1914.

Respectfully forwarded with the recommendation that the above request be complied with.

Warren D. Smith

Chief, Division of Mines.

2d INDORSEMENT

February 18, 1914.

Respectfully forwarded to the Dean of the School of Engineering, University of Kansas, Lawrence, Kansas. Because of the joint authorship under which this paper was published, in order that the merits of the application of Wallace E. Pratt for the degree of Mining Engineer can be fairly judged, I desire to state just how the study has been carried on.

In 1909, the first representative of the Bureau of Science visited the part of Bondoc Peninsula, Tayabas Province, in which the presence of petroleum is known, and spent a week there. In June, 1910, Wallace E. Pratt visited Bondoc Peninsula while engaged with Dr. Adams in a general reconnaissance of southeastern Luzon. The Philippine Journal of Science, Sec. A (1911), **6**, 449-81, contains data obtained during this visit. In January, 1911, Mr. Eddingfield and Mr. Pratt, both of this Bureau, spent two weeks in the oil field. In February, 1912, Dr. Smith, chief of the division of mines of this Bureau, went to the United States on leave for seven months with authority to visit and study the oil fields of California that the information might be applied to the examination of the local field, as it was the expectation that upon his return the geologists of this Bureau would undertake an accurate survey of the Tayabas oil fields. In the meantime circumstances arose which induced me to direct that the work be undertaken immediately.

Wallace E. Pratt was sent to the field on May 27, 1912, in charge of a party of geologists and the necessary assistants and laborers, and during ten weeks of reconnaissance work covered the entire field, including the areas which he had visited on the two previous occasions. Upon the return of Dr. Smith from the United States, he and Mr. Pratt spent nearly three weeks in the field reviewing the work of Mr. Pratt's party. Dr. Smith saw enough to be satisfied that he agreed with Mr. Pratt's findings. The manuscript, which is based upon the findings of Mr. Pratt and his party, was planned and prepared jointly, and the ideas, suggestions, and observations of each author are included therein, although the major portion of it was written by Mr. Pratt, who also prepared the maps and sections. The paleontologic determinations and the petrographic descriptions of igneous rocks were made by Dr. Smith. Mr. Dalburg, whose name appears on the map, assisted Mr. Pratt with much of the topographic work on the principal field trip when the topographic and geologic surveys were made. The article contains all the information at present available to the Bureau of Science.

The work of Mr. Pratt in this Bureau has been very satisfactory. He has been energetic, resourceful, and efficient, and my appreciation of his services is only indicated by the fact that he has been rewarded by four independent promotions. His work is of the caliber of those holding the academic doctor's degree, and I take great pleasure in recommending him for the degree for which he is a candidate.

Alvin J. Cox

Director, Bureau of Science.

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THE GEOLOGY AND PETROLEUM RESOURCES OF THE SOUTHERN PART OF BONDOC PENINSULA, TAYABAS PROVINCE, P. I.

By WALLACE E. PRATT AND WARREN D. SMITH

(From the Division of Mines, Bureau of Science, Manila, P. I.)

Ten plates, 1 text figure, and 1 map

CONTENTS

INTRODUCTION

GENERAL

The existence of petroleum seeps on the lower end of Bondoc Peninsula, especially on Bahay River, was known among the natives at least, during the Spanish régime, but no steps were taken to explore the region, and no mention of petroleum in Tayabas is found in the records of the Spanish mining bureau. Soon after American occupation, however, prospectors reported oil from Bondoc Peninsula, and the field began to receive attention. E. W. McDaniel, S. W. Tilden, and the late Olney Bondourant were among the earliest prospectors to locate petroleum placer claims in Tayabas. Samples of the petroleum were submitted to the Bureau of Government Laboratories (now Bureau of Science) in 1903.

A shallow well was sunk on Bahay River in 1906 by the Tayabas Mutual Oil Association, with E. W. McDaniel as managing director. It is stated that 46 gallons of oil were obtained from this well in one day. The well was sunk "to a depth of 127 feet using a 3¾ by 2½ inch by 3-foot bit operated by a hand power springpole and duplex block attachment." Another well, 23 meters deep, was sunk on Malipa Creek by Mr. E. J. Cooke and likewise is reported to have encountered oil.

Gradually, business firms in Manila became interested in the field, and the area over which claims were located constantly grew larger. Castle Bros. Wolf & Sons (now Pacific Commercial Company) acquired a number of claims on Bahay River, and, about the time of the publication by the Bureau of Science of a report [1] on the physical and chemical nature of the petroleum from the well drilled by Mr. McDaniel, this firm organized the Bahay Valley Oil Company and started to sink a deep well. The new well (Bahay 2) was located on Bahay River within 50 meters of the old well (Bahay 1), and was drilled by Mr. O. A. Leary. The well reached a depth of less than 100 meters, and obtained no more oil than the old well.

With the beginning of drilling by the Bahay Valley Oil Company, in 1910, interest in the Tayabas field reached fever heat, and claims were staked far and wide, but no further exploration was undertaken. Since that time most of the locators have merely awaited developments.

PREVIOUS KNOWLEDGE OF THE REGION AND SOURCES OF INFORMATION

The earliest published reference to petroleum in Tayabas is an anonymous article [2] dealing with the activity of the Tayabas Mutual Oil Association in 1906. A short discussion of the occurrence of petroleum in the Philippines by Smith [3] contains

[1] Richmond, Geo. F., *This Journal, Sec.* A (1910), **5**, 1.
[2] Oil fields of Tayabas, *Far Eastern Rev.* (1906), **3**, 102.
[3] *Ibid.* (1907), **3**, 9.

a general statement concerning Bondoc Peninsula. Later in the same year another article[4] on the Tayabas oil fields was published.

Richmond's[5] investigation of the physical and chemical properties of several samples from Bahay 1 well was cited above. Geo. I. Adams, formerly a geologist in the Bureau of Science, spent two weeks on Bondoc Peninsula in 1909, and his observations were included in a geologic reconnaissance of southeastern Luzon,[6] together with the results of a few days additional field work by the authors of that paper.

In January, 1911, F. T. Eddingfield and Wallace E. Pratt spent two weeks in a geologic investigation of the southern part of Bondoc Peninsula, and a short discussion based on this work was published later in that year.[7]

During the summer of 1912, Wallace E. Pratt and F. A. Dalburg were engaged for nearly three months in geologic and topographic field work on Bondoc Peninsula. The results of this work were confirmed and amplified in three weeks of field work by Warren D. Smith and Wallace E. Pratt in February, 1913. These two periods of field work constitute the basis of this report, although the results of previous field work have been drawn upon freely and have facilitated the work.

SCOPE OF THE PRESENT WORK

The time spent in the field would scarcely permit of the detailed study of the area covered—700 square kilometers—even if the country were easily traversed and the geology clearly defined. As it is, the lack of an accurate map, the absence of trails, the prevalence of jungle along the streams, and the heavy growth of cogon and *talahib*[8] have made it impossible to include detailed or complete information in this report. The vegetation usually conceals the geologic relations, and often renders impossible a proper examination of places where precise information is important. The mere physical effort of cutting through a jungle or of "breaking trail" in the open, where the process involved is one of literally burrowing through the tall rank grass, fre-

[4] *Ibid.* (1907), 4, 19.

[5] *Loc. cit.*

[6] Adams, Geo. I., and Pratt, Wallace E., *This Journal, Sec. A* (1911), 6, 473. Adams's report also appeared as Bureau of Science press bulletin 2 which was printed in *Philippine Resources* (1909), 1, 19, together with The Oilfields of Tayabas, a descriptive article by H. C. Hosty.

[7] Eddingfield, F. T., *Min. Resources P. I. for 1910, Bur. Sci.* (1911) 64.

[8] Cogon, *Imperata cylindrica* Beauv.; talahib, *Saccharum spontaneum* Linn.

quently leaves the observer inefficient through exhaustion before his day's work is fairly begun.

If the petroleum resources are developed, it is anticipated that the additional and more accurate data which will become available as the jungle is cleared away and deep wells are drilled will modify, or perhaps reverse, some of the conclusions of this preliminary report. However, the present work should serve as a basis for future investigation.

METHODS OF FIELD WORK

Field work on Bondoc Peninsula requires complete camp equipment and the importation of all supplies from Manila. Moving camp—a frequent task because of the limited area to which operations from each center are necessarily confined—involves packing everything on the backs of carriers, except along the coast where small boats can be employed. The carabao, which is used to a small extent as a pack animal by the native, is not efficient in the interior, because water in quantity for its requirements is not usually available.

The geologic and topographic mapping, which is embodied in the map accompanying this report, was executed in large part with improved compasses, known as pocket transits, during the main period of field work. The coast line and the elevations of the principal points, the altitudes of which could be determined by triangulation from the sea, are taken from a coast survey by the Bureau of Coast and Geodetic Survey. Upon this base is plotted a triangulation survey which established the relative locations of a number of points between Mount Maglihi and Mount Cambagaco, made by Mr. Dalburg, using a standard surveying transit. A stadia traverse by Mr. W. D. Buxton, of the Bureau of Lands, from the town of Bondoc, via Bacau, to the mouth of Bahay River and the small number of public land surveys in the region are likewise included. For the rest, compass surveys along the principal trails and stream lines—the distances being paced—with vertical angle calculations and aneroid barometer readings for elevations were made to serve.

The measurements and observations involved in defining the stratigraphy and the geologic structure were made a part of the compass traverses, data of this sort being most readily obtained along water courses. It is recognized that the reliability of stratigraphic and structural determinations made from measurements along streams has been questioned by eminent geologists, and the objection may be admitted, but the fact remains that usually in the tropics the only clue to the nature of the rocks beneath the surface débris is to be obtained in the streams.

Even in stream beds, geological observations are generally confined to sections where active erosion is in progress. Where limestone forms a part of the rock series, as in Tayabas, the universal deposition of travertine by flowing water is another factor which tends to conceal the geologic relations.

The best criterion of the degree of accuracy which should be accorded to this report is to be gained from a consideration of the relative precision of the field methods employed. In one sense, the closely determined elevations usually required for the proper correlation of deep-well records were not essential to this preliminary work in as much as no deep wells have been drilled in the area described. Owing to the lack of deep wells, on the other hand, the degree of conformity between surface and underground strata in their structural relations and thicknesses is unknown, and the structure recorded may not be that of the deep-lying formations.

GEOGRAPHY

The established native usage is followed in this paper for place names, the names of natural features, rivers, mountains, etc. Where words have been passed upon by the United States Geographic Board, the accepted spelling is adopted.

SITUATION

The area over which oil seeps are known to occur in Tayabas, as shown on the accompanying map, includes that part of Bondoc Peninsula south of the towns of Catanauan and San Narciso, or approximately the southern half of the peninsula. The territory mapped has an average width of 17 kilometers, is 50 kilometers long, and contains an area of 700 square kilometers. Bondoc Peninsula marks the southern termination of the Eastern Cordillera of Luzon. It is a long, narrow strip of land protruding to the south-southeast from the southern coast of the mainland of Luzon. The parallel of 13 degrees and 30 minutes of north latitude and the meridian of 122 degrees and 30 minutes of east longitude pass through the region in which the oil seeps occur. The principal towns at which steamers touch, Catanauan and Mulanay on the west coast, are about 320 kilometers (sailing distance) from Manila. The position of Bondoc Peninsula with reference to the other parts of the Philippine Archipelago is shown on the index map.

TRANSPORTATION

The only access to the lower part of Bondoc Peninsula at present is by steamship. Several small boats touch at Catanauan irregularly, averaging once a week, while the same boats stop at Mulanay somewhat less frequently. The nearest railroad station is at Lucena, about 70 kilometers northeast of Catanauan. None of the rivers in the oil field are navigable. No improved roads have been built on the peninsula; there are poor trails between Catanauan and Mulanay, Mulanay and San Narciso, Mulanay and Bondoc, and between Bondoc and San Andres. A few of the smaller outlying villages are connected by trails, but these are used so little that they are not kept open and are generally hard to follow. The principal trails are indicated on the map.

CLIMATE AND VEGETATION

The months of March, April, and May constitute the dry season, and are the best months for field work on the peninsula. The rains begin in June, and continue regularly through July and August. During the other months of the year the rainfall is intermediate between that of the dry season and that of the wet season. The Weather Bureau has no station in this region, and consequently exact meteorologic data are not available.

The more precipitous valleys and the mountainous regions are wooded. Parts of the woods are good forest and fairly open, but a large area has been cut over by the natives and is now an impassible jungle of undergrowth. The country of intermediate elevation is usually not wooded, but is covered with a rank growth of cogon. Mangrove swamps are encountered near the mouths of some of the rivers and on other areas of low ground along the coasts.

POPULATION

In 1903 the total population in the area shown on the map was 10,088. More than 40 per cent of this number lived in the municipality of Catanauan. Bondoc and San Narciso, which were listed as municipalities in the census of 1903, subsequently fell to the rank of barrios, although the latter again has been made a municipality within the last year. The population is little if any greater, and it may be slightly less, than in 1903.

Coconut growing is the main resource of the region. Small herds of cattle are encountered in the interior, but the number is far less than the available grazing territory could support. There are limited areas suitable for the cultivation of rice at a number of places, but here again the opportunity is not generally improved. A natural asset of the country is the buri palm which grows without cultivation everywhere. From it the native secures the material for his house and for the manufacture of mats and bags—a household industry. His shoes are of buri bark, and in times of want the wood of the tree is ground into buri flour which feeds his family.

It may be anticipated that labor will be scarce should this field become active and that the efficiency of the local supply will be low.

GEOLOGY

GENERAL STATEMENT

Bondoc Peninsula is made up almost entirely of sedimentary rocks, and, if the regions of more recent sedimentary material, such as the alluvium and raised shore deposits of the central plain of Luzon and the volcanic tuff of southwestern Luzon, be excepted, is one of the largest areas in the Philippines where the rocks are essentially sedimentary and not seriously affected by intrusion or vulcanism.

The series is principally shale and sandstone, with subordinate thicknesses of limestone in the higher portion. The youngest beds, disregarding the recent unconformable deposits, are Pliocene limestones, while the oldest rocks encountered are lower Miocene or Oligocene shales. The measured sections show an aggregate thickness of from 1,700 to 1,800 meters, and the base of the shale series is not exposed. Possible repetition of beds through minor faulting may make the apparent thickness greater than the actual. The strata have been forced into folds along lines trending approximately parallel to the axis of the peninsula; namely, north-northwest and south-southeast. The folding has resulted in a principal anticline along the central portion of the peninsula, separated by wide shallow synclines from subordinate, more or less parallel, anticlines near the coasts on each side. This simple structure is complicated by the presence of minor folds approximately at right angles to the general trend. The limestone at the top of the series has been folded in general conformity with the lowest shale, so that the major lines of structure are common to the entire stratigraphic column. The anticlines of the folds are sharp, but the occurrence of extensive faulting is not established.

PHYSIOGRAPHY

Excluding San Narciso Peninsula, the lower part of Bondoc Peninsula may be considered as a single geographic and orographic province. The outline is regular, with the lateral coast lines parallel, and the width maintained fairly constant to the extreme end. The coasts swing to the west as the southern end of the peninsula is approached, giving the southern portion of the field an almost north and south axis, while farther north the axis trends north-northwest and south-southeast. Pusgo Bay, lying between San Narciso Peninsula and the mainland, is the largest coastal indentation. San Narciso Peninsula is remarkably similar in form and contour to the larger parent mass.

OROGRAPHY

The surface of Bondoc Peninsula rises from the seashore on both sides to a generally high, but dissected, interior. Before erosion became effective, the peninsula must have had a flattened, arch-like cross section. Through erosion, however, a great deal of the material of the former arch has been removed, the relative proportion which remains varying locally. In the northern part of the field, but little of the old surface is left—a ridge of tilted beds dipping toward the sea along the lateral coasts represents the lower part of the sides of the arch, while the highest elevations, farther inland, lie just below the former surface of the crown portion. Farther south erosion is not so far advanced and the larger part of the crown remains as a high interior plateau, incised by deep cañons.

From San Narciso south along the eastern coast the coastal ridge continues unbroken to the mouth of Vigo River, which cuts through it between the peaks of Cambagaco (elevation, 300 meters) on the north and Dagmit (elevation, 350 meters) on the south. South of Mount Dagmit, the ridge is continuous to Bahay River, which like the Vigo empties into the sea through a narrow steep-walled valley. South of Bahay River the crest of the ridge is broken by the valleys of several small streams which flow across it, and the elevation decreases; although Mount Maglihi, one of the southernmost peaks, is 390 meters high and is mountainous in aspect.

On the western coast, the marginal hills are lower (elevation, from 100 to 200 meters), the chain contains no conspicuous peaks, and the ridge is generally less prominent than the eastern coastal ridge.

In the central portion of the peninsula, the dissected plateau is formed by Cudiapi Range (highest elevation, 443 meters) on the north, with Balinsog Hill (elevation, 394 meters), Malumbang Plain (elevation, 250 to 270 meters), Mount Malasimbahan (elevation, 360 meters), Mount Anuing (elevation, 350 meters), Mount Banaba (elevation, 355 meters), and their environs making up the southeastern portion. South of Cudiapi Range and west of Mount Banaba, the high tableland persists across Pinamalijuan Plain to the vicinity of Tala and Sili. On the north this interior plateau drops abruptly to the low-lying valleys of

Matataja and Vigo Rivers and is separated from the coastal ridges on both sides by other erosional valleys. To the southeast the plateau is not perfectly detached from the coastal ridge, the intermediate valleys being shallow.

The southern termination of the interior plateau is at some distance from the seashore, and a strip of low ground, several kilometers wide, intervenes between it and Bondoc Head (elevation, 392 meters)—a conspicuous landmark for navigators rounding the southern point of the peninsula.

Mount Maclayao, 398 meters in height, is the most prominent elevation in the north-central part of the field. It is really a part of the west coast ridge, although it extends eastward into the interior, and forms an area of high ground common to the headwaters of the main drainage systems north of the plateau region.

HYDROGRAPHY

The main streams debouching upon the lateral coasts are confined in comparatively narrow valleys near their mouths. Where erosion is well developed, their middle courses are meandering and are bordered by wide flat terraces of alluvium. The main lines of flow follow the trend of the peninsula, so that streams working back from the east and west coasts attain relatively short lengths in the direction of their lower courses, but develop their principal tributaries at right angles on each side, draining long strips of territory to the northwest and southeast. Vigo River, for example, flows almost east into the sea at its mouth; but its largest affluent, Malipa Creek, flows north for a distance greater than the length of the Vigo below the junction of the two. Tagatay River, or the upper part of the Vigo, flows southeast for a distance equal to the length of the lower east-flowing portion of the stream, and other large tributaries come into Vigo River from the northwest.

Pagsanhan and Talisay Rivers, which empty into the sea on the southern coast, flow throughout their lengths in comparatively straight lines. Talisay, or Malumbang River, and Silonguin, or Canguinsa River,[9] are remarkable in having no important tributaries. In the plateau region these rivers and the Amoguis branch of Pagsanhan River flow through narrow cañons. Bahay River also has a deeply eroded valley, but has developed large tributaries.

Ayoni, Matataha, and Mulanay Rivers are formed of several

[9] In the native usage a river assumes the name applied to the locality through which it flows; consequently the same river may have several different names.

affluents of nearly equal importance which unite in one stream as they approach the western coast. The Ajus, farther north, is like the Vigo in the orientation of its branches. Guinhalinan River, which is one of the largest rivers on Bondoc Peninsula, consists of two principal tributaries coming together from almost exactly opposite directions. Its south fork heads in the northeastern part of the area mapped, and flows north-northwest for a distance of 15 kilometers where it meets the north fork, which comes an equal distance from the north-northwest. From the point of confluence the merged streams flow eastward into Ragay Gulf, a distance of 5 kilometers. Thus, the main drainage of Guinhalinan River is at right angles to the course of, and about six times as long as, the principal stream.

TOPOGRAPHIC CONTROL

The general alignment of the water courses parallel to the trend of the peninsula and the relatively short stream lines at right angles to this trend—an extreme example of which has been cited in the case of Guinhalinan River—are obviously due to the control exercised by the prevailing strike of the rock strata. Not only has the strike of the inclined beds affected in this manner the alignment of the rivers, but the structure has influenced the relative positions of the main valleys and uplands. Thus, the valleys find their greatest development in, or near, the crests of anticlines; while the higher elevations occur in synclinal troughs, on the limbs of the anticlines, or in regions where the folding has not been severe (see geologic sections).

The upper courses of Vigo, Matataha, and Canguinsa Rivers all lie in the crest portion of the Central anticline. The lower part of Vigo River has cut through the ridge bordering the east coast along the axis of a small anticline, and Silonguin River has followed a similar line of cross structure. At the mouth of Mulanay River, likewise, the beds strike east-northeast and are steeply inclined, although only the southern limb of this possible cross anticline has been proved. The high areas in Cudiapi Range and in Bondoc Head represent synclines, while the plateau to the south and southeast of Canguinsa River occupies a region which has not been greatly disturbed in the process of folding. The ridge on each of the lateral coasts consists of strata lying well down in the limbs of the general arch of the peninsula, with Mount Maclayao near the western coast, marking also the southern limb of the cross flexure at the mouth of Mulanay River.

It is believed that the processes which resulted in the folded condition of the strata were initiated prior to the emergence of

Bondoc Peninsula above sea level. Probably the elevation is due, in part at least, to the folding and the main folds were outlined in the original land surface. If this theory is correct, the early water courses must have occupied the structural troughs or synclines. As folding progressed the anticlines became very acute, and their position must have been marked by extensive local shattering of the nonyielding limestone and calcareous sandstone in the upper part of the stratigraphic column. The synclines, on the other hand, were left in broad gentle folds not sufficiently pronounced to break the strata. Obviously, these conditions would tend to hasten the progress of erosion along the anticlinal zones; valleys probably formed on the anticlines and developed with greater rapidity than was possible in the synclines. Consequently, the synclines were soon deprived of their streams through the piracy of the anticlinal drainage, and the translation of the main water courses from synclines to erosional valleys on the anticlines was accomplished.

There is a striking contrast between the low hills and wide valleys, which are found in regions where the soft shale in the lower part of the stratigraphic column has been exposed to erosion over large areas, and the steep-walled valleys and the general youthful appearance of the topography in parts of the field where the upper formations have been preserved. Once these protecting rocks are removed, the shale yields readily to the cutting action of the run-off and relatively mature land forms result.

It is probable that rivers emptying into the sea upon the lateral coasts and gradually working inland along the lines of cross structure have captured drainage, which previously had followed the general strike of the formations. An apparent example of a stream so captured is Canguinsa River, which probably at one time flowed south into Amoguis River.

STRATIGRAPHY

Table of stratigraphy.—Table I shows the stratigraphic and age relations of the rocks in the area under discussion. Tables II and III with similar data for the largest producing oil fields near the Philippine Archipelago are inserted for comparison.[10] Table II represents the Echigo field in Japan, and Table III[11] the Moera Enim field in southern Sumatra.

[10] Iki, Tounenaka, Preliminary notes on the geology of the Echigo oil field, *Mem. Imp. Geol. Surv. Japan* (1910), No. 2, 29.

[11] Tobler, Aug., Topographische und Geologische Beschreibung der Petroleum Gebiete bei Moera Enim (Süd Sumatra). Tidschrift van het Kominklijk Nederlandsch Aardrijkskundig Genootschap. (1906) Tweede Serie, 23, No. 2, 199.

TABLE I.—*Provisional scheme of stratigraphy. Bondoc Peninsula, Tayabas.*

Series.	Formation.	Subdivisions and character.	Thickness.	Characteristic fossils.	Geologic condition of deposition.
			Meters.		
Recent	Alluvium	Clay, sand, gravel, and travertine	0-10		Fluviatile.
Pleistocene and Recent	Coral reefs and litoral deposits.	Raised coral reefs, beaches, etc	0-15	*Trochus fenestratus, Cerithium nodulosum, Telescopium* sp., *Conus flavidus.*	Seashore deposits during slow elevation.
Unconformity					
Pliocene and upper or middle Miocene.	Malumbang series	Upper limestone. Coralline to sandy	20-50	*Pyrula gigas, Lucina bacauensis, Cerithium* sp., *Solecurtus grandis* sp. nov., *Spondylus imperialis, Operculina costata, Bulla ampulla, Pecten senatorius, Lithothamnium ramosissimum.*	Shallow seas, clear at times.
		Cudiapi sandstone. Bedded, calcareous, yellow to brown in color.	50-100		
		Lower limestone, white to yellow, coralline in part.	0-20		
Middle or lower Miocene.	Canguinsa sandstone.	Blue to gray, massive, clayey sandstone with gray calcareous sandstone and minor beds of limestone locally. A single small outcrop of volcanic agglomerate in base, not of general occurrence.	50-160	Large lepidocyclinas, *Cycloclypeus communis.*	Nonuniform conditions; both deep or quiet and shallow seas indicated; local extrusion.
Unconformity. Mechanical discordance and possible erosion.					

Lower Miocene or Oligocene. (?)	Vigo shale	Sandstone and fine sandy conglomerate, in alternate beds.	(?)	*Mitra* sp., *Pyrula* sp	Local extrusion. Shallow seas, gradual subsidence. Water deepened late in the period but became very shallow at close.
		Bacau stage. Massive or imperfectly bedded, bluish black shale with minor sandy zones. The principal oil seeps are associated with the Bacau stage and shallow wells have obtained fair showings of oil in it. A single outcrop of volcanic agglomerate at this horizon, but not of general occurrence.	50-100	*Conus loroisii*, *Conus striatellus*, *Globigerina*, *Conus hochstetteri*, *Tapes rimosa*.	
		Gray shale, black shale, yellow and brown sandy shale, and sandstone interbedded in thin layers. Traces of oil and gas. Possible oil horizon in unexposed base. A single small exposure of volcanic agglomerate; not of general occurrence.	[a]1,400:	*Globigerina*, *Polystomella*	
Eocene		Concealed or lacking			
Unconformity					
(?)		Basal conglomerate over diorite			

[a] Base not exposed.

TABLE II.—*Stratigraphy of the Echigo oil field, Echigo, Japan, according to T. Iki.*

Series.	Character.	Thickness.
		Meters.
Recent	Alluvium; clay, sand, and gravel	----------
Pleistocene	Diluvium; ancient river terraces	----------
Pleistocene or Pliocene	Unconsolidated clay, sand, and gravel	----------
Pliocene	Clayey shale, sandstone and conglomerate, and lignite beds.	----------
Miocene	Gray sandy shale and subordinate layers of sandstone in which oil exists. A bed of fossiliferous limestone in this stage contains *Lithothamnium ramosissimum* Reuss. Shale is locally petroliferous. Interbedded andesitic agglomerate.	300–600
Miocene? (Lowest beds Eocene?)	Black hard shale grading upward into gray sandstone. Interbedded andesitic agglomerate.	600
	Black shale with thin beds of bluish sandstone and thick beds of white or bluish tuff sandstone which is oil bearing.	1,800+

TABLE III.—*Stratigraphy of the Moëra Enim oil field in southern Sumatra according to Aug. Tobler.*

Series.	Character.	Thickness.
		Meters.
Recent and younger Pleistocene	River alluvium, most recent tuff deposits, terraces, etc.	
Older Pleistocene	Tuff and agglomerate, older terraces, etc. Effusive rocks locally.	
Unconformity		
Pliocene (?)	Upper Palembang formation. Tuff, sandstone, and conglomerate. Fresh-water forms in the lower, well-bedded part, silicified wood. Subaërial and lacrustine origin. Effusive rocks locally.	830
	Middle Palembang formation. Marl and marly sandstones. Bedded sandstones and unbedded clays with lignite beds. Estuary formation. Important oil horizon.	650
Miocene: Middle	Lower Palembang formation. Shale and fine-grained sandstone. Marine fossils. Volcanic material, marl, and local coral reefs. Important oil horizon.	1,100+
Miocene: Lower	Shale with interbedded limestone and calcareous sandstone. Locally, clastic sediments, conglomerate, tuff, agglomerate, sandstone, and marl. Marine formation. Doubtful oil horizon.	
Unconformity	Andesitic effusive rocks	
Oligocene	Stage IV. Orbitoidal limestone	
	Stage III. Bedded marl and fossiliferous limestone. Petroleum bearing?	
	Marl with leaf impressions and fossil fish scales	
Eocene	Stage II. Clay, shale, and thin beds of coal	
	Stage I. Breccia and conglomerate. Coal bearing	
Gneiss and schist with granite and diorite intrusions.		

General geologic sections.—An adequate description of the individual stages is made difficult by the irregularity and variability of the upper strata. The limestones and calcareous sandstone of the Malumbang series are especially troublesome in this respect and cannot be sharply defined. In reality all the strata above the Vigo shale might be described as one formation—massive sandy clay at the base, grading upward into sandstone and limestone. Thus defined, the formation has a thickness of about 250 meters.

As a preface to the discussion of the separate formations, general geologic sections obtained in different parts of the region will be recorded. It should be remembered that the thicknesses assigned to the various formations are estimates only, and are not based upon accurate data.

In the latitude of Matataha and Vigo Rivers a thickness of the Vigo shale greater than is exposed elsewhere is encountered in the limbs of the Central anticline near the middle of the peninsula. Toward the coasts on either side the upper formations appear overlying the Vigo shale. The section through the rocks east of the anticlinal axis is shown in Table IV.

TABLE IV.—*Geologic section from the seacoast westward through Cambagaco Ridge and Vigo Valley to the axis of the Central anticline.*

Formation.	Description.	Approximate thickness.
		Meters.
Recent	Raised coral reefs and alluvium. Coastal plain	10
Unconformity		
Malumbang series	Upper limestone. Coralline; eastern slope of Cambagaco Ridge; thick bedded to massive; dip 30° northeast.	30
	Cudiapi sandstone. Bedded, yellow to brown sandstone; calcareous and of medium-grain size; local crossbedding; summit of Mount Cambagaco.	40
	Lower limestone; gray to white; thick bedded or massive; locally concretionary; dip 45° northeast.	20
Canguinsa sandstone	Gray clayey sandstone, usually bedded; west slope of Cambagaco Ridge.	70
	Sandy massive clay; blue to gray in color: close jointed in some exposures; dip 30° to 40° (north of Vigo River to northeast, south of Vigo River to southeast); abundant fossils in parts of base; a single outcrop of volcanic agglomerate interbedded (?) in base on Vigo River at the mouth of Bagacay Creek.	80
Unconformity	Abrupt increase in the angle of dip; western base of Cambagaco Ridge.	
Vigo shale	Bacau stage. Grayish blue to black shale; fine grained and bedded; dip 60° to 80° east-northeast; traces of oil and inflammable gas. Volcanic agglomerate and massive andesite (flow?), a single outcrop on Tangob Creek; included in shale.	100
	Shale interbedded with sandy shale and occasional layers of sandstone, all thin bedded; strikes in various directions, dips usually steep; nearer axis of anticline, dips become uniform 55° to 65° east-northeast. Vertical in axis; base not exposed. Regular strata east of the anticlinal axis probably at least 800 meters thick.	

On Dumalog Creek (Table XIII) north of the line of the section in Table IV, sandstone and conglomeratic sandstone occur above the Bacau stage of the Vigo shale apparently bedded in conformity with the shale below them, and a small outcrop of volcanic agglomerate is found at an apparently lower horizon in the Vigo shale than that of the agglomerate on Tangob Creek.

The Vigo shale appears to undergo a change in character from east to west in that the upper beds become more sandy. This lateral transition from shale to sandstone is revealed by comparing Table V, which is a section of the western limb of the Central anticline, exposed in Matataha River, with Table IV. The Canguinsa sandstone is not well exposed along the western coast, and cannot be separated sharply from the Vigo shale. The evidence of unconformity at the base of the Canguinsa sandstone which was noted in Table IV does not appear in the Matataha River section.

TABLE V.—*Geologic section along Matataha River from the western coast to the axis of the Central anticline.*

Formation.	Description.	Approximate thickness.
		Meters.
Malumbang series	Lower limestone, yellow to white coralline limestone overlying sandy, bedded limestone; dip 35° southwest.	30
Canguinsa sandstone	Concealed interval	50
Canguinsa sandstone, Vigo shale	Interbedded sandstone, sandy shale, and shale with occasional conglomeratic sandstone beds with small pebbles of diorite, andesite, etc.; gray to brown or yellow; almost horizontal in Mount Cancalao.	250
Vigo shale	Blue to black shale (Bacau stage?); traces of inflammable gas; base of Mount Cancalao.	20
	Sandstone and shale interbedded, dip southwest, increasing toward the east up to 25°.	800
	Thin-bedded shale, sandy shale, and sandstone, general color brown or yellow; dip west-southwest increasing toward the east from 25° to 70°; strata vertical in axis of anticline.	500

The upper formations are exposed in section along the crest of the Central anticline in the valley of upper Canguinsa River while the Vigo shale is uncovered in scattered outcrops only. The section in Table VI was obtained in Balinsog Hill and the eastern wall of the valley of Canguinsa River. Table VII shows the relations in the opposite (western) limb of the anticline observed in the western slope of South Cudiapi Mountain and the western wall of Canguinsa River valley along Amuntay Creek. Table VIII is a section in the eastern limb at Bacau.

TABLE VI.—*Geologic section from the summit of Balinsog Hill downward to the bed of Canguinsa River.*

Formation.	Description.	Approximate thickness.
		Meters.
Malumbang series	Upper limestone. Coralline, massive, yellow to white limestone; not present except in remnants on Balinsog Hill, but found on neighboring hills.	20
	Cudiapi sandstone. Bedded, brown to yellow, calcareous sandstone; alternate beds of different thicknesses; dip 15° eastward.	100
Canguinsa sandstone	Lower limestone? Concealed or lacking	
	Gray calcareous sandstone; bedded, dip slight to eastward.	100
	Gray medium-grained sandstone with abundant sandstone concretions.	10
	Gray sandy clay, massive; fossiliferous	20
Unconformity?		
Vigo shale	Bacau stage. Blue to black thin-bedded shale; occasional outcrops only.	

TABLE VII.—*Geologic section down the east slope of South Cudiapi Mountain along Amuntay Creek to upper Canguinsa River.*

Formation.	Description.	Approximate thickness.
		Meters.
Malumbang series	Upper limestone? Not present; removed by erosion?	
	Cudiapi sandstone. Yellow to brown calcareous sandstone, bedded; medium-grain size; summit of South Cudiapi Mountain.	80
	Lower limestone. Yellow to white coralline limestone exposed at base of peak of South Cudiapi Mountain.	20
Canguinsa sandstone	Imperfectly bedded, gray to yellow calcareous sandstone; dip to westward.	60
	Gray to light blue sandy clay; compact and jointed; not bedded; fossiliferous.	100
Unconformity?		
Vigo shale	Bacau stage. Occasional outcrops only, along Canguinsa River; blue to black, thin-bedded shale; dips steep to east and west.	

TABLE VIII.—*Geologic section in the eastern wall of Canguinsa Valley at Bacau; from the rim of the valley to the bed of the river.*

Formation.	Description.	Approximate thickness.
		Meters.
Malumbang series	Upper limestone; yellow to white coralline and sandy limestone, imperfectly bedded; dip 15° to 25° northeast.	30
	Cudiapi sandstone; calcareous, medium-grained sandstone; alternate beds of different thicknesses; dip 15° to 45° northeast.	80
	Lower limestone; coralline; poor exposures, not certainly in place.	20
Canguinsa sandstone	Gray sandstone, jointed and clayey; exposures poor	100
Unconformity; abrupt change in angle of dip.		
Vigo shale	Bacau stage; blue to black petroliferous shale, petroleum seep; bedding is indistinct and appearance massive; fine-grained clay shale with irregular, subordinate sandy zones; dip 55° east-northeast.	30
	Thin-bedded blue to black shale; occasional layers of sandstone; dip 60° east-northeast; outcrops in stream floor.	

Above the Vigo shale in the western wall of Canguinsa Valley at Bacau there are about 100 meters of clayey gray sandstone. About 1 kilometer farther to the northwest the Lower limestone occurs above this sandstone.

The section in Table IX represents the eastern face of South Cudiapi Mountain down to Cauayan Creek. The rocks here dip eastward at low angles, lying in the western limb of the Ayoni anticline.

TABLE IX.—*Geologic section down the western slope of South Cudiapi Mountain to Cauayan Creek.*

Formation.	Description.	Approximate thickness.
		Meters.
Malumbang series	Upper limestone; not present; removed by erosion?	
	Cudiapi sandstone; yellow to brown calcareous sandstone; bedded, medium-grain size; summit of South Cudiapi Mountain.	80
	Lower limestone; yellow to white coralline limestone.	20
Canguinsa sandstone	Gray clayey sandstone; bedded and calcareous in upper portion; massive, sandy fossiliferous clay at base.	170
Unconformity		
Vigo shale	Bacau stage; blue to black thin-bedded shale, traces of inflammable gas; occasional exposures only.	

The lower part of Bahay River, where it cuts through the eastern limb of the Maglihi anticline to the eastern coast, exposes the section recorded in Table X.

TABLE X.—*Geologic section on the lower part of Bahay River; from the mouth of the river inland.*

Formation.	Description.	Approximate thickness.
		Meters.
Recent	Yellow to brown raised coral reefs and coral sand; coastal plain.	10
Unconformity		
Malumbang series	Upper limestone; coralline; dip 30° northeast; east slope of the ridge near coast.	15
	Cudiapi sandstone? Lower limestone? concealed interval	100
Canguinsa sandstone	Gray, bedded, clayey sandstone; dip 35° northeast.	140
Canguinsa sandstone?	Gravel or conglomerate, sandy matrix, large pebbles of diorite, quartz, crystalline orbitoidal limestone, etc.	5
	Coralline limestone grading into calcareous sandstone at base; dip 45° northeast.	8
Unconformity?		
Vigo shale?	Sandstone and shale, irregular thin beds; small seams of lignite; dip 55° northeast.	10
	Sandy blue clay	3
Vigo shale	Brown coarse-grained sandstone, thick bedded to massive; carbonized leaf impressions.	10
	Blue to black carbonaceous shale; sandy; base not exposed; dip 55° northeast; occasional outcrops only; 1,500 meters northwest of the line of this section at about this horizon oil seeps from Bacau stage of Vigo shale on Milipilijuan Creek and at a somewhat greater distance southeast at Bahay, oil seeps from a concealed formation.	

The gravel and coralline limestone between the Vigo shale proper and the Canguinsa sandstone in the foregoing section are unusual and their correlation is doubtful. It should be stated that the character of the gravel and the relations of its occurrence allay any suspicion that it is a recent, superimposed deposit.

Near Mount Morabi in the eastern limb of the Maglihi anticline, south of Bahay, the section shown in Table XI was obtained.

TABLE XI.—*Geologic section in the vicinity of Mount Morabi; from the coast at San Andres to the summit of the mountain.*

Formation.	Description.	Approximate thickness.
		Meters.
Recent	Yellow to brown, coralline, sandy limestone, lies nearly horizontal; narrow coastal plain, vicinity of San Andres.	10
Malumbang series	Upper limestone, coralline	15
	Cudiapi sandstone. Bedded calcareous sandstone. Dip 30° east.	30
	Lower limestone, coralline to sandy	30
Canguinsa sandstone	Bedded, gray, calcareous sandstone; dip 55° east: east face of Mount Maglihi and Mount Morabi.	50
	Yellow to white limestone with abundant coarse sand, locally small pebbles of diorite and quartz, large lepidocyclinas; dips steeply to east, vertical and even overturned to west; summits of Mount Maglihi and Mount Morabi.	5
	Gray calcareous sandstone, bedded; west face of Mount Maglihi.	20
	Clayey, massive sandstone; valley west of Mount Maglihi.	40
Unconformity?		
Vigo shale	Bacau stage; bedded blue to gray shale with sandstone. Occasional outcrops in Canibo Creek; steep dips to east and west, thickness of a few meters only exposed; oil seep at Banco; salt water in Maalat Creek.	

A final section obtained at the village of Cubcub (outside the area mapped), about 15 kilometers northwest of San Narciso, is shown in Table XII.

TABLE XII.—*Geologic section on Guinhalinan River in the vicinity of Cubcub, Peris.*

Formation.	Description.	Approximate thickness.
		Meters.
Malumbang series	Upper limestone; coralline; isolated patches only; summit of Mount Bogas.	10
	Cudiapi sandstone; bedded, calcareous, fossiliferous; toward base, clayey.	80
	Lower limestone? Concealed or lacking	-----------
Canguinsa sandstone	Gray, sandy clay, massive and fossiliferous. Tinaplaca Creek.	100
Vigo shale	Brown coarse-grained sandstone; traces of inflammable gas. Tinalpaca Creek.	8
	Thin-bedded shale with occasional sandstone beds; Tinaplaca Creek, Pigsaan Creek and Guinhalinan River at Cubcub. Extensive exposure at Cubcub; in upper part, sandstone beds 10 centimeters to 1 meter thick with blue to gray, fine-grained, thin-bedded shale and brown, sandy shale; farther down in series fewer sandstone beds, more sandy shale in thin beds alternating with shale of finer grain. Strata lie inclined at an angle of 30° and show subordinate buckling in lower part of series; thickness in continuous exposure, 250 meters; indicated additional thickness, 350 meters; base not exposed.	600+

Alluvium and travertine.—Recent alluvium is found along the valleys of Pagsanhan, Vigo, Mulanay, and Ayoni Rivers. It occurs near the mouth of the Pagsanhan, but on the other rivers it is most extensive along the middle courses above the gaps through which these rivers enter the sea. The material consists of clay and sand with subordinate quantities of sandstone and limestone gravel. Fresh-water shells and occasionally pieces of wood partly carbonized are found in the alluvium. The river terraces usually rise less than 6 meters above the level of the stream.

Travertine is also deposited by running water throughout Bondoc Peninsula and is of more general distribution than alluvium, although as a geologic formation it is subordinate. The salts of calcium which are deposited as travertine are leached from the limestone and calcareous sandstone strata, usually by surface waters. Deposits from springs are exceptional. As is usual with travertine deposited by streams, the formation is most extensive over faces of waterfalls where beautiful rounded terraces often develop; but wherever the streams flow rapidly enough to break into ripples, travertine is precipitated abundantly, and even in still water a veneer of travertine covers the whole stream floor.

Where the flow is rapid, the travertine is eventually built up so as to raise the stream level. As soon as the travertine forms a barrier in this way it accelerates its own growth and ultimately becomes a natural dam. Stream ponding is thus developed, or the water may be diverted to a new channel adjacent to the old bed. A curious interpretation of this phenomenon has grown up among some of the prospectors familiar with the Tayabas field. As it is commonly expressed: "Where a river dams itself up, you are close to oil." A possible slight basis for this belief may be found in the fact that the petroliferous or carbonaceous beds precipitate the calcareous salts from the water, and are usually coated with travertine in consequence. However, since decomposing vegetable matter, such as fallen leaves and twigs, and evaporation from the surface of the water are active precipitating agents, this rule of thumb method of prospecting leaves much to be desired. On the other hand, the travertine seriously retards geologic study in that it often conceals the formations along the streams where they would otherwise be open to examination.

Littoral deposits and recent coral reefs.—Narrow coastal plains, composed mainly of raised coral reefs, occur at intervals, bordering the peninsula. Clay, sand, and other shore materials are intermingled with the corals in varying degrees. The result is a yellow to white, heterogeneous, unconsolidated formation without distinct or regular bedding planes, which is generally youthful in aspect. Shells and fragments of coral closely related to species that are to be found alive in the adjacent seas are prominent constituents of the rock. The disintegration product is a brownish yellow sandy clay which generally covers the ground surface.

These deposits lie nearly horizontal and are found from sea level to an elevation of at least 15 meters. The coastal plain between the mouth of Ajus River and Catanauan attains a greater elevation than 15 meters, but here, as well as elsewhere, it is difficult to delimit the raised reefs from the older coralline limestone. Numerous small areas of mangrove-covered littoral deposits are to be seen farther south along this coast. On the west coast, the formation is to be found in the region of Minajero Bay and north beyond San Andres. Between the mouths of Bahay and Vigo Rivers and farther north near San Narciso, the vicinity of the coast line is made up of littoral deposits.

At various places over the surface of the littoral formation shells were observed which probably represent the molluscan fauna existing when the benches were below sea level. All the species identified are still living, and many of them are edible. Numerous deserted kitchen middens are encountered near the coast, and it is possible that some of the shells collected came from these middens and do not represent the formation upon which they were found.

The genera and species noted are as follows (Plate I):

Spondylus.
Conus flavidus Lamarck.
Trochus fenestratus Gmel.
Arca cecillei Phil. (?)
Astralium stellare Gmel.
Cerithium nodulosum Brug.
Cerithium jenkinsi K. Mart. (?)
Potamides sp.
Voluta sp.
Natica sp.
Crista pectinata Linn.
Strombus canarium Linn.
Telescopium telescopium Linn.

Malumbang series.—The Malumbang series at the top of the column of folded strata consists of the Cudiapi sandstone, which is generally, but not invariably, included between limestones. The limestones are sandy and at many places are either missing or cannot be distinguished from the sandstone which is usually calcareous. They are brownish yellow to white, and generally massive or in thick poorly defined beds. Locally, and usually in the sandy facies, the limestone is bedded, the individual layers averaging from 15 to 30 centimeters thick.

The Upper limestone is generally coralline, although the transition between it and the calcareous sandstone below is gradual. At places on the coast where it is not highly inclined, it cannot be delimited from the recently raised reefs. In representative exposures it shows a thickness of about 30 meters.

The Cudiapi sandstone is named from a type occurrence in the summit of South Cudiapi Mountain. In many places it exhibits alternate beds of different thicknesses; the thinner beds are more calcareous and harder than the intervening thicker beds, and are more resistant to weathering so that the outcrops are characterized by the protruding edges of the thin beds. Where the Lower limestone is missing, the Cudiapi sandstone cannot be separated sharply from the underlying Canguinsa sandstone. The estimated thickness of the Cudiapi sandstone ranges from 40 to 135 meters. The exposure on the summit of South Cudiapi Mountain is about 80 meters thick.

The Lower limestone is generally less than 20 meters thick. It is harder and more compact than the Upper limestone, and is more frequently bedded. In other respects, the limestones of the two horizons are similar and hardly to be distinguished.

On Mount Cambagaco, in the stratigraphic position of the Lower limestone, a rock of unusual appearance is to be seen. It is composed mainly of limestone concretions, 1 centimeter or more in diameter, which have a concentric structure. The concretions lie close together in a cement which is also calcareous, giving the rocks a magnified oölitic texture. This particular variety of the Lower limestone was not observed outside the one vicinity near Mount Cambagaco.

The Malumbang series attains its greatest development in the vicinity of Malumbang Plain extending north beyond Balinsog Hill, south through Mount Banaba and Mount Guinamuan, and southwest to Tala and Sili with a detached area farther south on top of Bondoc Head (see geologic map). The lower two members are found in the Cudiapi Range, while the ridge along the east coast consists of a single limestone (Lower?) overlying the Vigo shale with a concealed interval between. San Narciso Peninsula is covered by the Upper limestone.

All three horizons in the Malumbang series are fossiliferous. Fossils were collected at two places on the hills at the northern edge of Malumbang Plain, which are capped by the Upper limestone. Specimens from fossil locality 61 were obtained on the hills north of Mount Anuing near the eastern rim of Canguinsa River valley at Bacau, and others (fossil locality 63) were found on the hills immediately to the east on the northern border on Malumbang Plain. The Upper limestone in this vicinity is sandy, and grades imperceptibly into the Cudiapi sandstone below it. The fossils are embedded in sandy, calcareous material which might be designated either as sandstone or limestone.

Fossils collected at locality 61.

Pecten senatorius Gmel. +
Pecten leopardus (?) Reeve. +
Cytherea indet.
Cardium indet.
Schizaster subrhomboidalis Herkl.
Xenophora dunkeri K. Mart. (?)
Turbo indet.
Conus indet.
Olivia indet.
Strombus labiosus Gray. +
Melania sp.
Dosinia sp.
Lagenum multiforme K. Mart. var. *tayabum* var. nov.

Fossils collected at locality 63.

Conus indet.
Pecten senatorius Gmel. +
Mitra indet.
Xenophora indet.
Spondylus imperialis Chem. +
Operculina costata d'Orb. +
Turbo borneënsis (?) Bttg.
Trochus sp.
Bulla ampulla Linn. +
Oliva indet.
Pattalophyllia sp. +
Cycloseries sp.

Of the determinable fossils in these and the following lists, those which represent living species are indicated by a plus sign.

Fossils were obtained from the Cudiapi sandstone at three different places, as follows: (1) Fossil locality 65, calcareous sandstone immediately beneath the Upper limestone in the hills north of Malumbang Plain, adjacent to fossil locality 61; (2) fossil locality 4, calcareous sandstone beneath the Upper limestone about 450 meters south of Balinsog Hill, at an elevation of 360 meters; (3) fossil locality 13, sandstone, at an elevation of 270 meters on the high ground between Apad and Milipilijuan Creeks, affluents of the Bahay River. The Upper limestone does not occur over the sandstone at this place, but the sandstone itself is very calcareous.

The fossils from the Cudiapi sandstone were determined as follows:

From fossil locality 65.

Pecten sp.
Schizaster subrhomboidalis Herkl.
Dosinia sp.

From fossil locality 4.

Turbo sp. indet.
Nassa sp. indet.
Fusus sp. indet.
Pleurotoma sp. indet.
Melania sp. indet.

From fossil locality 13.

Clementia sp. indet.
Xenophora dunkeri K. Mart.
Ostrea orientalis Chem. (?) +
Pecten senatorius Gmel. +
Cerithium herklotsi K. Mart.
Pleurotoma tjemoroënsis K. Mart.
Pleurotoma carinata Gray. +

Fossils from limestone at a horizon corresponding stratigraphically with that of the Lower limestone were collected at three localities, namely: Fossil locality 44, at the mouth of Ayoni River; fossil locality 59, on a prominent hill (elevation, 250 meters) 2 kilometers west of Tala; and fossil locality 25, near Tambo, a barrio of San Narciso. However, as will appear in the discussion of the field relations at these localities, only the last group in the foregoing list represents certainly the Lower limestone; the fossils from the other localities may belong to either the Upper or Lower limestone.

On the north side of Ayoni River near its mouth, fossils were found in the limestone which forms the ridge along the western coast of the peninsula.

Fossils collected at locality 44.

Cypraea sp. indet.
Arca nodosa K. Mart. (?)
Schizaster sp.
Cerithium sp. indet.; large internal cast.

Along the western coast from Ayoni north to Catanauan, this limestone is found in the coastal ridge, and occurs conformably only a short distance above beds which clearly belong to the Vigo shale. A short distance inland from Ayoni similar limestone occurs above the Canguinsa sandstone, and is overlain at places by the Cudiapi sandstone. This relation suggests that the limestone at Ayoni is the Lower limestone, but the evidence is not conclusive and either limestone horizon may be represented by the fossils from this locality.

Fossils collected at locality 59.

Pyrula gigas K. Mart.
Balanus sp.
Pecten leopardus K. Mart.

The limestone in which these fossils were found occurs on the top of a hill; below the limestone, with a concealed interval between, the Canguinsa sandstone was observed. The thickness of the concealed beds is hardly great enough to include the Cudiapi sandstone and the Lower limestone in their usual thicknesses. The fossils, therefore, are assigned to the Lower limestone, although they may represent the Upper limestone instead.

A sample of limestone (fossil locality 25), which certainly came from the Lower limestone horizon, was collected near the Cabongahan-San Narciso trail at an elevation of 180 meters, on the east side of the ridge extending northwest from Mount Cambagaco. Thin sections of this rock show small fragments of limestone and the well-known alga, *Lithothamnium ramosissimum* Reuss, intermingled in a cement of calcite.

Plates II and III are photographs of typical fossils from the Malumbang series. Plate II represents the Upper limestone and the Cudiapi sandstone, while Plate III shows fossils from the Lower (?) limestone.

The most conclusive evidence as to the age of the Malumbang series is found in the Lower limestone, which, on the basis of the fossil *Lithothamnium ramosissimum* Reuss (fossil locality 25) may be assigned to the Miocene. The upper beds in the series are apparently as young as the upper Miocene or the Pliocene. The formation is similar to the "étage marneux" which Verbeek[12] assigns to the middle stage of the upper Tertiary for Java, and describes as follows:

IX. Middle stage of the upper Tertiary. Formations called the marl stage. Abundant marl and marly sandstones. Less abundant sandstone and shale with some calcareous beds.	Middle and upper Miocene highest beds in part Pliocene.

* * * IX The second stage or the middle Neo-Tertiary stage m_2, probably contains at a slightly lesser depth than the lower division, some beds of Middle and Neo-Miocene and even Pliocene age, which cannot always be distinguished in the field and are called by us the "marl stage" on account of the principal rock. One finds here, besides some calcareous sandstones with numerous marine shells, beds of conglomerates and breccias (much less than in the stage M), then some shales, noncalcareous sandstones and calcareous beds, the last named having occasionally orbitoides with spatula shaped chambers (lepidocyclines) * * *.

The Cudiapi sandstone, the principal rock in the Malumbang series, might be called a marly sandstone, and the limestones are likewise often sandy or clayey. Shale is not present, but some exposures of the Cudiapi sandstone are argillaceous.

No indications of petroleum have been observed in the Malumbang series. It is above the horizon at which oil seeps occur, and bears on the possible petroleum industry only in the fact that it must be drilled through before the petroliferous zones can be explored in parts of the promising territory.

Canguinsa sandstone.—The Canguinsa sandstone is a close-grained, gray or blue rock to which the term sandstone applies in a general way. It is distinguished from the Cudiapi sandstone by its massive or less perfectly bedded appearance and by the considerable proportion of clay which characterizes it. The upper portion is usually a soft, clayey sandstone, imperfectly bedded and occasionally close jointed. This sandstone is calcareous, and several exposures on the upper part of the Canguinsa River are concretionary. The concretions are aligned so as to lend a bedded appearance to the exposure. The concretionary sandstone was not observed to be of general distribution.

Toward the base of the formation either a typical sandstone or an indurated massive or jointed clay is encountered. Both sandstone and clay occur in heavy banks from 3 to 6 meters thick, and both are slightly calcareous. The sandstone facies in the basal portion is deep blue on fresh exposure, but weathered surfaces are gray or brown. Ordinarily, it is of medium-grain size, and shows little evidence of bedding. The clay is also blue

[12] Verbeek and Fennema, Description Géologique de Java et Madoura. Amsterdam (1896), 1, 38, 41.

when freshly exposed, and becomes gray upon weathering; it is fine and compact, but not bedded. Some of the rocks which have been classed as marl in Java and Sumatra are probably similar to the slightly calcareous clayey zone in the Canguinsa sandstone.

The clay and sandstone banks in the base of the formation are fossiliferous and sometimes contain myriads of small shells. The fossils are often greasy and appear to be well preserved, but in reality they are very fragile, and can be removed entire only with care.

In the section on lower Bahay River, the Canguinsa sandstone includes a few meters of limestone and conglomerate. On Mount Maglihi and Mount Morabi limestone which contains coarse sand and small pebbles of diorite, quartz, and andesite is present in the Canguinsa sandstone, but no conglomerate was observed. In the lower part of the gorge on Canguinsa River, also, a subordinate thickness of limestone was found in the Canguinsa sandstone.

Volcanic agglomerate, with some appearance of bedding, outcrops at the junction of Bagacay Creek and Vigo River in the base of the Canguinsa sandstone, or possibly between it and the underlying formation. The outcrop is of limited extent, and is the only instance of volcanic rocks above the Vigo shale.

The thickness of the Canguinsa sandstone varies from 50 to 160 meters. Although it occurs unconformably over the Vigo shale, the contact between the two formations is found always near the same horizon in the Vigo shale, and the base of the Canguinsa sandstone serves as a datum for rough correlation.

The Canguinsa sandstone is not encountered in large areas, but occurs in steep slopes along streams where it has been protected from erosion by the overlying Malumbang series. It is exposed at the surface or overlain by patches of the Lower limestone, in parts of Malipa Creek valley, and is prominent among the rocks of the Cambagaco-Dagmit ridge along the eastern coast. On the western coast it is little in evidence, although it occurs in the western slope of South Cudiapi Mountain. Calcareous sandstone and limestone, overlying Vigo shale and consequently referred to the Canguinsa formation, cap a ridge between two branches af Mulanay River in the northern part of the field. Pieces of agglomerate, in which, among other constituents, pebbles of schist were noted, are found in this vicinity, and are probably to be referred to the volcanic agglomerate horizon.

Two groups of fossils from the Canguinsa sandstone proper (fossil localities 7 and 12); and fossils from the included limestone beds on Mount Morabi (fossil locality 62) and Mount Maglihi (fossil locality 67) have been studied; photographs of some of the specimens appear on Plate IV.

Fossils were found in the Canguinsa sandstone on Amuntay Creek (affluent of Canguinsa River) at an elevation of 150 meters. Here the Canguinsa sandstone is about 160 meters thick (see geological section, Table VII). The fossils were found about 40 meters above the base of the formation in tough jointed gray clay. They include:

Fossils collected at locality 7.

Pecten fricatum Rv. +	*Dosinia* sp. indet.
Pecten sp.	*Pleurotoma suturalis* Gray (?) +
Pecten senatorius Gmel. +	

The following fossils were collected from a clayey, blue sandstone in the base of the Canguinsa immediately above the Vigo shale on the upper part of Tangob Creek, about 50 meters northeast of the main occurrence of volcanic agglomerate shown on the geologic map.

Fossils collected at locality 12.

Strombus canarium Linn.	*Pattalophyllia* sp.
Conus ornatissimus K. Mart.	*Septarea arenaria* Lam. +
Corbula socialis K. Mart.	*Mitra javana* K. Mart.
Cypraea erosa Linn. +	*Natica mamilla* Linn. +
Hindsia sp.	*Ranella* sp.
Pleurotoma flavidula Lam.	

A microscopic section through a specimen of the limestone occurring in the Canguinsa sandstone on Mount Maglihi (fossil locality 67) showed it to be made up of fragments of sandstone, quartz, and limestone in a calcareous cement and to contain Foraminifera with lozenge-shaped cells, probably of the genus *Lepidocyclina*. The limestone from Mount Morabi (fossil locality 62) contains *Cycloclypeus communis* K. Martin, which represents the middle Miocene, and large lepidocyclinas some of which are 45 millimeters in diameter and 5 millimeters broad in the thickened central portion. *Lepidocyclina richthofeni* Smith was identified among these. This species has been referred by Douvillé[13] to the lower Miocene.

No definite age determinations can be made from the fossils in the Canguinsa sandstone proper. The fossils in the included limestone, however, are well known and have been used in correlation by various authorities. From their presence it is concluded that the Canguinsa sandstone should be placed in the middle Miocene, extending, perhaps, into the lower Miocene.

The Canguinsa sandstone occurs immediately above the prin-

[13] *Compt. rend. Soc. géol. de France* (1909), 14, 130.

cipal known oil horizon. It is not porous enough to afford a reservoir in which oil might accumulate, and no oil has been observed in it. Because of its compact nature on the other hand, it would tend to confine any oil collecting below it. At several promising drilling sites the Canguinsa sandstone must be drilled through before the petroleum zone is encountered.

Vigo shale.—The base of the Canguinsa sandstone is marked by an unconformity, which is partly of a mechanical nature, but may represent also a period during which the underlying formation, the Vigo shale, was subjected to erosion. The subject of unconformities is discussed in connection with the geologic structure, page 337.

The Vigo shale is the most extensive and the most uniform series in the stratigraphic column of Bondoc Peninsula. The beds belonging to this formation, although they are closely related in type to some of the overlying beds, constitute a separate stratigraphic division which is readily distinguished.

The type exposures in the valley of Vigo River consist of fine-grained shale and sandy shale interstratified in thin regular beds from 5 to 10 centimeters in thickness. Occasional beds of sandstone occur varying from 10 centimeters to 1 meter in thickness. The fine-grained shale is gray, blue, or black, and is made up almost entirely of clay. The sandstone is gray or brown, and consists of uniform, medium-sized, not completely rounded grains of quartz, diorite, andesite, and metamorphic rocks. The sandy shale is yellow or brown and of intermediate composition.

There is an apparent transition from east to west in the character of the Vigo shale. In the eastern limb of the Central anticline, exposed in the valley of Vigo River, the formation is predominately shale throughout, sandstone occurring only at intervals. In the western limb shale predominates in the exposure near the axis only, that is, the lower part of the series. Farther to the west the sandstone beds increase in number, until in the upper horizons they become more prominent than the shale. The grain-size likewise increases in the upper beds, and small pebbles occur, forming layers of sandy conglomerate.

The blue or black, fine-grained shale in the Vigo formation usually emits a slight odor of light oils upon fresh fracture, and in some outcrops is highly petroliferous. The material loses this odor and assumes a light gray color after it has been exposed to the air and has become thoroughly dry. The petroliferous shale forms a loosely defined stage in the upper part of the Vigo, which will be referred to as the Bacau stage, although it cannot be sharply delimited.

Among the fossils collected the following were identified.

Fossils collected at locality 11.

Conus loroisii Kien. +	*Tapes rimosa* Phil. +
Pyrula sp.	*Conus striatellus* Jenk.
Arca sp.	*Conus hochstetteri* K. Mart.
Natica sp. indet.	*Fusus* sp. indet.

In a specimen of the conglomeratic sandstone which occurs in the upper part of the Vigo shale in Matataha Valley one species of *Mitra* and one of *Pyrula* were noted. *Globigerina* (Plate V) was found in the Vigo shale, more abundantly in the Bacau stage.

The general aspect of the fossils in the Bacau stage of the Vigo shale is very similar to that of the fossils in the base of the Canguinsa sandstone (Plate IV). The age of the beds is not fixed definitely, but the fresh appearance of the shells and the number of species still living make it improbable that they represent a period earlier than the Miocene. The base of the series may be as old as the Oligocene.

The Vigo shale includes all the known petroliferous horizons in this field. Seeps of petroleum and inflammable gas occur in the Bacau stage, generally within a few meters below the base of the Canguinsa sandstone; on Malipa Creek, however, traces of oil and gas are observed with 250 meters of Vigo shale exposed above them. The occurrence of petroleum is discussed on page 349.

As to the character of the rocks which occur below the Vigo shale, there is little evidence. The shale may rest directly upon the basal diorite which is cited by Becker[14] as probably the oldest formation in the Philippine stratigraphic column, or upon a sedimentary series older than the Vigo shale. Elsewhere in the Philippines, Miocene shale has been found in some cases to overlie Eocene shale and limestone, in others to rest immediately upon a base of older igneous rocks, and rarely to be underlain by older "slates" which are probably of Jurassic age.

At Peris, about 25 kilometers northwest of San Narciso, the common basal diorite occurs, overlain unconformably by the Cudiapi sandstone. Toward the south, successively older formations, down to and including the Vigo shale, at least, undoubtedly overlap the diorite base just as the Cudiapi sandstone does at Peris. Possibly sedimentary rocks older than the Vigo shale intervene between it and the lowest parts of the diorite floor.

[14] Becker, G. F., *21st Ann. Rep. U. S. Geol. Surv., 1899–1900*, pt. III (1901), 24 of reprint.

Volcanic agglomerate.—In the northeastern part of the area shown on the map several exposures of andesitic agglomerate were encountered. Two outcrops were found at different horizons in the Vigo shale and one in the base of the Canguinsa sandstone.

The most extensive outcrop is a conical hill about 1 hectare in area and 50 meters high. The form is not unlike that of an old volcanic plug, but may be due entirely to the work of erosion. The material is principally agglomerate; but apparently massive andesite is to be seen in the central part of the exposure, while an intermediate zone consists of andesite in which the fragments occur in a stony crystalline matrix. The other exposures are also conical in form, but are much smaller and consist entirely of agglomerate, angular fragments of andesite, varying in weight from a fraction of a kilogram to 10 kilograms, embedded closely in andesitic tuff. There is a suggestion of bedding in the agglomerate in the base of the Canguinsa sandstone on Vigo River. The outcrops are gray to dark brown, and are weathered in a manner that leaves the fragments protruding irregularly from the matrix. The agglomerate appears to be interbedded in the shale, but the contacts are obscure and it is not certain that it does not lie upon an eroded surface of shale.

Near the village of Bato, bowlders of fragmental rocks, probably volcanic agglomerate, were observed in which sedimentary types—sandstone and shale—are most prominent, but are accompanied by andesite. A thin section of fragmental andesite from this agglomerate was examined under the microscope. The texture is decidedly porphyritic with a large proportion of phenocrysts, consisting of dark green to brown hornblende and plagioclase feldspar crystals. In the subordinate groundmass occasional crystals and fragments of magnetite are scattered. The petrographic character indicates an extrusive, certainly not a plutonic and probably not an intrusive, rock. A more homogeneous specimen of andesite taken from the main exposure on Tangob Creek shows similar characteristics. It is porphyritic, one of the hornblende phenocrysts measuring more than 1 centimeter in length. The hornblende crystals are more abundant than in the previously described rock, and show well-defined reaction rims.

The several outcrops of volcanic agglomerate occur along a line roughly parallel to the general strike of the sedimentary beds. They are of small area, the distances between them are relatively great, and there is little reason to believe that they represent a continuous formation. The fact that parts of the formation are typical agglomerate with a tuffaceous matrix makes it very improbable that these outcrops represent an intrusion. The material appears to be clearly of volcanic origin and to consist principally of fragmental ejecta. Whether each outcrop represents a center of local effusion, or is the remnant of a larger sheet of agglomerate which came from a distance and was interbedded in the shale, cannot be decided without further investigation.

The importance of the igneous rocks relative to the accumulation of petroleum is problematical. Traces of oil and gas are found in the shale on Tangob Creek adjacent to the largest outcrop of agglomerate. If the observed outcrops mark local centers of extrusion, then the beds stratigraphically below them must be pierced and more or less broken by the volcanic vents from which the agglomerate was thrown out. In the light of drilling experience in most large oil fields this condition probably would be looked upon with disfavor. However, it is well known that large flows of oil have been obtained in Mexico near volcanic rocks which have come up through sedimentary beds, and it has been suggested [15] that the vulcanism has supplied the conditions necessary for the accumulation of the petroleum. Thus, even if the agglomerate in Tayabas has been extruded locally, it should not condemn any part of the field, and may have had a desirable effect.

If the agglomerate has not been extruded locally but has been thrown out from a distant center, its presence probably has little bearing on the question of petroleum exploitation. It is conceivable, of course, that an impervious sheet of interbedded agglomerate might influence the accumulation of any petroleum in the rocks below it, but the data available do not warrant any procedure based on this possibility.

On the whole, in view of their limited extent and of their probable extrusive origin, it may be concluded that the igneous rocks have no important bearing, either favorable or unfavorable, on the possibilities of this oil field.

STRUCTURE

General.—Bondoc Peninsula occupies a geanticlinal zone in the folded strata of southern Luzon and the adjacent islands. Ragay Gulf, lying east of the peninsula and between it and the larger peninsula of southeastern Luzon, probably occupies an

[15] Garfias, V. R., *Journ. Geol.* (1912), 20, 2, 666.

adjacent geosyncline. The elevation of Bondoc Peninsula above sea level is due, in part at least, to its anticlinal structure.

In the general arch which the strata form across the width of the peninsula there are minor undulations which have been studied as individual folds. Among these folds the anticlines are more sharply defined, and hence more easily traced, than the synclines. Because of this and of their probably greater importance in connection with petroleum accumulation the anticlines have received more attention than the synclines. In connection with the discussion of the structure reference should be made to the geologic sections shown on the map.

Confusing irregularity is encountered in the strikes and dips of the Vigo shale in parts of the field, particularly in the upper valley of Mulanay River and in a small area north of Cabongahan. At the latter place along small streams, outcrop after outcrop was examined, the strikes and dips of which are utterly at variance, even when all but the most reliable-appearing exposures are ignored. Because of this fact, the structural relations have proved locally undeterminable.

The Vigo shale is a thinly laminated and nonfrangible formation which would scarcely be maintained as a competent arch in folding, but probably would break and move upon itself where the strains were most severe, leaving the strata in confused disorder at these points. In the crest region of the Central anticline the shale is much disturbed, and extreme confusion in the attitude of the beds is encountered near the intersection of this fold with the minor cross anticlines, while the strikes are regular and uniform only in the limbs or far down in the core of the anticline. The squeezing and distortion, due to close folding in a formation structurally incompetent, together with superficial displacement and caving due to erosion, are probably the main causes of the observed irregularity in the Vigo shale.

Unconformities.—In addition to the unconformity at the base of the recent deposits on Bondoc Peninsula there is considerable discordance between the Canguinsa sandstone and the Vigo shale. No exposures were found showing an eroded surface of the Vigo shale beneath the Canguinsa sandstone, but in regions where the inclination of the beds is steep an abrupt increase in the angle of dip is apparent on passing from the higher to the lower formation, although the strike remains more or less constant.

The change in the degree of inclination of the two formations is best illustrated by the conditions on the upper part of Malipa Creek where steeply dipping Vigo shale is overlain by almost horizontal Canguinsa sandstone. Similar relations are to be observed along the western base of Mount Cambabaco.

Overlap on the part of the Canguinsa sandstone, which would be expected if this member were laid down upon the truncated edges of the Vigo shale, is not very extensive. At a number of places the Canguinsa sandstone is encountered above approximately the same horizon in the Bacau stage of the Vigo shale. Elsewhere, as is shown in the section on Dumalog Creek, page 333, and the section on Guinhalinan River, page 322, more or less sandstone or sandstone and fine conglomerate, bedded conformably with the Vigo shale, intervene between the Bacau stage and the Canguinsa sandstone.

The volcanic agglomerate might be taken as evidence of a distinct break in the process of sedimentation if it occurred uniformly between the discordant members, but the outcrops do not appear to lie along the unconformity nor to be confined to a single horizon. It is possible, however, that more detailed work would show that the agglomerate does occur along the unconformity, and thus indicate a decided break between the Vigo shale and the overlying formations. In the data at hand, however, the overlap of the Canguinsa sandstone and the steeper dips in the Vigo shale are the principal evidences of unconformity.

If the steeper angle of dip in the Vigo shale, as compared with the overlying formations, is accounted for by assuming that the later rocks were laid down on an eroded surface of previously folded Vigo shale and were themselves thrown into folds subsequently, two periods of folding are involved with a remarkable coincidence in the position and trend of the later folds along the axes previously established in the Vigo shale. A theory of a single period of folding is simpler and is in accord with the observations in the field, if mechanical unconformity, resulting from the different frangibility of the Vigo shale and the overlying formations, be admitted as adequate to account for the overlap of the Canguinsa sandstone and the lesser inclination in the beds above the Vigo. On the other hand, there is evidence in the sandstones and conglomerates immediately above the Bacau stage that the seas became very shallow before the deposition of the Canguinsa sandstone began, and it is possible that the Vigo shale emerged from the sea and became subject to erosion, although positive evidence of erosion is lacking. The fossils in the two formations indicate that there was no great interval of time between them.

Whether the unconformity is one of erosion or of mechanical discordance only, the Canguinsa sandstone appears to overlap the Vigo shale, and this is of practical importance in that the overlap may conceal petroliferous members of the Vigo shale above the Bacau stage. The conclusions in this report regarding the general lines of structure—the position of the main anticlines etc.—are to a degree independent of the unconformity, since the larger folds are approximately coincident above and below the discordance.

Central anticline.—The principal structural feature of Bondoc Peninsula is the series of folds whose trend conforms roughly to that of the peninsula. These folds are made up of broad shallow synclines and narrow acute anticlines. Subordinate anticlines occur near both lateral coasts, and a larger anticline designated as the Central anticline marks the axis of the peninsula.

The Central anticline is asymmetric in that the eastern limb is more highly inclined than the western. The fold is sharp, especially in the lower strata which are vertical along the axis, and about 25 kilometers in length. The general strike of the axis—north 30° west—is not maintained with absolute uniformity, but becomes almost north and south toward the southern end of the peninsula. A general southerly plunge of the anticlinal axis is indicated by the fact that, from north to south along the axis, beds successively higher in the stratigraphic column are encountered at the same elevation.

In the northern part of the field the axis coincides with the summit of the low divide between Sibuyanin and Vigo Rivers. From this point it follows more or less closely a straight line south-southeast as far as Cuyocuyo Creek. Farther south the crest of the fold appears to coincide with the upper part of Canguinsa River, so that south of Cuyocuyo Creek the axis must trend about north and south. Beyond Bacau, the sharp fold dies out, and was not certainly identified farther south; although the gentle overturn of the strata, indicated in the western part of Amoguis Valley, probably marks its continuation. North from the divide between Matataha and Sibuyanin Rivers the Central anticline can be traced as far as the eastern slope of Mount Maclayao. In Mount Maclayao, Vigo shale is encountered, striking east-northeast and dipping steeply to the south, and at the intersection of this line of strike with the Central anticline the identity of the latter is lost in a confusion of varying strikes and dips.

In the axial portion of the fold at the head of Sibuyanin River, vertically dipping beds of Vigo shale are exposed. In the western limb the dip decreases rapidly, and within a few hundred meters to the west-southwest of the axis it amounts to only 45°, while 2 kilometers from the axis the dip—west-southwest—is as low as from 15° to 20°. Still farther west the beds lie horizontal in the syncline between the Central anticline and the Ayoni anticline. In the opposite or eastern limb a dip of from 55° to 65° to the east-northeast persists for a distance of 1 kilometer to the eastward from the axis. Farther east, the relations are uncertain and are discussed in connection with the Malipa anticline (page 342).

To the south the western limb can be identified in the beds exposed along the eastern slope of Cudiapi Range. The upper part of the Vigo shale, which outcrops along Cambagnaon and Cuyocuyo Creeks, dips from 25° to 30° to the west-southwest; but the beds lower in the formation and nearer the axis of the anticline are steeper, dipping from 60° to 70°. The Canguinsa sandstone which has been removed by erosion farther north reappears in Cudiapi Range, overlying the Vigo shale and dipping

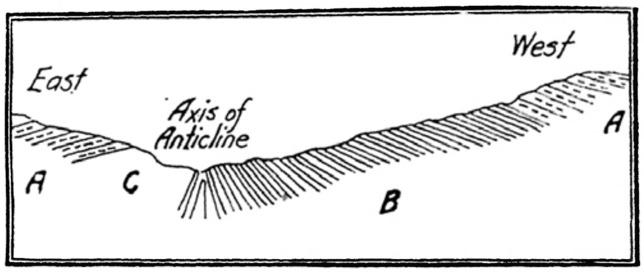

FIG. 1. Diagrammatic section across axis of central anticline in the upper valley of Malipa Creek. (*a*) Canguinsa sandstone; (*b*) Vigo shale; (*c*) concealed.

at low angles to the west-southwest. In the eastern limb of the fold in this vicinity the Canguinsa sandstone is encountered very close to the axis dipping gently to the eastward. The nearest exposures of the underlying Vigo shale are vertical, or dip at high angles to the east in the axial portion of the fold. There appears to be insufficient room between the axis and the Canguinsa sandstone in the eastern limb for a thickness of Vigo shale equivalent to that exposed in the western limb. The relations are shown in text fig. 1.

Possibly faulting has occurred in the plane of the axis as a result of sharp folding, and the western limb has been thrust upward along the fault. Such a condition would explain the position of the lower part of the Vigo shale in the western limb so nearly in contact with Canguinsa sandstone in the eastern limb.

In the headwaters of Canguinsa River an exposure of Vigo shale was observed dipping 45° to the westward, the later formations lying above it and dipping in the same general direction at a lesser angle. South of Balinsog, as far as Bacau, the Canguinsa sandstone is intact across the axis of the anticline, and the upper formations dip gently away to the east and west on either side of Canguinsa River. The Bacau stage of the Vigo shale is exposed in the river at Bacau, dipping 55° east-northeast; and above this exposure, in the eastern wall of the valley, the Canguinsa and Malumbang formations are encountered dipping at low angles to the eastward. Up and down stream from the outcrop of Vigo shale at Bacau the relations are concealed; the river swings to the southwest at this point, and the next exposures downstream are of Canguinsa sandstone dipping gently westward.

The existence of a minor cross-anticline, the axis of which coincides roughly with the lower part of Canguinsa (Silonguin) River, is suggested in the discussion of the geologic control of the topography. In the upper part of the gorge, which Canguinsa River enters after its abrupt turn to the southwest, the Canguinsa sandstone dips to the north of west, while farther downstream the direction of dip has swung to south of west, indicating that the river in its course to the southwest has passed over the axis of a small anticline trending east and west in the general western limb of the larger fold. In a profile view of a cross section of the gorge, which may be obtained from Mount Anuing, the effect of this small anticline may be detected in the slope of the land surface to the north and south away from the rims of the gorge. The northerly dip of the beds in the hills along the north edge of Malumbang Plain probably represents the northern limb of this cross-flexure.

It is probably due to the presence of the cross anticline at Bacau that the Vigo shale is thrown up so as to appear again at the surface after having been carried down by the general southerly plunge of the axis, far enough to escape erosion at the same elevation farther north.

Structure in the region north of the Central anticline.—In Sobo Creek, which drains a part of the western slope of Mount Maclayo, strata in the upper part of the Vigo shale were observed striking north 65° east and dipping 65° to the south. On Mulanay River, above the point where the tidal influence ceases, numerous outcrops of Vigo shale are to be seen in a majority of which the strikes are a few degrees north of west, and the dips are either vertical or steep both to the north and south. A smaller number of exposures show the usual north-northwest strike with dips to the west or occasionally to the east.

Northeast of this region, between Guinhalinan River and the eastern coast, the formations are found in their usual relations—striking north-northwest and dipping to the east from 35° to 40°. On Ajus River to the northwest, likewise, the prevailing strike conforms to the established order; but the position of the beds indicates an overturned fold with the lower part of the Vigo shale, which dips to the eastward at angles of from 60° to 90°, recumbent upon the sandstones and conglomerates in its upper portion. The overturn does not persist through the younger formations apparently, since these are found in the range of hills along the coast, dipping at an angle of about 45°, westward.

Inland from Catanauan and northwest of Ajus, the limestone in the coastal ridge dips to the southwest at an angle of about 45°. In the valley east of this ridge, Vigo shale is exposed, dipping 50° to the southwest. Thus, the slight overturn at Ajus appears to adjust itself along the strike of the formations; the strata resume a steep southwestern inclination, northwest of Ajus, corresponding to the lesser dip in the same direction at Matataha and Ayoni, southeast of Ajus.

Summarizing the discussion of the structure north of the Central anticline, the seaward dipping formations near each coast may be interpreted as evidence of a general arch across the width of the peninsula. The relations in the crest portion of the suggested arch are complicated and obscure. It appears that folding at right angles to the general structural lines has occurred, together with close folding and overturns along the main lines of structure.

Malipa anticline.—The strikes and dips in the Vigo shale near Cabongahan indicate the presence of a subordinate anticlinal undulation in the eastern limb of the Central anticline. The smaller fold, known as the Malipa anticline, trends north 65° to 70° west, making an angle of about 40° with the axis of the Central anticline. Its crest is roughly coincident with the lower course of Vigo River. The fold is well developed in the Vigo shale, but is only faintly reflected in the younger formations lying in the ridge near the eastern coast. In the southern limb of the anticline, along Malipa Creek, a thickness of 800 meters of Vigo shale is exposed, dipping to the south-southwest at an angle of about 55°. Above the Vigo shale, the Canguinsa sandstone appears, overlain by patches of coralline limestone.

Only a few exposures were observed which can be referred to the northern limb of the Malipa anticline. These are found along Vigo River, and dip about 45° to the north-northeast. Farther north the dips and strikes are much confused, and the structure is not clear. The volcanic agglomerate is encountered at the head of Tangob Creek. In this vicinity the Vigo shale dips steeply to the east-northeast in perhaps a majority of the exposures, but its relations are not uniform.

Bato anticline.—Near the small village of Bato, north of Cabongahan, the lay of the beds indicates a local anticline in the Vigo shale, the axis of which is roughly parallel to the Central anticline. Like the Malipa anticline this fold appears to be a minor overturn in the general eastern limb of the Central anticline. It is a sharp flexure, the strata in each limb dipping at angles of 60° or more, but is persistent over a length of a few hundred meters only. The stream between Bato and the ridge to the east appears to follow the axis of this anticline. The Bacau stage of the Vigo shale is exposed along its crest and dips away from the stream line on either side. The upper formations appear on top of the Vigo shale in the eastern limb, forming the high ridge between the anticline and the eastern coast. The dip in the uppermost beds is from 30° to 45° east-northeast. Pusgo Bay which lies off the eastern coast at this point occupies a syncline, and San Narciso Peninsula, east of the bay, is a monocline dipping gently westward toward this syncline. West of the axis of the Bato anticline only Vigo shale is exposed and the westerly dip of its beds persists for a short distance only, beyond which the shale dips steeply to the east-northeast, marking the eastern limb of the Central anticline.

In the Florence, Colorado, oil field,[16] the stream lines are sometimes marked by small sharp anticlines, which are attributed to purely superficial phenomena, such as the expansion of rocks through weathering and consequent thrust of surface beds into the valleys formed by streams. It is possible that the Bato anticline is of this type, but the fact that petroleum is found along its crest argues that it is more than superficial in effect, since petroleum is found usually in true anticlinal zones, elsewhere in the field.

Ayoni anticline.—Inland from the villages of Ayoni and Bondoc on the west coast, the dip measurements and the hill forms reveal an upward flexing of the strata along a line directed north 35° west. This axis is about 1,200 meters and 2,000 meters from the coast at Ayoni and Bondoc, respectively. The

[16] Washburne, C. W., *Bull. U. S. Geol. Surv.* (1909), 381, 49.

gentle anticline which is defined along it becomes evident a short distance south of Matataha River and persists over a length of 10 kilometers to a point east of Bondoc. Sandstones, about 300 meters in thickness, are exposed in the western limb at Ayoni, dipping from 35° to 40° west-southwest and overlain conformably by limestone. The sandstones probably represent the Canguinsa and part of the Vigo formation, and the limestone, the lower stage of the Malumbang series. East of the axis in the west slope of the Cudiapi Range, a similar section culminating in limestone and calcareous sandstone is revealed. The inclination of the strata in the eastern limb is generally less than 15°.

Between the northern end of the Ayoni anticline and the cross fold at Mulanay, an area in which the strata are horizontal intervenes. Mount Cancalao, left by erosion in the Matataha Valley, affords a section of horizontal strata in which bluish black shale at the base is covered by beds of sandstone, sandy micaceous shales, and sandstone conglomerate with a total thickness of nearly 200 meters. On the coast west of Mount Cancalao, the strata dip seaward as they do at Ayoni, and precise measurements would probably reveal a slight anticlinal fold between the mountain and the coast.

South of the Ayoni anticline as far as Silonguin (Canguinsa) River, the structural relations are uncertain. The identity of the smaller fold is lost in a general slight dip to the southwest, which probably marks the western limb of the Central anticline.

Cudiapi syncline.—The Cudiapi syncline is a shallow structural basin lying between the Central and Ayoni anticlines. The rocks have been preserved from erosion within this zone and form the rather flat-topped Cudiapi Range extending southeast from the headwaters of Sibuyanin River to Silonguin River. The Canguinsa sandstone and the Lower limestone of the Malumbang series are exposed over most of the surface, but remnants of the Cudiapi sandstone occur locally.

Maglihi anticline.—The Maglihi anticline—marked by Mount Maglihi, a conspicuous peak formed by the almost vertical strata in its crest—is an acute upward flexure in the eastern part of the monocline which persists with a gentle eastward dip across the southern end of the peninsula. The anticline is most clearly revealed in the vicinity of Mount Maglihi, where the axis strikes north 5° east, and the eastern limb is much steeper than the western. South of the mountain, the axis plunges so that the fold is barely perceptible in the strata near the southern coast. Northward, it can be traced with some difficulty for several kilometers and probably continues to Bahay where a similar fold is indicated. At Bahay, however, the western limb is not clearly defined in the younger formations and the axis has changed its direction to the north-northwest, in conformity with the general strike in the field.

In the region of Mount Maglihi, the western limb of the fold can be identified without difficulty. For several hundred meters west of the axis, the Upper limestone and Cudiapi sandstone dip from 15° to 20° to the westward, reversing the monoclinal slope from the summit of Mount Banaba and forming the eastern limb of a shallow syncline occupied by Malumbang Valley. The Vigo shale, exposed at the oil seep near Banco, likewise dips to the westward, but at a greater angle (45°). North of Banco, the crest of the fold is less deeply eroded, and the base of the Canguinsa sandstone is not uncovered. On Mount Maglihi and Mount Morabi, which are in the eastern limb close to the axis, the Canguinsa sandstone dips generally about 55° to the east, but locally it is vertical, or even overturned slightly to the west. The Canguinsa sandstone is calcareous in this locality, and in the summits of the hills just mentioned contains sandy limestone a few meters thick (Table XI). In the Malumbang series, lying farther from the axis in the eastern flank of the fold, the angle of dip decreases regularly to about 30°.

The more highly inclined strata east of the anticlinal axis are exposed in apparently greater thickness than is evident in the western limb, and the lower part of the Canguinsa sandstone in the eastern limb is brought into close association with the Malumbang series in the opposite limb. The relations suggest faulting along the strike of the beds in the crest of the anticline with an upward thrust of the eastern limb, but in the absence of precise measurements actual movement along the suspected fault plane cannot be established.

A commonly stated law applying to asymmetric anticlines is that the active thrust came from the side of gentler slope, that is, in the case under discussion, from the west. If the force came from the west, the eastern limb could scarcely have been thrust up over the western. Since the evidence of the overthrust of the eastern limb is not conclusive, and the law as to the direction of the active forces—while not of universal application—is assumed to hold true generally, the occurrence of actual displacement along a fault plane in this fold must be questioned.

At Bahay the relations are similar to those in the region just described. Bahay River, flowing north, and Milipilijuan Creek, flowing south, have cut out a deep valley along the axis of the flexure and parallel to the coast line. Between this valley and the coast is a ridge in which the strata from the Canguinsa sandstone to the Upper limestone are found dipping from 30° to 40° east-northeast. The top of the Vigo shale, exposed at several places along Bahay River and Milipilijuan Creek, is the lowest horizon reached by erosion. Most of the outcrops are in the eastern limb of the fold and dip 55° east-northeast.

West of Bahay River, which marks the axis of the flexure, the formations still dip to the eastward, but at very low angles. At the mouth of Apad Creek, which flows into Bahay River from the west, the Canguinsa sandstone dips slightly eastward. Farther up the creek, the Cudiapi sandstone appears above the Canguinsa and dips to the southeast from 15° to 30°. Several of the exposures of Vigo shale in Milipilijuan Creek dip to the westward, and it is probable that the Vigo shale forms a true anticline at Bahay with dips to the east-northeast and to the west-southwest away from the axis. The flexure in the upper, less easily folded, strata is anticlinal in character in that the strata are differently inclined on either side of its axis so as to form an arch, although the dips are all in a single general direction (eastward). In these beds there is only an abrupt increase in the eastward dip along a line which becomes the axis of an anticline farther south.

There is evidence of displacement at Bahay similar to that near Mount Maglihi. Acute folding with erosion along the crest might account for the observed relations, but an accompanying upward thrust of the eastern limb along a fault plane is indicated. The objection to the theory of an overthrust of the eastern limb at Mount Maglihi, discussed on page 345, applies with equal force to the conditions at Bahay.

Banaba monocline.—An extensive monocline, the general northeast dip of which is conspicuous in Mount Banaba, forms the southern portion of the peninsula. Based on rather meager evidence, a minor overturn in the region of Sili and Tala and a close fold near the southwestern coast are shown in the geologic section (Map I) as modifications of this structure.

The strike of the beds varies in different parts of the area. On Mount Banaba it is north 30° west, near Bondoc Head it is north 50° west, and in the western part of the monoclinal area it is north 15° west, parallel to the adjacent coast line. From Mount Banaba to Sili the average dip is probably 15°, and in the section between these places only the strata in the Malumbang and Canguinsa formations come to the surface. It it surprising, in view of the general northeast dip, that the upper part of the Vigo shale is not exposed in the deep valley of Amoguis River. The difference in elevation between the summit of Mount Banaba and the floor of the valley is great enough that the entire thickness of the strata above the Vigo shale should be included in the section exposed in the eastern wall of the valley, unless the upper formations are thicker here than they were found to be farther north.

On Sili Creek, a few hundred meters south of Sili, the Bacau stage of the Vigo shale is exposed, but only over a small area, and west of Sili the upper formations reappear and are found in the floor of the next valley to the westward, at an elevation as low as that of Sili Creek. This condition suggests that the general northeast dip of the strata is reversed to a westward dip for a short distance west of Sili. Faulting might produce the same effect, but there is no evidence of faulting in this vicinity. Neither were the suggested westward dips detected at Sili proper, but north of Sili, at Tala, dips to the west are found in the upper formations. On the basis of this evidence, a small anticline is shown along this line in the geologic section. It will be noted that this fold is approximately in the position which a southward continuation of the Central anticline would occupy.

West of Tumbaga River, the Vigo shale reappears, dipping 35° east-northeast, and the exposure extends southwest to the seacoast. The dip of the beds increases regularly toward the southwest, becoming almost vertical at the eastern base of the chain of hills along the western and southwestern coast. On top of Bondoc Head the Canguinsa sandstone and part of the Malumbang series occur, lying almost horizontal. West of Bondoc Head on the seacoast, the Vigo shale, dipping 30° to the northeast, is encountered again. In the summit of the ridge near the mouth of Bataniog Creek are sandstone and sandy conglomerate, similar to the strata in the upper part of the Vigo shale near Matataha. These beds dip to the east at an angle of 70° and strike about north.

If the monoclinal structure persists to the southwestern coast, Bondoc Head should consist of steeply inclined beds of Vigo shale. Instead, the summit of this mountain is covered with younger formations. At the mouth of Bataniog Creek, again, are the sandstones and conglomerates which are found usually at the top of the Vigo shale. If there is no reversal in the general monocline, these beds are out of their usual stratigraphic position, and the indicated thickness of the Vigo shale is at least 3,600 meters. Both these conditions seem improbable, and a close fold recumbent to the southwest, as shown in the geologic section, is a more reasonable interpretation of the data in hand. The relations may be complicated by faulting analogous to the suspected faulting in the Maglihi anticline.

GEOLOGIC HISTORY

The southern part of Bondoc Peninsula appears to have been the site of shallow water deposition during the larger part of Miocene time. Of the conditions prior to the Miocene, there is little evidence. Quartz-veined diorite and schist, both older than the Miocene, occur farther north on Bondoc Peninsula and probably continue into the region under discussion, lying beneath the sedimentary strata. That rocks of this character formed a part of the land mass from which the sedimentary beds in the oil field were derived is proved by the presence of rounded quartz, diorite, and schist fragments in the sandstone and conglomerate members of the series.

The fact that the highest beds are folded in fair accord with those at the base of the stratigraphic column indicates that the major part of the folding occurred after the close of the Miocene and the completion of sedimentary processes in this region. From the steeper dip in the eastern limbs of most of the anticlinal folds, it might be inferred that the folding stresses were transmitted from the west. Not all the evidence obtained confirms this view, however, and without more data a conclusion is hardly justified.

The interbedding in thin layers of fine-grained shale, sandy shale, and sandstone shows that the Vigo shale formed in moderately shallow water. The thickness of the series and the regularity of the beds imply uniform conditions over the area throughout which they are distributed. Continued deposition of sediment in shallow water, until a succession of strata equal in thickness to the Vigo shale is built up, would appear to require an accompanying gradual subsidence of the sea floor. The less clearly defined bedding planes and the increased proportion of fine sediment in the Bacau stage, as compared with the lower part of the Vigo shale, suggest that deposition became more constant and regular and that the water became deeper before the beds in this stage were deposited; however, shallow water conditions must have prevailed at the close of the period when the sandstones and fine conglomerates were laid down. The Vigo shale may have emerged above sea level, entirely or in part, and have been subject to erosion before the succeeding beds were deposited. A period of volcanic activity in or adjacent to the region, at about this time, is attested by the presence of the volcanic agglomerate near the top of the Vigo shale.

The thick massive beds of fine sediment in the Canguinsa sandstone appear to have been formed as a continuous deposition in deep or quiet water. Parts of the formation, however, are coarse grained and were probably laid down in shallow seas similar to those which must have prevailed during the deposition of the Malumbang series. The growth of coral in the limestones in the Malumbang series indicates that the water was clear at times toward the end of sedimentation.

The Pleistocene and Recent deposits of volcanic tuff, which are extensive in the neighboring territory of southwestern Luzon, do not reach as far to the southeast as Bondoc Peninsula. Subsequent to the Pliocene, apparently, the mass of Bondoc Peninsula has been above sea level, and subject to erosion which has been very extensive and has removed great thicknesses of strata.

OCCURRENCE OF THE PETROLEUM

The petroleum on Bondoc Peninsula appears as seepage from the floors or sides of streams. At some places the oil rises spontaneously and floats away on the surface of the water. More commonly it appears only after the prospector has disturbed the rocks at the bottom of the stream. Digging in the shale of the Bacau stage where it has been freshly exposed by stream erosion generally yields small quantities of petroleum. The oil is invariably accompanied by inflammable gas, and in a number of instances inflammable gas is encountered in the absence of oil. At none of the seeps is there evidence of a large flow of oil at the surface. To collect as much as a liter of oil from any of the seeps involves a considerable amount of work in turning over the rocks and stirring up the mud in the streams along which the oil is found. The petroleum contains a large proportion of volatile constituents, and all trace of oil is lost soon after it appears on the surface. There is no discoloration of the ground around the seeps, but a scum gathers on the water and on stones or sticks in the water for a short distance downstream from an oil seep. The proximity of a seep is usually manifested first by the odor of kerosene which is evolved rather than by visible evidence of the petroleum.

In all cases where oil has been found, it occurs in or near the Bacau stage of the Vigo shale, more or less closely below the Canguinsa sandstone in the stratigraphic column. The seep on Malipa Creek, near Cabongahan, is at the lowest horizon in the Vigo shale at which oil has been encountered. Here Vigo shale some 250 meters thick intervenes between the oil seep and the base of the Canguinsa sandstone. In the lowest exposed portions of the Vigo shale but little oil is to be observed.

The oil is associated with the shale, rather than with the sandstone, where sandy layers are interbedded, and in several cases it comes directly from the shale. The absence of oil in the interbedded sandstone at the outcrop may be due in part to the rapidity with which it volatilizes and thus escapes from porous media.

Petroleum seeps were encountered at Banco, at Bahay, and on Milipilijuan Creek along the Maglihi anticline; on Sili Creek, a branch of Pagsanhan River; at Bacau on the Central anticline; on Malipa and Tangob Creeks in the vicinity of Cabongahan; at Bato, north of Cabongahan; and on Ajus River in the northeastern part of the field. Traces of oil and inflammable gas were detected at several other places, including the outcrops of Vigo shale dipping steeply south-southwest on the upper part of Sobo Creek, south of Mulanay.

PETROLEUM AT BANCO

Petroleum is found at Banco near the head of Canibo Creek which flows to the south from the small valley in the crest of the Maglihi anticline. The seep is at an elevation of about 200 meters. A strong odor of kerosene reveals the presence of the oil, which on closer inspection may be seen to rise in globules from the bottom of the small stream and to float away in films on the surface of the water. The seepage is accelerated by probing in the rocks and débris in the bed of the stream, and a small quantity of petroleum can be collected by skimming the globules and films from the water. The underlying rocks are concealed at the immediate point of escape, but 20 meters downstream bedded petroliferous shale and sandstone, belonging to the Bacau stage of the Vigo shale, are exposed. . These beds dip to the west at an angle of 45°, so that the seep is in the western limb of the anticline. The wall of the valley rises steeply on the west to an elevation of more than 300 meters, and is made up of the rocks of the Canguinsa sandstone and Malumbang series.

About 200 meters south of the main seep, oil may be detected in blue to black petroliferous shale on the floor of an arroyo in the western wall of the valley. Maalat Creek, an adjacent tributary of Canibo Creek, contains salt water, as the native name, "Maalat," implies.

PETROLEUM AT BAHAY

The strongest seep in the Bondoc field is, perhaps, that at Bahay, the drilling site of the Bahay Valley Oil Company on Bahay River. Bahay River is about 15 meters in width at this point, and the oil appears at numerous places over the whole surface of the stream throughout a length of 50 meters. It comes up spontaneously, accompanied by bubbles of inflammable gas, and forms an extensive surface film. An unusual cloudiness in the water is commonly attributed to the presence of the oil. The river bed is covered by pebbles and small bowlders of limestone eroded from the Lower limestone which is exposed several hundred meters upstream, and the oil is trapped beneath the larger rocks and escapes to the surface after the temporary reservoirs which these afford are filled. The elevation of the seeps above sea level is about 50 meters.

The formation is concealed within the area covered by the seeps. Fossiliferous sandy clays, believed to represent the Canguinsa sandstone, were observed upstream—about 300 meters south of the seep. The structural relations of this outcrop could not be determined since no planes of stratification are discernible. North of the seeps—approximately 150 meters downstream—imperfectly bedded shale occurs, dipping to the east-northeast at an angle of 55°. This shale is sandy, blue to black in color, and contains carbonized impressions of leaves and broken plant stems. From the position and dip of this shale it appears that the seeps are probably in the eastern limb of the anticline and from the relations elsewhere it is evident that they are very close to the axis.

Two wells have been drilled near the seeps. The first well, Bahay 1, is located a few meters west of the river bank opposite the point where the seeps are most numerous. It was drilled by hand in 1906 under the direction of Mr. E. W. McDaniel, managing director for the Tayabas Mutual Oil Association. It is cased with 4-inch pipe, and reached a depth of 38.7 meters. A record of this well is not available, but the following data appeared in the Far Eastern Review:[17]

> The first oil sand occurred at a depth of 62 feet and continued through six feet to a depth of 68 feet. From this strata using the mud bailer as a pump, 46 gallons of crude oil of an excellent quality was secured in one day's work, * * *. Owing to the crumbling nature of the formation above

[17] *Loc. cit.*

and below, this oil bearing strata was cased out and the well continued to its present depth of 127 feet and the casing extended down to 103 feet. The second oil strata was found at a depth of 117 feet extending downward 5 feet or to a depth of 122 feet. The yield of oil at this depth was practically the same as that of the first strata, but a satisfactory pumping test could not be carried out with the mud bailer, there being no other appliance at hand.

It is believed that the strata, "the crumbling nature" of which made it necessary to case out the oil from the upper horizon, were principally shale, and probably represent the Bacau stage of the Vigo shale. Mr. McDaniel has stated in conversation that both the zones from which oil was obtained are sandy. Probably the shale above and below the "oil sands" was petroliferous throughout. Occasional sandy beds have been noted in the petroliferous shale, and it would be expected that where the conditions were such as to prevent its escape more oil would accumulate in the sandy beds than in the closer-grained shale.

If the wells are east of the anticlinal axis, as the relations indicate, the strata encountered probably dip at an angle of about 55°. Well 1, consequently, pierces beds aggregating only 22 meters in thickness, and the upper and lower sandy zones are 0.87 meter and 1.04 meters thick, respectively.

In February, 1913, the well was pumped dry with the bailer. About 30 liters of oil were obtained from the column of water and oil which filled the casing to within 21 meters of the surface. The well proved to be 35 meters deep, the original casing having been driven to that depth recently. Apparently, the well is caved above the lower oil horizon reported, while the upper horizon is sealed off by the casing. It is probable that by proper treatment this well could be made to yield daily a barrel or so of oil.

Bahay well 2 is located 50 meters north of well 1 on the west bank of Bahay River. If the assumed structural relations are correct, well 2 is about 25 meters farther east of the anticlinal axis than well 1. Well 2 was drilled with a standard rig by Mr. O. A. Leary, and reached a depth of 91.5 meters. The casing at the collar of the well is 10 inches in diameter. Mr. Leary has kindly furnished the following statement which constitutes the only information available concerning this well:

Log of Bahay oil well 2.

0 to 25 feet.

Conglomerate, yellow sand, clay and gravel with large bowlders.

25 to 100 feet.

Brown shale showing evidences of oil and gas.

100 to 105 feet.
Coarse gravel with considerable quantity of oil and gas, and at this depth pipe was roughly packed and one-half-inch connection inserted. The gas was ignited and allowed to burn for fourteen hours without showing any decrease in volume, the blaze being approximately 10 feet in length.

105 to 115 feet.
Very hard gray rock; experienced considerable difficulty in drilling, owing to hardness.

115 to 170 feet.
Blue clay, showing streaks of clay lighter in color.

170 to 225 feet.
Brown shale heavily saturated with oil.

225 to 300 feet.
Brown shale very compact and of an elastic sticky nature. Drilling very difficult owing to this feature.

Very little water was encountered during the entire drilling of this well. At 20 feet a slight showing of fresh water; at 100 to 105 feet the presence of a small quantity of salt water was noticed. The well was practically free from water. Temperature of formation, normal.

Below the surface débris, which extends to a depth of 25 feet (7.6 meters), this well appears to have entered the Bacau stage of the Vigo shale and to have continued in this formation throughout. However, it may be that the "coarse gravel" and "hard gray rock" encountered in the well represent the conglomerate or gravel and the limestone exposed in Bahay River section (Table X, page 320) above the Vigo shale. The "evidence of oil and gas" in the "brown shale" above the "coarse gravel" is not in accord with this possibility, however, since the gray clayey sandstone exposed in Bahay River section above the conglomerate certainly shows no trace of oil or gas.

If the eastward dip of 55° in the shale north of the wells prevails at the site of well 2, the total thickness of strata pierced is 52.2 meters, the "coarse gravel" is 0.9 meter thick, and the "hard gray rock" is 1.9 meters thick.

PETROLEUM ON MILIPILIJUAN CREEK

Near the head of Milipilijuan Creek, which flows into Bahay River from the north, oil is encountered seeping directly from bluish to brownish black shale. The seep is at an elevation of 85 meters, and is approximately 1,500 meters north-northwest of the junction of Milipilijuan Creek and Bahay River. The shale from which the oil escapes dips northeast at an angle of 53° and contains some interbedded sandstone. Downstream a short distance, similar shale outcrops at several places, striking northwest and dipping steeply both to the northeast and southwest. Farther downstream the Canguinsa sandstone—massive and clayey—appears on top of the bedded shale. The oil comes, therefore, from the usual petroliferous horizon in the Vigo shale, immediately beneath the Canguinsa sandstone. The seepage is sufficient to permit of the collection of a liter of oil without much difficulty.

PETROLEUM ON SILI CREEK

A large exposure of petroliferous shale occurs on Sili Creek, about 2 kilometers south of Tala. The outcrop is at the confluence of two small streams which constitute the headwaters of Sili Creek, and is at an elevation of 100 meters. The shale, which probably represents the Bacau stage of the Vigo shale, is exposed in banks about 12 meters high along either side of both branches of the creek for a distance of 100 meters. Overlying the shale, the Canguinsa and Malumbang formations are exposed in the surrounding hills. The structure in this region is not clear, but it appears that the exposure lies near the crest of a small anticline, trending north. Faint bedding planes dipping to the east-northeast at angles of from 30° to 40° may be discerned in the shale. No actual seepage of petroleum was observed, but the streams which flow across the shale are small and afford little chance for detecting films or seepage. The odor of light oils is very strong in the neighborhood, and traces of oil can be obtained by macerating the shale in water.

Part of the shale outcrop at Sili is always barren of vegetation, a condition due, in part at least, to the instability of the surface which is constantly crumbling and sliding down into the streams. The natives attribute the absence of the generally present cogon to the petroleum in the shale. They maintain that the shale has been known "to burn." Two similar barren places occur in the vicinity of Bondoc Head. The latter places are held by the natives to mark the graves of *asuan* (spirits). The ground is said always to be hot and to have "burned with flames" in the past. The reports of prospectors who had heard this story from the natives, but probably had not visited the site of the alleged phenomena, undoubtedly gave rise to the widely circulated statement that a vent, from which natural gas escaped and was continuously burning, existed near Bondoc Head.

The "graves of the asuan" are on Lomboy Creek above a village called Dyap, in a region covered with cogon. Unlike the exposures on Sili Creek they are not steep slopes, but are on fairly level ground. Each has an area of several square meters which is barren of vegetation. The ground to a depth of a meter, at least, below the surface is unusually warm and feels hot to the hands. The temperature is not so high at the surface as it is at a depth of 30 centimeters, where the ground has a moldy, charred appearance and emits a rancid odor.

The sandy strata on which these bare spots occur are decidedly carbonaceous, and the surface is covered with decaying vegetable matter. It appears that a slow oxidation of the carbonaceous material in the sandy beds and of plant remains on the surface is in progress locally in this vicinity. The combustion may have been started originally by the fires which burn off the surrounding grass periodically. While the sandstone and shale near Bondoc Head are strongly carbonaceous, they show little evidence of oil or gas.

PETROLEUM AT BACAU

Petroleum at Bacau appears as films or small globules on the surface of a pool in Canguinsa River at the foot of a steep bank of massive, blue-black shale. The oil comes up intermittently from several places at the bottom of the pool, in quantity about equal to that encountered at Banco. The seeps are at an elevation of about 100 meters. The shale in the adjacent bank is petroliferous, and when fresh pieces are raked down into the stream they give off a film of oil. The strata dip to the east at angles of from 50° to 60°, and apparently lie in the eastern limb near the axis of the Central anticline. The Canguinsa sandstone occurs in the walls of the valley on either side immediately above the petroliferous shale, which is the type exposure of the Bacau stage of the Vigo shale.

PETROLEUM ON MALIPA CREEK

Inflammable gas bubbles up continuously from the bottom of Malipa Creek about 800 meters above the confluence of this stream and Vigo River. Small films of oil are observed occasionally on the surface of the water in the vicinity. The gas seeps from the Vigo shale in the south limb of the Malipa anticline. A thickness of approximately 550 meters of shale is indicated by the outcrops between the horizon from which the gas comes and the axis of the anticline, while 250 meters of shale lie stratigraphically above the seep and below the Canguinsa sandstone.

A sample of the gas collected and analyzed by the Bureau of Science showed the following composition.

TABLE XIV.—*Composition of the gas from a gas seep on Malipa Creek.*

Constituent.	Per cent by volume.
Hydrogen	0.7
Methane	62.3
Ethane	0.3
Carbon dioxide	2.3
Nitrogen	25.5
Oxygen	7.2
Carbon monoxide	2.0

It will be noted that the gas contains an unusually large percentage of oxygen. Some of the oxygen may be due to contamination of the sample by air, although care was exercised to prevent contamination. Not all the oxygen can be due to the admixture of air, however, because the gas does not contain the corresponding proportion of nitrogen. It is probable, therefore, that the oxygen is an original constituent of the gas.

Mr. E. J. Cooke, in 1906, drilled a well on the west bank of Malipa Creek about 50 meters upstream from the gas vent. This well is said to have reached a depth of 21 meters and to have encountered a small quantity of oil. The top of the well is at an elevation of 20 meters.

PETROLEUM ON TANGOB CREEK

Inflammable gas and traces of petroleum can be obtained on the upper part of Tangob Creek by moving the stones and débris which cover the Vigo shale in the bed of the creek. In this vicinity Tangob Creek flows between Cambagaco Ridge on the east and a hill of volcanic agglomerate on the west. The outcrop of agglomerate is surrounded by Vigo shale, and the gas and oil are encountered within a few meters of the igneous rock. In the base of Cambagaco Ridge, Canguinsa sandstone occurs, overlying the shale and dipping to the east-northeast at an angle of about 20°. The lower part of the Canguinsa is rich in fossils where Tangob Creek flows across it. The shale at the point where the oil was observed is blue to black, and occurs in thin beds dipping east-northeast at an angle of 65°. The dip and strike of the shale are not constant, however, but vary greatly in this region. The petroleum seep is about in line with the axis of the Bato anticline, but the strata in which it occurs are part of the confused structure in the eastern limb of the Central anticline north of the Cabongahan.

PETROLEUM AT BATO

Petroleum has been found on the little creek just east of Bato in the shale forming the western limb of the acute fold described as the Bato anticline. This locality is about 120 meters above sea level. There is no visible seepage, but petroleum may be obtained by digging into the banks of petroliferous shale along the stream. The strata belong to the Bacau stage of the Vigo shale.

PETROLEUM ON AJUS RIVER

At a point on Ajus River above the village of Ajus and about 4 kilometers from the mouth of the river, bubbles of inflammable gas and traces of petroleum appear on the surface of the water after a pole has been forced into the mud on the bottom. The oil occurs in the Vigo shale which dips steeply to the east and appears to be part of an overturned fold. The shale is bedded and petroliferous; layers of sandstone are interbedded in it, one of which, outcropping near the oil seep, is also slightly petroliferous. The elevation at the oil seep is about 45 meters.

PHYSICAL AND CHEMICAL PROPERTIES OF THE PETROLEUM

The petroleum encountered in the Tayabas field has a paraffin base, is low in specific gravity (36° to 39° Baume), and unusually mobile. It is light brown to wine-red by transmitted light, pale blue by reflected light. Different seeps afford petroleums which appear to be similar in character, although anaylses are available on the oil from only one source; namely, Bahay well 1 on Bahay River. Distillation yields a remarkably high proportion of gasoline, and the crude oil has an odor distinctly suggestive of light oils. George F. Richmond,[18] formerly of the Bureau of Science, made the earliest analyses of Tayabas petroleum, and later analyses have only confirmed his results. Richmond first tested a sample submitted by a commercial firm; and later, because the percentage of light distillates was so high as to arouse a suspicion that the sample was not authentic, he verified his findings upon samples collected at the well by Dr. George I. Adams, formerly of the Bureau of Science. Samples taken from the same well during the field work for this report were examined in the division of organic chemistry, Bureau of Science. The following table gives Richmond's analyses and other analyses of Tayabas petroleum made upon samples collected recently. For comparison, analyses of petroleums from neighboring islands and of well-known petroleums from other parts of the world are inserted.

[18] *Loc. cit.*

TABLE XV.—*Physical and chemical properties of petroleum from Bondoc Peninsula, Tayabas, from neighboring islands, and from important fields elsewhere.*

Description of petroleum.	References.	Crude oil.		Distillation products.							Remarks.
		Color by transmitted light.	Specific gravity.	Gasoline, to 150° C.		Kerosene, 150–300° C.		Heavy oils, 300–400° C.		Residue above 400° C.	
				Volume.	Specific gravity.	Volume.	Specific gravity.	Volume.	Specific gravity.		
Tayabas, Bahay well 1, depth 40 meters:				*Per cent.*		*Per cent.*		*Per cent.*		*Per cent.*	
1. Sampled by Castle Bros.-Wolf & Sons, Manila.	1	Brown to wine red.	0.826	39.0	0.756	47.1	0.832	13.9	----------	2.0	Specific gravity at 15° C.
2. Sampled by division of mines, well not recently pumped.	1	----do ----------	.845	27.0	----------	56.8	----------	16.2	----------	----------	Do.
3.	2	----do ----------	[a].8323	30.4	[b].7692	50.9	[c].8333	15.1	[b].9061	3.6	Sulphur absent. Viscosity 61.5 seconds at 32° C. (Engler apparatus.)
4. Sampled by division of mines 24 hours after well had been drained.	1	----do ----------	.8325	39.0	.770	44.5	.850	16.5	----------	----------	Flash point 0° C. (32° F.). Sulphur absent. Initial boiling point, 91° C. Paraffin, 8.1 per cent. Specific gravity at 15° C.
Cebu, Philippines:											
1. Well at Toledo, Cebu.	3	Dark brown------	.885	6.2	.762	42.32	.832	38.3	.901	13.17	Residue above 375° C. Specific gravity at 15° C.
2. Oil seep at Alegria, Cebu.	4	----do ----------	----------	17.5	----------	30.5	----------	35.0	----------	----------	Residue contained foreign sediment.
3. ----------------------	5	----do ----------	.842	13.5	----------	37.5	----------	31.5	----------	2.9	Residue, coke.

4.	5	do	.809								
5.	5	do	.838	12.6		34.5		46.8			Flash point 12° C. (54° F.).
6.	5	do	.819	18.4		29.6		47.2		3.1	Flash point 27° C. (80° F.). Residue, coke.
Leyte, Philippines	5		.926								Flash point 74° C. (166° F.).
Sumatra:											
1.	5	Reddish brown	.833	19.7		46.9		31.1		.8	Residue, coke.
2.	5	do	.813	30.4		51.7		11.2		1.7	Do.
Java	5	Dark brown	.844	1.5		56.6		41.1		1.4	Do.
Borneo:											
Sarawak	5	do	.924					94.3		3.3	Do.
Kutei	5	do	.859	17.4		46.0		33.3		1.3	Do.
Japan: Echigo	6		.862	21.8		38.8		39.9			Paraffin. Mabery.
United States:											
California (Coalinga)	7		.9243	2.8	.7677	40.1	.867	38.1	.921	10.1	
Oklahoma (Glenn Pool)	8	Black	.8459	8.5	.7566	42.0	.8001	49.9	.9032		6.98 per cent paraffin.
Pennsylvania, Bradford.	5		.810	20.0		50.0		23.3		1.12	Residue, coke.
Russia: Grosny	6		.869	13.4	.730	25.6	.809	60.9			
Roumania: Campina	6		.824	37.7	.729	30.5	.823	31.8			Edeleanau.

[a] At 29° C. [b] At 30° C. [c] At 28° C.

1. C. F. Richmond, *loc cit.*
2. Division of organic chemistry, Bureau of Science, E. R. Dovey, analyst.
3. Division of organic chemistry, Bureau of Science, H. C. Brill, analyst.
4. Division of organic chemistry, Bureau of Science, D. S. Pratt, analyst.
5. Sir Boverton Redwood, Petroleum and its Products (1906), 7 2d ed., 216.
6. A. Beeby Thompson, Petroleum Mining (1910), 189.
7. T. C. Allen, Bulletin 398 U. S. G. S. (1910), 264.
8. David T. Day, *loc cit.*

A number of other samples said to represent Tayabas petroleum have been submitted to the Bureau of Science. One sample with the characteristic appearance of the Tayabas product, collected by Mr. E. J. Cooke, shows a specific gravity as low as 0.805. This sample probably came from the well on Malipa Creek.

Tayabas petroleum is of lower specific gravity than other known Philippine oils, and the fraction distilled below 150° C. is large enough to make the petroleum remarkable, although by no means unprecedented among natural products. By composition, Tayabas petroleum is more nearly related to some of the Sumatra oils than to those encountered in Cebu or Borneo. The lighter and most valuable grade of Japanese petroleum, that which is encountered in the lower productive horizons, is similar in character to Tayabas petroleum.

In studying sample 4, from Bahay well 1, Richmond found that 30 per cent of the crude oil, 16 per cent of the gasoline fraction, and 24 per cent of the kerosene fraction consisted of unsaturated hydrocarbons. Upon fractional distillation, the unsaturated hydrocarbons extracted from the crude oil began to boil at 130° C., and 7.5 per cent remained undistilled at a temperature of 300° C. The derivatives from the fractions showed a homologous series of aromatic hydrocarbons beginning with xylene (C_8H_{10}). Benzene, tuolene, nor any of the naphthalene series were found in them.

Mr. E. R. Dovey of the Bureau of Science examined sample 3 for optical activity. His results appear in Table XVI.

TABLE XVI.—*Optical properties of Tayabas petroleum. Sample No. 3.*

	Specific gravity at 29° C.	Refractive index at 29° C.	Optical rotation 29° C. (200-millimeter).
			Degrees.
Crude petroleum	0.8323	1.4639	....
Gasoline fraction	.7692	1.4263	−0.55
Kerosene fraction	.8333	1.4670	−.11

ORIGIN AND PROBABLE QUANTITY OF THE PETROLEUM

Before discussing the particular features of this field having to do with the question of the origin of petroleum a few words should be devoted to the subject in general.

At present there are two sharply divided schools, in one of which the majority of geologists are to be found maintaining that petroleum is of organic origin. In the other school are those who believe in the inorganic origin of petroleum, some of whom assert that there is a close relation between volcanic activity and the production of the natural hydrocarbons. It is only fair to admit, that the matter is by no means settled and that there is much which seems to support the inorganic theory.

The conditions of vulcanism under which petroleum is supposed to originate are still obscure, and it is impossible to say what kind of volcanic activity gives rise to petroleum. Coste,[19] the principal adherent of the volcanic theory, believes that the origin of oil is associated with solfataric emanations. If this be so, there are numerous localities in the Philippines where it might be advantageous to prospect. In the Tayabas field, however, where more oil is encountered than anywhere else in the Archipelago, the phenomena of vulcanism are least abundant and solfataric activity is unknown.

The observed facts bearing upon the question of the source of oil in this field are:

1. The formations are practically all sedimentary. Small isolated patches of volcanic agglomerate occur, but these are confined to the northeastern portion of the field and aside from the presence of this agglomerate there is no evidence of volcanic phenomena.

2. The known oil seeps are associated with bluish to brownish black shale and subordinate sandstone which occurs in the Bacau stage of the Vigo shale. Where traces of oil are found below the Bacau stage, they are always associated with beds of fine-grained compact shale. Material of this character occurs in other formations above the Vigo shale, but no petroleum has been observed in the upper formations.

3. In the petroliferous shale are numerous tests of *Globigerina* (Plate V) and some minute fragments of carbonaceous matter.

4. *Globigerina* has not been noted except in the Vigo shale. They were found most abundantly in the Bacau stage, but occur also at lower horizons.

5. None of the oil seeps in Tayabas appears to give off a large quantity of petroleum. However, all trace of the oil which is seen to be given off disappears in a remarkably short time, due probably to the light nature of the oil. Hence, it is possible that the quantity of oil which escapes from the seeps is larger than it appears to be.

6. Natural sections afford opportunity for the examination

[19] *Trans. Am. Inst. Min. Eng.* (1906), 35, 288.

of all the strata above the Vigo shale. The lower part of this formation and the beds which underlie it are not exposed anywhere within the field, and their character is unknown. There is a possibility also that some members of the Vigo shale above the Bacau stage are concealed by the overlap of the unconformable Canguinsa sandstone and, therefore, have escaped examination.

7. The petroleum is of low specific gravity, and contains a large proportion of light oils. It has been suggested that its properties are those of a clarified, or partly refined, oil. The lighter fractions are weakly levorotatory in their effect on polarized light.

Considering the field relations alone, the logical conclusion would be that the petroleum in Tayabas is of organic origin and is in no way connected with volcanic activity or other inorganic processes. By some authorities,[20] the property of rotating the plane of polarized light which Tayabas petroleum exhibits would be accepted as conclusive evidence of organic origin.

If a definite organic source is sought, the presence of *Globigerina* and vegetable remains in the Vigo shale at once attracts attention. Most of the oil observed occurs in the shale which contains organic matter of this nature, and it is well known that the decomposition, under certain conditions, of animal matter similar to the soft parts of *Globigerina* does give rise to petroleum.

The decomposition of organic matter, both *Globigerina* and vegetable remains, in the Bacau stage of the Vigo shale may have yielded the petroleum which is found in these beds. However, neither *Globigerina* nor the vegetable remains are especially abundant in the petroliferous beds, and it may be questioned whether the quantity of organic matter which was contained in the Bacau stage was adequate to have supplied a large quantity of petroleum, or even the quantity of petroleum which is to be observed.

Some of the properties of the Tayabas petroleum suggest that the oil may have migrated to its present position. Most oils obtained directly from the rocks in which it is certain that they have originated are high in specific gravity, and consist largely of heavy oils, with a very small gasoline content. On the other hand, oils which are believed to have migrated from a distant source, to the natural reservoirs in which they have accumulated, are of low specific gravity and are rich in volatile constituents.

[20] Engler, C., *Chem. Zentralbl.* (1908), 2, 376.

The refining or fractionation of petroleum by diffusion through porous media is well known, and the characteristic clarified or refined appearance of Tayabas oil might be so explained. It has been shown [21] experimentally that the diffusion of petroleum through porous media exercises also a selective function by which the unsaturated hydrocarbons are removed. The Tayabas petroleum has a moderately high content (30 per cent) of unsaturated hydrocarbons, the presence of which would seem to dispute the theory that the petroleum had been subjected to the refining effect of diffusion. However, a discussion of the origin of the petroleum in the oil fields of Kansas [22] quotes Dr. David T. Day in an expression of the belief that the Kansas petroleum shows the effects of diffusion, while according to the same authority [23] Kansas petroleums contain from 12 to 50 per cent of unsaturated hydrocarbons. Apparently, therefore, the presence of unsaturated hydrocarbons in the Tayabas oil is not incompatible with the theory that the oil has been refined by diffusion.

If the Tayabas petroleum has been refined by diffusion, the diffusion may have been either a lateral migration through the Bacau stage or a migration upward or downward from the neighboring strata. The formations exposed at the surface above the Bacau stage show no indication of oil. If the oil was ever present in these beds, the greater part of it must have escaped from their truncated edges along the anticlines. The Canguinsa sandstone is locally of such fine-grained and compact texture that it should retain traces of petroleum just as the shale in the Bacau stage does, if petroleum had originated in, or moved through, it. Apparently there is little chance that petroleum occurs in the formations above the Vigo shale.

It is possible that concealed members of the Vigo shale beneath the overlapping Canguinsa sandstone are petroliferous, and that petroleum from them migrates along the unconformity to the Bacau stage, which often appears at the surface immediately below the Canguinsa sandstone. If the petroleum were coming to the Bacau stage along the unconformity, it would be expected that the base of the Canguinsa sandstone would be most strongly petroliferous. This is not the case; usually, the petroleum appears in the beds of the Bacau stage and not along the unconformity. Moreover, in some places the Canguinsa sandstone

[21] Gilpin, J. E., and Cram, M. P., *Bull. U. S. Geol. Surv.* (1908), **365**.
[22] Univ. Geol. Surv. of Kansas (1908), **9**, 191.
[23] Day, David T., *Bull. U. S. Geol. Surv.* (1908), **381**, pt. 2, 22.

has been removed by erosion so as to expose sandstone belonging to the Vigo shale above the Bacau stage, and this sandstone generally has not been found to be petroliferous. Thus, while the overlap of the Canguinsa sandstone may conceal petroliferous horizons, there is little direct evidence that these concealed horizons supply the petroleum which appears in the Bacau stage of the Vigo shale.

Similarly, there is a chance that the unexposed basal portion of the Vigo shale or a separate underlying formation is the source of petroleum which has moved upward through cracks and joints in the intervening beds to the Bacau stage. However, a relatively great thickness of strata is exposed in the limbs of the Central anticline between the Bacau stage and the lowest beds of the Vigo which have been uncovered by erosion, and there is but little evidence of oil in these intervening strata. Fresh surfaces in the occasional fine-grained beds only show traces of oil. Petroleum passing upward to the Bacau stage from a reservoir in the hidden lower part of the Vigo might be expected to leave traces along the outcrops of its passage through the intermediate rocks. From the fact that the petroliferous shale in the Bacau stage loses all evidence of oil after a short period of exposure, it might be argued that the relatively coarse sandy shales and sandstones between the Bacau stage and the lowest exposed part of the Vigo shale would retain no oil at the surface. In the data at hand, however, there is little evidence that the petroleum in the Bacau stage came there by diffusion from the base of the Vigo shale or from an underlying formation.

It appears, therefore, that while other accumulations of petroleum may exist in the concealed members of the Vigo shale, the petroleum in the Bacau stage probably originated somewhere in that stage, although it may have migrated laterally through the beds to the points at which it is now found.

If exploration proves that no oil exists in this field, except that which is evident in the Bacau stage of the Vigo shale, the possible production of petroleum will be confined to the area over which the strata are intact below the Canguinsa sandstone. The oil content of the petroliferous shale in the Bacau stage is probably low. Distillation of a sample, taken from a surface outcrop and kept in a sealed package before testing, yielded less than 1 per cent of oil. Beneath the surface where there has been no chance for volatilization to take place the proportion of oil is probably greater, but must still be relatively small because of the close-grained nature of the shale.

However, the petroliferous shale and interbedded sandstones make up the larger part of at least 50 meters thickness in some places, and probably approach this aggregate thickness on an average. Even with the low petroleum content specified, these beds would store up a volume of oil which assumes commercial proportions. Distributed throughout the shale, the oil could hardly be recovered in any quantity by ordinary methods, but if the saturation is great enough to cause an accumulation in the interbedded sandstones commercial exploitation should be possible. If the lenses of sandstone in the Bacau stage which are not exposed at the surface and consequently have not been broken open by erosion are saturated, the usual absence of oil in the sandstones along the outcrops of the petroliferous beds must be attributed to the rapid volatilization of the light oil from the surface of the porous materials.

The pore space in the interbedded sandstones is an important factor in this connection. Much of the coarser grained sandstone is so poorly consolidated that the actual pore space in the beds as they occur cannot be determined. A sample of the harder fine-grained sandstones taken from the vicinity of the Ajus petroleum seep contains 11 per cent of pore space. Probably the coarser sandstones are more porous.

Earlier examinations of Bondoc Peninsula have led to the published statement by two independent observers that the surface showing of oil is as favorable as those in other fields which have become large producers after development. It may now be added that the oil is associated with certain zones in an extensive series of shale and sandstone, and that the geologic structure is locally suitable for the accumulation of whatever petroleum is present.

A definite estimate of the quantity of petroleum available in this field, based solely on the data recorded in this report, in advance of any exploration is not justified. It would be a simple matter to estimate the thickness and area of the sands in the Bacau stage which could be reached by the drill in structurally favorable regions and to calculate the quantity of petroleum contained in these sands on the basis of their porosity as stated above, but the figure so obtained would have little real significance. The present knowledge of the field, however, does afford a basis for the belief that properly located wells could be made to yield at least small individual productions from the Bacau stage of the Vigo shale. From the thinness of the sandstone beds and the alternation of sandstone and shale it may be concluded that the sandstone reservoirs are of small lateral extent and, consequently, that wells could be spaced closely without affecting each other. This being the case, the structurally favorable area over which the Bacau stage could be reached by drilling is large enough to make the total possible production of commercial importance. In addition to the possibilities of the Bacau stage there is the chance, which has been discussed, of obtaining oil at other horizons in the Vigo shale.

As evidence which bears somewhat on the question of obtaining petroleum on Bondoc Peninsula, it may be worth while to consider, briefly, the results of exploration for petroleum in other oriental fields. The general geology of the two important productive fields in the Orient, the Echigo field in Japan and the Moera Enim field in Sumatra, is similar to that of Bondoc Peninsula (compare Tables I, II, and III).

There are productive fields in Sarawak and in the eastern part of Borneo, but in British North Borneo the attempts to obtain petroleum have been unsuccessful. Although Borneo is adjacent to the Philippines, very little information is available concerning its economic geology and nothing is known of the geology of its petroleum resources.

In Formosa (Taiwan) which is also adjacent to the Philippines, only a small production, 6,200 barrels in 1908,[24] is recorded, although many shallow wells have been drilled. One of the few deep wells in the Byritsu Field on Formosa is said to yield a good flow of oil, and there is a possibility that with deeper drilling the Formosa petroleum fields will assume greater importance.

A well drilled in 1896 on Cebu Island in the Philippines, is said to have reached a depth of 300 meters; while it encountered considerable petroleum, it did not yield a satisfactory flow. The exploration was suspended before completion, because of the outbreak of an insurrection, and it has never been resumed. While the general geology of the two regions is similar, the local conditions at the site of the well in Cebu are different from those in Bondoc Peninsula. The drilling site at Toledo, Cebu, is located on the outcrop of the petroleum-bearing strata, and is within a few kilometers of the basal igneous complex upon the flank of which the beds lie, inclined at a high angle.

[24] Fukotome, K., Mineral Resources of Formosa (1910), 13. The Mineral Resources of the United States for 1911 reports 8,304 barrels of oil from Formosa in 1908 and 1,638 in 1911.

The foregoing brief statement includes practically all that is known concerning petroleum fields in the vicinity of the Philippine Archipelago.

AREAS TO BE PROSPECTED

Drilling on Bondoc Peninsula should be directed so as to answer three questions. It should determine (1) whether a sufficient quantity of oil is accumulated in the Bacau stage of the Vigo shale to afford a commercial production, (2) whether any members of the Vigo shale concealed by the overlap of the Canguinsa sandstone may be made to yield petroleum, and (3) whether there is petroleum in the unexposed base of the Vigo shale.

The same work should serve to determine points (1) and (2), since if wells are drilled through the Canguinsa sandstone to the Bacau stage of the Vigo shale on the limbs of the anticlines at varying distances from the axes, as is recommended later in this discussion, they will necessarily pass through any higher beds in the Vigo shale which may be covered unconformably by the Canguinsa sandstone.

If the Vigo shale is constant in the thickness which it displays in the Matataha River sections, it would not be feasible to explore both the Bacau stage and the basal portion of the Vigo shale with a single well, since the depth involved—even if the strata were horizontal—would approach 2,000 meters. It is possible that the Vigo shale is not of uniform thickness and that in some parts of the field a deep well might penetrate the entire series. Even so, however, wells from 400 to 600 meters in depth, located so as to pierce different horizons in the shale, would probably be less expensive and more suitable for initial exploration than a smaller number of very deep wells.

Without more data the anticlines in Bondoc Peninsula must be considered as the most favorable zones for exploration. The oil seeps are near the crests of anticlines generally and possibly in all cases. Experience in other oil fields has proved the theory of the accumulation of petroleum in anticlinal zones [25] to be of wide application. In the South Sumatra field and the Echigo field in Japan, which have been cited in comparison with the Bondoc field, production is reported to have come largely from the anticlines. In the former field only wells on the immediate crests of anticlines have been productive.

[25] For a discussion of this theory consult *Bull. U. S. Geol. Surv.* (1907), 322, 71 et seq.

In the local field a distinction must be made between those anticlines in which erosion has left the possible productive horizons intact across the arch and those in which erosion has proceeded along the crest until the oil-bearing strata have been cut through. Where the oil-bearing rocks are preserved across the anticline, oil—or gas—would be expected in the crest of the fold and wells should be located so as to explore the crest first. Where the productive beds are cut through along the crest and their edges exposed in the limbs of the anticline, the petroleum may be supposed to have escaped from outcrops along the axis and wells should be driven on the flanks of the fold in the hope of encountering a natural reservoir which does not appear at the surface and, consequently, has not been drained by seepage from its outcrop.

The anticlines in Bondoc Peninsula are generally asymetric; that is, one limb is steeper than the other. In drilling on an anticline of this character the limb with the lesser inclination affords better opportunity for exploration than the steeper limb. It is probably true, also, that the gentler limb of a sharp asymmetric anticline more generally has been found to be productive than the steeper limb.

The Maglihi anticline is probably the most suitable territory for the initial exploration of this field. The structure is favorable in that an anticlinal fold exists, although the anticline is more acute than would generally be considered desirable, and the petroleum-bearing strata are intact generally along its axis. The presence of petroleum in this anticline is established by the seeps at Banco, at Bahay, and on Milipilijuan Creek.

In the matter of the actual location of prospect wells, the factor of comparative accessibility will demand attention. The Maglihi anticline appears to be most favorable in structure near Mount Morabi. It would be desirable to have several test wells drilled through the crest and the western limb of the fold in this vicinity. The eastern limb should also be explored, but in it the strata dip very steeply, and the best location for the first wells would be difficult to determine exactly. The vicinity of Mount Morabi is relatively inaccessible as compared with Bahay farther north along the same flexure. The valley along the anticlinal crest near Mount Morabi is at least 250 meters above sea level, and the distance to the coast is about 6 kilometers.

At Bahay the anticline is not so clearly revealed as it is near Mount Morabi, and the structure may be less favorable, although the general conditions are similar. It would be feasible to prospect the eastern limb of the anticline through the Bacau stage of the Vigo shale by two or three wells located at varying distances from the axis in the valley of Bahay River below the mouth of Milipilijuan Creek. Wells in this position would also pass through any members of the Vigo shale which may be concealed by the overlap of the Canguinsa sandstone. Similarly, the crest and the western limb could be explored by a line of wells up the valley of Apad Creek.

This general site is from 40 to 50 meters above sea level and from 4 to 5 kilometers from the coast. An old roadway, which might be utilized, leads into the region from the beach at the mouth of Bahay River.

Exploration of the limbs of the Maglihi anticline in the immediate vicinity of the oil seep on Bahay River or that on Milipilijuan Creek would involve more difficult transportation problems. Moreover, while the earliest drilling in many oil fields has been done in the vicinity of actual seeps, very often the larger production has developed in areas where oil seeps are not prominent. In exploration on Bondoc Peninsula it would be unwise to ignore the presence and distribution of the oil seeps, but it would be equally unwise to drill only where oil is to be seen.

The Central anticline should be explored by series of wells across its axis and both limbs adjacent to the axis in the vicinity of Bacau and, also, farther north near Balinsog. The structure is favorable at these places, and the presence of oil is established by the seep at Bacau. On account of its larger size, the Central anticline may contain larger accumulations of petroleum than would be expected in the Maglihi anticline. Bacau and Balinsog are each about 9 kilometers from the coast, and the intervening country reaches an elevation of 300 meters making these regions very inaccessible.

The Central anticline in the northern part of the field will afford valuable drilling territory if petroleum is found in the Vigo shale below the Bacau stage. On the other hand, if only the Bacau stage proves to be productive, the northern part of the Central anticline from which the Bacau stage has been removed by erosion loses its importance. South of Bacau the southerly plunge of the Central anticline probably carries the petroleum horizons down beyond the reach of the drill. Prospecting in the southern part of the peninsula in line with the Central anticline would determine this point and might prove successful.

The possible locations which have been discussed are all near oil seeps and are on sharp anticlinal folds. The Ayoni anticline has no oil seep on its crest, and it is a broad gentle fold. The fact that no petroleum escapes from it may be taken as an unfavorable or a favorable indication, arguing either the absence of petroleum or that the petroleum has been confined by the unbroken strata, there having been no opportunity for it to reach the surface here, such as is afforded by the cracked and fissured axial portions of the sharper folds. A broad gentle anticline is generally looked upon with more favor as a natural reservoir for petroleum than an acute anticline. Judged by this standard, the Ayoni anticline would be considered promising. It is readily accessible, and there has been comparatively little erosion along its crest. Wells on its crest and eastern limb should pierce the upper part of the Vigo shale under favorable conditions.

On the other hand, there is an apparent transition in the character of the Vigo shale from east to west at this latitude by which shale grades into sandstone. It is possible that the shales which appear to be the principal oil-bearing rocks are less extensive in the vicinity of Ayoni than elsewhere. The absence of seepage, however, which might be taken to indicate such a change in the character of the formations, can be accounted for readily enough on other grounds as suggested above.

Wells should be drilled along Malipa Creek, in the southern limb of the Malipa anticline, and also, probably, farther south in the eastern limb of the Central anticline. The structure is not unfavorable, and traces of oil and gas are in evidence. A well near the axis of the Malipa anticline would reach the beds in the lower part of the Vigo shale, and from a site farther up the creek higher strata including the Bacau stage could be investigated. This region could be reached with comparative ease by coming up the valley of Vigo River from the coast.

The Bato anticline is not easily accessible, and the structural relations are not clearly enough defined to make it a favorable site for the first drilling, although it appears to be relatively good territory. The lower part of the western base of Cambagaco Ridge would be a favorable site for testing the beds in the Vigo shale beneath the overlap of the Canguinsa sandstone. Wells so located, if drilled deep enough, would also encounter the Bacau stage of the Vigo shale in fairly good structural relations.

To reach the base of the Vigo shale and determine the value of this zone in connection with petroleum, wells should start at the lowest possible stratigraphic horizon. The upper valley of Sibuyanin River in the western limb near the axis of the Central anticline is probably the best site for such wells. The beds at the surface here appear to be about 1,400 meters, stratigraphically, below the base of the Canguinsa sandstone, and the dip is about 35°. The eastern limb just across the axis in the upper valley of Vigo River is equally desirable as a drilling site except for the steeper dip (from 60° to 70°) of the strata.

If oil is obtained in any of these localities, a number of places which have not been mentioned may become desirable territory, depending on what horizon the oil is encountered in and on other conditions which will be revealed by the drilling. More detailed work in the vicinities of Ajus and Sili may show that there are favorable drilling sites at these places, and as has been suggested the neighborhood of the volcanic agglomerate may prove valuable as drilling territory.

It will be apparent that companies entering this field should be prepared to drill several wells in order to prospect any locality thoroughly. The failure of a single drilling should not be accepted as establishing the absence of exploitable petroleum resources in any particular zone or in any one anticline, and certainly should not condemn the whole field. The drilling of unsuccessful wells is common in producing fields, where the geology is well known and the experience gained from many completed wells is available. It would be surprising, indeed, if the early drilling on Bondoc Peninsula did not result in a large proportion of "dry" wells, even if exploration were ultimately successful.

Skilled and experienced drillers should be secured. It is anticipated that drilling on Bondoc Peninsula will be rendered difficult by the unconsolidated, caving nature of the shale series, and, possibly, by the necessity of sealing off water-bearing sands. Because of the fact that these difficulties have been overcome successfully in the California oil fields, drillers from these fields should have experience that would be particularly valuable in the local field.

The exact location of wells should be preceded by further and more detailed geologic study of the region to be tested. The relation of possible sites to the known and suspected petroliferous zones should be carefully determined, and local variations or irregularities in the general structural and geologic features, as outlined in this report, should be noted before a decision is reached as to the best drilling site. The progress of the first drilling likewise should receive particularly close attention from a geological standpoint since it may reveal conditions not manifest at the surface which would alter the course of exploratory work.

CONCLUSIONS

The existence of petroleum on Bondoc Peninsula is established by the presence of seeps of petroleum associated with inflammable gas at various places throughout the oil field.

All the petroleum encountered so far is similar in character and of a good quality. It is of low specific gravity, and contains a large proportion of light oils which would make it of relatively high value as a commercial petroleum.

The seeps are in highly inclined strata which are probably in all cases part of the structure of anticlinal folds. From this association it is believed that the petroleum in this field has tended to collect in the crests of anticlines in accordance with the general law of petroleum accumulation.

The petroleum occurs associated with certain horizons in an extensive series of beds of sandstone and shale (Vigo shale), which is similar in character to the oil-bearing rocks of productive fields. The principal seeps are found in the upper part of this series in a zone designated as the Bacau stage, which is predominantly shale, but contains subordinate beds of sandstone. In its seepage, the petroleum is associated with the shale rather than the sandstone and may be observed in some cases to come directly from the shale, but this association may be due to the ready escape of the light oil from the outcrops of the coarse-grained beds and its retention at the surface in the fine-grained shale only.

The petroleum may have originated, in part at least, in the globigerina and other organic remains found in the strata with which the oil is associated. There is a possibility, however, that the oil is not indigenous to the strata in which it now occurs, but has migrated from its source in another horizon. Beds which are concealed so that they cannot be examined at the surface and which, consequently, may be sources of oil occur as follows: (1) Members of the Vigo shale above the Bacau stage, concealed by the overlap of the Canguinsa sandstone which overlies the Vigo shale unconformably; (2) the basal portion of the Vigo shale which has not been uncovered by erosion; and (3) any sedimentary formations which may underlie the Vigo shale.

The structure of Bondoc Peninsula includes a number of anticlinal folds, and the conditions along some of these anticlines are considered favorable for the accumulation and retention of the petroleum, whether it occurs in all or in any one of the horizons at which it is suspected.

Drilling exploration is recommended and should be conducted along lines which have been indicated. Wells should be so located as to explore the Bacau stage of the Vigo shale thoroughly under favorable conditions of structure. The possible sources of petroleum outside the Bacau stage likewise warrant exploration. Areas considered favorable for prospecting by test wells have been outlined.

The quantity of petroleum which might be recovered commercially from this field is undetermined. Certain geologic features which have been pointed out lead to the belief that only wells of small individual productions will be obtained; but it is also probable that wells of this character could be closely spaced without mutual interference and that the territory within which they could be located is large. A sufficient number of these wells, drilled in groups so as to be operated from local centers, might reasonably be expected to yield an aggregate quantity of limited commercial proportions. There is a possibility, conditioned largely upon the presence of oil at a horizon other than the Bacau stage of the Vigo shale, of obtaining wells of larger individual flow and a greater total production of petroleum.

ILLUSTRATIONS

PLATE I

Fossils from raised coral reefs (Recent and Pleistocene). About one-half natural size. (Photographs by Martin.)

FIG. 1. *Conus flavidus* Lam.
FIGS. 2 and 3. *Voluta* sp.
FIG. 4. *Potamides* sp.
5. *Spondylus* sp.
6. *Telescopium telescopium* Linn.
7. *Natica* sp.
8. *Trochus fenestratus* Gmel.
FIG. 9. *Crista pectinata* Linn.
10. *Cerithium nodulosum* Brug.
11. *Circe pectinata* Linn.
12. *Cerithium jenkinsi* K. Mart. (?)
13. *Arca cecillei* Phil. (?)
14. *Strombus canarium* Linn.

PLATE II

Fossils from the Upper limestone and the Cudiapi sandstone of the Malumbang series (Pliocene and upper or middle Miocene). About one-half natural size. (Photographs by Martin.)

FIG. 1. *Pecten senatorius* Gmel.
2. *Cytherea* sp.
3. *Lagenum multiforme* K. Mart. var. *tayabum* var. nov.
4. *Spondylus imperialis* Chem.
5. *Schizaster subrhomboidalis* Herkl.
FIG. 6. *Cyclolites* sp.
7. Indet.
8. *Turbo* sp.
9. *Cardium* sp.
10. *Conus* sp.

PLATE III

Fossils from the Lower limestone of the Malumbang series (upper or middle Miocene). About one-half natural size. (Photographs by Martin.)

FIG. 1. Indet.
2. *Cypraea* sp.
3. Portion of internal cast of *Cerithium* sp.
FIG. 4. *Schizaster subrhomboidalis* Herkl.
5. *Pyrula gigas* K. Mart.
6. *Macoma* sp.

PLATE IV

Fossils from the Canguinsa sandstone (middle or lower Miocene) and from the Vigo shale (lower Miocene or Oligocene). About one-half natural size. (Photographs by Martin.)

FIG. 1. *Conus loroisii* Kien.
2. *Conus ornatissimus* K. Mart.
3. *Pyrula bucephala* Lam. (?)
4. *Tapes rimosa* Phil.
5. *Corbula socialis* K. Mart.
6. *Conus djarianensis* K. Mart.
FIG. 7. Indet.
8. *Hindsia* sp.
9. *Arca* sp.
10. *Cyclolites* sp.
11. *Strombus triangulatus* K. Mart. (?)

PLATE V

Globigerina (Rhizopoda) from the Vigo shale; a possible source of petroleum. (Drawings by Moskaira.)

FIGS. 1 to 3. Characteristic shapes assumed. Magnification, 20 to 25 diameters.
4 and 5. Details of the structure of the shell. Magnification fig. 4, 20 to 25 diameters; fig. 5, 140 diameters.

PLATE VI

FIG. 1. Bahay well 2 on the property of the Bahay Valley Oil Company, Bahay. (Photograph by Pratt.)

2. Looking eastward near the mouth of Cambagnaon Creek. The hills in the distance lie on the eastern flank of the Central anticline. (Photograph by Manila Mining Association.)

PLATE VII

(Photographs by Manila Mining Association)

FIG. 1. Looking west-northwestward across Vigo River near the eastern coast of the peninsula; the eastern slope of Mount Dagmit to the left, and in the distance beyond the river, a part of Cambagaco Ridge with characteristic slope to the eastward resulting from the eastward dip of the strata.

2. The eastern wall of the upper valley of Canguinsa River south of Balinsog Hill.

PLATE VIII

(Photographs by Manila Mining Association)

FIG. 1. Looking northward from near Balinsog Hill.

2. Looking westward from near Balinsog Hill, across the upper valley of Canguinsa River, which marks the crest of the Central anticline, to Cudiapi Range on the western limb of the Central anticline; South Cudiapi Mountain in the middle distance.

PLATE IX

(Photographs by Pratt)

FIG. 1. Looking east-northeastward across the valley of Malipa Creek toward the ridge along the eastern coast, Mount Cambagaco to the left, gap formed by Vigo River in center, and Mount Dagmit to the right.

2. South Cudiapi Mountain across the valley of Bondoc River; looking northeastward from a point 2 kilometers south of Bondoc.

3. Mount Cancalao in the valley of Matataha River; looking westward.

PLATE X

(Photographs by Pratt)

FIG. 1. Outcrop of Cudiapi sandstone in the eastern limb of the Central anticline; looking northwestward from near the head of Canguinsa River.

2. Outcrop of Canguinsa sandstone in the eastern limb of the Maglihi anticline on the lower part of Bahay River; looking southward.

3. Nearly vertical Vigo shale near the axis of the Central anticline on the lower part of Cambagnaon Creek; looking southward.

4. Outcrop of volcanic agglomerate near Dumalog Creek.

MAP

Geologic reconnaissance map of a part of Bondoc Peninsula with 5 geologic sections.

TEXT FIGURE

FIG. 1. Diagrammatic section in the upper valley of Malipa Creek.

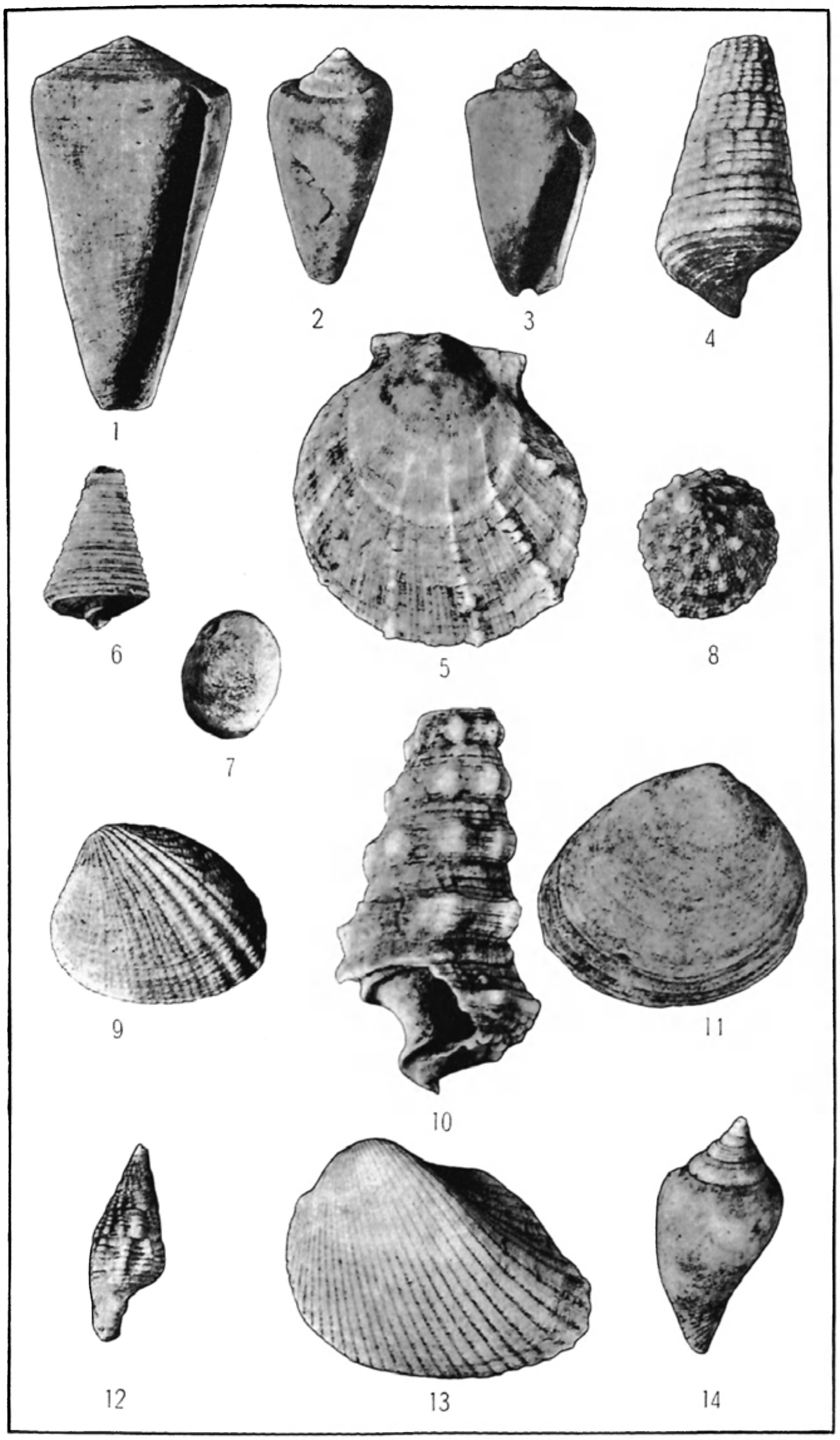

PLATE I.

Fossils from raised coral reefs (Recent and Pleistocene). Fig. 1. Conus flavidus Lam. 2, 3. Voluta sp. 4. Potamides sp. 5. Spondylus sp. 6. Telescopium telescopium Linn. 7. Natica sp. 8. Trochus fenestratus Gmel. 9. Crista pectinata Linn. 10. Cerithium nodulosum Brug. 11. Circe pectinata Linn. 12. Cerithium jenkinsi K. Mart. (?) 13. Arca cecillei Phil. (?) 14. Strombus canarium Linn. About one-half natural size.

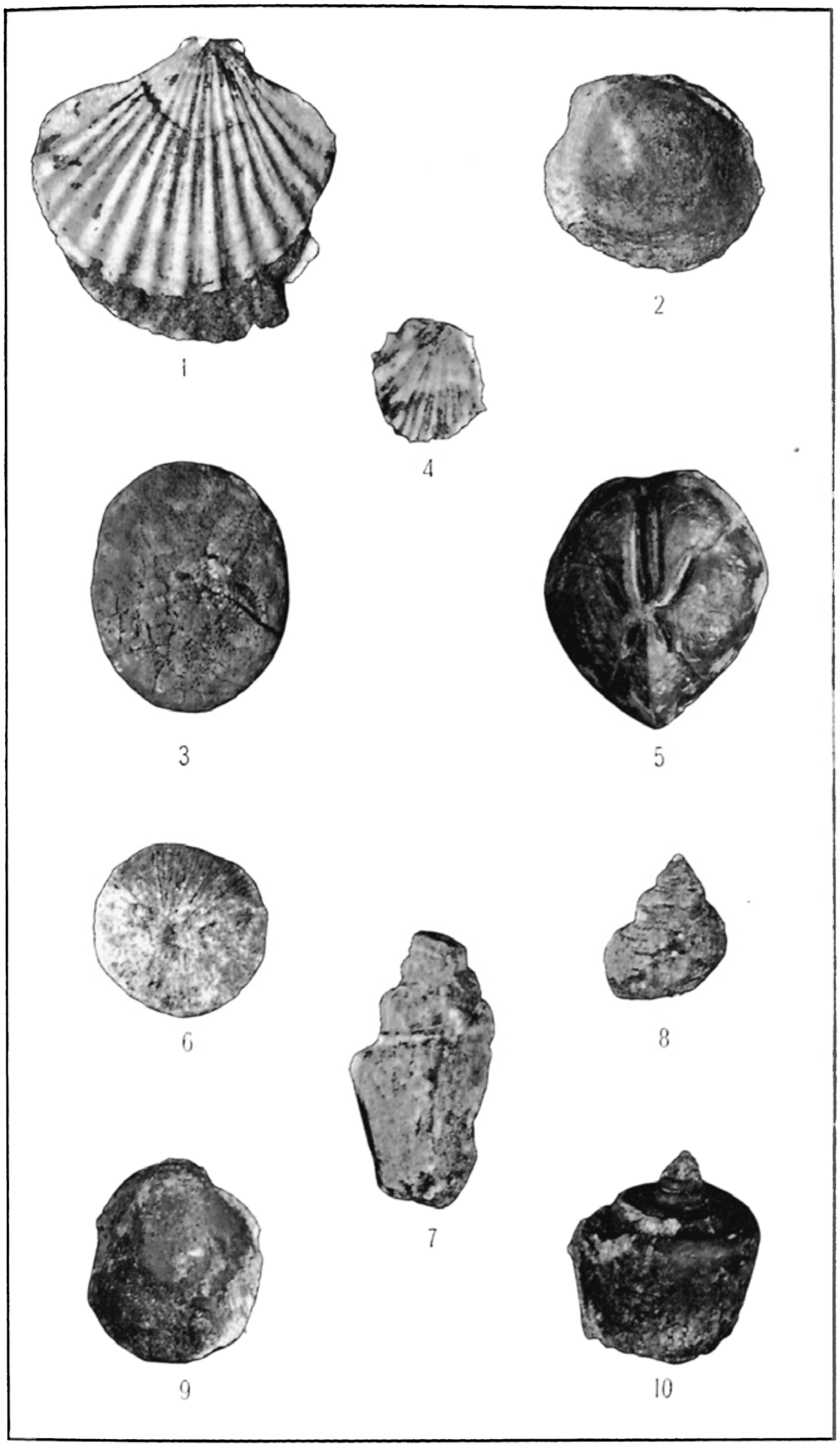

PLATE II.

Fossils from the Upper limestone and the Cudiapi sandstone of the Malumbang series (Pliocene and upper or middle Miocene). Fig. 1. Pecten senatorius Gmel. 2. Cytherea sp. 3. Lagenum multiforme K. Mart. var. tayabum var. nov. 4. Spondylus imperialis Chem. 5. Schizaster subrhomboidalis Herkl. 6. Cyclolites sp. 7. Indet. 8. Turbo sp. 9. Cardium sp. 10. Conus sp. About one-half natural size.

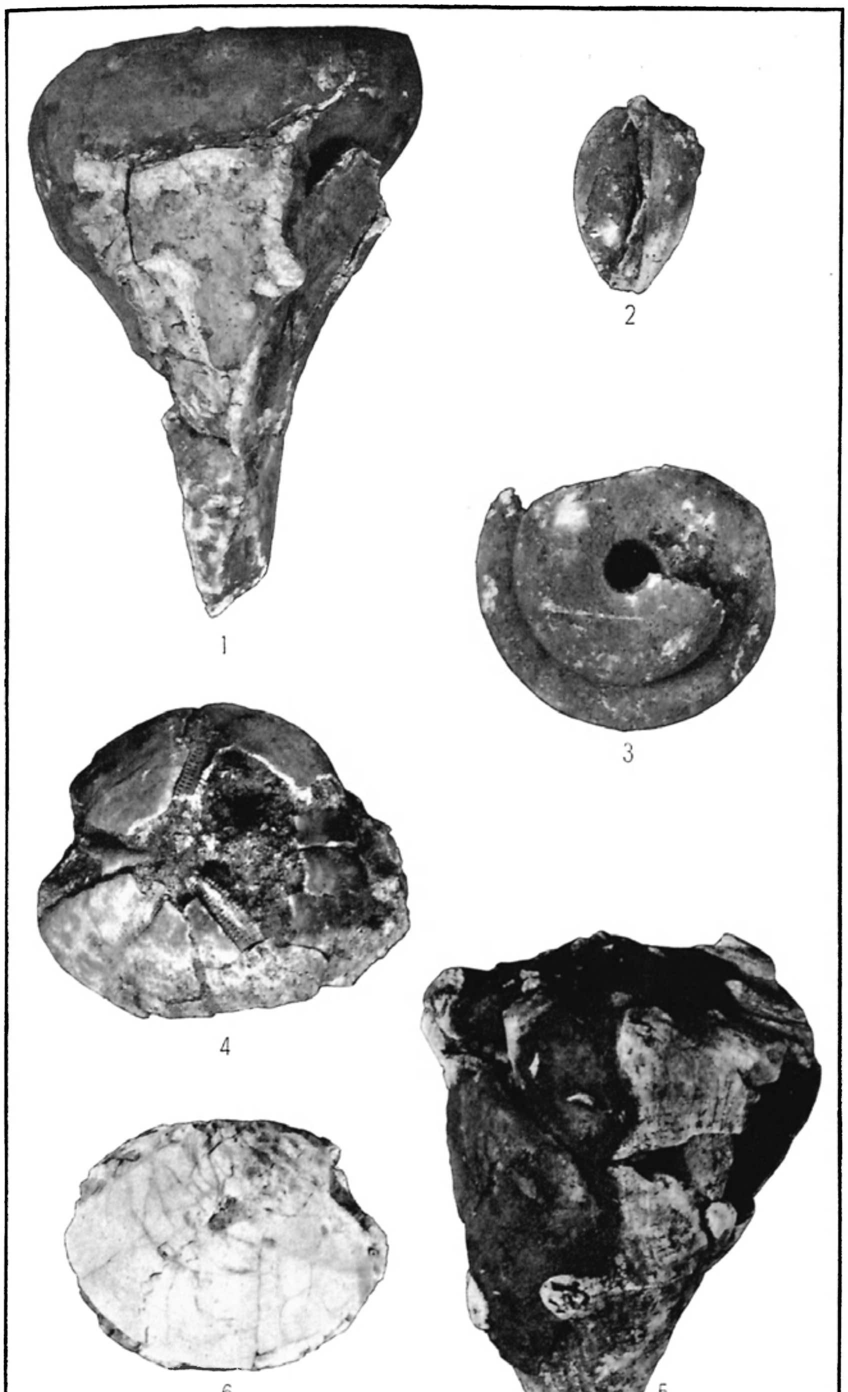

PLATE III.

Fossils from the Lower limestone of the Malumbang series (upper or middle Miocene). Fig. 1. Indet. 2. Cypraea sp. 3. Portion of internal cast of Cerithium sp. 4. Schizaster subrhomboidalis Herkl. 5. Pyrula gigas K. Mart. 6. Macoma sp. About one-half natural size.

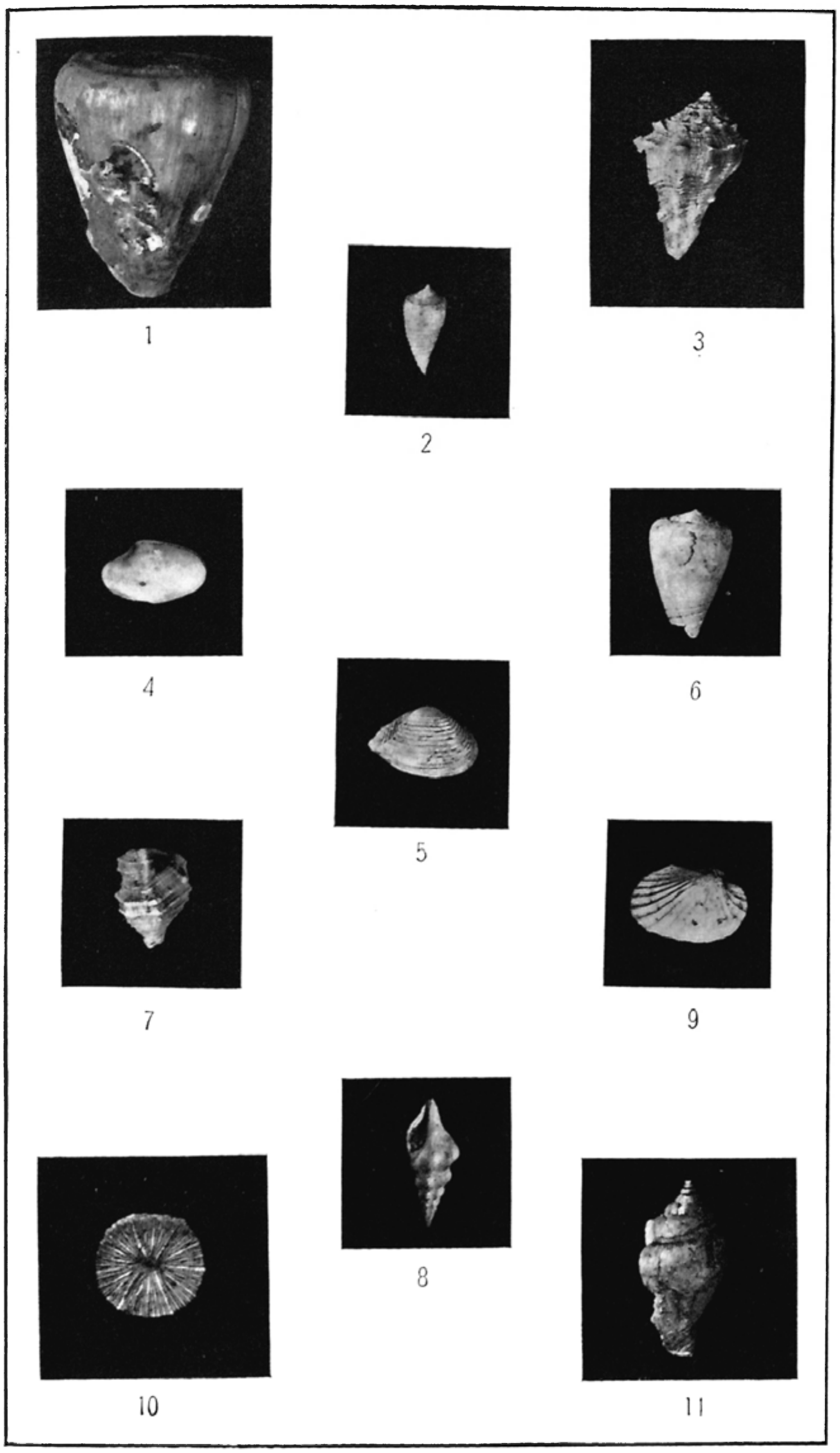

PLATE IV.

Fossils from the Canguinsa sandstone (middle or lower Miocene) and from the Vigo shale (lower Miocene or Oligocene). Fig. 1. Conus loroisii Kien. 2. Conus ornatissimus K. Mart. 3. Pyrula bucephala Lam. (?) 4. Tapes rimosa Phil. 5. Corbula socialis K. Mart. 6. Conus djarianensis K. Mart. 7. Indet. 8. Hindsia sp. 9. Arca sp. 10. Cyclolites sp. 11. Strombus triangulatus K. Mart. (?) About one-half natural size.

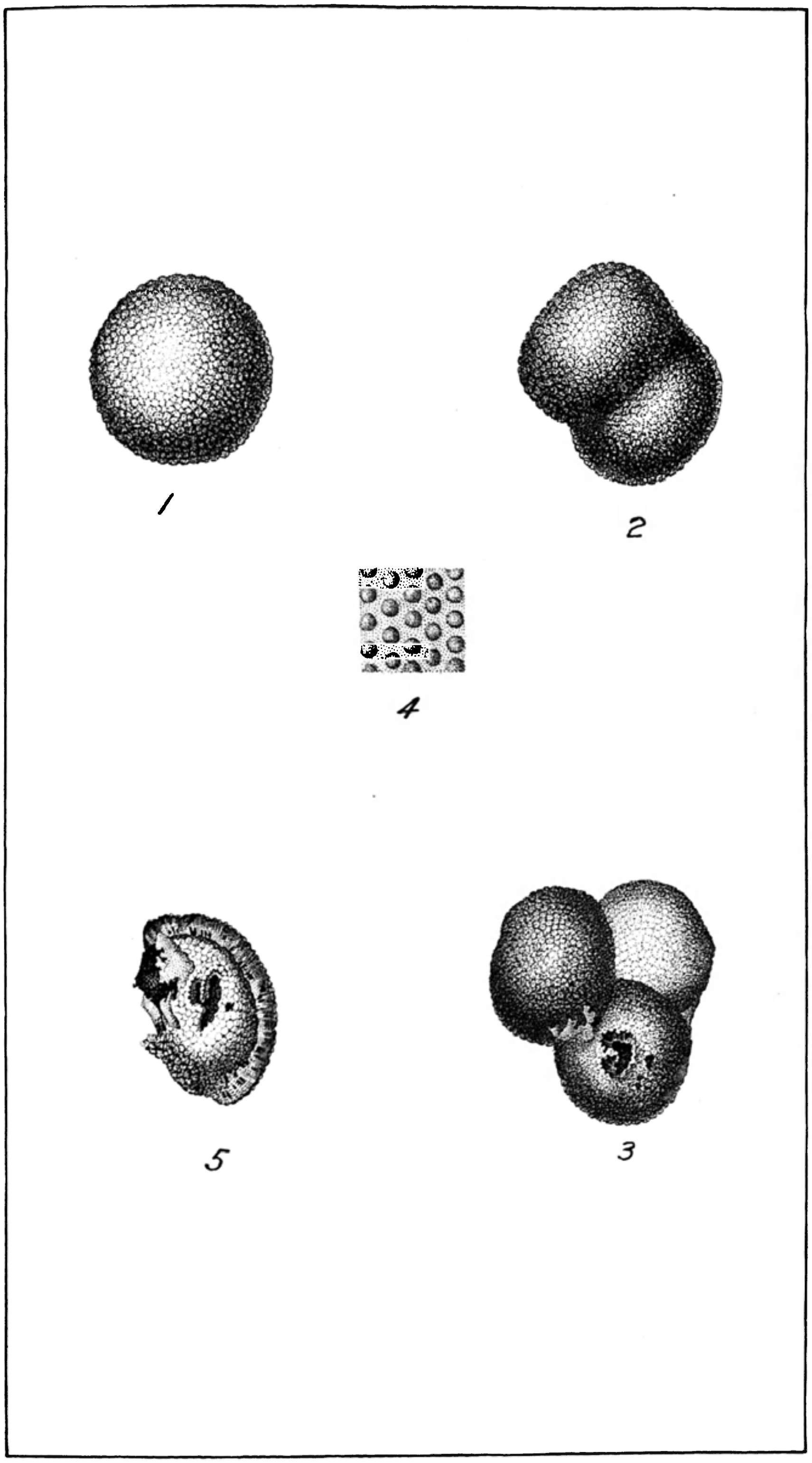

PLATE V.

Globigerina (Rhizopoda) from the Vigo shale; a possible source of petroleum. Figs. 1–3. Characteristic shapes assumed. 4, 5. Details of the structure of the shell.

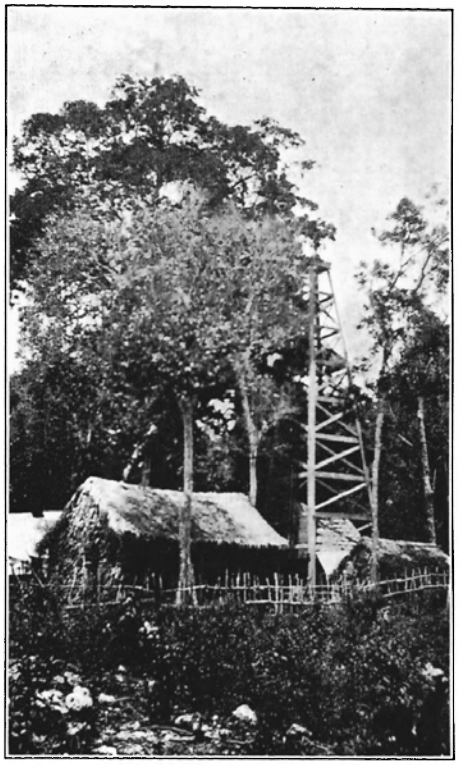

Fig. 1. Bahay well 2.

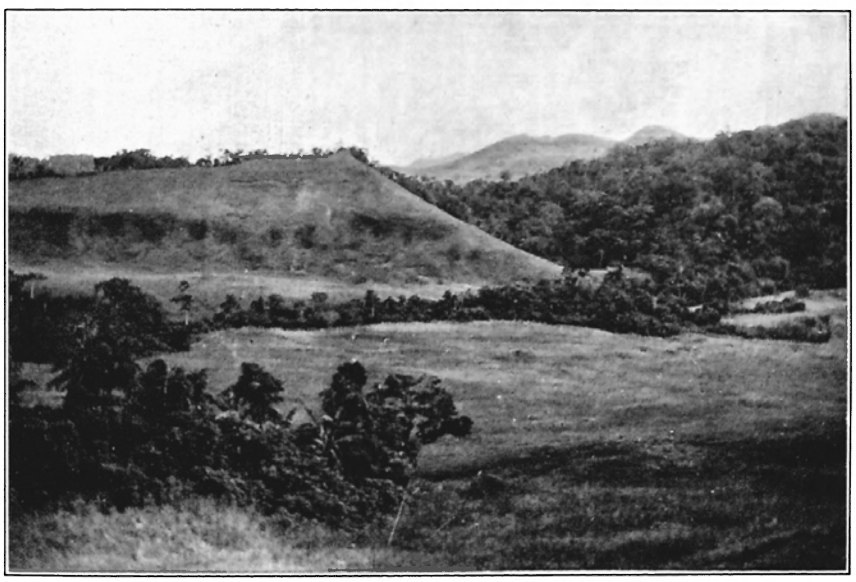

Fig. 2. Looking eastward near the mouth of Cambagnaon Creek.

PLATE VI.

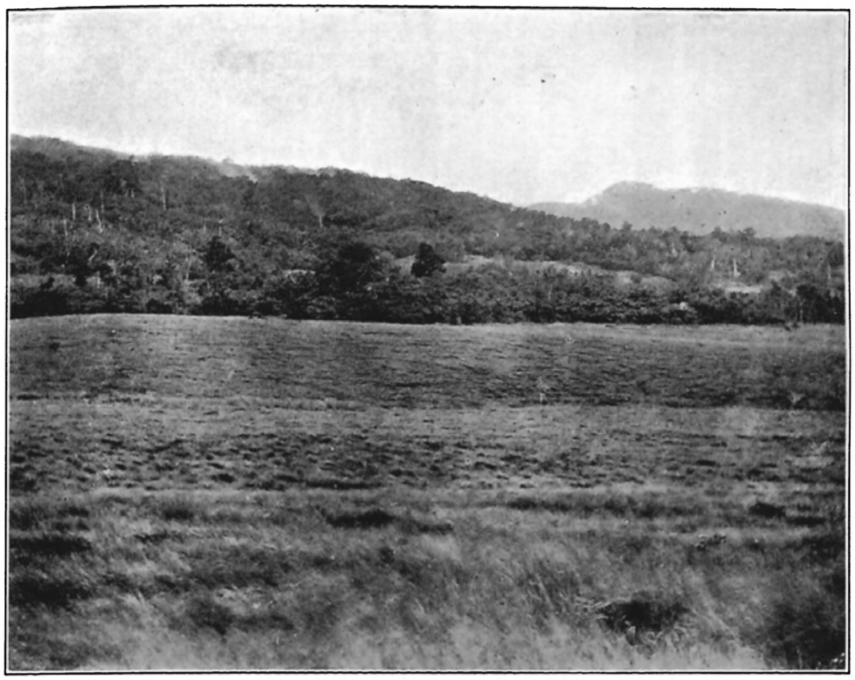

Fig. 1. Looking west-northwestward across Vigo River.

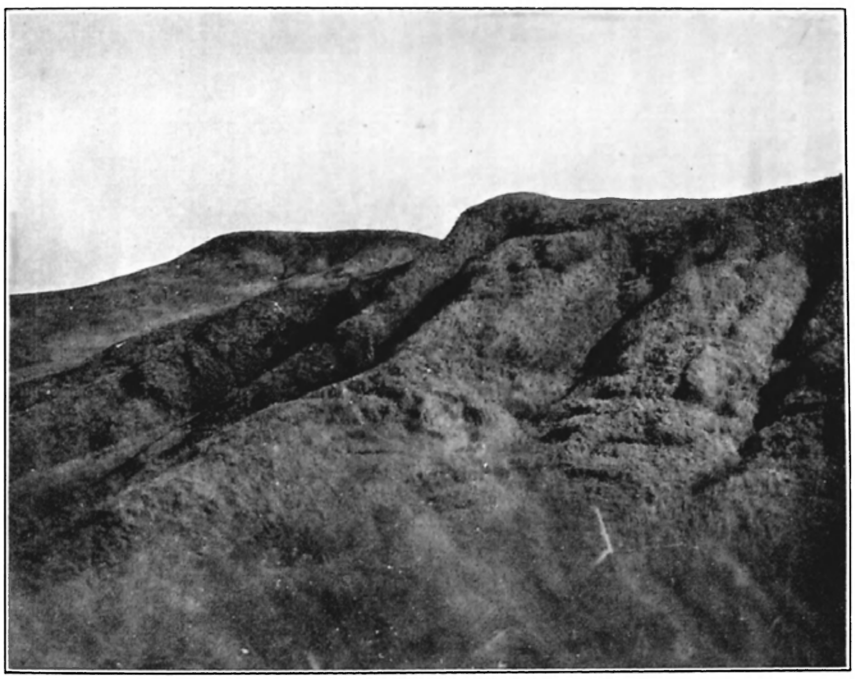

Fig. 2. The eastern wall of the upper valley of Canguinsa River.

PLATE VII.

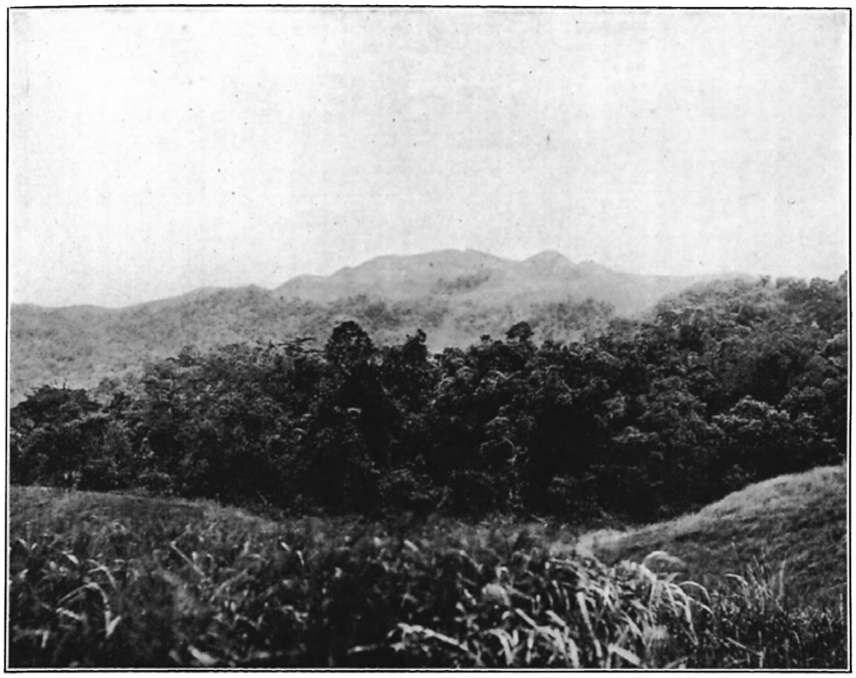

Fig. 1. Looking northward from near Balinsog Hill.

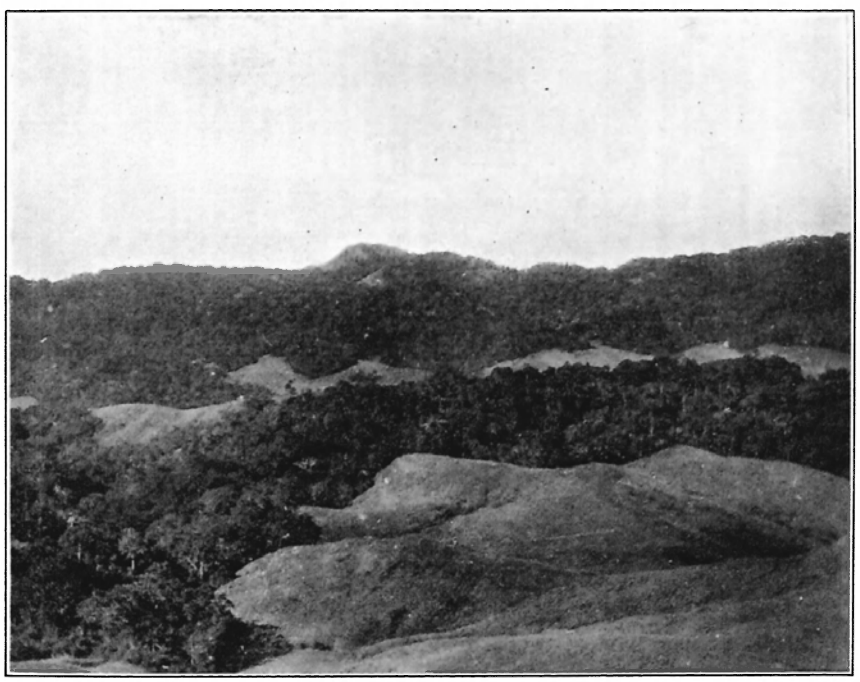

Fig. 2. Looking westward from near Balinsog Hill.

PLATE VIII.

Fig. 1. Looking east-northeastward across the valley of Malipa Creek.

Fig. 2. South Cudiapi Mountain across the valley of Bondoc River, looking northeastward.

Fig. 3. Mount Cancalao, looking westward.

PLATE IX.

Fig. 1. An outcrop of Cudiapi sandstone.

Fig. 2. An outcrop of Canguinsa sandstone.

Fig. 3. Nearly vertical Vigo shale.

Fig. 4. An outcrop of volcanic agglomerate.

PLATE X.