PETROLOGY AND PROVENANCE OF THE CRETACEOUS SEDIMENTS OF SOUTH-EASTERN ALEXANDER ISLAND

By R. R. Horne

Abstract. The petrology, textures and provenance of a thick succession of Cretaceous marine sediments in south-eastern Alexander Island are described in detail for the first time. The detrital fraction of these sediments is highly immature mineralogically and texturally, and it is considered to have been derived rapidly from an elevated source area composed of granodioritic, parametamorphic and volcanic rocks. Large amounts of andesitic volcanic fragments, lapilli and shards are present in certain sandstone horizons and they also occur as water-lain tuff horizons. This material was derived either aerially or by erosion and transport. It is concluded that the present igneous and metamorphic complex of Palmer Land represents the deeply eroded core of the eastern source area and that the sediments are post-orogenic, back-deep molasse deposits related to the Jurassic orogenesis of the Antarctic Peninsula section of the circum-Pacific cordillera.

A sequence of marine clastic sediments with a calculated composite thickness of about 10,000 m. is exposed in south-eastern Alexander Island (Fig. 1). The succession is composed predominantly of mudstones and sandstones with locally very thick conglomerates. The fossil content of the argillaceous rocks indicates that at least part of the sequence described in this paper is of Aptian age (Cox, 1953; Howarth, 1958; Adie, 1964; Taylor, 1965, 1966*a*, 1966*b*).

The areal distribution of these sediments reflects distinct facies variations resulting from the control of sedimentation by the morphology of the trough in which they were deposited. The eastern margin of this trough was close to the present east coast of Alexander Island and it trended north—south along the western side of the geanticlinal ridge from which the sediments

Fig. 1. Map of Alexander Island and Palmer Land showing the area studied.

were derived. Because of this geographical arrangement, distinct facies zones can be delineated within the sediments trending parallel to the linear north—south coastline. Adjacent to the coastline is a zone of inshore deltaic and inter-deltaic sediments. The inter-deltaic sequences are built up of repeated interbeds of massive claystones or hybrid mudstones and coarser sandy mudstones or impure sandstones. These beds are considered to have been deposited partly as proximal turbidites and partly by strongly turbid river currents. The argillaceous rocks are highly fossiliferous, containing a varied benthonic and nektonic fauna, and well-preserved plant fronds and leaves. The deltaic sequences are dominated by current-bedded and channelled sandstones with minor silt and clay interbeds. These more argillaceous horizons show extensive bioturbation by burrowing organisms but their fauna, in contrast to that of the inter-deltaic sequences, is very sparse and the abundant plant material is macerated and carbonized. Thick polymict pebble conglomerates are locally developed in the inshore inter-deltaic and outer deltaic environments.

West of the delta fronts, accumulation of equal amounts of sand and clay in more regular strata occurred on a westward-sloping marginal shelf. Intraformational slump-shear folding and faulting of the more plastic sediments, due to down-slope slumping of the lithified overburden, has occurred on this shelf. The western margin of the shelf is defined by a narrow belt of diamictites such as pebbly mudstones and breccias which have resulted from sediment flow down the steep face of the submarine scarp (Horne, 1968*a*). Westward of this is a wide zone of undetermined extent of unfossiliferous, deep-water turbidite sandstones and pyroclastic and effusive volcanic rocks, the proportion of volcanogenic material increasing towards the west. The association of volcanogenic material with the sediments of all environments indicates syn-depositional andesitic volcanic activity around and within the trough. The sediments were folded and faulted during a phase of high-level deformation in post-Aptian times (Horne, 1967) but, although they exhibit varying degrees of internal chemical reconstitution, they have not been regionally metamorphosed in the classical sense.

Petrology of the Sandstones

In terms of any of the widely accepted classifications of sandstones, such as those of Krynine (1948), Folk (1954, 1959) and Pettijohn (1954), all sediments of sand grade in south-eastern Alexander Island are arkoses. They are marine clastic sediments in which the quartz/feldspar ratios are generally below 1·0–1·5, the content of "basement" rock fragments is less than 10–15 per cent and interstitial clay, where present, is small in amount. The modal analyses of representative sandstones from Alexander Island are given in Table I and selected analyses are plotted on ternary partial mode diagrams in Fig. 2.

Quartz. The quartz clasts were probably derived from a source area composed of parametamorphic schists, foliated acid and basic plutonic igneous rocks and acid volcanic rocks, as discussed on p. 81. A study of representatives of these proposed source rocks indicates that the quartz derived from these plutonic rocks can be distinguished by its weak to moderate cannot be distinguished from one another on criteria such as shape, strain, inclusions, etc., which is a conclusion similar to that of Blatt and Christie (1963). However, in favourable cases the quartz derived from these plutonic rocks can be distinguished by its weak to moderate strain extinction and anhedral shape from the euhedral and unstrained quartz crystals derived from quartz-porphyry lavas.

Feldspar. In the form of plagioclase, orthoclase and microcline, feldspar is by far the most abundant detrital mineral in these sediments. In the 14 analyses in Table I the average feldspar content is 40 per cent, but respective proportions of the various feldspar species are variable. Microcline and perthitic feldspar form less than 1 per cent of the total rock except in some of the coarser sandstones in which they are more abundant. The relative proportions of plagioclase and potash feldspar in 14 specimens are indicated in Fig. 2b. The composition of the detrital plagioclase in any specimen is related to the provenance of the horizon sampled. In sandstones rich in detritus from granitic or granodioritic rocks such as quartz and alkali-feldspar (including microcline and perthite) the plagioclase composition is in the range An_{25-35}, whereas in sandstones composed predominantly of plagioclase and hornblende (Table I, column 11) derived from dioritic rocks, the plagioclase composition lies in the range An_{45-55}.

TABLE I. MODAL ANALYSES OF CRETACEOUS SANDSTONES FROM ALEXANDER ISLAND

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Quartz	13·1	11·4	6·9	14·4	21·8	31·7	36·7	49·4	39·6	53·8	—	0·2	1·0	4·2
Alkali-feldspar	3·8	11·9	11·0	16·2	24·7	21·9	15·6	14·2	20·4	9·7	—	—	5·4	2·2
Plagioclase	47·3	19·2	15·8	27·7	33·8	26·4	19·4	17·2	28·9	29·2	54·5	57·0	15·9	4·9
Biotite	2·7	4·7	2·0	0·3	4·0	5·4	14·9	6·0	4·4	3·6	11·7	10·1	1·8	tr
Calcite	20·0	49·0	46·0	4·1	12·8	14·5	—	2·0	2·8	—	—	7·8	—	19·3
Basement rock fragments	5·4	—	18·0	5·3	2·9	—	11·7	10·2	3·8	—	—	—	—	—
Volcanic rock fragments	—	—	—	—	—	—	—	—	—	—	—	—	62·1	59·7
Chlorite	3·6	—	—	17·1	—	—	—	—	—	—	15·0	11·0	—	9·7
Muscovite	—	tr	tr	—	—	—	1·6	0·4	—	—	—	—	—	—
Clay	—	—	—	11·8	—	—	—	—	—	—	—	—	—	—
Opaque minerals	—	1·4	—	—	—	—	—	4·3	—	—	4·3	—	3·2	—
Prehnite	1·0	—	—	3·0	—	—	—	—	—	—	—	—	4·0	tr
Green hornblende	3·0	2·3	—	—	—	—	—	—	—	3·6	14·4	13·9	—	—
Augite	—	—	—	—	—	—	—	—	—	—	—	—	6·7	—
Q : F ratio	0·26	0·36	0·26	0·33	0·37	0·28	1·04	1·57	0·80	1·4	—	—	—	—

1. KG.74.1 West of Triton Point.
2. KG.68.17 North Waitabit Cliffs.
3. KG.51.11 South side of Uranus Glacier.
4. KG.50.2 South side of Uranus Glacier.
5. KG.70.5 South side of Neptune Glacier.
6. KG.62.1 West of Keystone Cliffs.
7. KG.57.1 North of Mount Umbriel.
8. KG.57.6 North of Mount Umbriel.
9. KG.55.1 North of Mount Umbriel.
10. KG.68.18 North Waitabit Cliffs.
11. KG.69.3 South Waitabit Cliffs.
12. KG.69.6 South Waitabit Cliffs.
13. KG.72.8 West of Bandstone Block.
14. KG.71.2 Triton Point.

The plagioclase occurring in the coarser volcanic fragments and as discrete broken crystals with frequent oscillatory zoning in strongly tuffaceous horizons has a composition in the range An_{38-50}. The alteration of plagioclase to kaolinite, epidote, prehnite and laumontite is locally extensive but it varies greatly between different horizons. The development of authigenic minerals in these sediments will be discussed in a later paper (Horne, 1968*b*). The freshness or absence of alteration in feldspars is greater in those sandstones cemented by calcite than in those with a chloritic or sparse clay cement. The feldspars in carbonate-cemented sandstone concretions show virtually no alteration.

Basement rock fragments. Four types of detrital rock fragments can be recognized in the coarser sandstones and gravels: the first are coarse-grained granitic or granodioritic fragments and the second are fragments of feldspar-porphyry or more rarely quartz-feldspar-porphyry, both of which are approximately equal in abundance. Fragments of the first type often comprise only two or three bonded grains. The third type are composite fragments composed entirely of interlocking quartz grains with sutured boundaries and they have been derived from foliated gneissose granodiorites. The fourth type are of parametamorphic origin, usually derived from quartz-mica-schists (Fig. 3a), and they are relatively small in number. Where little mica is present, these fragments can resemble the quartz composites of stressed granodioritic origin.

Indigenous rock fragments. Certain of the coarser sandstones and gravels, particularly in the deltaic facies sequence, contain quantities of flakes and pellets of mudstone identical to that forming the mudstone horizons in the same succession. They would appear to represent earlier sediment of the same trough which has been re-worked by energetic fluvial currents. Hence such indigenous fragments commonly form part of the infilling of wash-out channels. The rounding of these clasts increases significantly down-current. Other rock fragments enclosed in the massive sandstones seem to have been derived by the fracturing of overlying beds after the accumulation and partial lithification of some thickness of overburden. Such fragments are frequently rimmed by an aureole of laumontite-rich sandstone.

FERROMAGNESIAN FRAMEWORK COMPONENTS

Because of their rapid derivation from a mixed igneous and metamorphic source under conditions favourable to the preservation of labile minerals, these sediments are unusually

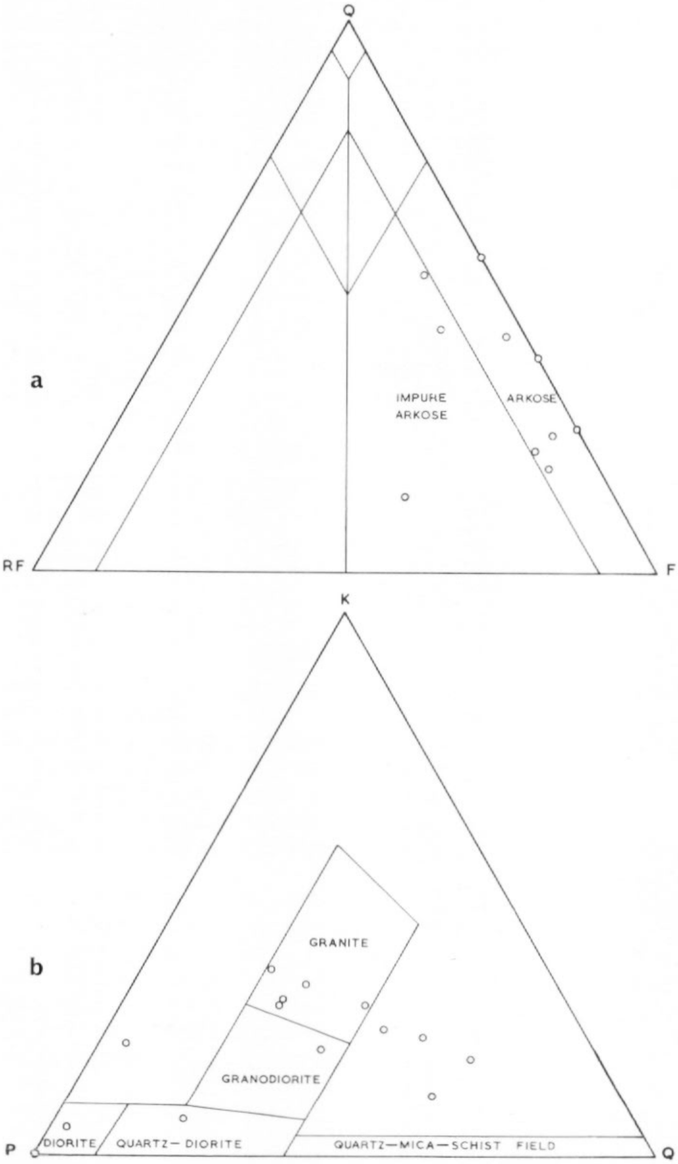

Fig. 2. Partial mode diagrams of sandstones from south-eastern Alexander Island.
a. *Q* quartz, *F* total feldspar, *RF* "basement" rock fragments (excluding contemporaneous volcanic fragments). Field limits after Folk (1954).
b. *Q* quartz, *P* plagioclase, *K* potash feldspar. Field limits modified after Chayes (1957).

rich in ferromagnesian components, particularly biotite and green hornblende. The stable part of the heavy mineral suite is discussed on p. 79.

Biotite. There is an abundance of biotite, of plutonic and metamorphic derivation, throughout these sediments and in amount it vastly exceeds muscovite. The biotite flakes almost invariably show moderate to strong bending or, in extreme cases, kink banding (Fig. 3b). It is considered (p. 79) that this bending is an intrastratal post-depositional strain. The biotite appears to be remarkably stable chemically, although the flakes become more ragged and distorted down-current and there is evidence of a progressive loss of colour.

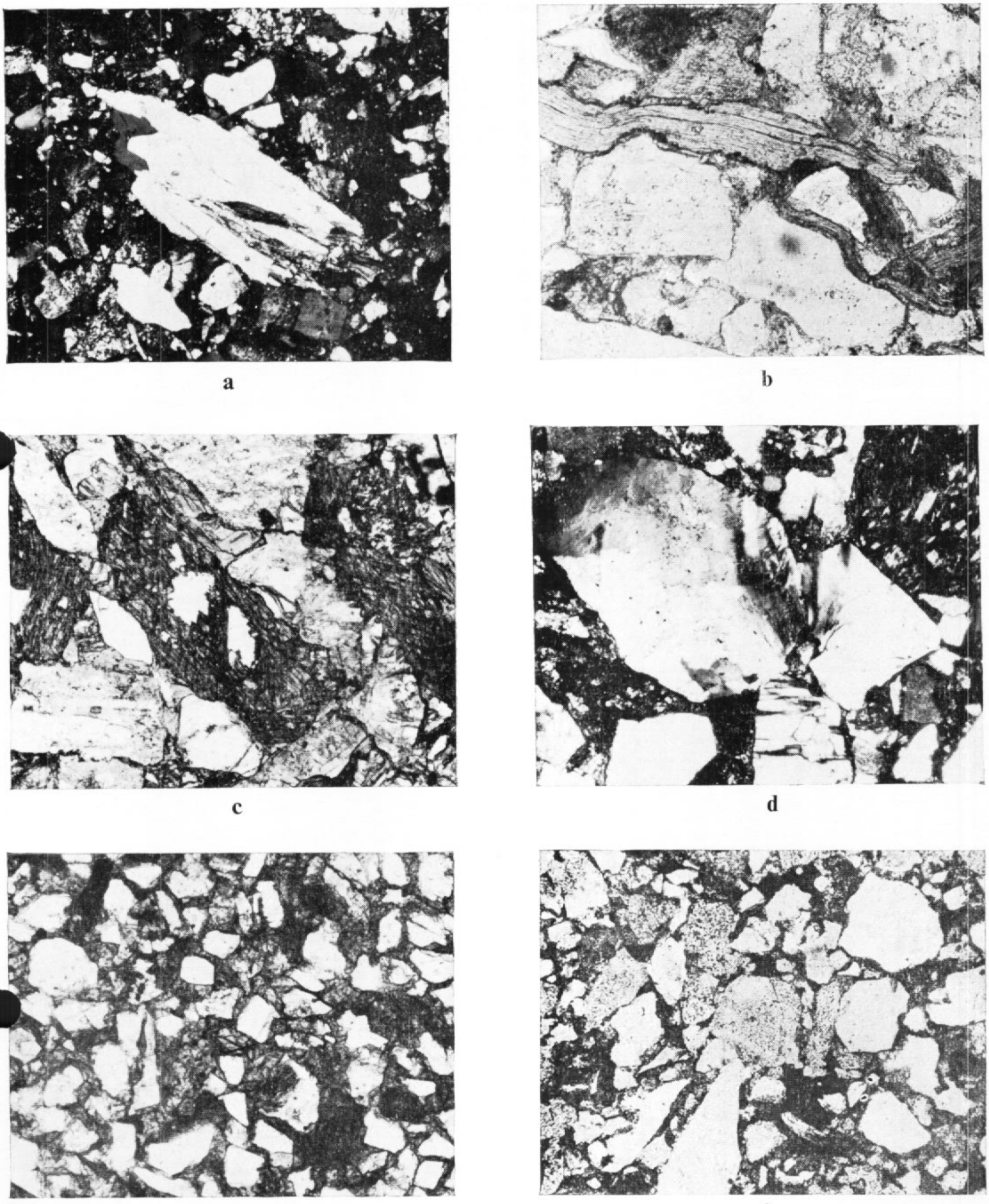

Fig. 3. a. Quartz-mica-schist fragment in sandstone (KG.70.2; X-nicols; ×28·5).
b. Biotite moulded around detrital grains (KG.57.7; ordinary light; ×28·5).
c. Green hornblende and biotite in a feldspathic sandstone (KG.70.14; ordinary light; 2×8·5).
d. Strain effects in quartz grains at a contact with a feldspar grain (KG.50.2; X-nicols; ×28·5).
e. Calcareous sandstone (KG.68.17; ordinary light; ×28·5).
f. Massive turbidite sandstone (KG.57.7; ordinary light; ×28·5).

Green hornblende. Detrital green hornblende is a minor component of most of the sandstones. Considerable amounts of this mineral are present in many of the sandstones from the lowermost parts of the succession studied and the dominant middle-grade parametamorphic provenance of this sequence suggests that the hornblende is of amphibolitic origin. Green hornblende is also abundant in some of the plagioclase-rich calcareous sandstones (Fig. 3c) of unusual composition, a typical example containing 13·9 per cent of green hornblende (Table II, A). The significance of the similarity in composition between this material and a hornblende-gabbro is discussed on p. 81.

TABLE II. MODAL ANALYSES OF SANDSTONES FROM ALEXANDER ISLAND AND THEIR INFERRED SOURCE ROCKS FROM PALMER LAND

	A	B	C	D	E	F	G	H	J
Quartz	0·2	—	35·4	12·4	53·0	28·3	31·4	27·3	33·1
Potash feldspar	} 57·0	65·6	39·1	16·8	—	18·2	20·2	16·0	19·4
Plagioclase			20·1	48·0	—	29·0	32·2	28·6	34·7
Biotite	10·1	10·7	4·8	—	29·0	8·4	9·3	10·5	12·7
Muscovite	—	—	—	—	18·0	4·5	5·0	tr	tr
Hornblende	13·9	19·7	—	12·0	—	6·0	—	—	—
Epidote	—	0·8	—	6·0	—	3·0	—	—	—
Sphene	—	0·9	—	1·6	—	0·8	0·9	—	tr
Chlorite	11·0	—	—	0·8	—	0·4	—	—	—
Calcite	7·8	—	—	0·8	—	0·4	—	—	—
Magnetite	—	2·6	0·6	1·2	—	0·9	1·0	—	tr
Rock fragments	—	—	—	—	—	—	—	17·6	—
Plagioclase composition	An_{52}	An_{57}	An_{10}	An_{50}					
Q : F ratio			0·6	0·2		0·60	0·60	0·61	0·61

A. KG.69.6 Calcareous sandstone, South Waitabit Cliffs.
B. KG.408.3 Hornblende-gabbro, Palmer Land.
C. KG.415.5 Biotite-granite, Palmer Land.
D. KG.412.1 Granodiorite, Palmer Land.
E. KG.414.5 Quartz-mica-schist, Palmer Land.
F. Average of 1C + 2D + 1E.
G. Analysis F recalculated without labiles.
H. Average of ten sandstones from Alexander Island.
J. Analysis H recalculated without rock fragments.

CONTEMPORANEOUS VOLCANIC MATERIAL

Contemporaneous volcanic fragments, crystals and shards are present throughout the succession, but horizons containing more than 25 per cent of this material which could be termed tuffaceous sandstones or tuffs are concentrated at distinct horizons in the succession studied. Compositionally, this material appears to be identical to the matrix of the agglomerate described on p. 79. The presence of plagioclase with a composition in the range An_{38-50}, brown hornblende and augite in both occurrences indicates that the volcanism was of an andesitic character. In certain horizons the fragments are almost aphanitic but in others there are numerous large twinned plagioclase crystals set in a vitric groundmass. Similarly, a distinct trachytic flow texture is apparent in some volcanic fragments, whereas in others the feldspars are more equant and exhibit random alignment. The association of agglomerates with the deep-water facies turbidites suggests a westerly source for part of the pyroclastic fraction of the sediments, but the lateral persistence of beds of laumontitized vitric shards and examples of finely graded tuff layers, which have settled into the top of soft mudstone horizons, suggests that part of the pyroclastic material may have been deposited aerially from ash clouds. Taylor (1966*a*) has described two other types of volcanic material from tuffaceous sediments in the Fossil Bluff area; these he has considered were deposited in the trough from ash clouds. The first type are flattened crystal lapilli, one or two crystals thick and 10 to 30 mm. in diameter.

Less common are devitrified glass pellets, resembling accretionary lapilli, consisting of green chloritized glass and often having a crystal or rock fragment as a nucleus. It is probable, however, that the bulk of the fragments of basic volcanic material were derived from easily eroded tuffs that accumulated in the eastern source area as a result of syn-depositional volcanism.

Agglomerate

A large mass of agglomerate of undetermined shape and extent is interbedded with the deeper-water marine sediments in the west of the area studied. The matrix of the agglomerate is a hard, compact grey-blue tuff with admixed lithic, vitric and crystal fractions. The groundmass of the tuff is a weakly polarizing aggregate of compacted shards and small feldspar crystals. Enclosed in this groundmass are totally altered, zoned feldspar crystals, fresh euhedral, twinned and zoned augite crystals, and lava fragments with flow-aligned plagioclase laths in a vitric matrix. These lava fragments are identical to those in the adjacent sandstones. Embedded in this tuffaceous matrix are blocks of basement plutonic rocks and brown porphyritic lava up to 50 cm. in diameter. Discrete masses of tuff which are identical in lithology to the enclosing matrix can be distinguished and they clearly represent disrupted blocks of an earlier pyroclastic accumulate of the same extrusive centre.

Strain Effects in Detrital Minerals

Many of the detrital minerals in these sediments exhibit bending, cracking and strain lamellae, most of which have resulted from deformation within the sediment after deposition. Other features are tectonic strains induced in the source rocks before their disaggregation and transport.

Of definite pre-depositional origin is the bulk of the straining and suturing of plutonic and parametamorphic quartz composites. Similarly, the weak to moderate strain extinction in the quartz clasts of plutonic igneous derivation is considered, in the light of conclusions regarding its provenance (p. 81), to be of primary origin.

A considerable number of quartz clasts show bands of strain lamellae and undulatory extinction which are disposed around contact points with other grains (Fig. 3d). The strain lamellae are irregular and related to local grain dispositions; they appear to have been generated only when suitably orientated grains impinge upon one another in sediments without adequate matrix to accommodate compaction. Such strain lamellae have not been observed in rocks from the proposed source area in Palmer Land. Also, some of the quartz and feldspar grains are extensively fractured and broken apart, and they could not possibly have survived transport in this state. Biotite flakes have almost invariably been strongly bent or corrugated, appearing to be moulded around adjacent grains. Extreme examples show kink banding. These latter strains are of post-depositional intrastratal origin and they probably were the result of loading stress. This stress has no doubt exploited any derived weaknesses in the detrital grains.

Where extensive carbonate cement has been introduced into the sandstones, many of the grains have been penetrated by veins of cement. Frequently biotite flakes have been expanded by the introduction of calcite parallel to their cleavages. Authigenic chlorite occasionally has a similar penetrative relationship to the detrital grains.

Heavy Minerals

In these sediments the detrital mineral fraction with a specific gravity greater than 2·9 comprises, in approximate order of abundance, biotite, green hornblende, magnetite, sphene, garnet, zircon, apatite, epidote, muscovite and allanite. The grains occasionally have a derived primary sphericity but they show no rounding and are entirely of first-cycle, igneous and metamorphic origin. The zircon and apatite grains possess strong idiomorphism and the former mineral frequently contains bubble-shaped inclusions. Part of the original apatite content may have been lost since most of the samples were prepared by acid digestion in the laboratory.

The heavy mineral fraction shows the same textural and mineralogical immaturity as the light fraction due to rapid derivation and resulting absence of weathering, selective sorting and intrastratal solution (Van Andel, 1959). The assemblage, therefore, directly reflects the changing composition of the source area. The zircon, sphene, apatite, magnetite, allanite and part of the biotite and green hornblende are clearly of plutonic igneous and metamorphic origin. However, the garnet, epidote, muscovite and part of the biotite and green hornblende were undoubtedly derived from low- to medium-grade parametamorphic rocks and amphibolites.

Cementation

More than half of the sandstones in the succession have a calcareous cement. Both in these rocks and in the calcareous concretions present in otherwise non-calcareous sandstones this cement appears to have removed the finer interstitial fractions and it has dissolved and embayed the detrital grains. As a result of this they have a clean well-sorted appearance (Fig. 3e). Other sandstones are cemented either by authigenic minerals such as laumontite or chlorite or by the partially recrystallized fine-grained matrix. Laumontite, which has been produced at the expense of plagioclase and tuffaceous material, is particularly abundant in the tuffaceous sandstones, and such rocks are typified by a strong mottling and by a fine, white chalky appearance on weathered surfaces. The formation of authigenic minerals such as laumonite and prehnite will be described in a later paper (Horne, 1968*b*). The turbidite sandstones of the axial facies are cemented by the recrystallized fine-grained matrix which includes feldspar and micaceous material (Fig. 3f).

Numerous features such as slump convolutions (Horne, 1968*a*), "xenolithic" fragments in massive sandstone and clastic dykes, indicate that much of the sediment deposited in the trough during Lower Cretaceous times remained in a water-saturated and "quick" or mobile state for an abnormally long period after its deposition. It is clear from the testimony of such features as "lubrication zones of thrusting" (Horne, 1967) and clastic dykes that lithification had not reached an irreversible stage by the time that deformation of the sedimentary sequence was initiated. A combination of three factors seems to have been responsible for the retarded lithification of these sediments. The first of these is the availability of suitable cements. This is indicated by the observation that the calcareous sandstones do not show "soft-sediment structures", whereas they are widespread in thick mottled sandstones which are now cemented by late-stage authigenic minerals. Secondly, the abundance of gravity-controlled slump structures and mass-flow deposits suggests that the trough underwent frequent seismic shocks resulting from tectogenesis in the hinterland. Such shocks may have been instrumental in re-mobilizing partly lithified bodies of sediment, particularly in the sloping shelf environment. The third factor is the great thickness of sediment which accumulated within a relatively short time interval. The absence of non-clastic deposits, the gross lack of sorting and the influx of large quantities of volcanogenic material all point to rapid rates of accumulation.

Provenance

In his review of recent sandstone classifications, Klein (1963) concluded that "provenance and mineralogical maturity are the only factors controlling the mineral composition of sandstones". From the preceding descriptions it is apparent that the Cretaceous sediments of south-eastern Alexander Island are grossly immature mineralogically. Hence their mineralogy, both qualitatively and to an unusual degree quantitatively, is a direct reflection of their provenance.

All of the gravity-controlled structures reveal a westerly bottom slope, and directional current structures consistently indicate that the clastic material was derived from the east from a rapidly eroding geanticline. It is therefore proposed that the igneous and metamorphic complex at present exposed in Palmer Land, which comprises the southern part of the Antarctic Peninsula in the same latitudes, now represents the deeply eroded remnant of this geanticline. Various aspects of the petrography of the Cretaceous sediments of Alexander Island and the petrography of the igneous and metamorphic rocks of Palmer Land, based on the field observations of M. E. Ayling, J. F. Pagella and the present author in Palmer Land, are presented here to support this hypothesis. In making this comparison it is recognized that in a rapidly eroding source area there will be changes in overall composition as successively deeper levels are exposed. However, three main considerations are believed to justify this comparison with the rock types at present exposed in Palmer Land. These are that the sediments studied are close to the top of the derived succession, that the rate of compositional variation in the source area will probably decrease almost exponentially with depth of erosion and that extensive denudation of the Palmer Land geanticline has not occurred since Lower Cretaceous times.

The bulk of the plagioclase, alkali-feldspar and moderately to weakly strained quartz was derived from plutonic rocks of granitic-granodioritic composition. In the ternary partial-mode diagram (Fig. 2b), the analyses of 14 sandstones from Alexander Island fall near the granite-granodiorite field (Chayes, 1957). Of the heavy mineral suite, such source rocks would yield zircon, sphene, allanite, apatite and magnetite. The preservation of labile components in calcareous rocks makes their clastic assemblage particularly valuable indicators of provenance. One of the most notable examples is a calcareous sandstone whose modal analysis is given in Table II, column A. Apart from the carbonate cement, this sandstone has the approximate composition of a hornblende-gabbro. For comparison, the modal analysis of a sheared hornblende-gabbro from Palmer Land is given in the same table. In addition to the striking mineralogical similarities, minor features such as the shearing and composition of the plagioclase are identical in both the sediment and the hornblende-gabbro.

The composite clasts of quartz-mica-schist and some of the composite grains of sutured strained quartz are undoubtedly of parametamorphic derivation. Medium-grade metamorphic species in the heavy mineral suite include biotite, muscovite, garnet, epidote, green hornblende and possibly some chlorite. Part of the abundant biotite may have been derived from plutonic igneous sources but the muscovite is of parametamorphic origin, since the foliated, plutonic igneous source rocks seem to have been predominantly granodioritic rather than granitic.

The field investigations of Procter (1959), Ayling (1966), J. F. Pagella (personal communication) and the author have shown that the present exposures in Palmer Land are composed approximately of 17 per cent granitic rocks, 33 per cent granodioritic rocks, 33 per cent volcanic rocks and 17 per cent parametamorphic rocks. The volcanic rocks are predominantly porphyritic lavas, tuffs and minor agglomerates. In the main they are composed of deeply altered feldspar and, less frequently, unaltered quartz phenocrysts set in vitric or microcrystalline matrices. On weathering, such rocks would yield mainly quartz with a little feldspar as a coarse sand phase, the remainder of the rock degrading rapidly to silt- or clay-size material. Clear, unstrained and often euhedral volcanic quartz clasts are notable in many of the coarser siltstones.

Almost all of the sand-grade material in the Alexander Island Cretaceous sediments is therefore derived from the three other major rock groups mentioned above. In Table II the average of ten analyses of Alexander Island sandstones is compared with the average composition of one part of granitic rock, two parts of granodioritic rock and one part of parametamorphic schist, since this roughly represents the proportions in which these rock types are now present in Palmer Land. Typical examples of these three rock types collected in Palmer Land have been used in this comparison. The resulting averages (Table II, G and J) show a strong correlation and, in view of the immaturity and easterly provenance of the sediments and of the considerations outlined above, this similarity supports the hypothesis that the igneous and metamorphic complex of Palmer Land represents the "basement" and degraded source area of the Lower Cretaceous sediments of south-eastern Alexander Island.

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