GEOLOGICAL SURVEY DEPARTMENT
BRITISH TERRITORIES IN BORNEO

THE GEOLOGY AND MINERAL RESOURCES OF THE SUAI-BARAM AREA, NORTH SARAWAK

BY

N.S. Haile

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MEMOIR 13

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BY

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Geologist
Geological Survey Department
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With contributions to the palaeontology
by J. Harlan Johnson, C. G. Adams
and R. Haak

A coloured geological map on a scale of 1:250,000 is in the pocket inside the back cover

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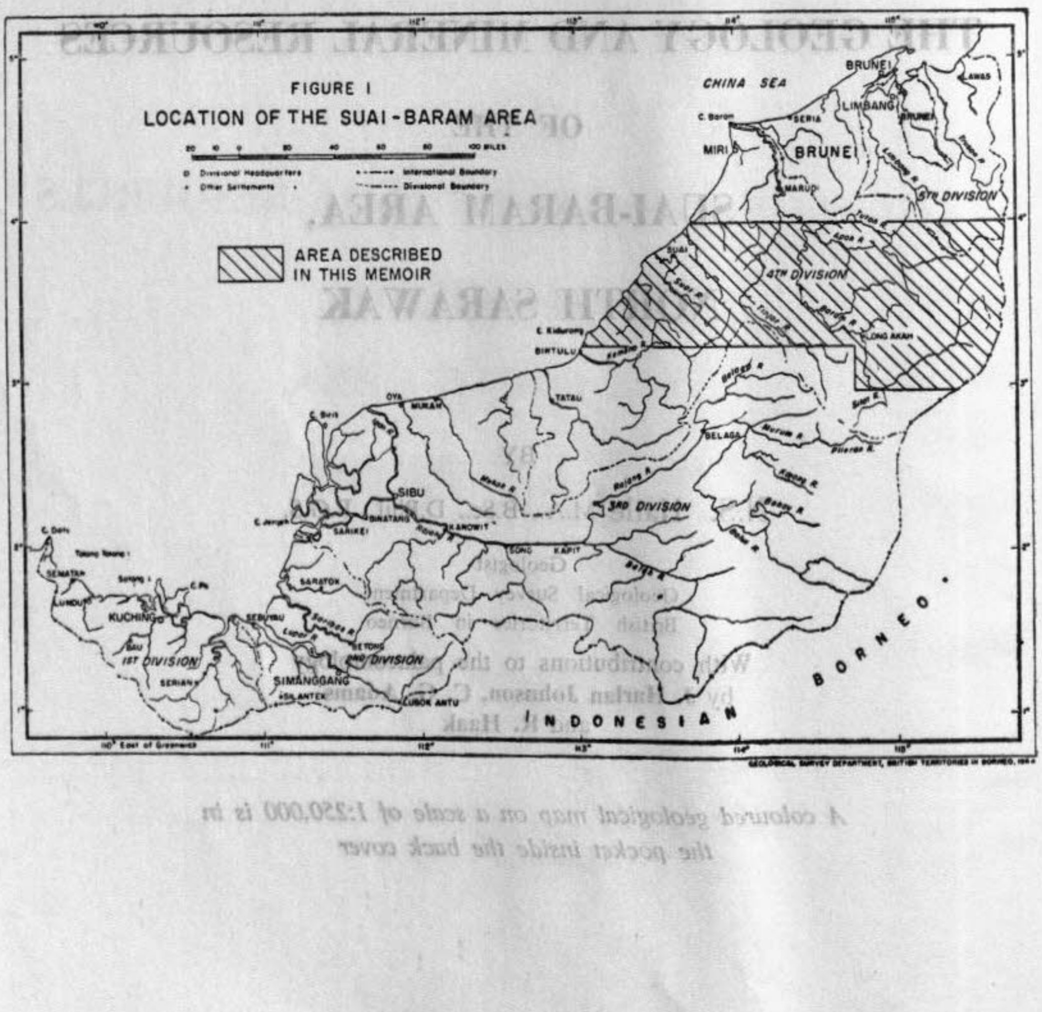

FIGURE I
LOCATION OF THE SUAI-BARAM AREA

PREFACE

This memoir by Dr N. S. Haile, on the geology and mineral resources of the Suai-Baram area in north Sarawak, completes the series describing the reconnaissance surveying of Sarawak. This reconnaissance was designed to give overall coverage in the shortest possible time, and the only areas now unsurveyed are parts of the Kelabit Highlands for which no air photographs are yet available, and which have been left uncoloured on the geological map accompanying the memoir; regional indications of the probable geology of these small unsurveyed areas are such that the expense of a ground survey unaided by air photographs could not be justified at present. The reconnaissance of Sarawak has, as expected, revealed areas worthy of more detailed and thorough examination, mainly in west Sarawak and around Bintulu, and the Geological Survey Department has already begun work on this second phase of systematic geological investigation.

Parts of the Suai-Baram area, which includes the highest country and most turbulent rivers in Sarawak, had already been examined by geologists of Sarawak Shell Oilfields Limited, and their results, generously made available by the company, have been included in the map and memoir. Their work was, however, mainly in the coastal Suai area, and the survey by Dr Haile has added considerably to the scanty geological information previously available for the Baram Valley and Kelabit Highlands. Of special importance are the discovery by him of the Temala Anticlinorium, a large anticlinal inlier of Eocene strata in the middle Baram, and establishment of the fact that the Kelabit Highlands are not an unfaulted block of Eocene rocks, as previously believed, but are composed of younger strata.

Few mineral materials of potential economic importance have been found in the area, and the regional geology indicates that, except for a remote chance that oil and natural gas may occur, mineral developments are likely to be of the more prosaic kind. Limestone is at present quarried for use as roadstone, salt is obtained from salt springs in the more remote areas, and small amounts of phosphate (guano) are dug from caves for local use as fertiliser. Reserves of limestone and shale suitable for cement manufacture are large, and a special study of cement-making possibilities by Dr Haile is recorded in this memoir.

F. H. Fitch
Director
Geological Survey Department
British Territories in Borneo

1 July 1961

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The Geological Survey Department, British Territories in Borneo, operates in Sarawak and North Borneo, and may work in the State of Brunei on request.

References cited in this Memoir are listed on page 165, and are indicated in the text as follows: (Hose, 1910, pp.60-77). Unpublished Reports of Sarawak Shell Oilfields Limited are listed on page 167, and are indicated in the text thus: (Rijsterborgh, *1953*, p.10).

Specimen numbers e.g. S4123, refer to specimens in the Museum of the Geological Survey, Kuching, Sarawak.

The following Malay and Kayan geographic terms are used in the report:

Batang	Main River	Long	Mouth of tributary
Bukit (Bt)	Hill or mountain	Sungai (S.)	River
Gunong (G.)	Mountain	Tanjong (Tg)	Headland or cape
Kuala	Estuary	Ulu	Headwaters of a river

PLATE I TUTOH VALLEY AND MOUNT MULU. The aerial view, looking northwest, shows deeply dissected ntry built of Kelalan and Setap Shale Formation in the foreground and middle distance, covered by unbroken nary forest. In the far distance the mountains built of Mulu Formation can be seen. The river in the r left is the Tutoh just below the Kuba'an tributary (*see p.10*)

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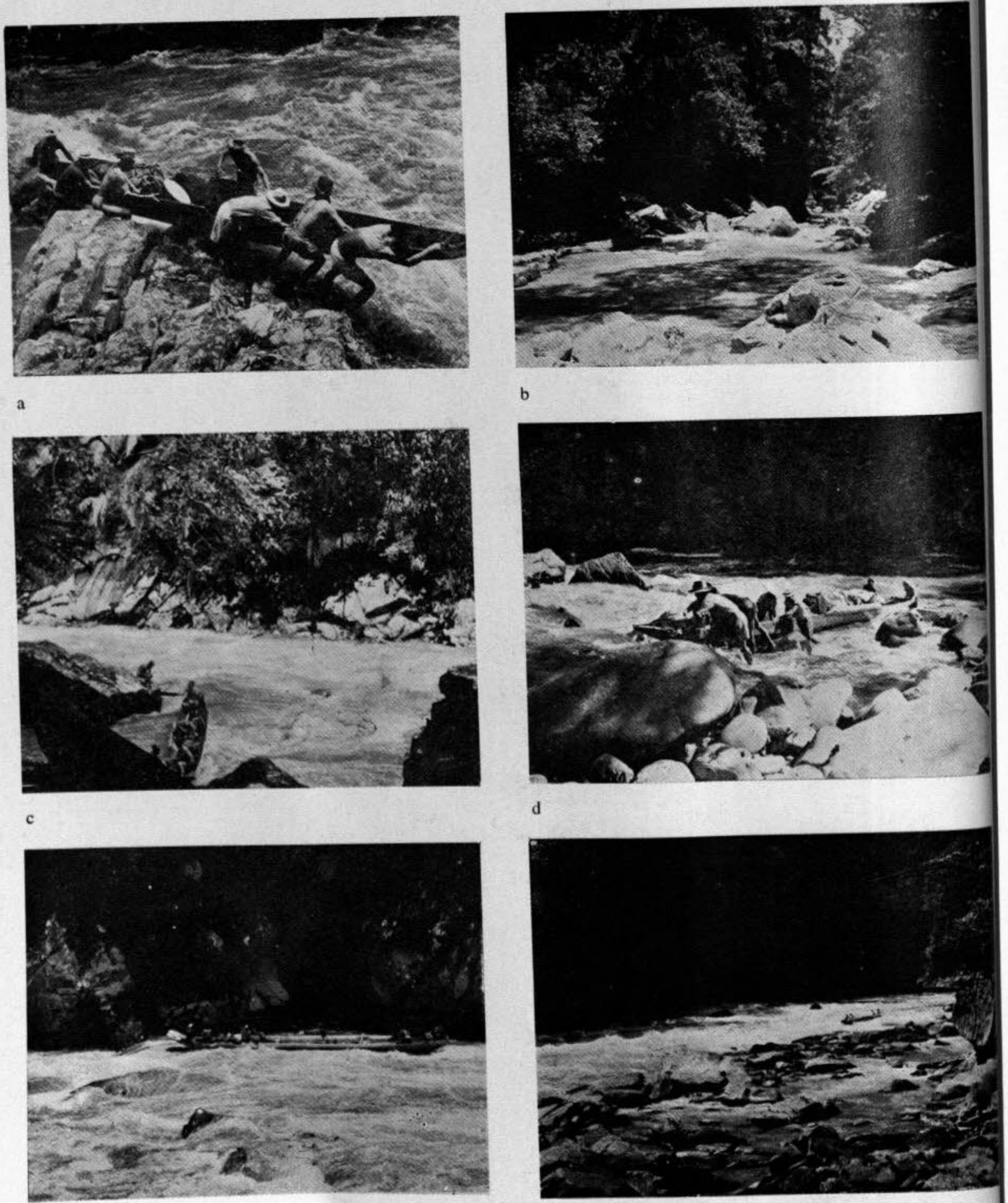


a b c d e f

PLATE II. RIVER SCENES. a-d Akah River; e-f Tutoh Gorge (*see pp.15, 16, and 29*)

Photographs e and f: I.A.N. Urquhar

Chapter I

INTRODUCTION

SUMMARY

The memoir describes the geology and mineral resources of about 9,100 square miles in north Sarawak, comprising the Suai Valley and adjacent coastal areas, most of the Baram Valley, and the Kelabit Highlands.

The area is built almost entirely of sedimentary rocks that range in age from Upper Cretaceous to Recent, and include Palaeocene, Eocene, Oligocene, Miocene, probable Pliocene, and Pleistocene, strata. The total maximum thickness of the systems outcropping in the area is estimated at about 45,000 feet. The rocks are sandstone and shale, with a few limestone lenses. A major unconformity occurs between the Upper Pliocene and Miocene, and there is an unconformity or disconformity between the Miocene and Upper Eocene over most of the area.

Igneous rocks are rare and comprise sparse tuffitic material indicative of Palaeocene extrusive activity, dykes of olivine basalt in the Tinjar Valley, probably Pliocene or younger, and tuffaceous material in strata of probable Pliocene age.

The regional strike is northeast becoming north in the Kelabit Highlands. Folding is intense in the older formations, gentle to moderate in the younger ones.

The mineral resources include: limestone and shale suitable for the manufacture of cement; sand and gravel; pure sand probably suitable for glass making; lignite; phosphate (guano); salt springs; and small occurrences of ores of antimony and arsenic. At present limestone worked as roadstone, salt, and phosphate (guano), are the only mineral resources exploited. There is some chance of oil and natural gas being found in the area but exploration and drilling have so far not resulted in the discovery of any commercial deposits.

METHOD OF INVESTIGATION

The writer started work in the area in October 1956, when he mapped limestone at Batu Gading and nearby. In October 1957, mapping of the limestone was continued, and an investigation of antimony, arsenic, and reported mercury was made. A start was made in assembling and studying the few available published records on the geology of the area, and the unpublished reports of geologists of Sarawak Shell Oilfields Limited (hereafter referred to as SSOL). In 1958, regional mapping of the middle Baram and its eastern tributaries (the Akah, Patah, and Tutoh) was started, concentrating on unsolved problems and on parts which had not been surveyed by SSOL geologists. In 1959, this mapping was extended into the Kelabit Highlands by a traverse from the Limbang River down the Magoh River, thence up the Tutoh to Kuba'an, Bareo, and Lio Matu. In 1960, a field trip was made with C. G. Adams of the British Museum to the Niah area and the upper Baram, mainly to collect foraminiferal limestones. Between field trips, compilation from SSOL reports, preparation of maps, photogeology, and petrography were done in Kuching. Until February 1960 the work was under the general supervision of F. W. Roe; afterwards under F. H. Fitch.

The present report is based largely on reports of SSOL geologists, whose work is outlined below. This is especially so in the west, where a number of detailed surveys were made by them. In the central and eastern parts, only reconnaissance surveys had been made, and the present survey was able to supplement these, resulting in several advances in stratigraphic knowledge. Contributions to the palaeontology by C. G. Adams and R. Haak (Foraminifera) and J. Harlan Johnson (Algae) are an addition to the considerable knowledge gained by several decades of painstaking research by palaeontologists of SSOL. Finally, this memoir includes results of investigations of mineral resources other than oil, which were naturally not investigated by geologists of SSOL.

The topographical base of the map in this report is essentially that of the unpublished 1:250,000 geological maps prepared by the topographical department of SSOL in Seria. This base is comparatively reliable in the west, becoming increasingly less so in the east where ground control is virtually absent. Some improvements have been made to this map since a number of astrofixes were done by the Land and Survey Department, Sarawak, in late 1959. As the map stands, the most serious distortions occur in the upper Tutoh River, and along the Kuba'an tributary in particular. Nevertheless, it is probably more accurate than any map of the area published so far.

Published maps showing the area are the 1:500,000 geological map accompanying the compilation report by Liechti et al (1960), and the 1:250,000 Land Utilization Map of Sarawak and Brunei, Sheets 4 and 6, published by the Land and Survey Department, Kuching.

The coloured map accompanying this report has been drafted in the Kuching office of the Geological Survey by Mr Balia bin Haji Mohamad, while the text figures and maps have been drafted by Messrs Lett bin Ali and Goh Geok Soon.

Field parties consisted of the writer and one or two Technical Assistants. Porters and boatmen were recruited locally for each trip, and, as everywhere in Sarawak, proved excellent workmen, cheerful companions and guides, and generous hosts. The field parties lived in long-houses or in camps in the forest. At various times the writer was assisted in the field by Mr Teo Chai Khoi, Senior Technical Assistant, and by Messrs Nyambong anak Ah Beng and Joscellyn Sullang, Junior Technical Assistants.

As in all recent geological surveys in Borneo, air photographs played an essential part in interpreting both the stratigraphy and the structure. Photographs on scales 1:25,000 and 1:35,000 are available of most of the areas with the exception of the Kelabit Highlands, which had still not been photographed by the end of 1960. SSOL photogeologists had already made detailed photogeological maps of the west and central parts of the area and reconnaissance photogeological maps of such other parts where photographs were available. The photogeology on the map in this report is mainly compiled from these with slight amendments in the central part (i.e. middle Baram Valley) and some additions in the west from photographs taken after the SSOL maps were made.

HISTORICAL REFERENCES

The area was originally part of the Brunei Sultanate until its piecemeal cession to the Rajahs of Sarawak in 1861 (Kemena and Rajang Valleys), 1882 (Suai and Baram Valleys), and 1890 (Limbang Valley). Robert Burns was the first traveller to make scientific observations in the area. In 1848, he followed the Kemena River to its source. Later on, he went up the Baram River as far as the Kayan villages, and wrote the first account of this tribe. Tom Harrisson has reviewed Burns' work (1951).

One of the first accounts of the area is given by Spencer St John (then H.M.'s Commissioner in Borneo) who first went up the Baram River to near Long Lama in 1851. In his book *Life in the forests of the Far East* (1862, pp.79-124), he records a visit he made to the Kayan tribes at the request of the Brunei Malays, and describes their method of smelting iron.

Charles Hose arrived in Sarawak in 1884 and was posted as a Cadet to Marudi, under the Honourable Claude Champion de Crespigny, then Resident, and except for a short period in the Rajang was stationed in the Baram until 1907. He made many expeditions in the area, collecting animals and plants, and native artefacts, and described them in various books (Hose and McDougal, 1912; Hose, 1926, 1927, 1929). He made the first recorded ascent of Dulit in 1891, with A. H. Everett.

The first Oxford expedition to Borneo made investigations in the Dulit Range, and recorded their results in a popular book (Harrisson, Editor, 1938) and numerous papers which were later collected and republished (Various authors, 1952).

During and after the Second World War, T.H. Harrisson explored the Kelabit Highlands, and has published numerous papers on the geography, ethnology, and archaeology of the area (see Harrisson, 1959, which includes a list of most of the important recent references).

Numerous papers by various authors on the archaeology and zoology of the Niah Caves at Bukit Subis have been published in the *Sarawak Museum Journal* since 1954 (see especially vol. 8, No. 12, 1958; vol. 9, No. 13-14, 1959).

PREVIOUS GEOLOGICAL INVESTIGATIONS

The area was prospected for antimony and other minerals from 1843 onwards. Some of the details were published in the *Sarawak Gazette,* and extracts are given in Chapter IX below. During the course of these investigations, H. T. Burls, geologist to the Rajah, collected rock specimens, including some fossiliferous limestones from 'Silungen in Soubis' and from Batu Gading, that were reported on by A. V. Jennings (1888).

Since 1910, various field parties of the Royal Dutch/Shell Group have investigated the area, concentrating on the Suai District. The more important investigations are listed in table 1, and details of exploration wells are shown in table 2.

G. E. Wilford of the Geological Survey made an investigation of the phosphate deposits of the Niah Caves at Bukit Subis (1951) and later made a brief examination of limestone in the middle Baram (1955a). He compiled data on salt springs in the Kelabit Highlands (1955b) and later visited the area and published a comprehensive account of them (1957). Progress reports on the present writer's investigations were published in departmental annual reports (1956; 1957; 1958a and b), and F. W. Roe reviewed cement-making possibilities in the area (1957). From 1958 to 1959 P. Liechti of SSOL, in collaboration with the Geological Survey, compiled all the available geological data of the whole of Sarawak on maps on a scale of 1:250,000, mainly from reports of the Shell Group but including available results of the present survey. During this investigation, parts of the Suai area were re-mapped photogeologically by P. Scanlon of SSOL. The results were published on a scale of 1:500,000 with a comprehensive text (Liechti, P., Roe, F. W., and N. S. Haile, 1960). Parts of the present report, in particular the formation

TABLE 1. OUTLINE OF THE MAIN PREVIOUS INVESTIGATIONS OF THE SUAI-BARAM AREA

All previous investigations were by geologists of the Shell Group; the results were not published.

Date	*Investigations*	*Remarks*
1913-14	A. R. Andrew	Made the first observations on the coast in the area of Semilajau and Likau Rivers.
1927	E. Braendlin	Short investigation of the coast from the Bintulu River to the northeast. Determined larger Foraminifera from sandy limestones and calcareous sandstones found in five places north of the mouth of the Likau, and correctly assigned them to the Aquitanian.
1928	O. Wilhelm	First reconnaissance of the Tinjar River, also examined the Batu Gading limestones.
1928	J. B. Woolley	Geological observations in the upper Baram while on local leave. Reported mainly sandstones and dark shales, mostly with steep dips and often contorted.
1928	H. Knecht	Batu Blah and Linei area.
1930	H. Knecht	A reconnaissance of the Subis structure and its southwestern extension.
1931	D. Morgan	Middle Baram Valley.
1933	D. Trumpy and D. E. Morgan	Preliminary notes on the geology of the Mulu Range.
1933	D. Trumpy	Baram Valley, Mulu, and Tinjar Valley.
1933-34	D. Trumpy and J. Irving	Rapid reconnaissance of the Kelabit Highlands. Walked 17 days from the Upper Limbang to Lio Matu. Noted the steep folding throughout the area except for the Kelabit Highlands.
1940	A. M. Oosterbaan	Reviewed distribution of larger Foraminifera in the Bintulu and north Semilajau area.
1940	W. R. Royd	Explored the coast between the Likau and Semilajau, as well as these rivers, and also made a connecting survey along the Siud and Tekan Rivers.
1940	W. F. Schneeberger and R. Bachlin	Reconnaissance of the 'Tidoengsche Landen en Boeloengan' (mainly in Kalimantan). Also covered part of the boundary area between the Kelabit Highlands and Kalimantan.
1950	I. L. Burr and W. E. Crews	Subis-Bintulu area.
1951	I. L. Burr	Likau-Bintulu area.
1951	J. B. Hanson-Lowe	Sabulong anticline photogeology.
1952	K. A. Rijsterborgh and R. Haak	Subis-Bintulu area.
1952	P. Heybroek	Detailed photogeological analysis of the Sabulong area.
1953	H. Widmer	Reconnaissance of the Tinjar and Upper Baram areas.
1954	M. F. Shepherd	Gunong Mulu-Belinau [i.e. Melinau] area.
1954	H. C. Kavelaars	Detailed investigation of the Selungun Anticline in the Subis area.
1955	H. A. Jordi and K. A. Wijkhuizen	Reconnaissance of the Ulu Limbang to Ulu Trusan area, extending into the northeast corner of the Suai-Baram area.
1956	M. F. Shepherd and J. R. van de Fliert	Engkabang, Linei, and Batu Blah area, in the middle Baram around the mouth of the Tutoh River.

TABLE 2. EXPLORATION WELLS DRILLED BY SARAWAK SHELL OILFIELDS LIMITED IN THE SUAI-BARAM AREA

Well	Year	Depth (feet)	Formations penetrated
Subis 1	1951-53	1,000	Tangap, Nyalau, and Setap Shale Formations
Subis 2		10,708	
Suai 1	1952	3,833	Quaternary and Lambir Formation
2	1952-53	3,567	Quaternary, Lambir Formation, Setap Shale Formation, and Tangap Formation
3	1953	1,286	
4	1954-55	2,232	
5	1955	5,443	
6	1955	1,979	
Selungun 1	1956	7,374	Nyalau and Setap Shale Formations

descriptions and map are based on this joint compilation. C. G. Adams of the British Museum made a trip with the writer to the Batu Gading and Batu Tujoh areas in April 1960 and collected foraminiferal samples for study.

ACKNOWLEDGEMENTS

Assistance from the following is especially acknowledged:

The Exploration Department of Sarawak Shell Oilfields Limited made numerous identifications of Foraminifera, and made available unpublished reports and maps.

Dr E. I. White, Keeper of Geology at the British Museum (Natural History), arranged for fossils to be identified by the late Mr A. G. Davis, and Dr C. G. Adams and Mr G. F. Elliott.

The Mineral Resources Division of the Overseas Geological Surveys, London, made many chemical analyses, supplied photomicrographs, and gave technical advice on cement-making possibilities.

Mrs Hedda Morrison, and Mr I. A. N. Urquhart, M.C., gave a number of photographs of the Baram area.

Mr J. A. R. Anderson, M.C. and bar, of the Forestry Department, Kuching, supplied the photograph of Batu Lawi.

Mr T. H. Harrisson, D.S.O., M.B.E., Curator of the Sarawak Museum, gave assistance and advice on travelling to the Kelabit Highlands and visiting the Niah Caves.

Officers of the Sarawak Civil Service and others helped in arranging field trips, in particular Mr H. A. L. Ferguson, Penghulu Lawai, B.E.M., Mr. M. M. McSporran, Temonggong Oyong Lawai Jau, B.E.M., Mr R. Pole-Evans, Mr C. H. Southwell, and Mr I. A. N. Urquhart, M.C.

The Baram people, especially the skilled boatmen of Saridan and Buyo Villages (including the intrepid humorist Tai Rajah), who twice accompanied the writer on the difficult traverse of the upper Tutoh gorge.

Chapter II

GEOGRAPHY AND PHYSIOGRAPHY

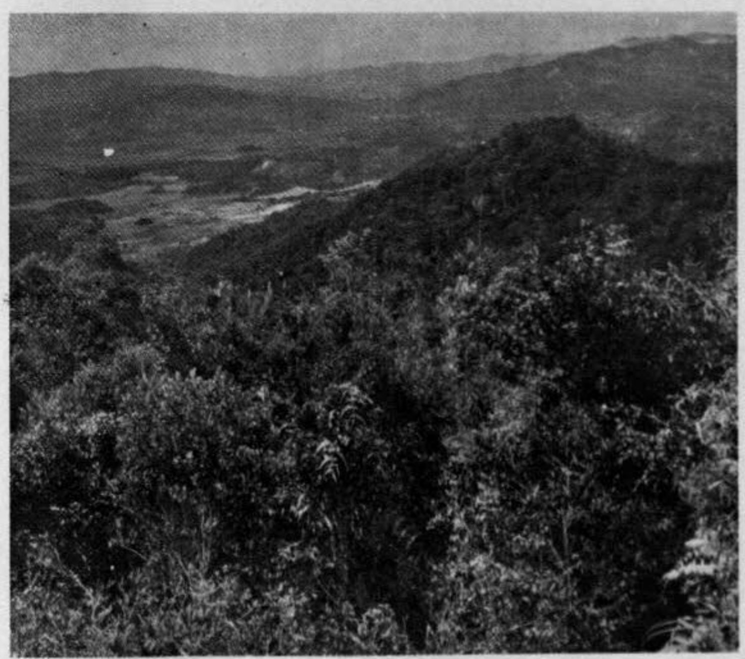
GENERAL GEOGRAPHY

The area surveyed is about 9,200 square miles. The northern boundary is latitude 4°00′N; west of longitude 115°45′N, the southern boundary is latitude 3°15′N, and, east of that longitude, is latitude 2°58′N. On the west, the area is bounded by the South China Sea; on the east by the international boundary with Kalimantan (Indonesian Borneo), which follows the unsurveyed watershed between the Baram and Limbang Rivers of Sarawak, and the Kajan and Sesajap Rivers of Kalimantan. For convenience of description three subdivisions are distinguished in the account: the Suai area, west of 114°E; the Tinjar and middle Baram area, between 114° and 115°E; and the Kelabit Highlands, east of 115°E.

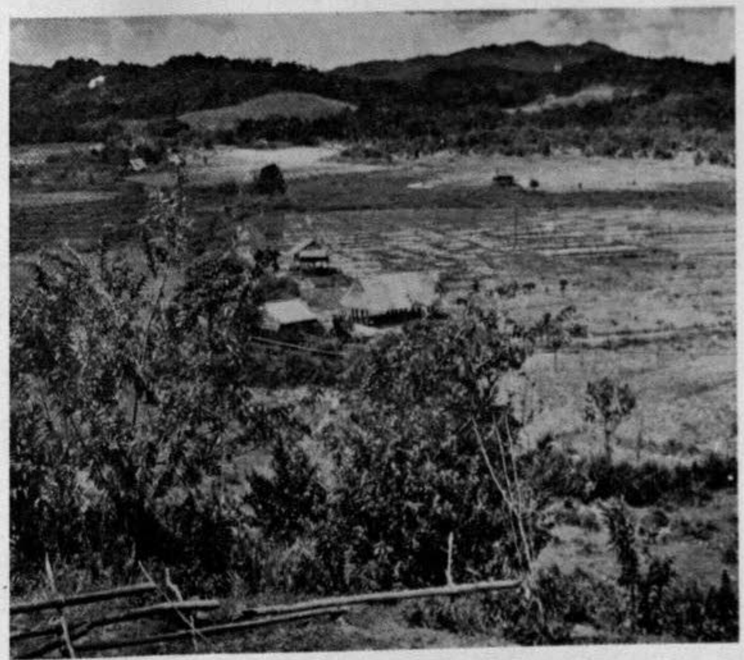
The area lies mainly in the Fourth Division, but includes a small part of the Third Division in the south, and of the Fifth Division in the northeast. It includes most of the Marudi and Miri Districts, although the administrative headquarters of these districts lie north of the area, and small parts of the Bintulu, Kapit, Limbang, and Lawas Districts. Government stations with court-houses are maintained at Niah and Suai on the coast and at Long Lama and Long Akah inland. Sometimes a junior administrative officer is stationed at Niah, otherwise there are no administrative officers in the area. There are small Chinese bazaars at these stations and elsewhere in in the area.

The climate is humid. According to Seal (1958, map I) the annual rainfall over most of the area is 120 to 160 inches; Long Akah, however, has the highest rainfall in Sarawak with an average of 236 inches a year (see table 3). The rain is fairly evenly distributed throughout the year, with slightly more falling from October to March. The temperature on the coastal belt is probably similar to that of Miri, about 80°F, and rarely exceeds 90° or drops below 70°. In the Kelabit Highlands the temperature is much lower, especially at night. No systematic temperature records are available for any part of the Suai-Baram area.

Most of the area is covered by primary lowland rain forest. Shifting cultivation of hill rice is mainly confined to areas adjacent to the main rivers. Swamp forest occurs in the lower reaches of the rivers, and moss forest on the mountains above 4,000 feet.



a



b

PLATE III. BAREO. Looking southeast from Tamabo Range (a), and from the Kubu (b) (*see pp.11, 12*)

Photographs by Hedda Morrison

a

b

PLATE IV. TINJAR VALLEY. The serrated scarp of the Dulit Range (a), and view of the Tinjar River near the Tisam tributary (b) (*see pp. 11, 57*)

Photographs by Hedda Morrison

TABLE 3. RECORDS OF MONTHLY RAINFALL

(in inches)

	Long Akah Lat. 3° 46′N Long. 114° 24′E										Tanjong Tahap Baram Lat. 4° 00′N Long. 114° 30′E		
	1951	1952	1953	1954	1955	1956	1957	1958	1959	Average 1951-56: 1958-59	1955	1956	1957
Jan	14·0	13·5	18·0	16·1	23·9	22·3	24·7	20·1	7·1	16·9	11·9	13·1	11·5
Feb	21·2	17·8	26·8	14·9	23·4	21·8	12·1	24·6	19·6	21·3	12·4	12·0	7·7
Mar	20·5	29·4	7·3	19·7	18·0	17·3	18·6	18·9	17·9	18·6	10·5	11·5	12·0
Apr	15·7	14·8	21·7	32·2	24·0	13·0	22·4	13·5	15·8	18·8	13·2	6·7	9·7
May	17·3	15·2	25·6	31·8	13·0	21·4	27·5	18·9	21·7	20·6	16·7	16·5	16·4
Jun	6·3	7·6	10·8	21·2	16·2	17·3	26·5	20·3	21·2	15·1	9·9	17·6	12·4
Jul	18·7	17·7	26·1	9·0	16·0	22·7	25·5	7·2	16·3	16·7	15·7	11·7	7·3
Aug	13·4	10·6	14·2	31·1	23·3	18·1	12·3	16·4	24·1	18·9	13·2	6·8	5·6
Sep	9·9	15·8	19·1	25·0	26·0	15·4	22·7	17·9	26·6	19·5	24·1	13·0	11·2
Oct	23·5	17·4	24·7	32·2	16·0	29·9	NR	14·8	19·0	22·2	10·7	11·6	15·9
Nov	32·6	22·3	21·9	21·2	33·1	29·7	17·8	23·4	21·1	25·7	12·3	9·8	11·2
Dec	20·9	19·1	21·2	22·8	23·9	14·5	11·3	23·4	27·1	21·6	14·1	20·0	16·3
TOTAL	214·0	201·3	233·2	277·0	256·9	243·4	NR	219·4	237·5	235·9	164·7	150·3	137·2

NR = Not recorded

Transport is mainly by rivers, as there are no roads in the area. Small launches can reach Long Teru on the Tinjar, Long Laput on the Baram, and Batu Niah on the Niah, and not far above Suai town on the Suai. Above these places, travel is by long-boats (*perahus*) powered by outboard motors. There are airstrips at Long Akah, Bareo, Long Tebangan, and Ba Kelalan.

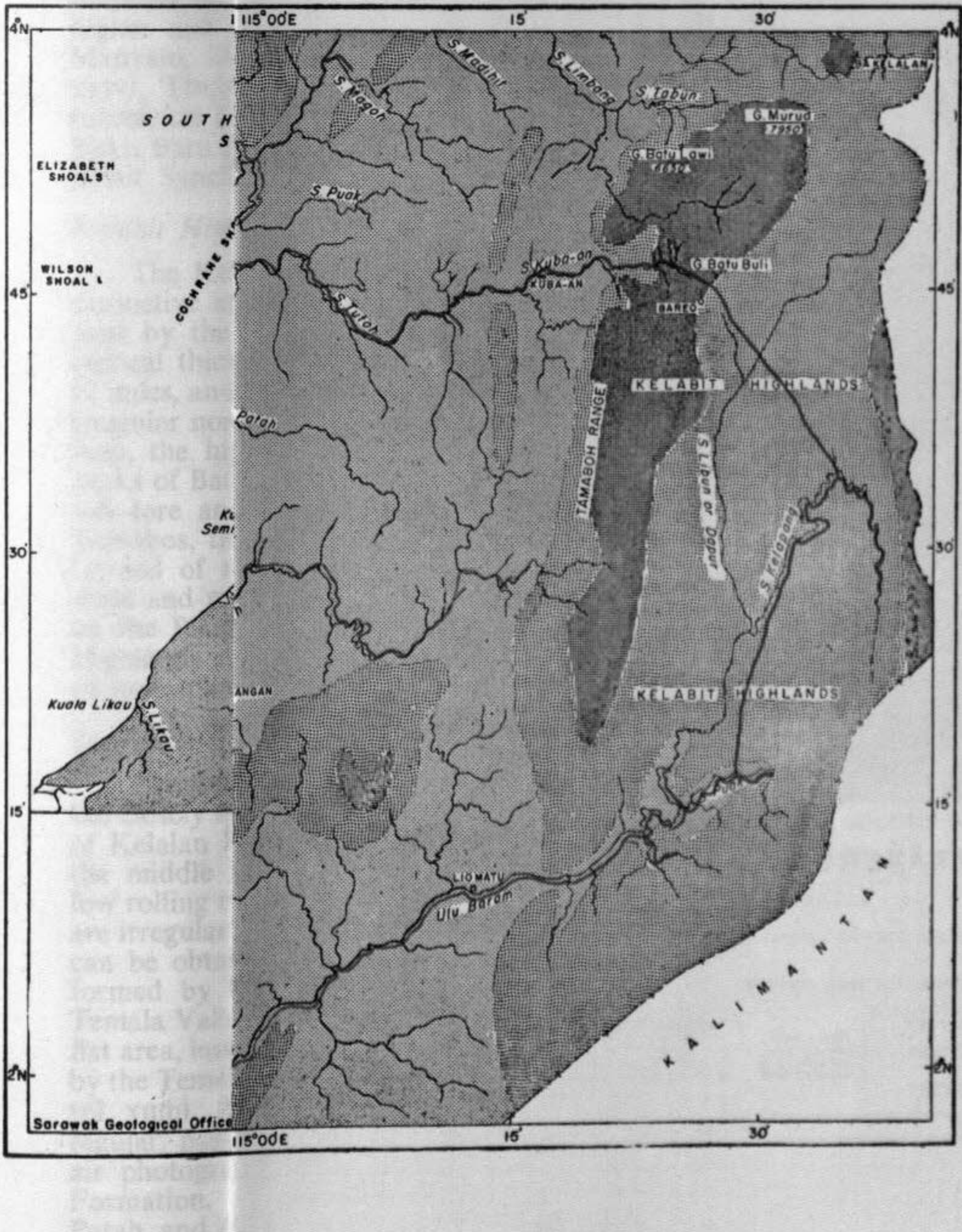
The area is sparsely inhabited, mostly by indigenous people. A few Muslims (Malays, Melanaus, and Kedayans) live in the coastal strip; inland these give way to Ibans, who live in the upper Kemena, Suai, and Niah, and the lower Tinjar. Kayans and Kenyahs inhabit the middle Baram and upper Tinjar, and Berawans, a tribe now reduced to a few villages, live in the Tinjar. The Kelabit Highlands take their name from the Kelabits who live there. A few hundred nomadic Punans inhabit the vast areas of forest east of the Baram, and some Punans have settled on the Apoh. Chinese traders have settled along the lower parts of the rivers, and venture farther upriver in small trading boats. The only European residents are missionaries from the Roman Catholic and Borneo Evangelical Missions, with the sole exception (in 1955) of a Government Community Development Officer at Long Lama. The population density on the coasts is probably about 6 to the square mile and about 2 to 3 over the rest of the area. Most of the inhabitants are farmers, planting hill rice by a system of shifting cultivation.

TOPOGRAPHY AND GEOMORPHOLOGY

Most of the area consists of broken irregular hilly lowlands built of Setap Shale Formation from which rise mountain ranges formed of anticlinal inliers of older strata and synclinal outliers of younger strata (see figs. 2 and 7). Alluvial plains occur in the Baram Valley and in the Suai area. The grain of the country and the trend of the ranges in general closely reflect the regional strike, which is northeast in the west, becoming more northerly in the east. The various topographic units are described below:

Isolated Mountain Ranges

The Mulu Range is a remarkable assemblage of chaotic steep ridges, on either side of the Tutoh Gorge. The highest peak is Mulu (7,789 feet), which lies beyond the northern limit of the area described (see pl. I). The name 'Mulu' is unknown to the inhabitants of the Tutoh, who call the mountain Ubong, from the river which rises there. The ridges, formed by the strongly folded sandstone and slate of the Mulu Formation, trend in various directions, and most do not follow the strike as observed in the field.



4°N
115°00'E
15'
30'
SOUTH
ELIZABETH SHOALS
WILSON SHOAL
COCHRANE SH
45'
30'
15'
2°N
S. Madihit
S. Limbang
S. Tabun
S. Kelalan
S. Magoh
G. Murud 7950
G. Batu Lawi 6652
S. Puak
S. Kuba-an
KUBA-AN
G. Batu Buli
BAREO
S. Tutoh
KELABIT HIGHLANDS
TAMABOH RANGE
Patah
S. Libun or Dapur
S. Kelapang
KELABIT HIGHLANDS
Kuala Likau
S. Likau
LIO MATU
Ulu Baram
KALIMANTAN
Sarawak Geological Office

Transport is mainly by rivers, as there are no roads in the area. Small launches can reach Long Teru on the Tinjar, Long Laput on the Baram, and Batu Niah on the Niah, and not far above Suai town on the Suai. Above these places, travel is by long-boats (*perahus*) powered by outboard motors. There are airstrips at Long Akah, Bareo, Long Tebangan, and Ba Kelalan.

The area is sparsely inhabited, mostly by indigenous people. A few Muslims (Malays, Melanaus, and Kedayans) live in the coastal strip; inland these give way to Ibans, who live in the upper Kemena, Suai, and Niah, and the lower Tinjar. Kayans and Kenyahs inhabit the middle Baram and upper Tinjar, and Berawans, a tribe now reduced to a few villages, live in the Tinjar. The Kelabit Highlands take their name from the Kelabits who live there. A few hundred nomadic Punans inhabit the vast areas of forest east of the Baram, and some Punans have settled on the Apoh. Chinese traders have settled along the lower parts of the rivers, and venture farther upriver in small trading boats. The only European residents are missionaries from the Roman Catholic and Borneo Evangelical Missions, with the sole exception (in 1955) of a Government Community Development Officer at Long Lama. The population density on the coasts is probably about 6 to the square mile and about 2 to 3 over the rest of the area. Most of the inhabitants are farmers, planting hill rice by a system of shifting cultivation.

TOPOGRAPHY AND GEOMORPHOLOGY

Most of the area consists of broken irregular hilly lowlands built of Setap Shale Formation from which rise mountain ranges formed of anticlinal inliers of older strata and synclinal outliers of younger strata (see figs. 2 and 7). Alluvial plains occur in the Baram Valley and in the Suai area. The grain of the country and the trend of the ranges in general closely reflect the regional strike, which is northeast in the west, becoming more northerly in the east. The various topographic units are described below:

Isolated Mountain Ranges

The Mulu Range is a remarkable assemblage of chaotic steep ridges, on either side of the Tutoh Gorge. The highest peak is Mulu (7,789 feet), which lies beyond the northern limit of the area described (see pl. I). The name 'Mulu' is unknown to the inhabitants of the Tutoh, who call the mountain Ubong, from the river which rises there. The ridges, formed by the strongly folded sandstone and slate of the Mulu Formation, trend in various directions, and most do not follow the strike as observed in the field.

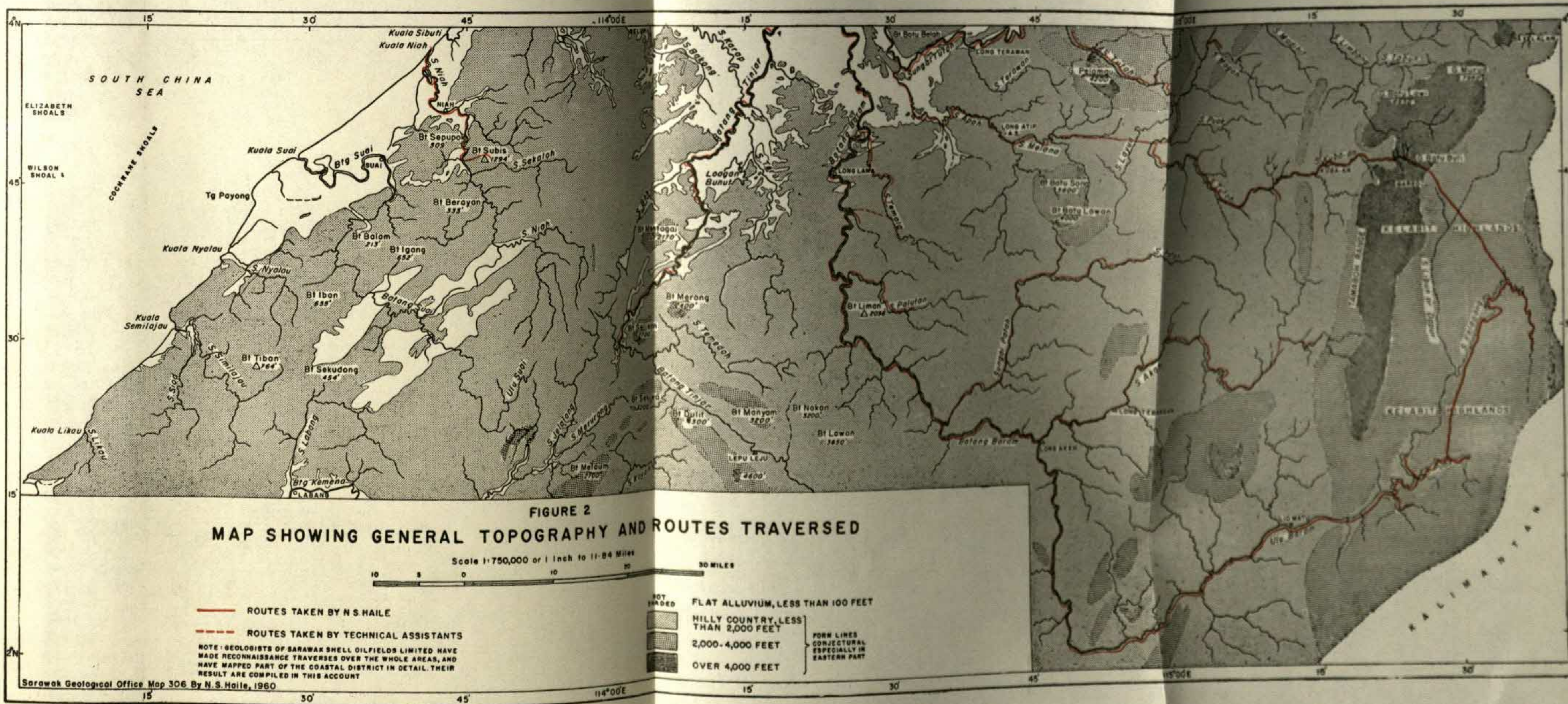


FIGURE 2
MAP SHOWING GENERAL TOPOGRAPHY AND ROUTES TRAVERSED

Impressive and rugged mountain ranges bordered by steep scarps are formed by the thick sandstone beds of the Belait and Meligan Formations, which occur in synclinal outliers on the lowlands. The largest outlier is the complicated series of synclines between the Tinjar River and the Suai and Niah Rivers. To the east, higher and more typical isolated ranges of this type are Selikan, Manyam, Dulit, Liman, Lawan, and Murud Kechil (pls. IV, XXIII, XXIV). The southwest flank of the Dulit Range is formed by a thick succession of sandstones assigned to the Nyalau Formation (pl. XX). Bukit Batu Blah in the Tutoh Valley is the southern tip of the large Belait Syncline.

Kelabit Highlands

The Kelabit Highlands in the eastern part of the area have a distinctive and more regular topography. They are bounded on the west by the Tamabo Range, a series of ridges formed by nearly vertical thick sandstone beds, which extends north-south for some 12 miles, and average 4,000 to 5,000 feet in height (pls. XXI, XXII). The irregular northern extension of these sandstones builds Murud (7,950 feet), the highest mountain in Sarawak, and the remarkable twin peaks of Batu Lawi (6,650 feet) which have a prominent place in the folk-lore and religion of the Kelabit people (pl. X). East of the Tamabos, the highlands consist of a number of north-south ridges, formed of successions of sandstone beds, separated by valleys of shale and marl, with encased areas of alluvium, especially extensive on the Plain of Bah round Bareo (pl. III). The topography of the Highlands is largely unknown in detail, owing to the lack of air photographs.

Lowlands

The lowlands are formed mainly of Setap Shale Formation and the closely allied Sibuti, Tangap, and Nyalau Formations, and inliers of Kelalan Formation. Near the coast and in the northern part of the middle Baram Valley, these formations express themselves as low rolling rather featureless country (pl. VIIIa). Most of these ridges are irregular in trend; only a general and uncertain idea of the strike can be obtained from air photographs. Some of the lowlands are formed by the Eocene Kelalan Formation, such as those in the Temala Valley, where the Temala Member forms a distinctive rather flat area, less dissected than the Setap Shale Formation, and breached by the Temala River which cuts through the anticline in a steep gorge (pl. XIIIb). Along the flanks of the anticline, the topography is less regular, passing into ridges which cannot be easily distinguished on air photographs from those formed by the overlying Setap Shale Formation. Other inliers of Kelalan Formation, e.g. in the Tutoh, Patah, and Akah Valleys, form belts which likewise cannot be distinguished topographically from the Setap Shale Formation. The Nyalau Formation, a predominantly sandy succession which overlies and interfingers with the Setap Shale in the Suai area, forms more regular features. In this area, the Subis Limestone forms a prominent flat-topped mountain bounded by cliffs (see pls. VIa, XVIII, XIX).

Alluvial plains and terraces

Small raised terraces of beach sand occur along the coast south-west from Kuala Nyalau. This and short sections at Miri and near Lawas are the only parts of the Sarawak coast north of the Lupar estuary where there is no swampy alluvial plain and where pre-Quaternary rocks outcrop in low cliffs along the beaches. Together with the existence of encased areas of alluvium in the upper Suai and Niah Rivers, these cliffs point to recent uplift there. The coast north-east of Kuala Nyalau is backed by an alluvial plain as much as 8 miles wide, covered with swamp forest. Similar swampy alluvial plains occur in the northern part of the middle Baram and the Tutoh and Tinjar tributaries. Encased alluvial plains and alluvial terraces occur in the Kelabit Highlands (pl. III). Small terraces of sand and cobble gravel occur along the middle Baram and its tributaries, especially in the Akah and Patah (pl. XXV).

Caves

The limestone hills of the area contain numerous caves, of which the largest, best known, and most spectacular are the Niah Caves in the limestone at Bukit Subis (pls. VIb-c, VIIa). They are renowned for their immense population of bats and of swiftlets which produce edible nests, for their deposits of guano and rock phosphate, and for archaeological remains which include fossils of man and other animals, at present being excavated by the Sarawak Museum under the direction of the curator, Mr Tom Harrisson.

The caves in the middle Baram around Long Lama are also well known for edible birds' nests (see Banks, 1935). The swifts which nest there are of a different species from those at Niah, and produce the valuable white nests, uncontaminated by feathers, which may fetch £10 a pound (pl. XIVc-d). The caves around Long Lama are all in Melinau Limestone Formation. The localities of caves encountered in this survey are listed below:

Batu Gading — one small cave. Figure 15 shows some of the limestone hills near Batu Gading.

Bukit Besungai — a cave in Bukit Besungai north, numerous caves in Bukit Besungai south, and at least one in Bukit Besungai east.

Bukit Betok — at least one cave in Bukit Betok east.

Temala River — Numerous small birds' nest caves by the Temala River. The cave (Lobang Mering Josing) in the Maloi tributary about 2¾ miles east of the lower Temala is the best known. Another occurs farther up, opposite the Gramat tributary, about 200 yards north of the bank of the Temala stream. Others are reported in the Menyakit and Sepaiang tributaries of the Temala.

Kejin River — a well known and productive birds' nest cave occurs in the Kejin tributary of the Baram above Long Lama. The cave is in limestone on the north bank of the Kejin Tugang tributary about 1 mile east of the mouth of the Kejin.

Lobang Salai — perhaps the best known and most productive cave in the Long Lama area, west of the Baram about a mile west-northwest of the mouth of the Liang tributary. It consists of a small chamber, not much larger than about 10 to 20 yards across, the walls of which are crowded with white birds' nests (pl. XIVc-d). Another small cave a few yards away is the home of vast numbers of bats and few or no swiftlets (pl. VIIc).

Bukit Batu Pedan (i.e. Bat rock hill) — a small cave in another limestone hill southwest of Lobang Salai, which contains only bats.

Giam Asa — a little known cave in Miocene limestone farther up the Baram, about 1½ miles downstream from Long Akah, north of the river and about 300 yards northwest of a small stream known as Sungai Selirong. The cave consists of a small high chamber which is crowded with bats (pl. VIId).

Batu Asi, Batu Tujoh, and Bukit Siman — numerous caves are reported from these limestone ridges in the Upper Baram, but have not been visited in the course of this survey.

In the Akah Valley, caves occur near Long Siniai. Batu Pedan is in the valley of the Siniai tributary, about 1,800 feet above sea level, whereas Batu Pedan Kitan is in the valley of the Kitan, about half a mile from a small stream, Sungai Pedan. Both these small caves contain numerous bats but few or no swiftlets.

Many small caves occur in sandstone throughout the area, such as in the Suai headwaters, the Bakong Valley, the Dulit Range and at Batu Salit north of Long Peluan in the Kelapang Valley (Kelabit Highlands).

DRAINAGE

The western part of the area contains the Niah, Suai, and Semilajau drainage basins, and part of the Kemena basin in the south. The rest of the area is drained by the Baram, except for the extreme northeast, which includes the headwaters of the Limbang and Trusan, and a small area in the south, which is drained by the Koyan, a tributary of the Belaga.

The Baram River, second in size in Sarawak only to the Rajang, may be divided, for purposes of description, into three sections:

(a) Upper Baram. Above the mouth of the Paku tributary. The Upper Baram can be divided into:
  (i) Ulu Baram (below the mouth of the Puak);
  (ii) Kelapang River (or Pa Kelapang) (above the Puak; 'Kelapang' is the Kelabit name for the Baram headwaters).

(b) Middle Baram. From the Paku tributary to the mouth of the Tutoh (just beyond the north limit of the Suai-Baram area).

(c) Lower Baram. Below the mouth of the Tutoh. The Lower Baram lies north of the Suai-Baram area.

Upper Baram

The Kelapang River (the Baram headwaters) is largely controlled by the north-south strike of the Kelabit Formation. It rises on the Sarawak-Kalimantan Border at the south end of the Apo Duat Range, and flows due north until it curves back on itself at Pa Mada to flow south-southwest to the mouth of the Puak. In this stretch, the Kelapang is joined by the south-flowing Libun tributary. Both the Libun and the Kelapang consist of graded reaches, occupying shale belts (pl. vc), separated by rapids caused by massive sandstones. There are a number of small areas of encased alluvium, particularly in the upper Libun (the largest of which is the Plain of Bah, around Bareo).

Downstream from the Puak mouth, the river, now called the Baram, plunges southwest down a series of rapids to Lio Matu, (pls. va, IXe). It continues its southwest course to the Paku tributary, with frequent dangerous rapids caused by sandstone rocks. This generally southwest-flowing part is made up of comparatively slow south-southwest reaches, following the strike of shaly belts, and turbulent west-flowing reaches where the river cuts across successions of thick sandstone beds.

Middle Baram

At the mouth of the Paku tributary, the river changes to a northerly course; this may be related to the regional strike, which there swings round from east-southeast to north-northeast. Thence the river flows north over Setap Shale Formation to Long Akah, then west to above the Patah tributary, then northwest to Bukit Liman (pl. IXa-c). From Bukit Liman, the river is nearly at grade, and follows an increasingly meandering northerly course along the west of the Temala Anticlinorium to reach the wide alluvial plain north of Batu Gading (pl. VIIIb).

The western tributaries of the Middle Baram are short and small. The main eastern tributaries, the Patah and the Akah, both follow a similar course, with westerly flowing upper reaches and south-southwesterly flowing lower reaches which clearly follow the strike of shale belts. Their course is very similar to that of the upper Baram.

The *Akah River* is considered to be the most turbulent of Sarawak rivers, with the exception of the Tutoh. The upper reaches, from its source to the Meligong rapids, are the calmest, but even these include boulder races and the dangerous Telak rapids, where a portage has to be made (pl. IIa-d). In these upper reaches there are a number of small alluvial flats underlain by cobble gravel. Below the Meligong rapids (where a portage of about a mile has to be made) the river is made up of many turbulent boulder races, and some rocky rapids and gorges, including the Tebangan Gorge, about a mile below Long Tebangan. The boulder beds (or *karangan*) are extensive and coarse, in places being composed of boulders averaging 2 to 3 feet in diameter, and extending along the river for half a mile or more (pls. IId, XId).

The *Patah River* is similar in type to the Akah. The upper and middle reaches include many boulder races, and some narrow gorges, but the rapids are not as severe as those of the Akah. Downstream from the Danau tributary, the river flows through several narrow gorges (pl. XIa-b).

North of the Patah, the more easterly regional strike is reflected in the west-flowing *Palutan* tributary, whereas the *Temala* flows northwest across the strike, crossing the Temala Anticlinorium in a gorge in much the same way as the Tutoh crosses the Mulu Anticline. Its course, like that of the Tutoh, is probably superimposed (pl. XIIIb).

The *Tutoh River* is probably the most turbulent of all Sarawak rivers, and the most dangerous to navigate. It rises in the southeast part of the area. The headwater stream which is called the Ulu Tutoh is in fact smaller than the Sabai tributary, but the Sabai can be navigated only as far as the gorge and rapids at Batu Sikan, caused by the river cutting through a thick sandstone ridge, whereas the Ulu Tutoh can be travelled in a small *perahu* for 2 or 3 days upstream from the mouth of the Sabai (Long Sabai). Below Long Sabai the river is fairly well graded, and is navigable as far downriver as the mouth of the Labid (Long Labid). Below this are impassable rapids and gorges. The upper Tutoh above Long Labid is thus used only by *perahus* made in that area; none can enter it from down-river.

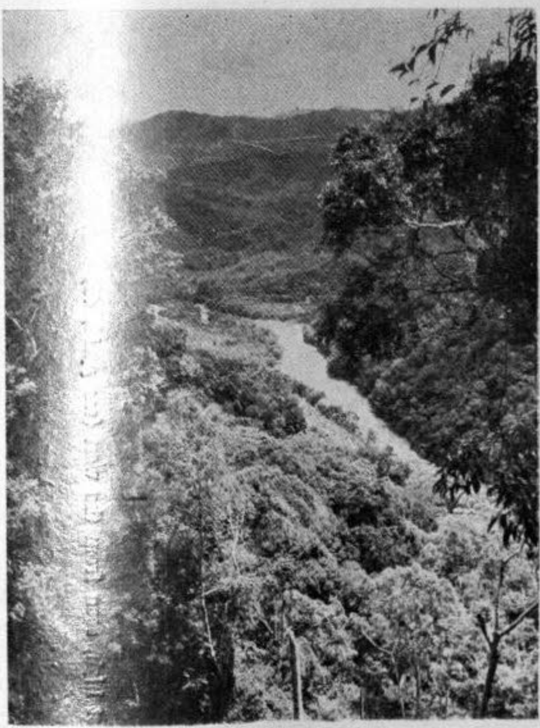
Below the Kuba'an tributary, the river follows a winding course over continuous rapids and boulder races, until it enters the gorge at the mouth of the Pangi (pl. XIIe), where it flows in straight or curving reaches to the west-northwest for about 6 miles. The gorge is narrow and the walls are steep, though the vertical part does not as a rule exceed about 30 feet in height. Below the gorge, the river resumes a tortuous course, with many boulder beds (*karangan*) and boulder races, and grows in size as it is joined by the Puak, Magoh, and Layun tributaries.

In the main Tutoh Gorge, the river crosses the mountainous country formed by the Mulu Formation and its course there is almost certainly superimposed. The gorge extends from below the mouth of the Ubong for some 12 miles to below the Tapin tributary. The river flows through a series of narrow defiles, often with vertical walls 50 feet or more high, with many rocky rapids (pls. IIe-f, XII). When the water level in the river is very low, with a crew of expert and experienced boatmen (only the Kelabits from the Magoh River know the gorge), and in a *perahu* with added planks along the side and a built-up prow of bark, the gorge may be attempted downstream with a fair chance of avoiding disaster. In any other conditions, however, success is unlikely. Mr F. Drake, when District Officer, Baram, managed to go up the gorge in several weeks but only by calling in Punans to carry most of the luggage across country, and at the cost of wrecking a *perahu*. It is doubtful whether the Kelabits and Berawans below the gorge could be persuaded to make the attempt a second time. The normal route into and out of the middle Tutoh is overland from the Apoh, following up the Melana and its tributary the Sadam; the local people never go up the gorge and rarely risk going down it.

Below the Tutoh Gorge, the river widens and flows across extensive gravel beds. It reaches grade within a few miles and then meanders through alluvial flats for the rest of its course.

The *Tinjar River*, which joins the lower Baram north of the area, follows a remarkably straight northwest course in its upper reaches, flowing between the Dulit Range and Bukit Manyam. It runs parallel to the strike as far as Bukit Sekiwa, where the strike changes to east-northeast, though the river still maintains its northwestward course, and hence possibly follows a fault.

The river turns abruptly northeast at Long Tisam, where it impinges on the scarp of the rim of the Jelalong Syncline (pl. XXIVa); this right-angle bend has been given the descriptive name 'Tinjar Knee' by P. Liechti (Liechti et al, 1960). From Long Tisam, the northwest course of the river follows the axis of the Tinjar Anticline



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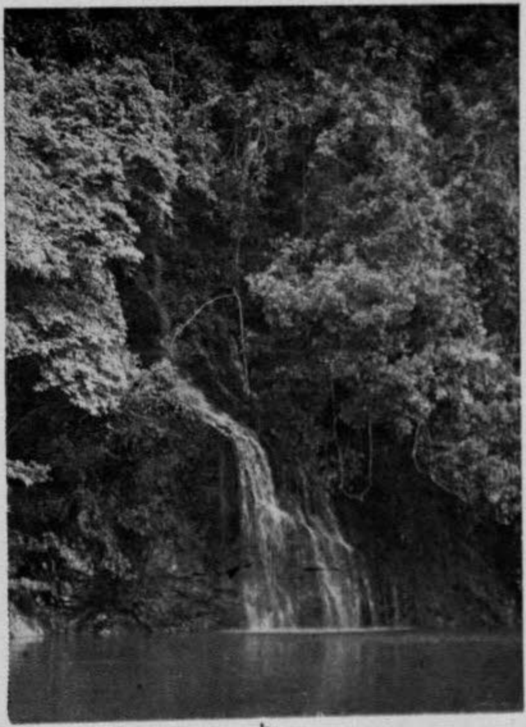

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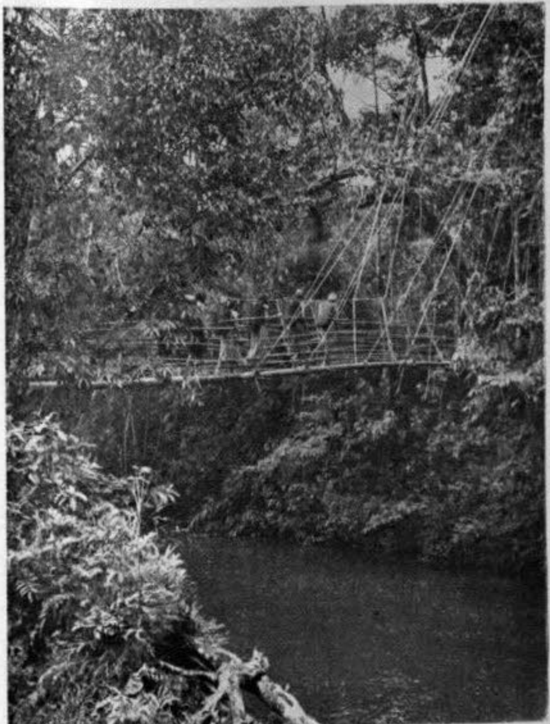

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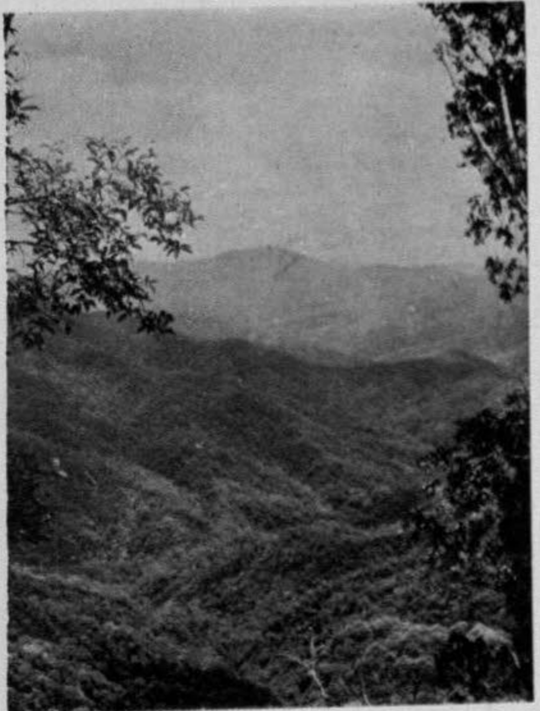

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PLATE V. UPPER BARAM AND KELABIT AREA. The Baram above Lio Matu (a); small waterfall at the mouth of a tributary between Long Akah and Lio Matu (b); bamboo bridge across a tributary of the Kelapang (Baram) (c); view of Kelabit Highlands looking southeast from between Tutoh and Magoh Rivers (*see p.14*)

Photographs a-c: Hedda Morrison
d: I.A.N. Urquhart

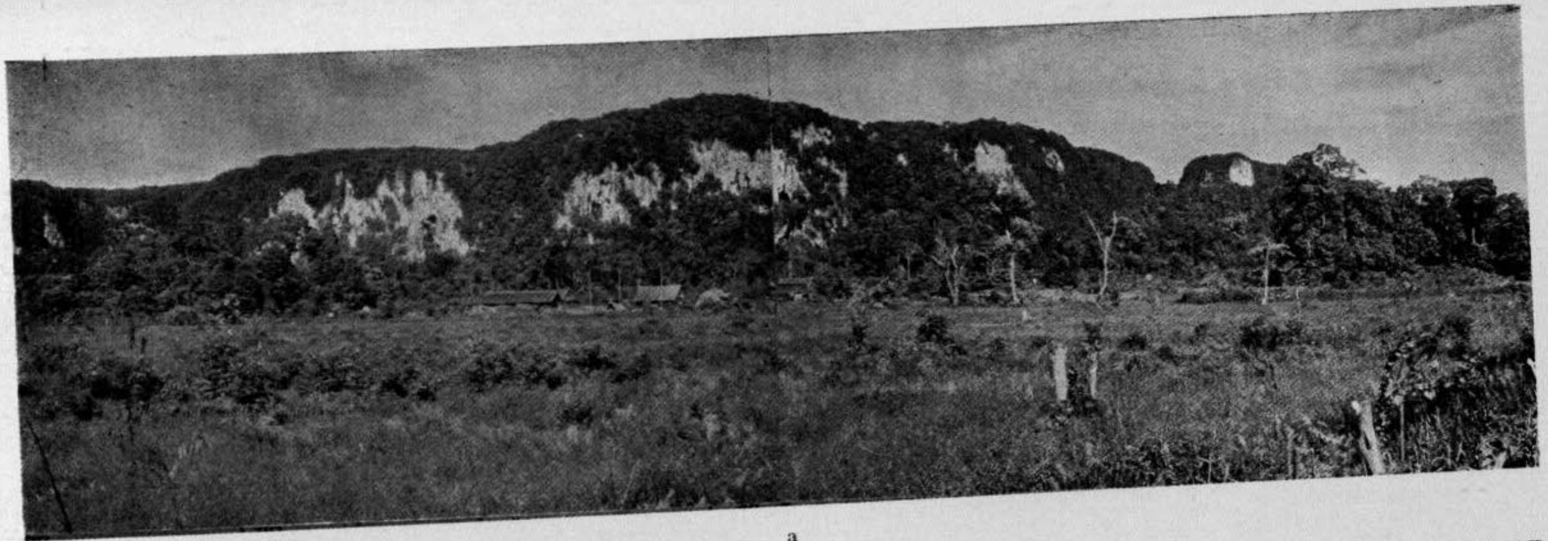

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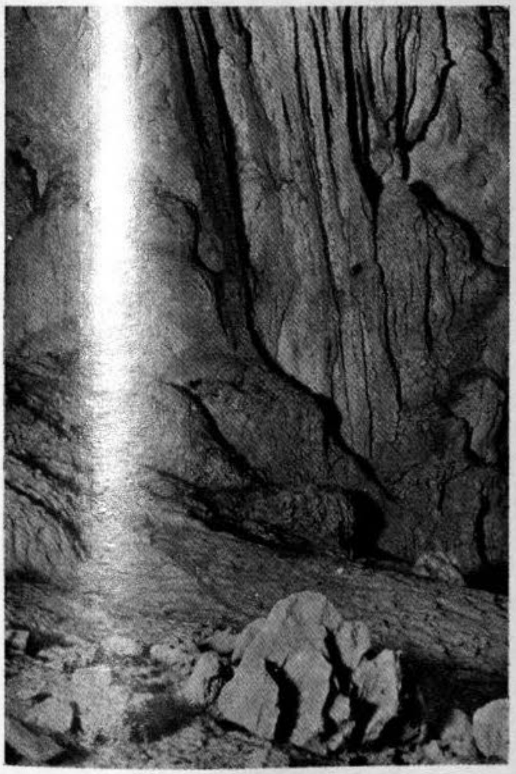
PLATE VIa. BUKIT SUBIS. The limestone cliffs of Bukit Subis, over 1,000 feet high, seen from the west (*see pp.12, 45*)

PLATE VIb and c. NIAH CAVES, IN BUKIT SUBIS. Looking out from the mouth of Niah Great Cave (b), and scene inside the caves (c) (*see p.12*)

Photographs a and c: G. E. Wilford



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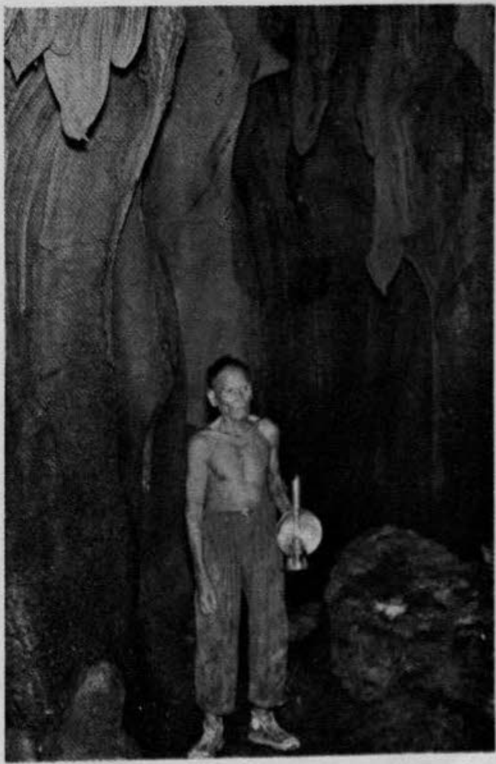

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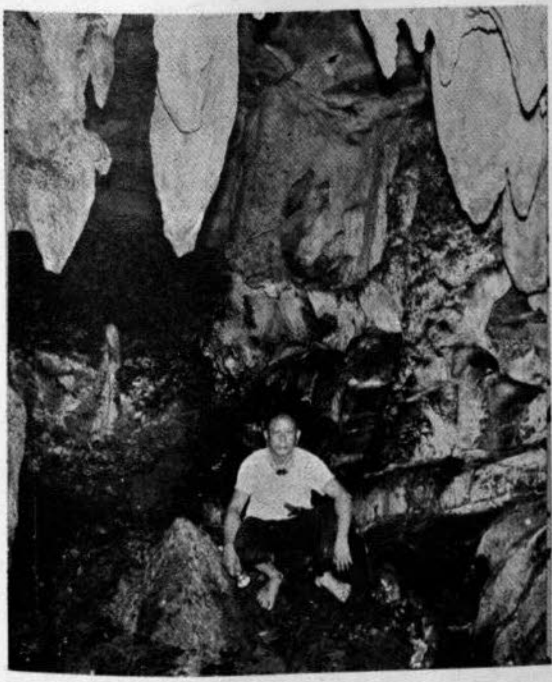

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PLATE VII. LIMESTONE CAVES. Stalactites in Niah Cave (a) and Batu Gading cave (b); bat-caves at Lobang Salai (c) and at Giam Asa near Long Akah (d) (*see pp. 12, 13*)

Photograph a: G. E. Wilford

a

b

PLATE VIII. AIR PHOTOGRAPHS OF SETAP SHALE AND ALLUVIUM. Low, undulating, slightly dissected featureless, country, formed by Setap Shale Formation is shown in the vertical air photograph (a). Plate VIIIb shows the varied texture of swamp forest on recent alluvium in the Baram Valley below Long Bunio. Low hills of Setap Shale Formation occur in the lower part of the until it turns north, breaking through the Belait Formation scarp to the wide alluvial plain beyond. In the Teru tributary, the extensive lake known as Loagan Bunut, which is the only permanent lake in Sarawak, may have resulted from slight recent downwarping along the Mentagai Syncline (pl. XIIIa). The lake appears to be mainly fed by Baram flood-water backing up the Tinjar.

The rivers of the *Suai area* (the Niah, Suai, and Semilajau) flow across the strike in a general northwest direction, with some reaches following the northeast strike.

River capture and possible tilting

It appears probable that capture of tributaries of the Tutoh by those of the main Baram River has been going on for some time, since the Tutoh basin on the southwest side is very narrow. This is probably due to the main Baram having cut down faster and deeper than the Tutoh, because the Tutoh flows across the Mulu Anticlinorium, and the rocks of the Mulu Formation are much more resistant than the Setap Shale Formation of the middle Baram Valley. The fact that the drainage basin of the middle Baram shows a similar eccentricity, with disproportionally short tributaries on the southwest side, suggests that tilting (uplift of the northeast relative to the southwest) may also have affected the drainage pattern.

At two places on the Baram-Tutoh watershed, river capture seems about to occur in the (geologically) near future. The part of the Tutoh Valley above the Ubong tributary is considerably higher than the main valleys and headwater tributaries of the Apoh, Patah, and Akah. This is strikingly apparent in the crossing from the Akah headwaters to the Tutoh. The Akah headwaters are turbulent and run over almost continuous boulder races. Long Datih on the Potok tributary of the Akah is about 1,350 feet above sea level, and the watershed between the Potok and the Tutoh to the east is about 2,000 feet high. The main Tutoh River is only a few hundred yards from the watershed, and 100 feet below it, (i.e. 650 feet above Long Datih) and is a comparatively sluggish river there. It seems only a matter of time before the Akah River cuts back there and beheads the Tutoh River. Similarly, the Sadam tributary of the Apoh appears to be several hundred feet below the Layun tributary of the Tutoh. The Sadam will probably eventually capture the Layun, and in due course the flow of water in the lower Layun may be reversed, and the whole of the Tutoh above the gorge flow down the Apoh, thus skirting the area of the resistant Mulu Formation.

Chapter III

STRATIGRAPHY

The area is formed almost exclusively of sedimentary rocks that were deposited in the Northwest Borneo Geosyncline. The rocks range in age from Upper Cretaceous to Recent, and include Palaeocene, Eocene, Oligocene, Miocene, probable Pliocene, and Pleistocene, strata. This almost complete succession is of sandstone and shale, with a few limestone lenses. The estimated maximum thickness of each system in the area is shown in table 4. All the systems do not occur in their maximum thickness in any one area, so that the total thickness of 45,000 feet is not present in any vertical section. A major unconformity occurs between the Upper Pliocene and Miocene, and there is an unconformity or disconformity between the Miocene and Upper Eocene in the Middle Baram, whereas in the Kelabit Highlands a considerable thickness of Oligocene strata is present, and there is no evidence of a disconformity there. A slight unconformity occurs between the Quaternary deposits and the Plio-Pleistocene Liang Formation.

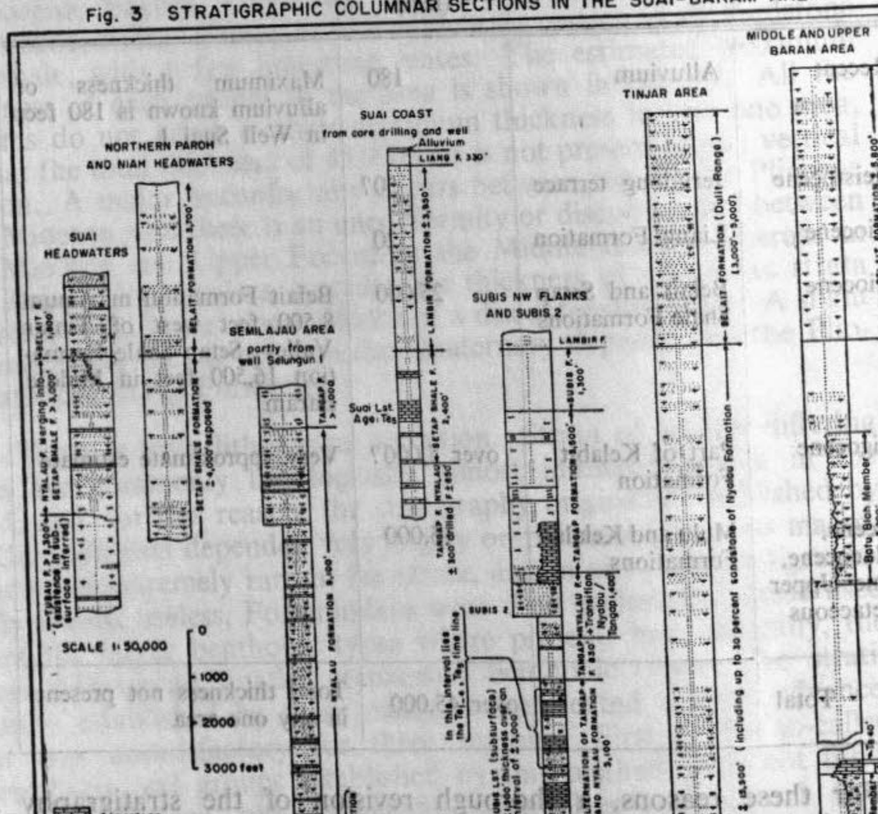
There is little lithological variation. Strata of widely differing ages are commonly lithologically almost indistinguishable in the field, and, for this reason, the stratigraphy originally established by SSOL geologists depended very largely on palaeontology. As macro-fossils are extremely rare in the strata, and in any case stratigraphically almost useless, Foraminifera were used exclusively; those used were the larger benthonic types where present, but, generally, the more widespread smaller arenaceous benthonic types. The stratigraphy established by these methods represented a great advance, but was unsatisfactory for three reasons. Firstly, the so-called formations and groups established by this method were not lithological units but bio-stratigraphic assemblage zones, and their boundaries seldom coincided with the few fairly clear-cut lithological boundaries in the area, such as that between the Belait and Setap Shale Formations as now defined. Secondly, the smaller Foraminifera were usually identified only generically, the species being indicated by a number referred to a collection in headquarters, and so the stratigraphic range of species could not be established by comparison with other parts of the world. In fact it was found that a number of species and assemblages had a greater range than had originally been assumed, and their appearance and disappearance in the stratigraphic column was determined by changes in depositional environment as much as evolutionary changes. Thirdly, it was found that re-deposition of Foraminifera from older into younger strata had commonly occurred and confused the record.

TABLE 4. THICKNESS OF SYSTEMS IN THE AREA

System	*Formation*	*Estimated maximum thickness* (feet)	*Remarks*
Recent	Alluvium	180	Maximum thickness of alluvium known is 180 feet in Well Suai 1
Pleistocene	Jerudong terrace	50?	
Pliocene	Liang Formation	320	
Miocene	Belait and Setap Shale Formations	25,000	Belait Formation maximum 8,500 feet west of Tinjar Valley; Setap Shale Formation 16,500 feet in Middle Baram
Oligocene	Part of Kelabit Formation	over 5,000?	Very approximate estimate
Eocene, Palaeocene, some Upper Cretaceous	Mulu and Kelalan Formations	15,000	
Total		over 45,000	Total thickness not present in any one area

For these reasons, a thorough revision of the stratigraphy was made by SSOL geologists, and the formations were redefined, as far as possible, on lithology. A study of air photographs enabled some formations to be delineated on the distinctive topography they form. A general lithological change, such as relative increase in sandiness, which may not be easy to distinguish in the field, can more clearly be seen on air photographs. The revision has resulted in a more satisfactory stratigraphy, and one which is less likely to be upset by changes in palaeontology, for instance in the accepted range of a zone fossil. Nevertheless it must be admitted that the delineation of some formations, for instance of the Eocene Kelalan from the Miocene Setap Shale, still depends in fact to a large extent on palaeontology. The attempt to redefine what were bio-stratigraphic assemblage zones as litho-stratigraphic units has been particularly difficult in the area. For example the Tangap and Sibuti, originally defined on palaeontology, would probably be more correctly regarded as assemblage zones of the Setap Shale Formation. However, any gain in accuracy resulting from re-definition would probably be offset by the confusion and inconvenience of continual changes in terminology.

Fig. 3 STRATIGRAPHIC COLUMNAR SECTIONS IN THE SUAI–BARAM AREA



Redrawn with slight modifications from compilation by P Liechti, 1960, from various reports of Sarawak Shell Oilfields Limited

SARAWAK GEOLOGICAL OFFICE DIAGRAM 172 BY N. S. HAILE, 1960

NOTE: Full column from outcrop data, half column from well data.

At the same time as the formations were redefined, more attention was paid by SSOL palaeontologists to pelagic (or planktonic) Foraminifera (mainly *Globigerina* and allied genera), which are less likely to be affected by changes in depositional environment on the sea floor, and, being widely distributed by currents, are more reliable zonal fossils. Moreover, since they have a delicate calcareous test, they are less likely to be redeposited in younger strata. The zonation based on pelagic Foraminifera has enabled the formations to be dated more accurately than before.

The compilation by P. Liechti and others (1960) incorporates the revised stratigraphy, and the present account follows the nomenclature with a few exceptions. The main modification is in the Kelabit Formation, which is now redefined in a way which is thought to be more satisfactory.

Although the formations are now defined lithologically, no formal rock-stratigraphic groups are now recognised in the area. For the purpose of this description, the formations have been informally classified as follows:

1. Main Geosynclinal Formations (Upper Cretaceous to Miocene): Mulu, Kelalan, Kelabit, Melinau Limestone, Setap Shale, Sibuti, Tangap, Tubau and Nyalau.
2. Neogene Basin and post-orogenic Formations (Upper Miocene to Recent)
   - (a) Neogene Basin Formations (Mio-Pliocene): Meligan, Belait, and Lambir.
   - (b) Post-orogenic Formations (Pliocene and Quaternary): Liang, Quaternary terrace deposits and alluvium.

A brief account of these 'groups' and their mutual relationships is given below, with a discusssion of special stratigraphic problems, and more detailed systematic descriptions of each formation follow in chapters IV and V. A general impression of the stratigraphic relations can be seen on the legend of the coloured map, and stratigraphic columnar sections are shown on figure 3; the area occupied by each formation is shown in table 5.

MAIN GEOSYNCLINAL FORMATIONS

These formations comprise the oldest rocks, namely the Mulu and Kelalan (mainly Palaeocene and Eocene), the Kelabit (Oligocene and Lower Miocene), the Melinau Limestone (Upper Eocene to

TABLE 5. AREAS OCCUPIED BY DIFFERENT FORMATIONS IN THE SUAI-BARAM AREA

Formation	*Approximate area* (square miles)	*Percent of total area*
Alluvium	784	8·6
Jerudong Terrace	3½	0·04
Liang Formation	2	0·02
Belait Formation	755	8·3
Lambir Formation	79	0·87
Meligan Formation	502	5·5
Setap Shale and Sibuti Formations	4,236	46·6
Tangap Formation	62	0·69
Nyalau Formation	841	9·2
Kelabit Formation	154	1·7
Melinau Limestone Formation	6½	0·08
Kelalan Formation	825	9·1
Mulu Formation	154	1·7
Igneous rocks	(less than 1)	—
Unknown; probably mainly Meligan and Kelabit Formation	696	7·6
Total	9,100	

Lower Miocene), and the Setap Shale, Sibuti, Tangap, Tubau and Nyalau Formations (Miocene).

KELALAN AND MULU FORMATIONS

The oldest strata, the Mulu and Kelalan Formations, outcrop in the Middle and Upper Baram area. These formations are largely Palaeocene and Eocene. (Cretaceous fossils were found in one place within the outcrop mapped as Temala Member of the Kelalan Formation, but the relationship of these Cretaceous strata to the Eocene strata is unknown. The determination was made after the field survey had been completed, and the occurrence has not been re-investigated).

The Mulu and Kelalan Formations are predominantly hard dark-grey shale and subgraywacke sandstone. Limestone occurs in the Palaeocene part of the Kelalan Formation, and in the Upper Eocene Temala Member, which is the term applied to sandy and calcareous strata of the Kelalan Formation underlying the Melinau Limestone Formation in the Middle Baram. The Kelalan Formation is the rock-stratigraphic and time-stratigraphic equivalent of the Belaga Formation in the Rajang Valley (formerly known as Rajang Formation). Kirk (1957) shows the present Kelalan Formation in the Upper Baram as Rajang (i.e. Belaga) Formation, Stage III (Lower Eocene). The Belaga Formation passes laterally into the Kelalan Formation, and the limit between the two is placed somewhat arbitrarily at the Rajang/Baram watershed; however, the Palaeocene to Lower Eocene fauna of the Kelalan limestone makes a correlation of them with Stage III unacceptable; they are more likely the equivalent of Stage II. In general the stages of the Belaga Formation cannot be distinguished in the Kelalan Formation; indeed, their distinction in the Belaga Formation itself is in many areas based on very meagre fossil evidence. The Kelalan and Mulu Formations could advantageously be included in the Rajang Group, which, as presently defined (Liechti, 1960, p.47) includes only the Lupar, Belaga, and Engkilili Formations. A broader definition of the Rajang Group should be considered in any future revision of the regional stratigraphy.

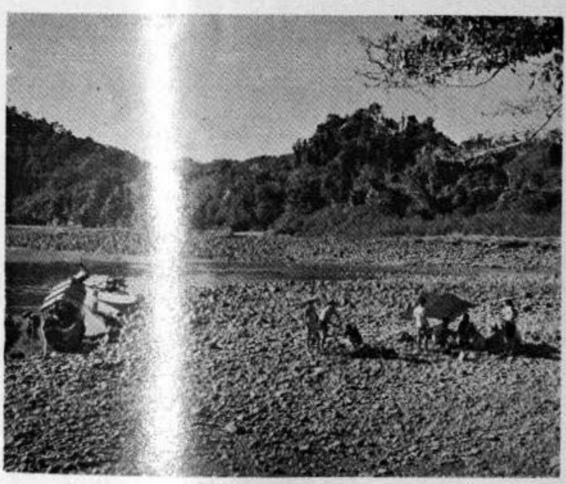
RELATIONSHIP OF MELINAU LIMESTONE AND SETAP SHALE FORMATIONS TO THE MULU AND KELALAN FORMATIONS

The Mulu and Kelalan Formations are overlain by Setap Shale Formation or, where present, Melinau Limestone Formation, but the nature of the boundary is uncertain. The Mulu Formation is believed, from evidence just north of the area, to pass up conformably into Melinau Limestone Formation. Likewise, the Temala Member of the Kelalan Formation in the Middle Baram appears to pass up conformably into Melinau Limestone Formation. However, near Batu Gading (middle Baram) and in the Lower Temala River, the Melinau Limestone Formation apparently rests almost directly on steeply dipping alternating sandstone and shale, although the actual contact has not been seen. The writer formerly considered this to be due to disharmonic folding of the strata beneath the limestone rather than an unconformity, particularly as in the middle Temala Valley several thousand feet of comparatively gently dipping sandstone of Temala Member (Upper Eocene) conformably underlie the limestone. However, Adams and Haak recently found a Cretaceous fauna in the underlying shale at Bukit Besungai. There appear to be two possible explanations: either the Melinau Limestone does, in fact, rest unconformably on Cretaceous strata, in which case the Temala Member must lens out rapidly to the north and west, and probably itself has an unconformity at its base, or the Cretaceous strata have been faulted up. The first alternative seems the more probable, and if it is accepted, the Temala strata are best regarded as a separate formation, or as a sandy facies at the base of the Melinau Limestone, rather than as a member of the Kelalan Formation, the Cretaceous rocks being allocated to the Kelalan. The Cretaceous determination, however, was received after field work had been completed, and so the problem could not be further checked in the field, and the question must be left open for the time being.

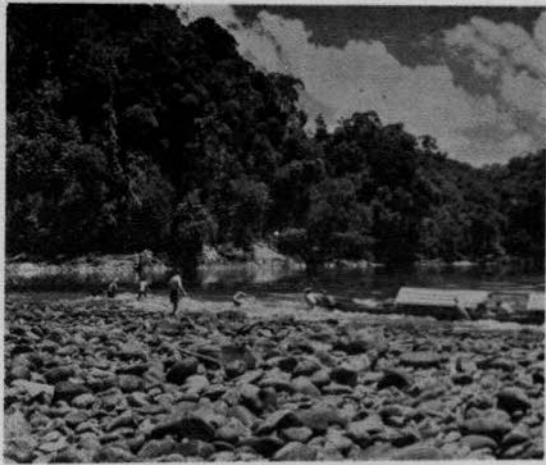
In the Upper Baram the Eocene part of the Melinau Limestone appears to be absent, Miocene limestone resting directly on Palaeocene limestone and slaty shale of the Kelalan Formation, and there is clearly a major disconformity between the two formations in that area.

The Melinau Limestone is only locally present, and over most of the area Setap Shale Formation (Miocene) is presumed to rest directly on Kelalan or Mulu Formation. The Setap Shale Formation differs lithologically from those underlying formations only in its generally more argillaceous nature, slightly lower degree of induration, and less intense folding. However, locally the Setap Shale Formation is as slaty and as sandy as the Kelalan and Mulu Formations. Thus the delineation of the boundary depends partly on palaeontology, partly on extrapolation from places where the Melinau Limestone Formation occurs, and partly on the general lithological differences noted above.

The nature of the boundary between the Setap Shale and Kelalan Formations is not known with certainty. In the Sela'an River, Widmer (cited by Liechti, 1960, p.75, p.48) found an unconformity which is now thought to be between Setap Shale Formation and Kelalan Formation (see figure 4). Elsewhere, in spite of a special search in the field, no direct evidence of an unconformity between the two formations has been found. Owing to the intense folding and consequent difficulty in mapping the boundary exactly, it is possible that an unconformity exists elsewhere but has not yet been observed. Oligocene strata have been found only in the Kelabit Highlands and at one place in the Sela'an River (too small to show on the map) and appear to be missing over most of the Middle Baram. They are certainly missing at Batu Gading, where a disconformity occurs within the Melinau Limestone between the



a



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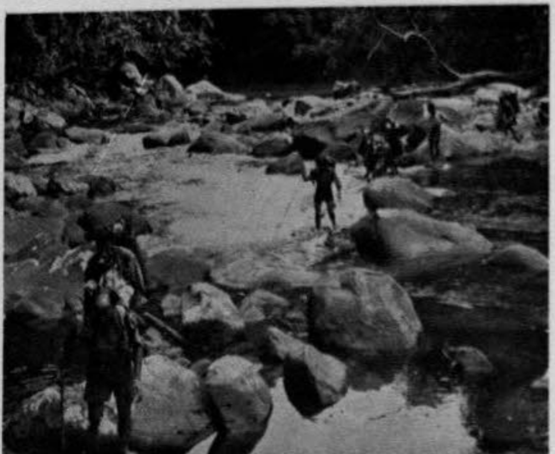
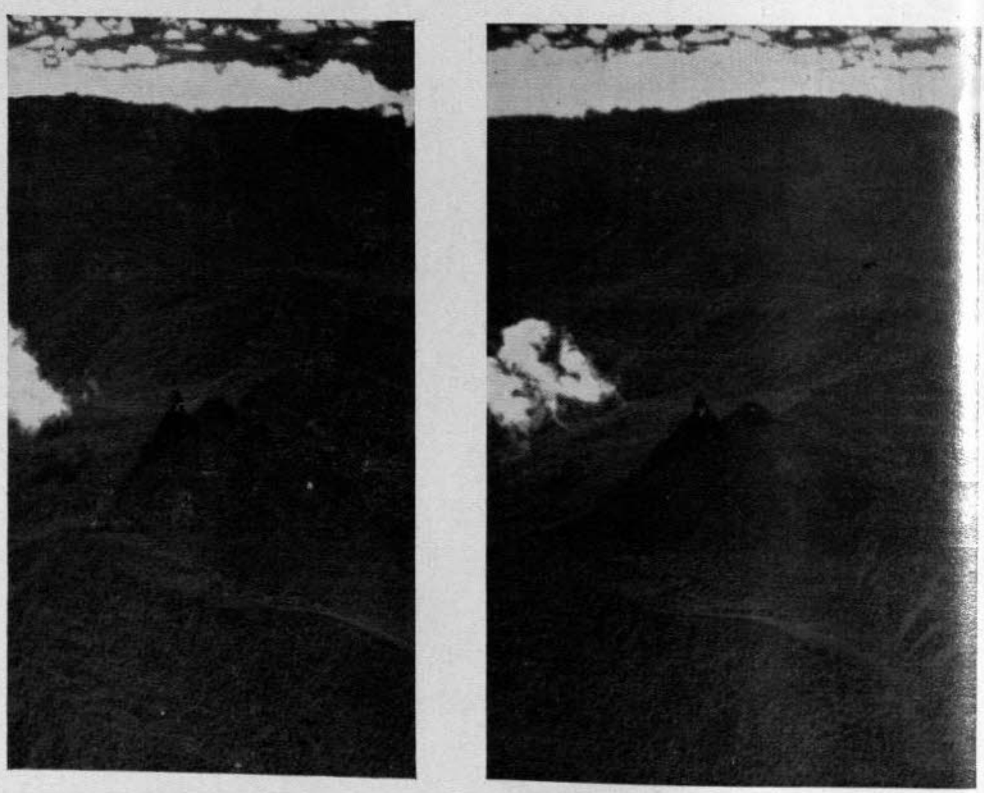
e



f

PLATE IX. VIEWS ON THE BARAM RIVER. Gravel and boulder beds (*karangans*) below Long Akah (a and b); the river at Long Akah (c); an aerial view of Lio Matu (d); the river above Lio Matu near Kuala Tudan (e); crossing the Tudan tributary (f) (*see p.14*)

Photographs a-c, e, f: Hedda Morrison; d: I.A.N. Urquhart



a b

PLATE Xa-b. BATU LAWI. An oblique view from the air, looking northeast, shows the twin peaks of Batu Lawi, formed of vertical Meligan Formation Sandstone (*see pp.11, 54*)

The stereo-pair should be viewed through a pocket stereoscope

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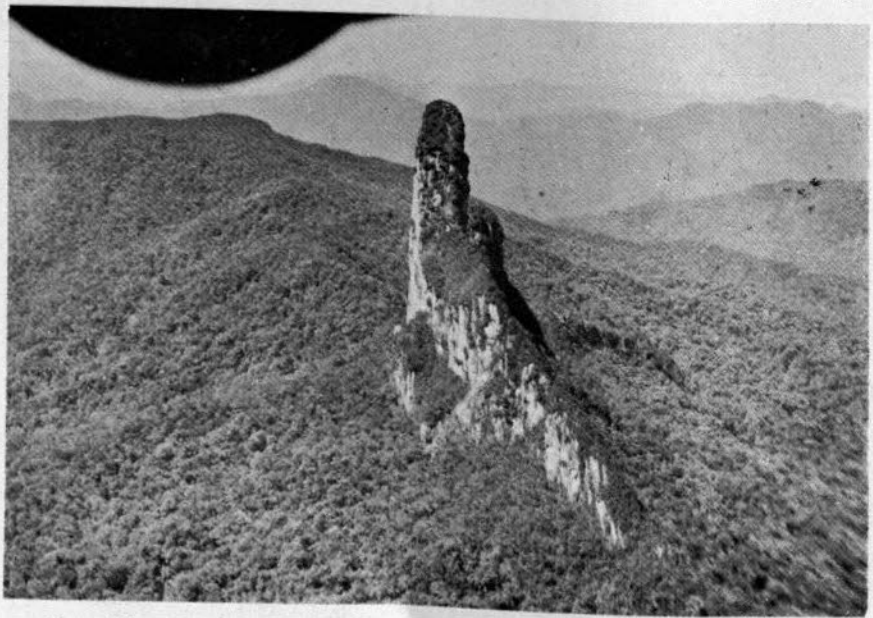
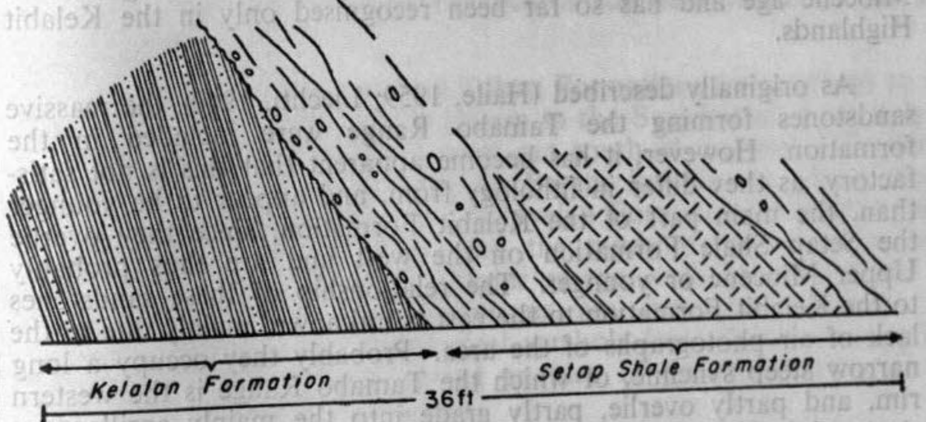


PLATE Xc. BATU LAWI. Aerial view from the north-northeast. The peak is about 6,650 feet high

Photograph: R. Anderson

FIGURE 4



UNCONFORMITY BETWEEN KELALAN AND SETAP SHALE FORMATION, IN SUNGAI SELA'AN, UPPER BARAM AFTER H. WIDMER

Miocene and the Upper Eocene parts. Thus a major disconformity probably occurs between the Setap Shale and Kelalan Formations over most of the area, and an angular unconformity also exists in places. Some folding of the Northwest Borneo Geosyncline is known to have been remarkably local in its effects, and it is quite possible for a unconformity to pass laterally into a disconformity and thence into a conformable junction within a distance of 20 or 30 miles.

Melinau Limestone Formation

The Melinau Limestone Formation, of Upper Eocene to Lower Miocene age, is a foraminiferal and algal limestone which occurs at some places between the Kelalan or Mulu Formations and the overlying Setap Shale Formation. The limestone is less than 200 feet thick, only a fraction of the thickness which it attains in the type locality immediately north of the area, where it is about 6,000 feet thick. The Oligocene is missing within the formation in the Suai-Baram Area, and the Miocene and Eocene are separated by a major disconformity within the formation. This is fully discussed in the separate paper, page 145, below. The Melinau Limestone has been found to pass up conformably into the Setap Shale Formation wherever the contact has been investigated.

Kelabit Formation

The Kelabit Formation is an unmetamorphosed succession of sandy clays and shales, alternating with sandstones, of Oligocene to Miocene age and has so far been recognised only in the Kelabit Highlands.

As originally described (Haile, 1959; Liechti, 1960), the massive sandstones forming the Tamabo Range were included in the formation. However, it has become apparent that this is not satisfactory, as they differ in lithology from, and appear to be younger than, the main part of the Kelabit Formation, since they overlie the Setap Shale Formation on the west and are thus probably Upper Miocene or younger. The relationship of these sandstones to the Kelabit Formation to the east is unknown, mainly due to the lack of air photographs of the area. Probably they occupy a long narrow steep syncline, of which the Tamabo Range is the western rim, and partly overlie, partly grade into the mainly argillaceous strata of the Kelabit Formation. When air photographs are available, the relationship can probably be quickly clarified. On the available evidence, however, it appears that the Tamabo sandstones overlie the Setap Shale and Kelabit Formations, and they are thus equivalent to the Nyalau, Belait, and Meligan Formations. Of these, they seem to have the closest lithological affinity with the Meligan Formation, into which they have therefore been provisionally moved from the Kelabit Formation.

Setap Shale, Sibuti, Tangap, Tubau, and Nyalau Formations

The Setap Shale, Sibuti, Tangap, and Tubau Formations comprise a huge thickness of predominantly argillaceous Miocene strata, occurring between the Mulu, Kelalan, and Melinau Limestone Formations and the overlying, arenaceous, Belait, Lambir, and Meligan Formations; the Nyalau Formation is a sandy facies which is a time-equivalent of the argillaceous formations.

The distinction between the argillaceous formations depends on differences in their calcareous and sandy content, supported by slight differences in micro-faunas. The boundaries between them are vague and transitional; in fact, Liechti remarks (1960, pp.159, 161, 169) that the Sibuti, Tangap, and probably also the Tubau Formation could be regarded as members of the Setap Shale Formation, but because the terms have become established, he preferred to retain them with formation status. Possibly even more appropriately they could be redefined as bio-stratigraphic assemblage zones of the Setap Shale.

The so-called Sibuti Formation is so vaguely differentiated from the Setap Shale that a boundary cannot be drawn between them, and they are represented on the map by different letter symbols imposed on the same colour, giving a general idea of the distribution of the two formations.

The Sibuti, Tangap, and Tubau Formations are confined to the coastal part, and the last is known in the Suai-Baram Area only in the subsurface, although it crops out south of the area. The Setap Shale Formation in the Middle Baram includes in places sandy strata that could be regarded as Nyalau Formation. However, little is known of the lithology, and the sandy parts have not been distinguished on the map. Major scarps, such as are formed by thick resistant santstone successions, are, however, shown on the map by different photogeological symbols from those showing less prominent strike ridges, giving an idea of the distribution of the sandier parts of the formation.

The relationships of the Setap Shale and older formations in the Middle Baram have already been discussed (pp.23-25). To the east, the formation may pass laterally into the upper part of the Kelabit Formation in the subsurface beneath the Tamabo Range, but this is of course conjectural. In the Suai area the base is not exposed, but from evidence to the south it seems probable that the Setap Shale and Nyalau Formations pass downwards into the Tubau Formation which rests unconformably on the Belaga Formation (Eocene).

NEOGENE BASIN AND POST-OROGENIC FORMATIONS

Neogene Basin Formations
(Mio-Pliocene)

The Belait, Lambir, and Meligan Formations are predominantly arenaceous strata which overlie the Setap Shale, Sibuti, and Nyalau Formations in synclinal basins. The contact is believed to be generally conformable, and steep dips in the underlying shale, formerly thought to indicate unconformity at some places, are now interpreted as a result of disharmonic folding; the boundary is strongly diachronous. The Lambir Formation is distinguished from the Belait Formation by its more calcareous lithology; it passes along the strike into the lower Belait. In this account, massive non-calcareous sandstone ('Grabit Sandstone') overlying the calcareous Lambir Formation in the Grabit Syncline (Bakong Valley), formerly mapped as Lambir, is assigned to the Belait Formation, which it resembles more closely. The Meligan Formation overlies the Setap Shale in the eastern part. The reasons for including the sandstones of the Tamabo Range and Batu Lawi in this formation have already been discussed (p.26).

POST-OROGENIC FORMATIONS

(Pliocene and Quaternary)

The Liang Formation was deposited after the Pliocene folding and overlies the Setap Shale Formation unconformably in a few widely separated places. Alluvium and terrace deposits overlie older formations with an unconformity, only slight over the Liang but strong over all other formations.

Chapter IV

MAIN GEOSYNCLINAL FORMATIONS

In this chapter the Mulu, Kelalan, Melinau Limestone, Kelabit, Setap Shale, Sibuti, Tangap, Tubau, and Nyalau Formations are described. Their mutual relationships have been discussed in Chapter III.

MULU FORMATION

The Mulu Formation is a thick succession of hard sandstones and sub-metamorphosed shales and slates, with a few conglomeratic sandstones. The Mulu Formation is confined to the Mulu Anticlinorium, of which only the southern half is in the Suai-Baram area.

Lithology

Along the western edges of the Mulu Anticlinorium, the formation comprises 'a monotonous succession of hard, splintery, slaty shales, becoming true slates in places, with subordinate quartz, sandstone, and occasional conglomeratic sandstones. The shales show widely varying degrees of sandiness and are often quartzitic and phyllitic in appearance. Throughout the shales and thinly bedded sandstones the bedding is usually obliterated by very strong cleavage . . .' (Shepherd, *1954a*). In the Tutoh Gorge slates predominate only on the flanks of the Mulu Anticlinorium, where they are commonly calcareous (S4591, S4592). Through most of the Tutoh Gorge, however, sandstones as much as 500 feet thick predominate, with subordinate slate with ironstone bands and quartz veins in places (pl. II e-f). In some of the exposures of slate, where sandy bands enable the original bedding to be distinguished, slaty cleavage can be seen cutting across the bedding at a high angle (upper Tutoh Gorge near the Ubong tributary).

Sandstones from the Tutoh Gorge include calcareous feldspathic sandstone (S4593) and calcareous subgraywacke (S4594, S4595). The subgraywacke (e.g. S4595) is composed of subangular grains of quartz (ranging from 0·2 to 1·0 mm in diameter), sodic plagioclase, microperthite, microcline, and chert, and flakes of muscovite up to 1 mm across, with an interstitial fine-gained calcitic matrix. A few grains of ?apatite, monazite, and magnetite and/or ilmenite occur, with secondary limonite and leucoxene (see pl. XXVIa). The calcareous feldspathic sandstone (S4593) is more equigranular, and has an average grain size of about 0·2 mm. It is composed of quartz, chert, microperthite, sodic plagioclase, and microcline. Fragments rich in chlorite and sericite occur, some of which may be decomposed fragments of volcanic rocks. A few grains of apatite, tourmaline, and pyrite occur, with secondary limonite, and calcite is common in patches.

Tectonic aspect

The formation is intensely folded. In the Tutoh Gorge, the strike is fairly consistently northeast, and nearly vertical dips towards the southwest prevail. Cleavage in slate dips in the same direction, in places cutting across contortions in bedded sandy slates. Intense and complicated folding, in places isoclinal, occurs in bedded sandstone in the Tutoh Gorge.

Thickness

The thickness cannot be measured, as the base is not exposed, and repetition due to folding and faulting is probable. Shepherd (*1954a*), assuming the simplest possible structural interpretation, estimated 15,000-18,000 feet as a maximum for the strata exposed.

Boundaries

The base is not exposed. The formation is overlain by Melinau Limestone Formation in the Tutoh Gorge at both the southeast and northwest ends, although the latter lies just north of the area. The boundary at the southeast end is tectonically disturbed, but at the northwest end it is apparently conformable. Calcareous slates occur in the Mulu Formation near the boundary. The northwest flank of the Mulu Anticlinorium is faulted against Setap Shale Formation and the Melinau Limestone is absent; either it was not deposited, or has been faulted out. The remainder of the boundary has been extrapolated with the help of air photographs. The boundary with the Setap Shale Formation, where the Melinau Limestone Formation is absent, is difficult to determine, since the Setap Shale Formation is slaty near the contact.

Fossils and age

Within the area only two samples have yielded determinate fossils (see Liechti et al., 1960, p.71):

Discocyclina sp. (from Sungai Iman)
Globorotalia wilcoxensis Cushman and Ponton (from the Tutoh River)

Both come from near the top of the Mulu Formation. *Globorotalia wilcoxensis* is regarded as indicative of Lower Eocene. Liechti concludes that the Mulu Formation is Palaeocene to Eocene, probably Palaeocene to Lower Eocene.

Environment

Liechti, (1960, p.71) considered that the formation is a typical catastrophic eugeosynclinal graywacke association which was probably deposited under bathyal conditions. However, the thick sandstones of subgraywacke type, and the conformably overlying shallow-water limestones of the Melinau Limestone Formation, would seem to indicate miogeosynclinal conditions.

KELALAN FORMATION

The Kelalan Formation comprises mainly sandstone and shale, with subordinate limestone, tuffite and tuffaceous limestone. The name was introduced by Jordi and Wijkhuizen (*1955*) for sedimentary rocks in the Limbang and Trusan headwaters, but somewhat similar sediments in the Baram were later included by P. Liechti (Liechti and others, 1960). The type section is along Sungai Kelalan, the main tributary of the Trusan River. The formation occupies fairly large areas in the Setap Shale Formation along anticlinal axes trending north-northeast from the upper Baram across the Akah, Patah, and Tutoh tributaries.

The formation as described by Jordi in the Kelalan area (Limbang and Trusan headwaters) shows some differences from that in the Tutoh, Patah, and upper Baram. Part of the massive sandstone originally included in the Kelalan Formation e.g. of Batu Lawi, has been provisionally allocated here to the Meligan Formation as explained above (p.26) and other sandstone such as those of the Balingat Syncline near Ba Kelalan are possibly also more appropriately considered as Meligan Formation. Moreover, some of the softer shales described by Jordi from the Kelalan area resemble those of the Oligocene-Miocene Kelabit Formation.

The upper part of the formation in an isolated anticlinal outcrop in the Middle Baram shows sufficient lithological distinction to merit its description as a member—the Temala Member.

Lithology

In the *Limbang and Trusan headwaters,* Jordi and Wijkhuizen (quoted in Liechti, 1960) described the following rock types:

(a) Massive or thick-bedded sandstone, medium grained to coarse grained, greenish grey or yellow grey, hard, sometimes slightly calcareous but with a siliceous matrix. The main component is quartz, accompanied by a very variable feldspathic content.

(b) Fine-grained to medium-grained sandstone, grey, commonly quartzitic, alternating with dark silty or sandy shales, or in places, coaly shales. Beds range from a few centimetres to several metres.

(c) Thin bedded, fine-grained, quartzitic sandstone, greenish, alternating with dark grey shales.

(d) Clays or shales, grey to dark grey, with a few thin sandy layers and frequent interbedding of coaly sand or clay layers.

(e) Thin medium bedded sandstone alternating with greenish siltstone and a green and red, or plain grey, shale which is commonly marly. The sequence of sandstone, siltstone, and shale is rhythmically repeated. This comparatively soft sequence commonly contains pyrite concretions and gypsum. It outcrops in the Ba Kelalan area.

(f) Variegated shales or clays resembling type (d) above but green or red and silty in places.

In the *Tutoh, Patah, Akah,* and *Upper Baram Rivers,* the Kelalan Formation consists of interbedded sandstone and hard grey shale, in many places slaty, and rare lenses of limestone. The formation in this part is difficult to distinguish from the Setap Shale Formation, the only difference being that the Kelalan Formation on the whole contains more and thicker sandstones, some distinctive limestones, and sandstones with volcanic admixture. The Kelalan Formation on the whole shows a greater induration and a higher degree of dynamic metamorphism than the Setap Shale Formation, but this is not a regular or consistent feature. The belts of Kelalan Formation in the Tutoh, Patah, and Akah Valleys have been mainly mapped from air photographs by extrapolation from a few known occurrences of the distinctive rocks, and their boundaries are largely conjectural.

The *sandstones* occur in beds ranging in thickness from a few inches to more than 50 feet. Alternations of sandstone and shale, in beds about 4 inches thick, are common, and in places extend over stratigraphic thicknesses of several hundred feet. The sandstones are usually fine to medium grained, grey, and most are probably subgraywackes (S4573). The *shales* are predominantly dark grey, commonly slaty (e.g. S6136). Calcareous shales are rare (S6307). Near Lio

Matu, reddish mudstone occurs (S6174). *Tuffite* (S6134) occurs interbedded with calcareous shale (6307) in the Tutoh River just below the Magait tributary (see p.65). *Limestones* occur at Batu Asi and Batu Tujoh in the upper Baram, in the Tutoh Valley near the Magait tributary, and in the Akah Valley near Long Siniai; some specimens from the Batu Asi area contain fragments of volcanic rocks.

The limestone forming Batu Asi and Batu Tujoh, the limestone outcrop east of Bukit Siman, and limestone outcrops in the Baram below the Silat and Paku tributaries, are assigned to the Kelalan Formation on the basis of their Palaeocene fauna and distinctive lithology. (Specimens are S6175-77, S7067-77, south bank of Baram below the Silat; S7057-59, south bank of the Baram below the Paku; S7060-66, north bank of Baram below the Silat, at south end of Batu Asi ridge; S7100-02, S7104-05, northeast end of Batu Asi, in Belukun River). Most of the limestone is fine grained (calcilutite), and contains small pelagic Foraminifera (e.g. S7065). Many specimens contain sponge spicules (e.g S7061), especially those from the southwest of Batu Asi ridge. Coarser grained limestone (calcarenite), composed of benthonic Foraminifera, Algae, and less common corals, also occurs (S7063, S7080). Limestone conglomerate crops out in the Baram below the Silat tributary (e.g. S6176). Tuffaceous material and volcanic rock fragments occur in all the limestone conglomerates, and in some of the finer grained limestones; these are described in more detail in chapter VI, below. Some limestone outcrops in the Belukun River downstream from the Kalai tributary resemble that of Batu Asi and probably belongs to the Kelalan Formation. The limestone of the main Batu Tujoh ridge, and the outcrop east of Bukit Siman are known only from five specimens collected by SSOL geologists, and the lithology has not been described.

The limestone outcropping in the Tutoh near the Magait tributary is light grey, fine grained and slaty (S4584, S6135), and shows no sign of fossils either in the hand specimen or the slide. It is interbedded in light-grey slaty shale as beds up to 50 feet thick. About a mile upstream from the Magait, a 10-inch boulder of limestone conglomerate with volcanic rock fragments (S4585) was found in a gravel bank. The limestone fragments contain some trace of fossils, probably Algae (see also p.65).

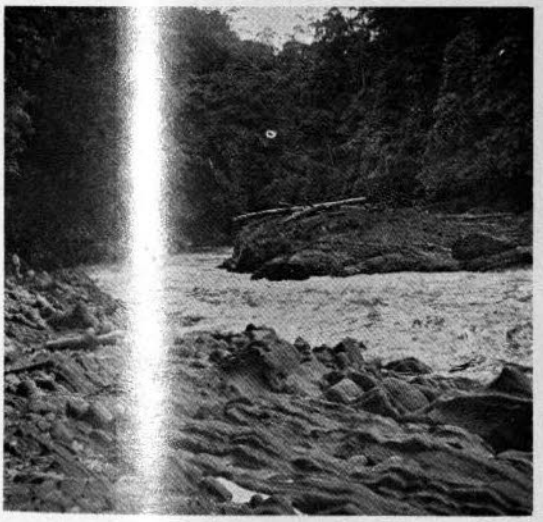
Limestone in the Akah Valley (S4559, S4562, S4564-66, S4568, S4570-72) comprises fossiliferous calcilutite, calcarenite, and calcirudite, interbedded with grey shale, calcareous sandstone, and red calcareous shale (S4560-61). The limestone crops out in the Kitan and Siniai tributaries, near Long Siniai, and occurs in several beds, of which the thickest seen is about 100 feet. It is of Eocene age.

The *Temala Member* comprises sandstone, shale, limestone, and sandy limestone. It differs from the main Kelalan Formation in its higher calcareous content and slighter folding.

The sandstones in the member are mostly fine grained subgraywackes grading into graywackes, and are exposed in the Temala River in the Temala Gorge, and upstream and downstream of the gorge. The subgraywackes and graywackes are grey to light bluish grey, and most are slightly calcareous. The quartz is clear, subangular to angular, and the feldspar is albite or oligoclase with orthoclase, microcline (S4492), and microperthite; muscovite occurs in some specimens (S4656; see pl. XXVIc). Interstitial clay-grade material, commonly sericitic, usually makes up an estimated 10-40 percent of the rock. The more calcareous varieties commonly contain fragments of large Foraminifera (*Nummulites, Discocyclina*) and Algae (e.g. S4491, S4642, S4650-51). A coarse sandstone exposed at low water in the Baram River at Batu Gading below the Melinau Limestone Formation is a crumbly whitish rock composed of subangular grains of quartz as much as 2 mm across, but mostly about 0·5 mm, and of orthoclase, microperthite and albite, with interstitial sericite and chlorite.

Graywacke apparently grades through calcareous subgraywacke to sandy limestone (arenaceous calcarenites and calcirudites). Examples of sandy limestones are S4654, S4657, which contain detrital grains of fresh albite (see pl. XXVId). The association of subgraywacke with calcarenite is apparently unusual.

The shales are dark grey, mostly poorly bedded, and sandy. Some of the specimens from above the Temala Gorge contain sericite in parallel orientation (S6024-28). Some



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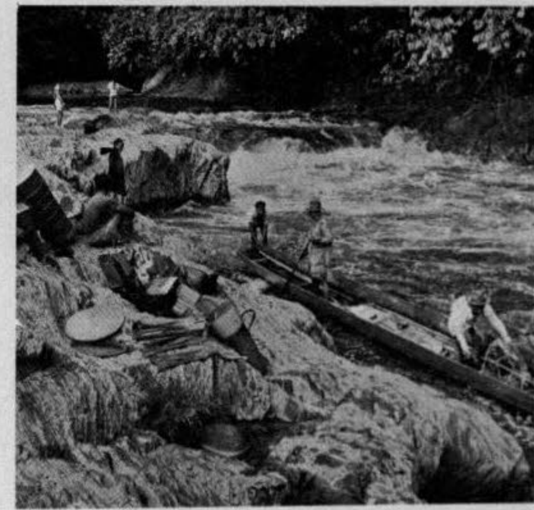
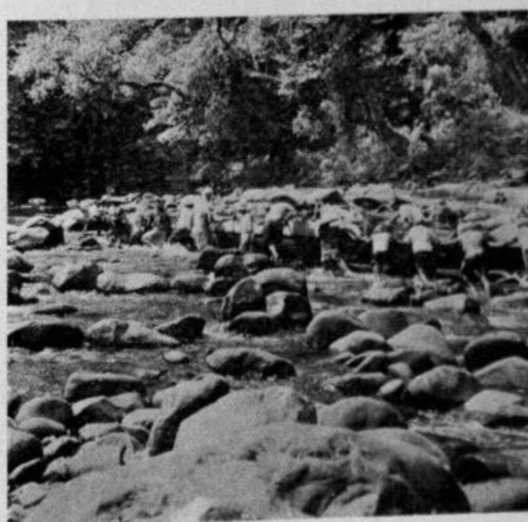


b

PLATE XIa-b. PATAH RIVER. Steeply dipping sandstone and shale of the Setap Shale Formation, cut by quartz veins (b) (*see p.15*)

c

PLATE XIc BARAM RIVER. Between Long Akah and Lio Matu



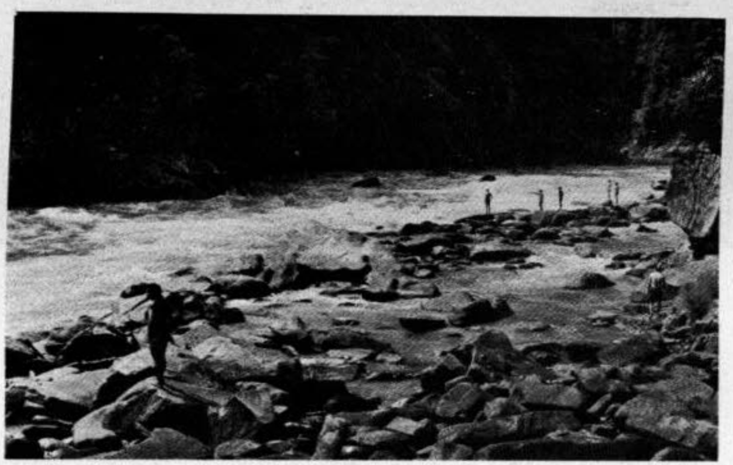
d

PLATE XId. AKAH RIVER. Boulder beds below Long Datih

Photographs by Hedda Morrison

a

b



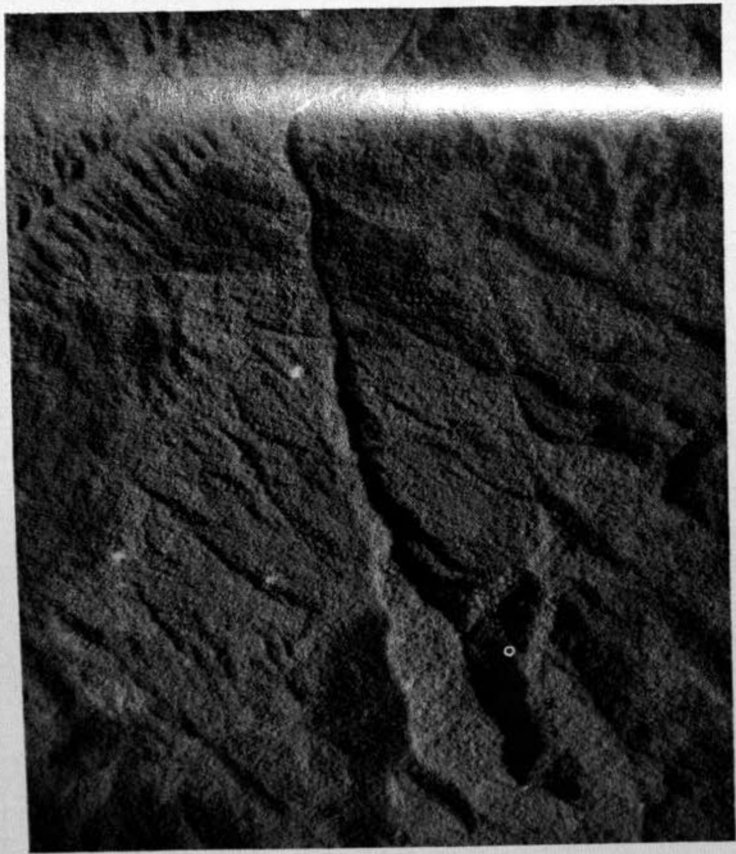
c

PLATE XII. TUTOH RIVER. a-d: scenes in the Tutoh Gorge. Note large sandstone boulders (*see p.16*)

Photographs by I.A.N. Urquhart

a

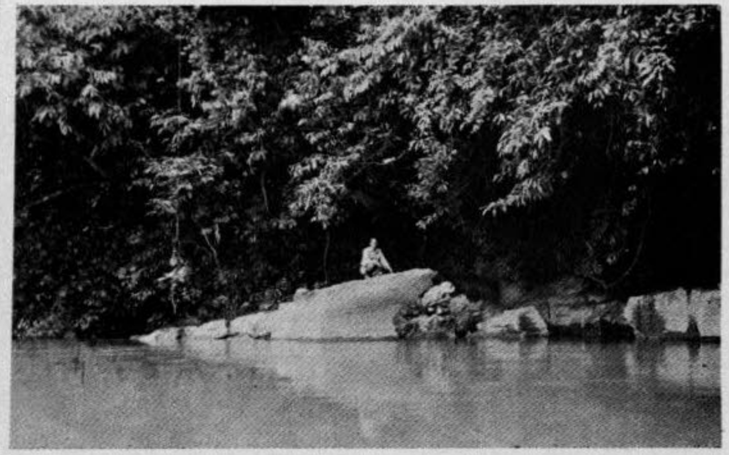
PLATE XIIIa. LOAGAN BUNUT. This small lake in the Tinjar Valley is the only permanent lake in Sarawak. It is filled mainly by flood water from the Tinjar which enters from the channel on the northeast side, and flows out the same way. Small rivers drain into the lake on the north, west and south. On the northwest, the typical fine texture of peat-swamp forest can be seen (*see p.17*)



b

PLATE XIIIb. TEMALA VALLEY. The air photograph shows the Temala River flowing through a gorge in massive sandstones of the Temala Member of the Kelalan Formation, which dip gently to north-northwest (*see pp.11, 15*)

a



b

c

d

PLATE XIV. OUTCROPS IN THE MIDDLE BARAM VALLEY. a: Eocene sandy shale (Temala Member of Kelalan Formation) on the west bank of the Baram opposite the Liang tributary; b: the top part (Miocene) of the Melinau Limestone at Batu Gading, dipping gently to the north (*see p.33*); c and d: the entrance to Lobang Salai cave, and edible birds' nest in the cave (*see pp.12, 13*) calcareous varieties contain pelagic Foraminifera (e.g. S6028, S6042). Hard sandy shales of the Temala Member also outcrop in the Baram River opposite the Liang tributary (pl. XIVa).

Tectonic aspect

The Kelalan Formation is in general intensely folded, dips within 10° of vertical being usual. The argillaceous rocks show poor slaty cleavage in places. The thick Palaeocene limestones are nearly vertical, possibly overturned in places, and folded into a curious sinuous trend; they are only slightly recrystallised. The Temala Member is more gently folded.

Thickness

The formation is too intensely folded for any reliable estimate of thickness to be calculated. Probably the thickness is of the order of 10,000-20,000 feet. The limestone at Batu Tujoh appears from air photographs to be about 800 feet thick, and that at Batu Asi slightly less. The exposed thickness of the Temala Member is estimated very approximately to be 3,000 feet.

Boundaries

The base of the formation is nowhere exposed. The top boundary with the Setap Shale Formation is problematic. There is believed to be a large disconformity separating the two formations over most of the area, and in places an unconformity. The boundary between the Temala Member and the overlying Melinau Limestone Formation is probably conformable in the Temala Valley, the Temala Member becoming increasingly calcareous towards the top, but near Batu Gading at Bukit Besungai (northeast) there are indications of an unconformable contact between Melinau Limestone and Cretaceous strata of the Kelalan Formation. It is possible that there is an unconformity between the Temala Member and the main part of the Kelalan Formation in the subsurface of the Temala Valley (see pp.23-24).

Fossils and age

The age of the formation is believed to range from ?Cretaceous to Upper Eocene, including Palaeocene. Cretaceous Foraminifera (probably *Globotruncana* sp.) have only been recorded from one specimen (S7042) beneath the Melinau Limestone at Bukit Besungai (northeast).

The limestones in the upper Baram (Batu Asi, Batu Tujoh, and east of Bukit Siman) have yielded *Alveolina* sp., *Nummulites* sp., *Discocyclina* sp., indicating a general Palaeocene to Middle Eocene age. Two specimens, one from the south end of Batu Asi, and the other from a boulder in the Sela'an River yielded:

Miscellanea miscella d'Archaic & Haime

Nummulites nuttalli Davies

(Identified by Crews and John, quoted by Liechti, 1960).

These indicate a Palaeocene to early Eocene age. A fuller investigation of samples from this area by C. G. Adams is in progress.

From the limestone outcrops in the Akah Valley near Long Siniai, Adams (1959, p.68) has identified the following fauna of Tb age:

> *Chiloguembelina* spp., *Discocyclina* sp., *Eorupertia* sp., *Globigerina* sp., *Gypsina globulus* (Reuss), *Halkyardia bikiniensis* Cole, *?Hantkenina* sp., *Nummulites* sp., *Operculina* sp., Textularids, Miliolids, Rotalids, Algal debris.

Shales from the formation have yielded a fauna of small benthonic Foraminifera, which are not now regarded as age-determining. Crews and John (*in* Widmer, *1953b*), give a list of genera, but this includes determinations from areas now regarded as Kelabit Formation, and as individual determinations for each specimen are not given, it is not of value. This fauna resembles in some species that of Stage III of the Belaga Formation of the Rajang Valley.

MELINAU LIMESTONE FORMATION

The Melinau Limestone Formation is composed of limestone, made up largely of Foraminifera, Algae, and some corals. It occurs between the Eocene formations (Kelalan and Mulu Formations) and the overlying Miocene Setap Shale Formation. The type locality is in the Melinau tributary of the Tutoh immediately to the north of the area described in this memoir. The main occurrences within the Suai-Baram area are in the Middle Baram on the flanks of the Temala Anticlinorium, where beds of limestone occur between the Temala Member of the Kelalan Formation and the overlying Setap Shale Formation. Limestone occurring apparently between the Kelalan and Setap Shale Formations, and provisionally allocated to the Melinau Limestone Formation, crops out at the head of the Tutoh Gorge, and at Bukit Siman, in the Belukun Valley, and in the Sela'an headwaters. The small outcrops shown on the 1:250,000 map are exaggerated.

Lithology

In the Middle Baram, the most complete sequence observed is at Bukit Besungai and Batu Gading. The lower 170 feet of limestone is Eocene, which is overlain by 6 to 40 feet of Miocene limestone. The sequence is shown in Paper I, figure 2, at the end of this memoir. The basal 50 feet of the Eocene limestone is exposed at Bukit Besungai, and is a dark grey to black sandy rock (e.g. S4466-72) composed mainly of large Nummulites, with Algae, and echinoid and mollusc fragments; some specimens contain pyrite.

This coarse sandy basal part is succeeded by 120 feet of massive compact limestone, typically pale grey, which is also composed of Foraminifera (smaller than the large Nummulites in the basal part), Algae, and corals. Bedding is impossible to distinguish in most of this part, even on the smooth fresh water-worn rock surface of the river section along the Baram at the west end of Batu Gading.

The Miocene part of the limestone at Batu Gading is 40 feet thick, and is composed of 25 feet of limestone breccia overlain by 15 feet of bedded limestone. This section is described in more detail in Paper I.

The lithology of the other outcrops around the flanks of the Temala Anticlinorium—namely in the Temala River and its tributary the Maloi, in the

Kejin River, and at Lobang Salai—is in general similar to that at Batu Gading though no section as complete as that at Batu Gading has been discovered. The limestone at Lobang Salai is much finer grained than at Batu Gading, and most is calcilutite. Large Foraminifera are rare or absent there, but the limestone contains a few pelagic forms (S4683, 4684).

Several hundred feet of limestone (S4587-90) interbedded with slaty shale crops out at the head of the Tutoh Gorge just below the Ubong tributary. The limestone has been dynamically metamorphosed and contains no determinate fossils.

In the upper Baram, lenses of Miocene limestone occur at Bukit Siman and in the Sela'an Valley; they have not been visited in the present survey but the lithology is said to be similar to that of the main Melinau Limestone (Liechti et al., 1960, p.135). Small outcrops of Miocene limestone in the Belukan Valley south and west of Batu Tujoh and at the northeast end of Batu Asi are also provisionally assigned to the Melinau Limestone. The rock types include calcarenite containing Algae and larger Foraminifera (e.g. S7082), calcilutite containing pelagic Foraminifera (S7084), and limestone breccia (S7100).

Tectonic aspect

In the Batu Gading area, the formation is gently dipping (10°-15°), and little diagenetically changed; at Bukit Siman and in the Belukun Valley it is vertical or nearly vertical; in the Tutoh Gorge it is steeply dipping and dynamically metamorphosed.

Thickness

Middle Baram. The thickness of the measured section at Bukit Besungai is about 176 feet (Eocene 170 feet; Miocene 6 feet); at Batu Gading about 160 feet (Eocene 120 feet; Miocene 40 feet), but the base is not exposed there (see Paper I, fig. 2). The thickness probably varies laterally, since the erosion surface at the top of the Eocene part is irregular. The other occurrences in the Middle Baram have not been measured accurately, but most seem to be between 70 and 200 feet thick.

Tutoh Gorge. The exposure of limestone in the Tutoh Gorge is several hundred feet thick.

Upper Baram. The Miocene limestone at Bukit Siman is estimated to be about 1,000 feet thick. The occurrences south of Batu Tujoh and below the Paku tributary are probably much thinner, since they do not form prominent features.

Boundaries

Middle Baram. The limestone in the Middle Baram is believed to be conformable on the Temala Member of the Kelalan Formation. At Bukit Besungai (north) the limestone overlies coarse crumbly sandstone. Around the south side of Bukit Besungai (northeast), however, the limestone appears to overlie steeply dipping alternating sandstone and shale, which occurs about 20 feet below the base of the gently dipping limestone. It is overlain conformably by Setap Shale Formation.

Tutoh Gorge. The limestone in the Tutoh Gorge dips at about 80° towards south-southwest. This is almost at right angles to the general dip in this part of the gorge, which is about 80° towards southeast. The folding in this part is so intense that no conclusions can be drawn as to the stratigraphic relations of the limestone to the surrounding strata.

Upper Baram. The limestone at Bukit Siman strikes approximately conformably with the Setap Shale and Kelalan Formations, but no contacts have been observed. In the Sela'an headwaters, however, Widmer observed 'typical thin-bedded sandstones and greenish and bluish-grey shales of the Eocene [i.e. Kelalan Formation] overlain unconformably by dark-grey sandy shales, at the base containing coarse sand grains and including some conglomerate pockets. A few metres higher in the succession we find a massive limestone, several metres thick, containing Te Foraminifera.'

In the Belukun River west of Batu Tujoh, Miocene limestone rests with a basal conglomerate on slaty calcareous strata of the Kelalan Formation which contain a fauna of pelagic Foraminifera indicating Ta age (probably Palaeocene). At the northeast end of Batu Asi ridge, Miocene limestone breccia overlies Palaeocene limestone of the Kelalan Formation. (Personal communication from Dr C. G. Adams).

Fossils and age

The age of the Melinau Limestone Formation is reliably established to range from Upper Eocene (Tb) to Lower Miocene ($Te_{1\text{-}4}$); Oligocene has not been found in the formation in the area, although it occurs at the type locality to the north. A disconformity proved within the limestone is believed to represent the whole of the Oligocene and presumably also part of the Upper Eocene and Lower Miocene, and an equivalent disconformity is probably present in the formation at the other occurrences within the area.

Middle Baram. Several hundred samples from the formation have been collected by the writer from the Middle Baram and, later, by C. G. Adams of the British Museum, in the course of this survey. Some of these have already been examined and reported on in some detail (Davies and others, 1956; Adams, 1958, 1959), and the whole collection is at present being examined by C. G. Adams, who plans to publish a detailed report in due course. For this reason, detailed lists of Foraminifera are not given here, but a preliminary account of the most carefully studied exposures, at Batu Gading and Bukit Besungai, is given by C. G. Adams and R. Haak in Paper I (see p.141). Algae from various outcrops in the Middle Baram have been studied by J. Harlan Johnson, whose detailed account is included as Paper II (p.151).

Tutoh Gorge. The limestone at the head of the Tutoh Gorge has been so intensely squeezed that no determinate fossils remain, though traces of Foraminifera can be seen in some slides (e.g. S4589, see pl. xxvib). However, its stratigraphical position on the flanks of the Mulu Anticlinorium and between the Mulu and Setap Shale Formations, leaves little doubt that it is an equivalent of the Melinau Limestone Formation.

Upper Baram. The Melinau limestone in the upper Baram has yielded Miocene faunas only, and Upper Eocene limestone has not been found there.

The limestone at Bukit Siman has yielded *Lepidocyclina* sp., *Operculina* sp., and *Spiroclypeus* sp., which indicate a Miocene age. The first two genera have also been identified from the small outcrop south of Batu Tujoh. The outcrop in Sungai Sela'an contains *Lepidocyclina* sp. and *Spiroclypeus* sp. A small outcrop in the Baram below Sungai Paku yielded *Discocylina* sp. and *Nummulites* sp. with Miocene forms such as *Lepidocyclina butonensis* van der Vlerk (Liechti and others, 1960, p.140); the Eocene forms are presumably reworked. The palaeontology of the other Miocene limestone outcrops in the the upper Baram is still being worked out.

Environment

The formation is inferred from its fossil content to have been formed under similar conditions to those that were operative at the type locality in the Melinau Valley to the north, namely, in a shallow sea generally not deeper than 75 to 100 feet. 'Rather short periods of more shallow water conditions with more or less prolific growth of corals and Algae occurred. There was not always a reef, but rather fore-reef shoals, and the limestones are of a fore-reef transition type with some reef talus . . . ' (Liechti et al., 1960, p.140). The small thickness of the occurrences in the Suai-Baram Area, as compared to the great thickness (over 6,000 feet) in the type area, is believed to be due in part to the large hiatus between Eocene and Miocene deposition, and in part to less subsidence and slower growth. Liechti concluded that 'all these limestones grew either on anticlinal crests or on the flanks [of anticlines] not far off the crest'.

KELABIT FORMATION

The Kelabit Formation comprises mudstone, sandstone, and thin lenses of impure limestone. As redefined here, the formation is known from outcrops in the Baram Headwaters (there known as the Kelapang) above the Puak tributary in the Kelabit Highlands. There is some palaeontological indication that belts of the formation may occur in the Kuba'an and Sela'an Rivers, but the evidence is insufficient to map them as such. The massive sandstones of the Tamabo Range and Batu Lawi, previously included in the formation, are here considered as Meligan Formation for reasons already discussed (p.26).

Lithology

Mudstone and sandstone are the main rock types, with some lignite and rare conglomerate. The mudstone is commonly calcareous, invariably sandy, poorly bedded, and typically shows spheroidal weathering and conchoidal fracture (pl. xva). The colour is brownish grey or light bluish grey. At many places it contains fragmentary plant remains and pieces of lignite (S6171). Nodules and lenses of clay-ironstone and of hard mudstone are common. Sandstone lenses and blocks, mostly 1 to 2 feet across, are common and have a distinctive irregular rather hackly surface. In most outcrops the sandstone is calcareous and pyritic, and at places contains beds and lenses of impure limestone (S6163) and veins of calcite. A number of salt springs are associated with this mudstone (see pp.107-113).

The sandstone is well bedded, and in places contains abundant coalified plant remains and seams and lenses of lignite up to 4 inches thick. This type of sandstone is commonly interbedded with soft, carbonaceous, very sandy black shale, and light-grey mudstone with conchoidal fracture. Widmer found lignite seams east of Pa Umor, and lignite is also reliably reported from the

Di'it tributary of the Kelapang, east of Pa Dali. Some beds of whitish quartzose sandstone occur.

Conglomerate (S6150) found as boulders at Batu Patong in the Kelapang headwaters, is composed of pebbles up to 2 cm across mainly of red radiolarian chert, vein quartz, sandstone, and agate; the last appears to have been derived from vesicles in a lava without having been rounded to pebbles.

At the mouth of the Benaleh (or Baleh) tributary is an exposure of the following rocks, which differ somewhat from any others seen in the Kelabit Formation:

Calcareous sandstone, in beds as much as 4 feet thick
Dark-grey, light-grey, and brown shale, alternating in beds 0·1 to 2 inches thick
Sandy calcareous shale with Foraminifera (*Nummulites* sp.) up to 5 mm across
Impure limestone, weathering to a reddish colour, containing pelagic foraminifers, in beds as much as 6 inches thick.

Red mudstone was found in the Kelapang below Ramudu, but this is not typical, and might represent an inlier of Kelalan Formation.

Tectonic aspect

The formation is moderately to steeply folded along north-south axes, and in general the dips are slightly less steep, and the folding more regular and less chaotic than those of the Setap Shale or Kelalan Formations. The mudstone is fairly hard, but no slaty rocks have been seen. The exposure at the mouth the Benaleh is unique in that it shows intense tight folding, including small recumbent folds a few feet across.

Thickness

As the boundaries are not known no reliable estimate of the thickness can be made. From the width of outcrop it seems probable that the exposed thickness is at least several thousand feet.

Boundaries

Neither the top nor the basal boundary has been discovered. On general structural evidence, and taking into account palaeontology and the regional geology, it seems probable that the Kelabit Formation overlies the Kelalan Formation either conformably or with a slight unconformity. To the west, the formation is probably overlain conformably by the Meligan Formation of the Tamabo Range. West of the Tamabo Range the formation has not been recognised. This is presumably due partly to the general hiatus in deposition in the Oligocene and partly to the lateral transition of the upper part of the formation into Setap Shale Formation. The single Oligocene sample found in the Sela'an River might represent a western outlier of Kelabit Formation resting on Kelalan Formation, but in view of the meagre evidence it has not been mapped as Kelabit Formation.

Fossils and age

Fossils indicating both Lower Oligocene (Tc) and Lower Miocene ($Te_{1\text{-}4}$) age have been found in the formation (see locations on coloured map):

A specimen of calcareous shale, S6164, from the Kelapang River at the mouth of the Benaleh tributary, was examined by R. Todd of the Palaeontology and Stratigraphy Branch of the U.S. Geological Survey (Report dated 13 May 1960). She wrote:

I list below the species of smaller Foraminifera found. Because of the very poor preservation, many of them are specifically undeterminable. I have included notes on the recorded ranges of the species in the planktonic part of the fauna, which is by far the predominant part. The benthonic part adds few if any clues to the interpretation of age or ecology. Its numerical insignificance suggests the deposit was not laid down close to shore or in connection with a reef, but rather suggests relatively deeper-water deposition.

Benthonic part:

Ammobaculites? sp.
Anomalina sp.
Asterigerina? sp.
Bolivina sp. aff. B. beyrichi Reuss
Bulimina ovata d'Orbigny
Cassidulina? sp.
Cibicides spp.
Dentalina? sp.
Dorothia? sp.
Eponides umbonatus (Reuss)
Gaudryina sp.
Gyroidina sp.
Nonion? sp. aff. N. advena (Cushman)
Nonionella? sp.
Plectina? sp.
Robulus spp.
Stilostomella? sp.
Uvigerina sp.
Vaginulina spp. aff. V. mexicana Nuttall
Verneuilina sp.
Verneuilina? (or Gaudryina?) sp. juv.

Planktonic part: (listed in order of abundance)

Globoquadrina venezuelana (Hedberg) (abundant)
(range from middle Eocene throughout the Miocene)

Globigerina ampliapertura Bolli (fairly common) (reported by Bolli[1] from uppermost Eocene to lowermost Oligocene, but Stainforth[2] reports it to range throughout the Oligocene)

Other globigerinids

Globigerinoides trilobus (Reuss)? (very rare)
(uppermost Oligocene to Recent)

Globorotalia centralis Cushman and Bermudez
(one specimen) (upper Eocene).

The planktonic assemblage resembles somewhat an assemblage I studied from Guam where the same two species (*Globoquadrina venezuelana* and *Globigerina ampliapertura*) are associated with reticulate nummulites as they are here. On Guam this assemblage is currently considered lower Oligocene (Tertiary *c*) in age, and I would estimate the age of this sample to be about the same.

---

[1]Bolli, H.M., 1957, Planktonic Foraminifera from the Oligocene-Miocene Cipero and Lengua formations of Trinidad, B.W.I., and Planktonic Foraminifera from the Eocene Navet and San Fernando formations of Trinidad, B.W.I.: *U.S. Nat. Mus. Bull.*, 215, text fig. 18 on p.99 and text fig. 26 on p.159.

[2]Stainforth, R.M., 1960, Current status of transatlantic Oligo-Miocene correlation by means of planktonic Foraminifera: *Revue de Micropaleontologie*, v. 4, No. 2, p.222, and range chart on p.221.

Other samples from the formation were examined by palaeontologists of Sarawak Shell Oilfields Limited with the results shown in table 6.

TABLE 6. FORAMINIFERA FROM THE KELABIT FORMATION

GENUS	S6151	S6152	S6154	S6155	S6156	S6157	S6158	S6159	S6160	S6162	S6164	S6165	S6166	S6167	S6169	S6170	S6171	S6172
Ammobaculites																x	x	
Ammodisus		x		x	x			x		x						x	x	
Arenobulimina				x				x							x			
Bathysyphon	+	x	+	+	+			x		+						+		
Bolivina	+								+									
Bulimina															x			
Cassidulina				+					x	+	x	x	x		x	+		
Chilostomella												x						
Cibicides									x									
Clavulina						x												
Cristellaria	x		x	x					x				+					
Cyclammina		+	+	+	+			x		+					+	x	+	
Ellipsoglandulina																x		
Eponides																x		
Gaudryina	+							+	+						+	x	x	
Globigerina	+	+	x	+			+		+	+	+	+	+	+	+	+	x	
Globoquadrina		+		x						x	+	+	+	+	+	+		
Glomospira										x					+			
Gyroidina				x						x				x	x	+		
Haplophragmoides	+		x	x						x						x		
Hormosina		x																
Lagenammina		x	x															
Nodosaria	x	+		+				x	x	+		x	+		x	+		
Nonion									x				+					
Nummulites											x		x					x
Operculina											x		x	x				
Pleurostomella				x						x					x	+		
Pullenia		+		x						x					x	+		
Reophax		x																
Rotalia									x									
Textularia	x								x						x		x	
Trochammina		+	+		x			x		x								
Trochamminoides		x	x	x	+					x								
Uvigerina		x							x				+	x	x			
Verneuilina			x															
Vulvulina		x		x						x			x	x	x	x		

Notes x One species recognized
\+ More than one species recognized

ROCK TYPE	LOCALITY	AGE ASSIGNED
S6151 Mudstone	Kelapang River, about 1 mile downstream from Mada tributary	Te_{1-4}
S6152 Claystone	Kelapang River, about 2 miles upstream from Ramudu	Te_{1-4}
S6154 Mudstone	Kelapang River about 1 mile below Ramudu	Indeterminate
S6155 Mudstone	Kelapang River about 2 miles below Ramudu	Tc-d
S6156 Mudstone	Kelapang River between Ramudu and Pa Merer	Indeterminate
S6157 Mudstone	Beruang tributary of Benaleh River	Indeterminate
S6158 Mudstone	Benaleh River above Long Peluan	Tc-d or early Te_{1-4}
S6159 Mudstone	Benaleh River above Long Peluan	Indeterminate
S6160 Mudstone	Kelapang River about ½ mile above Benaleh tributary	Tc-d
S6162 Mudstone	Kelapang River, about 4 miles above Benaleh tributary	Te_{1-4}
S6164 Shale	Kelapang River at mouth of Benaleh tributary	Tc-d
S6165 Limestone	Kelapang River at mouth of Benaleh tributary	Tc-d
S6166 Shale	Kelapang River at mouth of Benaleh tributary	Tc-d
S6167 Shale	Kelapang River at mouth of Benaleh tributary	Tc-d
S6169 Mudstone	Benaleh River near Long Peluan	Tc-d
S6170 Mudstone	Kelapang River ½ mile below Benaleh tributary	Tc-d
S6171 Mudstone	Kelapang River ½ mile below Benaleh tributary	Indeterminate
S6172 Mudstone	Kelapang River 2 miles above Balong tributary	Tc-d

Determinations by Sarawak Shell Oilfields Limited. Age determinations are based on pelagic Foraminifera, except for S6164 and S6172 which contain reticulate *Nummulites* sp.

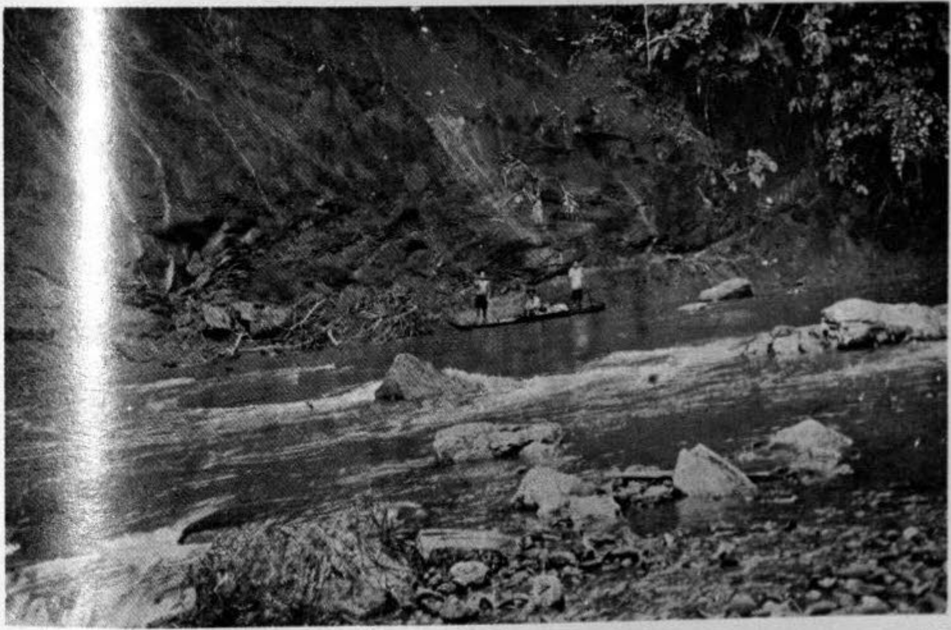


PLATE XVa. KELABIT FORMATION. Outcrop of mudstone in Kelapang River near Pa Dali in the Kelabit Highlands (*see p.37*)

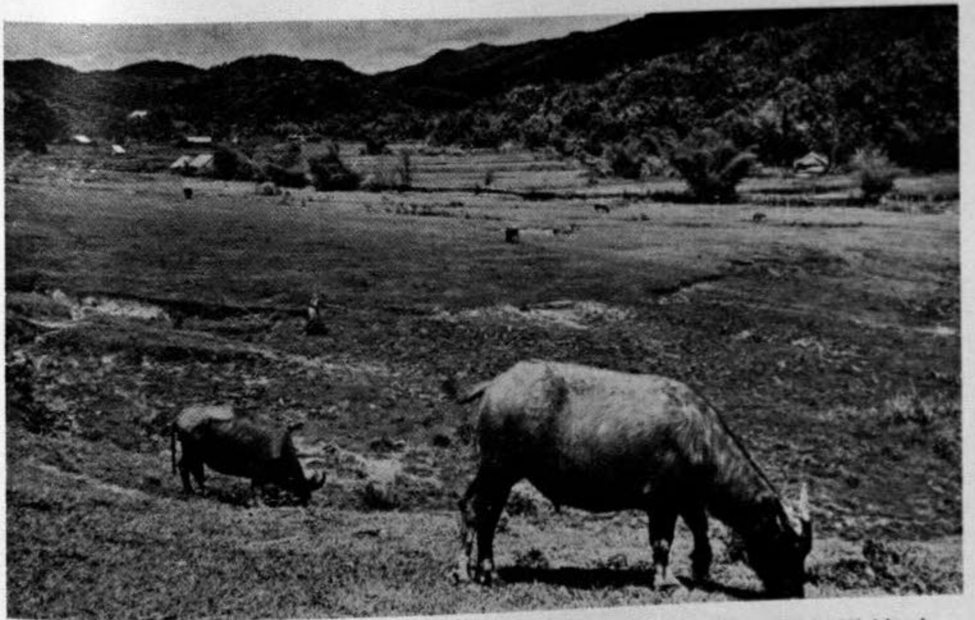


PLATE XVb. BAH KELALAN. Flat valleys surrounded by hills in the Kelabit Highlands

Photograph b: G. E. Wilford

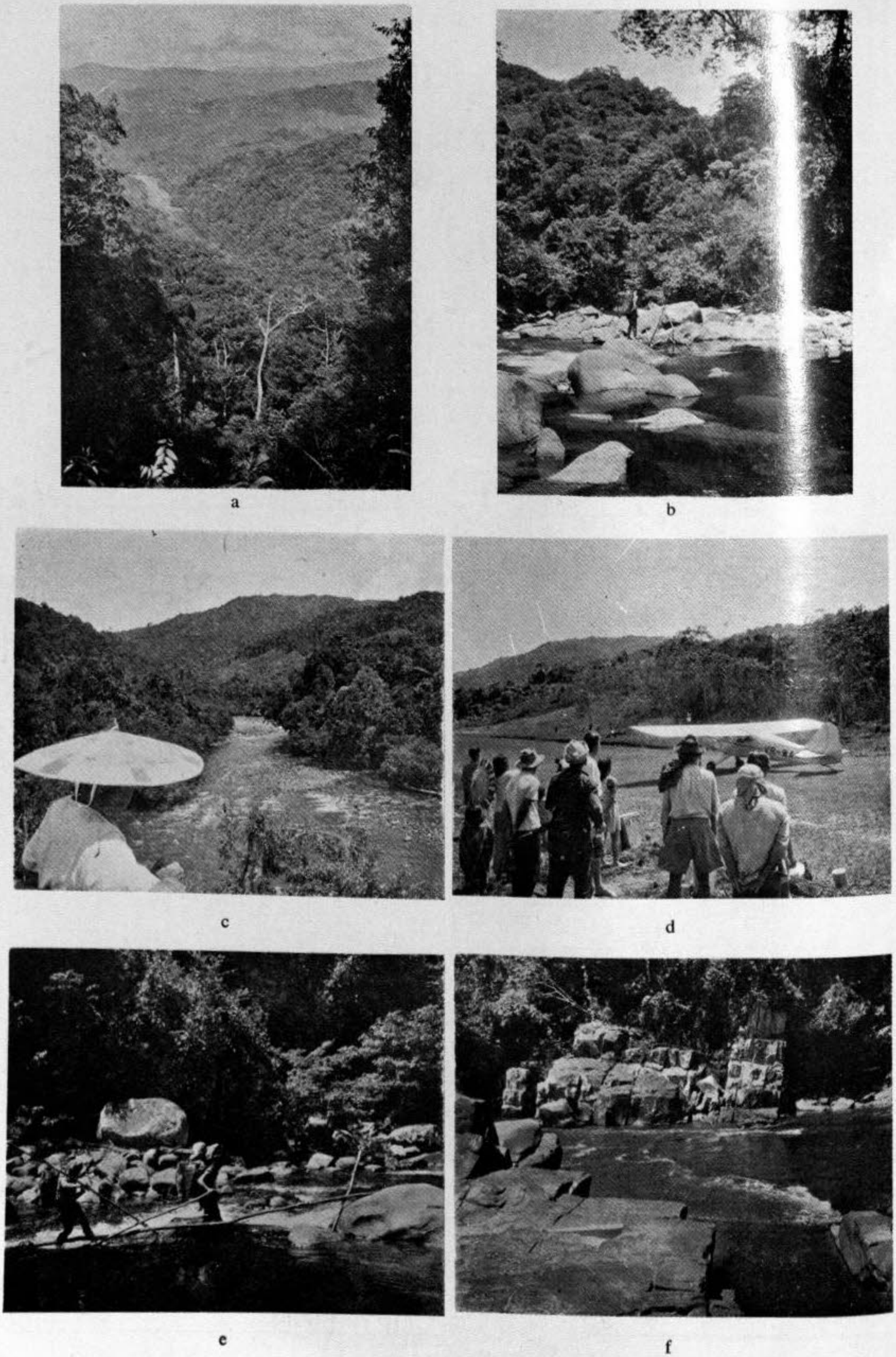


PLATE XVI. THE UPPER BARAM. The river above Lio Matu (a-c; e); Lio Matu airstrip (d); steeply dipping sandstone in the Baram near the Tudan tributary (f)

Photographs: G. E. Wilford

Radiolaria in chert pebbles in conglomerate (S6150, see above) were examined by G. F. Elliott of the Iraq Petroleum Company (report dated 2 December 1960 filed as GSKL 101A/63):

S6150 (large thin section): *Cenosphaera, Dictyomitra, Melitosphaera, Stylosphaera,* (in matrix, but may be derived). *Cenosphaera, Dorysphaera* (in grey radiolarite pebbles). *Cenosphaera* (elsewhere).

S6150 (Slide A): *Dictyomitra, ?Stichopera, Cenosphaera* (in different pebbles).

S6150 (Slide B): *Melitosphaera, ?Stylosphaera, Dicolocapsa* (in different pebbles).

None of these radiolaria are very well preserved. All range from various levels in the Palaeozoic upwards except *Melitosphaera,* which is Jurassic—Recent. The age of the constituents of the conglomerate, therefore, is Jurassic or younger.

SETAP SHALE FORMATION

The Setap Shale Formation is a thick monotonous succession of shale with subordinate sandstone, and a few, mostly thin, lenses of limestone. It occupies most of the Middle Baram Valley; in the Suai area, its outcrop is less extensive, as it is partly covered by younger deposits; nevertheless it probably extends under most of this country, except where its place is taken by the sandy Nyalau Formation. It is not known east of the Tamabo Range.

Lithology

The lithology, of grey shale, grey mudstone, sandstone and a few limestones, is very uniform and monotonous. Variation in the proportions of the constituents occurs, and there is some variation in the degree of induration, which in general is higher in the Baram Valley, particularly on the flanks of the Mulu Anticlinorium. The following account of the lithology is based mainly on the compilation by Liechti (1960), with the addition of further data from the writer's field work in the Baram Valley.

Suai Area. Along the Paroh Anticline in the upper Suai Valley, typical Setap Shale Formation crops out, and consists of shales and thin subordinate sandstones. South of the Paroh Anticline, the Setap Shale Formation is generally absent, its place being taken by the sandy Nyalau Formation. In the Lower Suai Valley, the formation consists of a monotonous succession of blue grey silty and clayey shales, occasionally sandy, well bedded, moderately soft and lignitic in some bands, but hard and nodular in others. The interbedded sandstones are grey or blue grey, fine to medium grained, and rarely exceed 100 feet in thickness. In the subsurface near the Suai Estuary (Suai Wells 1-6), about 1,000 feet of limestone of Te_5 age has been penetrated. In the Niah Valley, slightly more arenaceous beds occur near the top of the formation, where locally some sandy marlstone and calcareous sandstone are interbedded in sandstone.

Middle Baram (northwest part). Around the Bakong River, the formation is calcareous, and shows a facies transitional to that of the Sibuti Formation. The strata consist of shale and claystone, occasionally calcareous, with subordinate fine-grained, hard, argillaceous sandstone, also calcareous in places. The sandstone is more common towards the top of the formation, where carbonaceous material is more abundant. Lenses of limestone (5 to 30 feet thick) and lenses of calcareous argillaceous sandstone as much as 400 feet thick and over a mile long occur in the formation in this area. In the northern part of the Middle Baram, northeast of Long Ikang, the formation is predominantly argillaceous, with the exception of the Batu Belah Sandstone Member, which occurs in the uppermost part of the formation and forms a prominent escarpment between the Tutoh and Baram Rivers, about 2 miles southwest of Bukit Batu Belah. The member consists of at least seven major sandstone beds, most of which do not exceed 100 feet, separated by shale: the sandstones are mostly hard and fine grained, grey to bluish grey and commonly highly carbonaceous; the shales are silty or sandy, frequently lignitic and commonly indurated, and are interbedded with thin sandstone layers. Over the rest of the Middle Baram area, the proportion of sandstone increases from about 10 percent in the Tinjar Valley near the Tisam tributary to an estimated 20 to 30 percent in the southeast.

Tinjar Valley. Widmer (*1953a*) noted that the formation in the Tinjar Valley, as elsewhere, consists of alternating shale and sandstone. In the lowest part, the sandstones are fine grained, grey, mostly thin bedded, and hard. The shales are predominantly dark-grey, sandy to silty, and commonly contain mica. Plant remains and finely divided carbonaceous matter occur almost throughout the sequence, both in sandstones and shales. Towards the top thicker bedded to massive sandstones occur, and these are slightly clayey and softer. Some of the sandstones are calcareous, but limestone is rare. The only limestone lens of any size was found in a squeezed zone in the valley of the Merurong (a tributary of the Jelalong in the upper Kemena Valley) and was described as a light-grey, dense, fine grained rock with irregular clay films, containing *Globigerina* sp. A similar limestone was found by the writer in a bed a few feet thick in the Tisam Valley (S4510).

Middle Baram (central and eastern part). In the main Middle Baram River and its eastern tributaries, the Setap Shale Formation is similar to the exposures in the Tinjar. As described by Widmer (*1953b*), the shales are typically dark grey, sandy to silty and contain plant remains, accumulated in fine bands, or finely dispersed. Towards the top, paler, sometimes bluish-grey shales are present. Nodular shales, often with spherical weathering and conchoidal fracture, are typical (pl. XVIIa). The sandstones are usually thin-bedded, but towards the top may become massive. They are more common towards the south. In the lower part, they are commonly hard and show some degree of re-crystallization, while towards the top they are usually softer and often clayey. In a few places, slightly calcareous layers occur.

The writer agrees with the above description except that he found calcareous shale and mudstone to be quite common in the Middle Baram. Most of the argillaceous rocks which show conchoidal weathering are slightly calcareous. Calcareous strata are especially common around the Temala Anticlinorium, where Setap Shale Formation overlies the Melinau Limestone Formation. At least 100 feet of calcareous strata overlie the Melinau Limestone at Batu Gading and include calcareous mudstone (S4432, S4438, S4614-17, S6000-05, S6007, S6010-17, S6306), and also impure limestone (S4439, S6005-06, S6008-09) which forms a bed about 15 feet thick 50 feet stratigraphically above the top of the Melinau Limestone Formation. These strata contain abundant pelagic Foraminifera but no benthonic forms. Argillaceous limestone (S4494) and marl (S4618, S4620) occur about a quarter of a mile downstream from Batu Gading, and the limestone (S4494) contains Miocene benthonic Foraminifera. Similar calcareous shale with pelagic Foraminifera occurs above the Melinau Limestone at Bukit Besungai (S4482, S7023), in the Maloi tributary of the Tisam (S4662-63), and in the Kejin Valley (S7123-24). On the southwest side of the Temala Anticlinorium, the Setap Shale Formation (exposed in the Liang tributary of the Baram) consists of calcareous shale (S7129, S7130, S7132) with lenses of limestone conglomerate (S4686, S4687, S7131, S7133) and nodules or cobbles of fine grained limestone (S4685).

Limestone occurs a few hundred yards north of the Baram River at the Giam Asa rapids, about a mile downstream from Long Akah. It forms cliffs about 70 feet high, and contains a small cave remarkable for the pungency of the great number of bats which crowd it. The limestone contains Miocene benthonic Foraminifera and has been assigned to the Setap Shale Formation. Types of rock include compact, medium grained limestone (S4550), detrital limestone (S4551), and sandy limestone with shell fragments (S4552). A boulder of miliolid limestone about 10 inches across in the Akah River at Meligong Rapids is the only other limestone in the Middle Baram assigned to the Setap Shale Formation.

A few sandstone specimens from the formation in the Middle Baram were examined microscopically and found to include subgraywacke (S4509, S4612, S6141), calcareous subgraywacke, and some calcareous quartzose sandstone (S4554). In the Middle Akah Valley, downstream from Long Tebangan village, and in the Tebangan tributary, the strata are predominantly sandy. Beds of sandstone exceeding 50 feet and thick alternations of shale and sandstone in beds 4 inches to a foot thick are exposed. In the Tebangan tributary, thick exposures of poorly bedded grey shale occur, interbedded with grey sandstone and at one place a black sandstone (S4556), coloured apparently by carbonaceous matter. An unusual conglomerate was found in this stream, both as boulders (S4555) and as lenses about 4 inches thick (S4557) in massive shale. This conglomerate is composed of sub-rounded to rounded pebbles, 1 to 3 mm across, mostly of pink chert, with some of vein quartz, and siltstone, fine-grained sandstone, and crystalline carbonate. The chert contains numerous well preserved Radiolaria. Most of the chert pebbles contain abundant finely divided pyrite, and some are almost completely replaced by it. Carbonate (probably dolomite) occurs as rims round the chert pebbles and as rhombs in the chert. The sandstone matrix is mainly quartz and chert with rare grains of albite and some carbonate, and little or no clay-grade material. The lithology in this area is distinct from that of the normal Setap Shale Formation. Widmer (*1953b*) mapped a belt of probable Eocene across this section, and on strike extrapolation and photogeology showed it extending north-northeast across the Patah and Tutoh Valleys. However, the lithology of these strata appears to be as distinct from the Kelalan Formation as from the rest of the Setap Shale Formation, and, moreover, the typical Kelalan rocks have not been seen in this section nor in the continuation along the strike in the Patah and Tutoh Valleys. The writer considers on photogeology, and the position of the rocks not far from the base of a prominent scarp forming a synclinal structure, that their stratigraphical position is probably near the upper part of the Setap Shale Formation, and they have consequently been mapped as such, though with some reservations. Conglomerate containing similar radiolarian chert has been found as boulders in the Kelabit Highlands (see above, p.38).

Tectonic aspect

The formation shows moderate folding in the Suai Area, which increases in intensity to the east. In the Middle Baram the dips are mainly steep, within 20 degrees of vertical, and the strata are probably overturned in places; the structure is complicated (pl. XVIIb). No marker beds have been found in the formation and so the details of the structure within the formation cannot generally be deciphered. Where thick sandstone bodies occur, they enable the structure to be traced over small areas by the use of air photographs.

Thickness

Estimates of thickness are mostly unreliable, mainly because of uncertainty due to the unknown extent of structural repetition. The estimates shown in table 7 have been compiled by Liechti (1960).

TABLE 7. ESTIMATES OF THICKNESS OF THE SETAP SHALE FORMATION

Locality	*Thickness* (in feet)	*Remarks*
Suai Coast	at least 2,400	From drilling results; base not reached
Paroh Anticline	at least 4,000-5,000	Base not exposed
Tinjar Valley	15,500	
Middle Baram Valley	16,500	
Tutoh Valley	18,500	Most accurate estimate; section lies just north of Suai-Baram area

Boundaries

The basal boundary is not exposed in the Suai area. In the Middle Baram it is clearly defined where the formation rests on Melinau Limestone Formation, i.e. on the flanks of the Temala Anticlinorium, at the head of the Tutoh Gorge, and at Bukit Siman. Around the Temala Anticlinorium, the contact has been observed at Batu Gading, Bukit Besungai, Maloi Paku, and on the River Kejin and is conformable. Elsewhere it is problematic, as the lithology is not sufficiently different from the underlying Kelalan Formation to allow an accurate delimitation.

No general discordancy in the strike of the two formations has been observed, and the junction is therefore believed to be a disconformity, the Oligocene apparently being absent over most of the area. In the Sela'an Valley, Widmer (*1953b*) observed an unconformity at a single exposure between Miocene shale and limestone and 'Tab' (i.e. Kelalan Formation) shale and sandstone (see fig. 4) but this has not been observed elsewhere.

In the Suai area the formation is overlain conformably, and along a strongly diachronous boundary, partly by Nyalau Formation, and partly by Belait and Lambir Formations. The boundary with the Nyalau Formation, which is a sandy facies largely synchronous with the Setap Shale Formation, is a gradual transition, but where the Belait Formation directly overlies Setap Shale Formation the boundary is clear. In the Middle Baram area, the top boundary is with Belait Formation, and, towards the Kelabit Highlands, with Meligan Formation, and is also believed to be conformable and diachronous.

Fossils and age

The formation is believed to be exclusively of Miocene age. Most of the formation is Te, but it ranges as high as Tf in places. Much of the fossil evidence has come from outside the area described. The only fossils found in the formation are Foraminifera, and indeterminate plant remains.

In the *Suai Area*, only the upper part of the formation is exposed. From the Suai Wells *Floscullina botangensis* Rutten indicates a Tf_1 age. In the Middle Baram area a large number of shales have been sampled and have yielded mostly arenaceous faunas. A large number of genera have been determined by SSOL palaeontologists, but they are not listed here as they are of little age-determining value. A recent investigation by SSOL of pelagic Foraminifera has led to the provisional determination of Te_{1-4} to early Te_5 for a number of these samples. Identifications of some of the pelagic forms are given in Paper I.

In the *Middle Baram Area*, from the limestone below Long Akah, C. G. Adams (1959) identified the following faunas which he assigned to the Te:

S4550	*Spiroclypeus* sp.
	? *Eurupertia* sp.
S4551	*Lepidocyclina* sp.
	Spiroclypeus sp.
	Cycloclypeus sp.
	Miogypsinoides sp.
	Operculina sp.
	Gypsina globulus (Reuss)
	Algal debris

From the boulder of miliolid limestone in the Middle Akah Valley he identified a fauna as follows, which could only tentatively be assigned a Miocene age:

S4575	*Borelis* aff. *parvulus* Hanzawa
	Miliolids and rotalids

Radiolaria in chert pebbles in the conglomerate already described (S4555, S4557) were examined by G. F. Elliott of the Iraq Petroleum Company. These pebbles are almost certainly derived from an older formation.

Mr. Elliott (report dated 2 December 1960 filed as GSKL 101A/63) recorded:

S4555 (Slide A): *Cenosphaera, Dicolocapsa, Dictyomitra* (in pebble). *Cenosphaera, Melitosphaera, Tricolocapsium, Stylosphaera, Lithapium, Stichopodium, Meyenella* cf. *hensoni* Davis (in larger pebble).

S4555 (Slide B): *Blustrella* (in grey pebble). *Cenosphaera, Dictyomitra, Lithapium, Dicolocapsa, Meyenella hensoni, Cryptocapsa* (in buff pebble).

S4555 (large thin section): *Cenosphaera* (in black pebbles). *Lombardia* (problematicum: in grey pebble).

S4557 (including large thin section): *Cenosphaera* (in pebbles of black chert).

These radiolaria include some ranging from the Cretaceous (*Tricolocapsium, Stichopodium*) and the *Meyenella* sp. is in the writer's experience characteristic of the Cretaceous too. The age of the constituents on radiolarian evidence is therefore Cretaceous or later, probably the former. *Lombardia* is a thin-section microfossil characteristic of the European Upper Jurassic, and seen by me at the same level in Iraq, and recorded similarly from the Caribbean by Bronnimann. Verniory (*Arch. Sci. Geneve*, 1956) has shown that *Lombardia* is probably the thin-section appearance of plates of the pelagic crinoid *Saccocoma*. The age of the constituents in S4555 is therefore probably Cretaceous, perhaps with some Jurassic . . .

Mr. Elliott later pointed out (letter of 20 February 1961) that *Lombardia*, while typically Upper Jurassic, has recently been recorded in the Valanginian and perhaps Hauterivian in Southern Poland (Lefeld and Radwanski, *Act. Geol. Polon.*, *10*(4), 593-614, 1960).

TANGAP FORMATION

The Tangap Formation is a calcareous formation within the Setap Shale Formation, and includes the Subis Limestone Member. It is confined to the Subis Anticlinorium, and lies entirely within the Suai area. The type section is in the Tangap tributary of the Niah River, north of Bukit Subis. The formation builds the core of the Subis Anticline over a length of 37 miles; the outcrop is 6 to 10 miles wide in the Subis area, but narrows towards the northeast due to pitching of the anticline. The type area for the Subis Limestone Member is the limestone hill Bukit Subis, which extends over about 9½ square miles (see fig. 5 and pls. VIA, XVIII, XIX). Strata referred to Tangap Formation have been penetrated in the subsurface in wells near Bukit Subis and on the Suai Coast (see stratigraphical columnar sections, fig. 3).

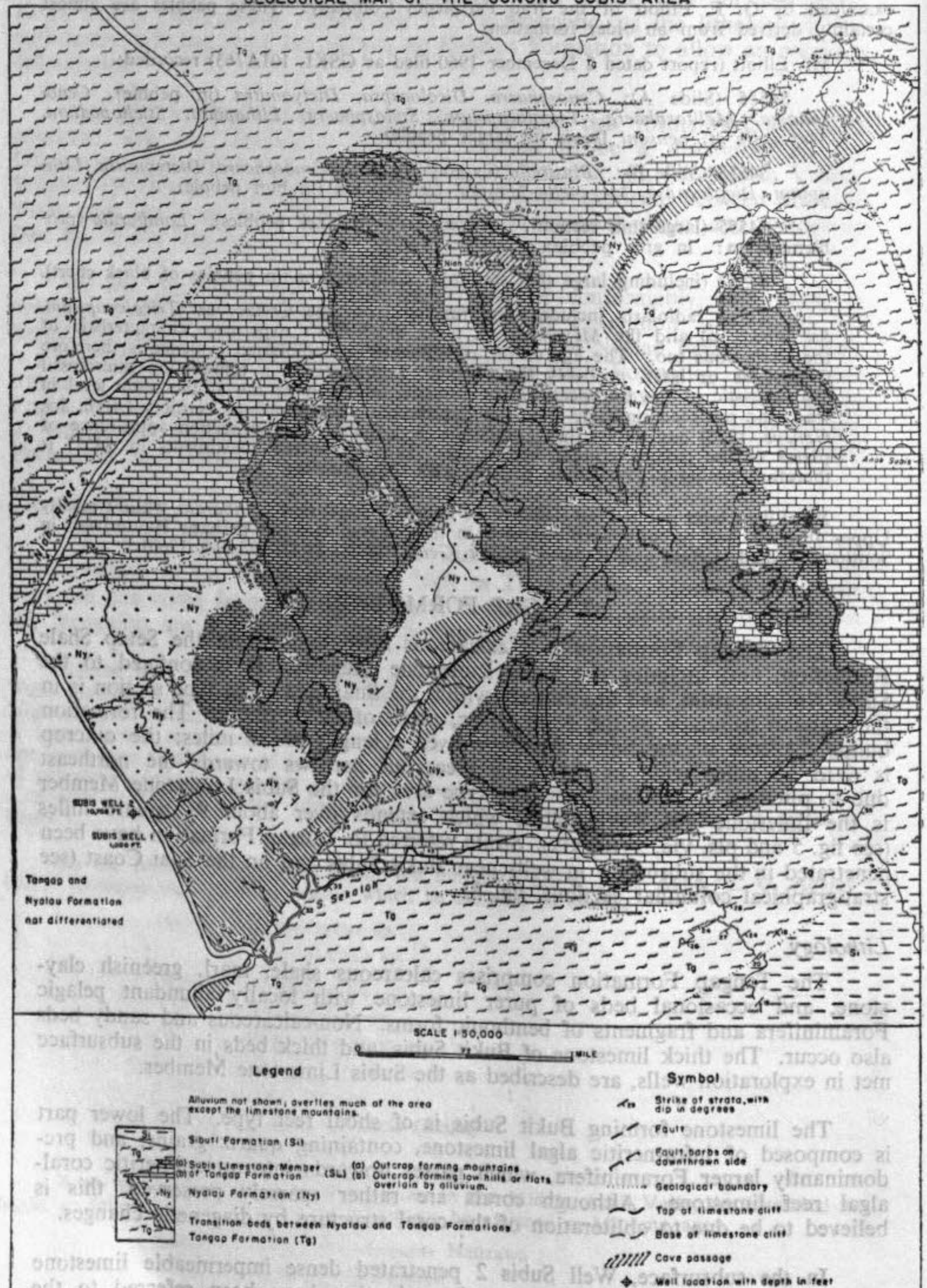
Lithology

The Tangap Formation comprises calcareous shale, marl, greenish claystone, and occasional beds of purer limestone with locally abundant pelagic Foraminifera and fragments of benthonic forms. Non-calcareous and sandy beds also occur. The thick limestone of Bukit Subis, and thick beds in the subsurface met in exploration wells, are described as the Subis Limestone Member.

The limestone forming Bukit Subis is of shoal reef type. The lower part is composed of infra-neritic algal limestone, containing quartz grains, and predominantly larger Foraminifera, which passes upwards into an epi-neritic coral-algal reef limestone. Although corals are rather sparsely preserved, this is believed to be due to obliteration of the coral structure by diagenetic changes.

In the subsurface, Well Subis 2 penetrated dense impermeable limestone which interfingers with sandstones and marls that have been referred to the

FIGURE 5
GEOLOGICAL MAP OF THE GUNONG SUBIS AREA



Sarawak Geological Office Map No 307, 1960 Based on surveys by Geologists of Sarawak Shell Oilfields Limited.

Nyalau Formation and the clastic part of the Tangap Formation respectively. The limestone is believed to have formed in the same cycle of reef growth as that forming Bukit Subis, and is considered to be part of the Subis Member.

Tectonic aspect

The Tangap Formation is fairly gently folded, dips of 5° to 20° being usual.

Thickness

The thickness of the formation in outcrop ranges from less than 2,000 feet to 5,700 feet. In the subsurface of Well Subis 2 the formation is 5,900 feet thick; it extends over a vertical distance of 9,000 feet, but this figure includes two tongues of Nyalau Formation of 1,400 feet and 1,700 feet.

The thickness of the Subis Limestone Member at the surface is about 1,200 feet; in the subsurface limestone it extends over a vertical distance of 3,100 feet, of which half is limestone, and half intercalated sandstone and shale assigned to the Nyalau and general Tangap Formations.

Boundaries

The boundaries of the formation are mostly known from the subsurface, where their delineation is difficult due to interfingering and lateral transition (see figure 3). The formation interfingers with Nyalau Formation, which underlies it (as at Bukit Subis) and overlies it (as at Suai). The base does not outcrop, but in the subsurface the formation also overlies Setap Shale Formation in places and possibly also Tubau Formation.

The top boundary is in general a gradual transition into Sibuti Formation, except in the southwest and in the subsurface of the Suai area, where Tangap Formation grades upwards into Setap Shale Formation.

Fossils and age

The age is established as Lower to Middle Miocene (Te_{1-4} to Te_5) on rich foraminiferal faunas.

The Tangap Formation in general (i.e. excluding the Subis Limestone Member) contains a foraminiferal fauna of mainly arenaceous species, with a much richer fauna in a few marls which includes pelagic forms (*Globigerina* spp.). The arenaceous faunas are not age-determining, although the pelagic forms would probably be so if specifically determined.

A Te_5 age is proved by scattered occurrences within the Tangap Formation of larger Foraminifera including:

Lepidocyclina sumatrensis Brady
Miogypsinoides lateralis Hanzawa
Miogypsinoides dehaarti v.d. Vlerk
Spiroclypeus orbitoideus Douville
Spiroclypeus tidunganensis v.d. Vlerk
Spiroclypeus higginsi Cole

(Determinations by W. E. Crews, quoted by Liechti, 1960, p.164).

The outcrop of the Subis Limestone Member is also proved to be of Te_5 age on abundant larger Foraminifera including the following (R. Haak and others, quoted by Liechti, 1960, pp.164-65):

Lepidocyclina (*Nephrolepidina*) *angulosa* Provale
Lepidocyclina (*Nephrolepidina*) *inflata* Provale
Lepidocyclina (*Nephrolepidina*) *sumatrensis* (Brady)
Lepidocyclina (*Nephrolepidina*) *verrucosa* (Scheffen)
Lepidocyclina (*Nephrolepidina*) *flexuosa* (Rutten)
Lepidocyclina (*Eulepidina*) *dilatata* (Michelotti)
Lepidocyclina (*Eulepidina*) *dilatata* var. *tidunganensis* v.d. Vlerk
Lepidocyclina (*Eulepidina*) *ephippoides* Jones & Chapman
Miogypsina irregularis Michelotti
Miogypsina primitiva Tan Sin Hok
Miogypsinoides dehaarti v.d. Vlerk
Miogypsinoides (*Conomiogypsinoides*) *abundensis* Tobler
Austrotrillina howchini (Schlumberger)
Spiroclypeus sp.
Cycloclypeus sp.
Operculina sp.
Amphistegina sp.

Corals are abundant in parts of the limestone, mostly of the branching-growth type; composite massive corals are also fairly common. The fragments are invariably angular and unsorted. Algae include the following:

Lythophyllum sp. (abundant); *Mesophyllum* sp. (abundant); *Lithoporella* sp. (abundant); *Archaeolithothamnium* sp. (less common); *?Lithothamnium* sp. (rare); *Corallina* sp.; *Jania* sp.; *Halimeda* sp. (locally abundant)

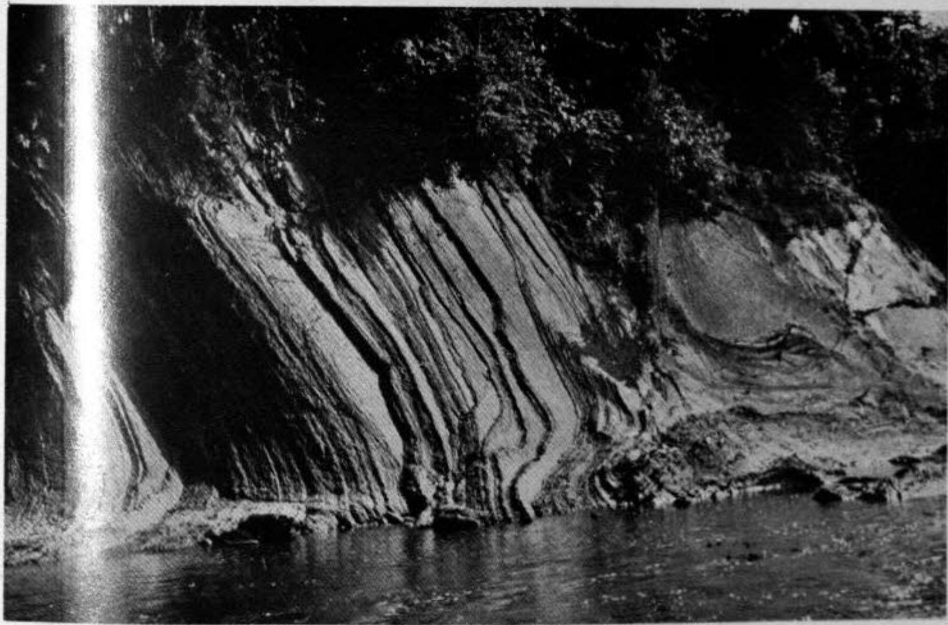
Fragments and spines of echinoids and bryozoans are common, and bryozoans also occur as large patches. Gastropods and fragments of lamellibranchs are occasionally found, as are rare sponge spicules.

The subcrop of the Subis Limestone, penetrated in Well Subis 2, is partly $Te_{1\text{-}4}$; partly Te_5. The dividing line runs through the middle to upper part of the limestone. The $Te_{1\text{-}4}$ fauna includes:

Operculina cf. *pyramidum* Ehrenberg
Heterostegina borneensis v.d. Vlerk
Neoalveolina pygmaea Hanzawa
Miogypsinoides ubaghsi Tan Sin Hock

Environment

Liechti (1960, pp.165-166) points out that the abundant pelagic Foraminifera of the marls of the Tangap Formation and the almost complete absence of sand indicate very quiet conditions, which might equally well be bathyal or outer neritic. The Subis Limestone Member is believed to have formed in a depth of water that did not exceed 200 feet, and probably was generally 100 feet or less. The lower part, containing Algae (*Melobesieae*) and *Cycloclypeus* spp., is considered to have formed under infra-neritic conditions (depth of water 160-200 feet), whereas the upper part, containing *Miogypsina*, *Miogypsinoides* and the algae *Corallina* and *Lithoporella*, was formed under epi-neritic conditions (depth of water 0-100 feet).



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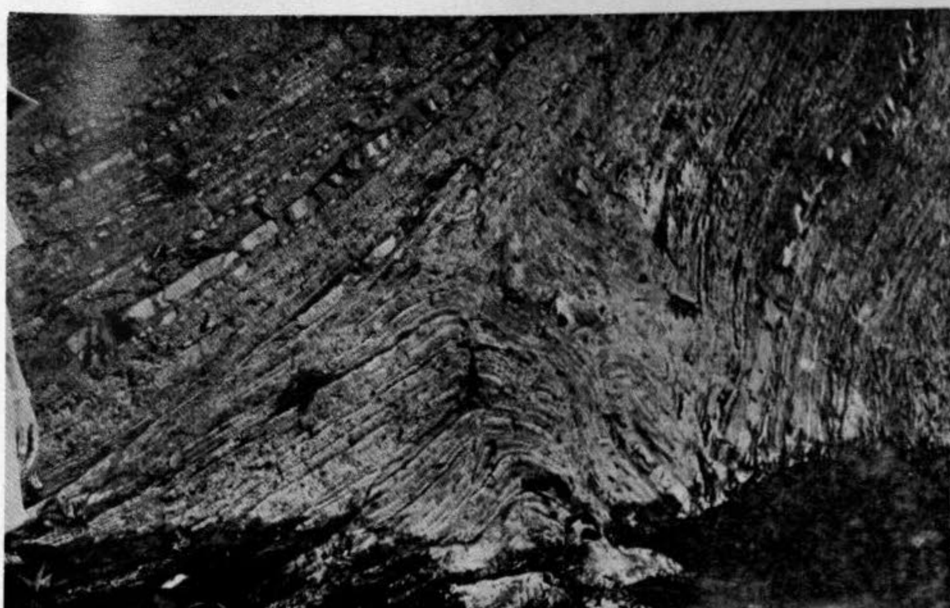

b

PLATE XVII. EXPOSURES OF SETAP SHALE FORMATION. Typical exposures in the Baram River below Long Akah (a), and in the Akah River below Long Tebangan (b) (*see p.42*)

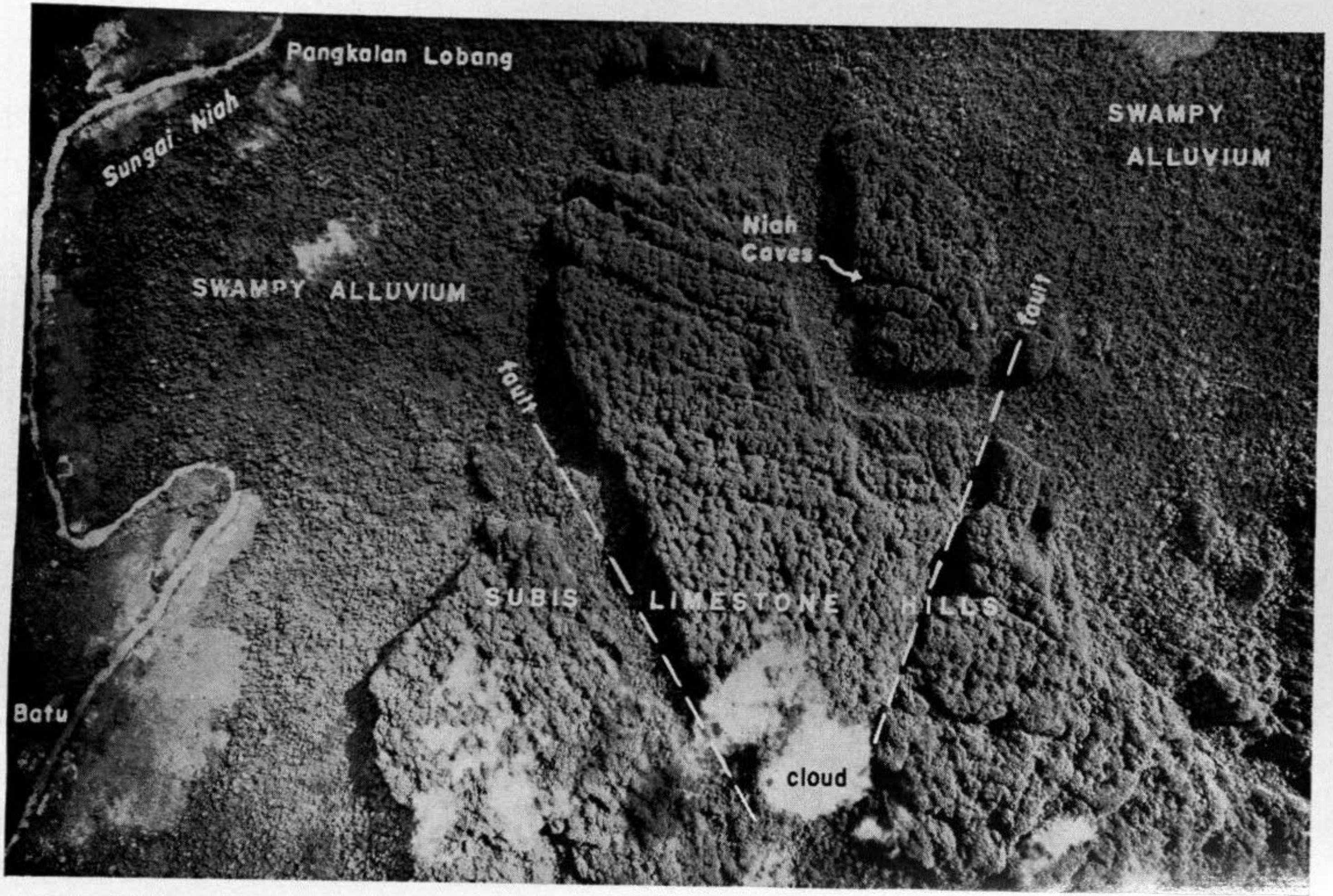

PLATE XVIII. AIR PHOTOGRAPH OF BUKIT SUBIS. The hills formed by the Subis Limestone Member of the Tangap Formation rise sheer to over 1,000 feet from flat swampy alluvium and are cut by gorges along fault lines (*see pp.12, 45*). *Scale about* 1:25,000

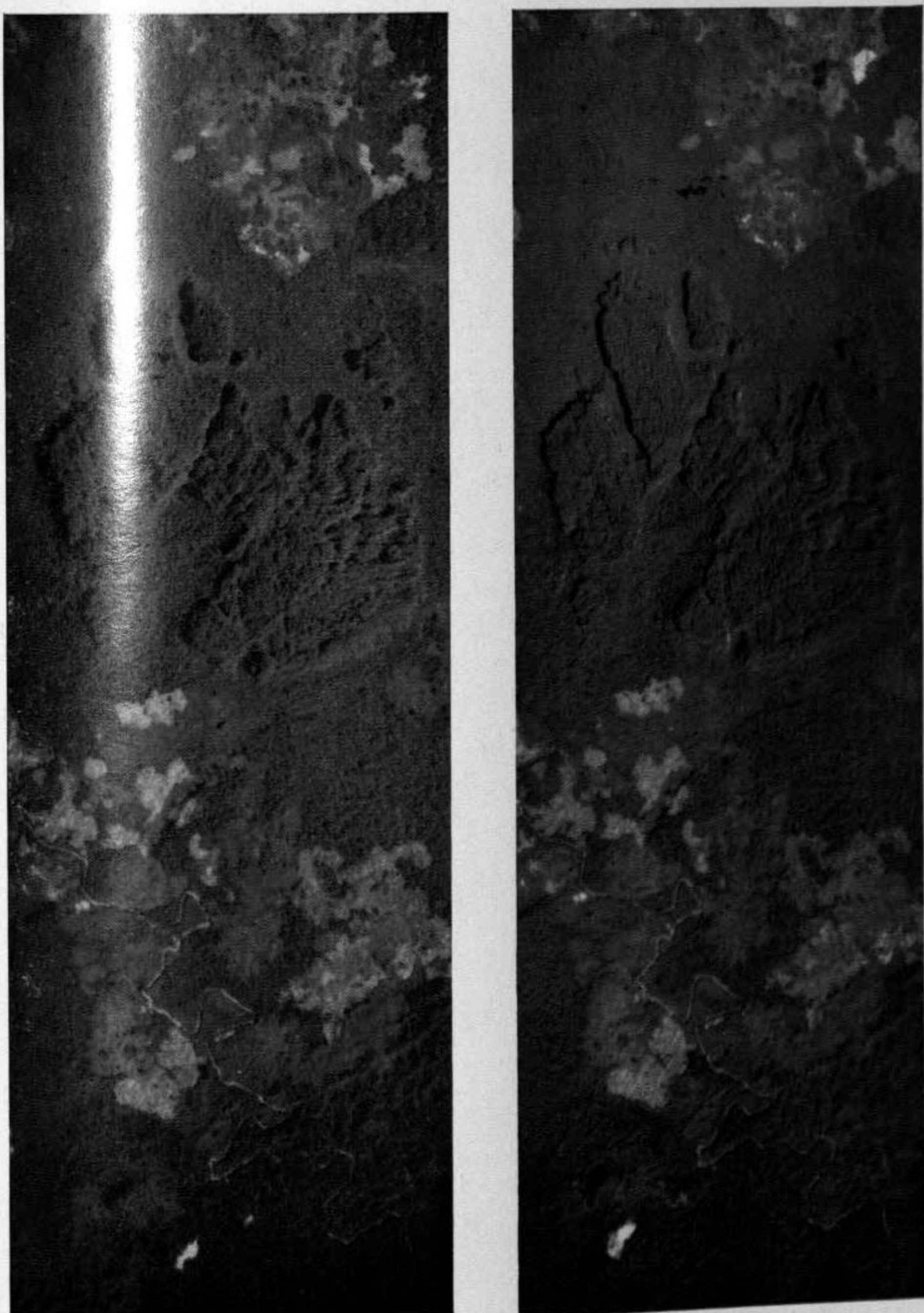

PLATE XIX. BUKIT SUBIS. The stereo-pair shows the entire outcrop of the Subis Limestone, with low hills of Nyalau and Sibuti Formations to the south. The light-coloured areas are patches where the primary forest (dark-coloured) has been felled for farming (*see pp.12, 45*). Scale about 1:90,000

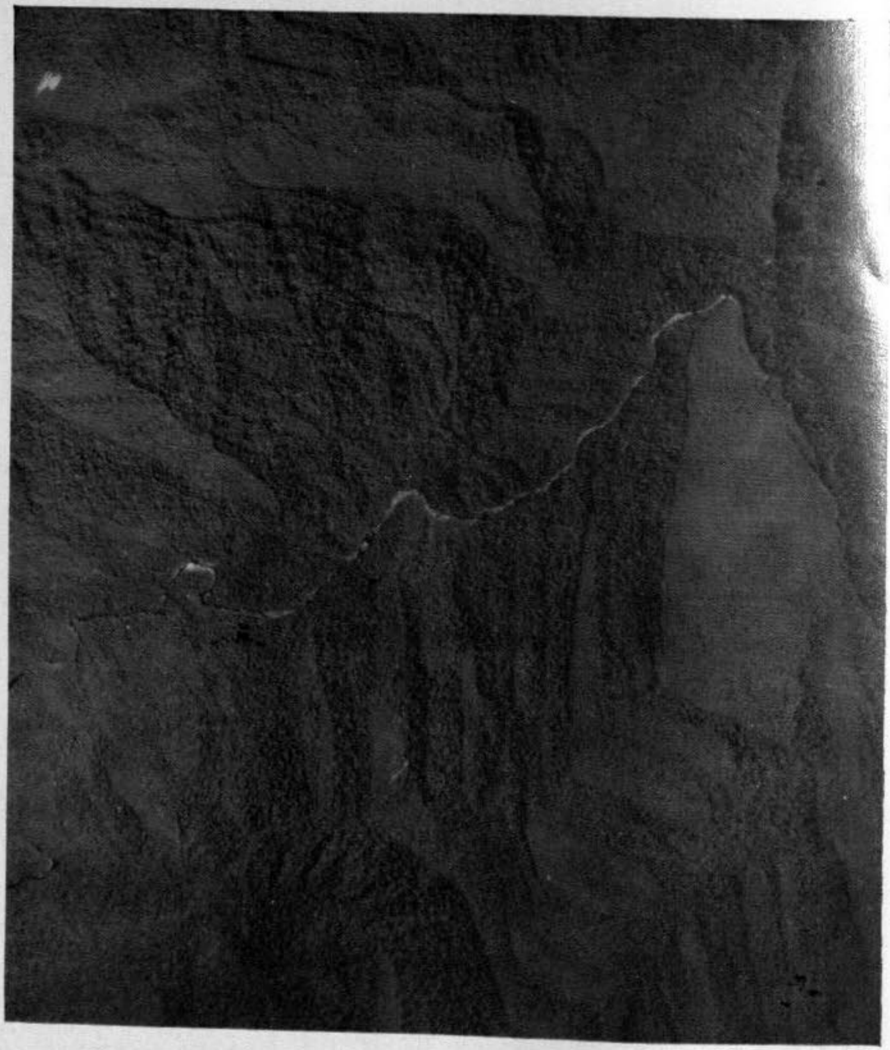

PLATE XX. NYALAU AND BELAIT FORMATIONS. The air photograph shows part of the Kayan Headwaters, south of the Dulit Range. Bedded sandstones of the Nyalau Formation, dipping northeast and forming a series of cuestas, pass conformably upwards into more massive sandstone of the Belait Formation (top right-hand corner). The stunted forest on the sandstone dip slopes has a typical light-coloured appearance on air photographs (*see pp.51, 57, 58*). Scale about 1:50,000

SIBUTI FORMATION

The Sibuti Formation is composed of shale, with some marl and thin lenses of limestone, and rare impersistent beds of siltstone and sandstone. It crops out in the Bakong area, extending west to the Niah Valley where it merges with the Setap Shale Formation. Part of the type locality, the Sibuti Valley, is included in the area.

Lithology

The formation (as described by S. T. Waite, quoted by Liechti, 1960, p.167) is predominantly and monotonously argillaceous. There are scattered lenses of siltstone and sandstone, but no single sandstone bed is continuous over a large area. Marls and thin lenses of limestone are characteristic, but are less common and thinner than those in the underlying Tangap Formation. The outcrop of the formation is practically featureless.

The lowest strata are poorly fossiliferous dark-grey shale, without intercalations of siltstone or limestone. Bedding planes are marked only by carbonaceous films, and rare sandy partings. These are succeeded by similar shales grading in places into fine grained argillaceous and marly siltstones and small limestone lenses. In the Niah Valley the so-called Niah Kubu sandstone occurs at this level. The foraminiferal fauna of this part is prolific.

The upper part consists of calcareous or sandy shales, with a few sandstone and limestone lenses.

Tectonic aspect

The formation is gently to moderately folded, to the same degree as the Setap Shale Formation in the area. However, abberrant dips of as much as 60°, due to irregular disharmonic folding or slumping during deposition, are common.

Thickness

The thickness is difficult to estimate accurately as the structure is not clearly understood. Pollock estimated the thickness to be 8,100 to 10,800 feet; Waite estimated it at 11,300 feet (quoted by Liechti, 1960, p.167); but Liechti considered these estimates to be somewhat high. Towards the flanks of the Subıs Anticlinorium in the Niah River, the thickness decreases markedly though gradually. Rijsterborgh estimated the thickness as 1,600 feet on the northwest flank, and about 2,500 feet on the southeast flank (Liechti, 1960, p.168).

Boundaries

The formation overlies Tangap Formation conformably. The boundary is vague and transitional, and its determination depends upon the less calcareous lithology of the Sibuti as compared with the Tangap.

The top boundary with the Lambir Formation is also conformable and transitional, but is better defined, although still somewhat arbitrary and strongly diachronous. It is drawn mainly on photogeology and relies on the distinction between the topography of the predominantly argillaceous Sibuti Formation and that of the arenaceous Lambir Formation. Laterally the Sibuti Formation merges into Tangap and Setap Shale Formations, but this takes place mostly in the subsurface.

Fossils and age

The formation is believed to be Middle to Upper Miocene, mainly Te_5, ranging into Tf. This is based on a provisional determination of pelagic Foraminifera (Haak, quoted by Liechti, 1960, p.168).

A few larger Foraminifera in limestones in the formation in the Bakong area corroborate a Te_5-?Tf age:

Lepidocyclina sp., *Nephrolepidina* sp.,
Miogypsina sp., and *Gypsina* sp.

Environment

The fauna indicates that the formation was deposited in shallower water than the Tangap Formation. Inner neritic conditions appear most probable.

NYALAU FORMATION

The Nyalau Formation is composed of sandstone and shale, commonly lignitic, with some impersistent beds and lenses of limestone and calcareous sandstone. Its most extensive outcrop in the Suai-Baram area is in the southwest, where it forms hilly country in the Semilajau, Kemena, and Koyan Valleys. The type area is in the coastal area, extending inland from Tanjong Kidurong to Kuala Nyalau. The type section as defined by Liechti (1960, p.118) is along the Sabulong River northeast of Tanjong Kidurong. Towards the northeast, in the Suai area, it gradually wedges out into Setap Shale and Sibuti Formations, and north of the Niah River is known only as a few lenses. It has not been distinguished in the Baram Valley, although thick arenaceous successions in the upper Setap Shale Formation there, for example south of the Lawan Syncline, could be regarded as Nyalau Formation. These are at present insufficiently known for correlation.

Lithology

In the *type area* (hills behind the coast from Tanjong Kidurong to Kuala Nyalau) the formation, as described by C. J. Mulder (*1952*), comprises:

Sandstone, which is fine to medium grained, thick bedded or flaggy, and which commonly contains mica, carbonaceous material, and fine granules of pyrite. All gradations from sandstone to sandy shale occur. Ripple marks, cross-bedding, graded-bedding, and depositional slump structures are reported to be common. The porosity is fairly high, eleven tested samples having a porosity ranging from 9·2 to 22·7 percent.

Shale, which alternates with thin beds of argillaceous sandstone and sandy shale. Shale successions do not usually exceed 15 feet in thickness. Plant remains and lignite films are ubiquitous. The only macrofossils are imprints of molluscs and a few Operculinids.

Limestones and *calcareous sandstone* are intercalated in sandstone, usually in lenses of as much as 30 feet long and 7 feet thick. These rocks usually contain abundant larger Foraminifera and lamellibranchs. Fine grained, dense varieties also occur, and in several places are in contact with discontinuous beds of reworked limestone.

Lignitic material is abundant in all rock types except the calcareous ones. Pitch-black clayey lignite bands, up to about three-quarters of an inch in thickness, occur most commonly in argillaceous sandstone or at the contact of sandstone with shale or sandy shale.

In the *Suai headwaters* the formation (described by M. F. Shepherd, *1954b*) is also predominantly sandy, but towards the northeast there are increasingly numerous thick shale intercalations. Sandstone successions, mostly 100 to 200 feet thick, rarely exceed 400 feet. As a result of a gentle regional dip (average about 8°), almost all the sandstone successions form well-defined escarpments that can be traced on air photographs. Two main sandstone types can be recognised in the Suai headwaters, causing characteristic topography and vegetation:

(a) A fine grained, hard, mostly massive, white to light-grey sandstone. This type is most easily recognizable and is usually strongly jointed, weathering to black-surfaced, rounded and subangular blocks. The very low permeability of these sandstones gives rise to typical badly drained dip slopes, on which the forest is stunted.

(b) Blue-grey, hard, fine grained sandstone giving rise to drier open-bush ridges. Two sub-types were recognised: one is thick-bedded (3 to 15 feet) with occasional lignite streaks, the other is thin bedded (3 inches to 2 feet) and lignitic; it contains more common shale partings and weathers in a typical platy and tabular way.

Throughout the sandstones in the Suai headwaters, coarser, probably local, lenses occur sporadically. Calcareous sandstones which grade into limestone occur at some places.

The subordinate shales occur in successions up to 200 feet thick. They are strongly lignitic. Thin layers of true silty clay or pure clay are common, some containing a rich fauna of smaller Foraminifera. Shales within sandstone successions are usually sandier and often strongly indurated.

In the Ulu Suai Dome a marl marker bed occurs about 2,000 feet stratigraphically below the top of the formation. This consists of light bluish-grey moderately soft marl, typically poorly bedded, locally sandy and hard. It contains a rich fauna of smaller calcareous Foraminifera. The maximum thickness observed is 75 feet.

On the compilation map, Liechti (1960, encl. 1) shows a thick sandstone member, the Biban Sandstone Member, immediately under the marl marker bed, occupying the core of the Ulu Suai Dome. The main occurrence of this member is south of the Suai-Baram area, and Liechti states (1960, p.120) that the Biban Sandstone Member can no longer be distinguished north of the Bintulu River. As the Biban Sandstone in the type area is at the base of the Nyalau Formation, it does not seem likely that the strata beneath the marl marker bed, which is only 2,000 feet stratigraphically below the top of the formation, are equivalent to the Biban Sandstone, and they have accordingly been mapped as undifferentiated Nyalau Formation in this account.

In the *Paroh Anticline* (Suai Valley, northwest of the Ulu Suai Dome), the lower part of the Nyalau Formation grades into Setap Shale Formation, except at the southwest end, where only Nyalau Formation is exposed. There the sandstones are mostly fine to medium grained, white and greyish white, often compact and massive, but with transitions to well-bedded flaggy varieties. The subordinate interbedded shales are dominantly grey and well bedded, commonly strongly sandy, and with abundant lignite in some layers.

The large outcrop of Nyalau Formation in the *Koyan Valley* west of the Dulit Range has been mapped from air photographs, on which a regular succession of sandstone scarps can be clearly distinguished (pl. xx); the area has not been explored in the field.

Tectonic aspect

The Nyalau Formation shows gentle to moderately steep dips and comparatively regular folding.

Thickness

The total thickness in the area from Subis southwest to Bintulu (which is just beyond the Suai-Baram Area) has been estimated at 10,000 feet (Rijsterborgh, quoted by Liechti, 1960, p.122). The thickness exposed in the type area is about 2,700 feet in the Sabulong Anticline. In the Suai headwaters, less than 4,000 feet is exposed.

Boundaries

The boundaries of the Nyalau Formation illustrate the complex and transitional nature of the formations in this area, and the difficulty of establishing a satisfactory stratigraphy in spite of detailed field surveys and painstaking palaeontological studies by SSOL.

In the Jelalong Valley (upper Kemena), the formation rests conformably on Setap Shale Formation. In the main Suai area, the basal boundary does not outcrop, but in the Niah Valley lenses of the formation are included conformably in the Sibuti and Setap Shale Formations. Evidence from wells indicates that in the Subis and Suai area the formation rests on, and interfingers with, Setap Shale, Tubau, and Tangap Formations. From the Semilajau Valley to the northeast, the formation passes laterally into Setap Shale Formation, and north of Bukit Subis, into Tangap and Sibuti Formations. The transition takes place by wedging and interfingering on both large and small scales. The top boundary throughout most of the area is an erosion surface but, in the Suai and Koyan headwaters, the formation is overlain conformably by Belait Formation. The boundary there is somewhat arbitrary, and its identification depends partly on micropalaeontology. In the middle Niah Valley, Nyalau Formation passes laterally into Belait Formation, which in turn passes to the northeast into Lambir Formation.

Fossils and age

The age of the Nyalau Formation within the Suai-Baram area is believed to range from $Te_{1\text{-}4}$ to Tf.

In the type area, the following larger Foraminifera from lenses of limestone and calcareous sandstone in Well Selungun 1 and from surface outcrop, prove a Miocene ($Te_{1\text{-}4}$) age (V. J. John in Mulder, *1952*):

Amphistegina sp.
Austrotrillina howchini (Schlumberger)
Cycloclypeus sp.
Gypsina sp.
Heterostegina borneensis (v.d. Vlerk)
Lepidocyclina angulosa Provale
Lepidocyclina spp.
Miogypsinoides ubaghsi (Tan Sin Hok)
Neoalveolina pygmaea Hanzawa
Operculina pyramidum (Ehrenberg)
Operculina sp.

A scanty badly preserved calcareous fauna was found in some samples, usually associated with large Foraminifera, including:

Asterigina sp., *Cibicides* spp., *Elphidium* sp., *Guttulina* sp., *Marginulina* sp., *Nonion* sp., *Quinqueloculina* spp., *Rotalia* sp., *Sigmoilina* sp., *Textularia* spp.

Many of the samples yielded scanty, exclusively arenaceous faunas indicating brackish-water conditions and composed of:

Ammobaculites sp., *Cyclammina* sp., *Glomospira* sp., *Hormosina* sp., *Textularia* spp., *Trochammina* sp.

In the Suai headwaters similar, though not identical, arenaceous faunas occur, but in the marl marker bed a rich fauna including age-determining larger Foraminifera, was found (W.E. Crews and V.J. John, *1955*). In this fauna *Miogypsina* s.s. was taken to indicate Te_5-Tf.

The Nyalau Formation is believed to range as high as Tf_1 since along the strike in the Bakong Valley it passes into the Lambir Formation which is of proved Tf_1 age.

Environment

Ripple markings, cross-bedding, brackish-water faunas, and lignitic matter indicate a shallow littoral to paralic environment, while the limestone lenses and marl bands suggest littoral to inner neritic conditions. In general, conditions became paralic towards the end of the deposition of the formation.

TUBAU FORMATION

The Tubau Formation consists mainly of shales, and differs from Setap Shale Formation in its more calcareous nature and in the colour of the shales. It does not outcrop in the area but is believed to occur beneath the Nyalau Formation in the Ulu Suai Dome (Liechti, 1960, p.160). Argillaceous strata penetrated in Wells Subis 2 and Selungun 1, formerly allocated to Tubau Formation, were considered by Liechti (loc. cit.) to be more properly regarded as Setap Shale Formation. The main outcrop of Tubau Formation lies south of the Suai Area, in the Kemena Valley. The Setap Shale Formation in the Jelalong Valley shows features transitional to Tubau Formation. The age of the formation is Miocene. A more detailed description is given by Liechti (1960, pp.158-161).

Chapter V

NEOGENE BASIN AND POST-OROGENIC FORMATIONS

(UPPER MIOCENE TO RECENT)

The formations described in this chapter are those occupying basin-shaped synclines, namely the Meligan, Belait, and Lambir Formations, of Mio-Pliocene age, and the sediments deposited after the Pliocene folding, namely the Liang Formation (Pliocene or Plio-Pleistocene), and the Quaternary terrace deposits and alluvium.

MELIGAN FORMATION

The Meligan Formation is composed mainly of massive sandstone. It forms the Tamabo Range (pls. XXI, XXII) and Batu Lawi (pl. X). Gunong Murud Kechil in the Upper Baram (pl. XXIIIA), and occurs as a small inlier in the Limbang Valley (Madihit tributary).

Lithology

The formation is composed of massive sandstones that form prominent mountain ranges, including Batu Lawi (6,650 feet) and the Tamabo Range (4,000-5,000 feet). The sandstones are grey, greenish, or yellowish grey and coarse to medium grained, in general quartzose. Little detailed information is available. In the Kuba'an River, above the Butoh tributary, sandstone, with small carbonaceous flecks in places (S6144) occurs interbedded with light brownish-grey mudstone (S6146) with thin carbonaceous streaks (S6145). Soft grey mudstone (S6143) also outcrops in this part, and contains lenses of calcareous conglomerate which includes pebbles of radiolarian chert (S6142).

Tectonic aspect

The formation in the Tamabo Range dips regularly at about 80° to the east; in the Batu Lawi area it occupies a complex faulted syncline, and dips are moderate to steep.

Thickness

The thickness in the Tamabo Range probably exceeds 10,000 feet, unless the succession has been repeated by faulting or overfolding.

Boundaries

Along the west of the Tamabo Range, and south of Batu Lawi, the formation appears on air photographs to rest conformably on Setap Shale Formation. Formerly these sandstones were considered to be older than the Setap Shale Formation and to be faulted up against it. However, the palaeontological evidence which led to that interpretation has now been discredited (see Haile, 1959). East of the Tamabo Range the formation probably rests on Kelabit Formation, since there is no evidence that the Setap Shale extends so far east. As there are no air photographs of this inaccessible country, the geology is little known. The relationship with the Kelalan Formation to the north is likewise obscure.

Fossils and age

Shale samples from the Batu Lawi area and the Kuba'an headwaters have yielded a few arenaceous Foraminifera which, however, are not age-determining.

A shale sample from the Tutoh Headwaters (Sabai tributary) above the lowest massive sandstone outcrop yielded:

Bathysiphon sp.
Trochammina sp.
Globoquadrina altispira (Cushman and Jarvis)
Globorotalia cf. *Mayeri* Cushman and Ellisor
Cyclammina sp.
Globigerinoides sp.

This fauna was identified by a palaeontologist of SSOL and is indicative of Miocene (Te) age.

Environment

The environment of deposition was probably shallow marine to littoral, although the lithology is too little known for this to be cetain.

LAMBIR FORMATION

The Lambir Formation is composed of sandstone, shale, and limestone. The formation occurs in the Bakong Valley near Beluru and extends from the southwest into the headwaters of the Sibuti and of the Sekaloh tributary of the Niah. A single lens of Lambir Formation extends into the Sibuti Valley from the main outcrop to the north.

Lithology

The formation in the Bakong area (as described by Mulder, *1953*) comprises alternating sandstone and shale with calcareous sandstone and limestone. Calcareous strata occur at two stratigraphic levels. The lower bed, about 75 feet thick, is exposed in the Mapoh River (see fig. 9), and consists of hard sandy limestone crowded with large Lepidocyclinas. The higher level is about 2,100 feet stratigraphically above these beds, where limestone about 60 feet thick forms a discontinuous curved ridge about 4½ miles long, extending from the Trus River to the Lapan River. The rock is a hard pure limestone, in places containing abundant large Foraminifera, and some bryozoans and corals, though it is not a typical coral-reef limestone. Analyses of specimens of this limestone are given below (p.133). These calcareous beds occur in a shale and sandstone succession. Thick sandstone overlying the calcareous and shaly beds in the Grabit Syncline, formerly regarded as part of the Lambir Formation, is here included in the Belait Formation as explained above (p.27).

Tectonic aspect

The formation occupies comparatively gentle synclines and is little diagenetically changed. The dip is generally about 10° to 20°; in some parts, however, such as the northern limb of the Grabit Syncline, it is as steep as 35° to 45°.

Thickness

The thickness in the Beluru Syncline is about 5,200 feet, according to Mulder's sections, measured from the top of the Setap Formation to the base of the 'Grabit Sandstone' (*1953*). On the north flank of the Grabit Syncline it is about 3,200 feet.

Boundaries

The *basal boundary* is a gradual, slightly diachronous transition from the predominantly argillaceous Sibuti Formation. It was originally defined palaeontologically, but now is placed at the first major sandstone in the Lambir Formation. It is somewhat arbitrary as lenses of sandstone and siltstone, some large enough to form ridges, occur in the Sibuti Formation well below the predominantly arenaceous strata of the Lambir Formation; moreover, both formations include calcareous rocks. The boundary now is drawn from air photographs, relying on the distinction between the predominantly arenaceous Lambir Formation and the predominantly argillaceous Sibuti Formation.

The *top boundary* was formerly considered to be an erosion surface in the Bakong area; if the 'Grabit Sandstone' is included in the Belait Formation, as in this account, the top boundary is a conformable transition into the Belait Formation. The change is marked by an increase in the number and thickness of sandstone members intercalated in the shale, and by the presence of fine to medium grained white sandstones, softer and purer than those of the underlying strata. Seams and lenses of impure lignite, up to several meters thick, occur in places in the Belait Formation near the boundary.

Fossils and age

The age is believed to the Upper Miocene (Tf) from larger Foraminifera, occurring in the limestone, namely:

Nephrolepidina sp.
Miogypsina sp.
Gypsina sp.
Lepidocyclina cf. *sumatrensis* (Brady)
Operculina sp.
Floscullinella bontangensis Rutten

The last species indicates Tf, but the others indicate a general Te_5-Tf age. The presence of *F. bontangensis* in some of the samples, and the absence in otherwise highly fossiliferous limestones of *Spiroclypeus, Miogypsinoides,* and *Austrotrillina,* were considered to point to a Tf_{2-3} age for these samples (W. E. Crews, quoted by Liechti, 1960, p.190). The formation may range throughout the Tf.

The shales have yielded a fauna of benthonic Foraminifera comprising:

Ammobaculites sp., *Anomalina* sp., *Asterigerina* sp., *Bigenerina* sp., *Bolivina* sp., *Cibicides* sp., *Cyclammina* sp., *Elphidium* spp., *Flosculinella* sp., *Hormosina* sp., *Loxostoma* sp., *Nodosaria* sp., *Nonion* sp., *Rectobolivina* spp., *Rotalia* spp., *Spirolina* sp., *Siphogenerina* sp., *Textularia* sp., *Triloculina* sp.

Environment

The limestones indicate inner neritic to littoral conditions, becoming entirely littoral towards the top at the transition to Belait Formation.

PLATE XXI. TAMABO RANGE. Part of the north-south trending Tamabo Range along the west side of the Kelabit Highlands. Thick sandstone beds of the Meligan Formation dipping steeply east, form a series of steep hog-back ridges about 4,000 feet high. Landslides have exposed bare rock on the dip slope of the ridge centre (*see pp.11, 54*). Scale about 1:20,000

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PLATE XXIIa. TAMABO RANGE. This oblique air photograph was taken looking northwest from the Tutoh Headwaters near the southern end of the Tamabo Range (lower right-hand corner). Beyond the Tamabo Range the great forests of the middle Baram extend to the horizon, where Mount Mulu can be seen (top right) (*see p.54*)

PLATE XXIIb. SYNCLINE AT SOUTHERN END OF TAMABO RANGE. This pitching syncline, with a perfect rim, shows that the sandstones building the Tamabo Range overlie both Kelabit Formation (to the east) and Setap Shale Formation (to the west) and belong to the Meligan Formation (*see p.54*). North is towards the top right. Scale about 1:50,000

BELAIT FORMATION

The Belait Formation is composed of thick massive beds of sandstone, with grey shale and some seams of lignite. In the Suai-Baram area it forms mountain ranges west of the lower Tinjar River and in the middle Tinjar Valley (Bukit Sekiwa, Bukit Selikan, Bukit Manyam, and the Dulit Range; see pls. IV, XX). The southern end of the Belait Syncline extends into the area in the Tutoh Valley, where the lower part of the formation builds Bukit Batu Belah. Sandstones in isolated synclinal basins overlying Setap Shale Formation in the Middle Baram Valley (Bukit Lawan and Bukit Liman) are also referred to the Belait Formation (pls. XXIII, XXIV).

Lithology

The formation is composed of thick-bedded sandstones which form prominent scarps and mountain ranges, with subordinate grey shale and clay, and some lignite. West of the Tinjar Valley and in the Dulit Range the formation (as described by Widmer, *1953a*) consists mainly of pure white, fairly soft, comparatively coarse sandstones that are commonly cross-bedded; intercalations of sandy clay are common in the lower part of the formation, but are fewer and thinner in the upper part. Towards the west, in the Niah headwaters, white sandstones are less common, and most of the sandstones are grey or mottled grey and white. They are more argillaceous than those in the Dulit Range.

Widmer (*1935b*) traversed the Tunyo tributary of the Apoh on the north side of the Lawan Syncline (Tutoh Valley; pl. XXIIIb) and described Belait Formation consisting of thick sandstone with subordinate shale intercalations, overlying dark-grey sandy to silty shales with abundant coaly matter, which alternate with grey, rather soft, clayey sandstones. At Bukit Liman in the Middle Baram, fine-grained, very hard, blue-grey sandstone (S4509) is exposed overlying typical Setap Shale Formation. The sandstone contains leaf remains and some fragments of coal about 3 mm in diameter, and is veined by quartz in small well-formed crystals.

Along the Batu Belah scarp (Tutoh Valley), only the lowest part of the formation is exposed. Shepherd (in Shepherd and van de Fliert, *1956*) describes grey and blue-grey, hard, fine grained to medium grained, coaly sandstones, in places interbedded with thin coal seams. They are massively bedded, contain rare thin clay layers, and show sporadic cross-bedding and ripple-marking throughout the succession. The shales, which are estimated to make up 40 percent of the succession, are bluish-grey, usually silty or sandy and moderately soft, and commonly strongly lignitic. Along the scarp formed by the basal sandstones of the Belait Formation north of the Tutoh, seams of lignite are interbedded with shale and whitish quartz sandstone (S4696). The lignite (S4693-95) is exposed in the Panai and Besungai tributaries; it is very hard, with subconchoidal fracture and contains sparse pieces of resin about 1 cm across (further description with analysis is given on p.106).

Tectonic aspect

The Belait Formation occurs in synclinal basins and is more regularly and gently folded than the underlying Setap Shale Formation. Dips are mostly moderate to steep (20°-60°), and the rocks show little diagenetic change.

Thickness

The relatively simple structure, clearly shown on air photographs, makes the estimation of the composite thickness of the Belait Formation comparatively easy. However, the pronounced foresetting and depositional dip lead to estimates of total composite thickness which is not present in any one place. Allowing for this, Liechti (1960) estimated that in the area west of the Tinjar, the thickness was about 8,500 feet, and in the Dulit Range 3,500 to 5,000 feet. At Batu Belah only the basal 2,000 to 3,000 feet of the succession, which in parts of the Belait Syncline to the north exceeds 30,000 feet in thickness, is exposed within the area. The thickness preserved in the Lawan Syncline is 5,000 to 6,000 feet, and at Bukit Liman 2,000 to 3,000 feet.

Boundaries

The Belait Formation everywhere overlies Setap Shale Formation or its sandy equivalent, the Nyalau Formation (pl. xx). Although there is in places a discordancy of strike between the Belait Formation and the Setap Shale Formation, the contact is generally believed to be conformable, and the discordancy is explained as the effect of disharmonic folding (Liechti, 1960, pp.183-184). The basal boundary to the north, where it has been investigated in detail, is strongly diachronous, the Setap Shale and Belait Formations wedging laterally into one another over a vertical thickness of many thousands of feet (Liechti, 1960, p.183). The boundary within the area described has not been investigated in such detail, but it is probably also diachronous. Where the formation overlies Nyalau Formation, the boundary is not clearly defined. In the Niah headwaters the Belait Formation is represented as passing laterally into Nyalau Formation along a rather arbitrary boundary. Towards the Bakong Valley (Beluru area), the formation grades laterally into calcareous Lambir Formation, and there again the boundary is vague and arbitrary. The top boundary of the Belait Formation has been eroded throughout the area.

Fossils and age

The formation is largely barren. In the Tinjar area a meagre assemblage of arenaceous Foraminifera includes: *Ammobaculites* sp., *Hormosina* sp., *Textularia* sp. From the Lawan Syncline the following have been identified: *Ammobaculites* spp., *Bathysiphon* sp., *Bolivina* sp., *Cyclammina* sp., *Gaudryina* sp., *Haplophragmoides* sp., *Textularia* spp.

These faunas are not age-determining. The basal part of the formation grades laterally into the uppermost Setap Shale Formation, of proved Tf (Upper Miocene) age. In the Bakong area, the formation similarly grades into Lambir Formation of Tf age. North of the area similar evidence indicates Tgh age (uppermost Miocene to Pliocene) for the highest part, but it is doubtful whether any of the formation in the Suai-Baram area is as young as this.

Environment

The presence of lignite, cross-bedding, and ripple-marks, with some bands containing small marine benthonic Foraminifera, indicates clearly a parallic environment with sporadic marine incursions.

LIANG FORMATION

The Liang Formation occurs in the coastal area, where it has been recognised in two small outcrops south of the Nyalau River, and also occurs in the Suai Valley beneath Quaternary deposits. A small group of outcrops between the Tutoh and Baram Rivers has been assigned to the Liang Formation by Liechti (1960) and named the Patan Member.

Lithology

The formation comprises sands, clays, gravel beds, and some lignites.

In the coastal area the two outcrops south of the Nyalau River are too small to show on the 1:250,000 scale. One is about 500 yards south-southwest of the fishermen's village in the Nyalau estuary, the other nearly 1½ miles S 5° W of the village. The deposits (described by Kavelaars, *1954*) consist of dark brownish-grey soft clay with abundant plant and wood remains and a mixture of shell fragments with sandy clay. In the more southerly outcrop, boulders about 1 foot across of very hard dark-grey siltstone with buff claystone lenses, pierced by worm borings, lie loosely on top of the soft shelly clay.

In the Suai Valley, the formation encountered in wells (described by Sheldon, *1950*, and Rijsterborgh, *1956*) consists of a lower, fossiliferous, part and an upper, unfossiliferous, part which is known as the Lumut Member. There is some evidence from Schlumberger logs of shallow core-drills that a slight angular unconformity occurs between the Lumut Member and the underlying general Liang Formation. Both parts consist of soft sandy clays, with occasional beds of sand and gravel. Lignite as films and thin beds occurs throughout but is more abundant in the upper part (Lumut Member), which is also recorded as containing some quartz crystals and tuffaceous material, not seen in the lower part. A conglomerate of quartz and sandstone pebbles and rare fragments of black chert occurs near the base of the Liang, and a second, higher, quartz-pebble conglomerate was found in a number of wells.

The Patan Member, between the Tutoh and Baram Rivers, consists of clay, sand, and lignite (see fig. 6 and table 8). The washed residue of some of the clays contained small very clear angular quartz fragments showing crystal faces, and relatively large flakes of dark mica (biotite or phlogopite), probably of volcanic origin (Shepherd and van de Fliert, *1956*).

Tectonic aspect

The formation in the subsurface of the coastal area is flat-lying, and dips probably do not in general exceed a few degrees. The Patan Member (in the Baram Valley) is described by Shepherd as virtually flat-lying; a few steep dips (up to 60°) shown on his map may be due to slumping.

Thickness

The thickness in the coastal area is estimated to be more than 300 feet. The Lumut Member is 70-120 feet and the remainder of the formation is about 200 feet thick (Liechti, 1960, p.213).

Liechti (l.c.) estimates the thickness of the Patan Member at 300 feet. However, he does not state the basis of this estimate. Shepherd and van de Fliert (*1956*) do not give an estimate of the thickness, but if their diagrammatic profile is approximately to scale, the thickness represented is only about 80 feet.

FIGURE 6

MAP SHOWING LIANG FORMATION (PATAN MEMBER) IN THE MIDDLE BARAM VALLEY

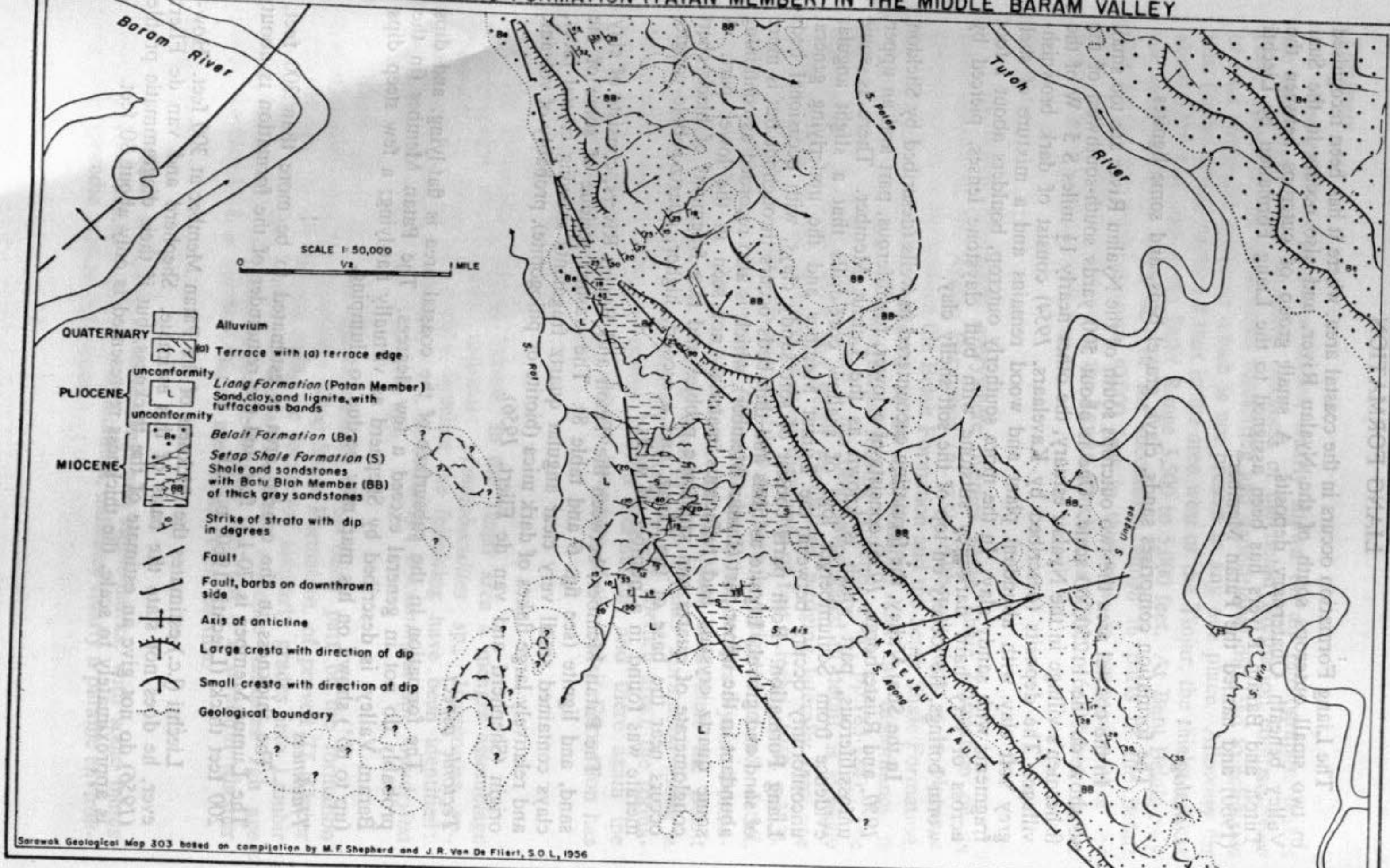
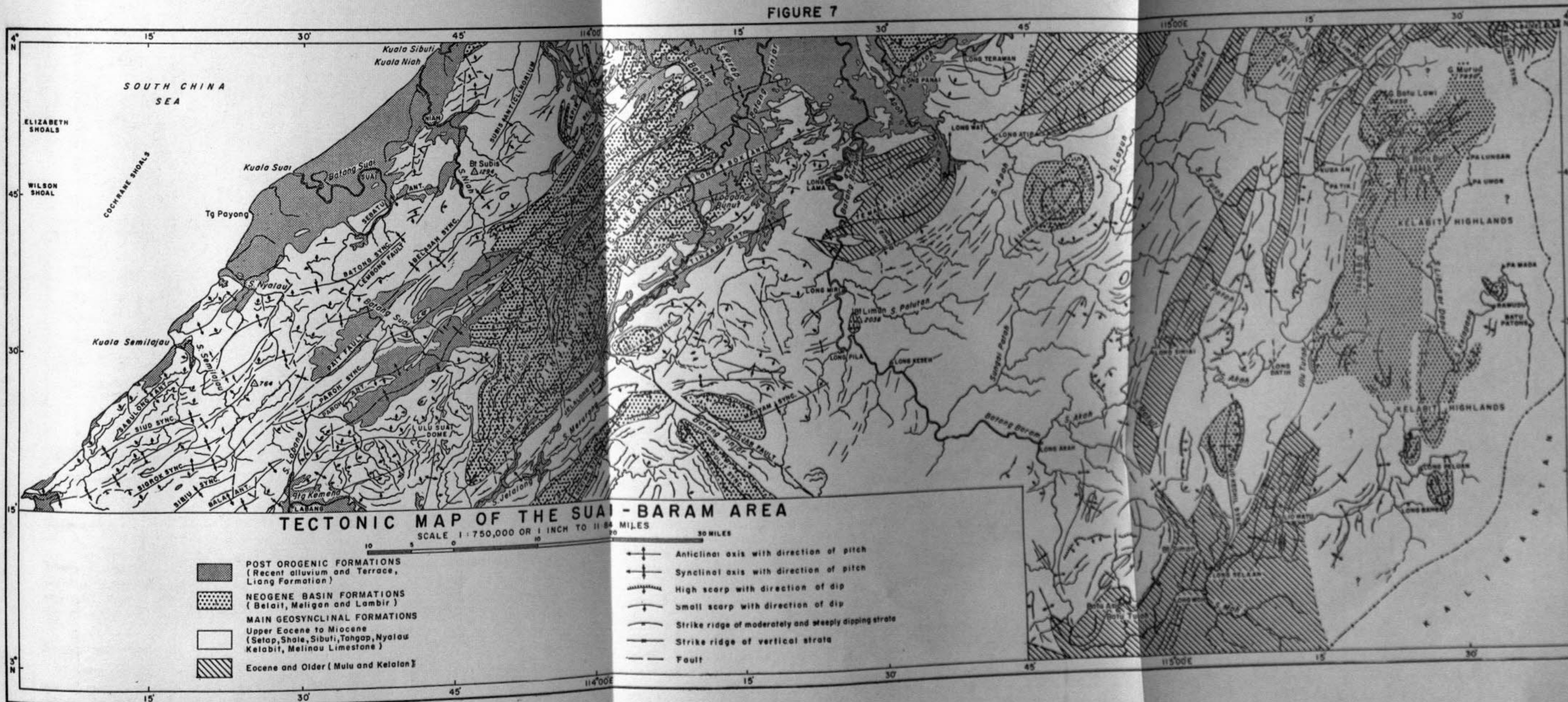


FIGURE 7



SARAWAK GEOLOGICAL OFFICE MAP 315 BY N.S.HAILE, 1961

FIGURE 6

TABLE 8. STRATIGRAPHY OF THE PATAN MEMBER

(after Shepherd and van de Fliert, *1956*)

	Thickness (feet)
QUATERNARY:	
Cobble gravel	
Disconformity	
PATAN MEMBER:	
Sand, orange and red, coarse	Not recorded
Sand, white, with clay laminae	
Clay, very sandy, with lignite and quartz grains and lenses of current-bedded sand	
Clay, silty, dark-grey to brown, very lignitic and coaly	
Clay, orange and white with root impressions. White clay contains fine ash and mica flakes	
Lignite	1
Clay, slightly silty	10
Clay, slightly silty, with sand lenses	12
Clay, very coaly, grey	10
Coal, brown	5
Clay, coaly, grey, soft, plastic	Not recorded
Clay, blue-grey silty, with abundant sand lenses grading down to very sandy clay and sand with quartz pebbles and coal lenses	
Unconformity (Not observed)	
SETAP SHALE FORMATION:	
Steeply dipping grey shale	

Boundaries

In the coastal area, the formation rests unconformably on calcareous Setap Shale Formation (formerly considered to be Lambir Formation) with an angle of unconformity ranging from 12° to more than 40°. The Patan Member also rests unconformably on Setap Shale Formation with a high angle of unconformity. The top boundary is an unconformity with overlying Quaternary deposits.

Fossils and age

The formation in the coastal area has yielded *Rotalia* spp. (six unidentified species recognised) and *Vulvulina* sp. The species of *Vulvulina* and four of the species of *Rotalia* have not been found in other formations.

The Patan Member has yielded only rare smaller Foraminifera almost certainly derived from the Setap Shale Formation.

The formation elsewhere rests on Pliocene strata, and is overlain by terrace deposits of Quaternary, probably Middle Pleistocene age. The age of the Liang Formation is almost certainly in part Pliocene, but the Lumut and Patan Members may extend into the Pleistocene.

Liechti suggests (1960, p.215) that the volcanic ash in the Lumut and Patan Members is correlative with the volcanism that formed the Usun Apau Plateau in the Rajang Hinterland, which (he states) is believed to be Quaternary on morphological grounds. This, together with the unconsolidated nature of the Liang Formation, is taken by Liechti to suggest a Quaternary age, at least for the Lumut and Patan Members. However, volcanic activity is believed also to have occurred in the late Tertiary and could equally well account for the ash in the formation, particularly as no mica-bearing tuffs or lavas are recorded in the Usun Apau. In fact, the boundary between Quaternary and Tertiary in Borneo is impossible to define satisfactorily at present.

Environment

A very shallow-water, near-shore marine environment is indicated by the lithology and fossils. The Lumut and Patan Members are wholly paralic, probably estuarine.

JERUDONG TERRACE DEPOSITS

Terrace deposits along the coast, especially in the Sabulong area, and also at a few places in the hinterland, were assigned by Liechti to his 'Jerudong Cycle' of erosion and deposition.

The terraces occur intermittently along the coast from the mouth of the Likau northeast of the Nyalau River. They have been described (Mulder, *1952*) as consisting of unbedded, pure white, medium grained sand composed of sub-angular semi-transparent grains of quartz. The sand contains some small lenses of gravel containing rounded white quartz pebbles up to an inch across. The deposits overlie Nyalau Formation unconformably and dip 1-2° seawards. In the Semilajau Valley, the terrace sands occur near the estuary only about 10 feet above sea level, but a few hundred yards inland they are 30 feet higher and on the higher hills occur at a height of about 60 feet. North of the Sabulong estuary, the sand and gravel overlie Nyalau Formation with an angular unconformity of more than 10° along an undulating surface, ranging from 6 to 10 feet above sea level within a short distance. The terrace deposits are 12 feet thick or more. At their contact, the terrace sands and the underlying Nyalau Formation, which is mostly sandstone, commonly show a dark-brown weathering (probably a humus-cemented layer that typically develops in such sands), which makes it difficult to distinguish the two formations. Further inland in the Sabulong Valley, patches of whitish sand were found by Mulder at several places, more than 150 feet above sea level; these might be terrace sands, but as no terraces have been distinguished on air photographs they are more probably weathered Nyalau Formation sandstone.

In the Baram Valley, a few small patches of cobble gravel about 60 feet above sea level overlie the Patan Member of the Liang Formation and are composed of cobbles of sandstone enclosed in sand (Shepherd, *1956*). An area of 'Medium high-terrace, Jerudong Cycle' is shown on the compilation map (Liechti et al, 1960, Enclosure I) between the Tinjar River and Loagan Bunut lake. However, it appears from air photographs that this is a patch of *Shorea albida*, a tree which grows typically on deep peat swamp, with high light-coloured crowns that give the impression on air photographs of a raised terrace area. This is confirmed by J. A. R. Anderson, Assistant Conservator of Forests, who has investigated the swamp forest of the lower Baram.

Small patches of terrace gravel fringe the middle Baram and its tributaries, and have been incised to a depth of 50 feet. The terraces are mainly cobble and boulder gravel, capped by brownish sand (see pl. XXV). They are particularly well exposed in the Akah River and in the Baram around Long Akah. The airstrips in the middle Baram at Long Tebangan, Lio Matu, Long Akah, and Long Atip are on these terraces. Widmer (*1953b*) describes various patches of sand on hills on the upper Baram, including one near Long Sela'an, where white loose sand grading down into very soft clayey sandstone occurs on a flat hill-top about 1,500 feet above the river bed. These could be terrace deposits or possibly only weathered sandstone.

In the Kelabit Highlands, considerable areas of encased sandy terrace alluvium about 3,000 to 3,500 feet above sea level, in which the rivers have cut down 25 feet or more, are assigned to the Jerudong Ccyle. The most extensive of these terraces is probably the Plain of Bah, around Bareo; when air photographs become available the terraces can be easily mapped. It is probable that slightly higher terraces (50-100 feet above river level) reported by G. E. Wilford to occur in the area around Bareo and Pa Lungan, belong to an early sub-cycle of the Jerudong.

Age of the Jerudong Terrace. The Jerudong Terrace deposits in the coastal and middle Baram areas are younger than the Liang Formation, which is of Pliocene and possibly Lower Pleistocene age, and are older than the flood-plain alluvium. From the evidence elsewhere, Liechti (1960, p.316) has shown that the Jerudong Cycle is probably Middle Pleistocene.

RECENT ALLUVIUM

The extensive alluvium in the northern and northwestern parts of the area consists of sand, sandy clay, and clay, with occasional beds or lenses of gravel. Peat, in some places more than 50 feet thick, covers large areas, especially in the Baram Valley. The surface of the peat is typically domed, the centre being in places more than 50 feet above the level of the nearest river bank. Where more than a few feet of peat occurs, a distinctive swamp forest of large *Shorea albida* trees grows; this vegetation, together with the dome-shaped surface of the peat-covered areas has led to their interpretation, from air photographs, as areas of 'Low Terrace'. In the area between the Baram and Tinjar Rivers near their confluence, and around the Piking tributary, these areas shown as 'Low Terrace' on the compilation map (Liechti et al, 1961, Enclosure I) have been shown to be peat by ground surveys (Sir Bruce White, Wolfe Barry and Partners, *1956*). All the other areas shown as Low Terrace in the Baram, and some of those in the Suai Area, are almost certainly deep peat, and many are shown as 'Alan Forest (on deep peat)' or as 'Padang Paya forest (on deep badly drained peat)' on the *1:250,000 Land Use Map of Sarawak*. Along the coast, some of the areas mapped as Low Terrace appear to be peat, but others (notably north of the Niah River) appear to be lighter, sandy areas, although whether these in fact represent remnants of a former sub-cycle of erosion and deposition, as suggested by Liechti, is not clear. The present writer has not attempted to delineate 'Low Terrace' on the map, because its presence has not been proved.

Backing the present coastline northeast from the Nyalau Estuary lies a narrow belt of slightly raised beach deposits 60 to 150 feet wide and as much as 15 feet thick, composed of sand and coral blocks (Sheldon, *1950*). Behind this belt, shallow core-drilling showed the alluvium to be soft sandy clay 12 to 140 feet thick. In Suai Well 1, 100 feet of Quaternary was logged; this thickness might be due to the well penetrating an old infilled channel of the Suai River or to the contamination of ditch samples of pre-Quaternary strata with Quaternary Foraminifera.

Some of the alluvial clays in the coastal area are marine, and have yielded *Rotalia* spp. (five unidentified species) and *Operculina* sp.

Fairly extensive belts of alluvium extend along the regional strike in the upper Niah and Subis Rivers. These belts are encased, but the rivers have not cut down into the alluvium, and so they are considered to be Recent. They mainly overlie the argillaceous Setap Shale and Sibuti Formations, and their origin may be explained by differential erosion of these softer beds combined with slight warping along the synclinal axes they overlie.

PLATE XXIIIa. GUNONG MURUD KECHIL. This is a synclinal basin-shaped outlier of Meligan Formation in the upper Baram. (*see pp.11, 54*). Scale about 1:50,000

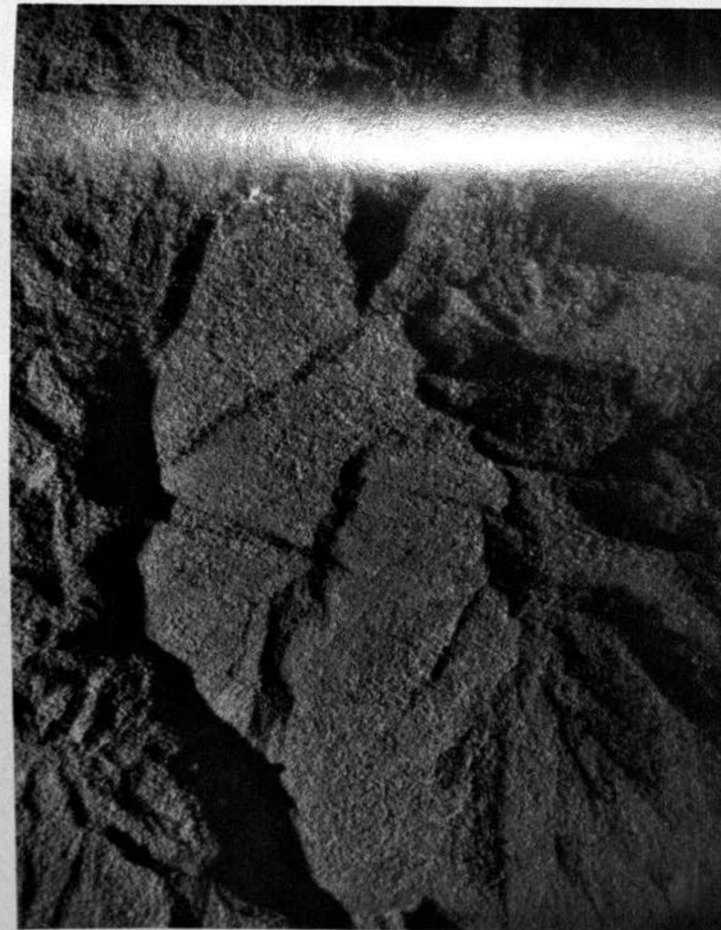


PLATE XXIIIb. LAWAN SYNCLINE. Part of the steep scarp of Belait Formation Sandstone on the rim of the Lawan Syncline in the Tutoh Valley. The Tutoh River can be seen flowing to the northwest (*see p.57*). Scale about 1:50,000

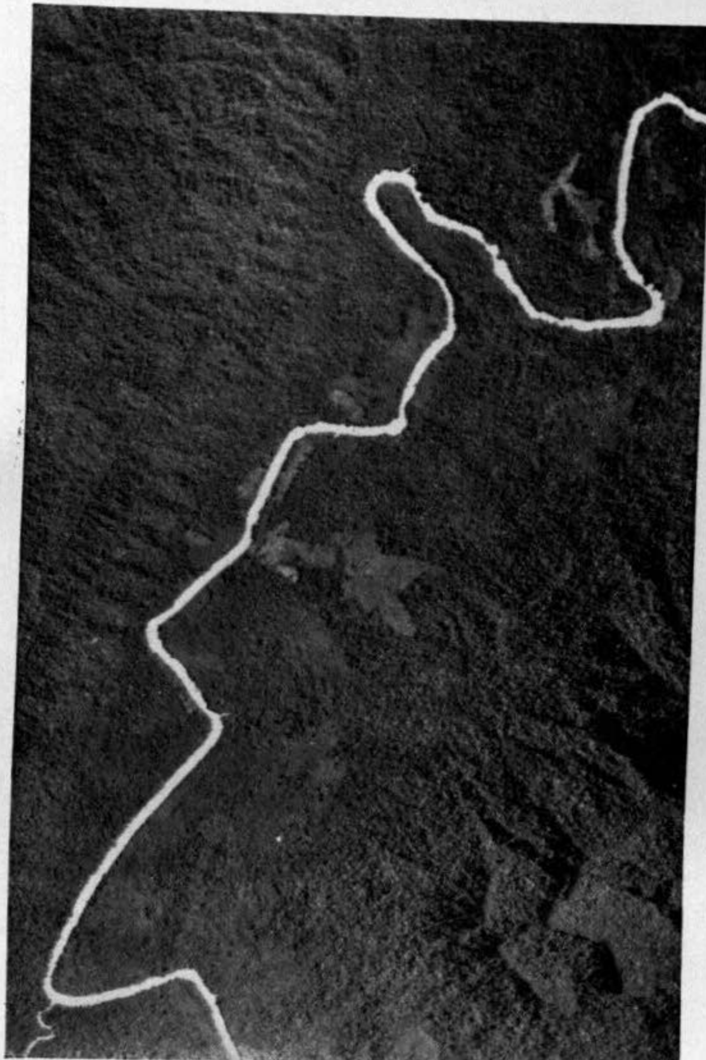


PLATE XXIVa. THE TINJAR VALLEY. The abrupt change of course of the Tinjar River from northwest to northeast takes place at the mouth of the Tisam Tributary (bottom left). The river follows a belt of Setap Shale and Nyalau Formations and flows between hills of Belait Formation (top left and lower right) (*see p.16*). Scale about 1:40,000

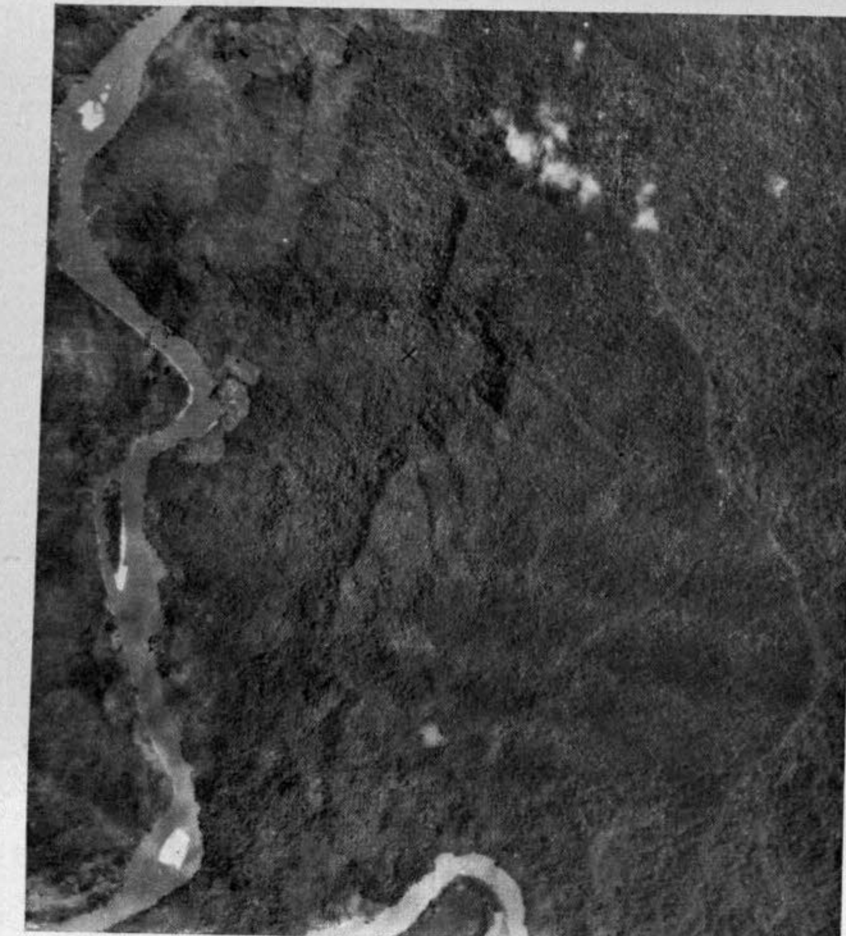


PLATE XXIVb. BUKIT LIMAN. A small synclinal outlier of Belait Formation in the middle Baram (*see p.11*). Scale about 1:50,000

Chapter VI

IGNEOUS ROCKS

Only small outcrops of igneous rock are present in the area. They comprise:

(a) Sparse calcareous tuffite and calcareous volcanic breccia in the Tutoh Valley, and tuffitic conglomeratic limestone in the Upper Baram, included in the Kelalan Formation, and indicative of Palaeocene extrusive activity.

(b) Dykes of olivine basalt in the Tinjar Valley, probably Pliocene or younger.

(c) Tuffaceous material in the Patan Member of the Liang Formation (probably Pliocene).

In addition there are hydrothermal veins in several places containing ores of arsenic and antimony, which may indicates past igneous activity at depth.

VOLCANIC AND PYROCLASTIC ROCKS IN THE KELALAN FORMATION

Tuffite is interbedded with calcareous shale in the Tutoh River at the mouth of the Rutanip, a few hundred yards downstream from the Magait tributary.

The tuffite (S6134) is indistinguishable in hand specimen from the common greyish fine grained impure sandstone of the Kelalan and Setap Shale Formations. The slide of the tuffite shows abundant calcite, and veinlets of calcite and quartz. Chloritic matter, glass, rhombs of carbonate, fragments of volcanic rock (some with pseudomorphs after olivine), and fragments of sandstone, occur interstitially (see pl. XXVIIc). One slide (S6134D) contains small circular areas which may be fossil Radiolaria.

A block of calcareous tuff agglomerate about 10 inches across was found in the Tutoh River above the Magait tributary, along the strike from S6134. The hand specimen (S4585) shows irregular fragments of limestone and lava in a greenish matrix; in places, feldspar crystals as much as 4 mm long are apparent. The slide shows fragments of limestone and of lavas of a variety of texture and composition (see pl. XXVIIa,b). All are rich in chlorite, and some have chlorite-filled vesicles. Most are contaminated by calcite. The feldspar is albite or oligoclase, and they appear to be albitized basalts. The fragments of limestone contain poorly preserved fossils (Algae?).

Palaeocene limestone conglomerate, calcarenite, and calcilutite containing volcanic fragments occur in the Kelalan Formation in the Upper Baram below Long Silat and in the Belukun tributary (specimens S6175-77, S7058, S7061, S7064, S7066-70, S7075-77, S7085, S7087, S7088, S7090-92, S7094-96, S7102, S7110). The volcanic material is a subordinate component. It comprises irregular fragments of fine grained volcanic rock, irregular grains and streaks of emerald-green and yellowish chlorite and crystals of plagioclase. The abundant fresh crystals of feldspar and fresh chlorite indicate that volcanic activity occurred contemporary with or not long before the deposition of the limestone.

The rock fragments are irregular and are mostly spilite, being composed of minute laths of albite in a turbid groundmass. Some have a microporphyritic texture (e.g. in S6177). Other fragments are variolitic basalt, vesicular glassy lava, and tuff (in S6176, Slide A). S7073 contains fragments of microporphyritic, partly glassy, lava with minute vesicles filled with yellowish and emerald green chlorite; the phenocrysts are albite, much altered and partly replaced by calcite. The plagioclase crystals are mostly less than 1 mm long and it is not certain whether they are all volcanic or whether some are of authigenic origin, although the former possibility is the more likely. Many are euhedral, clear, and show albite twining. Those which can be determined are albite, oligoclase, or andesine. Plagioclase crystals in S7087 (Slide A) and S7102 are very numerous, and are certainly of volcanic origin; they are oligoclase in S7087 and oligoclase-andesine in S7102.

OLIVINE BASALT DYKES IN THE TINJAR RIVER

Dykes of olivine basalt in the Tinjar Valley were recorded by Widmer (*1953a;* see also Kirk, 1957, p.97). He noted that they are exposed at several places above Lepu Leju, and most are a few metres thick. They are intruded into sandy shale and sandstones of the Setap Shale Formation, and are aligned along the southeast-trending disturbances of the upper Tinjar.

A specimen collected by Widmer from the dyke above Lepu Leju (S3728) is a dark grey fresh-looking fine grained rock in which phenocrysts of feldspar a few millimeters long are apparent. The slide shows phenocrysts of basic labradorite as much as 2 mm long, of composition about An68. The crystals show slight oscillatory zoning, and contain inclusions of glass (see pl. XXVIId). Many smaller laths of plagioclase occur as skeleton crystals, mostly less than 0·4 mm long, with abundant subhedral crystals of colourless olivine about 0·2 mm long, and some pyroxene, in a dark-brown nearly opaque glass. The glass contains microlites of a birefringent mineral, about 0·15 mm long by 0·01 mm wide, and skeleton crystals of feldspar. Numerous small vesicles (0·1 mm diameter) are filled with a pale green isotropic mineral with low refractive index (less than Canada Balsam), possibly a rather acid glass. Some vesicles have micro-crystalline chlorite and/or serpentine at the core. An orange-red birefringent mineral present in some slides may be iddingsite.

POSSIBLE TUFFACEOUS MATERIAL IN THE LIANG FORMATION

Small very clear angular quartz fragments, showing crystal faces, and relatively large flakes of dark mica (biotite or phlogopite) found in washed residues of the Patan Member of the Liang Formation were taken to be of volcanic origin by Shepherd and van de Fliert (*1956*). This is discussed above (p.59).

HYDROTHERMAL DEPOSITS

Hydrothermal activity and associated mineralization have resulted in small irregular veins of stibnite and realgar in the Tisam tributary of the Tinjar, of realgar in the Baram west of Bukit Liman, and of stibnite in the Palutan tributary of the Baram. These are described in more detail below (pp.97-106). The country rock is Setap Shale Formation. Associated with the metallic minerals are veinlets of a soft white mineral, probably a clay mineral of the kaolinite group. The Mineral Resources Division reported (letter of 18 March 1958 filed as GSS 207/241):

> 'A thin section of S4500 (Palutan River) demonstrates it to be a brecciated siltstone in which small quartz grains are abundant along with small dolomite rhombohedra, spongy limonite, and wisps of a colourless micaceous mineral with a moderate birefringence.
>
> The siltstone is veined extensively by the white mineral which has a tabular habit, perfect basal cleavage and low birefringence (less than ·005) in 1st order whites and greys. The plates are too small for an interference figure to be obtained, but the average R.I. = 1·566 ± 0·001. The mineral is length slow with approximately straight extinction to the cleavage. The plates are pseudohexagonal in outline and a concertina-like structure is presented when the plates are viewed end on. While birefringence is too low for sericite or talc, the R.I. is too high for a zeolite. The optical properties do suggest a clay mineral, particularly a member of the Kaolinite group. This same clay mineral is also present in S4508 (Long Liman, Baram River) and S4511 (Tisam tributary of Tinjar).'

Chapter VII
STRUCTURE

The pre-Pliocene rocks are moderately to intensely folded, and the structure, especially in detail, is complicated. The classical idea of periods of sedimentation interrupted by folding, causing neat and widespread unconformities, fails to explain the structure and stratigraphy of the Northwest Borneo Geosyncline. The intense folding of the older strata appears to be the cumulative result of repeated, gradual, and somewhat local folding rather than cataclysmic orogenies of wide extent and short duration. For example, well-marked angular unconformities can be traced laterally into conformable sequences within a few miles, as shown by Liechti (1960, pp.264-290) and Wolfenden (1960, pp.89-91); thus it is usually not possible to assign an exact age to the folding of any given formation.

The regional strike in the area is fairly regular and constant: in the Suai area it is northeast, in the Middle Baram east-northeast, changing to north-northeast towards the Kelabit Highlands, where there is also a north-south strike in places. The only major exception to the regional strike is in the upper Tinjar Valley, where a northwest strike prevails.

The main folding of the area appears to have taken place in Neogene, probably early Pliocene, times. According to Liechti (1960, p.280) this folding generally tended to produce structures trending northeast, but these are clearly expressed only in those areas where, due to the presence of plastic strata in the subsurface, superficial folding (*décollement*) was possible. Elsewhere, the Neogene structure was to some extent determined by pre-existing structures of late Eocene or older age, which interfered with the Neogene trend. An example is the northwest trend of the Dulit Syncline in the Tinjar Valley. Décollement has also probably occurred between the Setap Shale Formation and the underlying massive sandstone of the Temala Anticlinorium (Haile, 1958b, p.72).

A general account of the structure and features of special interest is given here. The structure can be seen in more detail on the coloured geological map and on figure 7, and brief notes on the tectonic aspect of each formation have already been given in chapters IV and V.

KELABIT HIGHLANDS

In the Kelabit Highlands the Kelabit Formation (Oligocene and Miocene) is steeply folded along north-south axes, but not so intensely contorted as the mainly younger Setap Shale to the west. The shale beds of the Kelabit Formation are comparatively soft. The Meligan Formation forms the Tamabo Range on the western edge of the Kelabit Highlands, and the complicated Batu Lawi Syncline; the dips of the Meligan Formation are in general very steep. The Tamabo Range is possibly the western limb of a long narrow syncline, since the older (Oligocene and Miocene) Kelabit Formation occurs to the east, but this part has been little surveyed and air photographs are still not available.

BARAM AREA

Middle and Upper Baram Valley. The older formations in general show the more intense degree of folding and induration.

The Mulu Formation is intensely folded, and consists in part of slate. Vertical and near vertical dips predominate. In the Tutoh Gorge narrow anticlines and synclines, some isoclinal, are exposed; in many of them the beds can be traced over the top of the folds, which have not been eroded, as is usual in other formations. The Mulu Anticlinorium pitches fairly steeply to the southwest.

The Kelalan Formation is in general intensely folded, although not quite so strongly as the Mulu. The folding of the formation in the Upper Baram area is complex; there the structure of the mainly vertical beds is expressed in the sinuous trends of the Palaeocene limestone of Batu Tujoh and Batu Asi. The double ridge of Batu Asi has been interpreted from air photographs as a partly overturned anticline, but the palaeontology has yet to be fully investigated, and the structural interpretation is only provisional. The strong folding of the older formations cannot be regarded as evidence of Eocene folding, or used to distinguish the Eocene formations from the Miocene Setap Shale Formation, since the Setap Shale is in places (especially adjacent to the Mulu Anticlinorium) as strongly folded and as slaty as the Eocene strata. The Temala Member of the Kelalan, composed of massive sandstone, is more gently folded than the Mulu and the rest of the Kelalan, and, moreover, than the younger (Miocene) Setap Shale. This is an example of disharmonic folding due to differences in lithology. The Mulu and Temala Anticlinoria are rather broad ovals in plan, and somewhat dome-shaped, and contrast with the long narrow inliers of Kelalan Formation farther east. The reason is unknown, but is probably connected with the nature of the basement.

The Setap Shale in the Middle Baram and the main part of the Kelalan Formation may be regarded as forming a single tectonic unit. Where thick shale successions prevail the strata are intensely puckered and contorted; in one outcrop the dips may box the compass. Because of this, and of the absence of any marker beds apart from a few impersistent limestone and sandstone lenses, the detailed structure of the Setap and Kelalan Formations remains largely unknown; there is indeed, little inducement to attempt to unravel it, as, although more detailed field work would undoubtedly produce some results, they are likely to be of local significance only. Photogeology is the best method of investigation, and, where sandy beds occur, has provided a much better idea of the structure than detailed field work.

The massive sandstones of the Belait Formation in the Middle Baram form two comparatively small basin-like synclinal outliers (Lawan and Liman Synclines) and the much larger Belait Syncline, only the southern tip of which extends into the Suai-Baram area. These sandstones are much more regularly and gently folded than the underlying Setap Shale Formation. There is a divergence of dip, and in some places of strike, along the contact which has led geologists in the past to postulate an unconformity between the two formations. However, as Liechti points out (1960, p.286), wherever the contact has been investigated in the field it has been found to be conformable, and the discordancy is best explained by disharmonic folding and minor local disturbance of the Setap Shale Formation, the thick overlying sandstones of the outliers being more rigid than the underlying shales. The Lawan and Liman Synclines are not elongated along the direction of regional strike, the former being almost circular in plan, and the latter slightly elongated north-south. The Meligan Formation, farther east, is probably an almost exact rock-stratigraphic equivalent of the Belait Formation. It forms the isolated Murud Kechil Syncline, and the southern end of a synclinal belt in the Limbang Valley.

Tinjar Valley. In the Upper Tinjar Valley, Belait Formation in the Dulit and Manyam Synclines, and Setap Shale Formation in the intervening anticline, trend northwest, at right-angles to the regional northeast trend, as expressed in the Sekiwa Syncline to the west. The two trends meet and interfere northwest of the Dulit Range. The northwest-flowing Tinjar River, above the Tisam tributary, is believed to follow a fault or fault zone, with a throw possibly in the order of 1,000 feet, along which basalt dykes have been intruded. The northwest trend of the Dulit Syncline truncates northeast trends in the Nyalau Formation to the west. The structure of the Setap Shale between the Tinjar and the Baram above Long Lama is rather irregular and probably is a result of the interference of the two trends. Similarly, the isolated syncline at Bukit Selikan shows a slight east-west elongation.

The aberrent northwest Dulit trend has been discussed by Liechti (1960, p.281), who suggests that it may be secondary, being partly a result of interaction between the Neogene folding and pre-existing late Eocene structure in that area. Re-activated disturbance along the line of the Upper Tinjar may also have been significant. Liechti further points out that the Dulit trend marks a facies boundary between the predominantly arenaceous Nyalau Formation to the southwest and the argillaceous Setap Shale to the northeast; this probably implies that faster subsidence occurred in the Miocene northeast of the Dulit trend.

The Sekiwa Syncline is separated from the Jelalong Syncline by the northeast-trending Jelalong Anticline, of which the Tinjar Anticline is the en echelon continuation. Setap Shale Formation is exposed in the core of both of these anticlines.

The Jelalong Syncline (a term introduced here) is the southwest end of the complex synclinal basin of Belait and Lambir Formations that lies along the watershed between the Baram and the coastal rivers (Suai, Niah, etc.) which is here termed the Tinjar-Suai Synclinorium. The trend of the synclines is northeast, except for a north-south trend which lies on the northwest extension of the Dulit trend (coinciding approximately with the section line B-B′ on the coloured map).

Towards the Bakong Valley in the northeast, the separate elements of the complex structure become more distinct, and a number of subparallel anticlines, with steep to vertical cores of Setap Shale Formation (e.g. Teman, Bakong, and Long Bok Anticlines) are separated by gently deformed, fairly broad synclines (Beluru, Grabit, Ulu Bok, and Mentagai Synclines). Liechti, who revised the photogeology of this part (1960, p.280), points out that the area displays clearly the characteristics of what is termed by him *tectonique de couverture* (i.e. superficial folding, apparently meaning décollement, or a type of décollement), the Lambir, Belait, and part of the Setap Shale Formations probably having been sheared off from the deeper parts of the Setap Shale Formation.

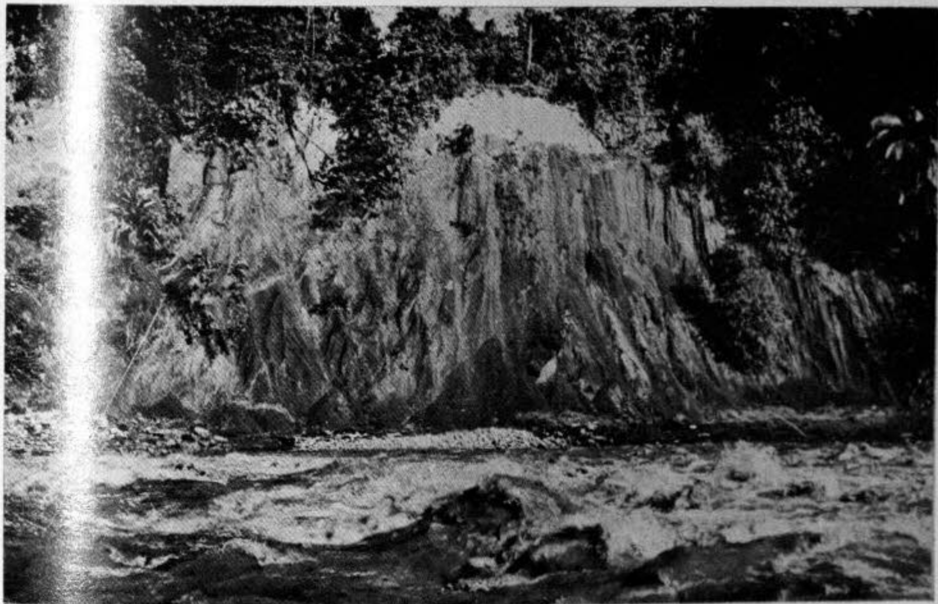
SUAI AREA

The structure of the Suai Area west of the Tinjar-Suai Synclinorium consists of nearly parallel anticlines and synclines trending northeast and has been closely investigated by geologists of Sarawak Shell Oilfields Ltd, as described by Liechti (1960, pp.279-280):

'As in the Pandan-Kakus Area, the synclines are wider, more gently deformed and thus more easily recognised, than the comparatively narrow anticlinal trends, which are either flat roofed with steep to vertical flanks or—if exposed at a deeper level of denudation—consist of a crestal steep zone only. The steep flanks develop in some cases into longitudinal flexures or major faults (Lembong fault, Pait fault), but major faulting has been found to be less common than postulated previously, when rapid lithofacies changes, steep zones, and in some cases the irregular distribution of facies-bound foraminiferal faunas were accepted as fault evidence.

'A number of the more important faults shown on the map appear to be reverse faults. In addition to the longitudinal main fault, trending northeast-southwest, subsidiary oblique faulting, trending north-northeast, north or even northwest, is also in evidence. Scanlon convincingly advances the view that faulting was contemporaneous with, or post-dates, folding, and that lithofacies, in particular the interfingering of the Nyalau with the Setap Shale Formation played an important part in the tectonic evolution of the area. He states 'it is probable that the structure started to grow asymmetrically but later the forces of compression were relieved by steep zones which sometimes developed into reverse faults or fault zones. These reverse faults had the greatest effect when coupled with a resistant arenaceous facies adjoining a more pliable shale facies. Thus the longitudinal reverse faults are most clearly expressed along the western flanks of the anticlinal highs, where the competent sandstones of the Nyalau Formation adjoin the more pliable Setap Shale Formation of the adjoining synclines; where these faults had their greatest throws, they caused a swing in the axial trends of the synclines, a fact which explains previous ambiguities of the tectonic pattern of the area. Diversities of dip direction in the Setap Shale facies may be due to local disharmonic folding caused by incompetence of the shale. Minor overfolding, though rare, may have occurred locally, i.e. Bala Anticline. Secondary folding and faulting occurred at a later date, as is evident from the detailing of the Selungun and Sabulong Anticlines, but had only a minor or negative effect on the regional structure picture . . .'

'The Ulu Suai Area, adjoining the Bintulu-Subis Area to the east, is characterised by exceptionally gentle structures. The main feature is the medium-sized, gentle Ulu Suai Dome, accompanied to the east by a large Neogene Syncline filled with Belait Formation. The almost circular dome lies in the northern continuation of the north-south trending Tubau trend [south of the Suai-Baram area] with which it is obviously related. On the other hand an east-west axis is also in evidence which crosses the dominant north-south trend at a right angle. The culmination lies at the crossing of the two trends, which adjust themselves in their northern and western continuation respectively to the regional northeast-southwest strike. The gentle folding is probably merely due to the competence of the Nyalau Sandstones. The possible presence of a subsurface disturbance as hinted at in explaining the Tubau Valley tectonics, may be another contributory factor. Lastly the large competent synclinal occurrence of . . . [the Tinjar-Suai Synclinorium] has possibly shielded the dome against strong deformation. In any case it is situated in the marginal area of Nyalau development, where to the north the Setap Shale Formation begins to replace the arenaceous lithofacies of the Nyalau and, due to its incompetence,

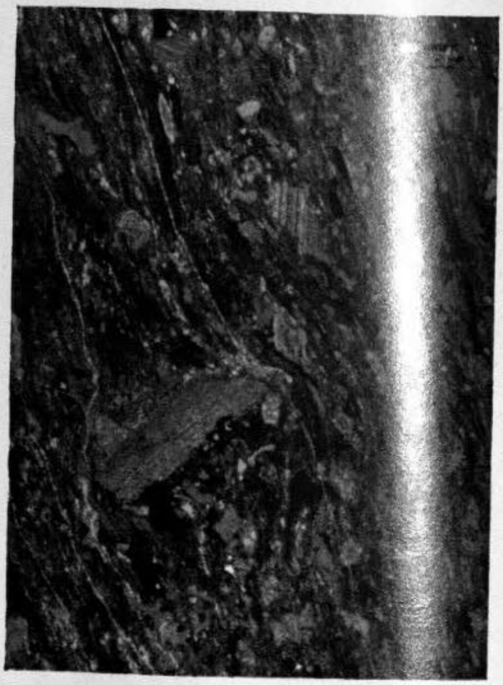


a

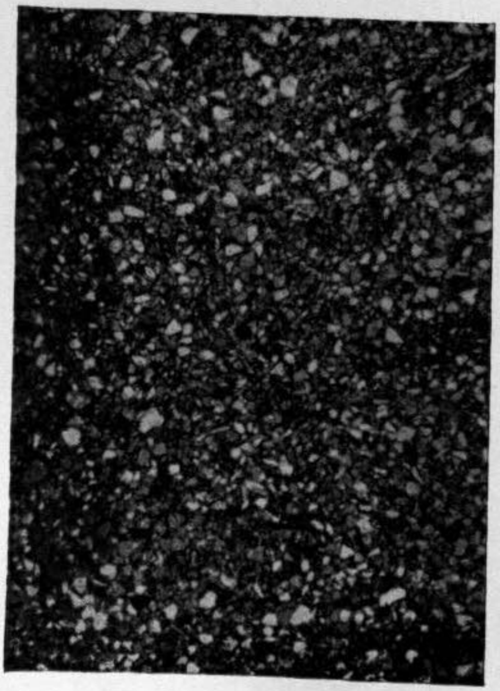
b

PLATE XXV. TERRACE GRAVEL OVERLYING SETAP SHALE FORMATION. Shows gravel overlying shale by the Akah River, about 50 feet above river level (a); and in the Baram opposite Long San (b) (*see p.12*)

a



b



c

d

PLATE XXVI. PHOTOMICROGRAPHS OF SEDIMENTARY ROCKS

a. Subgreywacke from the Mulu Formation, Tutoh Gorge, S4595 (× 23) (*see p.29*)
b. Metamorphosed limestone from the Melinau Limestone Formation, upper Tutoh Gorge, S4589 (× 8) (*see p.36*)
c. Fine-grained subgreywacke from the Temala Member of the Kelalan Formation, S4656 (× 17) (*see p.32*)
d. Sandy limestone from the Temala Member (S4654). Contains Foraminifera of Upper Eocene age (× 23) (*see p.32*)

Photomicrographs by Mineral Resources Division would have afforded the possibility of releasing tectonic forces without affecting the competent Nyalau Formation to any greater extent . . .'

'The Subis anticlinal trend, north-northeast to northwest, is another major and comparatively gently folded trend, which connects with the Sebatu Anticline to the south . . . the gentleness of folding may be ascribed to competent biohermal limestone occurring both at the surface (1,250 feet thick) and in depth . . . Similar bioherms in the subsurface of the Subis . . . area may possibly be of wider occurrence than has been so far suspected. Moreover the Tangap Marls may increase the competence of the anticlinal core as compared to the surrounding shales of the Sibuti and Setap Shale Formations . . .'

Chapter VIII

GEOLOGICAL HISTORY

The area formed part of the Northwest Borneo Geosyncline, which was a subsiding area covered by sea in which an enormous thickness of sediment was deposited. The subsidence started, it is believed, in Cretaceous times, and the axis of the geosyncline migrated gradually northwards throughout the Tertiary. The source of the huge quantity of detritus is not known, but it was probably derived in part at least from the central granitic part of Borneo, which was being uplifted and eroded at this time. During the middle and late Tertiary most of the detritus was probably derived from Cretaceous and Lower Eocene sedimentary rocks which had been uplifted and exposed to erosion along the southern flanks of the geosyncline. As practically nothing is known of the geology of the floor of the South China Sea, and little about east Kalimantan, the palaeogeography cannot be reconstructed accurately. Probably the main source of sediment, and the land areas, were somewhere south of the Suai-Baram area, and the open sea lay to the northwest, as it does to-day. The history of the Northwest Borneo Geosyncline has been described in the compilation report (Liechti et al., 1960, pp.2-5, 292-302).

UPPER CRETACEOUS TO OLIGOCENE

The pre-Cretaceous history is unknown, and Upper Cretaceous rocks are known from only one outcrop. It seems probable, however, on consideration of the regional geology, that the area already formed part of the geosyncline in Upper Cretaceous times, and that a considerable thickness of sediments was deposited at that time, particularly in the area of the middle Baram and Kelabit Highlands. Conditions of deposition of the Kelalan and Mulu Formations were probably mainly miogeosynclinal, since typical eugeosynclinal rocks such as graywacke, ophiolites, and radiolarian cherts are not known, and limestones were formed both in the Palaeocene and at the end of the deposition of the Kelalan and Mulu in the late Eocene. The Palaeocene limestones, now preserved at Batu Asi and Batu Tujoh, were probably deposited over a much wider area. The limestones are not true reef limestones, being mostly fine grained and containing pelagic Foraminifera, but Algae and larger benthonic Foraminifera, common in some of the limestone, indicate deposition in a fairly shallow sea. At this time, or just before, volcanic activity took place somewhere in the region, as testified by the admixture of chlorite and fragments of lava in the Palaeocene limestones and limestone conglomerates. This is the only known Palaeocene volcanism in Borneo, and the position of the centre of volcanism is not known.

In late Eocene times the area was still probably entirely covered by sea, but the amount of detritus being brought in from the land diminished, and gradual folding movements started, causing anticlines which formed shoals, or, perhaps, even islands. On the flanks of these anticlines, especially the Mulu and Temala Anticlinoria, limestone reef-complexes began to form—the Meligan Limestone Formation. These were built of Foraminifera, Algae, and corals, and in part are probably true reefs, in part reworked reef debris. Uplift, probably accompanied by continued gentle folding, occurred towards the end of the Eocene. In the middle Baram apparently little or no sedimentation took place in Oligocene times, or, if Oligocene strata were deposited, they were eroded before deposition continued in the Miocene. In the Kelabit Highlands, however, deposition of the Kelabit Formation started at least as early as the Oligocene, and probably continued into Miocene and even younger times. In the Melinau Valley, just beyond the northern limit of the area, deposition of the Melinau Limestone Formation was, in places, continuous from Upper Eocene to Miocene, whereas in the upper Baram Miocene limestone rests directly on Palaeocene rocks.

MIOCENE DEPOSITION

In the middle Baram area, general subsidence and sedimentation started again in early Miocene times. On the eroded surface of the Upper Eocene reef-complex limestone, which occurred in patches in the early Miocene sea, similar limestone began to form again, composed of Miocene Foraminifera and Algae mixed with fossils derived from parts of the old reef that were still being eroded. At Batu Gading, the Miocene part of the limestone has a breccia at its base, but no angular unconformity can be detected, indicating that no folding occurred between Upper Eocene and Miocene there. This limestone growth did not continue long, however, probably because subsidence caused the reefs to sink below the depth at which they could grow, and because the water became too muddy. Over the drowned reefs, and locally elsewhere in the middle Baram, calcareous shales with pelagic Foraminifera were deposited, but over most of the Kelalan and Mulu Formations in this area non-calcareous shales, with thin sandstones of subgraywacke type, were laid down. In places, such as the area north of Batu Tujoh, thicker successions of sandstone, resembling Nyalau Formation, were deposited in the argillaceous strata of the Setap Shale Formation.

South and west of the Tinjar River, deposition in the Miocene was predominantly sandy, especially southwest of a line joining the Dulit Syncline with Gunong Subis. This line represents a primary facies boundary, which, in the early Miocene, separated an area of predominantly sandy deposition to the southwest (Nyalau Formation), from one of mainly shaly and marly deposition to the northeast (Setap Shale, Tangap, Sibuti, and Tubau Formations).

The *Subis limestone reef complex* formed on the line of this facies boundary. Growth of this limestone started in early Miocene (Te_{1-4}) times; this older part is known only from Well Subis 2, and consists of an alternation of limestone with marls and sandstone (see fig. 3). The history of the present surface outcrop, of Te_5 age, is much better known, from detailed studies by geologists and palaeontologists of Sarawak Shell Oilfields Limited (notably I. L. Burr and W. E. Crews, *1950*; H. A. Jordi, *1954*; R. Haak, *1955*; and J. U. Todd, *1955*). They concluded that the limestone formed as an isolated 'biohermal growth' of shoal-reef character and was confined to clear shallow waters (down to a depth of about 180 feet) in the infra-neritic zone. In general, the area must have been subsiding during the Miocene, even over the shoals such as at Subis, as proved by the great thickness of strata that accumulated. To describe these shoals as due to uplift would therefore be misleading; they are merely areas where subsidence was slower, and where sedimentation or reef growth at times out-paced subsidence. The distinction is not merely one of words, as will be shown below.

Relatively slow subsidence in the Subis area probably caused shallow shoals to form, on which fine sands were deposited (Nyalau Formation); on these sandy shoals crustose calcareous red Algae (Melobesioidea) and larger benthonic Foraminifera were able to live, and their fossil remains accumulated to form a limestone platform. The contact between these sands and the overlying limestone is transitional, strongly suggesting that sedimentation was continuous. The sea depth at this time is estimated to have been about 150-180 feet. By building up of the reef through normal growth, the growing surface of the reef eventually reached into shallower water, the epi-neritic zone (less than 120 feet), with a corresponding change of fauna (large Foraminifera, echinoids, corals, Bryozoa) and flora (especially characterized by articulate red Algae). The prolific growth of corals and calcareous red Algae, together with the absence of significant clastic material in the Subis Limestone, indicate clear water conditions over the Subis shoal during the time the limestone was deposited. However, muddy water in the immediate neighbourhood around the shoal is strongly suggested by the rapid increase

FIGURE 8. DIAGRAMMATIC SECTIONS SHOWING GROWTH AND EROSION OF THE SUBIS LIMESTONE
(After I.L. Burr, 1950; for explanation see text)

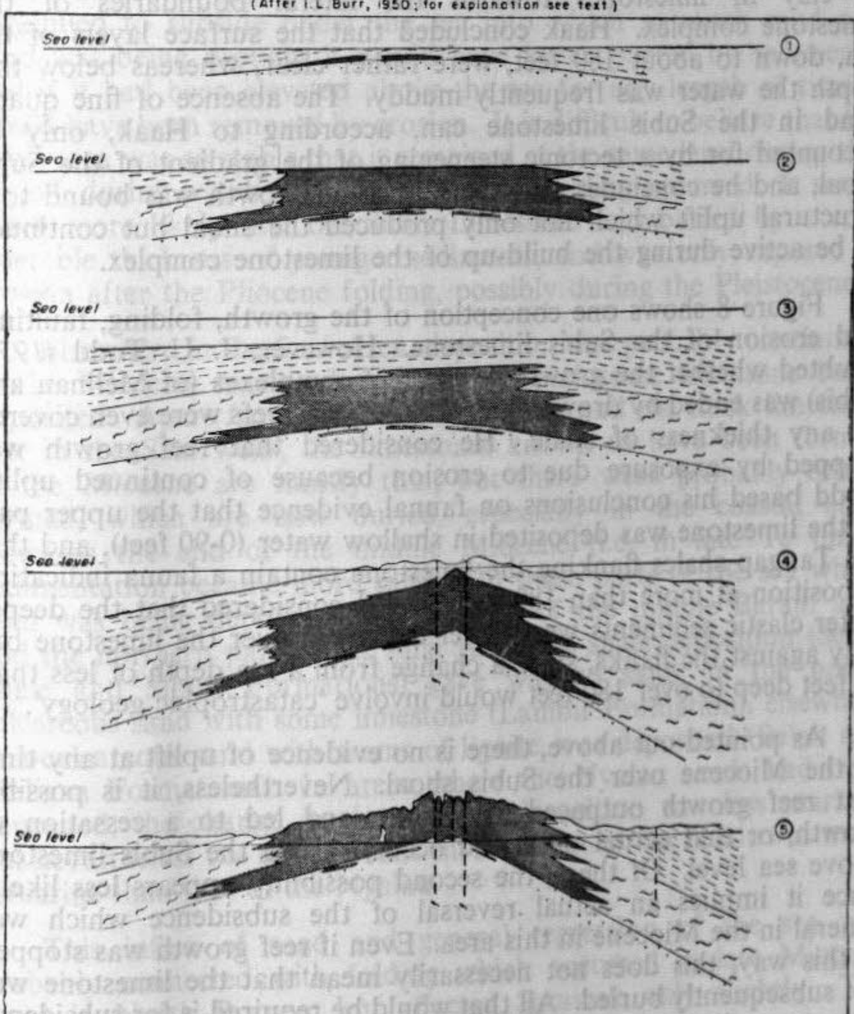


Diagram 194 reproduced from I.L. Burr, (1950) by courtesy of Sarawak Shell Oilfields Limited of clay in limestones towards the lateral boundaries of the limestone complex. Haak concluded that the surface layers of the sea, down to about 180 feet, were rather clear, whereas below this depth the water was frequently muddy. The absence of fine quartz sand in the Subis limestone can, according to Haak, only be accounted for by a tectonic steepening of the gradient of the Subis shoal, and he concludes that the biohermal growth was bound to a structural uplift which not only produced the shoal but continued to be active during the build-up of the limestone complex.

Figure 8 shows one conception of the growth, folding, faulting, and erosion of the Subis limestone. However, J. U. Todd (*1955*) doubted whether the growth of the reef complexes (of Melinau and Subis) was ended by drowning or whether the reefs were even covered by any thickness of shale. He considered that reef growth was stopped by exposure due to erosion because of continued uplift. Todd based his conclusions on faunal evidence that the upper part of the limestone was deposited in shallow water (0-90 feet), and that the Tangap shales flanking the limestone contain a fauna indicating deposition at more than 180 feet. Todd considered that the deeper water clastic sediments were never deposited over the limestone but only against the flanks, since a change from a sea depth of less than 90 feet deep to over 180 feet would involve 'catastrophic geology'.

As pointed out above, there is no evidence of uplift at any time in the Miocene over the Subis shoal. Nevertheless, it is possible that reef growth outpaced subsidence and led to a cessation of growth, or that actual uplift did occur, raising the Subis limestone above sea level. Of these, the second possibility appears less likely, since it implies an actual reversal of the subsidence which was general in the Miocene in this area. Even if reef growth was stopped in this way, this does not necessarily mean that the limestone was not subsequently buried. All that would be required is for subsidence to outpace limestone growth, either because of an increase in the rate of subsidence, or because of a change in conditions, such as an influx of muddy water, which would stop reef growth. No catastrophic event need be postulated. Moreover, the Melinau Limestone in the Batu Gading area, which is very similar to the Subis Limestone, was certainly buried by younger shales, as was the limestone in the Setap Shale found in deep exploration wells at Suai (see fig. 3).

The suggestion by Todd that the Subis Limestone was probably never buried under any considerable thickness of later sediments is more difficult to believe for another reason. It involves the supposition that the Subis area remained about the same level relative to the sea from middle Miocene to Recent times, since if it had continued to subside under the sea into which so much mud and sand was being brought it would have been covered by sediments; and if it had been elevated above the sea for any length of time it would have been removed by erosion. It is difficult to believe that the Subis area was so stable that it remained at the same level during this period, during which the intense Pliocene folding occurred. It seems much more likely that the Subis Limestone was buried by a considerable thickness of younger sediments, and was only exposed to erosion after the Pliocene folding, possibly during the Pleistocene.

Elsewhere in the Suai Area, deposition was probably continuous in the Miocene, mud, calcareous mud, and some limestone being deposited. Apart from the Subis limestone and the thick limestone met in the Suai wells, the limestones known to have been formed in the Miocene are mostly thin, but there were probably others formed, which are now buried, especially in the coastal area. Towards the end of the middle Miocene (i.e. in late Te times) sedimentation became more sandy. In those parts of the sea where mud was being deposited, that is most of the middle Baram area and the northern part of the Suai Area, the shale deposition (Setap Shale and Sibuti Formations) gave way to sand; in the north, calcareous sand with some limestone (Lambir Formation), elsewhere non-calcareous sand with seams of lignite, was deposited (Belait and Meligan Formations). In areas where the Nyalau sands had been deposited, the change in the type of deposition was less marked, but nevertheless the depositional environment of the Belait was more estuarine than that of the Nyalau.

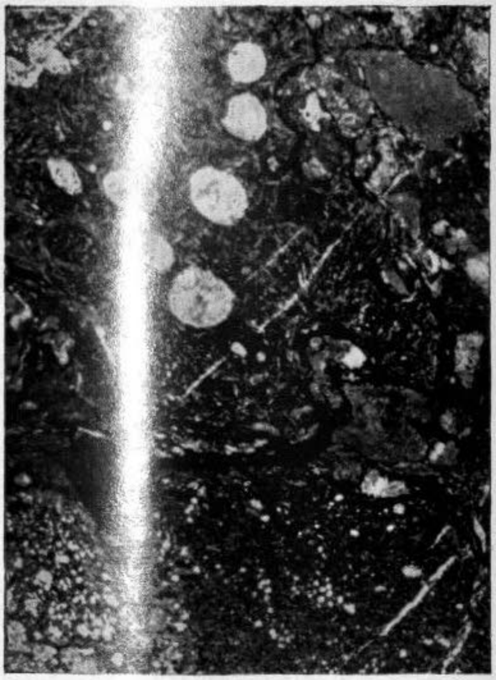
This influx of sand and general regression of the sea was probably connected with folding which occurred in late Miocene times in North Borneo, but affected Sarawak only slightly. The thick sandstones of Upper Miocene (Tf) age now occupy only synclines, separated by anticlinal areas of Setap Shale Formation. The formation of these synclines, with their great thicknesses of strata, all of which appear to have been deposited in coastal swamp (i.e. paralic) or deltaic conditions, requires special explanation. The main difficulties are to account for the apparently contemporaneous deposition of the Tf part of the argillaceous Setap Shale Formation and the arenaceous Belait Formation, and to explain the restricted geographical distribution of the Belait Formation.

Liechti considers that the present synclines mark the approximate limit of deposition of the Belait sediments (1960, pp.299-300):

'Whereas deposition up to late Te time was widespread and connected, in the later Tertiary a number of Isolated Basins came into existence in the coastal and near coastal area . . . These basins are separated by cores of steeply folded Setap Shale, which are inferred to have controlled deposition to some extent . . . The Setap Shale cores apparently subsided less rapidly than the basins and so formed barriers separating them. The cores received only an occasional influx of sand or none at all. Obviously currents and wave action carried the incoming sand across them, dropping it in the somewhat deeper adjacent basinal slope, whilst the clay particles reached the deepest, central part of the basins. It must be added, however, that the environment in the deepest parts of the basin does not point to much greater depth than that in the flanks. The stratigraphic evidence leaves no doubt about a general deltaic-paralic environment of the Belait Formation that changes towards the coast into a shallow littoral-paralic environment of the Lambir and Miri Formations. It is thus concluded that the gradients from the incipient crestal highs to the bottom of the basins were small, and that the pronounced difference in thickness between synchronous deposits of Setap Shale and Belait Formation is due mainly to rapid basinal subsidence. This implies that Belait Sandstones have never been deposited across the Setap Shale cores . . .'

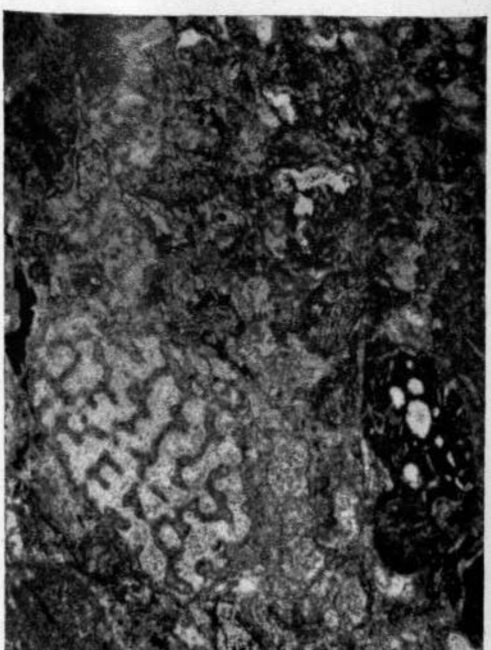
This explanation is not wholly satisfactory. It has not been proved beyond doubt that the deposition of the Belait Formation was confined to the present outcrop in synclinal basins. The alternative, that the formation was deposited over much wider areas, was then folded, eroded, and is now preserved only as outliers in synclinal basins, still has to be considered; some of the facts in the Suai-Baram area, for instance, the small outliers at Liman, Lawan, Manyam and Selikan, are more easily explained on this theory. It is difficult to believe that each one of these synclinal outliers, of various sizes, was a discrete depositional basin.

On the whole, however, deposition of the Belait Formation was probably concentrated in, if not confined to, the main areas of the present outcrop. Even so, the suggested reasons for this are not wholly convincing. The idea that mud was deposited on shallow areas, whereas sand was being swept across them to be deposited in deeper basins, is, in the writer's opinion, not tenable. The Tf part of the Setap Shale contains pelagic Foraminifera, and the depositional environment was clearly more marine than that of the supposedly contemporaneous lower Belait, which contains coal seams, normally a clear indication of paralic (coastal swamp) to



a

b



c

d

PLATE XXVII. PHOTOMICROGRAPHS OF VOLCANIC ROCKS

a and b. Calcareous tuff agglomerate from the Kelalan Formation, Tutoh River (S4585A & B), composed of fragments of vesicular lava and limestone (× 4) (*see p.65*)

c. Tuffite from the Tutoh River (S6134), composed of calcite, chloritic matter, glass, and fragments of volcanic rock (× 17) (*see p.65*)

d. Olivine basalt from the Tinjar River (S3728B), showing phenocrysts of labradorite containing glass inclusions (crossed nicols, × 23) (*see p.66*)

Photomicrographs by Mineral Resources Division

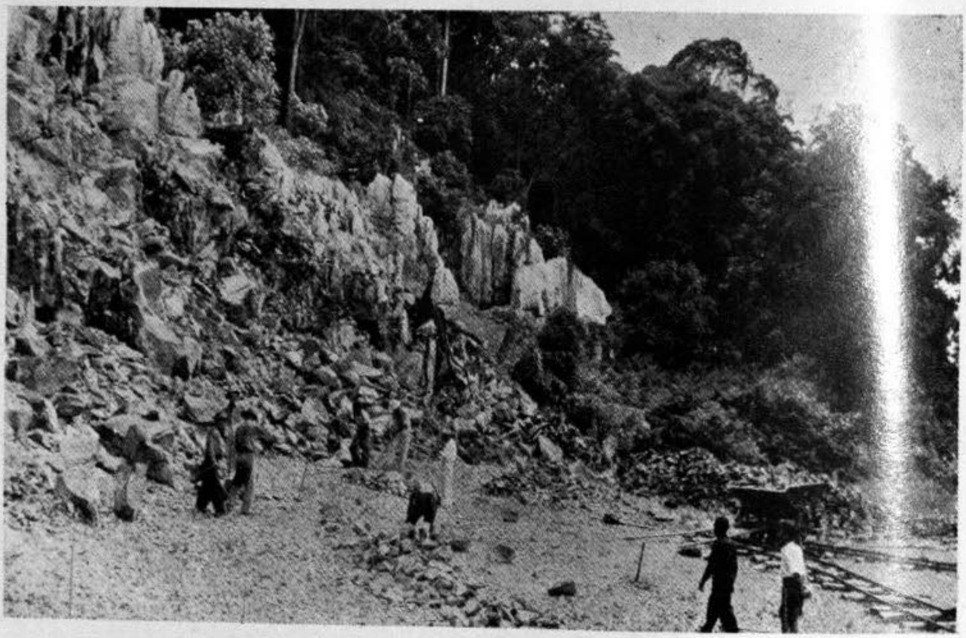


PLATE XXVIII. BATU GADING QUARRY. The quarry face, in Melinau Limestone Formation (a); and Kelabit workers near the small crusher (b) (*see p.117*)

deltaic conditions. It appears probable that at the beginning of Belait deposition the areas where Setap Shale was still being deposited were actually topographically lower than the Belait 'Basins', and not higher, as suggested by Liechti.

Nevertheless, it is clear that there was in fact very great subsidence in the areas now occupied by the synclinal basins, since the present thickness of strata in them is tens of thousands of feet. The cause of subsidence is problematical. Liechti (1960, p.283) considered that basinal downwarps may have originated by passive, differential, gravitational subsidence, due simply to heterogeneity of the Palaeogene and older substratum, or to differential compaction of the Setap Shale, rather than to a genuine structural phase. Formation of downwarps by differential compaction, or other mechanism, may have been combined with an influx of sandy detritus into the area due to folding and uplift of the hinterland. Once the process had started, it may have been sustained merely by increased subsidence due to the load of sediment, as Liechti points out (1960, p.284).

An alternative theory is that the load of sediment was the prime cause of subsidence. According to this, the distribution of the Neogene basins depended on the position of the spreads of sand deposited presumably as deltas after the late Te uplift of the hinterland had caused increased sand to be brought into the sea. It is possible that the floor of the late Setap sea was quite flat and the deltaic sands caused accretion of the land, and swamp forest forming peat grew on the deltas. The Setap Shale substratum was very soft and soon subsided where the deltas were forming and the peat was buried by younger sands and later became coal, the cycle probably being repeated several times. This hypothesis explains the formation of coal seams rather better than previous ideas, and moreover, the diachronous basal boundary of the Belait, which becomes progressively younger from south to north of the Suai-Baram area (see Liechti, 1960, p.182-183), can be explained by the progressive migration northwards of the deltas. Again the truncation of the Belait and Limbang Synclines in the north, and their northwards pitch is more easily explained on this 'deltaic theory'. The shape of the areas occupied by the present deltas of the Baram and Belait, of the rivers that flow into Brunei Bay, and of the coastal alluvium around Suai, resemble those of the Belait basins. Conditions in these present-day deltaic areas, which are largely covered by deep peat, might well be similar to those obtaining at the beginning of the Belait. An important difference, however, is that the Quaternary deposits in these deltas rest unconformably on the Tertiary in most places, so that the parallel is not complete.

In the Suai-Baram area the deltaic hypothesis does not fit the facts quite so well, as the Neogene basins are closed on all sides and seem to follow fundamental structural trends. Nevertheless the hypothesis does suggest certain lines along which future work can be done to elucidate the nature of the Neogene basins. Most useful would be a knowledge of the palaeogeography and source of the detritus, such as might be provided by detailed mapping of the orientation of current bedding. The nature of the coal and the areal extent of the seams could also throw some further light on the conditions of deposition. There is no information about the lower Belait Formation strata in the middle of the synclines, or about the Belait-Setap contact there, since these are invariably hidden by overlying rocks, and so far no deep drilling for oil has been done in those parts. The only hope of finding out anything about these strata would appear to be by drilling and geophysical surveys, which might eventually be done by oil companies, since there is a possibility of stratigraphic oil traps in the basins (especially the Belait Syncline); the extensive facies changes and wedging out of formations, which are known to occur in the area, certainly favour stratigraphic traps.

However the sedimentary Neogene Basins originated, and in the writer's opinion all of the factors discussed above, namely tectonic warping, differential compaction, and subsidence due to deltaic deposition, were probably involved, the later history of the basins is less problematic. As subsidence continued, the lower strata probably acquired an increasing dip towards the centre of the basins, which explains the present steeply dipping rims. In the Suai-Baram area the uppermost beds in the Neogene Synclines are still sandy; whereas to the north more clayey strata succeed the basal beds. It may be that sands were deposited in the Suai-Baram area at the same time as more clayey strata were laid down to the north, farther from the land.

PLIOCENE FOLDING

Deposition in the Neogene basins stopped in late Miocene or early Pliocene times in the Suai-Baram area, and was followed by the Pliocene folding (also called 'pre-Liang folding phase'), which was fairly intense in the Suai-Baram area. The general trend of the folding was northeast-southwest, and Liechti (1960, p.301) explains all other structural trends in the Neogene of this area as due to interference by reactivation of pre-existing structures mainly trending north-south, which originated in the late Eocene or earlier. Examples of structures which may have formed by interference between a northeast-southwest and a north-south trend are the Ulu Suai Dome, which lies due north of the Tubau trend (a north-south anticline which lies south of the Suai-Baram area), the north-northeast trending structures in the eastern part of the middle Baram, and the northwest Dulit trend.

The folding caused steepening of the dips around the rims of the Neogene basins and in the intervening shale cores. Probably this folding was mainly an accommodation of the underlying thick plastic shale to the unevenly distributed overlying strata, resulting in pressure folds, causing anticlinal cores of shale to rise between the synclinal basins. Recently, such a mechanism has been demonstrated experimentally by V. V. Belousov (1961), and explains how sedimentation could continue without interruption in some coastal areas of Sarawak and Brunei.

As Liechti has clearly proved, the 'bench-vice' conception of folding i.e. of compression of an area between two rigid blocks, fails to explain the folding in the Northwest Borneo Geosyncline, and the hypothesis of folding due to movement of the strata under their own weight after uplift fits the facts better.

PLIO-PLEISTOCENE HISTORY

Uplift in Pliocene times probably raised most of the area above the sea, except for the area now covered by alluvium. Along the coast and in the Baram Delta, sand, lignite, and clay of the Liang Formation was deposited, probably as isolated patches. Slight warping movements in early Pleistocene times (post-Liang folding phase) account for the scarcely detectable unconformity between the Liang and overlying alluvial terraces. Erosion of the land areas, which probably started in Pliocene times, continued after the post-Liang folding, and, on regional evidence, Liechti concluded that widespread regional peneplanation occurred after the Liang deposition, and named the cycle the *Peneplanation Cycle*. The peneplain is now preserved only as remnants, and in the Suai-Baram Area the only evidence of its existence is the similar height of the hills in many areas—the so-called *Gipfelflur* or summit plane. This can be seen in the Kelabit Highlands (with the exception of Gunong Murud which is higher), in the Dulit Range, and the hills between the Suai and Tinjar river basins, and at a lower level in the Suai Area.

The age of this Peneplanation Cycle is, however, doubtful. Liechti (1960, p.308-309) considers that it is probably early Pleistocene, but the evidence is not wholly convincing. In the writer's opinion, the Peneplanation Cycle may have started in Pliocene times in the hinterland, and the Liang Formation may be regarded as its depositional component. Nevertheless the area was probably eroded to a moderately low and mature relief by early Pleistocene times.

A new cycle, the *Jerudong Cycle,* was started in the early or mid-Pleistocene by uplift of the whole area, accompanied by slight warping. Further erosion caused dissection of the peneplain and deposition of sand terraces along the coast. Encased alluvium in the Kelabit Highlands may also have been formed at this time, although Wilford (1961, p.125) thought it possible that it was formed at a late stage in the Peneplanation Cycle, because it lies at about the same height as the Gipfelflur of the Peneplanation Cycle. Further uplift, probably about 100-200 feet in the coastal area, but as much as 2,000 feet in the Kelabit Highlands, started a third cycle, the *Alluvial Cycle* which caused rejuvenation of the rivers and dissection of the Jerudong Terrace, and corresponding deposition of river alluvium and peat in the Baram delta and coastal areas.

Chapter IX

MINERAL RESOURCES

The mineral resources include limestone and shale suitable for the manufacture of cement, sand and gravel, pure sand probably suitable for glass making, lignite, phosphate (guano), salt springs, and small occurrences of ores of antimony and arsenic. At present limestone worked as roadstone, salt, and phosphate (guano), are the only mineral resources exploited. There is some chance of oil and natural gas being found in the area but exploration and drilling by Sarawak Oilfields Limited have so far not resulted in the discovery of any commercial deposits.

LIMESTONE AND DOLOMITIC LIMESTONE

Limestone occurs at a number of places. It is quarried for use as roadstone at Batu Gading (on the Baram below Long Lama), and was formerly quarried near Bukit Subis on the Niah River. Most of the limestone is pure, and has a very low content of magnesia; a few specimens from the Beluru area, and one from Bukit Subis, were found on analysis to be dolomitic. Dolomite is in demand in Sarawak as fertilizer for pepper and rubber, but no workable deposits have been found so far. In this account the classification suggested by Pettijohn (1957) for limestone and dolomite is used, namely:

	Percent Dolomite	*Approx. Magnesia (MgO) equivalent percent*
High-calcium limestone	0 to 5	0 to 1·1
Magnesian limestone	5 to 10	1·1 to 2·1
Dolomitic limestone	10 to 50	2·1 to 10·8
Calcitic dolomite	50 to 90	10·8 to 19·5
Dolomite	90 to 100	19·5 to 21·6

Batu Gading. The Batu Gading limestone deposit is described in detail in the section on the Baram cement project, below. Recorded production from the quarry is:

1957	5,311* cu. yds
1958	12,396 cu. yds
1959	7,368 cu. yds

*Sold in Sarawak; exports to Brunei not included

The limestone samples analysed are all high-calcium limestone containing less than 1·1 percent magnesia (see tables 16a and b).

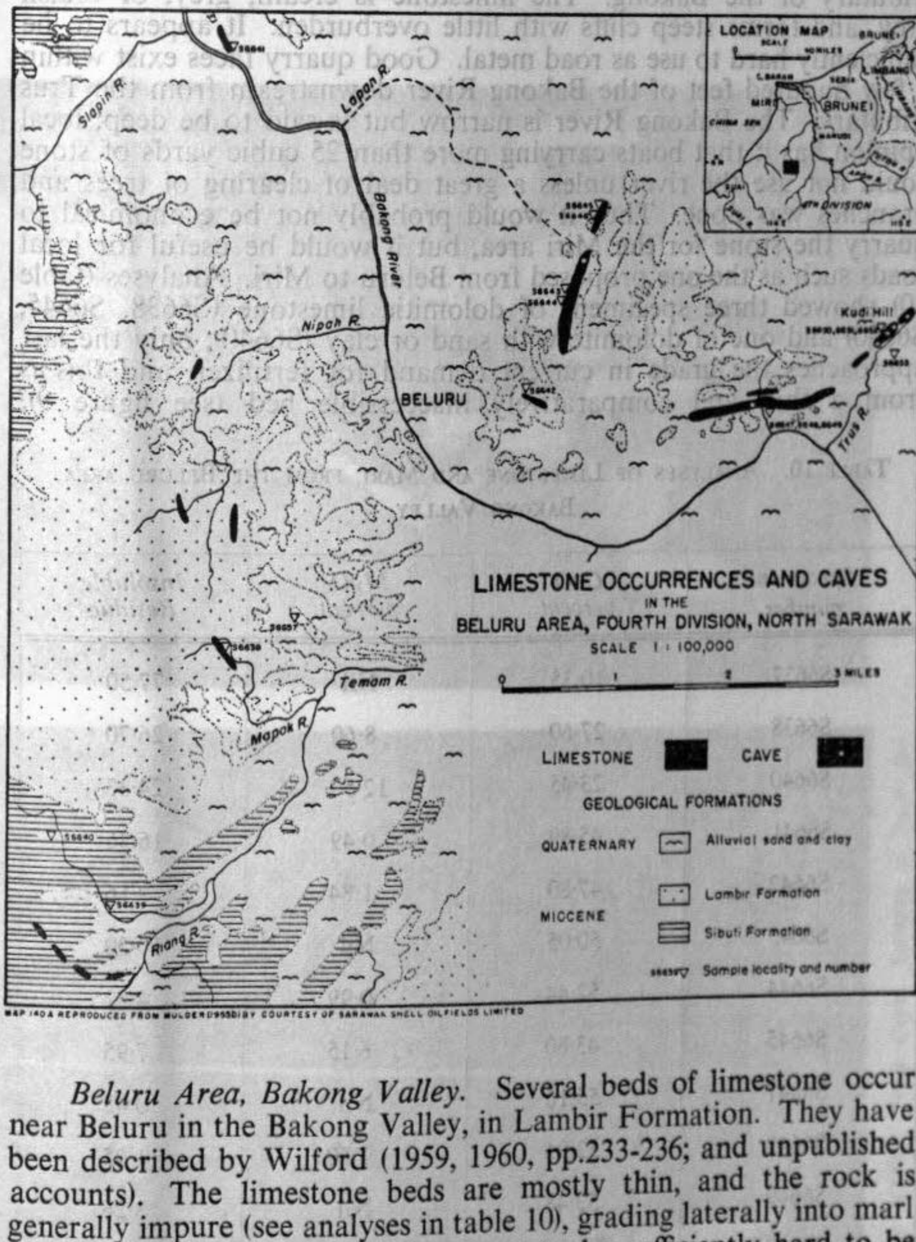
TABLE 9. ANALYSES OF LIMESTONE FROM BUKIT SUBIS

	SiO_2	Fe_2O_3	MgO	CaO	P_2O_5
	WEIGHT PERCENT				
S1132	0·30	0·09	0·98	54·3	0·05
1133	1·14	0·19	0·88	53·5	0·04
1134	3·03	0·45	0·90	52·0	0·05
1135	4·96	0·46	1·16	49·9	0·04
1136	5·72	0·80	1·15	48·9	0·04
1137	0·84	0·39	0·34	53·9	0·04
1138	2·02	0·21	1·98	51·7	0·02
1139	0·44	0·09	0·54	54·9	0·04

Analyses by the British Aluminium Company Limited

Bukit Subis. The limestone at Bukit Subis outcrops over about 9½ square miles, and forms mountains 700 to 1,000 feet high over most of that area. Reserves are thus unlimited for practical purposes. The limestone is chemically very pure, and contains very little insoluble residue. Analyses are given in table 9. Tests made in the Shell laboratories on a number of limestone samples from Bukit Subis showed that the insoluble residues of most samples was less than 1 percent weight, some were 1 to 2 percent and only very few above 2 percent. Dolomite was determined by electrical means for 51 samples in Shell laboratories, and by chemical analysis for 27 samples by the Soils Laboratory of the Agricultural Department, Kuching. Of these, 59 are high-calcium limestone, 15 magnesian limestone, 3 dolomitic limestone, and 1 calcitic dolomite. The calcitic dolomite sample contains 83 percent dolomite (equivalent to 18 percent magnesia); it was collected from the cliff face about a quarter of a mile south-southwest of the triangulation point on Bukit Subis. Other samples nearby are high-calcium limestone, and so it is probable that the dolomitization is only local. It nevertheless indicates the possibility that workable dolomite may occur at Bukit Subis.

FIGURE 9



Beluru Area, Bakong Valley. Several beds of limestone occur near Beluru in the Bakong Valley, in Lambir Formation. They have been described by Wilford (1959, 1960, pp.233-236; and unpublished accounts). The limestone beds are mostly thin, and the rock is generally impure (see analyses in table 10), grading laterally into marl and calcareous sandstone, but appears to be sufficiently hard to be used as road metal, though tests would be needed to confirm this. The thickest, hardest, and purest bed forms a discontinuous ridge extending from Kudi Hill west-southwest, and another ridge extending in a north-northeast direction in the headwaters of the Lapan tributary of the Bakong. The limestone is cream, grey, or bluish grey, and forms steep cliffs with little overburden. It appears to be sufficiently hard to use as road metal. Good quarry faces exist within a few hundred feet of the Bakong River downstream from the Trus tributary. The Bakong River is narrow but is said to be deep; local opinion has it that boats carrying more than 25 cubic yards of stone could not use the river unless a great deal of clearing of trees and branches was done. Thus it would probably not be economical to quarry the stone for the Miri area, but it would be useful for local roads such as the one proposed from Beluru to Miri. Analyses (table 10) showed three specimens of dolomitic limestone (S6638, S6645, S6650) and one of dolomite with sand or clay (S6640); only the last approaches the grade in current demand for fertilizer, and this is from a thin and comparatively inaccessible bed (see figure 9).

TABLE 10. ANALYSES OF LIMESTONE AND MARL FROM THE BELURU AREA, BAKONG VALLEY

Specimen number	*CaO percent*	*MgO percent*	*Insoluble Residue*
S6637	10·35	Nil	77·50
S6638	27·60	8·60	26·70
S6640	23·45	12·50	24·33
S6641	45·89	0·49	16·46
S6642	47·80	1·84	9·16
S6643	50·05	Nil	10·30
S6644	52·44	0·99	4·52
S6645	43·80	6·15	7·95
S6647	55·16	Nil	0·48
S6648	52·96	1·60	1·05
S6649	53·48	Nil	3·26
S6650	46·58	7·13	1·84
S6651	52·96	1·11	2·31

Analyses by D. Sutton, Soil Chemist, Department of Agriculture, Kuching

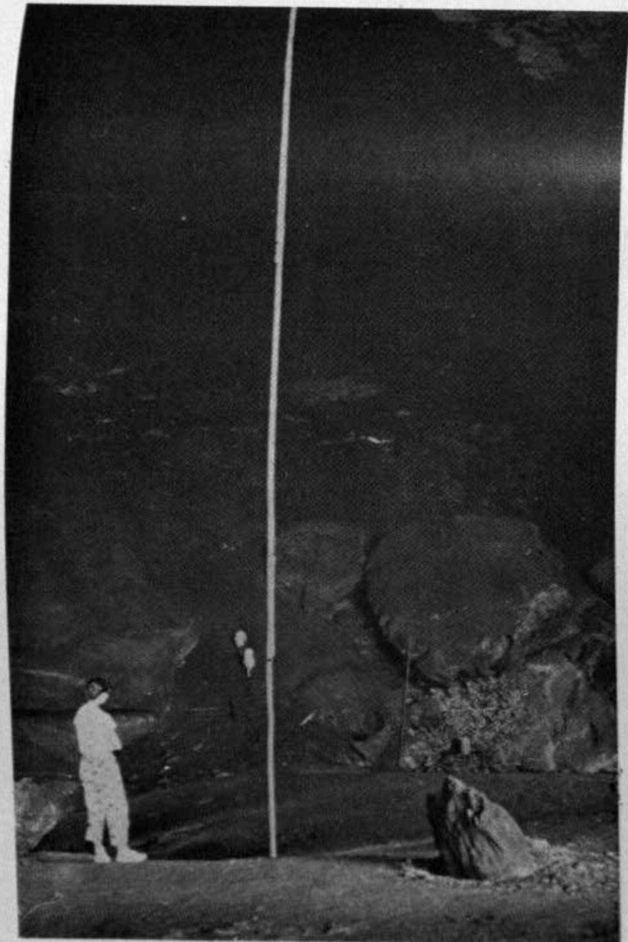


PLATE XXIXa. NIAH CAVE. Looking in from the mouth of Niah Great Cave, the two figures give an idea of the size of the cave. The pole in the foreground is made of iron wood posts pegged together and suspended from the roof, over 150 feet above; these poles are climbed by collectors of edible birds' nests (*see p.97*)

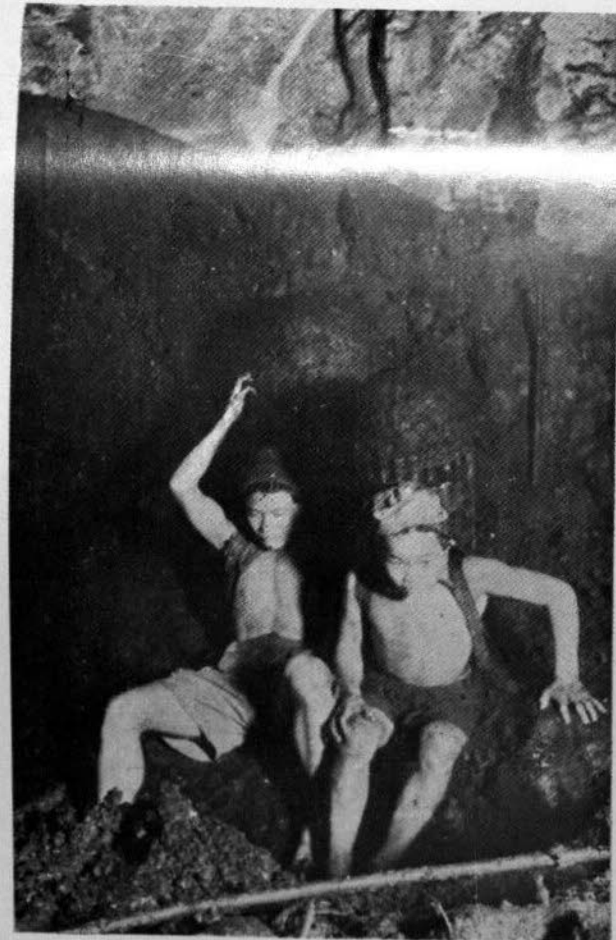
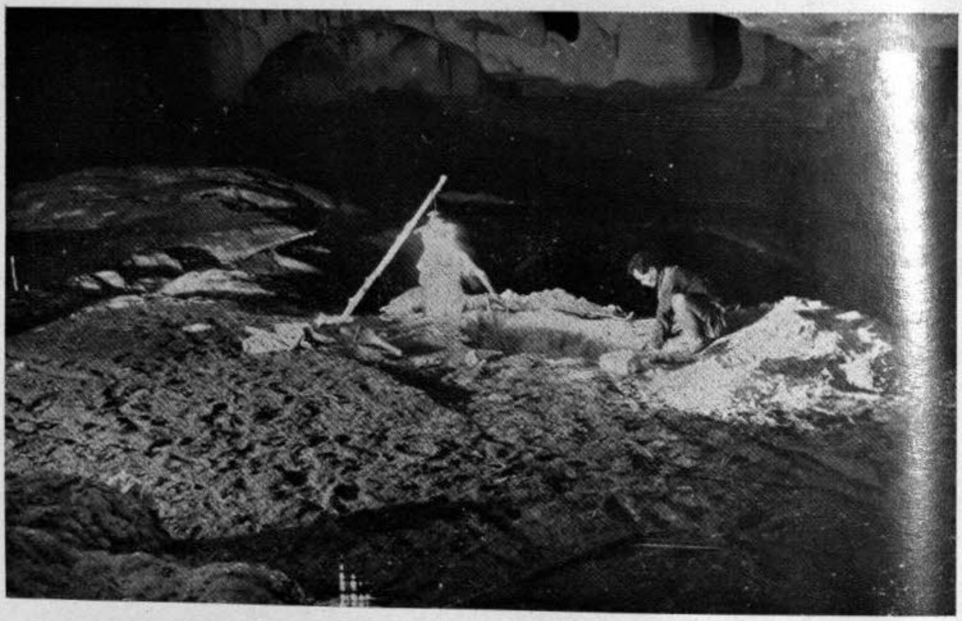


PLATE XXIXb. GUANO COLLECTORS IN NIAH CAVES

Photograph b by G. E. Wilford



a

b

PLATE XXX. PITTING PHOSPHATE DEPOSITS IN NIAH CAVES. The deposits consist of guano and 'fossil' guano (*see p.91*)

Photographs by G. E. Wilford

Detailed sampling of the main ridge would be warranted, however, on the evidence available, if the demand for dolomite persists and no other deposits are found in Sarawak.

Other limestone deposits. Other limestone deposits in the Suai-Baram area occur at Batu Tujoh, Batu Asi, and Batu Siman in the Upper Baram, near Long Lama, in the Siniai and Kitan tributaries of the Akah, and in the Tutoh River near the Ubong tributary. All these deposits are inaccessible and as there is no local demand are of no economic importance at present.

PHOSPHATE

The following account is taken from Wilford (1951), who investigated the deposits in 1951. His report has been brought up to date and some slight changes made.

Deposits of guano and rock phosphate, estimated to amount to 28,700 tons, occur in the Niah Caves at Bukit Subis in the Fourth Division of Sarawak. The caves are situated about 6 miles southwest of the village of Niah and 40 miles south-southwest of Miri (see fig. 10). This map of the caves was prepared from a chain and compass traverse made with the help of a surveyor from the Land and Survey Department, Miri.

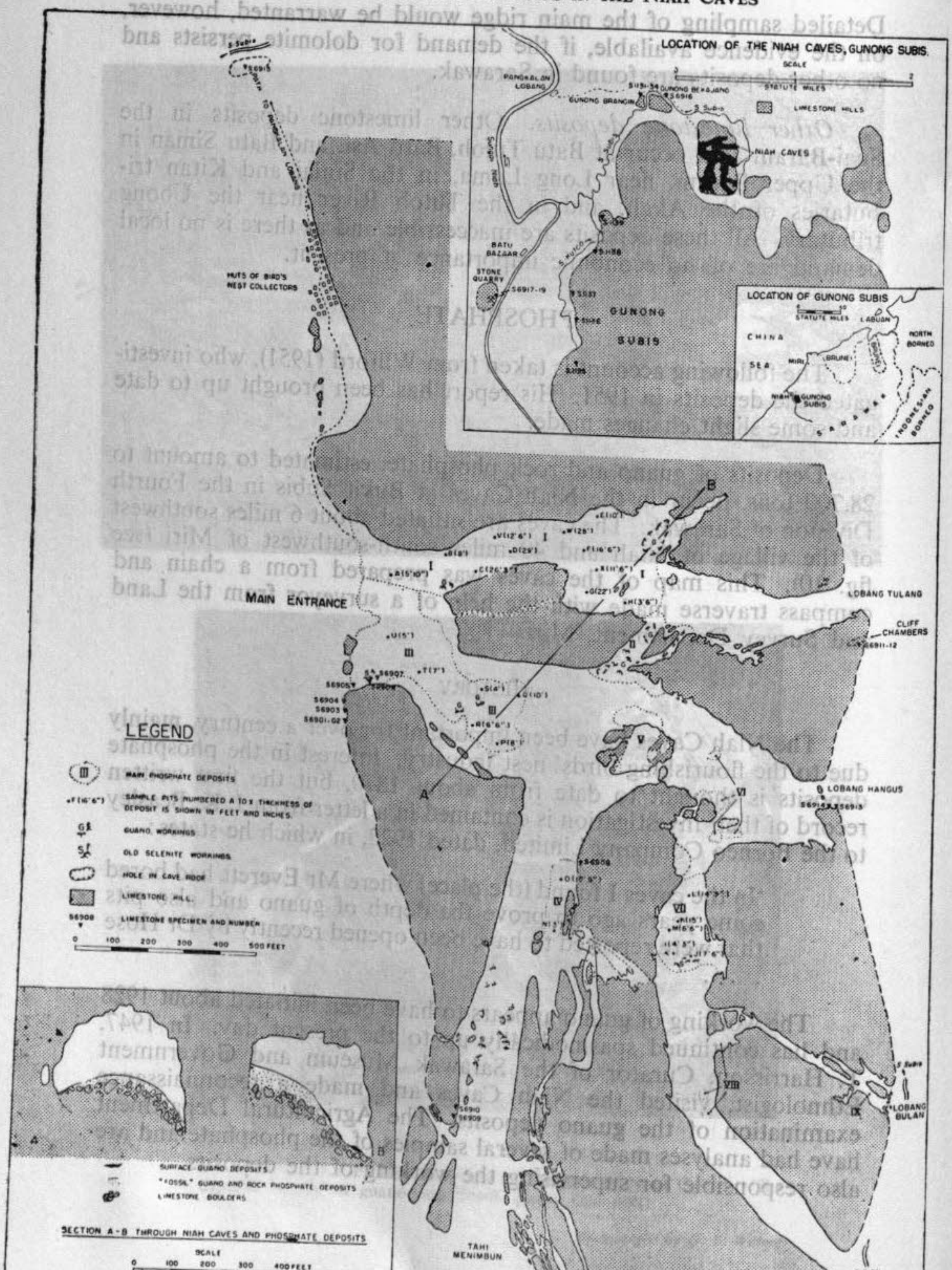
History

The Niah Caves have been important for over a century, mainly due to the flourishing birds' nest industry. Interest in the phosphate deposits is thought to date from about 1870, but the first written record of their investigation is contained in a letter from J. K. Beasley to the Borneo Company Limited, dated 1922, in which he states:

> 'In the caves I found [the place] where Mr Everett had bored some years ago to prove the depth of guano and also pits that were reported to have been opened recently by Dr Hose . . .'

The working of guano appears to have been initiated about 1928 and has continued spasmodically up to the present day. In 1947, T. Harrisson, Curator of the Sarawak Museum and Government Ethnologist, visited the Niah Caves and made a reconnaissance examination of the guano deposits. The Agricultural Department have had analyses made of several samples of the phosphate and are also responsible for supervising the working of the deposits.

FIGURE 10. PHOSPHATE DEPOSITS IN THE NIAH CAVES



SARAWAK GEOLOGICAL OFFICE PLAN 84A, BY G E WILFORD, 1951, ADDITIONS BY N S HAILE, 1960

Niah Caves

The Niah Caves consist of about 2 miles of explored passages covering an area of about 23 acres. Figure 10 is a plan of the caves and the main phosphate deposits. Entrances to the caves are located on the east, west, and south sides of Gunong Subis, and connections with the surface occur in at least five places in the roof of the caves. Small streams and water seepages from the roof are common in the caves.

The passages include two chief types:

(a) Narrow, high, rift-like passages, connected laterally by tube-like passages of small diameter. The rift-like passages are seen to follow the major direction of jointing and calcite veining in the limestone.

(b) Broad, long, passages, about 100 feet in height and 120 feet in width. These passages, where they coalesce, form large chambers as much as 300 feet in diameter and 200 feet in height. The floors are typically covered with large limestone boulders, mounds of clay, and the guano and rock phosphate deposits. Selenite occurs in both the clay and phosphate.

The Phosphate Deposits

The phosphate deposits originate chiefly from the accumulation of bat and swift droppings and the remains of insects which live in them. The deposits have taken thousands of years to form and, during this time, have reacted with the limestone and clay of the cave floors to form rock phosphate. The bulk of the phosphate is either dry or slightly damp; only in a few localities is it wet. Deposits averaging more than 6 inches in depth cover a total area of 150,000 square feet; thinner deposits have been omitted in calculating reserves. The areas containing the reserves are numbered I to IX in figure 10. The greatest depth of phosphate proved by pitting was 29 feet; the average depth attained in 24 pits was a little more than 11 feet (see pl. xxx). The deposits are of two types, as follows:

(a) *Guano.* This consists mainly of organic material; it is a soft, moist, dark-brown to black deposit which gives off ammonia, and has accumulated on steep (30°-50°) slopes in two chief areas in the caves: area II and the northeastern part of area I in figure 10. The generation of ammonia is probably due to the concentration of urine dropped from birds and bats which live in the roof of the cave above the deposits. The guano has the consistency of wet sawdust and consists of chitinous insect remains and a black clay-like substance. The fresh bird and bat droppings are clay-like and white but are soon digested by numerous insects, and it is the remains of these insects which give the guano its dark colour. Chemical analyses of this type of guano are given in table 12.

(b) *'Fossil' Guano and Rock Phosphate.* Deposits of this type consist mainly of aggregates of mineral particles. The material is soft, dry, powdery, reddish-brown (S1175), dark-brown (S1174) and cream (S1173), often containing nodules of the mineral newberyite (S1152) and buff nodular phosphate rock (S1148) at various depths.

The surface layers of these deposits were sampled to a depth of 1 foot with a view to determining if they differed considerably from the underlying material, or whether they were transitional to the guano which in part overlies them. This surface layer (S1169) is generally damp and dark brown or reddish brown, but analysis shows that chemically it is more closely allied to the underlying deposits than to the overlying guano.

A hard white rock phosphate, replacing limestone boulders or the limestone of the cave floor, was found in some pits. Where the phosphate deposits rest on a clay floor the clay is altered to rock phosphate (S1155, S1166 and S1167) to a depth of several feet, and fissures apparently due to contraction in the clay are filled with a breccia of soft powdery phosphate mineral (S1150, S1176). In pit X a layer of pale-blue material occurs interbedded with soft, cream and brown 'fossil' guano at a depth of 6 to 7 feet. The analyses of these different types are given in table 11.

FIGURE 11

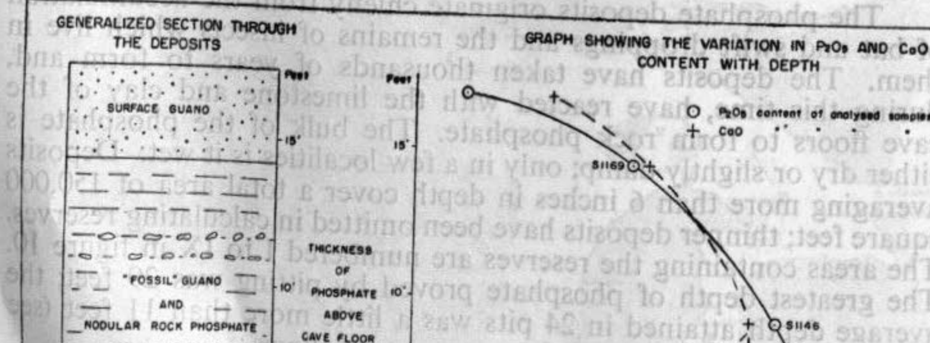


TABLE 11. ANALYSES OF 'FOSSIL' GUANO AND ROCK PHOSPHATE FROM NIAH CAVES
(weight percent)

Number and Description of Sample		Moisture (− 105°C)	Loss on Ignition (+ 105°C)	P_2O_5	CaO	N
S1146	Composite sample of "fossil" guano from nine pits	14·3	26·9	23·4	22·1	NOT DETERMINED
S1169	Composite sample from top of "fossil" guano deposit	19·5	39·9	16·2	17·8	
S1160	Red-brown powder from area frequented by bats	10·0	42·4	14·5	23·5	
S1173	Soft, cream powder	14·3	13·7	8·9	31·0	
S1174	Soft, dark-brown powder	17·0	30·9	20·5	21·2	
S1175	Soft, pale red-brown powder	15·1	23·0	18·8	28·1	
S1152	Nodules of newberyite[a]	5·7	27·5	42·6	7·1	
S1148	Hard nodular rock, buff-coloured	8·8	20·3	9·3	28·1	
S1155	Rock phosphate overlying clay	8·6	16·7	29·1	0·6	
S1150 S1176	Composite sample of rock phosphate breccia	8·2	7·7	19·3	0·4	
S1166 S1167	Composite sample of a banded clay altered to rock phosphate	7·2	7·1	10·0	0·9	
4.	Brown, rather moist coarse material, 2 feet below the surface of an old deposit in an area not now frequented by bats	36·53[b]	14·52[b]	14·23[b]	—	Nil[b]
		—	22·88[c]	22·42[c]	—	Nil[c]
5.	Light-grey material from an old deposit in an area now unfrequented by birds	34·75[b]	17·89[b]	9·21[b]	—	0·71[b]
		—	27·42[c]	14·11[c]	—	1·09[c]

[a] See pp.95-96 [b] Samples as received [c] Moisture-free sample

Analyses of samples 4 and 5 by T. A. Buckley, Senior Chemist, Agricultural Department, Federation of Malaya, for the Agricultural Department, Sarawak, and the remainder by W. A. Tooke, Chief Chemist, Geological Survey Department, Federation of Malaya

TABLE 12. ANALYSES OF RECENT SURFACE GUANO FROM NIAH CAVES

Description	*Total* P_2O_5	*Available* P_2O_5	*Water soluble* P_2O_5	N	K_2O	Na_2O	CaO	*Residue insoluble in acids*	*Moisture lost at 100°C*	*Loss on ignition*
1. Soft dark-brown, very damp and having a faint earthy smell	5·27[a]	4·47[a]	0·39[a]	7·33[a]	1·10[a]	0·33[a]	9·88[a]	1·25[a]	36·63[a]	71·50[b]
	6·77[b]	5·74[b]	0·50[b]	9·41[b]	1·41[b]	0·42[b]	12·68[b]	1·60[b]	18·65[b]	77·80[a]
2. An undisturbed deposit containing numerous chitinous insect remains	3·07[a]			4·21[a]					50·59[a]	34·49[a]
	6·21[c]			8·52[c]					Nil	71·83[c]
3. Dark-brown compact, moist subsurface material, similar to specimen 2 above but apparently containing less insect remains	4·68[a]	NOT DETERMINED		3·79[a]	NOT DETERMINED				41·97[a]	33·72[a]
	8·07[c]			6·53[c]					Nil	58·11[c]

a. Sample as received b. Air-dried sample c. Moisture-free sample

Analysis of sample 1 by the Imperial Institute, London, in 1932, and the remainder by T. A. Buckley, Senior Chemist, Agricultural Department, Federation of Malaya, for the Agricultural Department, Sarawak

Chemical Analysis and Mineralogy of the Deposits

The phosphate material varies considerably in chemical composition (see tables 11 and 12). Figure 11 shows the variation in P_2O_5 and CaO content in a typical section of the deposit; both the P_2O_5 and CaO contents increase with depth to near the base of the deposit, but nitrogen appears to be chiefly restricted to the surface guano deposits.

The guano of the Niah Caves has been examined, and the results have been compared with those of a mineralogical study of simliar guano deposits from Gunong Staat by the Mineral Resources Division of the Directorate of Colonial Geological Surveys. The conclusions reached are as follows:

(a) The surface guano consists chiefly of organic material.

(b) The 'fossil' guano consists chiefly of the calcium phosphates collophanite ($3CaO.P_2O_5.H_2O$), brushite ($CaHPO_4.2H_2O$), and monetite ($2CaO.P_2O_5H_2O$). Gypsum ($CaSO_4.2H_2O$) is common in the deposit. A layer of blue guano in pit X may consist in part of vivianite ($Fe_3P_2O_8.8H_2O$). Nodules of a hard crystalline rock (S1152), occurring in layers near the surface of the deposit, have been analysed and identified by the Geological Survey Department, Federation of Malaya as follows:

'The specimen S1152 shows crystals of platy habit associated with brown (organic) material and some pale yellowish-white material'.

'The microscopical section shows that the colourless transparent material is biaxial with a wide optic axial angle. Refractive index 1·525; sign indefinite. Chemical analysis: Mr Tooke carried out an approximate analysis of the crystals and obtained the following results.

	Percent
H_2O	31·2
P_2O_5	42·0
MgO	15·7
CaO	5·8
Al_2O_3	0·5
MnO	0·6
Insoluble (Organic)	2·7

'If it is assumed that the CaO is due to the admixture of a calcium phosphate the analysis after deduction of the calcium phosphate would be approximately:

	Percent
H_2O	37·3
P_2O_5	44·0
MgO	18·7

'The optical properties of the mineral suggest that it is newberyite (2 MgO. P_2O_5. $7H_2O$). The theoretical analysis of this (i.e. H_2O, 36·2%; P_2O_5, 40·8%; and MgO, 23%) bears reasonable relationship to the approximate analysis of the crystals from S1152'.

(c) The main minerals thought to be present at the base of the "fossil" guano deposits are the aluminium phosphate variscite ($AlPO_4$. $2H_2O$) where the bed rock is clay, and brushite ($CaPHO_4$. $2H_2O$) where the bed rock is limestone. Crystals of selenite are sometimes present in both the rock phosphate and underlying clay.

Quantity of Phosphate Deposits

Reserves of guano and rock phosphate are estimated to be at least 28,700 tons; 500 tons is surface guano containing about 5 percent N and 4·5 percent P_2O_5, and the remaining 28,200 tons 'fossil' guano and rock phosphate containing an average 23 percent P_2O_5. The nodular rocks and rock phosphate, which form less than 5 percent of the whole deposit, have P_2O_5 contents varying between 9·3 percent and 42·6 percent. Table 13 details the size of the deposits in the various cave passages.

Table 13. Reserves of Phosphate in the Niah Caves, Fourth Division, Sarawak

(long tons)

Area (See fig. 10)	*Surface Guano*	*'Fossil' Guano and Rock Phosphate*
I	320	24,300
II	144	180
III	Nil	1,645
IV	Nil	180
V	10	25
VI	5	10
VII	5	1,800
VIII	8	25
IX	8	35
Total	599	28,200

Phosphate Production

Guano production from the Niah Caves appears to have started about 1928. In 1930, the output began to increase, and a monopoly for collection and sale was granted to Kim Guan of Miri, who worked the deposits until 1944 when the Japanese took them over. The monopoly holder paid a royalty of $0.25 per pikul ($4.20 per long ton) on guano sold in Sarawak, and 10 percent ad valorem on exports. In 1945, the deposits were worked under contract for the British Military Administration, and in July 1947 the Sarawak Agricultural Department became responsible for supervision of the production and distribution. The recorded production is as follows:

	long tons
1946	201
1947	279
1948	420
1949	500
1950	643
1951	649
1952	696
1953	632
1954	620
1955	402
1956	385
1957	465
1958	153
1959	619
1960	Not recorded

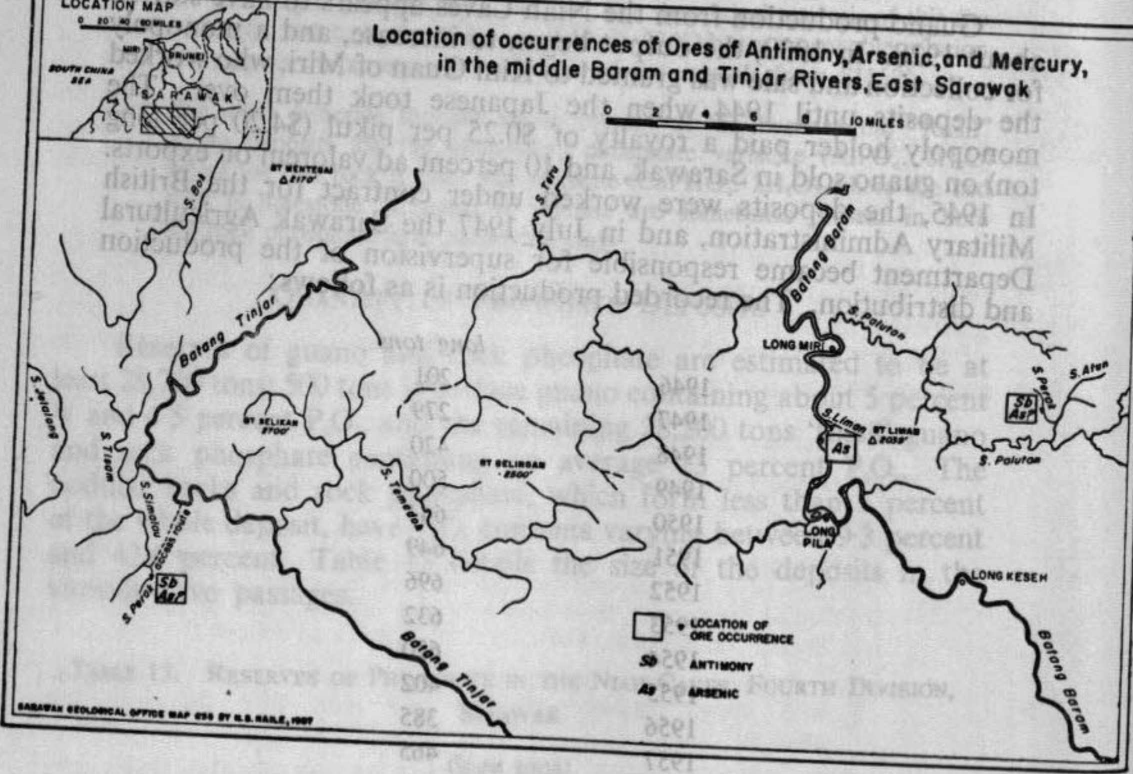
Transport

Guano is at present collected from the Niah Caves by hand labour and carried about 1½ miles to store at Pangkalan Lobang on the Niah River (pls. xxix, xxxia). From there it is taken by launch to Miri and other coastal towns in Sarawak. The terrain between the caves and the godown is for the most part low-lying, flat, and swampy. Planks of bilian raised on stilts 2 to 3 feet above ground level provide a path over the more swampy parts, and planks and ladders are used in rocky areas adjacent to limestone hills. The Subis, a small stream, is normally too shallow and too full of obstacles for the guano to be transported by boat.

ANTIMONY

Antimony ore (stibnite) is known to occur at two places in the Middle Baram and Tinjar, namely the Palutan and Tisam Valleys.

FIGURE 12



At both places the stibnite occurs as disseminations in shale and sandstone of the Setap Shale Formation (Miocene), and no igneous rocks are known to occur nearby.

Palutan Antimony

History. Robert Burns was interested in the Baram antimony and obtained a permit from the Sultan of Brunei to work the ore in 1843. This brought him into conflict with the first White Rajah (see Harrisson, *Sarawak Museum Journal*, V. 3, pp.463-494, 1951). The antimony deposits he was interested in were almost certainly those in the Palutan here described, although their location is not given by Burns in any surviving record.

Soon after the Baram District was ceded to Rajah Brooke, prospecting began for antimony and other minerals in the area. In 1884 the Resident, C. C. de Crespigny, was prospecting for cinnabar, and later in the year a Mr H. T. Burls was engaged by the Rajah, and started, in June, for the Palutan, indicating that the antimony there was already known, or at least rumoured to occur (*Sarawak Gazette* report). However, nothing more is heard of Mr Burls in the Gazette reports, and from a reference in Jennings (1888) it is clear that he died soon afterwards.

In 1885 antimony was reported in the Palutan by Malay prospectors working for the Rajah's government, and in 1886 C. W. Daubeny, Officer-in-Charge of Baram, visited the Palutan antimony. In 1888 a Mr Hay, probably working for the Borneo Company Limited, visited the Palutan antimony. In the 1890's the Borneo Minerals Company, probably a subsidiary company to the Borneo Company, was formed to prospect for antimony in the Baram District, and made some excavations of the Palutan occurrence. In 1907 T. S. King, Assistant Resident, examined the occurrence, apparently on instructions from the Rajah. The Japanese are said to have visited the occurrence during the occupation. The writer briefly examined the occurrence in October 1957.

Description. The antimony ore in the Palutan Valley is in a branch of a northern tributary called Sungai Atun, which is about 20 miles from the mouth of the Palutan by the stream route, or about 9 miles west of the Palutan mouth in a straight line (see fig. 13). The place is in Sungai Perak, the west branch of the Atun. Acess is by *prau* as far as the mouth of the Atun, which takes 2 days; only *praus* can be used on the Palutan. From the Atun mouth to the antimony occurrence is about an hour's walk up the stream, cutting across small steep hills. The area is formed of shale and sandstone of the Miocene Setap Shale Formation.

All that could be seen of the antimony occurrence, when examined on 10 October 1957, was a small flooded pit about 20 feet across and 6 feet deep, on the southwest side of Sungai Perak. The sides of the pit are formed of hard slaty shale (S4502), some (S4500) with veinlets of a soft white mineral, probably a clay mineral of the kaolinite group (see above, p.67). No ore was seen in the pit; a few small pieces of stibnite, the largest 9 inches across, were found about the pit and in the stream bed (S4501). One piece (S4504) contains a small grain of red mineral, probably realgar. The stibnite pieces contain ?kaolinite and very little crystalline quartz, but no vein quartz was seen in the country rock, although pebbles of vein quartz are quite common in the streams throughout the Palutan Valley. Panning in the stream showed a very low proportion of heavy minerals, and only a few grains of stibnite. Panning above the stream showed no stibnite or other ore minerals.

Conclusion. There are no indications of any antimony deposit approaching workable size in the Palutan. Access to the occurrence in the Atun valley of the Palutan is difficult, and to be workable an antimony deposit there would have to be large and rich.

Tisam Antimony

History. The Tisam antimony was probably known at least as early as 1884. Charles Hose (1929, p.45) quotes the following extract from the diary of the Resident, C. C. de Crespigny, for the year, which probably refers to the deposit:

> *April 26.* Jappar returned from Long Salai . . . Jappar found stibnite in the Tinjar, and brought specimens of the rock . . .
>
> *May 14.* Cinnabar is said certainly to exist up the Dapoi, a branch of the Tinjar, but very far up . . .

Helms, Manager of the Borneo Company, visited the occurrence in 1890. From 1891 to 1896 H. H. Everett and A. H. Everett examined the Tisam occurrence for the Central Borneo Company. The Japanese are reported to have examined the occurrence during the occupation in the 1940's. In 1956 Abdul Rajak of Marudi pitted the occurrence. The writer visited the occurrence on 16 October 1957.

Description. The antimony ore in the Tisam Valley (a tributary of the Tinjar) occurs in a headwater branch of Sungai Semalau, itself a southern tributary of the Tisam (see fig. 13). The stream in which the antimony occurs is called Sungai Perak. The nearest point on the Tinjar River—Long Nanga—can easily be reached by outboard motor *praus* when the river is high, but when the water is low the journey involves dragging the boat over shallows. Access from the Tinjar is by walking about 6 to 8 miles along a path which mostly follows the crest of a steep ridge about 800 feet high. The area is built of shale and sandstone of the Miocene Setap Shale Formation.

Three places where the ore occurs, within a radius of about 200 yards, were briefly examined by the writer on 16 October 1957. At each place the stibnite is associated with a soft white mineral, probably hydromica, and no vein quartz was seen:

No. 1 place consists of a number of irregular pits and trenches, on the bank of the stream, about 30 feet above stream level. Sandstone and shale are exposed in the pits, and the spoil consists of mudstone, brecciated shale (with a soft white mineral, possibly hydromica), and rare pieces of stibnite a few inches across. No ore was seen *in situ*.

No. 2 place is a vertical outcrop about 20 feet above river level and 100 yards downstream from No. 1. It consists of hard blue-grey sandstone dipping 75° towards N 140°E, and grey shale with plant remains. Thin veinlets of stibnite, about one-tenth of an inch thick, occur on some slickensided surfaces in sandstone, and there are also traces of a red mineral: realgar, and/or cinnabar (S4512). A soft white mineral occurs with the stibnite.

No. 3 place is an old pit at the base of a 20-foot sandstone cliff about 100 feet above the stream, and 150 yards upstream from No. 2 place. The pit is full of water, but signs of ore (stibnite) outcropping on the far side of the pit can be seen. About 8 yards below this pit is a new excavation (made during prospecting by Abdul Rajak in 1956) which shows vertical sandstone striking N 150°E. Pieces of stibnite up to 4 inches across lying about near this excavation are probably from the old pit.

Conclusion. No indications of a workable deposit of antimony were seen in the Tisam Valley. The area is difficult of access; it is doubtful whether even a large rich deposit of antimony could be profitably worked there.

ARSENIC AND ALLEGED MERCURY

Arsenic ore (realgar and ?arsenopyrite) occurs by the Baram River, west of Bukit Liman, and traces have been found in the Kejin tributary of the Baram, to the north. The first reference to the minerals near Bukit Liman is to an investigation of the occurrence by Everett in 1893 and 1894. E. Banks, the Curator of the Sarawak Museum, examined the occurrence in the 1930's. Former investigators recorded mercury ore also (see *Ann. Rept.*, 1957, para. 113), but this was not confirmed in samples of mineralized rock examined by the Mineral Resources Division. Small amounts of cinnabar, may, however, occur there. The deposit is not economically workable.

Irregular veinlets containing realgar occur in hard, grey non-calcareous shale and sandstone of the Setap Shale Formation in the right-hand (east) bank of the Baram about half a mile upstream from the mouth of Sungai Liman, west of Bukit Liman. The outcrop is about 50 yards long by 12 yards high; the sediments dip 75° towards N 290° E. The minerals occurring in the veinlets include realgar, dolomite (S4505, S4506), rare quartz (S4508) and ?kaolinite. The veins of dolomite are much more common than those of quartz; both minerals occur together and crystal faces are well-developed, indicating their formation under conditions of tension. They were probably formed at a shallow depth at the same time as the arsenic ore. The ore occurs as small disseminations, containing pure realgar, up to three-quarters of an inch thick; the presence of cinnabar has not been confirmed chemically. Some mineralized zones 6 inches thick can be seen and traced laterally for 10 feet or so, but mostly the mineralization is irregular. Slickensides occur, some of which are mineralized.

About 100 yards north of this exposure, in the same bank, is another smaller exposure with traces of red minerals, and above this, some 40 feet above the river, is a prospecting adit about 8 yards long, probably one driven by Everett. No mineralization was seen in the adit. Rocks in Sungai Liman up to the foot of Bukit Liman were examined. No trace of metallic mineralization was seen, although quartz veins are common in the sandstones. Panning showed no heavy minerals.

History of Prospecting for Antimony, Arsenic, and Mercury 1884-1907

A considerable amount of prospecting was done in the middle Baram and Tinjar Valleys from 1884 onwards. Records of this work were published in the *Sarawak Gazette*, from which the following extracts have been made:

1 MAY 1884, p.44. Baram Official Journal

Thursday, February 8, 1884. Jappar arrived. He found no cinnabar up-river although he searched well in the vicinity indicated by me and went up a good way further . . .

Thursday, February 28, 1884. . . . To Pangeran Nianai at Tutong begging him to be kind enough to let me know whereabouts in Baram it was that he and his men found cinnabar, and should it be in sufficient quantity to enable a company to work it the government will pay him $300 . . .

C. C. de Crespigny
Resident, 1st Class, 3rd Division

2 JUNE 1884 1, p.85, Baram Official Journal

Saturday, March 1, 1884. . . . Jappar returned from Long Salai . . . Jappar found in Simabah and brought specimens of rock, one of which is similar to silver ore rock supplied from Kuching, the other is faced with minute crystals which have the appearance as to form, of diamonds. But my glass is not a very powerful one.

Sunday, March 9, 1884. From H. H. the Rajah dated December 3rd 1883, saying that a paddle-wheel vessel is about to be built for the Baram trade. That he is in treaty with a geologist to come out to explore the new concession for minerals . . .

C. C. de Crespigny
Resident, 1st Class, 3rd Division

1 JULY 1884. Baram Official Journal

Tuesday, May 27th—S.S. *Lorna Doone* arrived, passengers Mr Daubeny, returned from leave, and Mr Burls who has been engaged by H. H. the Rajah to prospect for minerals between Kidurong point and Baram.

Tuesday, June 3rd—Mr Burls started on his expedition to Palutan in the *Bujang Baram*, which will convey him as far as the mouth of Tutu . . .

C. C. de Crespigny

1 AUGUST 1885. An account of His Highness visit to the outstations (Communicated).

Baram. April . . . Discoveries of antimony have been made up the river, which, if worked, will afford a steady and valuable export.

2 NOVEMBER 1885, p.108. Baram (Monthly Report)

. . . Tuanku Mudah brought also three mineral specimens, one of which, apparently cinnabar, was found in the river Mabalon by one Haji Abdullah—the other two specimens, one of which is, I think, antimony, were found by the Tuanku himself in Palutan; he described the river as full of minerals . . .

C. W. Daubeny
Officer-in-Charge

2 AUGUST 1886, p.124. Baram (Monthly Report)

.... Bulu Obong's corpse still lying in the house, I was informed that the people would be more ready to open up any discussion when the burial had been completed, probably in three or four days, so I accordingly started for Palutan on the morning of the 6th reaching the spot where the antimony was discovered on the morning of the 9th it being necessary to pole almost all the way up the Palutan on account of the continuous rapids. I returned the same day, sleeping that night at Long Asun (Akam Laut's house) and reaching Long Salai at midday on the 10th . . .

C. W. Daubeny
Officer-in-Charge

1 OCTOBER 1888, p.130. Baram (Monthly Report—August)

Mr Hay has visited during the month both the Antimony district in the Palutan and the oil wells at Miri . . .

1 DECEMBER 1890, p.160. Baram (Monthly Report—September)

On the 9th Mr Helms arrived having come *via* Limbang and Tatau and started again for the Tinjar . . . to prospect for antimony in that river. On the 26th I received a letter from him in which he stated that he had visited the antimony in the Tisam, a tributary of the Tinjar, and that he finds it to be a valuable lode of sulphide of antimony which he thinks can be worked at a small cost.

1 MAY 1891, p.65—Our Notes

At a general meeting of the General Borneo Company held in London on the 23rd February, the following allusion was made by the Chairman to the Baram concession:

'As to the Baram district property, you see what we state in the report as to the discovery of antimony and quicksilver. We are unable at present to tell you what the extent of the ground is in which this antimony has been discovered . . . Mr H. H. Everett—not our Mr Everett, the Manager . . . — a well-known man— has gone out there, and he has to report to us to what the extent of the ground is. The specimens of antimony sent home give the following results: one specimen was analysed by Sir Charles Cameron, who says:— ". . . The mineral contains 80 percent sulphide of antimony. The other analysis is from a Mr. Clude . . . and the result is that the metallic antimony is 68.57 percent. That is most excellent and wonderful proportion of antimony. If we have a large field of that, it represents an enormous value. I believe that the report says that the antimony would be worth £25 per ton; but I consider that is under the mark. I think that such antimony as that would be worth £30 a ton'.

1 JULY 1891—Baram (Monthly Report)

April. The *Sri Putri* arrived on the 25th with Mr Everett who came to examine the Antimony in Tisam. Mr Everett asked me to accompany him and we left Claudetown on the 26th arriving at the mouth of the Tisam on the 28th; we walked over to the Batang Taha on the 29th and saw the Antimony which appears to me to be in very small quantity. The distance from the Tinjar river is about 6 miles.

I returned on the 30th Mr Everett going further up the Tinjar to prospect for minerals.

May. On the 1st I left Long Tisam in the *Sri Putri* and arrived at the Fort the same day. Mr Everett started in a boat for the headwaters of the Tinjar river to prospect for minerals . . . Mr Everett arrived on the 10th, he reports a find of cinnabar in the Tinjar river near the mouth of Dapoi, also traces of gold and antimony in this district.

2 NOVEMBER 1891, p.1—Baram (Monthly Report—September)

. . . On the 20th Mr Everett chartered the launch to take him to Long Lunai. On the 14th the Resident and Mr A. H. Everett left for the Tinjar, the former to take out six weeks leave in search of natural history specimens, the latter to prospect for minerals . . .

E. A. W. Cox
Assistant Resident

1 FEBRUARY 1892, p.34—Baram (Monthly Report)

October 1891. On the 12th the S. L. *Cocoanut* made another trip to Long Nahassah. Mr Everett arrived the same night from Tinjar . . . The *Sri Putri* arrived and returned the next day from Labuan, with Mr Everett who has brought coolies to open the antimony in Tisam.

November (1891). Mr Everett returned from Tisam on the 2nd he reports that the antimony is like that of Lalang in the Rejang, he has left instructions with his coolies to turn out as much as they can at once, and Mr Lopez is left with them to look after the work.

December (1891). Mr Lopez who was employed by the Central Borneo Company died of 'beri beri' . . .

Charles Hose
Resident

1 JUNE 1892, p.111—Baram (Monthly Report)

April. Mr Everett the Manager of the Central Borneo Company arrived on the 13th in the *Sri Putri,* he examined the work done in Tisam and reports that the prospects of antimony appear more favourable, than when he last visited the Tisam . . .

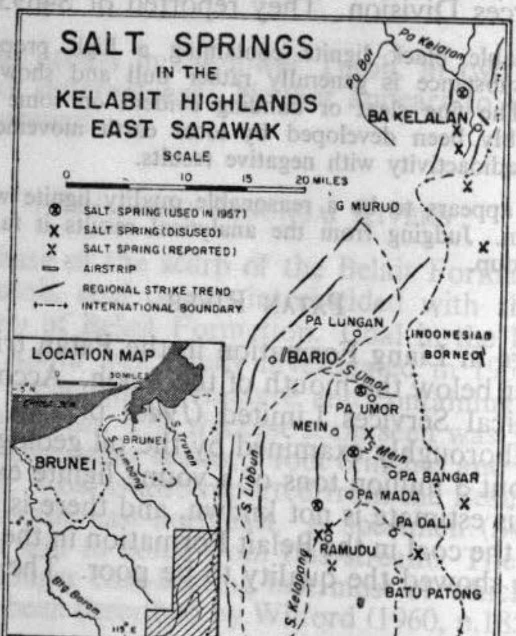
Charles Hose
Resident

1 NOVEMBER 1892, p.202—Baram (Monthly Report)

September (1891). She (the *Sri Putri*) came in again on the 25th Mr A. H. Everett was on board and he proceeded upriver to Tisam the same day in order to inspect the antimony worked there . . . Mr Everett was favourably impressed by the appearance of the Antimony. The Company are, however, going to stop work until after the North East Monsoon is over . . .

G. Pratt Barlow
Acting Resident

FIGURE 13



tree-trunk about 2 feet in diameter and as much as 8 feet long. When empty, a well may take up to 24 hours to be replenished, and so the seepage of salt water is slow, except at a few of the larger wells such as the one at Pa Mein where water flows in accompanied by bubbles of inflammable gas. Most of the wells are either in swampy alluvium, or on the banks of small rivers. Many springs in swampy areas are characterized by a surround of boggy ground criss-crossed by the tracks of the many animals which have come to drink the salt water.

The method of working at the best known and most frequently used springs, those at Pa Mein, was described in 1909 (*Sarawak Gazette*, 1 March 1909) as follows:

'... We then passed on to the factory, which was a bamboo house of about 60 feet long by 30 feet wide. Here a strange sight presented itself to our eyes, so accustomed to Bornean scenery and industry. The whole of the centre of the hut was taken up by rows and rows of furnaces running lengthwise and being fed at either end. On these furnaces were numbers of large iron cooking pots of about 4 feet in diameter, each furnace accommodating about 10 pots, which are filled with water from the spring and in various stages of boiling. The method employed is to keep on filling the pots with the water as it is boiled away, during which process the salt coagulates around the sides of the pot whence it is scooped out and poured into bamboo or bark vessels, which are then thrust into the furnace and kept there until the bamboo, or bark has been burnt off, by which time the salt has solidified and comes out in long cylinders or whatever the shape of the vessel in which it was burnt, four fillings of one of these large cooking pots producing one cylinder of salt about 8 inches long and 3 inches diameter.'

In 1957, almost 50 years after this account was written, identical methods are still used by the Kelabits. However, the Muruts at Ba Kelalan prefer to allow the salt to solidify on the sides of the iron pans, when they chip it off and crush it into powder with wooden hammers, rather than to dry the salt in bamboo.

Quantity of salt produced. As the springs are only worked on demand and by groups of people from different villages it is difficult to estimate the quantities of salt produced. Annual salt production at Pa Mein, the largest spring in the area, is estimated to be of the order of 3 tons and the total for the whole area to be about 5 tons. The annual production in the neighbouring parts of Indonesian Borneo is probably also several tons. The daily production at Pa Mein, when the springs were not diluted by rain water and when 24 iron pans were used night and day, was estimated by G. E. Wilford to be about 100 pounds. There is little doubt that production could be increased considerably if the demand rises but this seems unlikely unless supplies of imported salt are cut off. Improvements could be made in the quality of the salt produced if precautions were taken to prevent contamination of the salt water by ground water and animals; e.g. by the construction of concrete-lined and covered wells.

Quality of salt and chemical analysis. Most salt produced is a grey, buff or off-white colour; the main impurities responsible for the colour are vegetable remains in the salt water, burnt bamboo bark, and rust from iron pans. There is conspicuous variation in taste between the salt from different springs which is readily recognized by the inhabitants and is probably due to the variation in chemical content. A sample of salt was sent to the Mineral Resources Division of the Directorate of Overseas Geological Surveys for analysis with special reference to the iodine content, the presence of trace elements, and the possible presence of radioactive material. The Agricultural Department, Sarawak, also enquired about the desirability of using the salt for livestock. The results of the analysis are given below:

'The sample, which was damp, coarsely crystalline and grey in colour was submitted to chemical analysis with the following results:

(a) Moisture evolved at 300°C: 12.69 percent

Composition of the sample dried at 300°C

		Percent
Sodium	Na	37·61
Potassium	K	0·26
Calcium	Ca	0·90
Strontium	Sr	0·19
Barium	Ba	0·10
Magnesium	Mg	not detected (less than 0·01)
Chlorine	Cl	57·28
Iodine	I	0·052
Bromine	Br	not detected (less than 0·05)
Fluorine	F	0·013
Sulphate	SO_4	not detected (less than 0·10)
Borate	B_4O_7	1·77
Carbonate	CO_3	1·49
Phosphate	PO_4	trace, less than 0·01
Silica	SiO_2	0·12
Iron and aluminium oxides	Fe_2O_3 and Al_2O_3	0·055
		99·84

These results can be recalculated to give the following hypothetical compounds present in the sample dried at 300°C.

	Percent
NaCl	94·08
KCl	0·50
$Na_2B_4O_7$	2·30
$CaCO_3$	2·25
$SrCO_3$	0·32
$BaCO_3$	0·14
KI	0·068
SiO_2	0·12
$Al_2O_3 + Fe_2O_3$	0·06
	99·83

'The sample did not exhibit any detectable radioactivity. Nitrate, nitrites and ammonium salts were not detected. A considerable amount of water-insoluble matter was present, amounting to 2·68 percent of the dried salt. This is included in the above analysis and consists mainly of carbonate of calcium, strontium and barium.' It was commented that 'The presence of an appreciable quantity of borate is noteworthy. This is probably present in the original sample as borax, $Na_2B_4O_7.10H_2O$ (2·30 percent $Na_2B_4O_7$ is equivalent to4·36 percent $Na_2B_4O_7.10H_2O$), the water content of which would be evolved at the temperature necessary to remove the free moisture from the salt.

'It should be comparatively simple to avoid gross contamination by water insoluble carbonates by allowing the relatively concentrated brine to settle and decanting off the supernatant liquor from the residue. This is obviously a desirable step to introduce. In addition to an appreciable amount of borate the salt contains traces of iodine and fluorine, all of which might be more difficult to remove.

'In view of the suggested use for feeding livestock, the Commonwealth Bureau of Animal Nutrition, at the Rowett Research Institute, Backburn, Aberdeenshire, was asked for advice on the use of a salt of this composition and the following extract from their letter deals with this question.

"Apart from the strontium and barium which can be removed by solution and decantation, the only other elements which might be deleterious are fluorine and borate. In neither case, however, do we consider that these are present in amounts likely to be harmful to livestock. I enclose a short note on borate.

"We are of opinion, therefore, that the salt can safely be recommended for livestock.

BORON

"The quantities of borate likely to be consumed in this salt do not appear likely to be harmful. According to Sollmann's Manual of Pharmacology harmful effects may follow single doses of 2 to 5 g boric acid or borax in man and from 15 to 30 g may be fatal. The salt is readily absorbed and is excreted by the kidneys, and there is no immediate effect of taking up to 0·5 g daily, though if it is continued at this rate for a long time there may be some digestive disturbance. It seems likely that such large amounts could be obtained from the salt analysed. Owen (1944) has given dairy cows from 16 to 20 g borax daily for 40 days without ill effect; the milk contained up to 3 p.p.m. of boron, but this amount can be considered safe. Hove *et al.* (1939) found that hens could take 0·5 percent boric acid in the ration, and they transferred some of it to the eggs, but apparently not a harmful amount.

REFERENCES

OWEN, E. C. (1955): *Jour. Diary Res.*, 13, 243 "HOVE E., ELVEHJEM, C. A., AND E. B. HART (1939: *Amer. Jour. Physiol.*, 127.689".

'It should be emphasized that these comments apply only to material represented by this sample. Samples obtained from other springs or by varying the details of the evaporation process may vary considerably in composition due to the different solubilities of the constituent salts, and further samples of salt obtained under controlled conditions may need to be analysed if the intention is to develop the use of the salt on a significant scale. A much purer product could, of course, be obtained if the salt were recovered by less primitive means.

SUMMARY

'This sample is essentially impure sodium chloride containing a considerable amount of moisture, some soluble matter, some sodium borate and small amounts of iodine and fluorine.

'Providing care is taken to exclude insoluble matter, a material of this composition should have no harmful effect on livestock.'

Origin of the Salt. The salt springs occur in a belt parallel to the regional strike of the Eocene to Miocene rocks which build the area (see fig. 13), and the salt water is probably derived from salt-bearing beds in these rocks. Jordi (unpublished report of Sarawak Oilfields Limited) records near Ba Kelalan a rhythmic alternation of sandstone, siltstone and shale which contains concretions of pyrite and gypsum and which he considers to be probably the mother formation of the salt springs in that area.

The springs. The salt springs are described below in order from north to south under the names of the villages near which they occur. Their location is shown on figure 13.

(a) *Ba Kelalan.* Around this village there are three groups of wells. The largest group consists of three wood-lined walls about 10 feet apart in a small valley 500 yards west of the Kelalan River about 3 miles north of Ba Kelalan. The walls are about 2 feet in diameter and 6 feet deep and take about 24 hours to refill when used. These are the largest wells in the Kelalan area and were being worked in 1957 when 12 iron pans were in use.

which the gas escapes—presumably the snakes died of suffocation while exploring a possible ready-built home. Though the gas is non-inflammable there is a distinct smell of petroleum nearby; no oil film was present on the water, however. The low dip of the sediments nearby (18 degrees northeast) indicates the gas might be escaping from an anticlinal zone of normally steeply folded sediments.

There are two small seepages in marshy ground in raised alluvium bordering the Puak River about 3 miles southeast of Long Banga. The largest is situated in alluvium at the foot of a small boulder-strewn river terrace about 500 yards east of where the Senah tributary flows into the Puak. A small stream flows into the seepage which is much visited by animals. Part of a wooden wall and flat stones occur in the nearby marshy ground and are said to be the remains of a well used over 50 years ago by Kelabits. The second seepage is in flat ground about 300 yards south of where the Senah stream flows into the Puak. There is a slight flow of water and gas bubbles periodically rise to the surface of the pool and marshy ground which surrounds the seepage.

A disused spring, well-known to the Kelabits of Ramudu, is said to occur in the headwaters of the Balong River about half a day's walk south of Long Banga, not far from the Kalimantan border. A salt seepage is reported about 1 hour's walk up the Metapa, a small tributary of the Baram 6 miles east of Lio Matu.

(i) *Lio Matu.* Several springs or seepages are said to occur in the Selungo and its tributaries, north of Lio Matu. One spring in the Sa'it tributary is said to have a white rock formation nearby—probably calcareous tufa.

ROADSTONE, GRAVEL, AND SAND

Due to the sparse population and lack of roads and industry, there is at present little demand for constructional materials within the area, and so no detailed survey has been made, except of the Batu Gading limestone.

The limestone in the area would make good roadstone, and most would be suitable for concrete aggregate for general purposes, being clean, hard and compact. Some of the sandstone of all formations (except the Liang and younger) is hard enough to be used for local roads. Gravel and sand occur in the middle and upper reaches of the rivers.

Raised beaches along the coast southwest of Kuala Likau are composed of white sand some of which is probably of glass-sand quality. Equivalent terraces south of Tanjong Kidurong just south of the area contain large amounts of high-quality glass-sand (Kirk, 1957, p.155-157).

OIL

There are possibilities of oil accumulations in the area, especially near the coast, though prospecting and drilling by Sarawak Shell Oilfields Limited over several decades have failed to discover any in commercial quantity. Favourable factors are the great thickness of marine sediments and general absence of igneous intrusions; unfavourable factors are the intense folding over much of the area, and the absence of the known oil-producing formations.

The producing formations of the Miri and Seria oilfields to the north are the Seria and Miri Formations whose stratigraphic position is between the Belait and Liang Formations. They are not present in the Suai-Baram area.

Suai Area

The Suai area is one of very complex stratigraphy and structure. Some of the sandstones and biohermal limestone within the Setap Shale, Sibuti, and Tangap Formations are potential reservoir rocks. Sandstones of the Nyalau Formation are mostly rather impermeable, but locally they are slightly coarser and more permeable. The sandstones of the Belait Formation are also potential reservoir rocks, but they occur in synclinal basins which have few or no promising structures. Stratigraphic traps, formed by wedging out of sandstones into shale, may be present.

Deep drilling in the Suai area has been confined to six wells at Kuala Suai and along the coast to the southwest, two wells on the Subis Anticline southwest of the Subis Limestone outcrop, and one well at Selungun on the coast near Kuala Nyalau (see table 2). The Suai wells proved small quantities of oil, and gas was encountered under high pressure in Suai Well 3. The Suai wells encountered only small quantities of gas, and the Selungun well found neither oil nor gas.

Among the promising structures in this area is the ulu Suai Dome, which has not yet been tested by drilling.

Middle Baram Area

In the middle Baram area, only a few of the sandstones of the Setap Shale Formation are sufficiently thick or permeable to be possible reservoir rocks. Although no oil indications have been found in the middle Baram, the discovery at wells Engkabang 1 and 2 (in the lower Baram just north of the area) of small quantities of oil in a sandstone within the Setap Shale Formation indicates, however, that the formation must be considered a potential oil producer in this area. The most favourable part appears to be the northern part of the anticlinal structures in the Tinjar and Bakong tributaries.

Over the rest of the middle Baram the tightly folded Setap Shale, Kelalan, and Mulu Formations are comparatively unfavourable. The predominantly sandy Temala Member of the Kelalan Formation, exposed in the gentle Temala Anticline, is surrounded by more tightly folded, younger, Setap Shale Formation. This implies that disharmonic folding, and probably décollement, has taken place, and that relatively gentle anticlines of Kelalan and Melinau Limestone Formation may be concealed beneath tightly folded Setap Shale Formation. Such structures could form oil traps, although there is so far no indication of Eocene oil in north-west Borneo. The sandstones of the Belait Formation, as in the Suai area, form synclinal basins, in which structural traps are not likely to occur.

KELABIT HIGHLANDS

The gentler folding, and more frequent, thick, permeable sandstones, are favourable indications. However, no oil seeps are known, and the few hot salt springs, some with gas, do not appear to be associated with oil accumulations. The Kelabit Highlands are so remote and inaccessible that only a very good prospect would be worth drilling there.

Chapter X

CEMENT-MAKING POSSIBILITIES IN THE KUALA BARAM AREA, NORTH SARAWAK

INTRODUCTION

Large deposits of limestone suitable for cement-making occur in north Sarawak. The most accessible deposits are in the Batu Gading area, north of Long Lama, where more than 21,000,000 long tons of limestone has been measured. Shale suitable for blending with the limestone overlies the limestone at Batu Gading. Suitable sites for a cement plant exist in the Kuala Baram area (Baram river estuary), north of the Suai-Baram area, where natural gas from Seria Oilfield is available and where the river mud would provide an alternative source of clay material.

PREVIOUS INVESTIGATIONS

A first reconnaissance investigation of Batu Gading and a preliminary estimate of limestone reserves were made by G. E. Wilford in 1955 (GSKL 017/40 and *Ann. Rept.,* 1955, pp.54-57). Possible uses were outlined by F. W. Roe in the same year (GSKL 017/41) and later he gave a fuller account (*Ann. Rept.,* 1957, pp.61-66). More detailed surveys were made by N. S. Haile in 1956, 1957, and 1958 (GSKL 017/54 and *Ann. Rept.,* 1956, pp.30-38); laboratory investigations were done by the Mineral Resources Division of the Overseas Geological Surveys in 1957-59, and some of these results were published (*Ann. Rept.,* 1958, pp.42-48). In this account, previous work is compiled, and some hitherto unpublished laboratory and field results are included.

LIMESTONE

Limestone occurrences in Sarawak have been described by G. E. Wilford (*Ann. Rept.,* 1955, pp.41-161). The following occurrences in north Sarawak are listed in approximate order of their potential importance as sources of raw material for cement making. They are Batu Gading, Subis, Melinau, Beluru, Keramit, Long Lobang, and upper Baram. The first three of these are sufficiently large and accessible to merit more detailed description.

Batu Gading Area

Reserves

Estimated limestone reserves in the Batu Gading area exceed 21,000,000 long tons. Details are shown in table 15, page 132. (Tables are assembled at the end of this chapter). For Batu Gading and Bukit Besungai (north), these estimates are based on a levelled traverse round the hill made by a survey party from the Department of Lands and Surveys, Miri. The other hills were surveyed by tape-and-compass and heights of rock faces estimated visually or measured by aneroid. The surface of the rock is extremely irregular; pinnacles, gorges, and caves are numerous. The estimate of the average thickness is thus only approximate. The location of the deposits is shown on figures 15-18. The writer is indebted to Mr. R. Morris, Quarry Manager, Sebuyau, for estimates of the depth to which the limestone could be economically worked under overburden at Batu Gading and Bukit Besungai (north).

Batu Gading. Limestone forms cliffs along the south side of a ridge some 240 feet high at Batu Gading. The stone consists of a bed about 100 feet thick dipping about 10° towards north-northwest (see pl. xxviiia). The top of the limestone averages about 70 feet above swamp level in the western part of the ridge; above the limestone, the hill is composed of shale and rises steeply (about 1 in1);

FIGURE 14

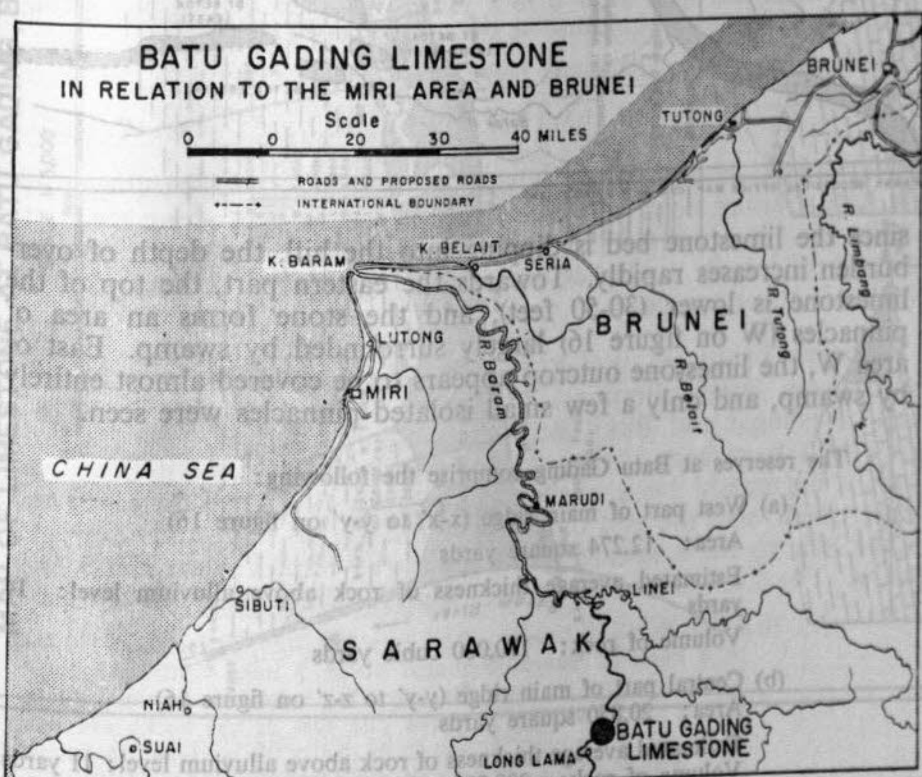
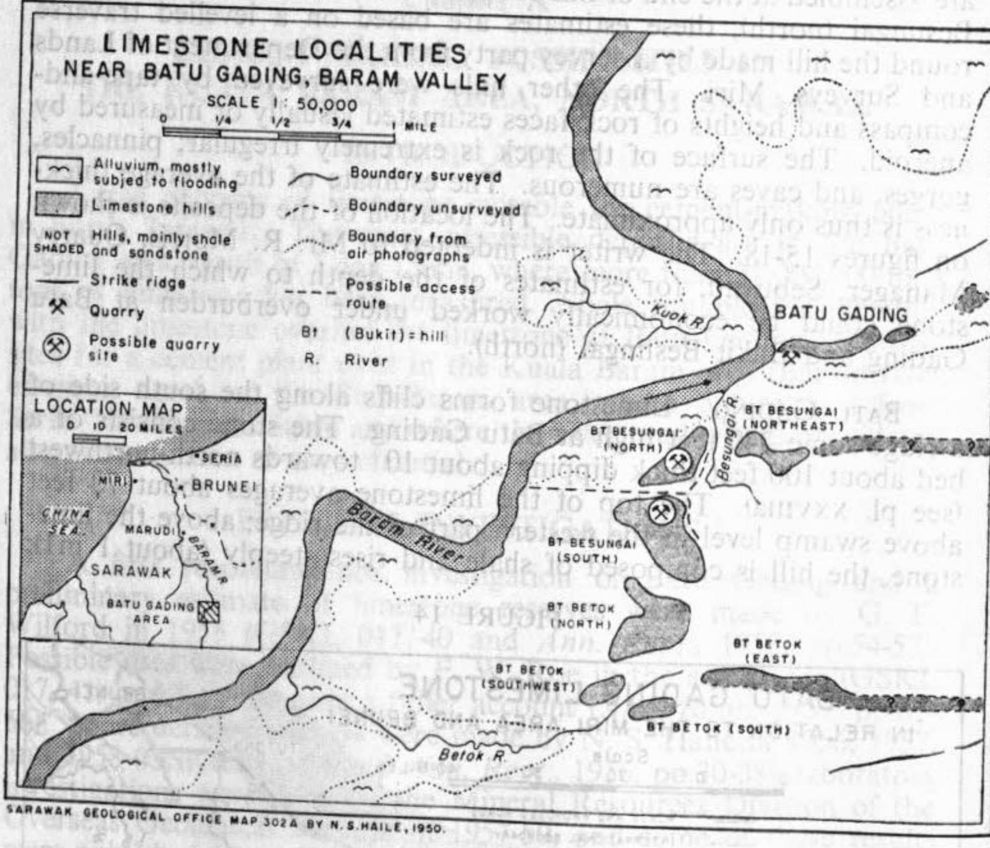


FIGURE 15



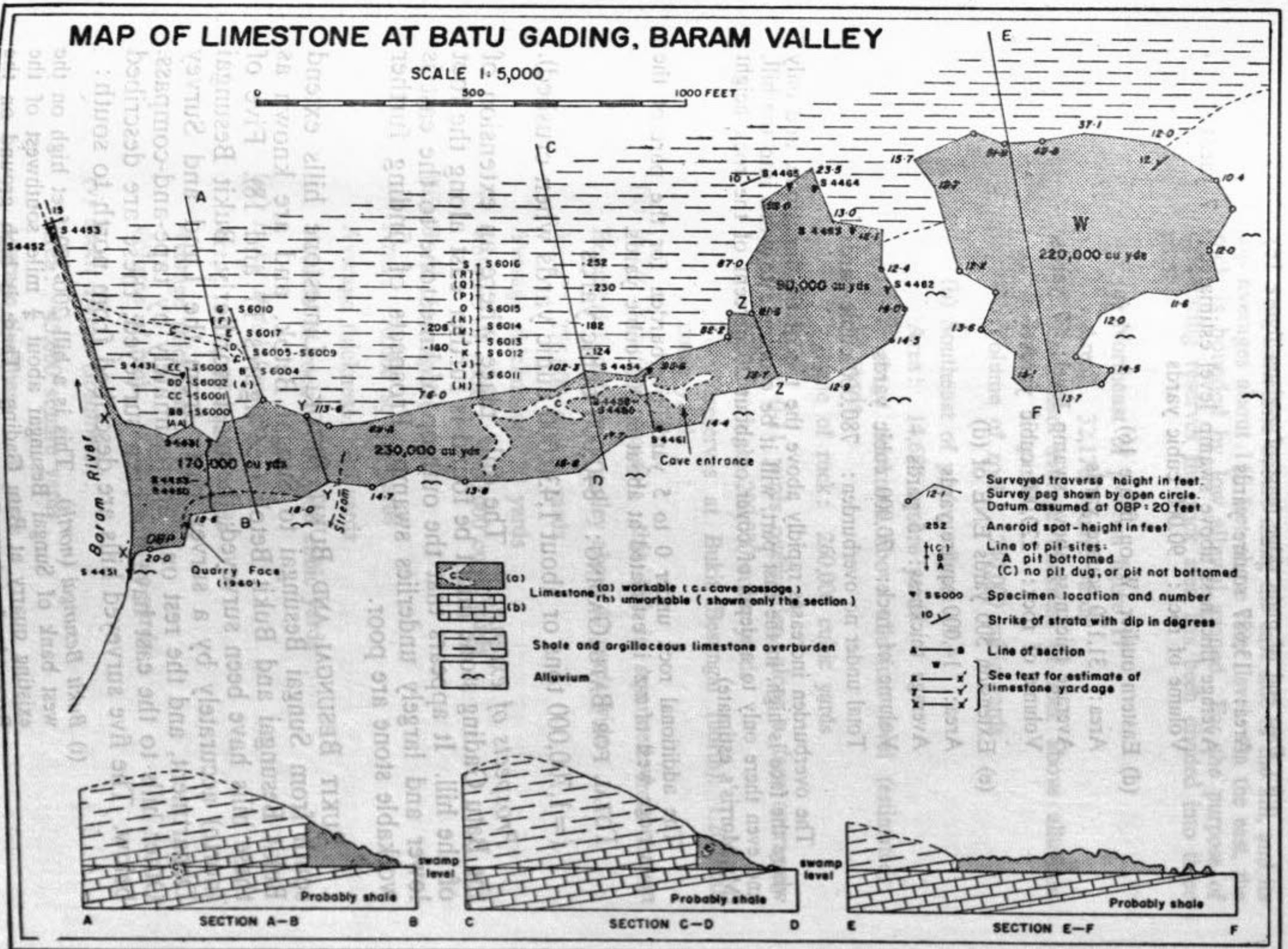
since the limestone bed is dipping into the hill, the depth of overburden increases rapidly. Towards the eastern part, the top of the limestone is lower (30-50 feet), and the stone forms an area of pinnacles (W on figure 16) largely surrounded by swamp. East of area W, the limestone outcrop appears to be covered almost entirely by swamp, and only a few small isolated pinnacles were seen.

The reserves at Batu Gading comprise the following:

(a) West part of main ridge (x-x′ to y-y′ on figure 16)
Area: 12,274 square yards
Estimated average thickness of rock above alluvium level: 14 yards
Volume of rock: 170,000 cubic yards

(b) Central part of main ridge (y-y′ to z-z′ on figure 16)
Area: 20,850 square yards
Estimated average thickness of rock above alluvium level: 11 yards
Volume of rock: 230,000 cubic yards

FIGURE 16



SARAWAK GEOLOGICAL OFFICE PLAN 1609 BY N.S. HAILE, 1960 BASED ON LANDS AND SURVEYS 2 CHAINS SHEET D8121-1-II

(c) East end of main ridge (east of z-z′ on figure 16)
Area: 13,687 square yards
Average thickness above swamp level estimated: 7 yards
Volume of rock: 90,000 cubic yards

(d) Eastern outlier (W on figure 16)
Area: 31,130 square yards
Average thickness above swamp level: 7 yards
Volume of rock: 220,000 cubic yards

(e) Extension 500 yards ENE of (d)
Area: 14,000 square yards
Average thickness: 5 yards
Volume of rock: 70,000 cubic yards
Total under no overburden: 780,000 cubic yards

The overburden increases rapidly above the top of the limestone, and only where the face is high, in the east part, will it be economic to work into the hill, and even there only to a depth of cover of about 20 percent of the rock height (Mr Morris's estimate).

The additional rock under 0 to 5 yards overburden for the part of the main ridge west of z-z′ is estimated at about 60,000 cubic yards.

TOTAL FOR BATU GADING: 840,000 cubic yards
(=1,700,000 tons or about 1,430,000 cubic yards when crushed).

Prospects of extension. The only place where an extension of the Batu Gading stone might be found is further east along the foot of the hill. It appears that the outcrop of limestone to the east is lower and largely underlies swamp. Prospects of finding further workable stone are poor.

BUKIT BESUNGAI AND BUKIT BETOK. Limestone hills extend south from Sungai Besungai to Sungai Betok, and are known as Bukit Besungai and Bukit Betok (see figures 17 and 18). Five of these hills have been surveyed; the most northerly, Bukit Besungai (north) accurately by a survey party from the Land and Survey Department, and the rest only approximately by tape-and-compass. Other hills to the east have not been surveyed; these are described below. The five surveyed hills are described from north to south:

(i) *Bukit Besungai* (*north*). This is a hill 200-300 feet high on the west bank of Sungai Besungai about ¾ mile southwest of the existing quarry at Batu Gading. There is high ground on the Baram banks about 700 yards due east of the rocks where a wharf might be built; access from this point is along the Sungai Alat Valley and appears to be quite easy.

The limestone occurs along the east side of the hill, and its top averages about 140 feet above river level. On the east, the rock is bounded by low alluvial ground. For the purpose of calculating reserves the rock area has been divided into three parts:

(a) Northeast of p-p′ on figure 17

Area: 32,176 square yards

Estimated average thickness of rock above alluvium level: 23 yards

Volume of rock: 740,000 cubic yards

(b) Southeast of p-p′ on figure 17

Area: 14,694 square yards

Average thickness above alluvium level (estimated): 18 yards

Volume of rock: 260,000 cubic yards

(c) Under 0-11 yards overburden, along a face averaging 140 feet high; 200,000 cubic yards

Total reserves at Bukit Besungai (north): 1,200,000 cubic yards

(ii) *Bukit Besungai (south)*: this hill is separated from Bukit Besungai (north) by a valley about 40 yards wide

Area: 276,000 square yards

Average thickness: 20 yards

Volume of rock: 5,500,000 cubic yards

(iii) *Bukit Besungai (east)*:

Area: 70,000 square yards

Average thickness: 10 yards

Volume of rock: 700,000 cubic yards

(iv) *Bukit Betok (north)*:

Area: 100,000 square yards

Average thickness: 17 yards

Volume of rock: 1,700,000 cubic yards

(v) *Bukit Betok (southwest)*:

Area: 45,000 square yards

Average thickness: 8 yards

Average thickness: 3·3 yards

Volume of rock: 360,000 cubic yards

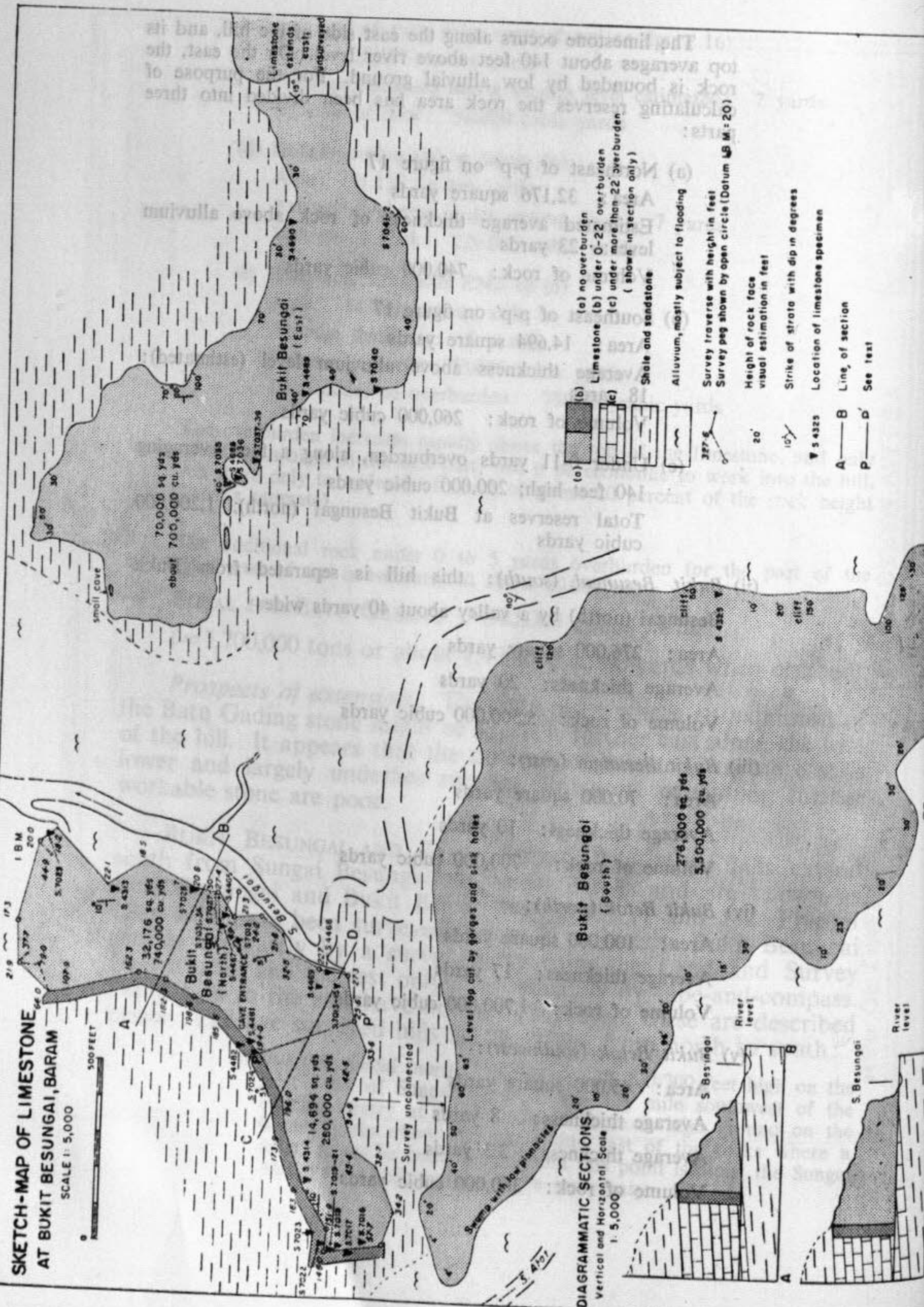

SKETCH-MAP OF LIMESTONE AT BUKIT BESUNGAI, BARAM
SCALE 1: 5,000
500 FEET
Bukit Besungai (East)
70,000 sq yds about 700,000 cu yds
Limestone extends east; unsurveyed
small cave
Bukit Besungai (North)
32,176 sq yds 740,000 cu yds
14,694 sq yds 260,000 cu yds
CAVE ENTRANCE
Survey unconnected
Bukit Besungai (South)
276,000 sq yds 5,500,000 cu yds
Level top cut by gorges and sink holes
Swamp with low pinnacles
S. Besungai
DIAGRAMMATIC SECTIONS
Vertical and Horizontal Scale 1: 5,000
River level
(a) no overburden
Limestone (b) under 0-22' overburden
(c) under more than 22' overburden (shown in section only)
Shale and sandstone
Alluvium, mostly subject to flooding
Survey traverse with height in feet
Survey peg shown by open circle (Datum I.B.M. = 20)
Height of rock face visual estimation in feet
Strike of strata with dip in degrees
Location of limestone specimen
Line of section
See text

FIGURE 17

(vi) *Bukit Betok (south)*:

Area: 30,000 square yards
Average thickness: 3·3 yards
Volume of rock: 100,000 cubic yards

TOTAL FOR BUKIT BESUNGAI AND BUKIT BETOK: 9,360,000 cubic yards

(=19,000,000 long tons or about 16,000,000 cubic yards when crushed).

NORTHEAST OF BUKIT BETOK. Limestone extends northeast of Bukit Betok as far as the Ulu Temala, where many caves are reported. Traverses have confirmed that large limestone hills occur northeast of Bukit Betok for at least a mile, and probably contain several more million cubic yards of limestone.

Quality of the Limestone

Analyses of limestone from Batu Gading (30 specimens), Bukit Besungai (17 specimens), and Bukit Betok (4 specimens) are shown in table 16A (p.133). Analyses made of 8 specimens previously, and expressed in a slightly different way, are shown in table 16B (p.134).

The Mineral Resources Division commented:

> The Batu Gading limestone is of excellent quality, and shows very little variation in composition. The Bukit Besungai limestone is variable in quality and the very sandy portions have a high silica modulus. In practice, there would appear to be no need to reject the siliceous material, as its effect would be balanced by the very low silica modulus of the limestone. The Bukit Betok limestone represents another reserve of good quality . . . The percentages of phosphate in composite samples of the limestone . . . were found to be too small to be of any significance in cement manufacture.

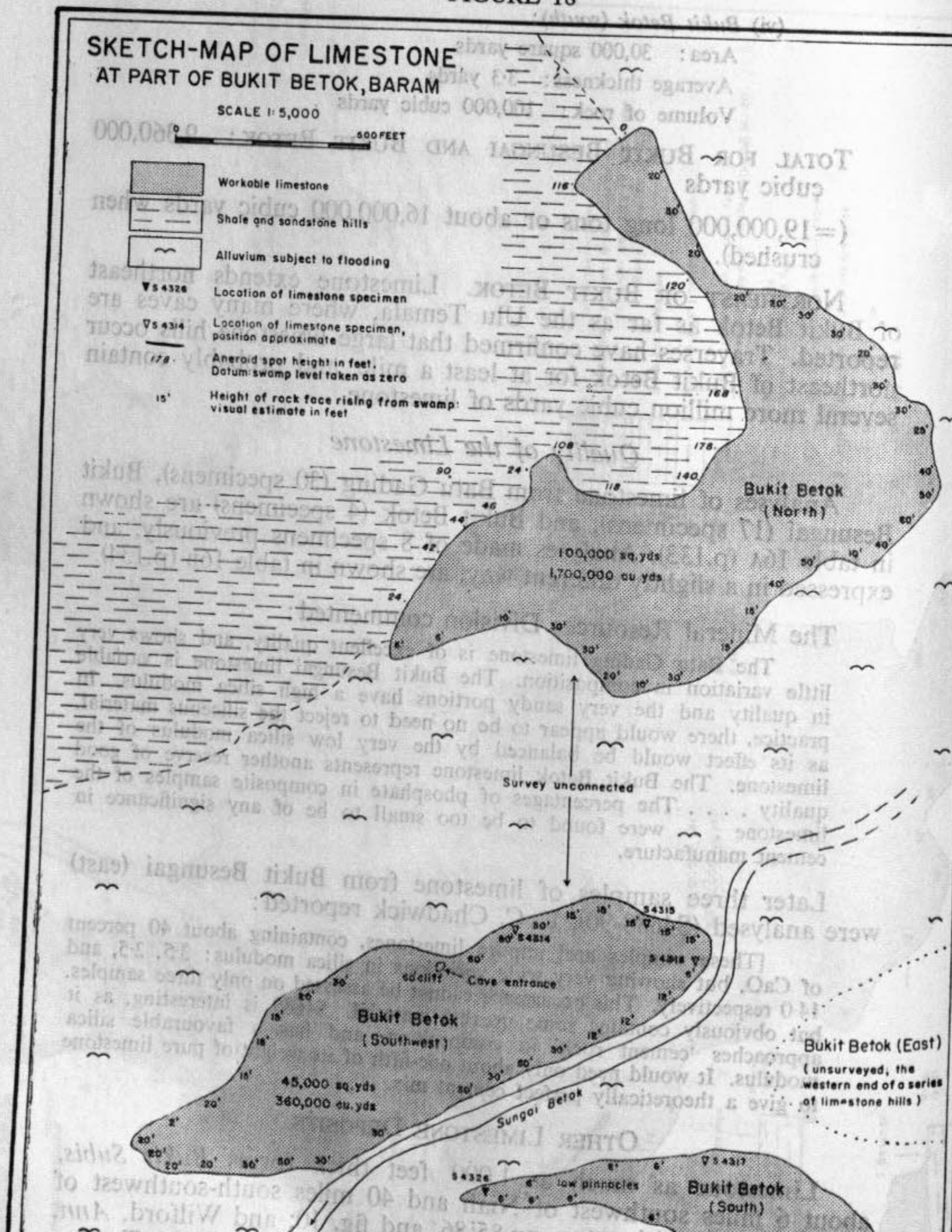
Later three samples of limestone from Bukit Besungai (east) were analysed (S4688-90); L. C. Chadwick reported:

> [These samples are] impure limestones, containing about 40 percent of CaO, but showing very wide variations in silica modulus: 3·5, 2·5, and 14·0 respectively. This occurrence cannot be assessed on only three samples, but obviously contains some useable material. S4689 is interesting, as it approaches 'cement rock' in composition, and has a favourable silica modulus. It would need only about one-fifth of its weight of pure limestone to give a theoretically perfect cement mix.

OTHER LIMESTONE DEPOSITS

Limestone as much as 1,000 feet thick forms *Bukit Subis*, about 6 miles southwest of Niah and 40 miles south-southwest of Miri, Fourth Division (see pp.85-86, and fig. 10; and Wilford, *Ann. Rept.*, 1955). This is the Subis Limestone Member of the Tangap

FIGURE 18


SKETCH-MAP OF LIMESTONE
AT PART OF BUKIT BETOK, BARAM
SCALE 1: 5,000
0
500 FEET
Workable limestone
Shale and sandstone hills
Alluvium subject to flooding
S 4326
Location of limestone specimen
S 4314
Location of limestone specimen, position approximate
178
Aneroid spot height in feet. Datum: swamp level taken as zero
15'
Height of rock face rising from swamp: visual estimate in feet
Bukit Betok
(North)
100,000 sq. yds
1,700,000 cu. yds
Survey unconnected
Bukit Betok
(Southwest)
45,000 sq. yds
360,000 cu. yds
Cave entrance
60' cliff
Sungai Betok
Bukit Betok (East)
(unsurveyed, the western end of a series of limestone hills)
low pinnacles
Bukit Betok
(South)
30,000 sq yds
100,000 cu. yds
25' cliff
BASED ON APPROXIMATE TAPE AND COMPASS TRAVERSE BY TEO CHAI KHOI
SARAWAK GEOLOGICAL OFFICE PLAN 182 BY N. S. HAILE, 1956

Formation (Miocene). The limestone is hard and pure. Analyses of of samples from the northern part of Bukit Subis are given in table 9, and show that the rock is chemically suitable for cement manufacture. Limestone which forms small outcrops near the west bank of the Niah River has been quarried on a small scale by Sarawak Oilfields Limited in 1940 and intermittently by a Chinese concern since 1955.

Although the reserves at Bukit Subis are virtually unlimited, and the limestone appears to be pure, it would be expensive to transport, as the Niah River is small and has a shallow bar at its mouth.

Small outcrops of Miocene limestone near *Beluru*, 20 miles southwest of Marudi, Fourth Division, are shown in figure 9. According to reports by Shell geologists the rock is sandy and grades laterally into calcareous sandstone. The limestone bed forms the core of a discontinuous ridge between Sungai Trus and Sungai Lapan. The bed is about 70 feet thick and is hard and pure, and in many places crowded with Foraminifera. The largest outcrops are east and northeast of Beluru. The deposit is less accessible than Batu Gading and so has not been re-investigated.

Large reserves of limestone occur in the *Melinau Valley* between the Tutoh River in Fourth Division and the Limbang River in Fifth Division. The limestone, which lies mostly north of the Suai-Baram area, covers about 150 square miles, and has a maximum thickness of at least 6,000 feet. It is in general pure, but parts are dolomitic. Access is more difficult than Batu Gading, as the Tutoh River is not navigable to barges as far as the limestone. A more detailed description is given by Wilford (*Mem.* 10, 1961).

Other occurrences of limestone in north Sarawak, which are not considered important as potential sources of raw material for a cement industry under present conditions, are listed here for the sake of completeness.

Beraya, about 20 miles southwest of Miri, and Keramit, in the Limbang Valley are described by Wilford (*Mem.* 10, 1961); Long Lobang in the Tinjar lies in the area described by Kirk (*Mem.* 8, 1957).

ARGILLACEOUS COMPONENT

Two possible sources of suitable argillaceous material for the cement have been found. The first is shale, mudstone, and clayey limestone overlying the main limestone at Batu Gading, the second is river mud in the Baram Estuary.

Shale, Mudstone, and Argillaceous Limestone Overlying the Main Limestone at Batu Gading

Analyses of 32 samples of argillaceous rock overlying the main limestone at Batu Gading show that the overburden there is very well suited for use with the underlying limestone for cement-making (see table 17, p.135). The ratio of Al_2O_3 to Fe_2O_3 in the argillaceous samples was found to be about 3½ to 1—a normal ratio—which shows that there is no danger of excessive Fe_2O_3. The percentage of phosphate in composite samples was found to be too small to be significant.

L. C. Chadwick wrote in regard to the argillaceous rocks:

> These samples differ very widely in composition, ranging from calcareous-argillaceous material containing over 30 percent of CaO to straightforward shale containing less than 1 percent of CaO. No sample approaches 'cement rock', and it seems fairly safe to conclude that the overburden as a whole is well over on the argillaceous side. This was tentatively put forward in a previous report, when only three samples (S4432, S4438 and S4439) had been taken [see *Ann. Rept.*, 1958, p.44].
>
> The silica modulus is very satisfactory, ranging in most cases from 2·3 to 2·7, and the overburden as a whole appears to be very well suited for use with the underlying limestone for cement-making. Variations in the composition of the overburden, which merely mean variations in CaO_3 content, would be correct simply by adding more or less of the very pure underlying limestone.

The overburden at Bukit Besungai, assessed from only two analyses, appears to be similar to the Batu Gading material, and thus also suitable for blending with limestone for cement-making.

Mud and Clay from the Baram and Belait Estuary Areas

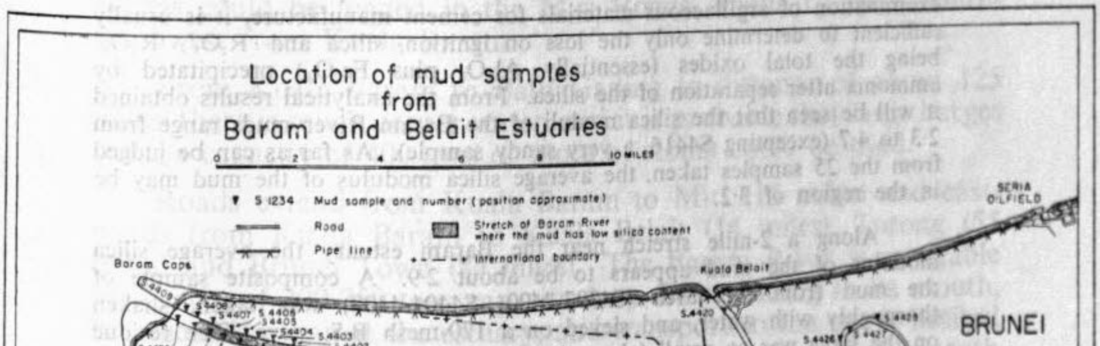
If the cement plant were built in the coastal area, a local source of argillaceous material would be advantageous, as it would save transport costs from Batu Gading. The only suitable material found so far is river mud in the Baram, some of which, however, is very promising and could be cheaply worked.

Samples from the Baram and Belait Estuary area were collected and sent for analysis as follows: 25 from the Baram Estuary; 9 from the Belait Estuary; one each from Badas on the Belait River, and from the Lumut Hills east of Seria. The results of the analyses given in table 18 (p.136), and the locations are shown on figure 19.

It was concluded that some of the Baram River muds are probably suitable for use as the argillaceous component in cement-making. The samples from the Belait were rather more siliceous, and, as the silica is in a very fine state and little could be removed by sedimentation, it was concluded that the Belait mud is unsuitable. The sample from Badas is a river mud that Brunei Shell Petroleum Company use as a base for drilling mud; that from Lumut Hills is a young Tertiary clay used by the company for dyke construction. Both showed a high silica modulus, and are thus probably not very suitable, although no firm conclusions can be drawn from single samples.

The samples from the Baram and Belait were collected from near the banks of the rivers, as no equipment for sampling the deeper parts was available. By sounding across the Baram about a quarter of a mile upstream from the ferry, it was established that mud extends across the river bed, except for one sounding which may have been on a sandy bank. The depths of water at half tide ranged from 14 feet near the banks to 29 feet in the central channel.

FIGURE 19



Detailed comments on the muds, by the Mineral Resources Division, are given below:

General Considerations: From the point of view of kiln operation in the manufacture of Portland cement, an important requirement is that the composition of the mix must be such as to yield a satisfactory clinker at a reasonable working temperature. The clinkering temperature depends on a number of factors, of which the most important is the silica modulus $\frac{\%SiO_2}{(\%Al_2O_3 + \%Fe_2O_3)}$. If this is too high, clinkering may not be attained at a reasonable working temperature, and if too low, the mix may tend to fuse instead of clinkering.

The silica modulus of grey Portland cement usually lies between 2·4 and 2·7 and seldom exceeds 3·0. In practice, it is sometimes necessary to make some adjustment to the silica modulus, or to the iron modulus ($\%Al_2O_3/\%Fe_2O_3$) either by adding small amounts of such materials as silica, sand, waste bauxite, or iron ore, or by removing excess silica by sedimentation or sieving.

Baram River Muds, S4395-4419: In the preliminary chemical examination of argillaceous materials for cement manufacture, it is usually sufficient to determine only the loss on ignition, silica and 'R_2O_3', 'R_2O_3' being the total oxides (essentially Al_2O_3 plus Fe_2O_3) precipitated by ammonia after separation of the silica. From the analytical results obtained it will be seen that the silica moduli of the Baram River muds range from 2·3 to 4·7 (excepting S4416, a very sandy sample). As far as can be judged from the 25 samples taken, the average silica modulus of the mud may be in the region of 3·2.

Along a 2-mile stretch near the Baram estuary the average silica modulus of the mud appears to be about 2·9. A composite sample of the mud from this area (S4397-4400; S4404-4408) was taken, shaken thoroughly with water, and sieved on a 170-mesh B.S. sieve. The residue on the sieve was so small (about 1 percent) that its removal would have a negligible effect on the silica modulus. The fineness of the mud in these lower reaches is, of course, not surprising, and would indeed be a great advantage in cement-making as no grinding would be necessary.

Belait River Muds: A washing test was done on a composite sample of the Belait River muds (S4420-4428). Before washing this sample had a silica modulus of 4·5; the residue on the 170-mesh sieve was approximately 20 percent, and the material passing the sieve was found to have a silica modulus of 3·8. It seems evident, therefore, that the mud in this river is very low in clay content, and is unsuitable for cement manufacture.

OTHER RAW MATERIALS

Gypsum. No commercial deposits of gypsum are known in Borneo, and gypsum required in the manufacture of Portland Cement would have to be imported.

Bauxite. Low-silica bauxite is produced in west Sarawak, and so is readily available if required to reduce the silica modulus.

CEMENT CALCULATIONS

Cement clinker compositions were worked out by the Mineral Resources Division from the average composition of the Batu Gading limestone and of (a) the Batu Gading overburden, (b) the Baram River mud (all samples), (c) the Baram River mud (from the 2-mile low-silica stretch only). The results are shown in table 19 and 29 (pp.137 and 138).

SITE FOR A CEMENT PLANT AND TRANSPORT

The most suitable sites for a cement plant in north Sarawak and Brunei are on the coast where the cement is needed, either at Kuala Belait or Kuala Baram. A natural gas pipe-line from Seria Oilfield to Lutong Refinery exists, and land and coast transport routes meet at these two river estuaries. This size of ship entering the Baram is limited by the bar. Recent surveys indicate that ships drawing as much as 8-9 feet could enter at high water. Ocean-going vessels could be loaded in the Miri Roads, about 12 miles south-southwest from Kuala Baram.

From Kuala Baram to Batu Gading (a distance of about 125 miles) there is much deeper water, and it is probable that large barges (with a capacity of 400 tons or more of stone) could be used.

Roads extend from Kuala Baram to Miri (15 miles) and eastwards from Kuala Baram to Kuala Belait (14 miles), Tutong (55 miles) and Brunei Town (84 miles). The Baram River is navigable for barges of 200-250 tons capacity from Batu Gading to its mouth, but there is a bar at the estuary, and transport to the sea is limited to ships of 8-foot draught or less; a similar bar occurs at the mouth of the Belait River. It has been suggested that the 2¼ mile Pagalayan Canal might be dredged to link the Baram and Belait Rivers, which would allow direct transport of raw materials by barge into the oilfield region.

Two possible sites exist: (a) Kuala Belait in Brunei, and (b) Kuala Baram in Sarawak. Preliminary testing shows that suitable mud exists in the Baram estuary, but samples from the Belait estuary are too high in silica. The Baram estuary thus appears to be more favourable.

The possibility of a small cement plant at Batu Gading has been considered. This would have the advantage that the major raw materials—limestone and clay—would be present on the site, and only the less bulky finished cement would require transport down the river. On the other hand, the lack of cheap natural gas for use as fuel probably outweighs the advantages.

FUEL

General

Natural gas is produced at Seria, and a considerable surplus is at present flared as no use can be found for it. W. N. Foster, Petroleum Technologist, estimated in 1954 that the amount of surplus gas (calorific value 38,000 B.Th.U/cu.m.) above company requirements at Seria would be:

	Cubic metres a day
End of 1954	2,000,000
End of 1964	750,000
End of 1974	250,000

(N.B.—Figures for 1964 and 1974 are 'conservative estimates')

Analyses of the gas are given in table 21 (p.139). The pipe line from Seria to Lutong in Sarawak, is working almost to capacity, and it is probable that a fresh line would have to be laid if the gas were to be used in a cement plant. The approximate cost of a pipe-line laid on the surface, assuming a minimum of clearing work and good access (i.e. laid alongside existing roads) is estimated at:

6-inch line	M$48,000 a mile
4-inch line	M$32,000 a mile

Note on Natural Gas used in Cement Manufacture in Trinidad (from Roe, *Ann. Rept.*, 1957)

Natural gas, piped from the oilfields, is used in Trinidad in the manufacture of cement. The company, Trinidad Cement Limited, is a subsidiary of the Rugby Portland Cement Company, Rugby, England. Cement-making started in 1954, and oil fuel was used until March 1956, when a change was made to natural gas, which has proved economically advantageous, and gas has given easier and more efficient working. Technical features of the plant are outlined below.

The plant is designed to produce 100,000 tons of cement annually, but local demand has proved so great that it is hoped to exceed this. A 350-foot rotary kiln is used and burns daily 2,400,000 cubic feet of gas to give an average kiln temperature of 1,450°C. (An analysis of the gas is given in table 8). Limestone comes from nearby Mayo; it is fairly soft, contains varying amounts of clay and 2-3 percent iron, but is low in magnesia (0·5 percent) and free from phosphorus. The purer and the more clayey varieties of limestone are blended to give a mixture containing 75-76 percent calcium carbonate; this is pulverised, then roasted, to produce cement. Should a smaller output be needed in Borneo a vertical kiln may have to be used; German vertical kilns working on the Lurgi system using the Sinterband process could be used with natural gas, and such kilns could be shut down for short periods and readily restarted.

SIZE OF THE CEMENT PLANT

In general, a rotary kiln is the most economical where about 100,000 tons or more of cement is needed annually. This type of plant is built where it is considered demand will increase but is estimated initially to be around 75,000 tons annually; in practice demand seems to exceed the estimates as soon as production starts, e.g. Trinidad and Malaya. Vertical kilns are used where the demand is likely to be smaller, e.g. 15,000 to 50,000 tons annually. Vertical kilns today are efficient and give an economic, easily controlled output. They require a source of argillaceous material that can be ground to a powder, and river mud could not be used unless it was dried. Moreover, should the demand increase to around 100,000 tons annually, it is more economic to have one rotary kiln with this capacity than say four vertical kilns each with a capacity of about 25,000 tons. Both in Malaya and Trinidad, where cement manufacturing has started since 1950, sales have exceeded original estimates of demand and the 100,000 ton rotary kiln is producing in excess of its designed output in Trinidad, and at capacity in Malaya.

POTENTIAL MARKETS

The initial market would be in Brunei and north Sarawak. With the advantages that come from the cheap fuel, i.e. natural gas, and the particularly suitable limestone at Batu Gading, there is a good chance that cement could not only be produced economically for Brunei and north Sarawak but would be in a strong position to compete with overseas cement coming into western Sarawak and North Borneo, so that there should be a good long-term market. The coastal areas of northwest Borneo, from the mouth of the Rajang in Sarawak to Kudat in North Borneo, are short of good quality stone, and so there is every incentive to use cement for purposes for which it would not otherwise be employed if good stone was readily available. For example, soil stabilization, using soil, sand, and gravel, with 3-5 percent cement, has been used for building roads in some coastal areas, and further use of this method would add to the demand for cement. The availability of reasonably cheap, home-produced cement would in itself tend to create a market for such purposes. Cement imports into British Borneo are listed in table 22 (p.140).

TABLE 15. LIMESTONE RESERVES IN THE BATU GADING AREA

Place	*Measured Reserves*		
	Cubic yards		*Long tons*
	Rock in place	*Estimated volume when broken*	
Batu Gading	840,000	1,430,000	1,700,000
Bukit Besungai (north)	1,200,000	2,040,000	2,440,000
Bukit Besungai (south)	5,500,000	9,350,000	11,170,000
Bukit Besungai (east)	700,000	1,190,000	1,420,000
Bukit Betok (north)	1,700,000	2,890,000	3,450,000
Bukit Betok (southwest)	360,000	610,000	730,000
Bukit Betok (southeast)	100,000	170,000	200,000
Total Measured Reserves	10,400,000	17,680,000	21,110,000

NOTE: Density of limestone taken as 2·03 long tons/cu. yd. It has been assumed that 1 cu. yd. in place will yield 1·7 cu. yd. broken rock

TABLE 16A. ANALYSES OF LIMESTONE FROM THE BATU GADING AREA

Specimen Number	SiO_2	R_2O_3	CaO	MgO	*Loss at 1000°C*	*Total*
	WEIGHT PERCENT					
BATU GADING						
S4431	0·88	0·67	54·18	0·65	43·50	99·88
4433	0·14	0·44	55·29	0·50	43·72	100·09
4434	0·44	0·56	54·98	0·71	43·16	99·85
4435	1·22	1·18	53·67	0·89	42·96	99·92
4436	0·40	0·72	54·78	0·47	43·48	99·85
4437	0·70	1·24	54·38	0·80	42·72	99·84
4440	0·74	0·90	54·78	0·41	43·42	100·25
4441	0·98	1·50	53·74	0·82	42·70	99·74
4442	0·30	0·80	54·98	0·62	43·68	100·38
4443	0·20	0·42	55·38	0·47	43·68	100·15
4444	0·38	0·80	54·78	0·85	43·20	100·01
4445	0·24	0·64	54·98	0·55	43·66	100·07
4446	0·71	0·82	54·78	0·74	43·44	100·40
4447	0·72	0·68	54·68	0·60	43·58	100·26
4448	1·28	1·20	53·76	0·76	42·82	99·82
4449	1·96	1·88	53·53	0·63	42·14	100·14
4450	1·72	1·56	53·16	0·74	42·72	99·90
4451	2·36	1·66	52·36	0·83	42·14	99·35
4452	1·32	1·36	53·57	0·68	42·88	99·81
4453	0·88	0·64	54·18	0·88	43·20	99·78
4454	0·72	0·98	54·38	0·53	43·16	99·77
4455	0·38	0·80	54·48	0·65	43·50	99·81
4456	0·56	1·34	54·28	0·70	42·68	99·56
4457	0·30	1·29	54·06	0·79	42·94	99·38
4458	0·46	0·24	54·58	0·71	43·60	99·59
4459	0·50	0·80	54·88	0·49	43·92	100·59
4460	0·20	0·50	54·98	0·73	43·60	100·01
4461	0·29	0·24	55·38	0·53	43·76	100·20
4462	1·20	1·44	52·85	0·70	43·18	99·37
4463	2·02	1·40	53·76	0·68	42·54	100·40
4464	0·68	0·56	54·37	0·70	43·38	99·69
4465	1·58	1·26	53·46	0·76	42·92	99·88
BUKIT BESUNGAI						
4466	30·14	10·38	31·42	0·76	24·84	97·54
4467	3·64	2·80	50·94	0·74	41·54	99·66
4468	24·94	7·26	34·63	0·95	30·60	98·58
4469	10·06	5·42	46·61	0·74	36·10	98·93
4470	39·28	11·48	25·17	0·92	20·32	97·17
4471	6·04	2·28	47·52	0·99	41·68	98·51
4472	4·26	3·04	50·75	0·92	40·68	99·65
4473	3·22	1·28	52·36	0·59	42·20	99·65
4474	1·86	1·98	52·55	0·77	42·62	99·78
4475	1·84	2·14	53·27	0·68	42·14	100·07
4476	1·84	1·74	53·69	0·73	42·54	100·54
4477	0·84	1·32	54·65	0·79	42·40	100·00
4478	0·24	1·04	55·59	0·74	42·82	100·43
4479	1·16	1·52	54·01	0·67	42·78	100·14
4480	1·72	1·90	53·27	0·68	42·56	100·13
4481	2·94	3·06	51·90	0·76	41·18	99·84
4483	1·16	1·60	54·33	0·58	42·48	100·15
BUKIT BETOK (EAST)						
4495	2·74	1·88	51·80	0·99	41·60	99·08
4496	0·92	3·56	52·23	0·83	41·72	99·26
4497	1·88	4·28	52·23	0·92	40·64	99·95
4498	2·42	2·94	52·64	0·77	41·20	99·97

TABLE 16B. ANALYSES FROM THE BATU GADING AREA
(from *British Borneo Geological Survey Annual Report*, 1955, table 7)

Locality	*Specimen Number*	CaO	MgO	P_2O_5	*Nature of residue*
		WEIGHT PERCENT			
Batu Gading	S3674A	54·04	0·94	0·07	Quartz 95, pyrite 5
	3674B	54·04	0·62	0·04	Quartz 80, pyrite 20
	3674C	54·12	0·88	0·05	Quartz 100
	3674D	45·72	0·52	0·04	Quartz 90, arseno-pyrite 10
	3674E	52·08	0·73	0·07	Quartz 95, pyrite 5
	3674F	52·53	0·83	0·07	Quartz 85, pyrite 15
Sungai Betok	3677	54·95	0·68	0·09	Quartz 95, ilmenite 5
Bukit Besungai	3680	49·82	1·09	0·03	Quartz 100

Analyses by W. A. Tooke, Chief Chemist; identification of residue by F. H. Flinter, Geologist, Geological Survey, Federation of Malaya

TABLE 17. ANALYSES OF SHALE AND ARGILLACEOUS LIMESTONE (OVERLYING THE MAIN LIMESTONE AT BATU GADING AND BUKIT BESUNGAI)

Specimen Number	SiO_2	R_2O_3	CaO	MgO	*Loss at 1000° C*	*Total*
	WEIGHT PERCENT					
BATU GADING						
S4432	31·89	13·30	28·60	0·62	25·52	99·95
4438	48·28	22·76	11·78	2·10	14·98	99·90
4439	29·84	13·54	29·60	1·39	24·98	99·35
4613	27·27	11·24	32·54	0·97	27·82	99·84
4614	49·89	18·95	12·38	1·34	14·63	97·19
4615	40·87	14·64	21·56	0·85	19·88	97·80
4616	23·84	12·73	33·66	0·66	28·98	99·87
4617	38·45	12·71	24·70	1·32	21·49	98·67
4618	32·16	13·86	27·15	1·34	23·16	97·67
4619	32·03	14·00	27·07	1·37	23·80	98·27
4620	38·64	19·00	19·32	2·08	18·47	97·51
4688	23·37	6·71	38·40	0·96	30·44	99·88
4689	18·01	7·32	40·37	0·90	32·68	99·28
4690	21·40	1·53	43·62	0·66	32·49	99·49
6000	37·66	12·47	25·24	0·56	22·39	98·32
6001	63·16	24·63	0·89	0·86	7·01	96·55
6002	46·46	16·06	16·86	1·06	17·20	97·64
6003	60·20	26·52	0·76	1·40	7·77	96·65
6004	43·43	17·81	18·41	0·67	18·29	98·61
6005	58·13	21·69	6·06	1·21	9·74	96·83
6006	32·24	13·55	27·22	1·28	24·22	98·51
6007	62·01	25·26	0·53	1·88	6·86	96·54
6008	53·43	22·86	8·06	1·41	11·06	96·82
6009	33·60	14·30	26·35	1·56	22·85	98·66
6010	51·85	21·26	9·72	1·46	13·05	97·34
6011	64·31	24·03	1·56	0·82	6·53	97·25
6012	46·94	18·65	14·55	0·86	16·04	97·04
6013	60·92	26·09	0·64	1·59	7·28	96·52
6014	41·23	15·74	20·68	1·40	18·92	97·97
6015	55·96	23·81	5·48	1·57	10·22	97·04
6016	60·52	27·05	0·26	0·71	8·10	96·64
6017	44·80	18·06	16·64	1·50	16·83	97·83
BUKIT BESUNGAI						
4482	44·78	18·84	16·43	1·44	16·30	97·79
4666	46·78	18·58	15·54	1·50	16·11	98·51

Analyses by the Mineral Resources Division, Overseas Geological Surveys, 1958 and 1959

TABLE 18. ANALYSES AND SILICA MODULUS OF MUD AND CLAY FROM THE BARAM AND BELAIT ESTUARIES, EAST SARAWAK AND BRUNEI

Specimen Number	*Locality*	*Loss on ignition*	SiO_2	R_2O_3	*Silica Modulus* SiO_2/R_2O_3
		WEIGHT PERCENT			
S4397	Baram River, Sarawak (2-mile stretch of low-silica muds)	12·56	56·08	24·18	2·32
4398		11·94	60·48	21·32	2·83
4399		11·82	58·90	21·53	2·74
4400		11·62	58·52	20·02	2·92
4404		11·12	59·22	20·77	2·85
4405		11·58	59·34	20·16	2·94
4406		11·35	62·19	20·54	3·03
4407		9·83	66·47	18·67	3·56
4408		11·72	58·54	21·28	2·75
4395	Baram River, Sarawak	18·02	58·96	19·68	3·00
4396		22·32	56·16	15·54	3·62
4401		10·44	61·88	19·70	3·14
4402		10·78	60·82	19·30	3·15
4403		10·26	63·28	20·52	3·08
4409		12·30	55·61	23·48	2·37
4410		10·87	62·18	20·52	3·03
4411		9·78	64·83	19·90	3·26
4412		10·11	65·31	19·96	3·27
4413		9·12	66·66	18·86	3·53
4414		10·73	64·10	19·60	3·27
4415		9·52	68·48	16·51	4·15
4416		6·49	82·43	8·58	9·61
4417		10·95	63·36	20·95	3·02
4418		9·22	66·52	18·14	3·67
4419		9·34	71·96	15·34	4·69
4420	Belait River, Brunei	10·96	68·30	14·84	4·60
4421		10·82	70·64	12·65	5·58
4422		13·10	65·04	16·40	3·97
4423		10·76	69·38	14·52	4·78
4424		11·20	70·89	14·20	4·99
4425		18·76	56·39	20·08	2·80
4426		10·54	70·39	13·63	5·17
4427		7·43	77·11	11·54	6·68
4428		9·13	65·41	18·48	3·54
4429	Badas, Belait River	6·10	72·69	17·52	4·15
4430	Lumut Hills, East of Seria, Brunei	7·27	70·54	19·26	3·66

Analyses of air dried samples by the Mineral Resources Division of the Overseas Geological Surveys, London

TABLE 19. AVERAGE COMPOSITION OF CEMENT MATERIALS

	Batu Gading limestone (32 samples)	*Batu Gading overburden (29 samples)*	*Baram River mud (25 samples)*	*Baram River mud (9 samples)*
	S4431	S4432	S4395-4419	S4397-4400
	S4433-4437	S4438-4439		S4404-4408
	S4440-4465	S6000-6017		*From 2-mile*
		S4613-4620		*stretch only*
	AVERAGE WEIGHT PERCENT		AVERAGE WEIGHT PERCENT OF AIR-DRIED SAMPLE	
SiO_2	0·83	45·17	62·89	59·97
R_2O_3	0·95	18·50	19·40	20·94
CaO	54·29	16·15	—	—
Loss on ignition	43·19	16·83	11·35	11·51
Silica moludus SiO_2/R_2O_3	0·87	2·44	3·24	2·86

TABLE 20. CALCULATED CLINKER COMPOSITION

	Batu Gading limestone (235 parts) and Batu Gading overburden (100 parts) (see note (a))	*Batu Gading limestone (360 parts) and Baram River mud (100 parts) (see note (b))*	*Batu Gading limestone (360 parts) and Baram River mud 2-mile stretch (100 parts) (see note (c))*
	WEIGHT PERCENT		
SiO_2	21·75	22·47	21·49
R_2O_3	9·57	7·78	8·31
CaO	66·33	66·67	66·70
Silica modulus	2·27	2·89	2·59
Lime Saturation Factor	0·94	0·94	0·97

Notes on Table 20

(a) *Batu Gading limestone and overburden.* These give a well-balanced mix requiring little or no adjustment.

The previous calculation (based on the same average limestone but only three overburden analyses) required rather less than 2 parts of limestone to 1 of overburden; the present calculation requires rather more than 2 parts of limestone, because the overburden as a whole appears to be less calcareous than was at first thought.

Good cement mixes can be calculated from about 3½ parts of limestone to 1 of overburden (when the latter is shale containing practically no CaO) or from 1 part of limestone to 1 of overburden (when the latter contains 30-35 percent CaO). These are the extreme cases, and the calculations are equally satisfactory for any intermediate mixes.

(b) *Batu Gading limestone and general Baram Estuary mud.* The limestone reduces the very high silica modulus of the general Baram mud, but the clinker composition still shows a modulus of 2·9, which is almost certainly too high. The limestone-mud mix would probably need a little adjustment to reduce the silica modulus, and waste bauxite (or iron ore) would be an appropriate additive.

(c) *Batu Gading limestone and mud from 2-mile stretch of Baram River.*

The limestone reduces the moderately high silica modulus of the Baram River mud (2-mile stretch) to the very satisfactory figure 2·6. It is concluded that the two materials are well suited, and the mix would require little or no adjustment.

TABLE 21. ANALYSES OF OILFIELD GAS FROM SERIA, COMPARED WITH TRINIDAD OILFIELD GAS

	A *Typical analysis of gas supplied from Seria to Miri and Lutong (Volume percent)*	B *Typical analysis of dry gas, Seria (Volume percent)*	*Natural gas used in Trinidad for cement manufacture*
Methane	90·8	89·0	86·9
Ethane	4·7	7·1	3·9
Propane	1·8	2·9	2·1
Iso-Butane	0·4	—	0·9
Normal Butane	0·4	—	—
Pentanes and Heavier	0·5	—	0·6
Carbon Dioxide	0·6	1·0	3·6
Oxygen	—	—	0·4
Nytrogen and other permanent gases	0·8	—	1·6
Hydrogen Sulphide	—	—	—
Sp. Gr. @ 60° F/760 mmHg (Air=1)	0·625	0·614	0·7
Net Calorific Value BTh.U/cu. ft.	985	989	1,000

NOTE: Supply of 'A' type gas can only be expected to be available for a relatively short period, whereas 'dry gas' 'B' will be available as long as gas processing operations continue.

TABLE 22. CEMENT IMPORTS, BRITISH BORNEO, 1950-59

(Values in Malayan Dollars)

Year	BRUNEI		SARAWAK		NORTH BORNEO				TOTAL, BRITISH BORNEO	
					EAST COAST	WEST COAST	TOTAL, NORTH BORNEO			
	Tons	*Value*	*Tons*	*Value*	*Tons*	*Tons*	*Tons*	*Value*	*Tons*	*Value*
1950	NA	NA	4,368	373,742	971	3,613	4,584	335,019	N.A.	N.A.
1951	NA	NA	4,881	523,579	1,161	5,318	6,479	571,045	N.A.	N.A.
1952	NA	NA	7,712	808,751	4,060	9,955	14,015	1,543,761	N.A.	N.A.
1953	NA	NA	9,652	967,487	4,370	7,132	11,502	950,143	N.A.	N.A.
1954	18,271	1,827,068	12,290	1,245,869	3,341	6,428	9,769	789,063	40,330	3,862,000
1955	17,291	1,739,143	12,323	1,208,668	5,466	8,592	14,058	1,105,193	43,672	4,053,004
1956	48,831	4,570,020	19,156	1,764,998	6,098	10,511	16,609	1,403,637	84,596	7,738,655
1957	22,973	2,207,864	18,119	1,753,286	10,205	7,515	17,720	1,568,534	58,712	5,529,684
1958	22,477	2,059,339	18,225	1,656,456	11,290	8,431	19,721	1,698,510	60,423	5,414,305
1959	NA	NA	17,324	1,481,924	10,015	8,742	18,847	1,503,764	N.A.	N.A.

NA = not available.

Paper I

THE STRATIGRAPHICAL SUCCESSION IN THE BATU GADING AREA, MIDDLE BARAM, NORTH SARAWAK

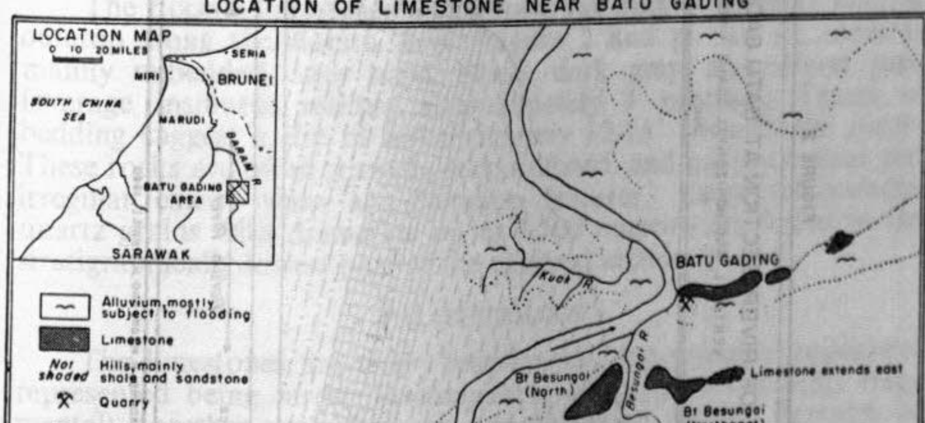
by

C. G. ADAMS AND R. HAAK

INTRODUCTION

The limestone formation in the Batu Gading area was mapped and sampled by N. S. Haile (1956) and was visited by R. Haak in 1958 at the request of the Geological Survey. As the main limestone outcrop proved to be of considerable stratigraphical and palaeontological interest, the opportunity was taken to re-examine it together with the nearby outcrop at Bukit Besungai during the course of a visit by C. G. Adams to Sarawak in 1960. The present paper embodies the results of these investigations.

FIGURE I
LOCATION OF LIMESTONE NEAR BATU GADING



Sarawak Geological Office Map 309 by N. S. Haile, 1960

The limestones at Batu Gading crop out over a distance of 810 feet along the middle part of the Baram River (figure 1). They have a total stratigraphical thickness of approximately 160 feet. The major part is formed by Upper Eocene (Tb) limestones (approximately 120

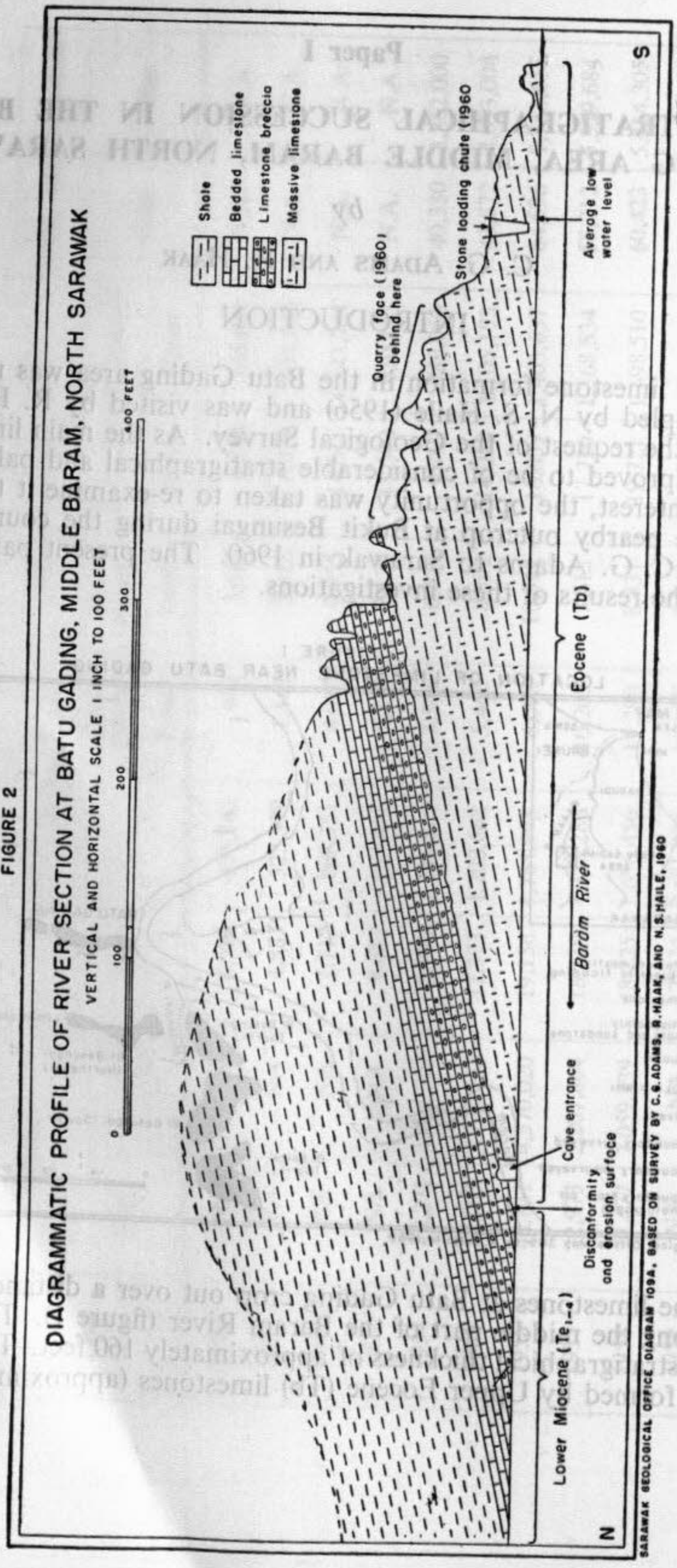


FIGURE 2

DIAGRAMMATIC PROFILE OF RIVER SECTION AT BATU GADING, MIDDLE BARAM, NORTH SARAWAK feet) which are disconformably overlain by limestones of Lower Miocene (Te_{1-4}) age. This limestone sequence is in turn conformably overlain by Lower Miocene calcareous shales.

Stratigraphical Succession at Batu Gading

(See figure 3)

The following succession is found:

feet		
>40	Calcareous shale*	Age Te_{1-4} (early Miocene)
±15	Bedded limestone	
±25	Limestone breccia including silty shales at the base	
	disconformity	
±120	Massive limestone	Age Tb (late Eocene)

EOCENE

Lithology

The Eocene limestones which form the bulk of the Batu Gading outcrop along the Baram River (figure 2 and pl. IA), are massive, mainly unbedded, very hard, dense, dark grey, and almost pure (average insoluble residue approximately 1 percent). Traces of bedding suggest a dip of approximately 12-15° towards the north. These rocks are often strongly recrystallized, and microstylolites and irregular calcite veins are common features. Large sub-rounded quartz grains with diameters up to 1,500 microns are found in the stratigraphically lowest part of the exposed section (pl. IIA).

Palaeontology

The limestones are richly fossiliferous, the principal organisms represented being larger Foraminifera, Algae, corals (mainly fragmental), together with echinoid and bryozoan debris. Remains of molluscs are occasionally found.

The presence of *Pellatispira* spp. in the following association of larger Foraminifera indicates a Tb age:

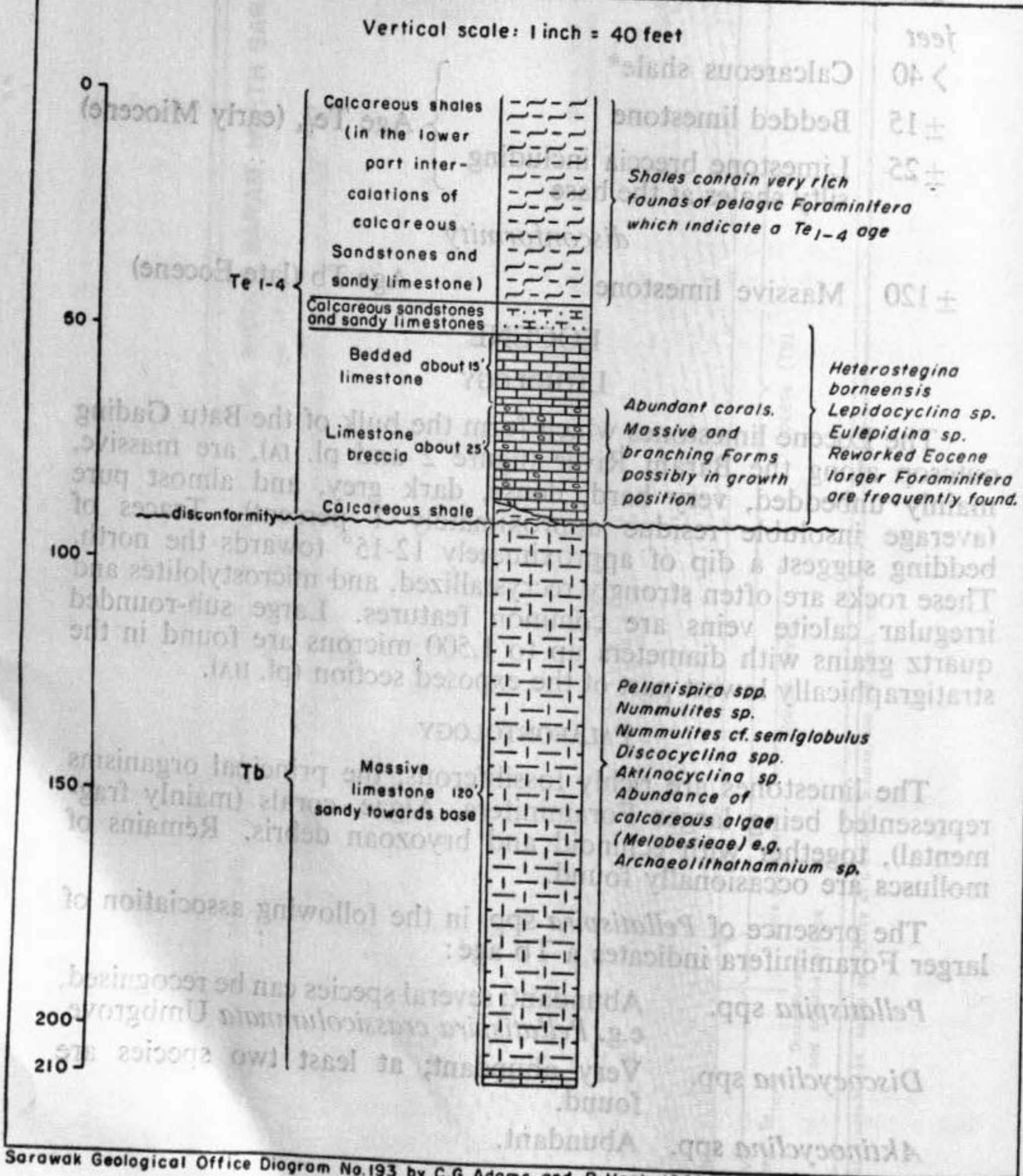
Pellatispira spp.	Abundant; several species can be recognised, e.g. *Pellatispira crassicolumnata* Umbgrove.
Discocyclina spp.	Very abundant; at least two species are found.
Aktinocyclina spp.	Abundant.

*Only the lowermost 40 feet were examined.

Nummulites spp.	Abundant; at least two species are found including *Nummulites* cf. *semiglobulus* (Doornink).
Operculina spp.	Very common; a small *Operculinella*-like species is frequently found.

FIGURE 3

STRATIGRAPHICAL COLUMN AT BATU GADING



Sarawak Geological Office Diagram No.193 by C.G. Adams and R. Hoak, 1960

PLATE IA. TYPICAL UPPER EOCENE LIMESTONE FROM BATU GADING. Foraminifera visible in this section are: *Discocylina* spp., *Nummulites* cf. *semiglobulus* (Doornink), and *Pellatispira* spp. ×9

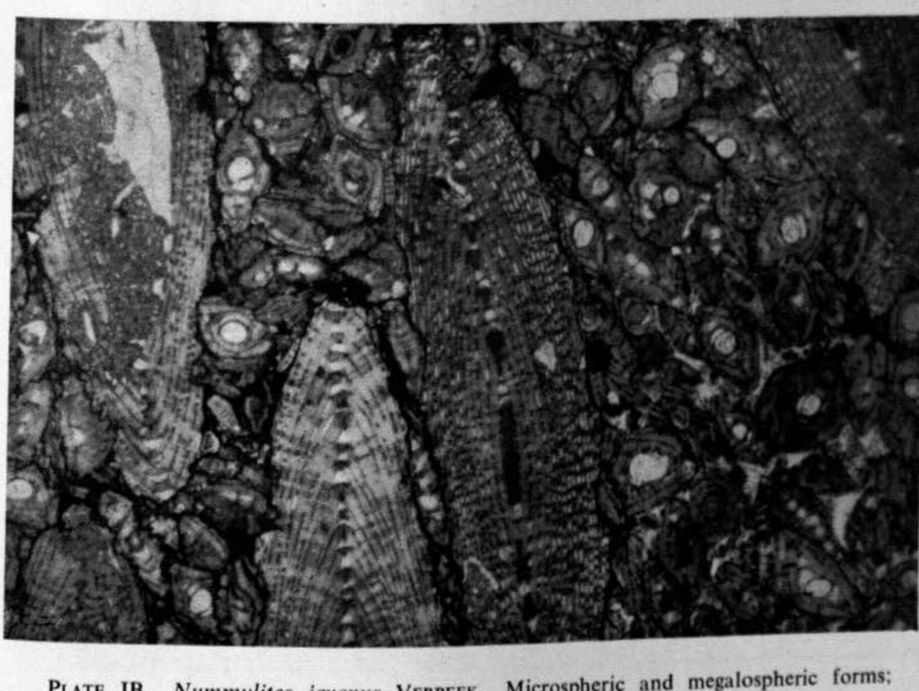


PLATE IB. *Nummulites javanus* VERBEEK. Microspheric and megalospheric forms; from the lower part of the Bukit Besungai Limestone

PLATE IIA. LOWEST LIMESTONE AT BATU GADING. Limestone containing large sub-rounded quartz grains; from the lowest stratigraphical level exposed at Batu Gading. × 9

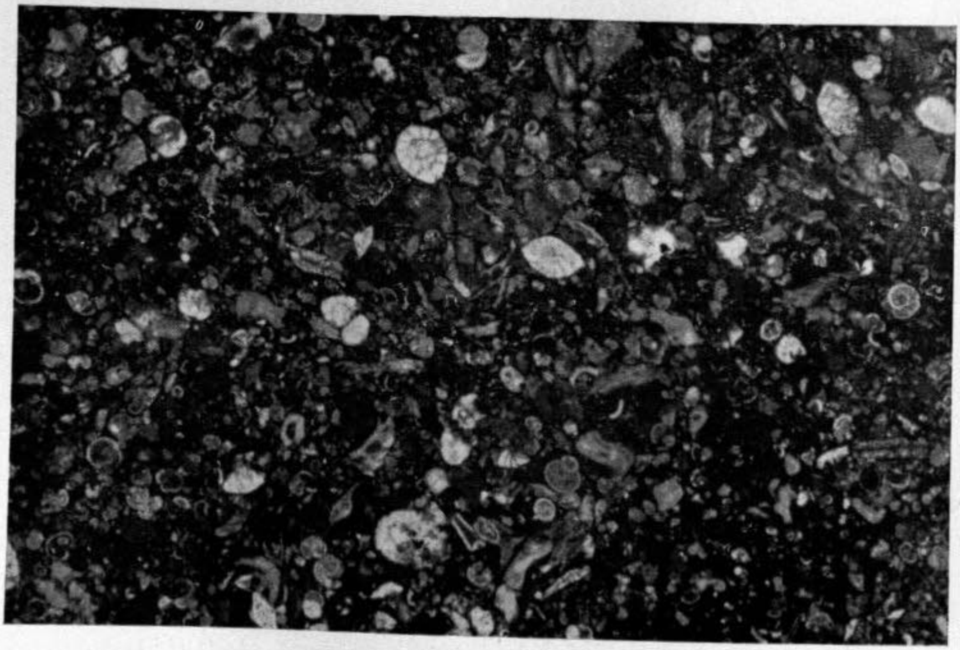


PLATE IIB. MARLY ROCK FROM BASE OF MIOCENE. Contains pelagic and smaller benthonic Foraminifera. From south of cave entrance, river section, Batu Gading. × 9

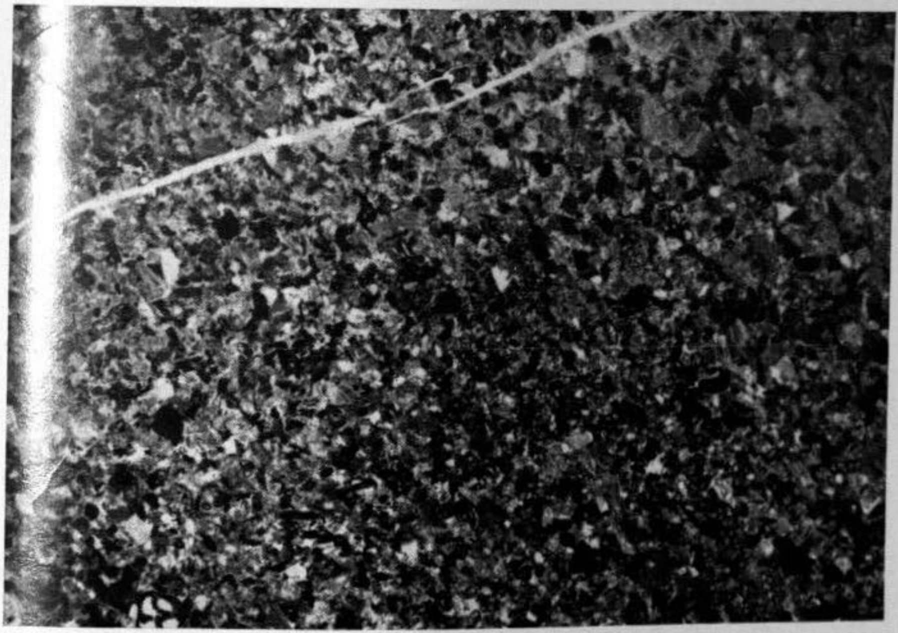


PLATE IIIA. ALGAL-FORAMINIFERAL CALCARENITE. From the uppermost 15 feet of Miocene limestone, Batu Gading. × 10

PLATE IIIB. MIOCENE-EOCENE CONTACT. The contact between Miocene and Eocene limestone near the cave mouth in the river section at Batu Gading. The disconformity is marked by a sandy band which can be clearly seen

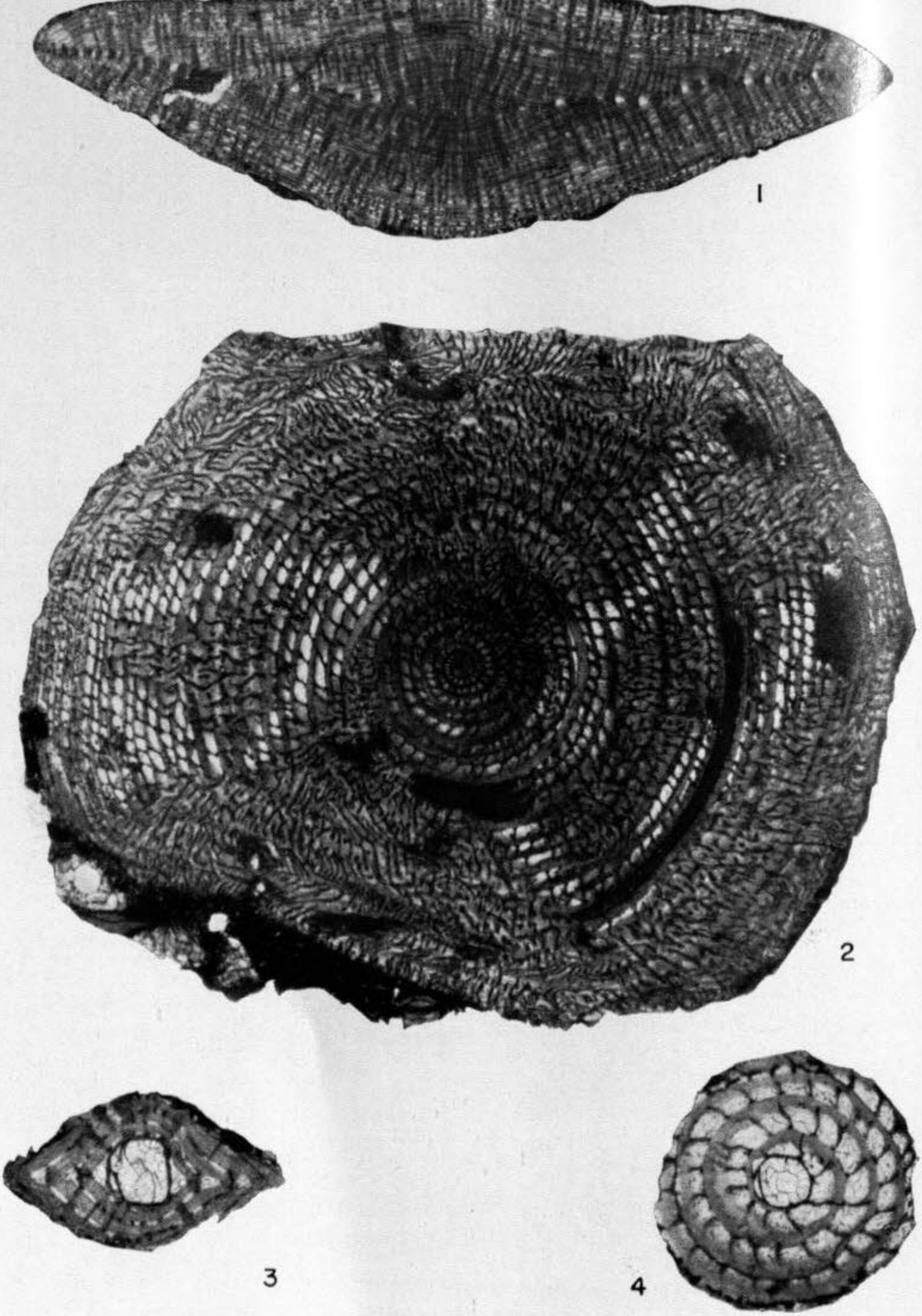


PLATE IV. *Nummulites javanus* VERBEEK.

1. Vertical section of microspheric form, × 5;
2. Equatorial section of micropheric form, × 5;
3. Vertical section of megalospheric form, × 12;
4. Equatorial section of megalospheric form, × 12.

With the exception of miliolids, which occur in abundance in the stratigraphically lowest part of the river section, small benthonic Foraminifera are rare throughout the Eocene part of the succession.

Calcareous algae, mainly Melobesieae, occur profusely throughout the limestones and occasionally form the bulk of the rock. Well-preserved specimens, both globular and encrusting forms, are found and occasionally attain a considerable size; the genus *Archaeolithothamnium* occurs in great profusion. Representatives of the Corallinaceae are only found in large numbers at the base of the Eocene where they occur together with *Halimeda*.

MIOCENE

The Lower Miocene (Te_{1-4}) limestones form only a minor part (40 feet vertical thickness) of the section cropping out along the river.

The Eocene/Miocene Contact

The Eocene-Miocene boundary is not always lithologically distinct, especially where limestones of the two systems are in contact. A clear-cut lithological boundary is, however, visible where the Eocene limestone is overlain by calcareous silty shales (figure 3). This can only be seen immediately north of the cave entrance (i.e. about 200 to 220 feet from the north end of the limestone outcrop) when the river level is very low. At the time of observation (Haak in 1958) these shaly beds could be followed over a distance of approximately 30 feet; they have a thickness of at least 2 feet 6 inches at water surface but gradually taper into the Miocene limestone when traced upstream. A 4-inch limestone band in the shales can be followed laterally into the main limestone. Irregular lumps (both large and small) of Eocene limestone were also found within the shale. These beds, which have been deposited on an eroded surface of Eocene limestone, contain rich Lower Miocene faunas of pelagic Foraminifera (pl. IIB).

The following species are found:

Globigerina dissimilis Cushman & Bermudez var.

Globigerina binaiensis Koch

Globigerinoides spp.

Globorotalia mayeri Cushman & Ellisor.

Globoquadrina venezuelana (Hedberg) var.

Shales are absent from the south side of the entrance to the cave. They are represented by the basal foot or so of the limestone breccia which forms the lower part of the Miocene at this point (pl. IIIB). This basal bed is fairly rich in small benthonic and pelagic Foraminifera.

LIMESTONE BRECCIA

The lowest 20 feet of the Miocene succession consists of limestone breccia. Irregular blocks of Eocene limestone, often of a darker colour than the surrounding matrix, occur in great abundance and some are of considerable size (up to 2 feet in diameter). This part of the Miocene is furthermore characterized by the presence of a large number of compound corals, both branching and massive types, their present attitudes sometimes strongly suggesting an original growth position. The upper 3 feet of this sequence is transitional from limestone breccia to bedded limestone (see below).

Rich occurrences of $Te_{1\text{-}4}$ larger Foraminifera are mainly found at the extreme base of the Miocene limestone sequence.

The following fauna occurs:

Heterostegina spp., e.g. *H. borneensis* van der Vlerk.

Spiroclypeus sp.

Lepidocyclina spp. of Nephrolepidine type.

Lepidocyclina (*Eulepidina*) sp.

Neoalveolina pygmaea (Hanzawa), rare occurrences only.

Reworked Eocene specimens are found throughout and are occasionally more abundant than the Miocene Foraminifera. The foraminiferal fauna in the derived blocks is, of course, entirely Eocene.

BEDDED LIMESTONE

The uppermost 15 feet of the limestone is well-bedded and it is the only part of the entire section which shows good stratification. These beds comprise alternating fine, medium and coarse grained bioclastic, algal-foraminiferal calcarenites (pl. IIIA); they are very hard, light grey, dense, and in the uppermost part somewhat sandy.

The fossil content of the rock is mainly fine algal, foraminiferal and echinoidal debris. Remains of bryozoa and molluscs also occur. Smaller Foraminifera, both benthonic and pelagic, are found in great abundance, e.g. *Amphistegina* sp., *Textularia* sp., and representatives of the families Miliolidae, and Globigerinidae. The pelagic Foraminifera are mainly confined to the uppermost part. Larger Foraminifera are only rarely found. The following Te_{1-4} association has been recorded:

Heterostegina sp.
Lepidocyclina spp. of Nephrolepidine type.
Miogypsinoides sp.
Operculina sp.
Neoalveolina pygmaea (Hanzawa)

Algal and echinoidal debris occurs in great abundance, the calcareous algae being represented by Corallinaceae and Melobesieae.

Calcareous Shales

The limestones are overlain by alternating calcareous sandstones (up to 7 inches thick) and sandy limestones. These beds are transitional into a mainly shaly sequence with intercalations of calcareous sandstones and detrital limestones, especially in the lower part. The shales are hard, light grey, silty or sandy and contain an extremely rich Lower Miocene fauna of pelagic Foraminifera. The following specific determinations were made:

Globigerina binaiensis Koch
Globigerina dissimilis Cushman & Bermudez var.
Globigerina cf. *ciperoensis* Bolli
Globigerina spp.
Globigerinoides spp.
Globoquadrina venezuelana (Hedberg) var.
Globorotalia mayeri Cushman & Ellisor.

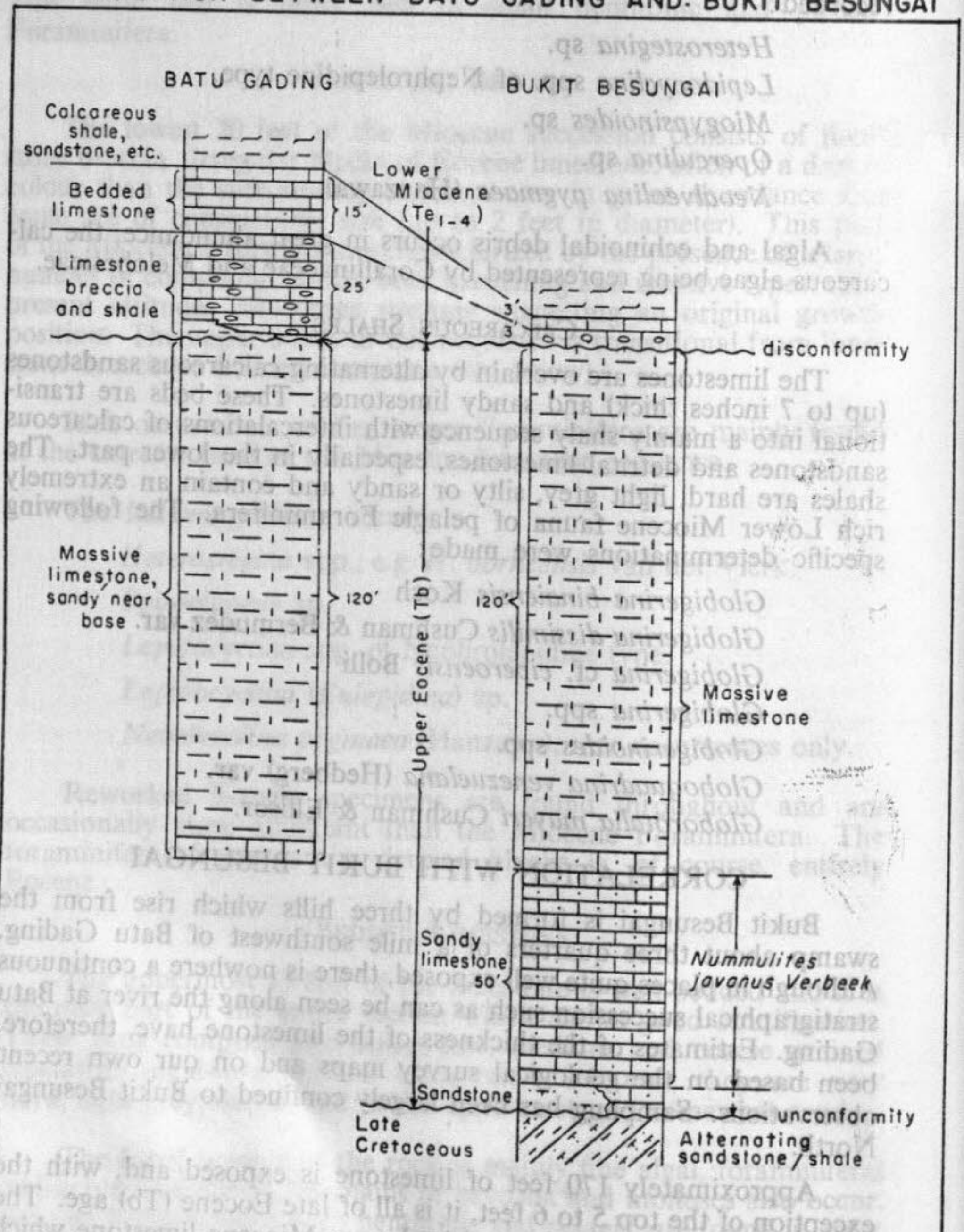
CORRELATION WITH BUKIT BESUNGAI

Bukit Besungai is formed by three hills which rise from the swamp about three quarters of a mile southwest of Batu Gading. Although in places quite well exposed, there is nowhere a continuous stratigraphical succession such as can be seen along the river at Batu Gading. Estimates of the thickness of the limestone have, therefore, been based on the geological survey maps and on our own recent observations. Sampling has been largely confined to Bukit Besungai North.

Approximately 170 feet of limestone is exposed and, with the exception of the top 5 to 6 feet, it is all of late Eocene (Tb) age. The uppermost 5 to 6 feet is formed by Lower Miocene limestone which is presumed to rest on an eroded surface of Eocene as at Batu Gading. Unfortunately, the contact could not be observed. The limestone

FIGURE 4

CORRELATION BETWEEN BATU GADING AND BUKIT BESUNGAI



Sarawak Geological Office Diagram 192 by C.G. Adams and R. Haak, 1960 succession overlies unconformably a series of steeply dipping sandstones and shales, the latter being known to contain a fauna indicative of a late Cretaceous age (see fig. 4).

The greater part of the Eocene limestone is very similar, both lithologically and faunistically, to that of Batu Gading. The same genera and species of Foraminifera are present in the two successions. The stratigraphically lowest 50 feet at Besungai (observed between the cave entrance on the east face and the swamp) is formed by a sandy limestone which becomes progressively more arenaceous towards the base. This limestone is rich in *Nummulites javanus* Verbeek, especially in its lower levels. Both megalospheric and microspheric forms occur in abundance (pl. IB and pl. IV, figs. 1-4). Associated with *N. javanus* are various species of *Discocyclina*, *Aktinocyclina*, *Operculina* and *Pellatispira*; the last named is, however, rare. *N. javanus* does not occur at Batu Gading.

As stated above, the topmost 5 to 6 feet of limestone is early Miocene in age. The upper 3 feet is formed by a fine grained, well-bedded calcarenite, identical with that seen at the top at Batu Gading; below this is found a few feet of limestone breccia which contains a $Te_{1\text{-}4}$ association of larger Foraminifera. This very thin development of Lower Miocene limestone is overlain conformably by calcareous shale of early Miocene age.

AGE OF THE BEDS

Unequivocal evidence for the age of the Batu Gading and for the greater part of the Bukit Besungai limestone successions is provided by the microfaunas. The only difficulty concerns the dating of the lowest 50 feet at Besungai. A. G. Davies (1956, p.55) believed that the presence of *N. javanus* probably indicated a Middle Eocene (Lutetian) age. This view can no longer be accepted. Not only are species closely related to *N. javanus* (e.g. *N. gizehensis*) known from the Upper Eocene of the Far East (Nagappa, 1957), but at Besungai and sometimes elsewhere in Sarawak, *N. javanus* occurs in association with *Pellatispira*. It is, therefore, considered that an Upper Eocene (Tb) age can be safely assigned to the base of the limestone at Besungai. It may be noted that *N. javanus* is most commonly found in the upper part of the Ta (i.e. Middle Eocene) of British Borneo and that its occurrence in the Tb is restricted to the stratigraphically lowest part.

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Paper II

CALCAREOUS ALGAE FROM SARAWAK

by

J. Harlan Johnson

The algae observed may be classified as follows:

	Family	Sub-family	Genus
Rhodophyta (red algae)	Corallinaceae	Melobesioideae	*Archaeolithothamnium*
			Lithothamnium
			Mesophyllum
			Lithophyllum
			Lithoporella
			Melobesia
			Dermatolithon
		Corallinoideae	*Corallina*
			Jania
Chlorophyta (green algae)	Dasycladaceae		*Cymopolia*
	Codiaceae		*Halimeda*
Uncertain			*Perforating algae*

SYSTEMATIC DESCRIPTIONS

RHODOPHYTA (RED ALGAE)

Family CORALLINACEAE

Sub-family MELOBESIOIDEAE

Genus ARCHAEOLITHOTHAMNIUM Rothpletz, 1891

Plants crustose, some species developing knobs or branches. Tissue differentiated into hypothallus and perithallus. Hypothallus of curved cell threads.

PLATE I. ARCHAEOLITHOTHAMNIUM AND CYMOPOLIA

Figures 1-2. *Archaeolithothamnium nummuliticum* (Gümbel) Rothpletz. Eocene. West end of Batu Gading (× 50)

1. Fragment of a branch showing several layers of sporangia.
2. Piece of a crust. Thin hypothallus at base and several layers of sporangia embedded in the perithallic tissue.

Figure 3. *Archaeolithothamnium* cf. *A. lugeoni* Pfender. Eocene? East end of Batu Gading (× 50)

Figure 4. *Archaeolithothamnium* cf. *A. myriosporum* Johnson. Probably Miocene. Batu Gading. Shows several thin thalli superimposed (× 100)

Figure 5. *Cymopolia saipania* Johnson. Miocene. East end of Batu Gading. An oblique cross section (× 25)

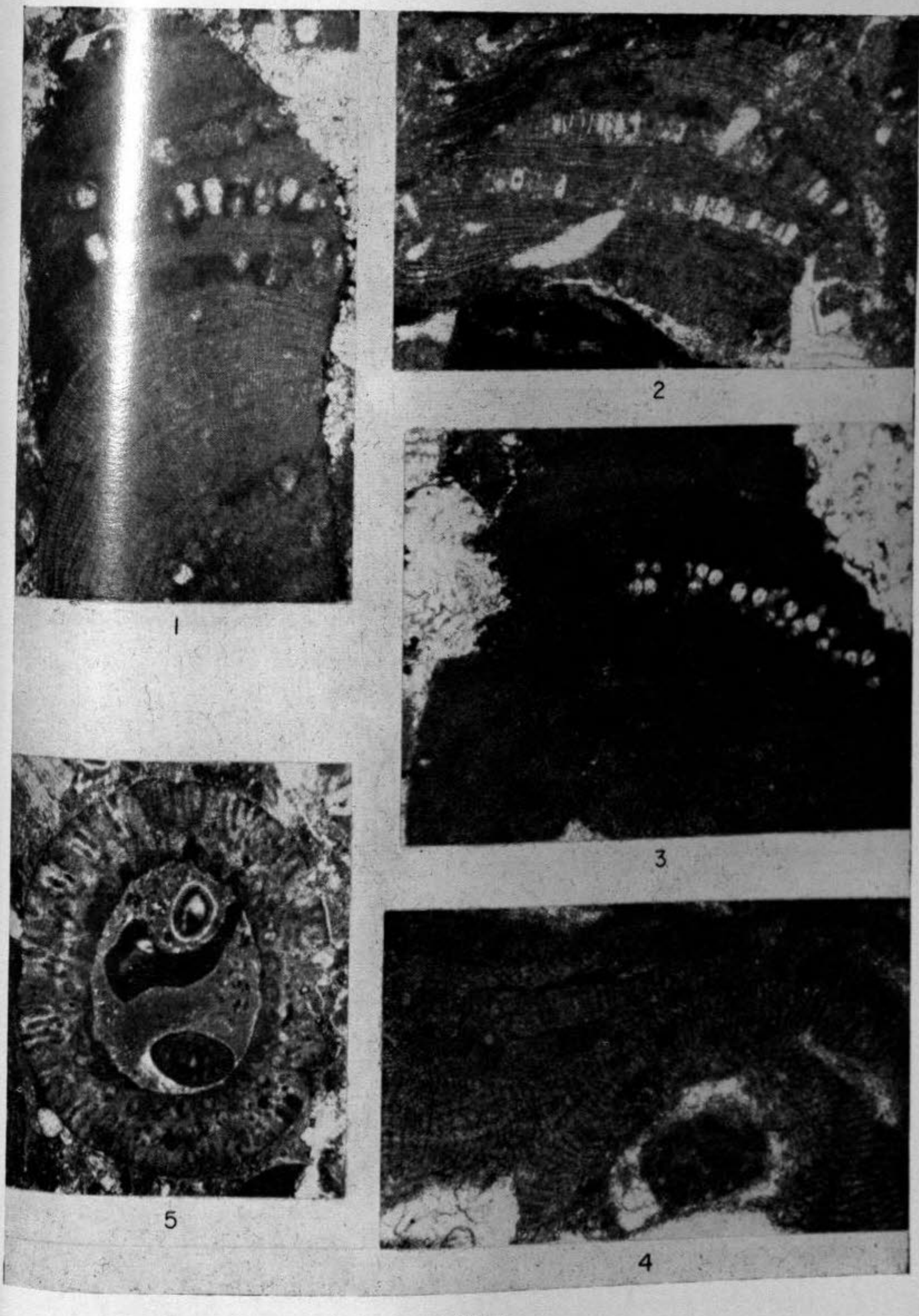

PLATE I

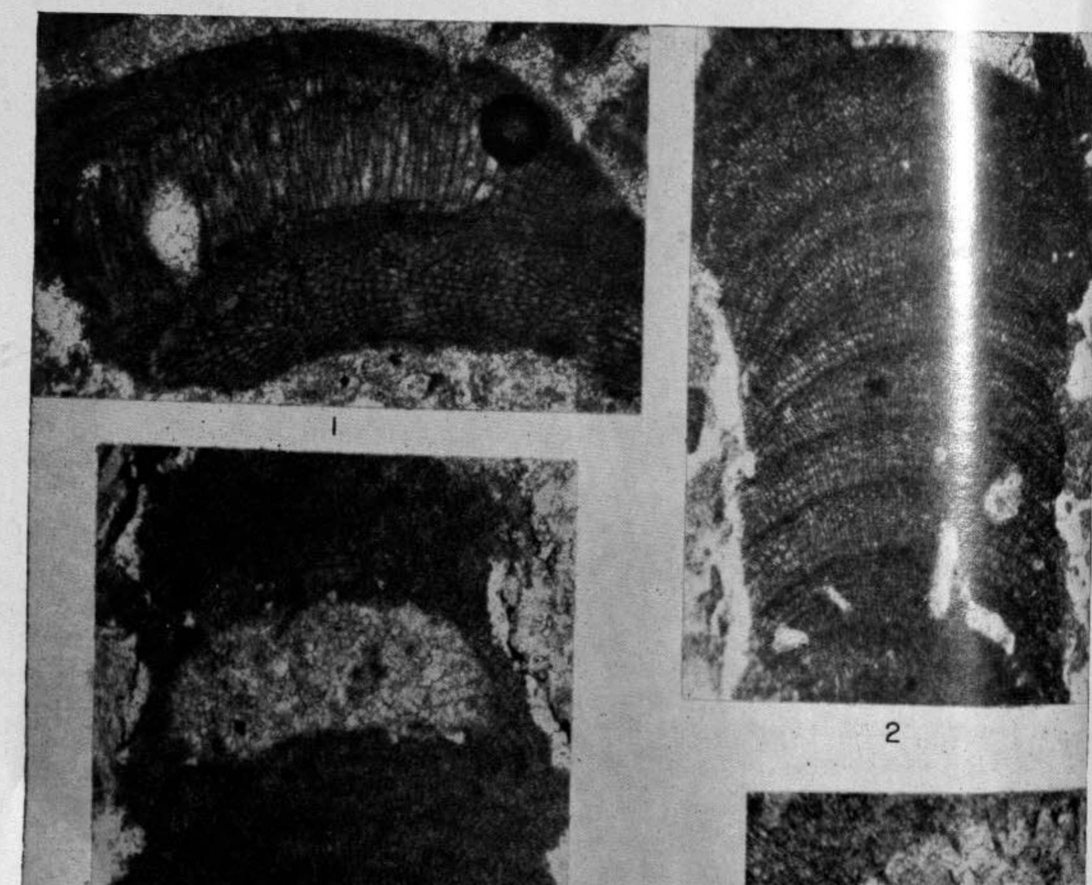

PLATE II

PLATE II. LITHOTHAMNIUM AND CYMOPOLIA

Figure 1. *Lithothamnium crispithallus* Johnson. Eocene. West end of Batu Gading. Shows a well developed plumose hypothallus, a thin perithallus, and a large conceptacle filled with sporangia (× 100)

Figures 2-3. *Lithothamnium marianae* Johnson. Eocene. Bukit Besungai

2. A badly worn fragment of a branch showing growth zones (× 50).

3. A frayed piece showing a conceptable chamber (× 50).

Figure 4. *Mesophyllum* species I. Eocene. Bukit Besungai. A nearly vertical section showing a thin hypothallus at the base with a thick perithallus with pronounced growth zones above. A large conceptacle is also present (× 50)

Figure 5. *Cymopolia saipania* Johnson. Miocene. Batu Gading. Cross section of a badly recrystallized specimen. Shows the large sporangia and traces of the branches (× 40)

The most characteristic and easily recognized feature is that the sporangia are not collected into conceptacles but occur in lenses or layers throughout the tissue. The genus reached its zenith during the Cretaceous and Eocene and has been declining slowly ever since. It forms an important element in most Eocene floras.

Archaeolithothamnium nummuliticum (Gümbel) Rothpletz

Plate I, figs. 1 and 2

Lithothamnium nummuliticum Gümbel, 1861, Geognostische Beschreibung des bayerischen Alpenbirges und seines Vorlandes, p.654.

Gümbel, 1871. Die sogennanten Nulliporen und ihre Betheiligung an der Zusammensetzung der Kalkgesteine, part 1, 42 p., 2 pls.

Lithothamnium nummuliticum (Gümbel) Rothpletz, 1891, Deutsche geol. Gesell. Zeitschr., v. 43, p.316, pl. 17, fig. 5.

Lithothamnium nummuliticum (Gümbel). Capeder, 1900, Malpighia, v. 14, p.176, pl. 6, fig. 2.

Archaeolithothamnium nummuliticum (Gümbel). Lemoine, 1917, Bull. géol. Soc. France, sér. 4, v. 17, p.247.

Lemoine, 1927, Bull. Mus. Nat. Hist., v. 6, p.546, fig. 1.

Lemoine, 1939, Mat. Carte géol. de l'Algérie, sér. 1, Paléont., no. 9, p.56.

Johnson, (manuscript), Fossil algae from Eniwetok, Funafuti, Kita-Daito-Jima; U.S. Geological Survey Professional Paper 260-(Z), pl. 2, fig. 6, pl. 3, fig. 2.

Description. Plant crustose with protuberances or short branches. Hypothallus commonly only slightly developed, of curved rows of cells. Perithallus quite regular. Hypothallic cells 18-20 microns by 8-12 microns; perithallic cells 8-26 microns by 8-14 microns. Sporangia in superimposed layers, 50-79 microns in diameter and 77-112 microns high.

Remarks. This is a common, very widespread, long-ranging species.

Geologic range. Late Cretaceous to lower Oligocene, but especially abundant during the late middle and early Upper Eocene.

Locality. West end of Batu Gading and Bukit Besungai.

Figured specimens. Slides 4450 II (3) and 4449 II (2).

Archaeolithothamnium cf. A. lugeoni Pfender

Plate I, figure 3

Archaeolithothamnium lugeoni Pfender, 1926, Soc. española historia nat. Bol., v. 26, p. 324, pls. 9, 12.

Archaeolithothamnium lugeoni Pfender. Lemoine, 1939, Mat. Carte géol. de l'Algérie, sér. 1, Paléont., no. 9, p. 52, text-figs. 14, 15, p. 62.

Archaeolithothamnium cf. *A. lugeoni* Pfender. Johnson, 1957, U.S. Geological Survey Professional Paper 280-E, p. 219, pl. 47, figs. 1-3.

Description. Fragments attributed to this form were observed in slides from only one locality. They contained perithallic cells measuring 11-29 microns by 11-16 microns, and sporangia with diameters of 45-55 microns and 55-70 microns high.

Remarks. This form differs from Pfender's *A. lugeoni* of the Mediterranean region in having somewhat longer cells and slightly shorter sporangia.

Age. Probably Upper Eocene.

Locality. East end of Batu Gading.

Figured specimen. Slide 4460.

Archaeolithothamnium cf. A. myriosporum Johnson

Plate I, figure 4

Archaeolithothamnium myriosporum Johnson, 1957, U.S. Geological Survey Professional Paper 280-E, p. 219, pl. 46, figs. 1-3.

Description. Plant develops as a crust with knobs or protuberances. Hypothallus fairly well developed; cells measure 10-18 microns by 9-14 microns. Perithallic tissue regular with cells 8-16 microns by 8-12 microns. Sporangia in tightly packed layers. They measure 11-36 microns in diameter and 36-38 microns high.

Remarks. Represented by two fragments in a single slide. The fertile specimen is cut at an angle which affects the measurements of the sporangia. However, the species represented closely resembles the common Saipan species, *A. myriosporum* Johnson.

Age. Miocene, probably Lower Miocene.

Locality. Batu Gading.

Figured specimen. Slide 3674 C.

Archaeolithothamnium species ?

Remarks. Fragments of *Archaeolithothamnium* cut at oblique angles were observed in slides 3674A, 4441, 4442, 4448, 4487 and 4495. Since accurate cell measurements could not be obtained, it is not possible to identify them specifically.

Genus LITHOTHAMNIUM Philippi, 1837

The tissue of *Lithothamnium* normally is clearly differentiated into hypothallus and perithallus, although in some species, the hypothallus is so thin and poorly calcified that it is not recognizable in fossil forms. Commonly, the hypothallus consists of curved threads of cells, but in some forms, it is plumose in vertical sections (see plate II, figure 1). The conceptacles are characterized by many roof openings for the escape of spores.

The known geologic range of the genus is from the Upper Jurassic (?) or Lower Cretaceous to the present.

Lithothamnium crispithallus Johnson

Plate II, figure 1

Lithothamnium crispithallus Johnson, 1957, U.S. Geological Survey Professional Paper 280-E, p. 223, pl. 42, figs. 6-8.

Description. Plant forms a small thin plate or crust. Hypothallus well developed, of curved threads of cells, with a plumose appearance in vertical section. Hypothallic cells rectangular or slightly rounded, 13-18 microns by 8-11 microns. Perithallus thin, but thickening around the conceptacles, with cells 6-8 microns by 6-8 microns. Conceptacle 660 microns by 197 microns.

Remarks. This tiny species with its small perithallic cells and large conceptacles is very distinctive.

Age. Upper Eocene.

Locality. West end of Batu Gading. In beds of probable Miocene age, containing reworked Eocene foraminifera.

Figured specimen. Slide 4453.

Lithothamnium marianae Johnson

Plate II, figures 2 and 3

Lithothamnium marianae Johnson, 1957, U.S. Geological Survey Professional Paper 280-E, p. 226, pl. 41, figs. 1-3.

Description. Plant develops strong branches. The tissue of the branches shows pronounced lenticular growth zones, composed of regular tissue with rectangular cells measuring 10-26 microns by 7-16 microns. The cells vary in size, especially in height from the centre to the margin of the growth zones. Conceptacle chambers observed ranged in diameter from 347-514 microns and in height from 160-198 microns.

Remarks. This form is identical with the species described from Saipan.

Age. Upper Eocene.

Locality. East end of Batu Gading and Bukit Besungai.

Figured specimens. Slides 4474 II (2) and 4475.

Lithothamnium species ?

Remarks. Infertile fragments of a thin crustose form with small rectangular cells were observed in slides 4433, 4434, 4435, 4436, and 4453. The perithallic cells measured 5-8 microns by 6-8 microns.

Only two fossil *Lithothamnium* are known from the Pacific region with this type of growth habit and such small perithallic cells. These are *L.* cf. *L. minae* Lemoine, described by Johnson and Ferris (1949) from the Miocene of West Java, and *L. crispithallus* Johnson, from the Upper Eocene of Saipan. The feature which distinguishes the two species from each other is the size of conceptacles. These are small in *L.* cf. *L. minae* (125-175 microns in diameter) and large in *L. crispithallus* (up to 685 microns).

A well preserved typical specimen of *L. crispithallus* was found in slide 4453, from a bed which immediately overlies those from which slides 4434, 4435, and 4436 were made. The writer, therefore, thinks it probable that the infertile fragments mentioned above belong to *L. crispithallus* rather than to *L.* cf. *L. minae,* and this would fit in with the Eocene foraminifera associated with them.

Additional Lithothamnium debris

Remarks. In addition to the species described above, fragments of *Lithothamnium* were observed in slides 3674A, 4433, 4449, 4452, 4455, 4456, 4457, 4460, 4462, 4474, 4478, 4481, 4497, 4498. Unfortunately, however, these were infertile and inadequate for specific identification.

Genus MESOPHYLLUM Lemoine, 1928

Structurally, this genus lies between *Lithothamnium* and *Lithophyllum.* The tissue resembles that of *Lithophyllum,* except that it more commonly shows pronounced growth zones. The conceptacles, however, are of the *Lithothamnium* type, with numerous apertures in the roofs.

Both crustose and branching types are known. The geologic range of the genus is from the Eocene to the present.

Mesophyllum vaughanii (Howe) Lemoine

Plate III, figures 1 and 2

Lithothamnium vaughanii Howe, 1918, U.S. Nat. Mus. Bull. 103, p. 6-7, pls. 7, 8.

Mesophyllum vaughanii (Howe) Lemoine, 1939, Mat.Carte géol. de l'Algèrie, sér. 1, Paléont., no. 9, p.89, pl. I, figs. 2, 8, 11, 15.

Johnson, (manuscript), Fossil algae from Ishigaki: U.S. Geological Survey Professional Paper.

Description. Plant forms a basal crust from which develop long branches or spines. The tissue of the branches consists of numerous, irregularly disposed, lenticular growth zones. The cells in these zones measure 7-22 microns by 7-12 microns. Conceptacles are numerous. As sectioned, they have diameters ranging up to 500 microns. The majority show sporangia.

Remarks. This is a widespread Upper Eocene species, known from the Mariana and southern Ryukyu Islands of the Pacific, the Mediterranean region, and the Panama Canal Zone.

Age. Upper Eocene.

Locality. Bukit Besungai and west end of Batu Gading.

Figured specimen. Slide 4477 II (2).

Mesophyllum species 1

Plate II, figure 4

Description. Thallus develops as a thin crust with rounded protuberances. Hypothallus thin (about 88 microns) and not well preserved. Perithallus with pronounced, more or less lenticular, growth zones (88 to 130 microns thick) with cells in regular rows. Cells show quite a size range, especially between the centre and margins of the growth lenses. Cells 10-22 microns by 9-12 microns. One large conceptacle observed, diameter 771 microns, height 176 microns, and crowded with sporangia.

Remarks. Represented in the collection studied by several fragments but only one fairly good specimen, which is the slightly oblique section figured. The combination of growth habit, cell measurements, and unusually large size suggests an undescribed species, but the material is inadequate for it to be given a name.

The nearest described species from the Pacific region is *M. savornini* Lemoine from the Lower Miocene of Saipan. It also suggests the Eocene species *M. suganum* (Rothpletz), but it has larger perithallic cells and slightly larger conceptacles.

Age. Probably Upper Eocene (but could be Lower Miocene).

Locality. Bukit Besungai.

Figured specimen. Slide 4481.

Mesophyllum species 2

Plate IV, figure 6

Description. Thallus crustose, probably with small rounded protuberances or short stubby branches. Hypothallus co-axial or plumose, averaging about 120 microns thick; cells 15-24 microns by 9-11 microns. Perithallus of slightly irregular cell layers; cells 10-18 microns by 9-12 microns. Conceptacles up to 468 microns in diameter and 101 microns high.

Remarks. This form suggests *Mesophyllum suganum* (Rothpletz) but has a much better developed hypothallus. Only a single reasonably complete specimen was observed.

Age. Upper Eocene.

Locality. Bukit Besungai.

Figured specimen. Slide 4476 II (1).

Genus LITHOPHYLLUM Philippi, 1837

This genus also has a tissue normally differentiated into a hypothallus and a perithallus. Characteristically, the basal hypothallus is co-axial; that is, formed of regularly curved or arched layers of cells. In some cases, however, it consists of a few irregular or curved rows of cells. Rarely, it is absent. The perithallus is formed of regular layers of cells. Branching species have a well developed co-axial medullary hypothallus surrounded by a thinner marginal perithallus. The sporangia are collected into conceptacles each of which is pierced by a single large opening in the roof for the escape of spores.

The geologic range of the genus is from the Upper Cretaceous to the present.

Lithophyllum borneoense Johnson, n. sp.

Plate IV, figures 1-3

Description. Plant develops as a thin crust with thick warty protuberances. Possibly these may give rise to small pointed branches. The crust consists of a well developed co-axial hypothallus 114-264 microns thick, covered by a few layers of perithallic tissue. Hypothallic cells 24-48 microns by 9-16 microns; perithallic cells 7-20 microns by 7-12 microns. Conceptacles unknown.

Dimensional details (in microns)

Slide	Thickness of hypothallus	Hypothallic cells		Perithallic cells		Cells at base of branch
		Length	*Width*	*Length*	*Width*	
4442	132-220	26-39	10-14	8-11	7-10	23-41 × 8-12
4435	211-264	24-42	10-16	12-20	9-12	
4445	176	36-46	9-16			
3674A	114-229	33-48	11-16	7-10	7-12	

Remarks. This is a rather striking and distinctive form with a crust consisting of strong, well developed, basal co-axial hypothallus, almost no perithallus, and knobs or branches on top. The crust strongly resembles the Miocene *Lithophyllum prelichenoides* Lemoine and has hypothallic cells of about the same size. However, it differs in developing protuberances or short branches.

Age. Upper Eocene.

Locality. West end of Batu Gading.

Type specimen. Slide 4442. Also figured, slides 3674A and 4435.

Lithophyllum besalotos Johnson, n. sp.

Plate IV, figures 4 and 5

Description. Plant forms a thin irregular crust. Several may grow superimposed. Hypothallus thin but distinct, of irregularly curved rows of cells. Perithallus shows irregular growth zones of layers of thick-walled cells. Cells wider than high, arranged like bricks in a wall, with the ends commonly not one above the other. Small conceptacle chambers observed on one specimen, but there is some question whether these represent male conceptacles or conceptacles of sporangia.

Dimensional details (in microns)

Slide	*Thickness of hypothallus*	*Hypothallic cells*		*Thickness of perithallus*	*Perithallic cells*		*Conceptacles*
		Length	*Width*		*Length*	*Width*	
4448	62-88	18-24	10	176-220	8-13	9-19	absent
4449	62	14-25	7-11	273	8-13	11-22	absent
4474II (2)	52-114			132-484	8-12	11-20	absent
4474II (1)	44-88	14-22	8-9	106-352	11-13	12-18 (25)	absent
4474II (1)	68-88	16-18	9-10	660	7-11	9-15	212-231 × 57-63

Remarks. This species is quite unique with its thin but distinct hypothallus suggestive of a *Lithothamnium* and its perithallic tissue looking like a brick wall in vertical section.

Age. Late Middle or Upper Eocene.

Locality. West end Batu Gading and also at Bukit Besungai.

Type specimen. Slide 4448.

Lithophyllum traceyi Johnson

Plate V, figure 4

Lithophyllum traceyi Johnson, (manuscript), Fossil algae from Guam; U.S. Geological Survey Professional Paper.

Description. This is a strongly branching form with relatively thick branches. Sections of the branches show a thick medullary hypothallus surrounded by a well developed marginal perithallus. Medullary hypothallus of arched cell layers showing growth zones. Cells measure 19-45 microns high and 7-12 microns wide. Perithallus of regular cell layers; cells 8-14 microns by 7-11 microns. No conceptacles present.

PLATE III. MESOPHYLLUM AND LITHOPORELLA

Figures 1-2. *Mesophyllum vaughanii* (Howe) Lemoine. Upper Eocene. Batu Gading

1. A nearly vertical section of a branch showing the irregular growth zones and numerous conceptacles filled with sporangia. (× 40).
2. A detail of the same (× 100).

Figure 3. *Lithoporella melobesioides* (Foslie) Foslie. East end of Batu Gading (× 100)

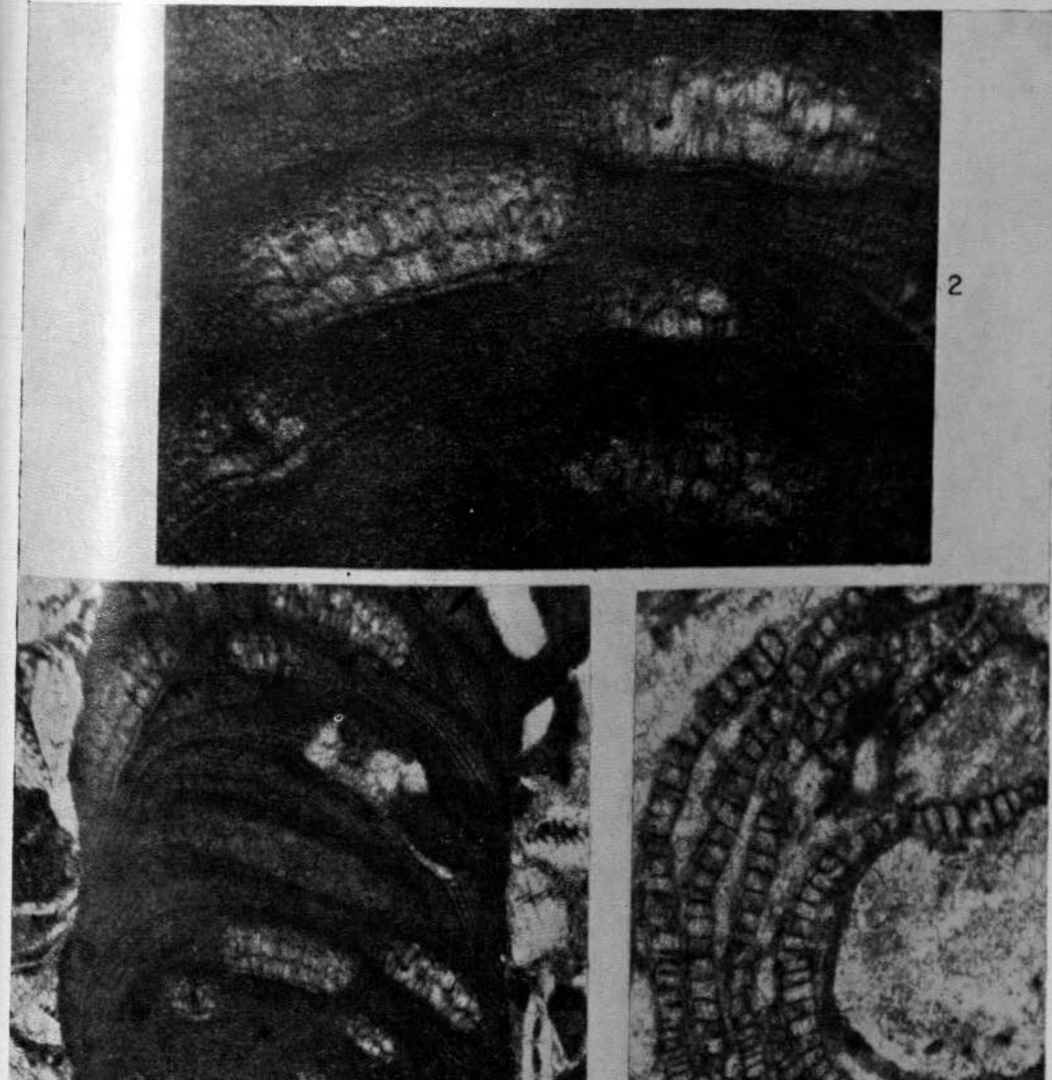

PLATE III

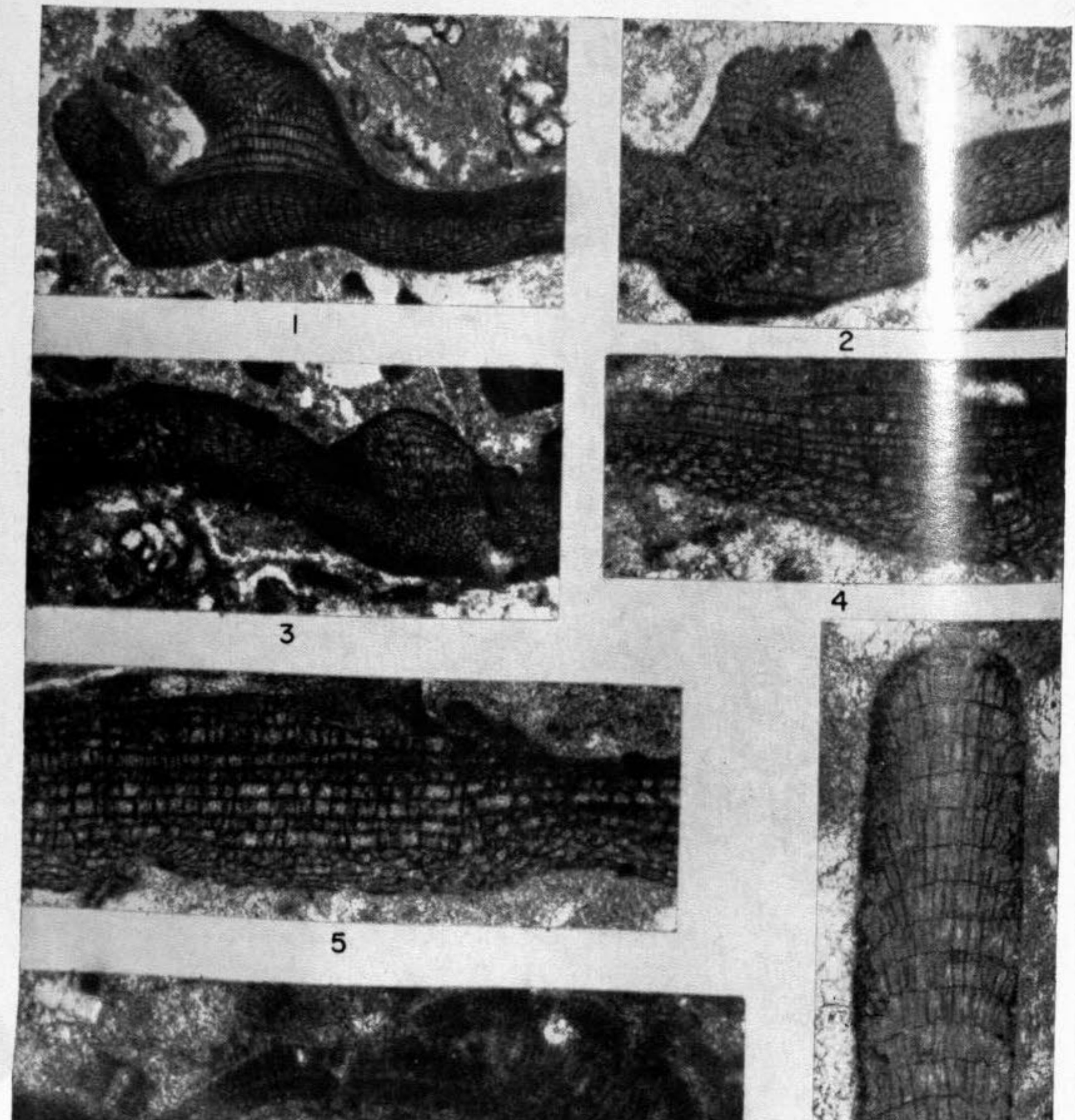

PLATE IV

PLATE IV. LITHOPHYLLUM, MESOPHYLLUM, AND JANIA

Figures 1-3. *Lithophyllum borneoense* Johnson, n. sp. Eocene. West end of Batu Gading. Nearly vertical sections of crusts showing the well developed hypothallus and the protuberances (× 50)

1. The type specimen.

Figures 4-5. *Lithophyllum besalotos* Johnson, n. sp. Eocene. West end of Batu Gading. Vertical sections of the type specimen (× 100)

Figure 6. *Mesophyllum* species 2. Eocene. Bukit Besungai. A vertical section (× 100)

Figure 7. *Jania* species. Bukit Betok (× 100)

Remarks. This species appears to be the same as one recently described by the author from Guam, where it occurs abundantly in the Miocene Maemong limestone (Tertiary E).

The cells of the medullary hypothallus are of about the same size as in *L. glangeaudi* Lemoine, but that species does not show the strongly differentiated tissue shown by *L. traceyi*. It also strongly resembles *L. kladosum* Johnson but has smaller cells.

Age. Miocene.

Locality. East end of Batu Gading.

Figured specimen. Slide 4457.

Lithophyllum sarawakense Johnson, n. sp.

Plate V, figure 1

Description. Plant develops as a thin crust with well differentiated hypothallus and perithallus. Hypothallus around 60-100 microns thick, of curved rows of cells. The cells measure 20-25 microns by 9-10 microns. Perithallus up to 225 microns thick, composed of layers of cells. Cells rectangular, measuring 8-13 microns by 7-11 microns. Conceptacles large, the one figured measured 583 microns in diameter and 192 microns high.

Remarks. The distinctive features of this species are the long, relatively narrow cells and the unusually large conceptacles.

The nearest species from the Pacific area known to the writer is the one described by him as *L.* cf. *L. lingusticum* Airoldi from the boring at Eniwetok, which has similar cell measurements (conceptacles unknown), but which differs in having a thicker and co-axial hypothallus.

Age. Probably Miocene.

Locality. West end of Batu Gading.

Type specimen. Slide 4434 II (2).

Lithophyllum prelichenoides Lemoine

Plate V, figures 2 and 3

Lithophyllum prelichenoides Lemoine, 1917, Soc. géol. France Bull., sér. 4, v. 17, p.262, figs. 8, 9 (1918).

Lemoine, 1939, Mat. Carte géol. de l'Algérie, sér. 1, Paléont., no. 9, p.99, figs. 65-66, p.107.

Johnson, 1957, U.S. Geological Survey Professional Paper 280-E, p.229, pl. 49, figs. 1, 2.

Description. Thallus thin, encrusting, with a well developed co-axial hypothallus and a thin perithallus. Hypothallus 132-270 microns thick, with cells 18-27 microns by 8-11 microns. Perithallic tissue quite regular, 100-275 microns thick, with cells 7-12 microns by 6-11 microns. No conceptacles observed.

Remarks. The Borneo specimens are typical of this widespread Miocene species.

Age. Miocene, probably Lower Miocene.

Locality. East end of Batu Gading.

Figured specimen. Slides 4457 II (1) and 4459.

Genus LITHOPORELLA Foslie, 1909

Thallus consists of a single layer of very long cells except around the conceptacles where several layers of smaller cells may be present. Cells show a large range in size in a single plant. Each conceptacle has a single pore.

Plants form small thin crusts which may grow attached to other algae, coral, shells, and other organisms. A number of thalli may grow superimposed to form crustose masses.

The geologic range of the genus is from the Upper Jurassic to the present.

Lithoporella melobesioides (Foslie) Foslie

Plate III, figure 3

Mastophora (*Lithoporella*) *melobesioides* Foslie. Weber van Bosse and Foslie, 1904, *Siboga-*Expeditie Mon. 61, p.73-77, figs. 30-32.

Melobesia (*Lithoporella*) *melobesiodes* Foslie. Lemoine, 1939, Mat. Carte géol. de l'Algérie, sér. 1, Paléont., 9, p.108-110, figs. 78-79.

Lithoporella melobesioides (Foslie) Foslie. Lignac- Grutterink, 1943, Geol.-mijnb. genootsch. Nederland en Kolonien Verh., Geol. ser., jagu 113, p.292-293, pl. 2, fig. 8.

Lithoporella (*Melobesia*) *melobesioides* (Foslie) Foslie. Johnson and Ferris, 1949, Jour. Paleontology, v. 23, no. 2, p.196-197, pl. 37, figs. 4-5, pl. 39, fig. 2.

Lithoporella melobesioides (Foslie) Foslie. Johnson and Ferris, 1950, B.P. Bishop Mus. Bull. 201, p.18, pl. 8, fig. A.

Johnson, 1957, U.S. Geological Survey Professional Paper 280-E, p.234, pl. 37, fig. 5, pl. 43, figs. 1-2, pl. 49, fig. 4, pl. 56, fig. 6.

Description. Thallus consists of a single layer of large cells except around the conceptacles. Cells elongated vertically and commonly slightly obliquely. Cells range greatly in size, even in a single slice across a thallus. Dimensions are tabulated below.

Dimensional details (in microns)

Slide	*Cell size*	*Conceptacle*
3674A	51-79 × 13-35	Not present
3674E	88-99 × 12-30	Not present
3674F	41-51 × 12-22	Not present
4434 II (3)	33-63 × 9-18	Diameter 324, height 213
4451	77-87 × 13-21	Not present
4457	25-56 × 11-28	Not present

Remarks. Fragments attributed to this species occur on many slides. Only a few were measured and used in this description. The above dimensions all fit within those of the ubiquitous, highly variable *L. melobesioides.*

Geologic range. Eocene to Recent. Hence of no stratigraphic value.

Locality. Batu Gading, both east and west ends.

Figured specimen. Slide 4457.

Genus MELOBESIA Lamouroux, 1812

The thallus forms a thin crust, one to several layers thick. Cells cubic or horizontally elongated. Conceptacles have several to many pores in the roofs.

Infertile specimens of this genus cannot always be distinguished from infertile specimens of *Dermatolithon.* The specimens discussed here were recognized by their similarity to the material previously described by the author from Saipan and Guam.

The genus has a geologic range from Eocene to Recent.

Melobesia cuboides Johnson

Plate V, figure 6

Melobesia ? cuboides Johnson, 1957, U.S. Geological Survey Professional Paper 280-E, p.234, pl. 43, figs. 6, 7.

Description. Thallus monostromatic. Cells cubic or horizontally elongated with thick walls. They measure 10-30 microns by 9-18 microns. No conceptacles present.

Remarks. These are identical with the material described from the Upper Eocene of Saipan.

Age. Upper Eocene.

Locality. Batu Gading and Kejin Tugang.

Figured specimen. Slide 4672.

Melobesia cf. M. cuboides Johnson

Melobesia ? cuboides Johnson, 1957, U.S. Geological Survey Professional Paper 280-E, p.234, pl. 43, figs. 6, 7.

Description. Similar to *M. cuboides* except having appreciably longer cells. Cells measured 9-17 microns by 19-43 microns.

Remarks. Represented by several fragments on a single slide (3674C).

Age. Eocene.

Locality. Lower part of Batu Gading.

Genus DERMATOLITHON Foslie, 1899

Plants belonging to this genus develop thin crusts that are circular or irregular in outline. They grow on other algae, coral, shell and other hard objects. Thalli may grow one on another. Hypothallus of one or two rows of cells that are vertically and obliquely elongated. Perithallus of a few layers of nearly cubic cells. Conceptacles slightly to strongly convex, with a single aperture in the roof of each.

The genus has a geologic range from the Eocene to the present.

Dermatolithon debris

Remarks. A number of small fragments attributed to this genus, but inadequate for specific description, were observed on slides 3674F, 4451, 4459, and 4480.

Sub-family CORALLINOIDEAE

The plants form small bushy growths composed of tufts of segmented branches. The segments are calcified, but the nodes between them are not. Consequently, the fossils commonly consist of the segments or fragments of them.

Numerous fragments of these algae were observed in the Borneo collections. The majority could be readily assigned to genera, but only a few could be identified specifically.

Genus JANIA Lamouroux, 1812

The plant consists of masses of slender dichotomously branching fronds. Each frond is a series of slender segments formed of tiers of hypothallic cells surrounded by a narrow perithallus that is characteristically restricted to a single layer of small rectangular cells. The hypothallic cells tend to be wider in proportion to length than in most genera of articulate corallines. In many instances, they are elongately wedge shaped in section, and the successive tiers of cells tend to meet along irregular lines.

The genus has a geologic range extending from the Late Cretaceous to the present.

Jania species

Plate IV, figure 7; plate V, figure 5

Remarks. A few slides contained fragments of algae belonging to this genus. All were so badly worn and fragmented that specific identification was not certain. On the basis of cell measurements alone, these may be compared with material described from Saipan as follows:

Dimensional details (in microns)

Slide	*Cells of medullary hypothallus*	*Resembles*
4435	38-78 × 12-20	*Jania vetus* Johnson
4441	69-85 × 10-14	*Jania vetus* Johnson
4453	42-55 × 14-18	*Jania* species B Johnson
3674	29-33 × 7-15	*Jania* species A Johnson
4495	43-54 × 11-15	*Jania* species A Johnson

It must be stated, however, that these identifications are too uncertain to be of any value in determining the age of the limestones.

Age. Eocene and Miocene.

Locality. Batu Gading and Bukit Betok.

Figured specimens. Slides 4495 and 4441.

Genus CORALLINA Linnaeus, 1758

The plants are clusters of segmented stems which branch at close intervals, ordinarily in a plane. Branching typically pinnate (dichotomous to trichotomous or irregular). Perithallus weakly developed and inconspicuous, the greater part of the individual segment consisting of hypothallic tissue. Segments mainly clavate, flattened cylindrical, or flattened Halimeda-like but varying widely in shape. Conceptacles lateral or terminal.

The genus has a geologic range from the Eocene to the present.

Corallina debris

Remarks. Fragments of loose segments of *Corallina* were observed in slides from practically all the localities, but none of them were sufficiently complete to warrant making cell measurements or description.

Slides containing debris of *Corallina* were 4431, 4433, 4434, 4435, 4436, 4437, 4440, 4441, 4442, 4445, 4451, 4452, 4453, 4454, 4455, 4456, 4457, 4458, 4459, 4460, 4461, 4464, 4465, 4472, 4486, 4494, 4495, 3674A, 3674D, 3674E, 3676, and 3679.

CHLOROPHYTA (GREEN ALGAE)

Family DASYCLADACEAE

Genus CYMOPOLIA Lamouroux, 1816

This genus includes small heavily calcified plants formed of a series of rounded cushion shaped or short cylindrical segments. Each segment consists of a thick central stem from which whorls of slender primary branches develop at regular intervals. Each primary branch then gives rise to a tuft of secondary branches. The spherical to nearly cylindrical sporangia are located within the cluster of secondary branches on a short modified secondary branch.

The genus has a geologic range from Late Cretaceous to Recent.

A few slides in the Borneo collections contained fragments of *Cymopolia.* Unfortunately, all the fragments were somewhat recrystallized and did not permit too accurate identification. They represent two species.

Cymopolia saipania Johnson

Plate I, figure 5; plate II, figure 5

Cympolia saipania Johnson, 1957, U.S. Geological Survey Professional Paper 280-E, p.241, pl. 51, figs. 7-12.

Remarks. Judging by the dimensions of the segments and the size of the sporangia, most of the observed fragments belong to this species.

Age. Probably Lower Miocene.

Locality. West end of Batu Gading and east end of Batu Gading.

Figured specimens. Slides 4434, 4459 II (3), and 4457.

Cymopolia species ?

Remarks. Specimens of *Cymopolia* too badly preserved to permit identification were observed in slides 3674E, 4441, and 4443.

Age. Eocene.

Locality. West end of Batu Gading.

Family CODIACEAE

Genus HALIMEDA Lamouroux, 1812

Halimeda plants are small bushy tufts of segmented branches. The segments show a variety of shapes and sizes. They may be broad and leaf-like, or flattened subcylindrical, or subconical. Calcification starts at the outer margins and works inward. Young growths show but little calcification, while older segments may be strongly calcified.

The genus has a geologic range from Late Cretaceous to Recent.

Recent species are separated largely on the shape of the segments, structure of the nodes between the segments, and character of the branching. The fossils commonly consist of individual segments which can seldom be assigned to species on the basis of fragments cut across in petrographic slides.

Halimeda fragments were observed in numerous slides from both Eocene and Miocene limestones from all the Borneo localities.

Slides containing *Halimeda*: 3674A, 3674D, 3674E, 3674F, 3677, 4434, 4435, 4441, 4442, 4443, 4444, 4447, 4451, 4455, 4456, 4457, 4460, 4461, 4464, 4474, 4478, 4480, 4483, 4495, 4498, 4636, 4667.

PERFORATING ALGAE

Fine algal threads perforating fragments of shell, coral, and other organic debris were observed in several of the slides examined. They were most common in the lower beds of the Miocene at Batu Gading. These were not studied but are mentioned as matter of scientific interest.

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PLATE V. LITHOPHYLLUM, MELOBESIA, AND JANIA

Figure 1. *Lithophyllum sarawakense* Johnson, n. sp. Probably Mocene. West end of Batu Gading A vertical section of the type specimen (× 100)

Figures 2-3. *Lithophyllum prelichenoides* Lemoine. Miocene. East end of Batu Gading. Sections showing the well developed co-axial hypothalus (× 50)

Figure 4. *Lithophyllum traceyi* Johnson. Miocene. aBtu Gading (× 50)

Figure 5. *Jania* species. Eocene. Batu Gading. Nearly longitudinal section of a fragment of a segment (× 40)

Figure 6. *Melobesia cuboides* Johnson. Eocene. Kejin Tugang. Section of a mass of intergrown plants (× 50)

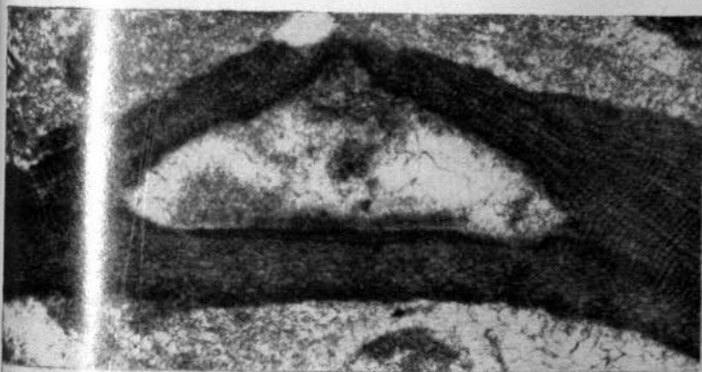

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PLATE V

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INDE

NOTE: The more important page erences are shown in italics

GEOLO

SEDIMENTARY ROCKS

AGE — LETTER CLASSIFICATION

SUAI AREA

QUATERNARY

ALLUVIUM Sand, silt, clay, and peat. Some low terraces of sand and gravel

JERUDONG TERRACE White sand and quartz-pebble gravel

Unconformity

PLIOCENE — Tgh

LIANG FORMATION Clay with shells and plant remains; boulder deposits. Outcrop too small to show on the map

MIOCENE including Aquitanian — Tf, Te

BELAIT FORMATION (Be) Sandstone, shale, and lignite

LAMBIR FORMATION (La) Sandstone, shale, lignite, calcareous sandstone, and limestone

SETAP SHALE FORMATION (S) Shale and subordinate sandstone. Some marl, and limestone (a)

SIBUTI FORMATION (Si) Shale, marl, siltstone, and thin limestone beds

TANGAP FORMATION (Tg) Marl and limestone including SUBIS LIMESTONE MEMBER (a) Limestone of mountains; (b) Limestone under flat country.

NYALAU FORMATION (Ny) Sandstone shale, and thin seams of lignite

OLIGOCENE — Tcd

EOCENE — Tb

PALAEOCENE — Ta

MIDDLE BARAM AREA

ALLUVIUM Possibly includin low terraces

JERUDONG TERRACE Small p of cobble gravel overlying Formation. Too small to show on t

Unconformity

LIANG FORMATION (L) PATAN M lignite, conglomerate, clay, sa tuffaceous beds

Unconformity

BELAIT FORMATION (Be) Sa shale, and lignite

MELIGAN FORMATION (Me) sandstone, subordinate shale mudstone

SETAP SHALE FORMATION (S) and subordinate sandstone, inc BATU BELAH MEMBER (BB), and limestone (a)

Disconformity, in places unconformity

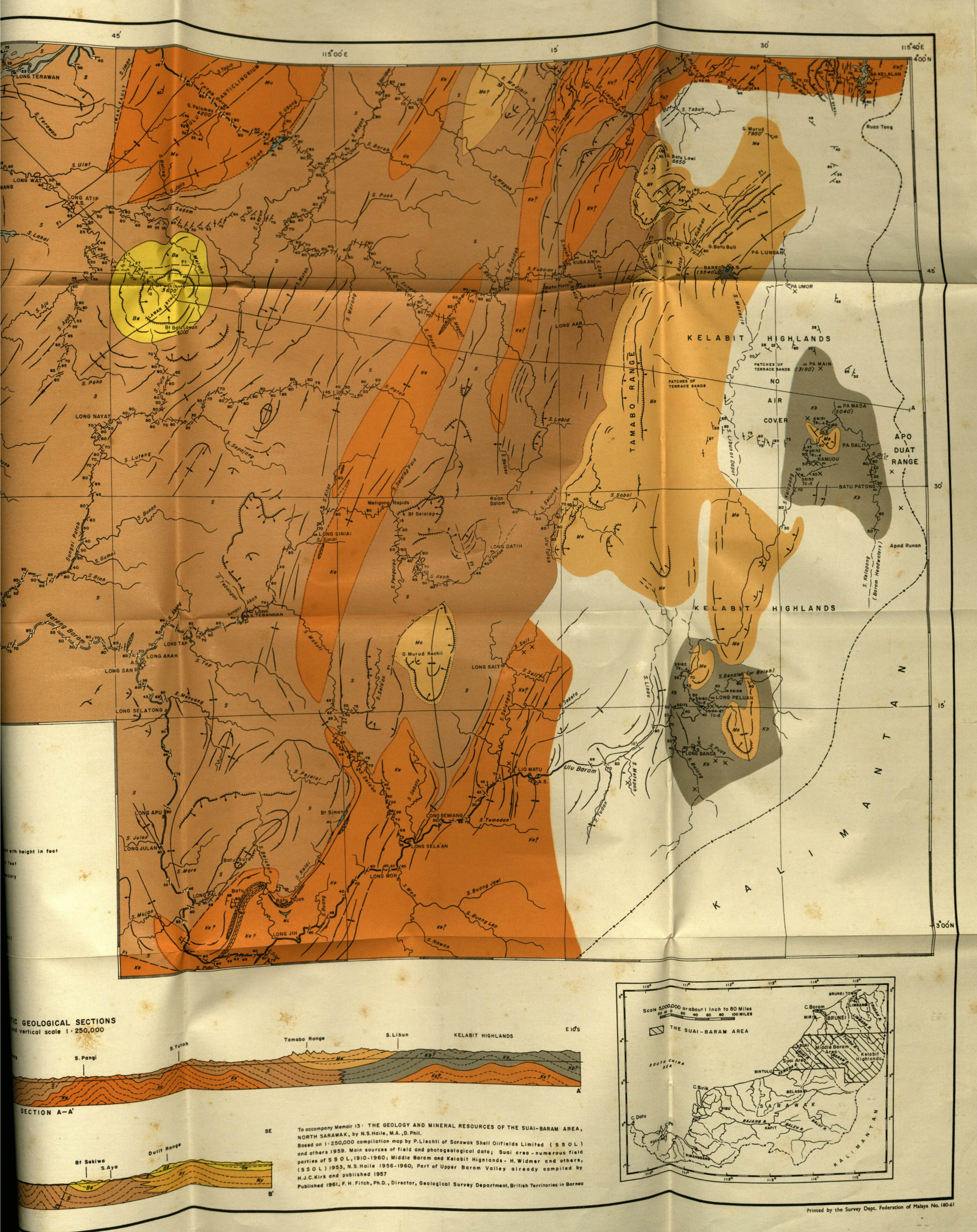
MELINAU LIMESTONE FORMATION Limestone, mostly massive. Out somewhat exaggerated

KELALAN FORMATION (Ke) S sandstone, and limestone (a) TE MEMBER (Tm) comprises sands calcareous sandstone, limestone subordinate shale

MULU FORMATION (Mu) S sandstone, and rare conglome

IGNEOUS ROCKS

BASALT DYKES, probably Pliocen younger (confined to Tinjar Val


KELABIT HIGHLANDS
TAMABO RANGE
APO DUAT RANGE
KALIMANTAN
NO AIR COVER
PATCHES OF TERRACE SANDS
LONG TERAWAN
LONG ATIP
LONG NAYAT
LONG SINIAI
LONG DATIH
LONG AKAH
LONG SAN
LONG SELATONG
LONG APU
LONG JULAN
LONG JIH
LONG MOH
LONG SELA'AN
LONG SEMIANG
LIO MATU
Ulu Baram
LONG SAIT
LONG PELUAN
LONG BANGA
LONG AAR
KUBAAN
BARIO
PA LUNGAN
PA UMOR
PA MAIN (3180')
PA MADA (3040')
PA DALI
RAMUDU
BATU PATONG
Apad Runan
Ruan Tang
PA KELALAN
G. Murud 7950'
Batu Lawi 6650
G. Murud Kechil
Meligong Rapids
Bt Selalap
Bt Simon
S. Kelapang (Baram Headwaters)
115°00'E
15'
30'
115°40'E
4°00'N
45'
3°00'N
GEOLOGICAL SECTIONS
vertical scale 1 : 250,000
SECTION A–A'
S. Pangi
S. Tutoh
Tamabo Range
S. Libun
KELABIT HIGHLANDS
E10°S
SE
Bt Sekiwa
S. Aya
Dulit Range
Scale 5,000,000 or about 1 inch to 80 Miles
THE SUAI-BARAM AREA
SOUTH CHINA SEA
BRUNEI TOWN
C. Baram
MIRI
BRUNEI
BINTULU
C. Sirik
C. Datu
SARAWAK
KALIMANTAN
To accompany Memoir 13: THE GEOLOGY AND MINERAL RESOURCES OF THE SUAI-BARAM AREA, NORTH SARAWAK, by N.S. Haile, M.A., D.Phil.
Based on 1:250,000 compilation map by P. Liechti of Sarawak Shell Oilfields Limited (S S O L) and others 1959. Main sources of field and photogeological data; Suai area - numerous field parties of S S O L, 1910-1960; Middle Baram and Kelabit Highlands - H. Widmer and others, (S S O L) 1953, N.S. Haile 1956-1960; Part of Upper Baram Valley already compiled by H.J.C. Kirk and published 1957
Published 1961, F. H. Fitch, Ph.D., Director, Geological Survey Department, British Territories in Borneo
Printed by the Survey Dept. Federation of Malaya No. 180-61