BASIC SURVEY REPORT OF KYOSUI-SEI-GASU DEVELOPMENT PROJECT IN ILOILO BASIN, PANAY ISLAND, PHILIPPINES

February 1982

JAPAN INTERNATIONAL COOPERATION AGENCY

BASIC SURVEY REPORT OF KYOSUI-SEI-GASU DEVELOPMENT PROJECT IN ILOILO BASIN, PANAY ISLAND, PHILIPPINES

February 1982

JAPAN INTERNATIONAL COOPERATION AGENCY

PREFACE

In response to the request of the Government of the Republic of the Philippines, the Government of Japan decided to conduct a survey on the Kyosui-sei-gasu (Natural gas accompanied with water) Development Project and entrusted the survey to the Japan International Cooperation Agency (JICA). The JICA sent to the Philippines a survey team headed by Dr. Hiro'o NATORI from October 13 to November 21, 1981.

The team exchanged views with the officials concerned of the Government of the Republic of the Philippines and conducted a field survey in Iloilo basin, Panay Island. After the team returned to Japan, further studies were made and the present report has been prepared.

I hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of the Republic of the Philippines for their close cooperation extended to the team.

Tokyo, February, 1982

Keisuke ARITA
President
Japan International Cooperation Agency

Investigation of natural gas in Iloilo basin, Panay Island, Philippines

BY

Hiro'o NATORI, D.Sc.	Geological Survey of Japan
Toru SAKAMOTO, D.Sc.	-do.-
Yoji TERAOKA, D.Sc.	-do.-
Shozo NAGATA	-do.-
Kazuo INAMI	-do.-
Katsuhiko OZAWA	Japan International Cooperation Agency
Raymundo A. REYES, Jr.	Philippine Bureau of Energy Development
Marietta M. DE LEON	-do.-
David R. BALADAD	-do.-
Ismael U. OCAMPO	-do.-
Isidoro R. SARIAN	-do.-

C O N T E N T S

1. Introduction

Based on the preliminary survey carried out during October to December 1980, the Iloilo basin in Panay Island has been choosen as a prospective field of kyosui-sei-gasu (Natural gas accompanied with water) deposits.

This report summarizes the second field survey conducted during October to November 1981, which aimed at obtaining data necessary for planning of exploratory drilling on the kyosui-sei-gasu in the Iloilo basin, and the results of sample analysis conducted in Japan after the survey.

During the field survey the followings were investigated.

- Geological survey - Geological survey and rock sampling mainly in the southwestern part of the basin.
- Geochemical survey - Geochemical survey of the existing groundwater wells, natural springs, and gas outcrops, and sampling of gases, water and source rocks for geochemical analysis.
- Geophysical survey - Analysis of logging data of exploratory drillings of oil and records of seismic surveys and field checking.
- Micropaleontological survey - Washing of rock samples and classification of planktonic and benthonic foraminifera.

After the field survey, the following analyses and measurements were prosecuted at the Geological Survey of Japan.

- Preparation and observation of thin sections of rock samples.
- Determination of gas component by gas chromatography.
- Chemical analysis of groundwater.
- Chemical analysis of organic matters in source rocks.
- Measurements of density and porosity of reservoir rocks.

A part of the foraminiferal analysis and classification was carried out at the Bureau of Energy Development of the Philippines.

Kyosui-sei-gasu deposit The kyosui-sei-gasu deposits with a commercial value are formed mainly in the Late Cenozoic marine deposits. For the formation of the gas deposits, the reservoir (aquifer) consisting of coarse grained deposits with a high porosity and permeability has to exist at an adequate depth. Since the volume of gas soluble in a fixed amount of ground water increases proportionally with hydrostatic pressure, a deeper reservoir can be higher potential in the kyosui-sei-gasu. However, the economic value of the kyosui-sei-gasu deposit decreases with the depth due to development costs. Unlike in the case of structural gas, the formation of kyosui-sei-gasu deposits does not require the presence of specific geological structure, but the basin structure which can prevent flowing out of groundwater containing dissolved gas and the geological condition which allows the formation of a closed environment against invasion of meteoric water are necessary.

Additional resources In the accompanying water of kyosui-sei-gasu, frequently iodine is contained, which contributes remarkably to payability in an industrial scale gas development. Accordingly, in kyosui-sei-gasu surveys, a great deal of attention should be paid on the iodine. In Japan, the kyosui-sei-gasu fields in Chiba, Niigata and Miyazaki Prefectures yield iodine, which share up to 80% of the world market in the free countries. It is considered that the iodine concentrated by botanical creatures in sea water was deposited on the sea bottom, dissolved into brine in strata with gas and then has been kept up to now. It is also well known that iodine is concentrated particularly in outer neritic and bathyal deposits.

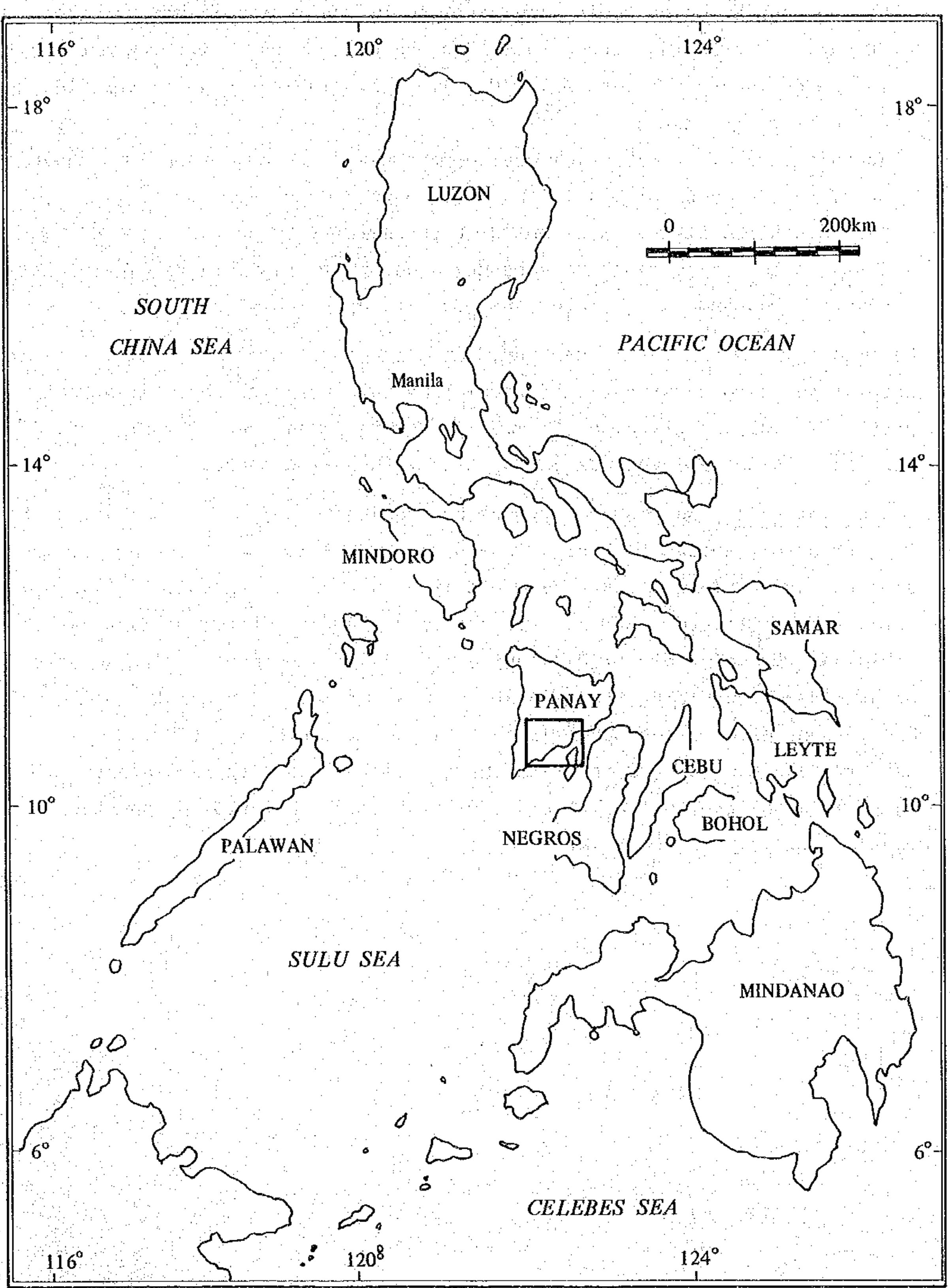
Formation condition of kyosui-sei-gasu deposits with iodine On the basis of the investigation in the Philippines and the experiences in Japan, the formation conditions of kyosui-sei-gasu deposits with iodine with a commercial value can be summarized as follows:

- The geological age of the source rock has to be between the Upper Miocene and the Pleistocene. In both younger and older rocks than this interval the potential of iodine decreases.
- The sedimentary environment of the source rock has to be outer neritic to bathyal. A high concentration of iodine can be seen especially in the sediments of this sedimentary environment.
- The reservoir has to lie at an interval between 400 and 1,500 m in depth. The reservoir shallower than 400 m is very often subject to flushing by meteoric water. Beyond a depth of 1,500 m, economical efficiency as a kyosui-sei-gasu deposit decreases due to development costs.
- The muddy source rocks with rich organic matters and the reservoirs with high porosity and permeability have to develop reasonably. Excessive development of the reservoirs brings about a decrease in gas and iodine potential. Poor reservoirs result in a decrease in productivity per production well.
- The geologic structure has to be basinal and closed, or have a monotonous, monoclinal structure, and the brine has to be kept very well from flowing out or from being flushed by meteoric water.

- The concentration of iodine in the brine in the reservoir has to exceed 40 mg/l. The iodine concentration in the brine used as the raw materials in iodine industry in Japan is 30 - 110 mg/l (there are a few examples which reach 140 mg/l).
- The altitude of the area for development has to be more than 10 m above sea level, because of minimizing the impact of land subsidence.
- Safe discharge of a vast amount of high salinity brine has to be ensured.
- The site has to be close to consumer areas where gas demands of at least several thousands cubic meters per day are expected.

Terminology "Kyosui-sei-gasu" used in this report means a general term for natural gas accompanying ground water, and this term includes "Suiyo-sei-gasu" (Natural gas dissolved in water) used in Japan, and "Low pressure gas" used in the Philippines as examples in a narrow sense.

Acknowledgments We wish to express our thanks to Atty. Wenceslao R. DE LA PAZ, Director, Bureau of Energy Development (BED) for his help and permission to use BED facilities. We would like to thank Dr. Arthur SALDIVAR-SALI, Deputy Director, BED and Mr. Apollo P. MADRID, Chief, Oil and Gas Division, BED for their kind encouragement and suggestions. Also we take pleasure in recognizing the help and support of Mr. Dominador B. VALENCIANO, Supervising Information Specialist, Data Bank and Library, BED and Ms. Griselda G. BAUSA, Officer-in-Charge, Energy Research Laboratory. We would also like to thank the staff of Oil and Gas Division, and Data Bank and Library for their kind help.

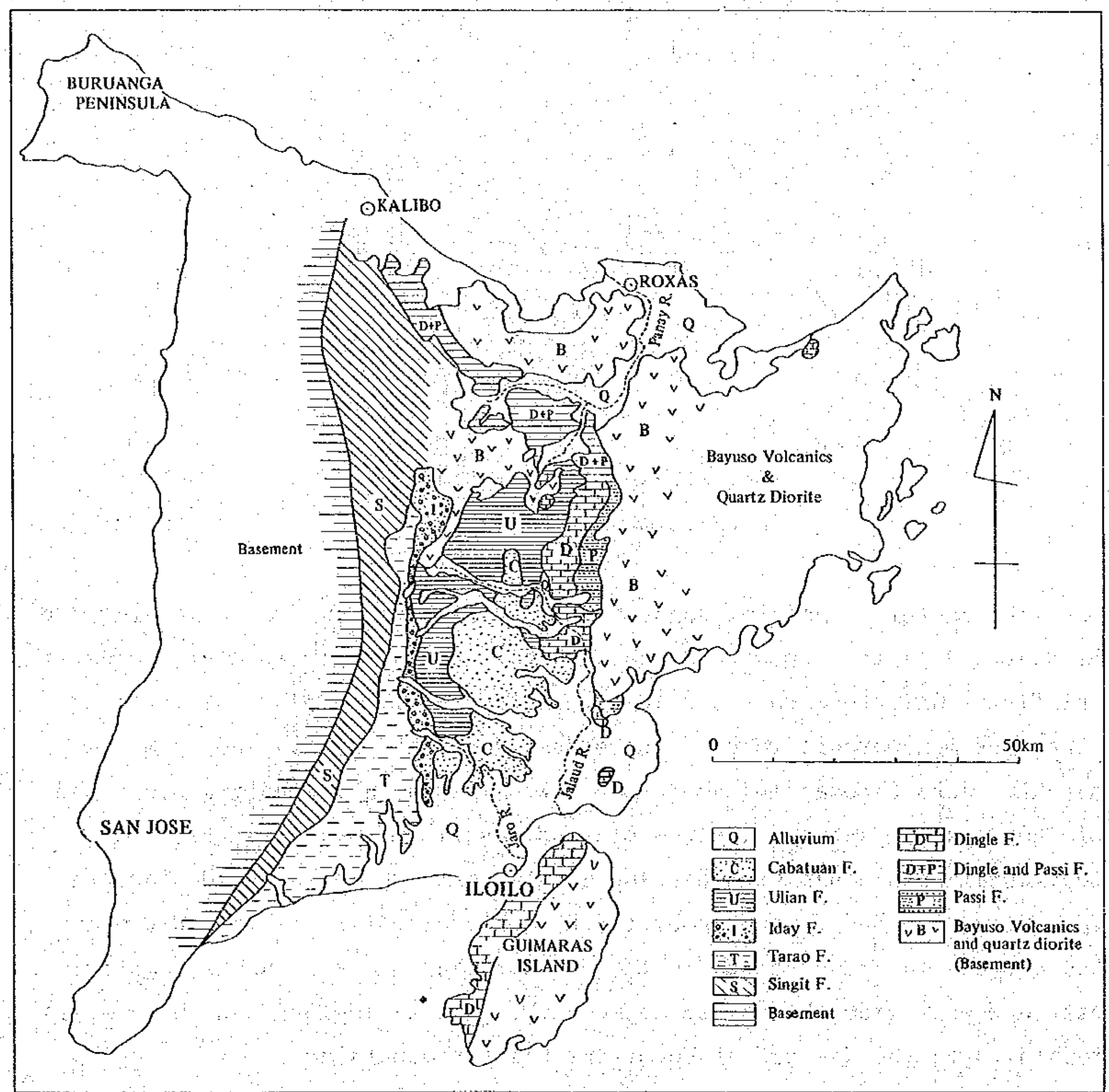


TEXT-FIGURE 2-1

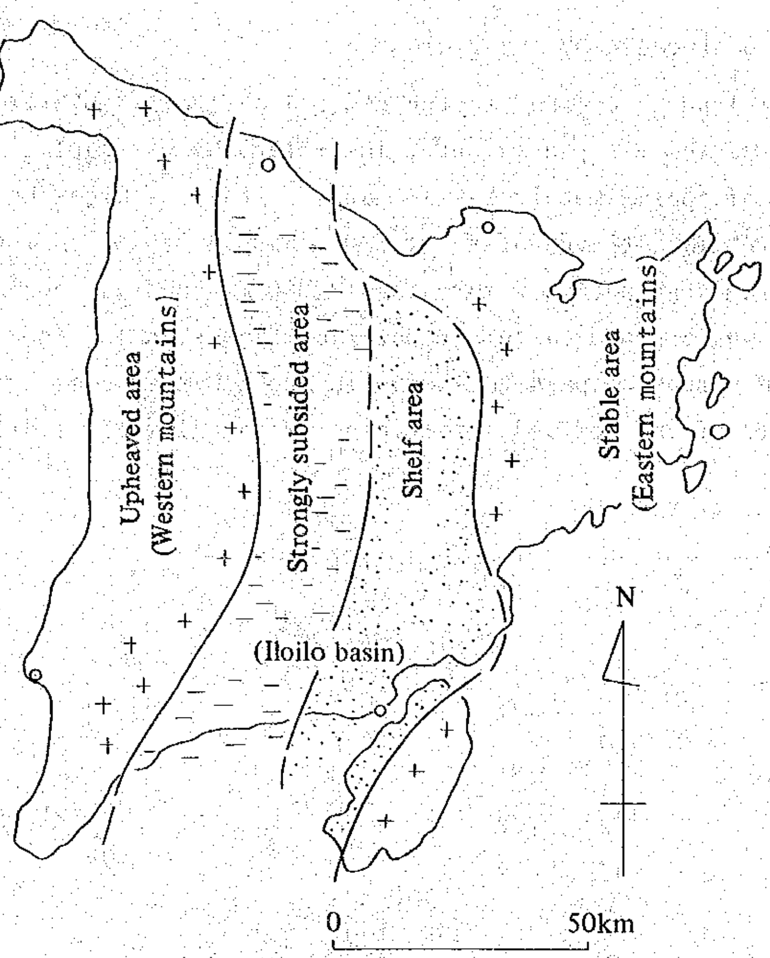
Location map.

2. Outline of topography and geology

Panay Island is located in the central part of the Philippines or the western end of the Visayan Islands. The island has a regular triangle shape with a side of approximately 150 km, and in its east side the eastern mountains with an altitude of about 500 m and in its west side the western mountains with high peaks of more than 2,000 m, running north to south. Between the western and eastern mountainous lands, a low land extends from Roxas in the northern coast to Iloilo in the southern coast, and over the southern part of the lowland is occupied by an alluvial, Iloilo plain.



TEXT-FIGURE 2-2
Geologic map of Panay Island.



TEXT-FIGURE 2-3
Tectonic map of Panay Island.

The eastern mountains consists mainly of Oligocene volcanics intruded by quartz diorite of probable Miocene age. The western mountains consist chiefly of Oligocene volcanic formation together with older ultrabasic rocks and metamorphic rocks. The oldest rock in Panay Island is metamorphic rocks exposed in the Buruanga Penninsula in the northwestern end of the island. Between the western and eastern mountain ranges, Iloilo sedimentary basin has been developed in a north to south trend since the Late Oligocene and filled up by thick marine deposits. This sedimentary basin opens towards the sea in the northern and southern parts, and extends east and west from the border between the central lowland and the eastern mountains to the eastern slope of the western mountains.

With respect to the Cenozoic strata distributed in the Iloilo basin, its stratigraphy, structure and fossils have been investigated in the both western and eastern parts of the basin, especially in its southern district.

In addition, as to subsurface geology in the south plain area, seismic surveys and gravitational surveys as well as many deep drillings have been carried out in connection with oil exploration.

The present investigation was conducted to search kyosui-sei-gasu potentiality and to get data to plan for exploratory drilling through geochemical survey and checking existing geophysical and drilling data of the Iloilo plain. Along with it, in order to grasp the geologic characteristics of the Iloilo basin including a possibility of the presence of natural gas, a geological survey was conducted in the east slope of the western mountains, a hinterland of the expected kyosui-sei-gasu field.

Correlation of the results of the survey and the existing data on stratigraphy are shown in Table 2-1.

TABLE 2-1

Stratigraphic correlation in Iloilo basin.

Age		Western part (This report)		Western part (SANTOS, 1968)		Eastern part (Reports on exploratory drillings)
Pleistocene		F formation		Iday Formation		Cabatuan Formation
Pliocene		E formation	E_2	Tarao Formation	Guimbal Mudstone	Ulian Formation
			E_1		Tubungan Siltstone	
Miocene	Late	D formation	D_3 - D_1			
	Middle	C formation	C_2 - C_1	Singit Formation	Barasan Sandstone	Dingle -Passi Formation
					Igtalongon Shale	
	Early	B formation	B_2			
			B_1		Sewaragan Complex	
Oligocene		A formation			Basement	Bayuso Volcanics

Based on the unified information of these data, the outline of the Iloilo basin can be summarized as follows:

(1) In the Oligocene intermediate to mafic volcanic activity took place over the whole area of Panay Island.

(2) From the Early Miocene to the early half of the Late Miocene the eastern half of the basin maintained a shelf einvironment with a little

subsidence and reefal limestones were accumulated remarkably.

(3) during the same period in the western half of the basin a shallow sea environment appeared for a short time at first followed by the accumulation of reefal limestone, and after that a rapid subsidence continued resulting in the sedimentation of thick turbidite sequences. Through this period, the western mountain area was being upheaved, and the sedimentation center represented by the thickest part of sediments was gradually shifting to the east.

(4) Through the later half of the Late Miocene to the Pliocene, the western half of the basin became gradually shallow sea, while the eastern half became a deep sea to some extent.

(5) In the Early Pleistocene the western part of the basin was emerged, while in the eastern half a shallow sea remained.

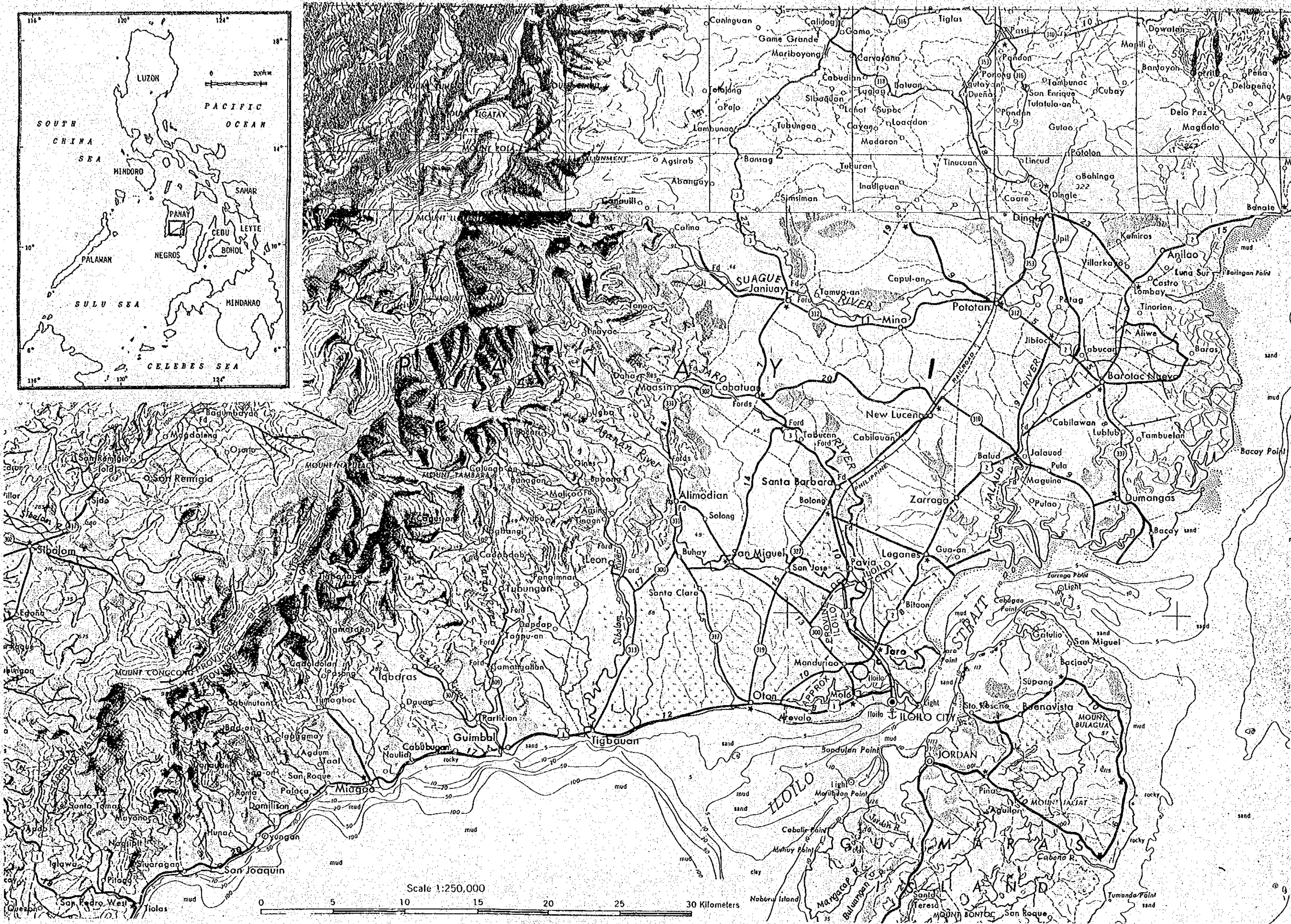
(6) As mentioned above, the geological history of Panay Island in the late Cenozoic is characterized by the development of a tectonic framework with a zonal arrangement of the following four zones running parallel north to south: (i) the non-subsidence zone covering the eastern mountains, (ii) the shelf zone characterized by the development of reefal limestone, (iii) the strongly subsidence zone where turbidite dominates, and (iv) the upheaval zone in the western mountains.

(7) The boundary between the shelf zone and the strongly subsidence zone in the southern part of the Iloilo basin was located near the western edge of the present Iloilo plain.

(8) In the eastern half of the basin, the depth to the basement rocks (volcanics) is 1,500 to 2,000 m, while in the western half the integrated thickness of the deposits is remarkably large, attaining more than 5,000 m.

(9) In the shelf zone the strata suffered little deformation and are almost flat, while in the subsidence zone, the strata incline east at an angle of 50 - 20° and show a remarkable zonal arrngement bounded by NNE-SSW trending faults.

(10) Indications of gas are detected almost all over the strata in the Iloilo sedimentary basin, but the iodine-type kyosui-sei-gasu deposits with a noticeable potential are assumed to exist in the Late Miocene to Pliocene strata with relatively deep sedimentary environment, which lie in the deeper part of the Iloilo plain.



TEXT-FIGURE 2-4 Topographic map of the survey area.

3. Geology of the southwestern part of the Iloilo sedimentary basin.

As one of the surveys to clarify the geology of the Iloilo basin, a surface geological survey of the mountainous and hilly lands on the west side of the plain was conducted. The efforts were concentrated on the area along the Sibalom and Aganan Rivers taking account of the conditions such as exposure of rocks, ease of accessibility to the survey area, availability of aerophotographs and easiness of connecting with the former investigations (Text-fig. 3-1). Since the area is located between the Tanian-Tarao basin investigated by GONZALES et al., (1963) and the Urian-Tigum area studied by SANTOS (1968), it is important for understanding the Tertiary stratigraphy of the Iloilo sedimentary basin.

1) Outline of topography and geology

The survey area is about 20 km east to west and 15 km north to south, extending from the western mountains with an altitude of 1,000 m to the hilly land with an altitude of 100 m on the west of the Iloilo plain, and consists mostly of Tertiary deposits.

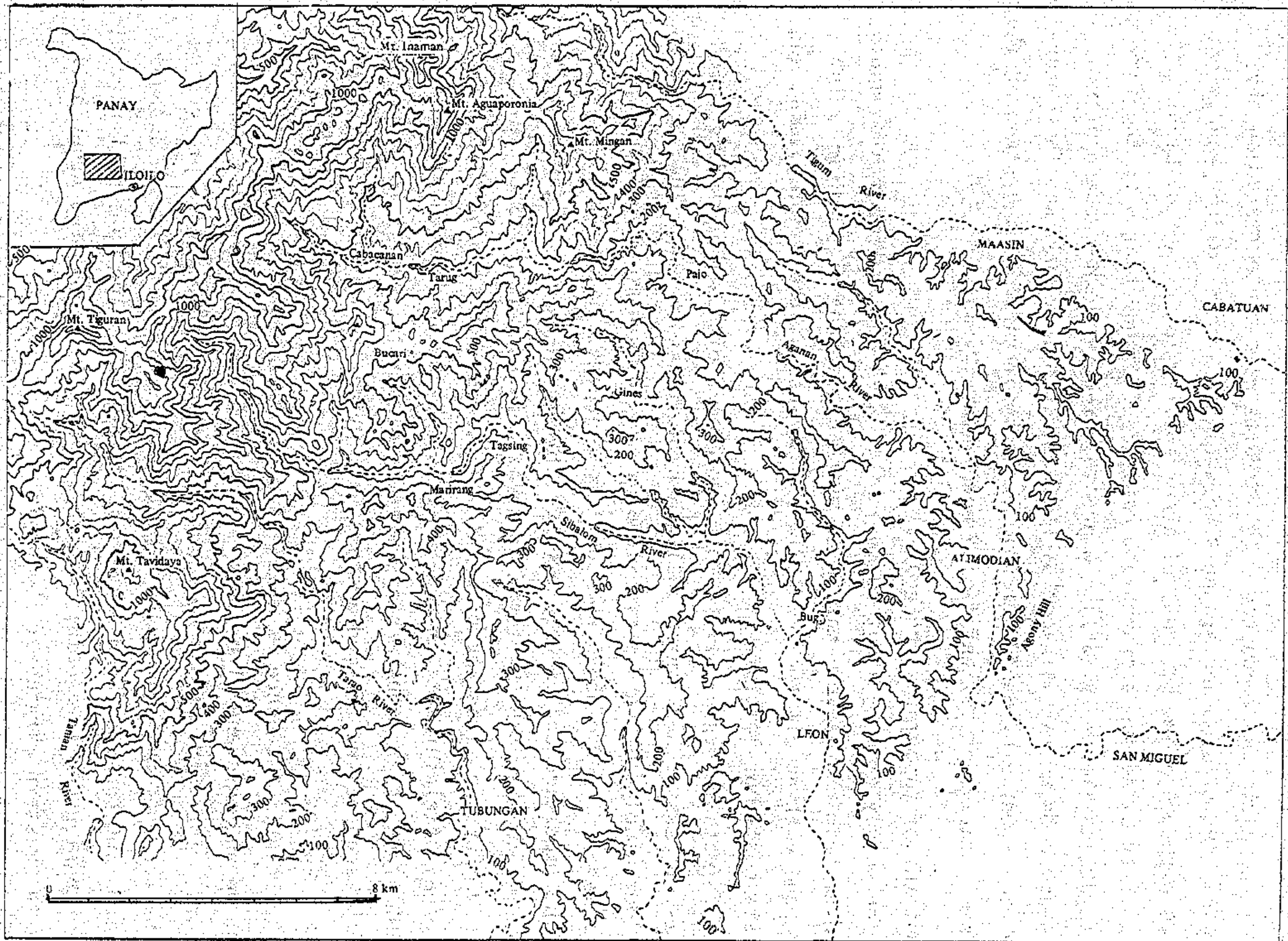
The Tertiary begins with a thick volcanic formation including some amounts of clastic sediments, followed by a limestone bed. The formation crops out widely on the eastern slope of the western mountains with Mt. Inaman (about 1,300 m above the sea level) and Mt. Tiguran (1,324 m).

The limestone bed is well exposed from Mt. Aguaporonia (about 1,300 m) to Bucari, forming NNE-SSW trending strike ridges (Pl. 1, fig. 2).

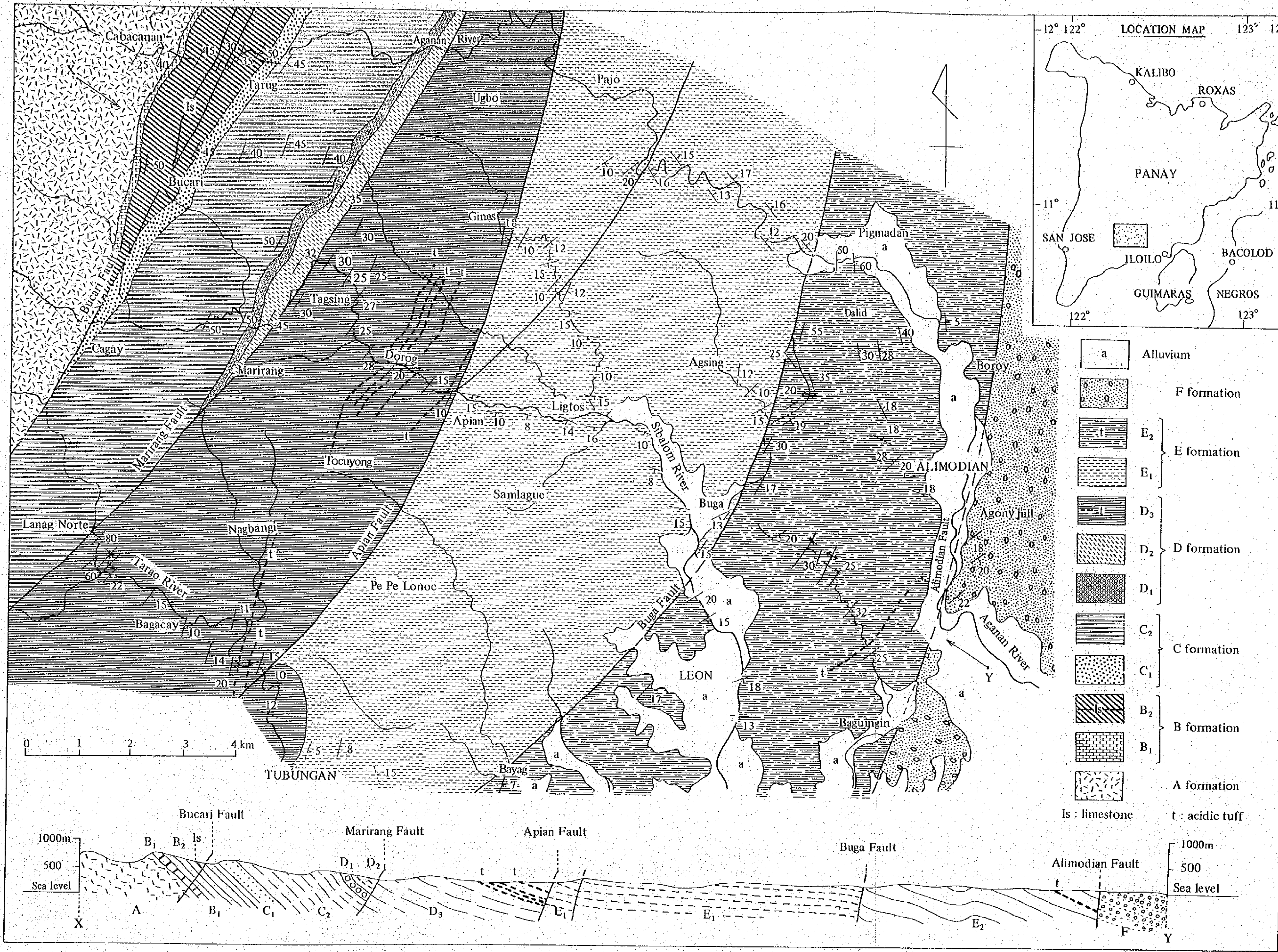
Covering the limestone bed, a thick clastic sequence of flysch type is developed, attaining more than 5,000 m thick. Owing to several faults of NNE-SSW trend, the sequence shows missing of strata, but it is assumed that the sequence was formed successively without serious stratigraphic gap as a whole.

The clastic sequence is characterized by thin-bedded alternation of sandstone and mudstone with pebbly mudstone and conglomerate at some horizons. The latter two occasionally form some sharp ridges projecting out the surroundings, although they are not as marked as in the case of the limestone bed described above (Pl. 7, fig. 1). The uppermost part of the succession consists mainly of conglomerate and forms the Agony hill along the western margine of the plain.

The Tertiary formations of this area were formed in the marine environments, although no evidence is obtained as to the volcanic formation and the conglomerate beds in the upper most part. Almost all of the

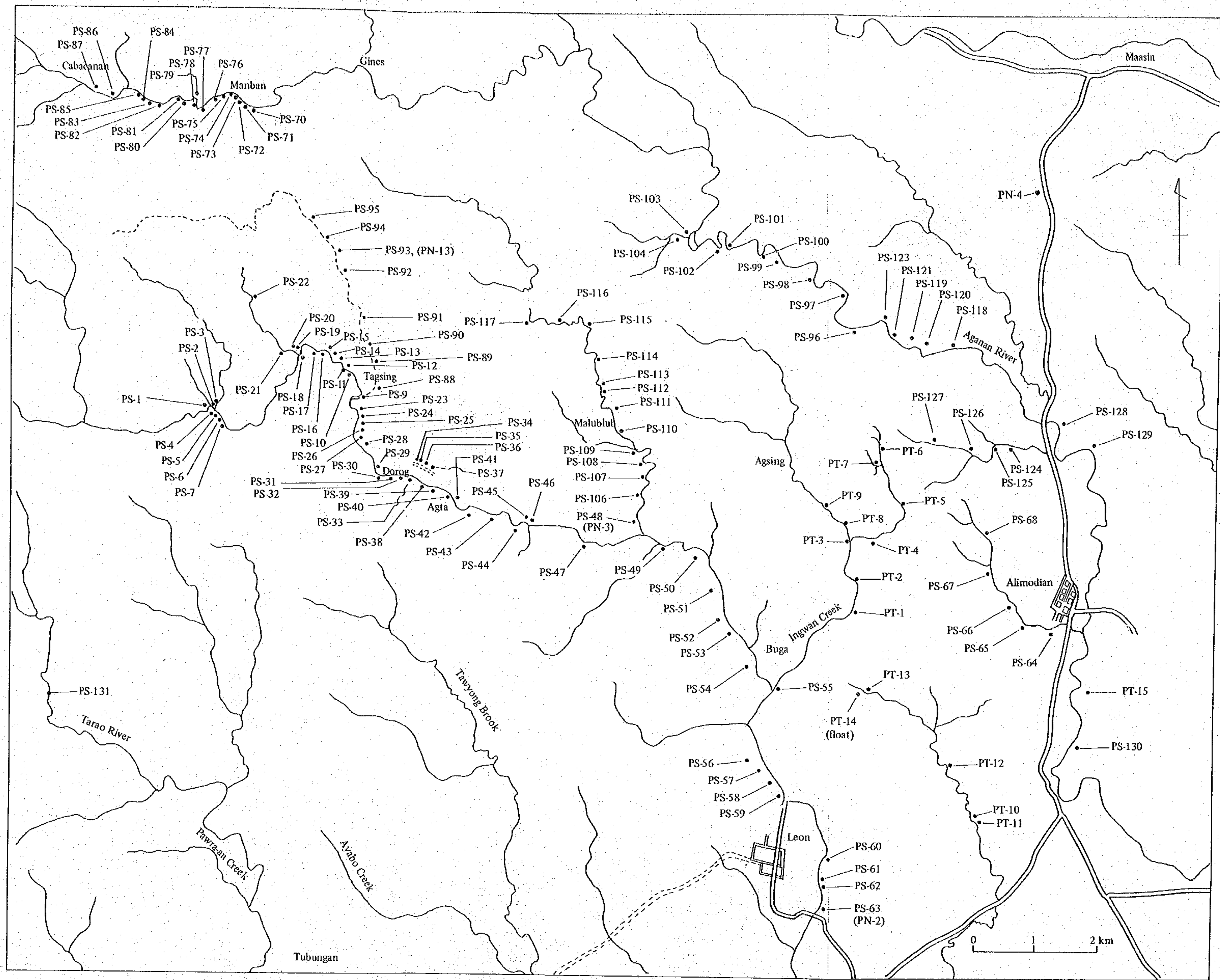


TEXT-FIGURE 3-1 Topography of the geological survey area in the southwestern part of the Iloilo basin.



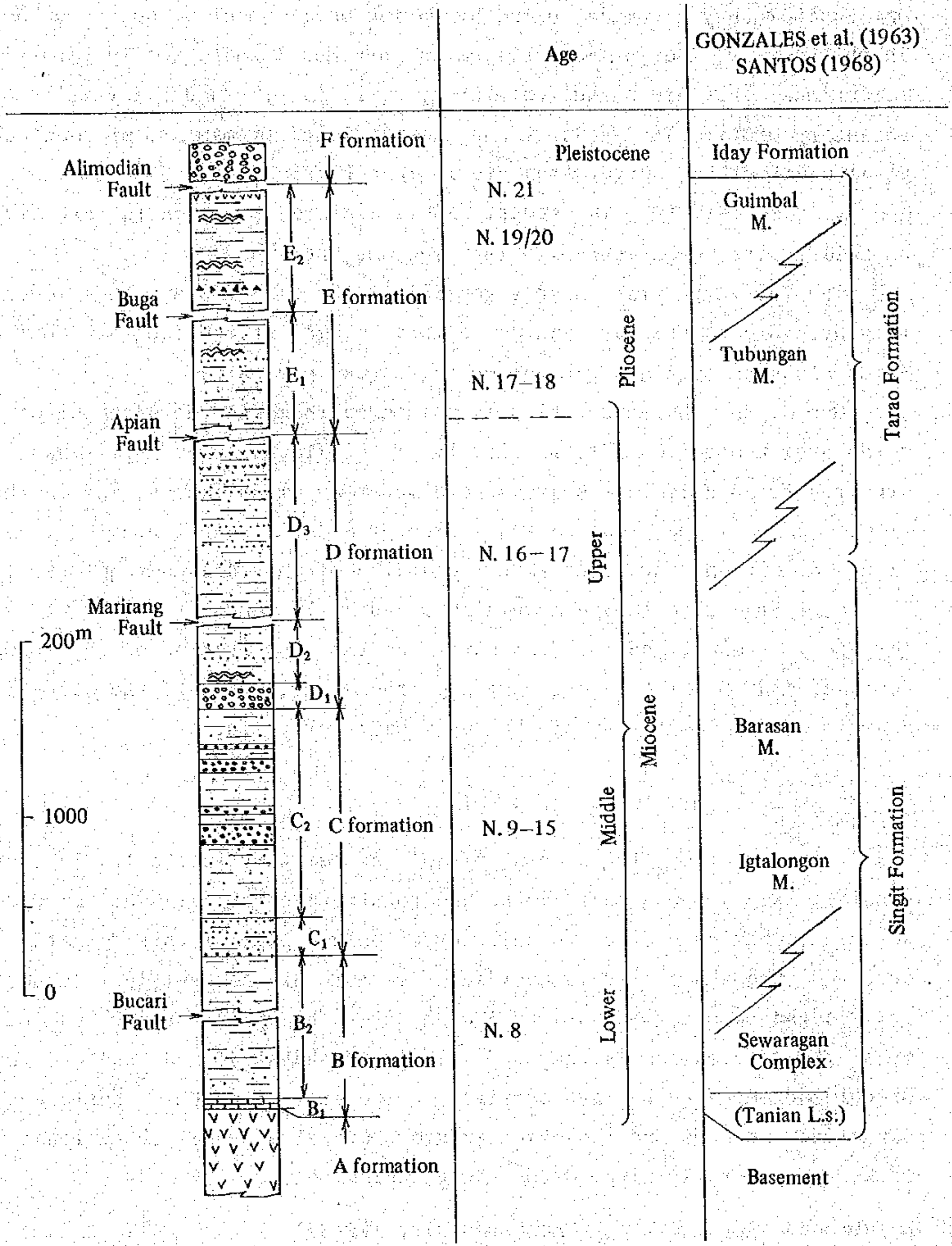
TEXT-FIGURE 3-2

Geologic map and profile of the southwestern part of Iloilo basin, Panay Island, Philippines.



TEXT-FIGURE 3-3

Sample locality map of the southwestern part of Iloilo basin.



(See legend in Text-fig. 3-5)

TEXT-FIGURE 3-4

Generalized columnar section of the Cenozoic sequences in the Sibalom-Aganan Area, Panay Island.

volcanics and associated sediments in the lowest part were formed in water, but whether they accumulated in the marine environment or not is unknown. In this survey, the Tertiary system was divided lithologically into six formations; they are named tentatively A, B, C, D, E and F formations in ascending order. The geologic map, sample locality map and micropaleontological chart of the survey area are in Text-figs. 3-2 and 3-3 and Table app.-1, respectively. The stratigraphic division is shown in Text-fig. 3-4, as well as its comparison with the previous one.

The Tertiary strata have a general strike of NNE-SSW with a moderate to gentle dip to the east and are cut by several strike faults. Gentle folds plunging east are recognized in the eastern part.

One of the characteristics in this area is marked development of land slide over the region (Pl. 1, fig. 1; Pl. 6, fig.3). Land slide has occurred frequently in the area where mudstone predominates, and in the western part of the area the land slide area forms longitudinal valleys with a direction concordant with the strike of mudstone-dominant strata. The land slide area in the mountainous and hilly lands is highly utilized for paddy farming, and the west margin of the distribution of the mudstone-dominant beds marks the west margin of the distribution of the paddy fields as well as the limitation of the development of villages.

2) Stratigraphy

A formation

This formation, the lowest unit of the Tertiary in the Iloilo basin, consists mainly of volcanic rocks and constitutes the main part of the western mountains. Since in this survey only a part of this formation was observed, the whole stratigraphy and structure are not yet fully understood.

In the upper stream of the Aganan River the uppermost part, about 500 m, of the A formation is composed chiefly of andesitic and basaltic tuff breccia accompanied by lava partly. Pumice tuff, fine tuff, tuffaceous sandstone and mudstone and black mudstone are also seen. The volcanic rocks are generally altered to show greenish colour.

Hornblende augite orthopyroxene andesite (PS-87)

Phenocryst: plagioclase, orthopyroxene, augite, hornblende and magnetite. Plagioclase contains dust inclusions in its core. Orthopyroxene is mostly replaced with carbonate minerals or quartz. Sometimes it has parallel growth with clinopyroxene. Hornblende has yellowish green pleochroism and its fringe is opacited.

Groundmass: showing felty texture and consisting of fine quartz and plagioclase with a little amount of iron minerals.

Augite hornblende dacite pumice tuff (PS-86)

Phenocryst: plagioclase, quartz, hornblende, augite and iron minerals.

Groundmass: pumice and glassy fragments, mostly replaced with clay and carbonate minerals.

Olivine augite basalt (PS-85)

Phenocryst: augite and olivine (pseudomorph)

Fine phenocryst: magnetite.

Groundmass: mainly consisting of plagioclase and having intergranular texture.

Olivine augite andesite (PS-84)

Phenocryst: plagioclase, augite, olivine (pseudomorph) and magnetite. Plagioclase is partially replaced with zeolite or clay minerals. Olivine is replaced by clay minerals and quartz.

Groundmass: A little amount of plagioclase and magnetite are dispersed. In addition, an assemblage of clay minerals, quartz and zeolite, or clay minerals fill cavities.

Olivine augite andesite (PS-83)

Phenocryst: plagioclase, augite, olivine (pseudomorph) and magnetite. Plagioclase is partly replaced with clay minerals. All of olivine is replaced with clay minerals and quartz.

Groundmass: Originally holocrystalline texture consisting of plagioclase, pyroxene and magnetite, but most of them are altered into clay minerals. An assemblage of clay and carbonate minerals are seen as cavity fillings.

As a whole, this formation strikes NNE-SSW with a dip of 30°E or so, locally several tens degrees. No fossils are found in the formation. This formation corresponds to the Sewaragan Complex of SANTOS (1968) and the Basement complex of CORBY (1951) and GONZALES (1963).

B formation (Text-fig. 3-5)

The B formation rests on the A formation conformably in appearance and is subdivided into B_1 and B_2 members.

B_1 member

This member consists of gray, massive, reefal limestone including fossils such as coral, and its thickness along the Aganan River ranges from 20 to 30 m. It is considered to correspond to the Tanian Limestone described by GONZALES et al. (1963) and SANTOS (1968). However, the Tanian Limestone in the upperstream of the Tanian River is distributed isolated and dispersed with a thickness of 150 m, and such occurrence differs remarkably from the member in the survey area. The age of the Tanian Limestone is regarded as early Miocene (f_1).

The B_1 member continues laterally very well forming a ridge running north northeast-south southwest such as Mt. Aguaporonia (Pl. 1, fig. 2) in the north side of the Aganan River and the ridge projecting in the west of Bucari village in the survey area. Although it looks conformable with the A formation lying below, this is not sure because of lack of the detailed data on the structure of the A formation.

B_2 member

The B_2 member lies on the B_1 member conformably. It is mainly composed of thin alternation of mudstone and sandstone with mudstone dominant. In the upperstream of the Aganan River it is observed successively. Since the member is cut by a fault in the middle part, the thickness of the whole member is not sure, but it seems to reach at least 700 m.

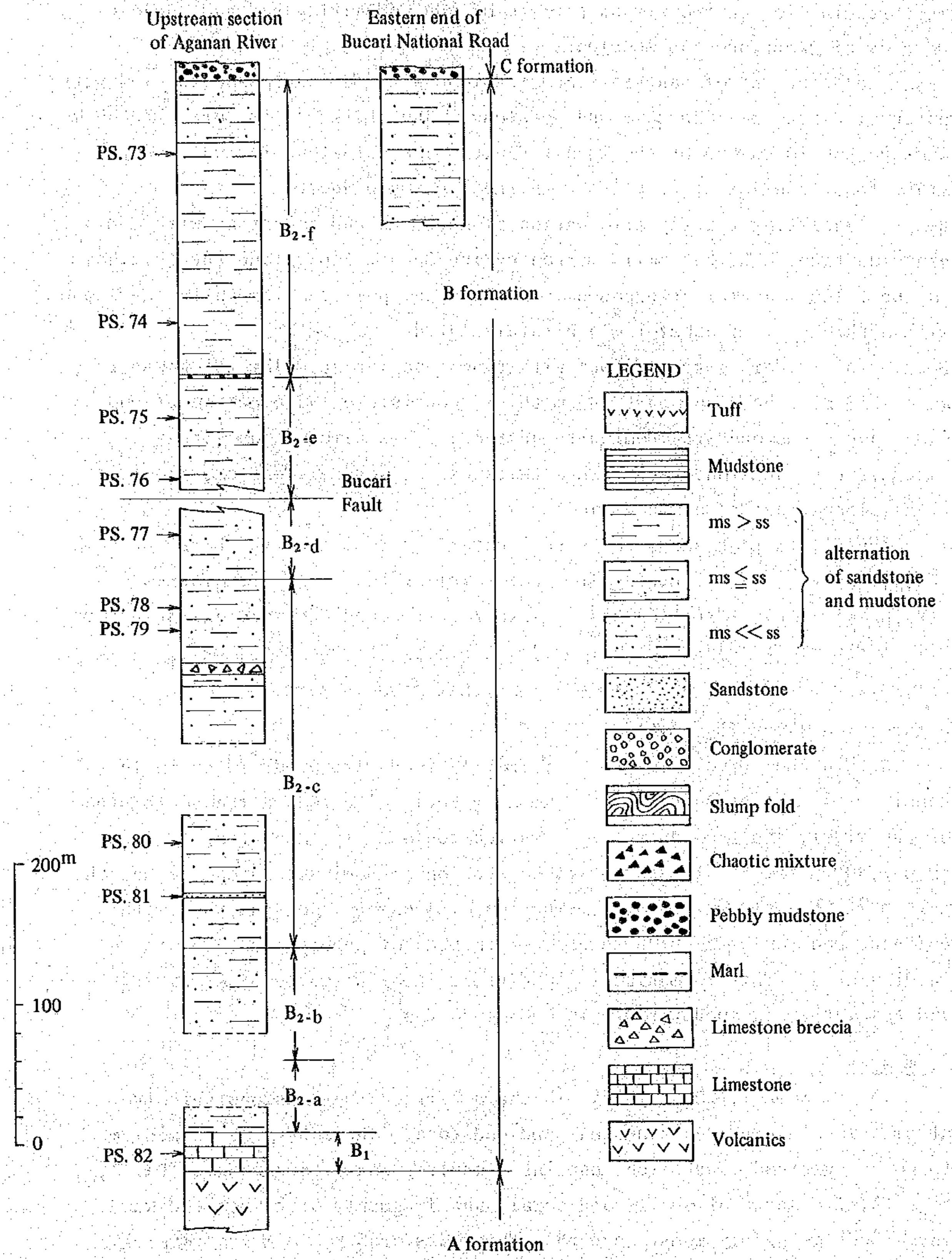
The B_2 member is further subdivided lithologically from the lower to the upper as follows:

B_{2-a}: dark gray mudstone with sandstone lamina. The thickness is about 200 m.

B_{2-b}: alternation of sandstone and mudstone with dominant sandstone or with an equivalent amount of sandstone and mudstone (Pl. 1, figs. 3, 4). The thickness is approximately 60 m.

B_{2-c}: dark gray mudstone with sandstone lamina. The thickness is about 260 m.

In the lower part of B_{2-c} medium to fine-grained sandstone with a thickness of 4 m is intercalated, and in the upper part of this sandstone bed ripple cross-bedding developes very well. In the upper part of B_{2-c} limestone breccia with a thickness of 10 to 15 m is intercalated.



TEXT-FIGURE 3-5

Columnar sections of the B formation.

The breccia lies on the eroded surface of the underlying bed and encloses pebbles of sandstone and mudstone.

B_{2-d}: alternation of sandstone and mudstone with dominant sandstone or with an equal amount of sandstone and mudstone. The thickness is more than 45 m and the top is marked by the Bucari Fault. The sandstone includes many trace fossils existing parallel with the bedding plane.

B_{2-e}: consisting chiefly alternation of mudstone and sandstone with dominant mudstone. The bottom is marked by the Bucari Fault, and the thickness is about 100 m as far as exposed. In the upper part conglomeratic sandstone with a thickness of about 1 m are intercalated.

B_{2-f}: mainly dark gray mudstone with sandstone lamina. The thickness is about 210 m. The upper part, 45 m thick, consists of alternation of mudstone and sandstone with dominant mudstone. This alternation often intercalates sandstone beds with a thickness of several tens cm, showing transitional facies to the C_1 member.

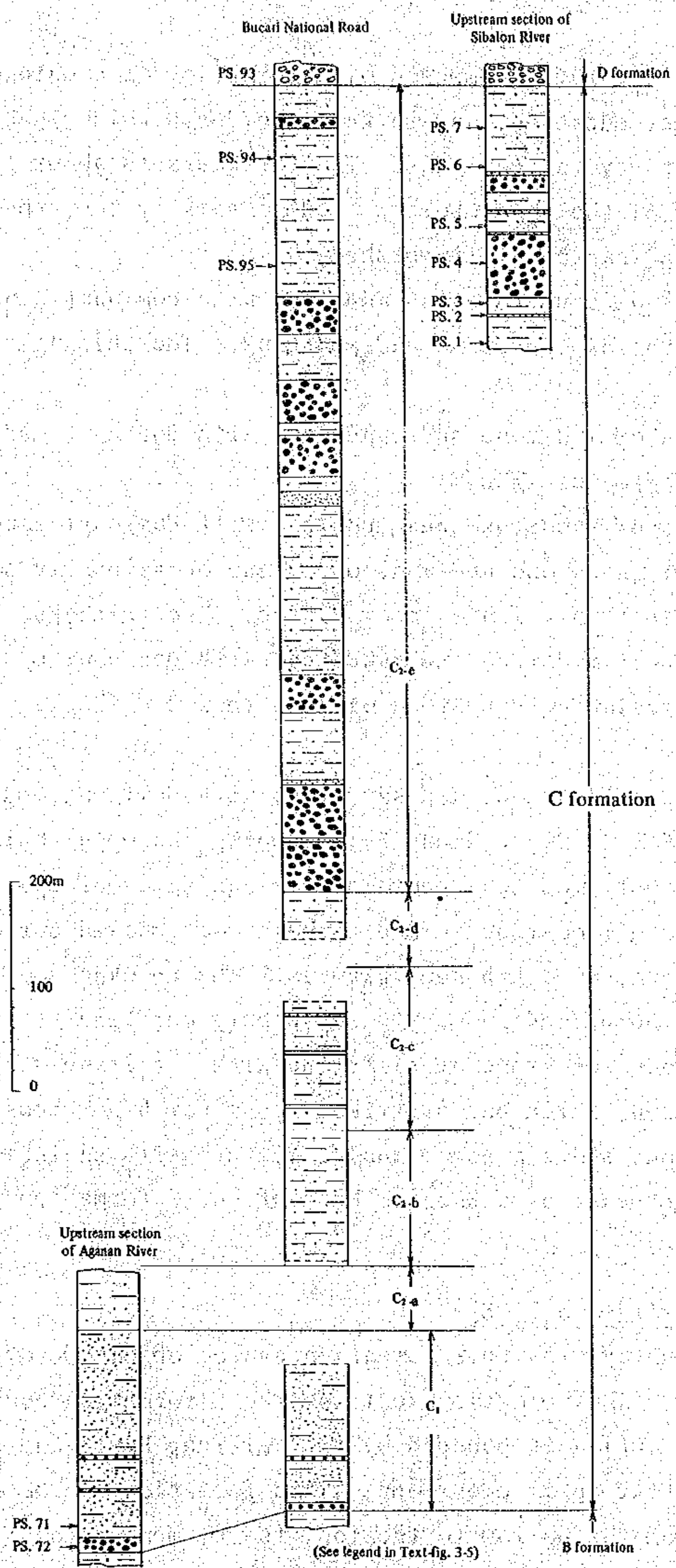
The B formation shows three sedimentary cycles, that is, B_1-B_{2-a}, B_{2-b}-B_{2-c}, and B_{2-d}-B_{2-f}, judging from the vertical change of lithofacies. Structually, this formation has a NNE-SSW strike and a homoclinal structure with a dip of 30 to 55° E. The geologic age of the B_2 member is the late Early Miocene (Zone N.8) based on planktonic foraminifera.

C formation (Text-fig. 3-6)

Within the survey area the C formation is distributed widely in the upper stream of the Aganan River and near Bucari located on the south side of the river, and lies on the B formation conformably, amounting to more than 1,400 m thick. It starts with a section of dominant sandstone and the main part consists mainly of alternation of mudstone and sandstone with dominant mudstone, in which several thick beds of pebbly mudstone are intercalated. This formation is subdivided into two members, C_1 and C_2, and the latter is subdivisible into C_{2-a} to C_{2-e}.

C_1 member

The C_1 member, 200 m thick, is characterized by sandstone thickly alternating interbedded sandstone and mudstone. The sandstone is medium to coarse-grained, and often contains granules, calcareous nodule (Pl. 2, fig. 1), fragments of shells and coral, and fragments of carbonized wood. Three beds of pebbly mudstone with a thickness of 5 to 10 m are intercalated in the lower part of the member.



TEXT-FIGURE 3-6
Columnar sections of the C formation.

C_2 member

This member is chiefly composed of alternation of mudstone and sandstone with dominant mudstone, and in the upper part thick pebbly mudstone is intercalated at several horizons. The thickness is about 1,400 m. In the lower half of the C_2 member two sedimentary cycles, that is, C_{2-a}-C_{2-b} and C_{2-c}-C_{2-d}, can be distinguished.

C_{2-a}: alternation of sandstone and mudstone with dominant sandstone or with an equal amount of sandstone and mudstone. The thickness is about 80 m.

C_{2-b}: alternation of mudstone and sandstone with dominant mudstone. The thickness is approximately 130 m.

C_{2-c}: alternation of sandstone and mudstone with dominant sandstone (or an equal amount of sandstone and mudstone), and occasionally sandstone with a thickness of less than 2 m are intercalated. The thickness is 120 m.

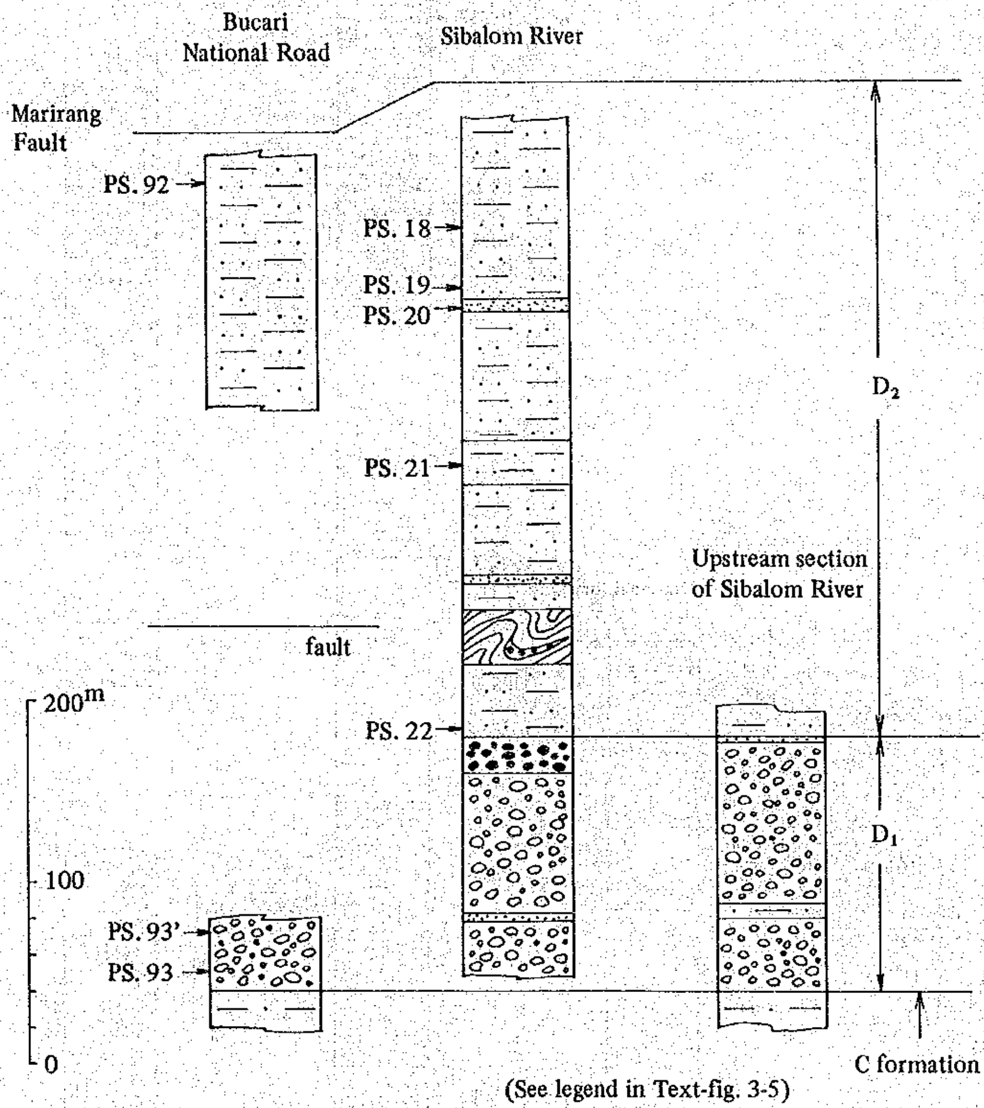
C_{2-d}: alternation of mudstone and sandstone with dominant mudstone, occasionally intercalating sandstone of less than 2 m thick. The thickness is 70 m or more.

C_{2-e}: Alternation of mudstone and sandstone with dominant mudstone and pebbly mudstone (Pl. 2, figs. 2 and 3), occuping the upper half of the C formation. The pebbly mudstone contains various sizes of clasts of mudstone, sandstone and limestone formed through contemporaneous erosion, as well as well-rounded, allochthonous gravels. The thickness of the pebbly mudstone is 10 to 60 m, and in many cases pebbly mudstone is overlain immediately by muddy sandstone or siltstone with a thickness of 2 to 8 m.

The C formation, which has a strike with a north northeast to south southwest direction, shows a homoclinal structure with an inclination of 30 to 50° east southeast as a whole. Most of the C formation may belong to the Middle Miocene.

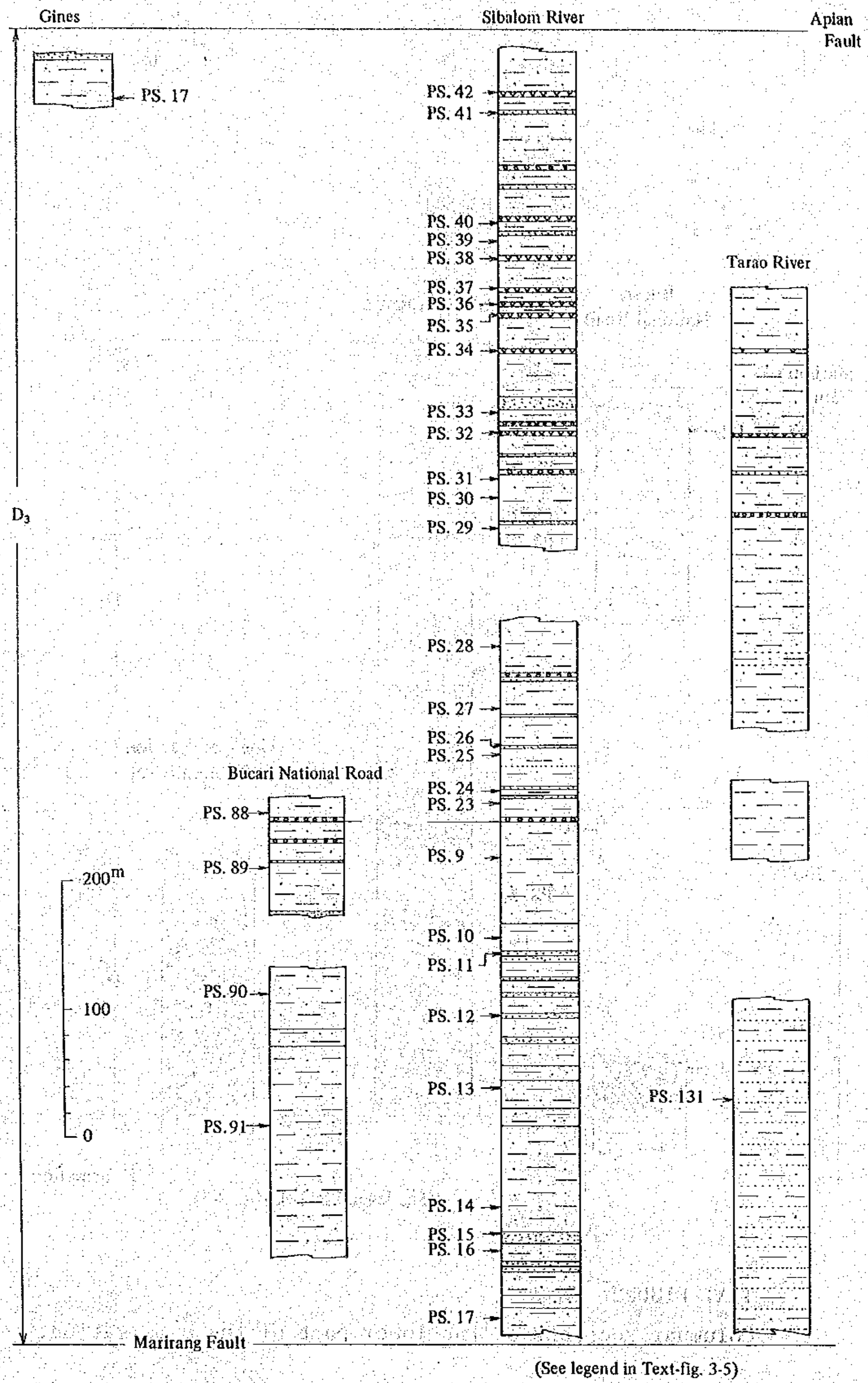
D formation (Text-figs. 3-7, 8)

Within the survey area this formation can be observed very well along the Sibalom River. The formation rests on the C formation conformably. The top of the formation is bounded by the Marirang Fault and the thickness is about 500 m as far as it crops out. This formation can be divided into three members; from the bottom to the top, the D_1 member consisting of conglomerate, and the D_2 and D_3 members mainly consisting of alternation of sandstone and mudstone accompanied by sandstone and slump deposits.



TEXT-FIGURE 3-7

Columnar sections of the lower part of the D formation.



TEXT-FIGURE 3-8
Columnar sections of the upper part of the D formation.

D_1 member

This member, 100 m thick, is composed of conglomerate and well exposed along the road running from Leon to Bucari and along the Sibalom River. The member forms clear strike ridges running north northeast to south southwest from the north side of the Aganan River to the south side of the Sibalom River.

The conglomerate mainly consisting of pebble and cobble is ill-sorted containing boulder, and its matrix is composed of ill-sorted sand or sandy mud. The gravel is generally well rounded, but accumulated in a jumble. So any regularity is not recognized in arrangement of gravels (Pl. 2, fig. 4). In part it contains more muddy matrix, so that a part of it may be called pebbly mudstone. The gravel constituting the conglomerate includes gabbro, amphibolite, dolerite, granophyre, basalt, andesite, andesitic tuff, shale, red chart or siliceous rock, sandstone, limestone and so forth. Quantitatively gabbro is most abundant. Pebbly mudstones are intercalated in various horizons in the C to E formations, and the kinds of gravels and their ratios are practically equal to those of the gravels in the D_1 member.

D_2 member

Along the Sibalom River this member lies on the D_1 member conformably. Along the road towards Bucari this member contacts with D_1 member with a reverse fault of NNE-SSW. The part of the D_2 member contacting with this fault is overturned at a width of several ten meters. The top of the member is cut off by the Marirang Fault, and the thickness of the member is about 350 m as far as it crops out.

The member is chiefly composed of alternation of sandstone and mudstone with dominant sandstone or with an equivalent quantity of sandstone and mudstone. In the lower part sandstones with a thickness of about 10 cm are intercalated frequently and large scale slump folds develop. In the middle part and the upper part alternation of mudstone and sandstone and several layers of sandstone with a thickness of 1 to 3 m are intercalated, respectively.

D_3 member

This is a thick member consisting of alternation of mudstone and sandstone. The bottom and the top are cut off by the Marirang and Apian Faults, respectively, and the thickness of the member reachs 1,250 m or more.

The lowest part of D_3 member is composed of alternation of mudstone and sandstone (about 250 m thick) with dominant mudstone which intercalates many sandstone layers as seen along the Tarao River (Pl. 3, figs. 1, 2). The next section consists of alternation of mudstone and sandstone with dominant mudstone and intercalates sandstones of a 0.5 to 3 m in thickness and crops out continuously along the Sibalom River. The thickness of the section amounts to about 1,000 m. The sandstone of this section contains calcareous nodules frequently and in the basal part of thick sandstones sometimes granule to pebble congromerates can be observed (Pl. 3, fig. 3). These conglomerates and sandstones contain many fragments of shells and coral.

On the other hand, in the upper part of this member seven layers of white tuff with a thickness of 1 to 3 m are intercalated (Pl. 3, fig. 4). They are composed of massive, white, fine-grained dacitic tuffs, and contain biotite, plagioclase and a little amount of quartz as phenocryst. Similar tuff can be observed along the Tarao River, and so these tuffs is considered to become useful marker beds over a wide area in this basin. Slump structures develop in many horizons of the D_3 member, but their scale are not so large. Generally, the D_3 member contains richly carbonaceous matter, lenticular coals with a thickness of 1 to 10 cm and ambers in the parts along the Marirang Fault.

As described above, the D formation starts with conglomerate, followed by alternation of sandstone and mudstone, and ends with alternation of mudstone and sandstone with dominant mudstone. This shows a large scale sedimentary cycle as a whole.

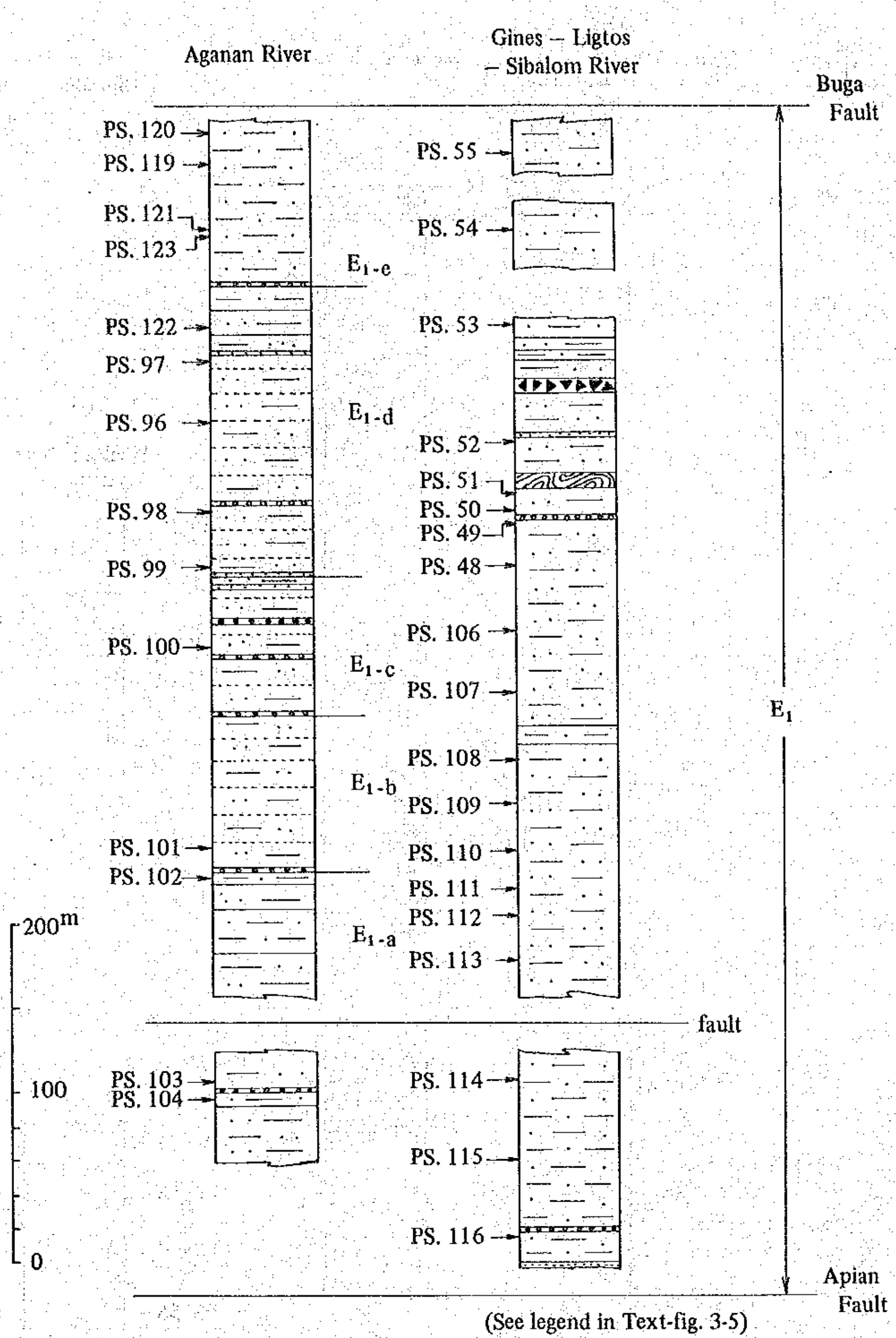
The D formation is Late Miocene (Zone N.16-17) in age based on studing of planctonic foraminifera.

E formation (Text-figs. 3-9, 10)

This formation, which can be observed in the route along the Aganan River in the northern part of the survey area and the Sibalom River in the central part, is divided lithologically into E_1 member below and E_2 member above. Both of the members are separated by a fault.

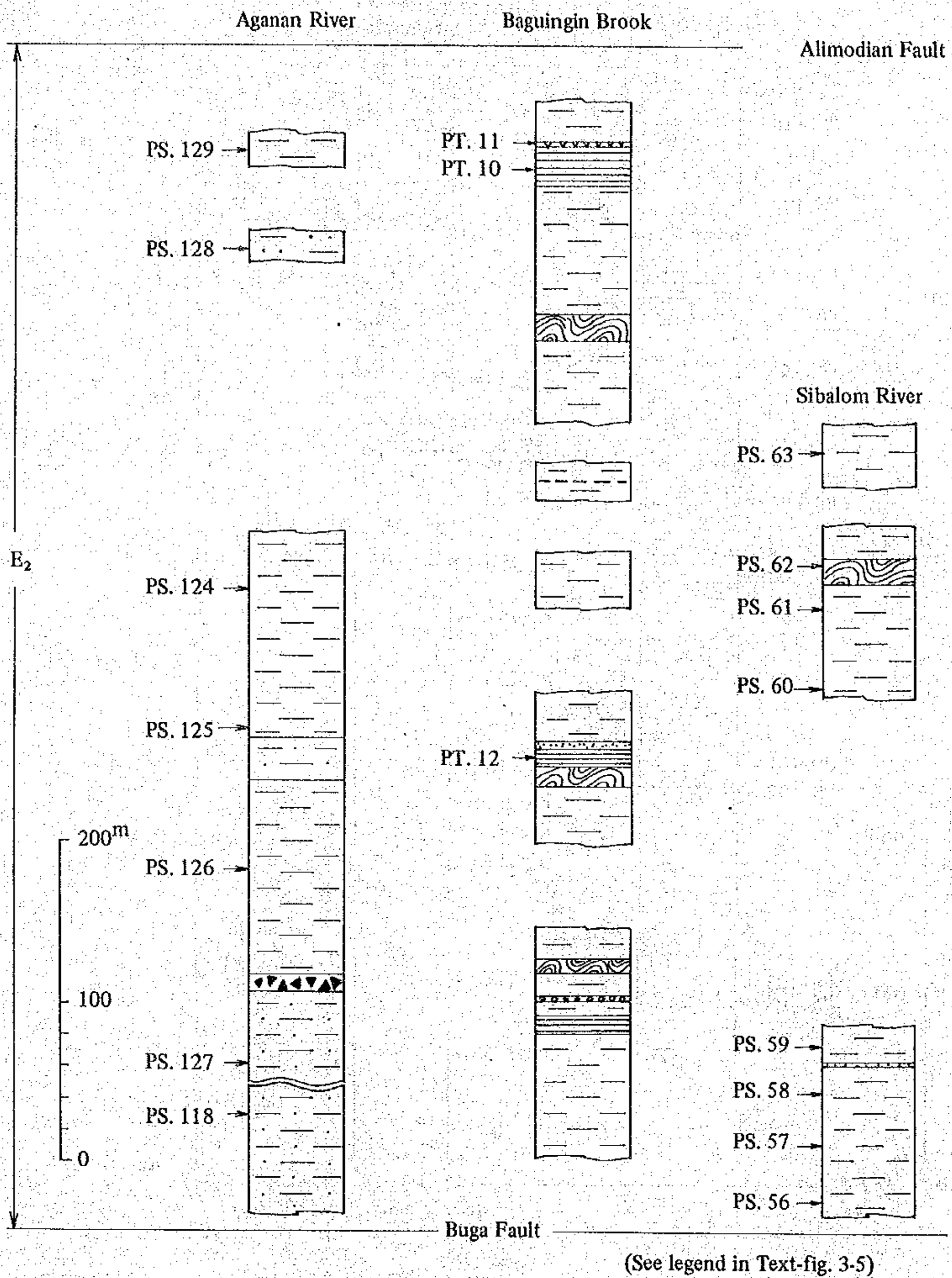
E_1 member

Since the bottom and the top of the member are cut by the Apian and Buga Faults, respectively, and furthermore there are faults in the middle part of the formation, the exact thickness of the member is not clear, but in the area along the Sibalom River this member has a thickness of 700 m or more. Almost all parts of this member are composed of alternation of sandstone and mudstone with dominant sandstone (Pl. 4, figs. 1, 2) accompa-



TEXT-FIGURE 3-9

Columnar sections of the lower part of the E formation.



TEXT-FIGURE 3-10

Columnar sections of the upper part of the E formation.

nied with sandstones, conglomerates and slump deposits. However, in the small block in the west side of the fault extending from the north of Apian to the east of Pajo, alternation of mudstone and sandstone with dominant mudstone can be observed in part. Its thickness is 50 m or more.

This member exposed along the Aganan River is subdivided from the bottom to the top as follows:

E_{1-a}: mainly consisting of alternation of sandstone and mudstone with dominant sandstone, and accompanying a little amount of alternation with dominant mudstone. About 200 m thick.

E_{1-b}: medium to coarse-grained sandstone (sometimes containing granule conglomerate) and alternation of sandstone and mudstone with dominant sandstone or with an equal amount of sandstone and mudstone lie alternately with regular intervals of 0.5 to 1 m. Its thickness is about 100 m.

E_{1-c}: chiefly consisting of alternation of sandstone and mudstone with sandstone dominant or with an equal amount of sandstone and mudstone, in which sandstone to sandy conglomerate or pebbly mudstone is contained very frequently. About 80 m thick.

E_{1-d}: mainly composed of alternation of sandstone and mudstone with dominant sandstone, in which conglomerate and pebbly mudstone are intercalated. About 100 m thick. In this section, generally, carbonaceous materials and fragments of wood are abundant, and sometimes the carbonaceous substances form a lens with a thickness of 2 to 3 cm. In the slightly thick sandstone, cross-bedding is recognized in rare occasion.

E_{1-e}: mainly consisting of alternation of sandstone and mudstone with dominant sandstone or with an equivalent amount of sandstone and mudstone. About 100 m thick.

Almost all parts of the E_1 member observed along the Sibalom River are composed of alternation of sandstone and mudstone with dominant sandstone, and because of a few pebbly beds subdivision like in the case of the Aganan River is difficult.

E_2 member

This layer develops in a wide range in the hilly land in the west of Alimodian as well as in the middle stream of the Sibalom River. The bottom and the top of the member are cut off by the Buga and Alimodian Faults, respectively, and its thickness is approximately 700 m or more as far as it crops out. This member is mainly composed of mudstone with sandstone lamina (Pl. 4, figs. 3, 4) accompanied with alternation of mudstone and sandstone with dominant mudstone and massive mudstone, and sometimes sandstone and conglomerate are intercalated. Various kinds of slump structure such as slump fold develops very well. This member is characterized by high content of well-preserved microfossils such as foraminifera in the mudstone. In the south part of Alimodian three beds of white, fine-grained dacite tuffs (30, 50, and 70 cm thick) are intercalated closely. Lithologically these tuffs are similar to the tuff lying in the upper part of the D_3 member, and contains plagioclase and biotite as phenocryst.

Intercalation of sandstone and conglomerate in the E_2 member tends to become frequent northward. Along the east bank of the Aganan River in the north of Alimodian the intercalated sandy conglomerate contains well-preserved fossils such as molluscan shell and coral. The layer with abundant molluscan fossils near Magsaysay seems to fall into the same horizon. In the south from Alimodian only a little sandstone with a thickness of 3 to 4 m can be observed. A tendency that lithofacies become more fine-grained from north to south can be recognized not only in the E_2 member, but also in whole the E formation.

The E_2 member mainly consisting of mudstone corresponds to the Guimbal Mudstone described by GONZALES et al. (1963) and SANTOS (1968) from a viewpoint of lithofacies.

The E formation has gentle folding with an axis in a west northwest-east southeast direction plunging towards east. Namely, in the E_1 member there is a large anticline of which north wing lies in the middle stream of the Aganan River and south wing lies in the Sibalom River, and in the south west part the formation forms a gentle syncline between the Sibalom and Tarao River. Although the details are not yet known, it is assumed that the E_2 member has an axis similar to that of the E_1 member and repeated folding with a smaller scale. The E formation has a quite different structure from the formations lower than the D, and especially the structual difference between the both sides of the Apian Fault is very remarkable.

According to the result of planktonic foraminiferal analysis, the E formation is referable to Zone N.17 - N.21 (E_1 member, N.17-18; E_2 member, N.19/20-21) and correlated with the upper part of the Tarao Formation of Tarao River section studied by TAKAYANAGI et al. (1977).

F formation

This formation is mainly consisting of conglomerate distributed in the Agony hill in the east side of the Aganan River near Alimodian, and the