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LABILE QUARTZ-POOR SEDIMENTS FROM YOUNG MOUNTAIN RANGES IN NORTHEAST PAPUA

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BY

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FIGS. 1–4, DECEMBER, 1970

LABILE QUARTZ-POOR SEDIMENTS FROM YOUNG MOUNTAIN RANGES IN NORTHEAST PAPUA[1]

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ABSTRACT

The young mountain ranges of northeast Papua have sharp crests and very steep side slopes mantled by shallow weakly weathered soils. Rock debris from slope denudation and stream corrasion is rapidly transported by streams and is deposited as alluvial fans and plains and littoral deltas and beaches.

The sediments range from coarse conglomerate in some fans to clay in freshwater and some tidal swamps. The present study has concentrated on the fine sand fractions which have about 4 percent of quartz and 1 percent opaque minerals. Of the remainder one-half is rock fragments in various stages of weathering, one-quarter is unstable light minerals (mostly plagioclase), and one-quarter is unstable heavy minerals (mostly ferromagnesian minerals). These sediments have a dioritic and gabbroic chemical composition and are classed as plagioclass-rich litharenites. It is concluded that the terrestrial part of the sedimentary cycle is extremely rapid in the active orogenic portions of the humid tropics.

Only the beach sands have reached a mature stage (with $\sigma\phi$ under 0.5), but the grains are mostly angular.

INTRODUCTION

Northeast Papua is an active orogenic mountain zone where differential rapid uplift and constructional volcanism have produced a high relief. With high rainfall downward corrasion has cut deep ravines and the very rapid weathering coupled with vigorous slope erosion have graded the interfluves to ridges with sharp crests and very steep straight slopes (35 to 40°) mantled by shallow weakly weathered soils and weathering profiles.

Rock debris from slope denudation and stream corrasion is rapidly transported by streams (and some mudflows) from the mountains and much of it is deposited as alluvial fans and plains and littoral deltas and beaches. There is a sharp topographic contrast, with abrupt transition, from very steep mountain and hill ridges to low-angle and nearly level plains.

Climate and vegetation range from subhumid tropical grassland and savannah to wet tropical rain forest (Ruxton *et al.*, 1967).

The major environments (fig. 1) of a 2,700 sq mile area in northeast Papua were mapped by photointerpretation and extensive ground traverses during a land resources survey in 1963 (Ruxton *et al.*, 1967). From some 470 auger holes 283 samples were collected and examined qualitatively both by eye and under the microscope and of these 74 were selected as being were then mechanically analysed and the fine sand (0.075 to 0.21 mm) separated into light and heavy fractions with bromoform. Some 30,000 grains of the fine sand were then counted under the microscope. These mineralogical data are presented in Table 1.

Rock fragments in various stages of weathering form a majority of the fine sand fractions and an attempt was made to identify the various rock types in the less weathered fragments (table 1). In size fractions coarser than fine sand the fragments are practically all bedrock except in a few samples where authigenic carbonate and/or ironstone concretions are common.

Discrete primary mineral grains are commonest in the fine sand and coarse silt, and clay minerals dominate the fine silt and clay fractions. Kaolin with subordinate chlorite and some illite dominates the clay fractions in soils on mountain slopes covered by rain forest whereas minerals of the smectite group dominate the soil clay in grassland and savannah. Volcanic ash layers, however, weather to allophane.

SOURCE AREAS

Erosional Mountains and Hills

Weakly weathered soils on the very steep slopes of mountains and hills are the source of most of the sediments deposited on the plains. Their pedology has been described by He-

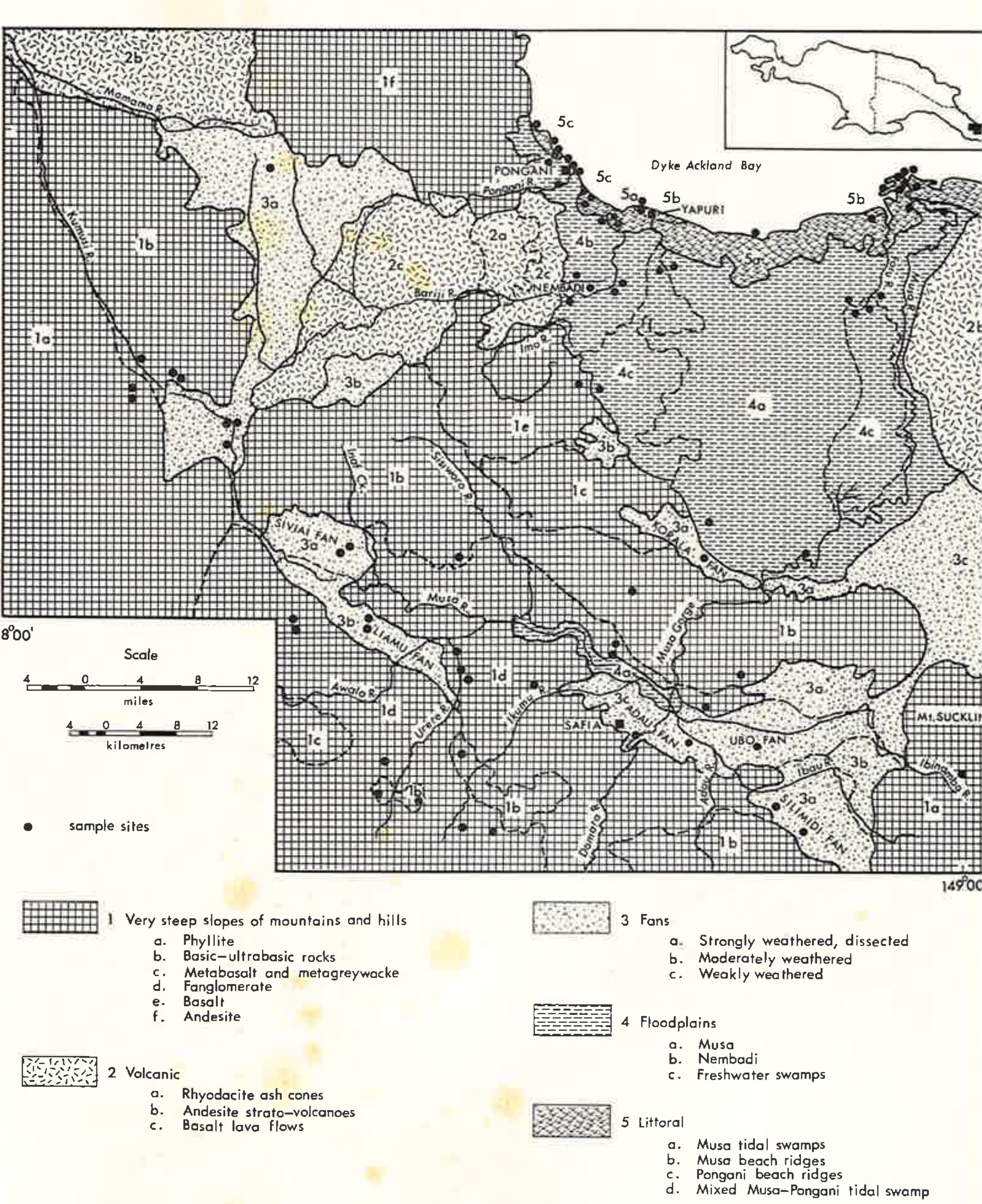


FIG. 1.—The major environments of the Safia-Pongani area in northeast Papua.

morphics (1a in fig. 1), produce minor plagioclase, quartz, opaques, pale clinoamphibole (mainly tremolite-actinolite) and epidote. Calcite is abundant around Mount Suckling in the southeast corner of the area.

The basic-ultrabasic rocks (1b in fig. 1) p duce common plagioclase, enstatite, serpent and pale clinoamphibole (mostly actinoli with minor opaques and augite.

The early Pleistocene fanglomerate, or

TABLE 1.—*Mineral composition of fine sand fractions from the major environments*

Environment			Number of samples	Number counted	Heavy fraction	Light fraction													Heavy fraction																								
													Rock fragments																					Hornblende									
						Quartz	Plagioclase	Potash feldspar	Sanidine	Muscovite	Calcite	Organic-carbonate	Chlorite-serpentine	Basalt	Andesite-dacite	Rhyodacite	Phyllite	Weathered	Clay grains	Magnetite-ilmenite	Hematite-limonite	Spinel	Rutile	Magnesite	Biotite	Epidote	Chlorite	Serpentine	Olivine	Lawsonite	Glaucophane	Pale clinoamphibole	Cummingtonite-grunerite	Green	Brown	Blue-green	Oxy-	Anthophyllite	Hypersthene	Enstatite	Augite	Titanaugite	Clinozoisite
Very strongly weathered crests			6	2200	38	30	3	+	1	0	0	0	1	1	1	1	0	0	[illegible]	97	2	+	+	0	0	0	+	+	0	0	0	0	0	1	+	+	+	0	+	+	+	0	0
Very steep mountain and hill slopes	Metabasalt and metagreywacke		4	1800	34	1	3	—12—		0	0	0	4	—31—		+	0	27	[illegible]	13	2	0	0	0	0	4	3	0	+	0	0	25	0	2	+	1	0	0	3	11	36	0	+
	Basic-ultrabasics		4	1600	43	0	18	0	1	0	0	0	33	2	1	0	0	30	[illegible]	11	1	0	0	0	+	1	+	24	2	0	0	22	0	1	+	1	0	+	1	28	6	2	0
	Phyllite		4	1200	10	3	4	+	+	+	1	0	4	+	0	0	67	5	[illegible]	24	12	1	+	0	2	17	4	0	1	0	0	20	0	4	4	0	+	3	1	2	5	0	0
	Fanglomerate		2	1200	23	2	28	+	12	+	+	0	7	2	1	1	+	40	[illegible]	14	3	0	0	0	1	8	1	0	0	0	0	19	1	20	5	+	1	0	10	12	5	0	0
Fans			3	1200	38	6	13	1	+	+	+	0	4	17	8	+	27	16	[illegible]	6	+	0	+	+	2	12	1	2	+	0	+	23	+	4	12	2	1	2	1	12	19	0	1
	Strongly-weathered Korala-Siviai		2	800	15	48	39	0	5	0	0	0	0	1	2	+	0	+	[illegible]	61	6	+	0	0	+	7	0	0	0	0	0	1	0	21	1	+	1	0	1	1	+	0	+
	Strongly weathered Silimidi		2	700	36	2	40	+	8	0	1	0	1	1	1	3	11	27	[illegible]	40	5	+	0	0	+	7	+	0	0	0	0	1	0	39	2	0	2	0	+	0	3	0	1
	Moderately weathered Liamu		2	700	18	6	38	+	12	0	0	0	0	1	4	1	0	30	[illegible]	18	14	0	0	17	2	2	5	0	0	0	0	10	0	10	2	+	+	0	4	13	3	0	0
	Weakly weathered Ubo-Adau		2	800	34	6	18	0	4	0	20	0	4	4	3	2	9	20	[illegible]	8	1	1	0	5	+	29	0	0	0	0	+	19	1	11	2	2	+	+	8	7	6	0	+
Floodplains	Upper Musa-Domara[1]		2	800	30	7	30	2	11	4	1	0	3	4	2	1	6	21	[illegible]	5	2	0	+	+	3	12	3	1	1	4	2	11	1	20	9	3	1	+	10	5	9	0	0
	Musa		5	2400	17	5	20	+	6	0	6	0	6	4	3	1	+	42	[illegible]	3	+	+	0	2	3	8	2	1	1	0	+	22	1	20	4	3	1	1	5	16	7	+	+
	Freshwater swamps		3	1100	27	6	42	0	13	0	2	0	2	2	4	4	+	17	[illegible]	4	1	+	+	+	2	11	+	+	1	+	0	11	+	36	6	2	2	+	6	13	6	0	+
	Nembadi		7	2500	18	6	41	+	4	0	+	0	+	2	22	18	0	4	[illegible]	13	1	0	+	+	15	6	0	0	3	0	+	2	0	23	5	+	7	+	12	4	9	0	0
Littoral	Delta	Sandy	4	1200	28	4	14	1	2	+	12	0	8	2	3	1	12	38	[illegible]	3	+	0	+	2	1	6	4	3	1	+	1	21	2	12	5	4	2	+	9	16	7	1	+
	Topset	Silty	4	2100	17	2	17	+	7	+	21	+	6	+	1	1	5	35	[illegible]	3	+	+	0	7	1	5	1	2	2	+	+	20	1	14	4	1	2	+	6	26	5	+	+
	Tidal mud		3	1800	34	3	19	+	7	+	2	+	2	2	3	2	8	46	[illegible]	2	+	0	+	+	3	4	+	1	1	+	+	24	2	19	5	1	1	+	6	23	9	+	+
	Beach sand	Musa	5	1800	28	3	17	+	1	0	4	+	5	3	2	2	12	48	[illegible]	4	+	+	+	2	2	8	12	3	4	+	+	23	+	9	4	3	1	1	7	10	6	1	+
		Pongani	5	1800	31	4	49	+	3	0	3	2	+	7	13	5	0	11	[illegible]	5	+	0	1	+	4	3	+	+	2	0	0	1	0	32	3	0	6	1	28	2	12	0	0
		Mixed	5	1800	32	5	42	+	3	0	+	+	1	8	15	7	3	13	[illegible]	4	+	+	1	0	3	5	2	1	2	0	0	11	+	24	6	2	5	1	16	5	12	+	+

[1] Alluvium from small terraces.

Volcanic Landforms and Ash Layers

In general the soils on the Late Pleistocene and Recent volcanoes and ash-fall layers are weakly weathered.

The rhyodacite ash cones, or Manna Volcanics (2a in fig. 1), have common quartz and plagioclase. The ash-fall layers are similar but have a notable content of sanidine.

The basalt lava flows and cones, or Uoivi Volcanics (2c in fig. 1) have minor augite, olivine and plagioclase.

There are two Recent andesite strato-volcanoes (2b in fig. 1), Mount Victory in the east with common plagioclase and brown hornblende, and Mount Lamington in the northwest with common plagioclase and green hornblende. Mount Lamington has also produced thick widely spread ash-fall layers which on weathering give dominant plagioclase and green hornblende (Ruxton, 1966).

DENUDATION AND TRANSPORTATION

The high rainfall and temperature of this humid tropical environment favours a high rate of chemical weathering. Thus dacite glass in ash-fall layers on ridge crests has a half-life of between 3,000 and 6,000 years and the average loss of silica per unit area is between 4 and 6 mg/cm²/year (Ruxton, 1968). The rate of denudation, effected by mass movement and slope wash, is also high, being about 45 cm (1.5 ft) per 1,000 years with a local relief of 365 m (1,200 ft) in the Hydrographers Range (1f in fig. 1; Ruxton and McDougall, 1967). Denudation rates are even higher on precipitous slopes (over 40°) where slumps and debris slides and avalanches occur. On the very steep slopes (35 to 40°) weathering and erosion are balanced giving shallow weakly weathered soils.

The detritus supplied by mass movement and slope wash plus that produced by vertical corrasion is rapidly transported from the mountains and hills by perennial, poorly graded torrents with bouldery or cobbly beds. In the northwest the Pongani and Bariji Rivers and their tributaries drain most of the volcanic landforms. Most of the remainder of the area is drained by the Musa River and its tributaries.

In about mid-Pleistocene time the Musa River cut a deep gorge through the basic-ultrabasic rocks and most of the coastal plain has been built by detritus transported through this gorge.

DEPOSITION

Fans

Two types of fan are developed at the mountain and hill fronts: mudflow fans and stream fans. Both types have surface slopes ranging from 15′ to 5°.

Debris from large slumps flows out of the mountains onto the plains as a mudflow leaving the mountain valley deeply aggraded. Fluvial action then transports this valley fill, depositing gravel and boulders over the mudflow. Repeated slumping leads to the formation of layered mudflow boulder fans. The Silimidi and Siviai fans are examples of this. Stream fans are built from the bedload of streams and range in texture from gravelly to bouldery. The Ubo and Adau fans are examples of this.

Stream fan sediment is nearly as poorly sorted as the weakly weathered soils on the very steep mountain and hill slopes (table 2 and fig. 4). Mineralogically each fan is a direct reflection of its source area (table 1 and fig. 1). The fans vary greatly in age and degree of dissection. With age there is a tendency for a concentration of opaque minerals and quartz as well as some growth of ironstone concretions. The early Pleistocene fans and basin-fill deposits, the Domara River Beds, have been uplifted and dissected into ridge and ravine landforms and are now contributing second cycle sediments to the recent fans.

TABLE 2.—*Inman's coefficients of some mechanically analysed soil and sediment (derived graphically)*

Environment	Median Diameter		Mean Diameter		Sorting $\sigma\phi$	Kurtosis $\beta\phi$	First Skewness Factor $\alpha\ \phi$	Second Skewness Factor $\alpha_2\phi$
	Md ϕ	mm	M ϕ	mm				
Weakly weathered soil on very steep slopes	0.60	0.66	1.59	0.33	4.37	n.d.	0.23	n.d.
Medium grained fan sediment	−0.90	1.87	−0.45	1.35	3.99	0.59	0.11	0.51
Fine grained fan sediment	2.00	0.25	1.51	0.35	2.61	1.43	−0.19	0.34

The toes of the larger fans are often swampy and at the base of the Ubo fan calcium carbonate is being deposited as concretions in the fan sediment and as travertine and pisolites in the smaller distributary streams. Here secondary calcite makes up one third of the fine sand fraction.

Floodplains

The alluvium is differentiated into gravelly and sandy deposits from bedload, forming local scroll plains, and deposits from suspended load (Table 2 and fig. 4). The deposits from suspended load are further differentiated into coarse silt on levees, fine silt on backplains and clay in freshwater swamps. The bedload and coarse silt on levees are in a submature textural stage (Folk, 1964).

Most of the coastal plain has been built up by prior meander tracts of the Musa River (4a in fig. 1) and it is margined on both sides by freshwater swamps (4c in fig. 1). In the northwest a small strip of alluvium (4b in fig. 1) is derived from the Pongani and Bariji Rivers which drain volcanic lands.

The Musa alluvium on the coastal plain contains common plagioclase and minor calcite, sanidine, quartz, pale clinoamphibole, green hornblende and epidote (table 1). Upstream in the headwaters of the Musa River the alluvium also contains minor brown hornblende and opaques with rare (0.5 percent) lawsonite and glaucophane, while in the Domara River alluvium there is also minor epidote, hypersthene, augite and muscovite.

In contrast the Nembadi alluvium derived from volcanic lands has abundant plagioclase with minor quartz, sanidine, green hornblende, biotite, opaques and hypersthene.

In the freshwater swamps deposition of the clay is so slow that there is a marked accession of volcanic ash-fall material. In the fine sand, which makes up 4 percent of the sediment, there is a mixture of "Musa alluvium" minerals and ash-fall minerals: plagioclase, green hornblende and sanidine from the intermediate and acid volcanoes.

Littoral Plains

Most of the intertidal zone is covered by tall mangrove forest (5a in fig. 1) and consists of undisturbed prior deltas of the Musa River and

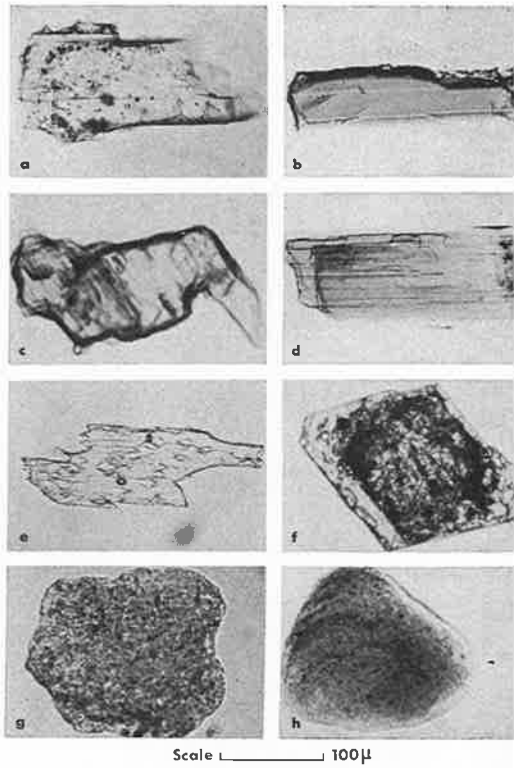


FIG. 2.—Mineral grains of the fine sand fracti
a, zoned plagioclase from alluvium; b, euhedral gre
hornblende from alluvium; c, ragged hypersthe
from beach sand; d, prismatic actinolite from san
topset delta beds; e, etched enstatite from immatu
soil; f, weathered euhedral lawsonite from alluviu
g, sub-round clay grain from beach sand; h, w
rounded clay grain from beach sand.

a notable content of concretionary carbonat
They have common plagioclase and calcite wi
minor enstatite, pale clinoamphibole and gre
hornblende (Table 1). Tidal muds accreting
the mangrove swamps, along with patches
peat, have a similar mineralogy in their fo
percent of fine sand except that calcite and ca
bonate concretions are absent.

The Musa beach sand (5b in fig. 1) has con
mon plagioclase with minor pale clinoamphibol
calcite, chlorite and enstatite.

The Pongani beach sand (5c in fig. 1) derive
largely from volcanic lands, has abundant pl
gioclase with minor green hornblende and hy
persthene.

Just west of Yapuri the beach sand on d
graded beach ridges (now tidal swamp) is

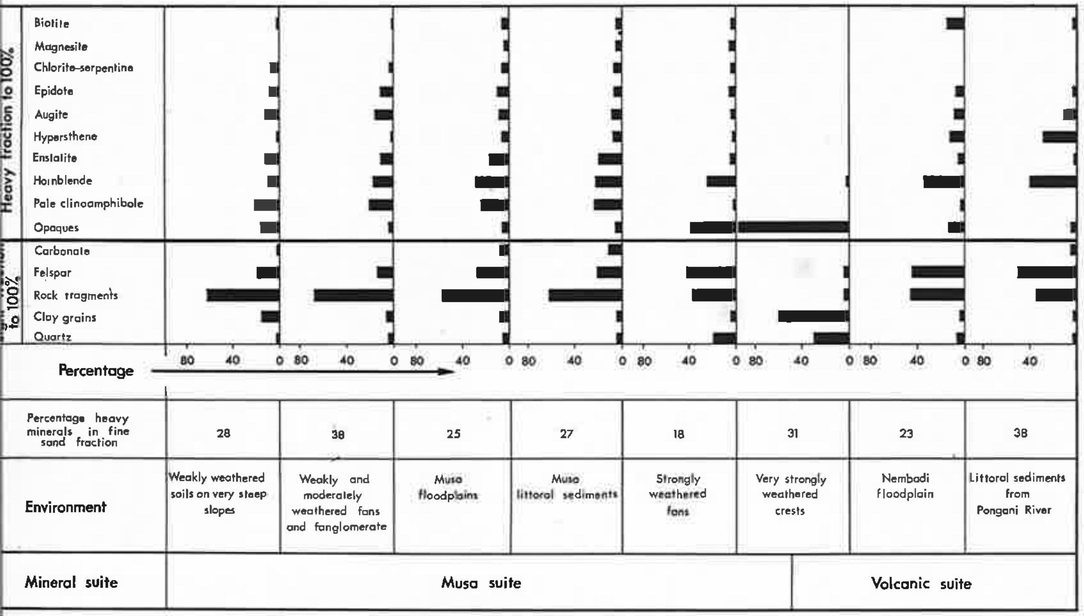


FIG. 3.—Histograms of the mineral suites.

DISCUSSION

Two sedimentary mineral associations are istinguished, the volcanic suite deposited by the Pongani and Bariji Rivers and the Musa suite erived from the rocks of the Musa catchment fig. 3).

The volcanic suite is characterized by abun- ant plagioclase and green hornblende with ommon hypersthene. It also contains minor au- ite, quartz, sanidine, calcite, opaques, oxyhorn- lende and biotite, rare brown hornblende, epi- ote, enstatite, anthophyllite, pale clinoamphi- ole and olivine, and very rare potash felspar, ircon, sphene, magnesite, chlorite, serpentine, laucophane and blue-green hornblende.

The volcanic mineral suite shows clearly the nfluence of Mount Lamington ash-fall layers ith the dominance of zoned plagioclase and reen hornblende. The high hypersthene content n the Pongani beach sands is due to the Pon- ani river headwaters draining the Hydrogra- hers Volcanics (1f in fig. 1).

The Musa suite is characterized by common lagioclase, pale clinoamphibole, green horn- lende and enstatite (fig. 3). It also has minor alcite, quartz, chlorite, hypersthene, augite, epi- ote and sanidine, rare biotite, opaques, serpen- ine, olivine, magnesite, brown and blue-green zircon. Other minerals occasionally seen include axinite, apatite, garnet, tourmaline and gibbsite.

The Musa suite is very uniform from the alluvial sediments to the littoral sediments on the coastal plain. The suite is also rather similar to the average of both all the fans and the weakly weathered soils on very steep slopes (fig. 3).

Both mineral suites are classes as plagioclase-rich litharenites with a predominance of rock fragments in various stages of weathering and subordinate angular primary unstable mineral grains. A small proportion of the mineral grains are both etched and partially weathered (fig. 2).

TABLE 3.—*Chemical analyses of Domara River Beds,* whole rock samples*

	Sandstone	Siltstone
SiO_2	G86 50.7	5269 49.3
Al_2O_3	12.6	14.4
Fe_2O_3	7.30	8.10
FeO	3.75	1.73
MgO	6.15	6.35
CaO	7.80	3.80
Na_2O	1.70	1.01
K_2O	1.04	0.47
H_2O^+	4.65	6.35
H_2O^-	2.30	7.00
CO	0.43	0.07

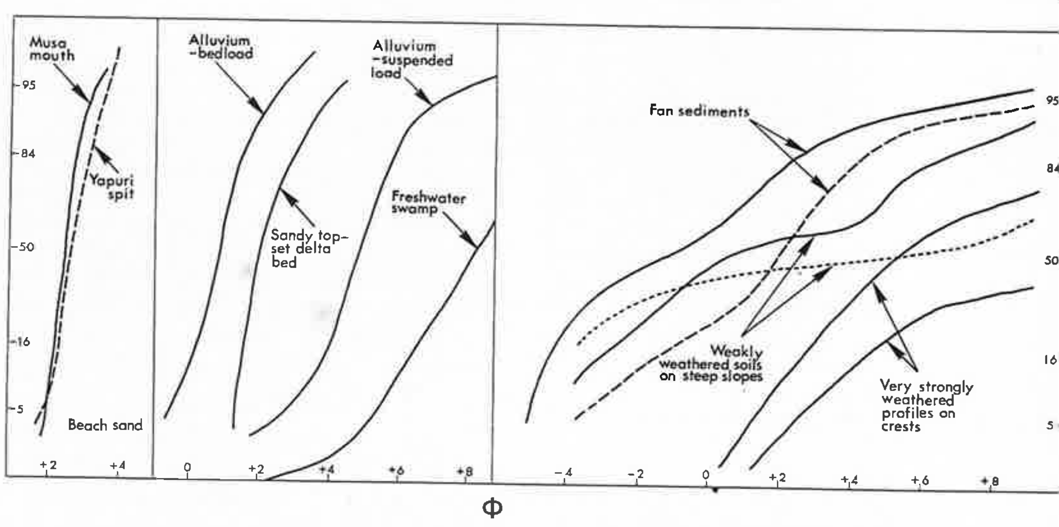


FIG. 4.—Textural evolution from soils through fans to alluvium and beach sand.

Amphiboles and pyroxenes often have hacksaw terminations in prismatic grains even in the beach sands and it appears that such delicate projections (fig. 2) can survive limited transport and reworking (cf. Pettijohn, 1957, p. 675).

Of considerable interest is the minor content of clay grains in all the sediments of both mineral suites. They vary from sub-angular to round and from white through yellow, green or brown to nearly opaque (fig. 2). They are often speckled or mottled in appearance and sometimes appear to retain the texture of a parent rock fragment. They are not aggregates or concretions but are organized crystalline assemblages (cf. Lelong, 1967). Such clay grains are also very common in the weakly weathered soils on the very steep mountain and hill slopes. Mineragraphic investigation of several typical clay grains (pers. comm. J. A. McDonald) show that they are kaolin and kaolin-illite mixtures with minor hydrated iron oxides.

The presence of clay grains and rock fragments in various stages of weathering suggests derivation of both these mineral suites from the weakly weathered soils on the very steep mountain slopes and not primarily from fresh unweathered bedrock in stream beds (cf. Krynine, 1936). The sharp decrease in opaque minerals from soils to alluvial and littoral sediment is, however, an unexplained feature. On the other

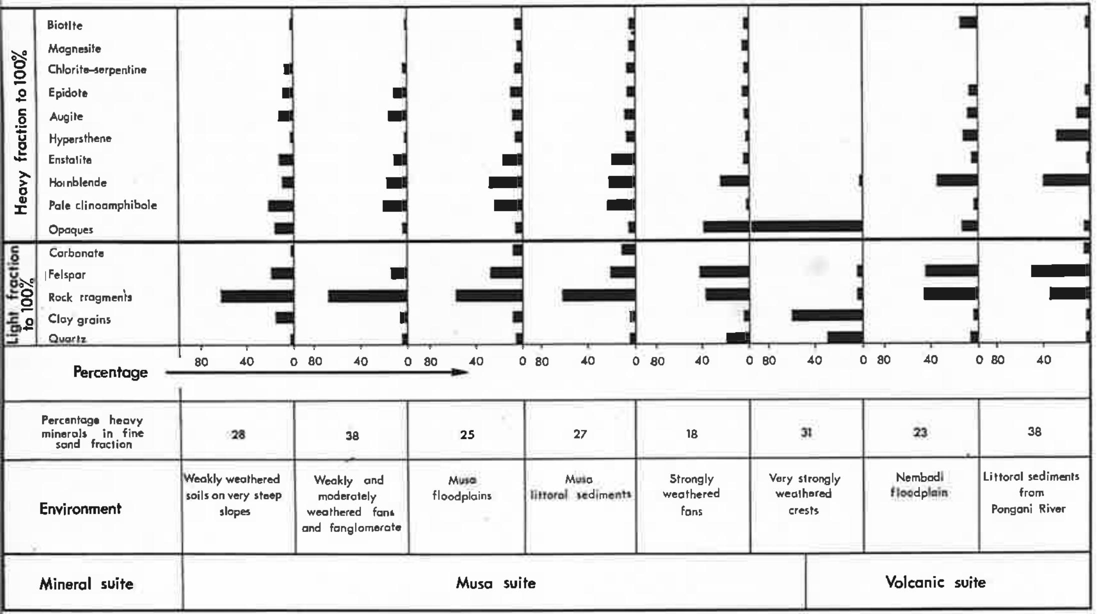
chemical composition and is reminiscent of the Miocene greywacke and mudstone of the Aure trough in Papua described by Edwards (1950).

The Musa suite, however, has a basaltic chemical composition and two chemical analyses of fresh whole rock from the Domara River Beds are shown in Table 3.

In the Musa catchment there is a very clear evolution of textural stage from the weakly weathered soils on the very steep slopes through fan sediments and bedload alluvium to beach sand (fig. 4 and Table 2). Of the 40 percent fine silt and clay produced in this sedimentary cycle only a small proportion is trapped in the fans or deposited in freshwater swamps. Most of it is swept out to sea.

Moss (1966) inferred that there could be significant geomorphic differences between rivers carrying quartz-rich and quartz-poor sediments. In northeast Papua, however, the fan, alluvial and littoral patterns are similar to those observed elsewhere and the role of sand-size quartz is adequately taken by rock fragments and unstable mineral grains.

In the humid tropics the rain forest is generally considered to inhibit mechanical erosion (Tricart and Cailleux, 1955), thus allowing deep penetration of chemical weathering. It is supposed that deep, fine-textured regoliths develop, leaving few tools for stream corrasion



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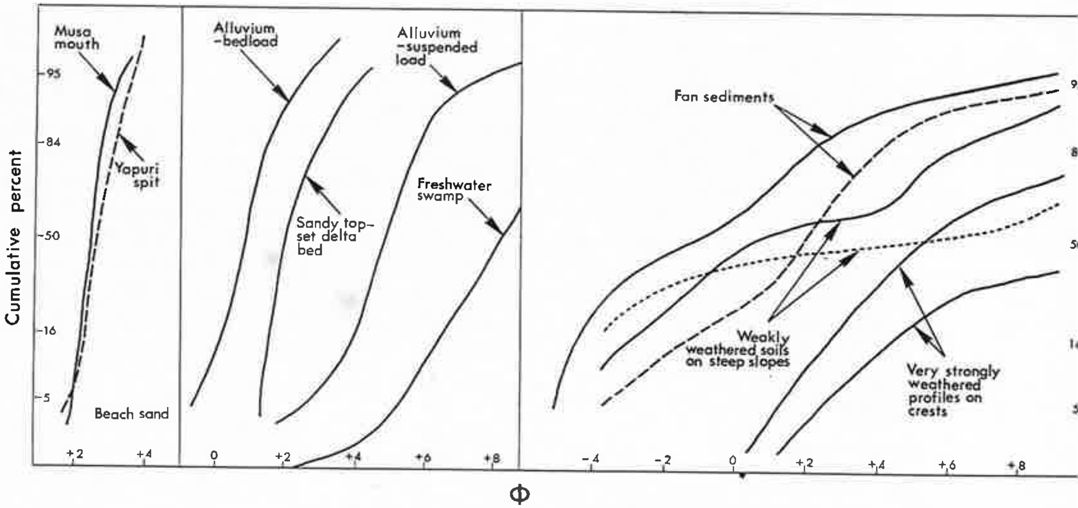

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Amphiboles and pyroxenes often have hacksaw terminations in prismatic grains even in the beach sands and it appears that such delicate projections (fig. 2) can survive limited transport and reworking (cf. Pettijohn, 1957, p. 675).

Of considerable interest is the minor content of clay grains in all the sediments of both mineral suites. They vary from sub-angular to round and from white through yellow, green or brown to nearly opaque (fig. 2). They are often speckled or mottled in appearance and sometimes appear to retain the texture of a parent rock fragment. They are not aggregates or concretions but are organized crystalline assemblages (cf. Lelong, 1967). Such clay grains are also very common in the weakly weathered soils on the very steep mountain and hill slopes. Mineragraphic investigation of several typical clay grains (pers. comm. J. A. McDonald) show that they are kaolin and kaolin-illite mixtures with minor hydrated iron oxides.

The presence of clay grains and rock fragments in various stages of weathering suggests derivation of both these mineral suites from the weakly weathered soils on the very steep mountain slopes and not primarily from fresh unweathered bedrock in stream beds (cf. Krynine, 1936). The sharp decrease in opaque minerals from soils to alluvial and littoral sediment is, however, an unexplained feature. On the other

chemical composition and is reminiscent of th Miocene greywacke and mudstone of the Aur trough in Papua described by Edwards (1950).

The Musa suite, however, has a basalti chemical composition and two chemical analyse of fresh whole rock from the Domara Rive Beds are shown in Table 3.

In the Musa catchment there is a very clea evolution of textural stage from the weakl weathered soils on the very steep slopes throug fan sediments and bedload alluvium to beac sand (fig. 4 and Table 2). Of the 40 percent fin silt and clay produced in this sedimentary cycl only a small proportion is trapped in the fans o deposited in freshwater swamps. Most of it i swept out to sea.

Moss (1966) inferred that there could be sig nificant geomorphic differences between river carrying quartz-rich and quartz-poor sediments In northeast Papua, however, the fan, alluvia and littoral patterns are similar to those ob served elsewhere and the role of sand-siz quartz is adequately taken by rock fragment and unstable mineral grains.

In the humid tropics the rain forest is gener ally considered to inhibit mechanical erosion (Tricart and Cailleux, 1955), thus allowing deep penetration of chemical weathering. It i supposed that deep, fine-textured regoliths de velop, leaving few tools for stream corrasion regions would be quartz-rich with abundant sesquioxides and clay minerals (cf. Gibbs, 1967).

In the Territory of Papua and New Guinea, however, the mountainous selva is being denuded so rapidly by mass movement and slope wash (Ruxton, 1967) that only weakly weathered soils develop on the prevailing very steep slopes. Transport and deposition are also very rapid and in general the depositional landscapes are so young that the sediments show only skeletal weathering (e.g. the leaching out of calcium carbonate in the surface layers). It is concluded that the terrestrial part of the sedimentary cycle is extremely rapid in the active orogenic portions of the humid tropics.

CONCLUSION

Rapid uplift in the humid tropical zone of northeast Papua gives a high relief and high rates of weathering, mass movement and slope erosion, and this leads to weakly weathered soils on the very steep mountain slopes. This incompletely weathered mantle provides most of the sediment that is rapidly transported by streams out onto the plains and deltas where deposition, with little reworking, is also rapid. Some further reworking occurs during longshore drift from the deltas to build beach ridge barriers.

The sediments are plagioclase-rich litharenite with dominant rock fragments in various stages of weathering and subordinate angular primary unstable mineral grains.

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