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MESOZOIC AND TERTIARY SEDIMENTS FROM THE WAHGI VALLEY, NEW GUINEA

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[Read 13 December 1951]

Introduction

The object of this paper is to present the results of a petrological study of the thick series of Mesozoic and Tertiary sediments exposed in the Lower Wahgi Valley, in the Chimbu-Hagen region of New Guinea (Fig. 1), and to discuss these results in relation to the available stratigraphic, palaeontological and regional data on the Chimbu Mesozoic section, which provides a useful standard for a sedimentary series of considerable geological interest.

The work derives from a detailed geological survey traverse of the Lower Chimbu and Lower Wahgi Valleys, in the Central Highlands of New Guinea, made in 1939 by Mr. L. C. Noakes, who was then Assistant Geologist of the Territory of New Guinea. This area had not been examined previously in detail. Dr. N. H. Fisher had visited the Wahgi Valley in his capacity of Government Geologist, and had collected some fossils, which were described by Miss I. Crespin (1938). Dr. K. Washington Gray visited the area early in 1939 and collected fossils and fossiliferous rock specimens, which were examined by Dr. F. W. Whitehouse and one of the writers (M.F.G.).

A report by Noakes (1939) was distributed in mimeographed form by the Territory of New Guinea authority, but has not yet appeared in print. Miss Crespin examined palaeontologically a series of rock specimens collected by Noakes, and a duplicate set was studied by one of us (M.F.G.) in 1940. Some results of this investigation are included in a publication on Mesozoic fossils from New Guinea (Glaessner, 1945). This duplicate set of specimens was lost in New Guinea during the war, except for a few Jurassic mollusca described in the 1945 publication.

A petrological examination of a suite of representative samples from Noakes' collection, which is preserved in the collections of the Commonwealth Bureau of Mineral Resources at Canberra, was made by one of us (A.B.E.) in 1949, and issued as a mimeographed report of the Commonwealth Scientific and Industrial Research Organization (Edwards, 1949). This, in a revised form, is the basis of the present study, and is published by permission of the C.S.I.R.O.

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Stratigraphy of the Wahgi-Chimbu Section

The total thickness of sediments exposed along the Lower Chimbu and Lower Wahgi Valleys is about 22,500 feet (Noakes, 1939). The topmost formation is the Lower Tertiary Chimbu Limestone, about 600 feet thick. The beds strike east-south-east, and dip in a northerly direction throughout, the angle of dip decreasing from about 45° near the Chimbu Limestone, to less than 20° near the base of the series. Noakes reports that shales and mudstones greatly predominate

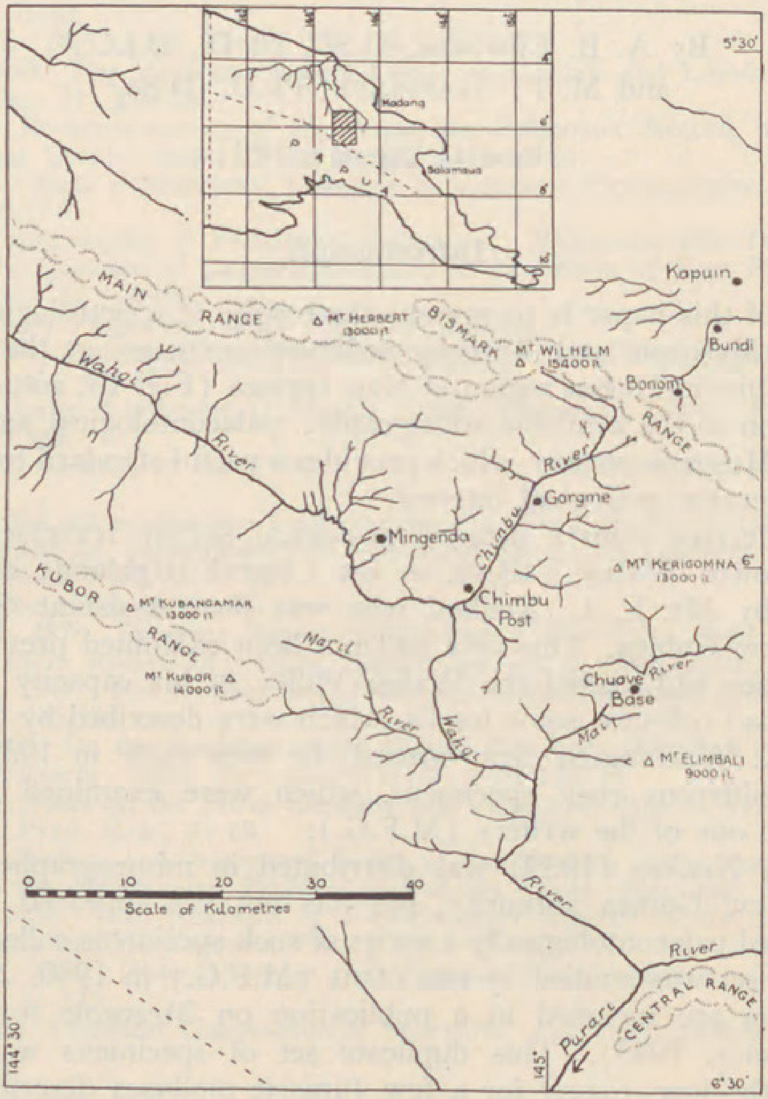

FIG. 1.

in the section, but that beds of fine-grained sandstone, some of them tuffaceous, are well distributed over the section (Fig. 2), and usually show a gradual transition to the finer sediments. Occasional grit and pebble beds mark coarser phases of the sandstones, and two horizons of conglomerate, with a total thickness of about 100 feet, were mapped. One horizon of water-sorted volcanic agglomerate was noted.

Apart from the Chimbu Limestone at the top of the section, limestones are restricted to four thin beds in the upper 10,000 feet of the section. In the lower 12,500 feet there is only a little impure limestone or calcareous slate near the base

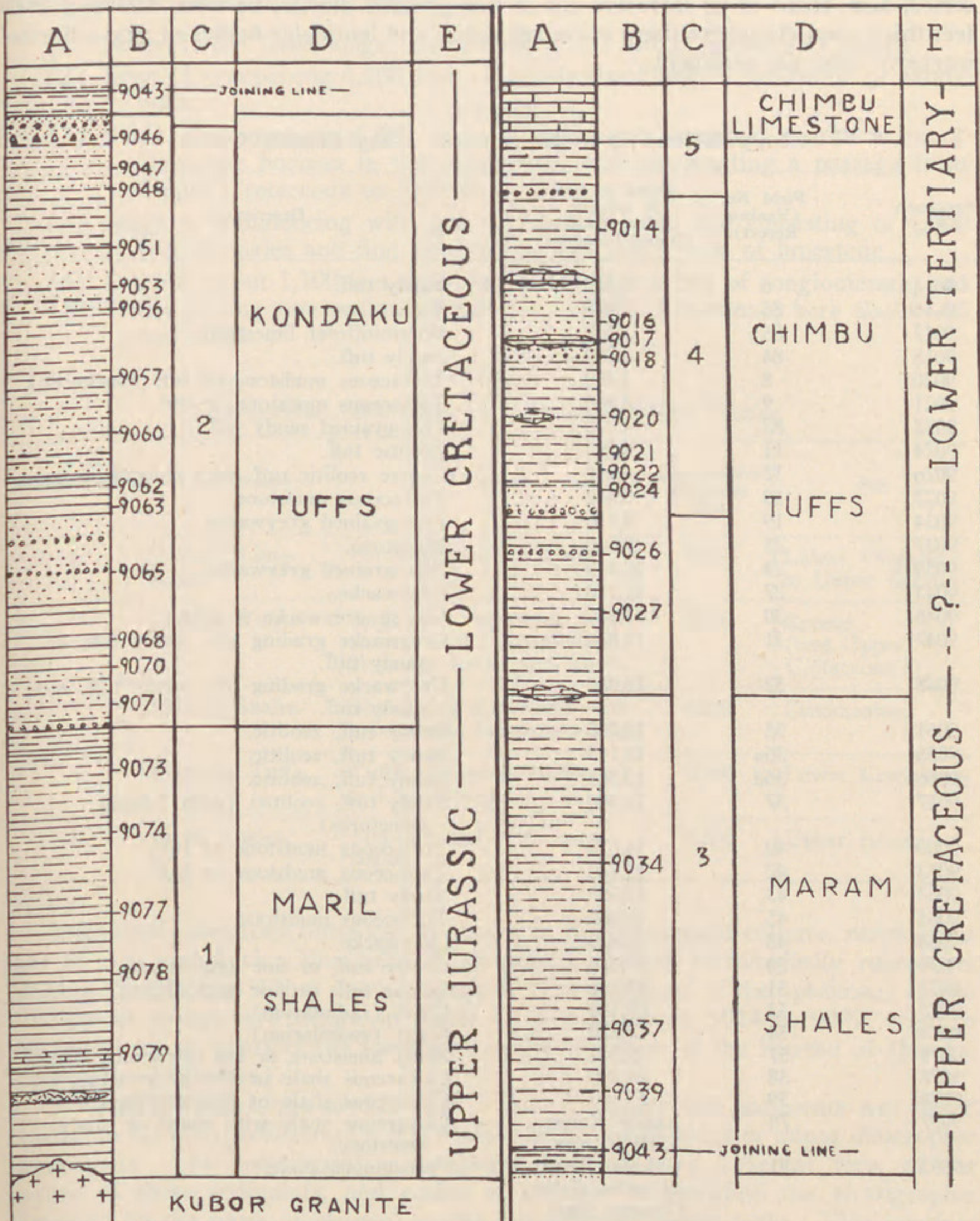
A
B
C
D
E
9043
JOINING LINE
9046
9047
9048
9051
9053
9056
9057
9060
9062
9063
9065
9068
9070
9071
9073
9074
9077
9078
9079
2
1
KONDAKU
TUFFS
MARIL
SHALES
UPPER JURASSIC — LOWER CRETACEOUS
KUBOR GRANITE
A
B
C
D
E
CHIMBU LIMESTONE
5
9014
9016
9017
9018
4
CHIMBU
TUFFS
9020
9021
9022
9024
9026
9027
9034
3
MARAM
SHALES
9037
9039
9043
JOINING LINE
UPPER CRETACEOUS — ? — LOWER TERTIARY

Fig. 2.

of the series. There are also occasional bands of chert. Near the base of the series, also, there is an intrusive sill of fine-grained diorite, between 100 and 200 feet thick; and elsewhere there are small dykes and lenticular bodies of granodiorite intrusive into the sediments.

TABLE 1

Classification of Specimens from the Wahgi-Chimbu Section

Specimen No.	Field No. (Noakes' Report).	Depth in feet of horizon below top of Chimbu limestone.	Description.
9014	6	1,530	Sandy tuff.
9016	86	2,470	Tuff.
9017	85	2,650	Foraminiferal limestone.
9018	84	2,840	Sandy tuff.
9020	8	3,480	Tuffaceous mudstone or tuff (puckered).
9021	9	3,850	Tuffaceous mudstone or tuff.
9022	82	4,010	Fine-grained sandy tuff.
9024	11	4,290	Zeolitic tuff.
9026	12	4,920	Coarse zeolitic tuff, with chloritic ovoids.
9027	13	5,540	Tuffaceous mudstone.
9034	19	8,110	Fine-grained greywacke.
9037	21	9,860	Mudstone.
9039	23	10,510	Fine-grained greywacke.
9043	27	11,120	Greywacke.
9046	30	11,580	Coarse greywacke or grit.
9047	31	11,850	Greywacke grading into sandy tuff, or sandy tuff.
9048	32	12,080	Greywacke grading into sandy tuff, or sandy tuff.
9051	35	12,730	Sandy tuff, zeolitic.
9053	36a	13,115	Sandy tuff, zeolitic.
9056	36d	13,385	Sandy tuff, zeolitic.
9057	37	14,080	Sandy tuff, zeolitici (with ?slump structures).
9060	40	14,670	Tuffaceous mudstone or tuff.
9062	42	15,240	Tuffaceous mudstone or tuff.
9063	43	15,530	Sandy tuff.
9065	45	16,080	Tuffaceous mudstone.
9068	48	16,820	Greywacke.
9070	50	17,075	Coarse tuff, or fine agglomerate.
9071	51	17,510	Coarse tuff, or fine agglomerate.
9073	53	18,180	Chert (radiolarian).
9074	54	18,810	Chert (radiolarian).
9077	57	19,540	Shaly limestone, or red calcareous shale.
9078	58	20,280	Calcareous shale or fine greywacke.
9079	59	21,140	Calcareous shale or fine greywacke.
9087	78	Kubor Range, 5,500 ft. elev.	Calcareous shale with shells or shaly limestone.
9093	91	Chimbu River, $2\frac{1}{2}$ miles above Gorgme Base Camp.	Ferruginous shale.
9094	92	Chimbu River, $1\frac{1}{4}$ miles below Gemboge Mission.	Sandy shale.

The lithological variations in the section are slight, but Noakes tentatively subdivided the series into five stages:

(1) Stage 1, the basal stage, comprising 4,500 feet of slates and shales.
(2) Stage 2, comprising 6,200 feet, of which about half is sandstone or sandy shale.
(3) Stage 3, comprising 6,500 feet of shales and sandstones, with a minor limestone horizon in the upper half, and representing a passage from Upper Cretaceous to Eocene.
(4) Stage 4, commencing with grit and pebble beds, and consisting of 4,000 feet of shales and fine sandstones, with some beds of limestone.
(5) Stage 5, about 1,100 feet thick, beginning with a bed of conglomerate, and comprising fine sediments and the Chimbu Limestone, here about 600 feet thick.

TABLE 2

Stratigraphic Subdivisions of the Wahgi-Chimbu Section

Noakes Stages	New Names	Lithology	Approximate Thickness (ft.)	Age
5	Chimbu Limestones.	Foraminiferal limestones.	600-	Lower Oligocene to Upper Eocene.
4	Chimbu Tuffs.	Tuffs and tuffaceous mudstones with foraminiferal limestone bands and lenses.	5,700	Eocene (and Upper Cretaceous ?).
3	Maram Shales.	Shales and mudstones with subordinate fine greywackes.	5,200	Cenomanian.
2	Kondaku Tuffs.	Tuffs, tuffaceous mudstones and greywackes.	6,100	Lower Cretaceous.
1	Maril Shales.	Siliceous and calcareous shales.	4,500	Upper Jurassic.

Individual sandstone horizons, as shown in his lithological column, range from 200 to 800 feet thick. The suite of specimens studied petrologically represents Noakes' Stages 1 to 4, but not his Stage 5. The positions of the specimens in the lithological column are shown in Table 1. The numbers, 9014 to 9079, refer to the registered numbers of the specimens in the collection of the Bureau of Mineral Resources (Canberra).

Noakes' field divisions of this thick series of conformable sediments was based chiefly on his interpretation of a few coarser beds as indicators of minor diastrophic movements. The petrological investigation had led to a different view of the nature of these sediments, and makes it possible to re-define the stratigraphic divisions on the basis of changes in the constitution of the rocks. This involves shifting the boundaries between Noakes' tentative Stages 3, 4 and 5 to horizons of lithological change. Taking into consideration the lithological characters of the rocks, and the results of palaeontological studies, as described herein, and following the new Code of Stratigraphic Nomenclature (Raggatt, 1950), we have named and tabulated Noakes' field stratigraphic subdivisions as shown in Table 2. The names of native villages and a stream (Maril), in the vicinity of the outcrops, were selected from unpublished maps in consultation with Mr. Noakes. Some further adjustments of the boundaries may become necessary when gaps in sampling are filled and the uncertain positions of some samples, particularly the positions of limestone bands and lenses in the upper part of the section, are rendered more precise.

Summary of Palaeontological Observations

Studies of the various collections of fossils made from the area have revealed that the sediments range in age from Upper Jurassic to Lower Oligocene.

Upper Jurassic

Numerous well-preserved specimens of the mollusc *Buchia malayomaorica* (Krumbeck) were found in a dark red shale about 2,700 feet above the base of the Wahgi-Chimbu section (Glaessner, 1945, p. 154, Pl. 6, Fig. 7). This species is known from many localities in the area between Celebes and New Zealand. In the eastern part of the Sunda Archipelago its age was determined as Oxfordian (Upper Jurassic). It is commonly accompanied by *Belemnopsis gerardi* (Oppel), but this species has not yet been found in the Wahgi Valley. Only fragmentary *Inoceramus* and other bivalves occur here with *Buchia*. Abundant radiolaria and sponge spicules were recorded by Miss Crespin from the upper 1,300 feet of the Maril Shales.

Lower Cretaceous

Most of the samples from the second division, the Kondaku Tuffs, are unfossiliferous. Miss Crespin recorded occasional radiolaria from the lower 2,500 feet of these beds. Worm burrowings were observed in a sample from the middle of this sequence, and occasional *Globigerina* and radiolaria are also recorded. The upper 1,500 feet of strata contain fragments of *Ostrea sp., Pseudavicula sp.,* and plant remains, which occur in some abundance. These fossils support the correlation with the Purari Formation.

Recently a number of fossils collected by natives from near Masul, a village about three miles east-south-east of Chimbu air strip, were presented to a geological survey party led by Mr. G. A. V. Stanley. These fossils included eight specimens of a large *Deshayesites n.sp.,* four specimens of *Cymatoceras sp.,* a fragment of a large belemnite phragmocone resembling *'Belemnites' sellheimi* Tenison-Woods, and nineteen specimens of *Pleuromya n.sp.,* which are specifically identical with the *'Panopaea'* or *'Pleuromya'* described by Erni (1944) from the area of the Gende tribe, near Bundi on the north-east slope of the Bismarck Mountains. These fossils are definitely Lower Cretaceous, the *Deshayesites* indicating Lower Aptian age. Two Cenomanian ammonites were obtained in the same manner from the same general locality (see below).

In the course of a geological traverse on behalf of Island Exploration Company, Mr. Stanley found other Lower Cretaceous fossils about eleven miles south-east of Chimbu (in the direction of the regional strike). These include a *Puzosia sp.,* about 16 inches in diameter, a large *Cymatoceras sp.,* and several specimens of *Aucellina gryphaeoides hughendenensis* (Etheridge). The fossils were found in some of the abundant calcareous nodules in shales which contain a large fauna of smaller foraminifera. This fauna will be described elsewhere. The *Aucellina,* which is a characteristic fossil of the Tambo formation of the great Artesian Basin of Australia, and some of the foraminifera, such as the distinctive *Pleurostomella reussi* Berthelin, indicate Albian age. These collections were taken from concretions in tuffaceous mudstones. They support the placing of at least part of the Kondaku Tuffs in the Aptian and Albian.

Upper Cretaceous

According to Noakes (1939), the Mingenda ammonite horizon corresponds to the lower part of his Stage 3. The ammonite locality at Mingenda airstrip and Korigu village has yielded *Euomphaloceras hoeltkeri* (Erni), described as *'Cunningtoniceras'* by Erni (1944), occurring commonly together with *Puzosia sp., Turrilites cf. scheuchzerianus* Bosc, and *Inoceramus sp.,* which were identified by F. W. Whitehouse, and a few foraminifera, including *Textularia cf. washitensis* Carsey. This is a Cenomanian fauna. Noakes' samples from the Chimbu section contained only a few foraminifera, including the same *Textularia.* Two ammonites collected by natives, together with the Aptian fauna, apparently as stream pebbles in a short south-east tributary of the Chimbu Valley, are a *Mantelliceras sp.* and a fragment of a whorl of *Turrilites cf. acutus* Passy, a well-known Cenomanian form.

Eocene

From a limestone shown on his map as a lens 1,000 feet long and 150 feet wide, Noakes obtained a sample containing Eocene Nummulites. He believed this to be identical with the rock from which Fisher had collected a sample with *Lacazina, Biplanispira, Pellatispira,* and other Eocene foraminifera (Crespin, 1938). Noakes concluded that his Stage 3 represented a record of uninterrupted sedimentation from Upper Cretaceous into Lower Tertiary time. This now appears questionable.

The distinctive faunas so far found are as low in the Upper Cretaceous as Cenomanian, and as high in the Tertiary as Middle or Upper Eocene (probably Late Eocene), without any representatives of Turonian, Senonian, Danian, Paleocene or Lower Eocene. There is also some uncertainty as to whether the limestone lens from which the sample was taken was *in situ.*

There is, however, a lithological difference between the samples examined from beds below and above this limestone. The samples from about 1,750 to 5,200 feet below the limestone are greywackes and mudstones, while the samples from 800 to 4,800 feet above it are tuffs and tuffaceous mudstones, containing in the upper 1,000 feet of this section further limestone bands with Upper Eocene, and possibly Lower Oligocene, foraminifera. A formation boundary is drawn tentatively at the approximate horizon of this change between the Maram Shales below and the Chimbu Tuffs above. If the lowest limestone 'lens' recorded by Noakes was not *in situ,* then the Chimbu Tuffs could still contain a record of uninterrupted sedimentation from the Uppermost Cretaceous (Upper Senonian), which is well represented in the Central Highlands, to Eocene, but otherwise they must be entirely Eocene. A representation of the entire sequence from Cenomanian to Eocene in the 5,200 feet of uniform Maram Shales and fine greywackes is considered unlikely. Fossils found in this part of the section are poor, and further collections are desirable.

Stratigraphic Correlation

A tentative correlation (Glaessner, 1945, Table 1) of the lower 17,200 feet of the Wahgi-Chimbu section placed the first stage, here called Maril Shales, in the Upper Jurassic. The Jurassic extends westward from the Wahgi-Chimbu section to the international border, and into Netherlands New Guinea, where similar faunas have been recorded from a number of localities. It has not been observed east of Chimbu.

The gap which appeared to exist regionally between Upper Jurassic and the lowest fossiliferous horizon in the Lower Cretaceous has been reduced by the discovery, about 75 miles south of Chimbu, in Papua, of a fauna with *Neocomites* and *Streblites,* apparently of basal Cretaceous age. This will be described by Dr. L. F. Spath. The siliceous beds at the top of the Maril Shales, or the basal part of the Kondaku Tuffs, may represent the basal Cretaceous.

The Kondaku Tuffs can be correlated with the Purari Formation. Fossils of Aptian or Albian affinities were found in the upper part of the Purari Formation (Glaessner, 1945), but its base was not exposed at the type locality (Carey, 1945). In view of the conformable sequence in the Wahgi-Chimbu section, the entire Lower Cretaceous could well be represented here, but unfortunately most of it is unfossiliferous, although the occurrence of Aptian and Albian was confirmed by the discoveries of fossils within a few miles of the section, leaving no doubt of the existence of a conformable sequence from the Lower Cretaceous tuffs to the Cenomanian shales, with an unbroken transition from Albian to Cenomanian. Rich faunas of Albian and Cenomanian smaller foraminifera have been found at various localities in the Wahgi Valley and in western Papua, so that further detailed work may make it possible to study such faunas from a single section. The foraminiferal assemblages are similar to those recorded in recent years from the southern Alps, North Africa, and Texas, where detailed zoning has been carried out, so that it will then be possible to give a more exact date for the change from tuffs to greywackes, which takes place in the vicinity of the Albian-Cenomanian boundary.

The lower part of the Chimbu Tuffs cannot be dated palaeontologically, as yet, and has not been recognized elsewhere; and there is as yet no palaeontological evidence of the occurrence in the Wahgi-Chimbu section of the Upper Senonian, which is widely distributed throughout New Guinea.

The Tertiary begins generally with Middle or Upper Eocene limestones, commonly containing *Lacazina, Pellatispira,* or *Biplanispira,* and resting on Cretaceous or on pre-Mesozoic basement rocks. In the Wahgi-Chimbu section these limestones seem to grade up into Lower Oligocene, and to lens out downward, and possibly westwards (Noakes, 1939), into tuffaceous sediments.

Petrology

The specimens studied petrologically include sandstones, mudstones, shales, cherts and limestones, with mudstones and sandstones prevailing. The sandstone members of the Wahgi series tend to be fine-grained, and are all more or less tuffaceous. They range between two extremes — quartz-rich greywackes and andesitic tuffs, with a number of the specimens predominantly tuffaceous, but showing an intermingling of source materials. The mudstones grade into the sandstones as regards grain size, and are composed of generally similar materials. A number of the specimens are more or less weathered, and the unweathered specimens are too well cemented for reliable sizing analyses to be made.

Greywackes

The greywackes are represented by specimens Nos. 9043 and 9068, a coarse greywacke or grit, No. 9046, and sandy mudstones, Nos. 9034 and 9039. They occur, therefore, in both the Upper and Lower Cretaceous (Table 1), with 9043 more or less marking the divisions between the two periods.

Specimen No. 9043 consists of grains of quartz, felspar, biotite, muscovite, chlorite, glauconite, and leucoxene, together with numerous fragments of fine-grained andesite, phyllite, shale, quartzite, and chert, in an abundant cement of carbonate, that appears to have replaced much of the original fine matrix and parts of the grains and rock fragments. The average size of the grains and fragments is about 0·25 mm., but the rocks are ill-sorted, and occasional grains, and particularly the fragments of shale, are up to 1 mm. long.

Quartz is the most abundant of the mineral grains. It occurs as fragments up to 0·5 mm. by 0·5 mm., with a tendency to be equidimensional. Some grains are well rounded, or partly rounded, with overgrowths of quartz, but the majority were angular before the development of the overgrowths (Pl. III, fig. 1). Others show partial replacement by the carbonate cement.

The felspar includes both orthoclase and plagioclase, but tends to be extensively replaced by the carbonate cement, so that it is difficult to assess their original proportions. Plagioclase is now the more abundant, occurring chiefly as stumpy prisms or laths, up to 0·3 mm. by 0·2 mm., or as fragments of such crystals. It shows broad lamellar twinning, with an extinction angle of about 10°, so that it is presumed to be oligoclase.

The biotite is a brown variety, though some flakes are pleochroic from green to brown. Some flakes have a weathered appearance. They are about 0·5 mm. by 0·1 mm., and tend to lie parallel to the bedding. Commonly they are bent through having been 'nipped' between other grains during compaction. In places the biotite is largely or completely altered to chlorite. The muscovite occurs as occasional flakes, less abundant than the biotite, but occurring in much the same way.

Glauconite is a minor but conspicuous component, occurring as well-rounded grains about 0·2 mm. by 0·1 mm. The majority are a bright green, with a typical cryptocrystalline appearance, in low colours, under crossed nicols. Some grains appear somewhat oxidized.

Brown tourmaline is present as occasional rounded grains, up to 0·2 mm. across, and there are occasional grains of zircon visible in thin sections. In addition there are grains of leucoxene, more or less rounded.

Of the abundant rock fragments, andesite, shale and phyllite are the chief components. The andesites are fine-grained varieties, with numerous microlites of plagioclase laths showing straight extinction, and commonly with parallel alignment, in a colourless to greenish glassy base. Occasional fragments are porphyritic, with microphenocrysts of sodic plagioclase. A few are studded with chlorite, presumably an alteration product of original finely divided femic minerals. The majority of the andesite fragments are equidimensional and well rounded. Fragments as large as 0·5 by 0·5 mm. occur, but 0·2 mm. by 0·2 mm. is a more common size. A few fragments are angular or sub-angular.

The phyllite and shale fragments, by contrast, are mainly anisodimensional. Coarse fragments are 1·0 mm. by 0·25 mm., but most are smaller than 0·5 mm. by 0·2 mm. The elongation is always parallel to the bedding or cleavage of the fragment. The majority of the shale and phyllite fragments are well rounded (Pl.

III, fig. 2). Some are carbonaceous, with films of carbonaceous material as a cement between the grains, and extending parallel to the bedding. The phyllite fragments contain an abundance of fine-grained biotite, in some instances chloritized.

The quartzite and chert fragments are generally smaller than the shale fragments, and are more nearly equidimensional, averaging about 0·2 mm. by 0·2 mm. Some are rounded, but as many are angular. The predominantly rounded form of the rock fragments is in marked contrast to the angular shape of the mineral grains. This arises, presumably, from the softer and more friable nature of many of the rock fragments as compared with the mineral grains. It indicates transport for the rock components as a whole.

Specimen No. 9068 (Pl. III, fig. 3) is generally similar to No. 9043, but contains in addition to the minerals listed above a number of grains of yellow epidote, of angular shape, and apparently authigenic. It contains more quartz than No. 9043, and fewer rock fragments, especially andesite.

Specimen No. 9046 is a coarse greywacke or grit. It is a grey rock spotted with fragments of andesite and black slate from 2 mm. to 5 mm. across. Some of the andesite fragments are deeply weathered, and a limonitic brown colour. The rock is severely carbonated, with seams of calcite in the joints. In thin section it appears as a coarser variation of No. 9043. The quartzite fragments are generally rounded, and vary somewhat in size. Some are composed of individual grains up to 0·2 mm. across, others are microcrystalline. The phyllite fragments are well rounded, but notably elongated, and tend to contain much carbonaceous matter. Andesitic fragments are more numerous than sedimentary fragments, and tend to be equidimensional and rounded or angular. One fragment showed partial replacement by glauconite.

Specimens Nos. 9034 and 9039 consist of extremely fine-grained greywacke, or coarse mudstone. In thin section they are of similar composition to No. 9043, the glauconite grains in particular being conspicuous.

Heavy Minerals

The heavy minerals of Nos. 9043 and 9068 were separated in acetylene tetrabromide of Sp.Gr. 2·90 from samples crushed to pass an 0·5 mm. aperture. Both specimens yielded relatively small heavy fractions, but these contain a variety of minerals, many of them water-worn, and some very perfectly rounded. The minerals present are topaz, tourmaline, zircon, apatite, biotite, rutile, garnet, glauconite, pyroxene, leucoxene, iron ores, epidote, carbonate and sulphides. The grain size of these mineral grains ranges from 0·02 mm. to 0·10 mm. diameter.

The topaz occurs as well rounded grains about 0·05 mm. to 0·10 mm. across, generally with a finely pitted surface. Some grains appear almost circular in cross-section, but others are rounded prisms. Grains with low polarization colours yield a positive biaxial figure, with 2V about 45°, which distinguishes them from similar grains of apatite.

The apatite, which is abundant, occurs partly as well rounded, pitted grains about 0·05 mm. diameter, and partly as small prismatic crystals from 0·02 to 0·05 mm. long. Many of these show no sign of water wear, and a few have dark to opaque cores. The small crystals may be derived from the biotite flakes of the rocks, being liberated during crushing.

The tourmaline occurs partly as well rounded grains, partly as prisms, which generally have their angles rounded. Three distinct varieties are present, one which is pleochroic from golden-brown to colourless, one which is pleochroic from smoky brown to grey-brown, and one which is pleochroic from deep to pale blue (indicolite). The blue variety occurs as well rounded grains, but the golden-brown and smoky varieties occur both as prisms and as well rounded grains.

Zircons are numerous. They are colourless, and mostly small, ranging from 0·02 to 0·05 mm. across. A few grains have a double-ended prismatic form, but squat pyramidal forms predominate. A few grains show perfect crystal shape, but most have their angles well rounded, and some are almost spherical.

The garnet includes colourless, brown, and pink varieties, some of the grains being clearly fragments of larger waterworn grains fractured during crushing. Others are sub-rounded or rounded small grains.

Biotite is an abundant constituent, particularly in No. 9043. It ranges from fresh brown biotite to pale greyish or greenish chloritized flakes. Glauconite is relatively abundant, more so in No. 9043 than in No. 9068. Rutile, on the contrary, appears more abundant in No. 9068. It occurs mostly as angular fragments broken from occasional larger grains. The leucoxene is abundant, generally as waterworn grains, and occasional grains of waterworn magnetite are also present.

Pyroxene occurs as a number of grains of colourless or green augite, all as angular fragments. Carbonate is present as numerous angular fragments broken from the cement, and there are occasional angular fragments of yellow epidote. A few particles of sulphide (pyrite or marcasite) occurred in No. 9068.

TABLE 3

Chemical Analyses of Some Wahgi-Chimbu Sediments

	Wahgi-Chimbu Sediments		Purari Greywacke	Aure Greywacke	
	Greywacke (9068)	Zeolitic Tuff (9024)	(U.P. 125)	(U.K. 1042)	
	1	2	3	4	4a
SiO_2	72·83	50·16	65·18	53·30	57·72
Al_2O_3	10·92	19·63	13·85	18·33	19·85
Fe_2O_3	0·13	2·59	1·30	2·41	2·61
FeO	4·88	2·15	5·43	2·36	2·55
MgO	1·09	1·96	1·87	2·62	2·85
CaO	2·06	8·31	0·72	5·88	5·39
Na_2O	1·20	0·20	1·48	2·18	2·36
K_2O	1·36	1·56	1·60	1·72	1·86
H_2O + 110° C.	2·03	9·22	3·94	3·14	3·40
H_2O − 110° C.	0·65	2·57	2·10	5·74	—
CO_2	1·00	tr.	tr.	1·00	—
TiO_2	0·72	0·90	0·90	0·84	0·91
P_2O_5	0·35	0·38	0·38	0·28	0·30
MnO	0·03	0·06	0·22	0·08	0·09
Cl	0·03	0·05	0·16	0·03	0·03
SO_3	0·46	0·09	0·90	0·08	0·09
	99·74	99·84	100·08	99·99	

1. Greywacke, No. 9068, from a horizon in the Kondaku Tuffs, 16,820 feet below the top of the Chimbu Limestone, Lower Wahgi River, New Guinea (Lower Cretaceous).
2. Zeolitic Tuff, No. 9024, from a horizon in the Chimbu Tuffs, 4,290 feet below the top of the Chimbu Limestone, Lower Wahgi River, New Guinea (Eocene).
3. Purari Greywacke (U.P. 125), (Edwards, 1950, *Proc. Roy. Soc. Vic.*, 60: 169).
4. Aure Greywacke (UK. 1042), (Edwards, 1950, *Proc. Roy. Soc. Vic.*, 60: 139).

4a. Analysis 4 recalculated free of $CaCO_3$ and H_2O − 105° C.

Analyst: Messrs. Avery & Anderson (Melbourne).

Chemical Analysis

A chemical analysis was made of Specimen No. 9068, which was selected on account of its freshness and relative freedom from carbonate cement. The analysis (Table 3, Analysis No. 1) provides further evidence of the 'mixed' or argillaceous character of the rock, in the presence of nearly 11 per cent of Al_2O_3, 2·5 per cent of alkalis, and 6 per cent of FeO and MgO.

The analysis shows the rock to be rather more siliceous than the typical Lower Cretaceous Purari greywacke (Table 3, Analysis No. 3) described by Edwards (1950), but similar to it in other respects. Of the greywackes in the Wahgi collection, it is the one that contains the highest proportion of quartz grains, and shows least intermingling of source materials, so that it may be expected that the other greywacke specimens approach more closely to the composition of the Purari greywacke.

The difference in composition between the greywacke and the zeolitic tuff (Table 3, Analysis No. 2) is so evident as not to require comment.

ANDESITE TUFFS

Marine tuffs, containing foraminifera, predominate among the sandy specimens.

Coarse Tuff or Fine Agglomerate

Three specimens, Nos. 9026, 9070 and 9071, are coarsely fragmental rocks, with individual fragments up to 1 cm. across. No. 9071, the freshest specimen, is a greenish-grey rock, consisting essentially of crystals of plagioclase and pyroxene, together with numerous fragments of andesite, set in a matrix of minute fragments of pyroxene, felspar, andesite and clay. It contains, in addition, occasional flakes of biotite and a little chlorite, but there is no quartz and no glauconite.

The plagioclase grains are crystals or fragments of crystals up to 1 mm. across, and from their zoning and twinning, and extinction angles, appear to consist of cores of andesine with outer zones of oligoclase, or else of oligoclase throughout. They can be matched with some of the felspar phenocrysts of the andesite fragments. The felspar is fresh, but in places is partly replaced by calcite.

The pyroxene grains are as large as 2 mm. by 1·5 mm., though most are smaller. They are quite fresh, and some are idiomorphic crystals, though angular fragments predominate. Augite is the most common species, and includes a colourless variety and a greenish variety. Hypersthene is present as an occasional grain, pleochroic from pale green to brownish. Similar pyroxenes occur as phenocrysts in some of the andesite fragments, so that there can be no doubt as to the source of the free grains. The biotite occurs as small flakes, pleochroic from straw-yellow to green, and in places twisted or flexed.

The numerous andesite fragments range in size from 0·2 mm. to 10 mm. across. They are angular and roughly equidimensional, and though replaced in part by calcite and chlorite, have a uniformly fresh appearance, indicating that there was no differential weathering of the fragments prior to deposition. The fragments vary considerably in texture, but not greatly as regards mineral composition. The larger fragments consist of phenocrysts of oligoclase about 0·2 to 0·5 mm. long, together with pyroxene phenocrysts of similar size, and chlorite pseudomorphs after (?)hornblende, in a fine-grained groundmass of oligoclase laths, small prisms and granules of pyroxene, and more or less devitrified brownish-green glass. Patches of calcite occur in some, partly replacing felspar phenocrysts, and some of the chlorite appears to be encrusting vesicles.

Other fragments contain corroded microphenocrysts of oligoclase, somewhat replaced by carbonate, in pilotaxitic or hyalopilitic groundmasses. Phenocrysts of fresh pyroxene are present in some of these fragments, in others only chlorite pseudomorphs occur. Other fragments consist of similar phenocrysts in a devitrified glassy base, and some fragments consist of groundmass only.

There are no fragments of sedimentary rocks.

Specimen No, 9070 is generally similar to No. 9071, but is severely weathered. It consists essentially of altered grains of plagioclase and pyroxene, and fragments of igneous rocks, in a fine matrix of similar material. The igneous rock fragments consist in part of fine-grained andesite, some with and some without phenocrysts of plagioclase and pyroxene, and in part of clots of altered, intergrown augite and enstatite crystals. The largest augite-enstatite fragment observed measured 5 mm. by 2 mm., and the individual pyroxene grains composing it were about 0·2 mm. across. In addition there are composite fragments 2 mm. by 2 mm. of coarse plagioclase crystals.

Zeolitic Tuffs

Specimen No. 9026 is a coarse fragmental rock, generally similar to No. 9071 in hand specimen—a greenish rock with limonite staining along joints, and containing rock fragments up to 10 mm. across, and white felspar crystals 2 to 3 mm. long, which show on a fractured surface.

Thin sections show that it is a coarse tuff, composed of numerous angular fragments, up to 5 mm. across, of fine-grained andesites, and prismatic crystals of plagioclase, some in glomeroporphyritic clusters, 2 to 3 mm. long, together with occasional grains of fresh pyroxene, chiefly augite, in an abundant cement consisting of a lime zeolite, probably laumontite, and some chlorite.

The andesite fragments show a variety of textures similar to the fragments in No. 9071. Some contain chloritized ferromagnesian phenocrysts, but the granules of pyroxene in the groundmass of such rocks tend to be fresh. The plagioclase crystals are zoned and twinned, and range in composition from labradorite at the core to marginal zones of oligoclase.

The cementing material is the most striking feature of the rock (Plate III, fig. 4). It is composed of more or less equigranular crystals of a zeolite, studded with swarms of ovoids or oolitic bodies of greenish chlorite, occasional ovoids of colourless zeolite, and very occasional ovoids of calcite.

The dominant zeolite forming the host to the various oolitic bodies is optically negative and biaxial, with 2V about 20° to 30°. It has a perfect cleavage in one direction, and a refractive index on cleavage fragments of 1·513. The birefringence is about 0·009. Occasional grains show traces of a second cleavage. These various properties indicate that the mineral is a lime zeolite, probably laumontite ($CaAl_2Si_4O_{12}.4H_2O$), or possibly scolescite or epistilbite. This finds confirmation from the chemical analysis of the zeolitic tuff, No. 9024 (Table 3, Analysis 2). The individual grains are 0·2 mm. across, and some are water clear, but the majority are cloudy from dust-like inclusions. Dispersed through this zeolite are occasional ovoids of other zeolites, one of which is biaxial and negative, closely resembling the main zeolite, and a second that is uniaxial and negative.

The prevailing ovoid bodies are composed of a greenish-yellow chlorite, and consist either at the core or throughout of spherulitic fibrous growths (Pl. III, fig. 4). Some show two or three sharply defined concentric zones, and most have a narrow brown marginal zone. An occasional ovoid has an outer zone of colourless zeolite, while some of the zeolitic ovoids have a rim of the chlorite. Some of the chlorite bodies are elongated or distorted by compaction between the grains or rock fragments, and some fill interstices, and are shaped accordingly. They range in size from 0·01 mm. to 0·10 mm. in major diameter, and occur in clusters of a hundred or more, in which all sizes in this range are represented. Generally in one field of view all of the adjacent ovoids have their longer axes parallel to one another (Pl. III, fig. 4); but the orientation varies from place to place in the section. Occasionally two and three ovoids can be seen to have coalesced, or to have been compressed against each other, with resulting distortion of their shape (Pl. III, fig. 5). The chlorite is pleochroic from pale green to apple green, and shows yellow polarization colours and negative elongation.

The zeolites and the chlorite bodies appear to have formed from the solution and redeposition as gels of the components of the felspars and ferromagnesian minerals of the tuff during diagenesis. The iron and magnesium could not be accommodated in the zeolites, and so formed separate bodies of chlorite.

The andesitic fragments are in general not replaced by the chlorite, but an occasional fragment has been severely chloritized, and one fragment was observed crowded with chlorite ovoids. Some of the plagioclase crystals have been invaded by narrow seams of chlorite along their cleavage planes, and some are partly replaced by calcite; but the pyroxene grains are quite unaffected by either chlorite or calcite. In places the groups of chlorite bodies are enclosed within areas of a green fibrous material, apparently a second chlorite substance, intensely pleochroic from emerald green to straw yellow, and suggestive of glaucophane.

In addition there are occasional grains about 0·15 mm. across of magnetite-ilmenite lattice intergrowths, in which the ilmenite lamellae of the lattice are altered to leucoxene, leaving the magnetite unaltered.

Specimen No. 9024 is a fine-grained variant of No. 9026, but lacks the chlorite ovoids. It consists of grains of plagioclase and fresh pyroxene, and numerous fragments of somewhat altered fine-grained andesite and chloritic material, together with very occasional fragments of quartzite, in an abundance of zeolitic cement, which appears identical with that of No. 9026, and is the dominant component of the rock, occurring as interlocking equigranular allotriomorphic crystals (Pl. III, fig. 6). In places the zeolite has formed elongated areas or narrow seams showing a tendency to radial fibrous growths from the walls. In addition there are occasional grains of bright yellow epidote, and areas of carbonate, or of carbonate replaced by zeolite, showing definite organic structures, relicts of some marine organism.

The felspar grains are sodic plagioclase, and are invaded by seams of chlorite and more or less replaced. The pyroxene is chiefly colourless augite with a large extinction angle, but some enstatite is also present. The andesite fragments are about 0·2 mm. across, and are rounded to sub-angular. They show varying stages of alteration from intense to only partial chloritization.

The chlorite, which is abundant, occurs as more or less discrete grains. It appears partly to be a product of the replacement of andesite fragments, and partly of biotite grains. Some of it may be altered glauconite.

Chemical Analysis

The unusual composition of these rocks is emphasized by a chemical analysis of Specimen No. 9024, shown in Table 3 (Analysis No. 2). The low silica, and the high lime, alumina and combined water contents, reflect the abundance of the zeolite cement, and the low soda content confirms that it is a lime zeolite.

The tuff is much more basic than the greywacke (Analysis No. 1), or even than the analysed Miocene greywacke of the Aure Series of Papua (Table 3, Analysis No. 4, 4a), which is largely derived from andesitic tuff, and contains practically no quartz (Edwards, 1950a). The tuff is notably richer in lime and combined water, and poorer in soda and silica than the Miocene greywacke, which approximates to average andesite in composition. However, the alumina and potash contents of the two rocks are similar. Since the Wahgi tuff originated from pyroxene andesites, it is evident that the zeolites in this tuff formed largely at the expense of the original felspar, and that soda and silica were lost in solution in the process.

The P_2O_5 content of the zeolitic tuff is the same as that of the greywacke (Analysis No. 1), despite the fact that apatite is practically absent from the heavy minerals of the tuffs, though it is prominent among the heavy minerals of the greywacke. This must indicate solution of the original apatite of the andesite fragments during the zeolitization of the tuff, and either (a) absorption of phosphorus in the zeolite, or (b) deposition of a secondary phosphate mineral not recognized as such in an examination of the thin sections.

Sandy Tuffs

With the appearance of quartz grains and glauconite or altered glauconite, these tuffs grade into sandy tuffs. Specimens Nos. 9051, 9053, 9056 and 9057 represent the initial stages of this transition from a zeolitic tuff, such as No. 9024, to the sandy tuff. All four are characterized by an abundance of grains of fresh pyroxene, with rather fewer grains of plagioclase, numerous fragments of andesite, a number of angular grains of quartz, and numerous grains of more or less altered glauconite, in a zeolitic cement. The pyroxene crystals are up to 0·3 mm. across, and are either fresh or have a rim of limonite in severely weathered rock. They are colourless to greenish. Both augite and enstatite are present, but augite is much the more abundant.

The andesite fragments are all fine-grained, and show the same range of texture and composition as in the tuffs proper. Some are severely chloritized, others practically unaltered. Some are more or less completely replaced by clots of yellow epidote. Sedimentary rock fragments are represented by only a very occasional fragment of quartzite, one of which was studded with growths of iron sulphide.

The quartz grains are uniformly distributed through the rocks, and are always angular. They are generally smaller than the other grains. Fresh glauconite, and grains showing all stages of alteration to a pale yellowish isotropic substance, are relatively numerous. Some are ovoid, others are more or less angular to subangular. These various grains are enclosed in a zeolitic cement, composed chiefly of laumontite.

These rocks are reported as unfossiliferous, but in the sections of both Nos. 9053 and 9056 there are occasional areas of calcite showing definite organic structure, suggestive of foraminifera.

Specimens Nos. 9014, 9018 and 9063 fall into this transitional group, but contain less zeolitic material, and more quartz. They consist essentially of closely packed angular fragments of andesite, about 0·2 to 0·5 mm. across, together with occasional grains of plagioclase and pyroxene, and a number of angular grains of quartz, which are about 0·1 mm. long in No. 9063, and occasionally as large as 0·3 mm. long in Nos. 9014 and 9018. This quartz occurs in the main as noticeably smaller grains than the other grain components. One fragment in No. 9018 showed a rounded embayment filled with chlorite. Both Nos. 9018 and 9063 are reported not to contain organisms, but No. 9018 can be seen in thin section to contain fragments of echinoids, mollusca, and calcareous algae.

Specimen No. 9022 is a fine-grained sandy tuff, verging on mudstone as regards grain size, and could be so classed. It is traversed by a narrow veinlet lined with quartz and (?) pyroxene needles.

Specimens Nos. 9047 and 9048 represent a further stage in the progression towards greywacke. They contain only a very little pyroxene, and much more quartz and glauconite than the other sandy tuffs, together with a little orthoclase, and fragments of chert, phyllite and shale, in addition to andesite. Specimen No. 9093 is generally similar, but is stained red-brown by iron oxide.

Heavy Minerals

The heavy minerals were extracted from two samples of tuff proper, Nos. 9026 and 9071, and two sandy tuffs, Nos. 9053 and 9063. The two tuff samples yielded an abundance of pyroxene fragments, consisting of colourless augite, green augite, and an occasional grain of hypersthene, a little epidote, and a few grains of iron ore and biotite, but no other minerals.

Of the sandy tuffs, the near tuff No. 9053 yielded an abundance of similar pyroxenes. In addition there is a very occasional grain of glauconite, an occasional minute prism of apatite, and a very occasional grain of brown tourmaline.

The more sandy specimen, No. 9063, by contrast, gave a relatively small heavy product, but it contains, in addition to a moderate proportion of the pyroxenes, all of the heavy minerals of the greywackes, though mostly as small grains only. They range between 0·02 and 0·05 mm. diameter. Apatite is the most abundant, occurring largely as minute water clear prisms, but partly as well-rounded dusty grains. Zircon occurs as occasional double-ended prisms, but chiefly as squat pyramidal grains, more or less completely rounded. Topaz is present as rather larger waterworn grains, and tourmaline occurs as the characteristic golden-brown and smoky varieties, in general waterworn. Rounded grains of glauconite occur in some abundance, and there are occasional grains of pink and brown garnet. The pyroxene occurs as fresh angular fragments of colourless and green augite, and there is an abundance of rounded leucoxene grains with a few rounded iron ores.

It appears from the relative proportions of heavy detrital minerals present in these two sandy tuffs that there is a direct correlation between abundance of detrital minerals and abundance of angular quartz as seen in thin sections.

MUDSTONES

A number of the rocks in the collection are mudstones, some verging on fine sandstone, namely Nos. 9020, 9021, 9060, 9062 and 9065. Some are too fine-grained for their components to be distinguished under the microscope, but most of them contain tuffaceous matter, felspar, pyroxene granules and zeolites, with a little angular quartz, in a clay matrix. Presumably they consist of intermingled tuffaceous and detrital material. No. 9020 shows complex crenulations suggestive of slump structures. No. 9078 is a heavily carbonated mudstone of this type.

Specimen No. 9094 is a black shale or sandy shale, with an abundance of fine angular quartz, cloudy felspar, shreds of biotite and muscovite, clayey patches, leucoxene, and carbonaceous matter, together with disseminated patches of carbonate and occasional shell fragments, but nothing suggestive of tuff. Blebs of iron sulphide are associated with the seams of carbonaceous matter.

Limestones

Three specimens of limestone are included in the collection. No. 9017, from Stage 4 (Chimbu Tuffs), in the Eocene portion of the section, is a brownish-grey limestone containing foraminifera and calcareous algae, reported as *Fasciolites wichmanni* (abundant), *Lacazina wichmanni, Textularia sp.,* and *Halimeda,* in a list of unpublished fossil determinations supplied with the suite of specimens by the Bureau of Mineral Resources. In thin section it shows no mineral grains or tuff fragments. Dissolution with acetic acid left a small residue of brownish clay-like material, but no mineral grains. Qualitative analysis showed the limestone to consist essentially of calcium carbonate, with a very minor amount of magnesium carbonate. Deposition of the limestone must have occurred, therefore, outside the range of sandy sediment, and during a period of volcanic quiescence.

The other two specimens, Nos. 9077 and 9087, consist of shells and shell fragments, of *Buchia malayomaoria* and *Inoceramus,* in a matrix of clay, carbonate material being the dominant component. Specimen No. 9077 might be described alternately as a red calcareous mudstone, the clay matrix being stained bright red with iron oxides. Some of the shell fragments enclose minute patches of zeolites. and some are fringed with a bright green pleochroic carbonate mineral. This rock contains no trace of quartz grains, but No. 9087 contains occasional grains of quartz about 0·01 mm. across.

In addition to these true limestones, there are two specimens of calcareous shale, Nos. 9078 and 9079, in which the carbonate occurs as a cement, replacing any original matrix in the rock, and to a large extent replacing the grains of the rock. It is probable that in these rocks the carbonate was introduced during diagenesis or lithification, and the original sediments were not limestones. No. 9078 contains fragments of andesite and ill-defined felspar, and very little quartz, so that it was tuffaceous in origin. No. 9079 contains abundant angular quartz and some muscovite, so was mainly sediment, probably similar to No. 9094.

Cherts

Two specimens, Nos. 9073 and 9074, consist of chert. No. 9073 is reported to contain radiolaria (*Spumellaria*), in part replaced by glauconite. It consists of a hard greenish chert, composed of sericite, chlorite, and amorphous silica, through which are distributed very occasional angular grains of quartz, small areas of chlorite, and patches of calcite. Distributed through the rock are stumpy, lens-like bodies, about 0·05 mm. long, of chlorite, or chlorite with a core of quartz. These may represent original radiolaria; but they bear some resemblance to the chlorite bodies in the zeolitic tuff (No. 9026). The chlorite is distinguished from glauconite by its apple green colour, and ultra-blue polarization colours.

Specimen No. 9074 is a similar rock, shattered by more or less rectangularly disposed fractures, which have been healed with carbonate, or fine-grained quartz. The rock contains less chlorite than No. 9073, but contains numerous radiolaria which appear as circular to ovoid areas of silica, calcite or chlorite. Some of the calcitic bodies show a reticulate structure, and many of them contain inclusions of minute opaque bodies.

Conditions of Sedimentation

The Wahgi sediments consist in part of tuff, and in part of detrital sediments, derived from a neighbouring landmass.

The tuffaceous material appears to have been deposited directly in the sea, since there is nothing in the way of differential weathering of the tuff fragments in a given thin section to indicate previous deposition on a land surface. The more or less crystalline character of the groundmass of many of the tuff fragments points to sub-aerial rather than submarine eruption. The fragments are invariably andesitic.

The detrital material appears to have been derived chiefly from older sediments, in view of the predominance of phyllite, shale and quartzite among the rock fragments. The abundant quartz grains are generally too fine-grained to be derived directly from granite, in view of the fact that their angular form indicates that they have not been transported any great distance. The well rounded form of many of the detrital heavy mineral grains in the greywackes indicates that these grains were derived from pre-existing sediments, and had undergone at least one previous cycle of erosion. It may be concluded, therefore, that the granite which the Wahgi sediments overlie, and which outcrops in the Bismark and Kubor Ranges, served as a surface of deposition, rather than as a source, for the sedimentary material.

The volcanic activity was intermittent, so that periods of sudden deposition of large volumes of tuffaceous material alternated with periods of volcanic quiescence, when the greywackes were formed. With less vigorous eruption the sandy tuffs resulted. The coarsely fragmental nature of some of the tuffs points to nearness to the volcanic vents; and the angular shape of the tuff fragments as compared with the rounded phyllite, shale, and quartzite fragments, suggests aerial transport for much of the tuff, and water transport for the sedimentary fragments.

The changes undergone by the rocks during diagenesis and lithification appear to be dependent on their original composition to a considerable degree. The greywackes tended to undergo more or less intensive carbonation, with development of calcite cement. The tuffs, with their abundant fine matrix of felspar and ferromagnesians, underwent some degree of hydration and solution that gave rise to an abundant cement of zeolites and some chlorite. These solidified at first as gels, subject to deformation.

The badly sorted nature of the sediments, their great thickness, and their fine-grained character, points to rapid deposition in a subsiding basin of deposition, which conforms with their situation in the Papuan geosyncline.

There is a general resemblance between the greywackes of the Wahgi section and the Purari greywackes (Edwards, 1950), emphasized by the presence of glauconite and apatite in both. The Wahgi rocks, however, tend to contain more quartz than the Purari rocks, and in addition lack the hornblende and fragments of hornblende andesite found in the Purari. The heavy mineral suites differ, also. Topaz is absent from the Purari sediments. Small pyramidal zircons characterize the Wahgi rocks, whereas prismatic zircons are more abundant in the Purari greywackes. Both series contain abundant apatite, but the abundant "dusky" apatites of the Purari suite are only weakly represented in the Wahgi rocks. Both contain abundant tourmaline, but the golden-brown variety characteristic of the Wahgi is lacking in the Purari.

The general indication; therefore, is that the two series were deposited under generally similar conditions, but derived from different terranes. Moreover, the vulcanicity was less pronounced in the Purari region.

Tectonic Environment of Sedimentation

The great thickness of the Mesozoic strata in the Wahgi Valley, amounting to nearly 16,000 feet for the sequence from about the base of the Upper Jurassic to the Cenomanian, corresponds to an estimated rate of deposition of about 0·1 mm. per year. This is a medium rate of deposition according to Stille (1944), who has recently analysed rates of deposition in various tectonic environments, and finds similar rates in the Tertiary idiogeosynclines of Indonesia, the Variscan foredeeps of Western Europe, and the intermontane basins in the Cordillera of Western America. He considers these depositional troughs as 'subsequent' or 'post-orogenic' undations.

The Wahgi Mesozoic sequence forms part of the 'folded sedimentary zone' of Central New Guinea (Glaessner, 1950), and similar sediments seem to underlie most of this zone. The Jurassic Maril Shales rest on the Kubor granite (Noakes, 1939), which is older than the Permian limestones overlying its western end (Glaessner, Llewellyn and Stanley, 1950). The uppermost members of the Wahgi sequence are locally overthrust from the north by similar granites, which form part of the Bismark Mountains. Remnants of Mesozoic strata, including equivalents of the Kondaku Tuffs, are faulted into the plutonic and metamorphic rocks of the 'crystalline zone', which lies north of the predominantly sedimentary zone. or are preserved as cappings on it. Towards the east the Wahgi sediments disappear under Upper Tertiary rocks which grade into the filling of the Aure Trough. The unaltered Mesozoic rocks are not seen again. Their place is taken by the Kaindi Metamorphics of the Owen Stanley Ranges, in which Cretaceous fossils occur locally.

The great thickness and areal extent of the Mesozoic rocks makes their geosynclinal character obvious. The rapid deposition of lithologically similar strata must have occurred in a subsiding trough. The rocks maintain uniform facies until Middle Eocene time, when shallow water limestones and conglomerates indicate a change in environment. The almost complete absence of initial vulcanism, and of synorogenic plutonism, which is usually accompanied by regional metamorphism, indicates that the Wahgi sediments were deposited in a miogeosyncline. This is confirmed by their position in relation to the cratonic stable area of Australia, which at the time of their deposition included the folded Palaeozoic rocks of the eastern geosyncline and the granitic batholiths of this zone extending across Torres Strait into southern New Guinea. Extensive basins in the Palaeozoic folded zone were being filled with lacustrine Triassic and Jurassic deposits, and with intermittently marine Cretaceous deposits, while other parts of this stable area provided a source of detrital material. This could account for the granitic and sedimentary material of the Purari greywackes (Edwards, 1950) and for the 'greensands' in the Cretaceous of Western Papua (Kerabi Valley, and other areas), but the detrital material of the greywackes in the Wahgi-Chimbu section, which is about 50 miles further north from the southern margin of the geosyncline, is of a different nature, and appears to be derived from a less granitic terrain. One locality cannot yield sufficient evidence of the direction of transport of this material, but as a working hypothesis it is suggested that its source lay to the north, where we also must look for the source of the abundant volcanic material. The Purari Formation contains less andesitic detritus at its type locality than its tuffaceous equivalents in the Wahgi Valley. The source of the material can be pictured not as a 'borderland', but as a zone of island arcs, which came into existence in a Mesozoic eugeosyncline. The Tertiary strata in northern New Guinea and the Bismarck Archipelago rest generally on a plutonic or metamorphic basement, indicating strong pre-Tertiary plutonism, which has wiped out all traces of unaltered Mesozoic sediments. This zone is considered to be the site of a late Mesozoic (or early Tertiary) eugeosyncline. The intermittent character of the vulcanism, which was weak or absent in the Jurassic, strong in the Lower Cretaceous, weak in the Cenomanian, and strong again in the Lower Chimbu Tuffs, is in keeping with the development of a geosynclinal zone in which volcanic island arcs appear, move, and disappear intermittently. The outward sequence from craton (with epi-continental deposition) to miogeosyncline (a marginal, rapidly sinking shelf) and thence to peripheral eugeosynclinal 'volcanic troughs and linear islands' not only parallels the conditions in the Appalachian geosyncline in Palaeozoic time (Kay, 1944), but is comparable with the conditions on the margin of Sundaland during the Tertiary.

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Explanation of Plate III

Fig. 1.—Greywacke No. 9403, showing an angular quartz grain, with quartz overgrowth, outlined by inclusions, together with fragments of andesite and shale. × 50.

Fig. 2.—A large rounded fragment of phyllite, characteristically elongated parallel to its bedding or cleavage, in greywacke No. 9403. × 50.

Fig. 3.—Greywacke No. 9608 (analysed specimen), showing characteristic texture, with ill-sorted angular grains of quartz and felspar as the dominant grains. × 25.

Fig. 4.—Chlorite ovoids showing parallel elongation and compaction effects, in a matrix of lime zeolite (?laumontite), in coarse zeolitic tuff No. 9206. × 25.

Fig. 5.—Three chlorite ovoids, enclosed in laumontite, and compressed into one another, presumably during compaction, in zeolitic tuff No. 9206. × 50.

Fig. 6.—Typical field of view of zeolitic tuff No. 9024 (analysed specimen), showing the abundance of coarse crystalline lime zeolite (?laumontite), colourless to light grey, with cleavage, together with small grains of fresh pyroxene (high relief) and fragments of altered andesite (dark). × 25.