MORPHOLOGY, PETROLOGY AND PROVENANCE OF PEBBLES FROM LOWER CRETACEOUS CONGLOMERATES OF SOUTH-EASTERN ALEXANDER ISLAND

By R. R. HORNE

ABSTRACT The palaeogeographical distribution of conglomerate beds in the Lower Cretaceous sediments of south-eastern Alexander Island is described. The morphology, petrology and provenance of pebbles from these conglomerates are discussed in relation to the composition of the proposed source area to the east.

IN earlier papers (Horne, 1968*a*, *b*, 1969) reference has been made to the palaeogeographical distribution of conglomerate beds in the Lower Cretaceous succession of south-eastern Alexander Island. In view of their importance, the morphology and petrology of the component pebbles* are now described in detail. Conclusions about the provenance of this sequence are reviewed in the light of the evidence provided by the petrology of the pebbles.

The greater part of the material, totalling about 2,800 cobbles, pebbles and granules, was collected in the Fossil Bluff area (Fig. 1) of Alexander Island by B. J. Taylor in the form of bulk samples from a small part of each outcrop. Smaller collections for petrographical examination were made by the author from the conglomerates of the Venus Glacier area. A number of isolated pebbles from Waitabit Cliffs (locality T) were contributed by M. R. A. Thomson. Size measurements of the coarse fraction of the conglomerate at Fossil Bluff were made by B. J. Taylor.

DISTRIBUTION

Conglomerate horizons composed of exotic phenoclasts of "basement" rocks are developed at a number of horizons in the Lower Cretaceous succession of south-eastern Alexander Island. They are concentrated in the Venus Glacier area (Horne, 1968*a*, *b*, 1969), in the Fossil Bluff–Succession Cliffs area (Taylor, 1966) and in the south-eastern corner of the island (Adie, 1958).

Fossil Bluff area

Details of the field occurrence of conglomerates in the Fossil Bluff area and at Succession Cliffs have been supplied by B. J. Taylor.

A massive-bedded polymict conglomerate, varying in thickness from 0·5 to 2·0 m., is exposed at localities M and Q (Fig. 2a and b). The phenoclasts are embedded in a sandy matrix, which comprises about one-third of the volume of the deposit and often occurs in irregular pockets or lenses. No preferred orientation of the clasts is apparent and close proximity to a shoreline is inferred. Similar conglomerates are exposed at locality J (Succession Cliffs) (Fig. 2c and d), where 38 m. of pebbly sandstone are overlain by 30 m. of coarser, less sandy conglomerate. Boulders about 1 m. in diameter are associated with large siltstone spheroids and calcareous sandstone concretions in the conglomerate. Here again no apparent grading or imbrication was observed.

The conglomerate at locality C varies rapidly in thickness from 1 to 12 m. Siltstone spheroids and calcareous sandstone concretions are again present together with plant fossils and shells. This conglomerate grades laterally into sandstones (containing *Trigonia* and abundant fossil wood fragments) of probably intertidal inshore facies. Taylor (1966) has suggested that these conglomerates are inshore littoral to sub-littoral deposits, the pebble to boulder material having been abraded *in situ*. This conclusion is broadly in agreement with that of the author (Horne, 1969), who has described them as littoral or offshore bars, or shoals accumulated in interdeltaic embayments.

* The word "pebble" is used in a general sense for all the phenoclasts studied, the vast proportion of which fall in the size range 4–64 mm. Where the term is used strictly for clasts in this size range this is obvious from the sense of the text.

Br. Antarct. Surv. Bull., No. 21, 1969, p. 51-60.

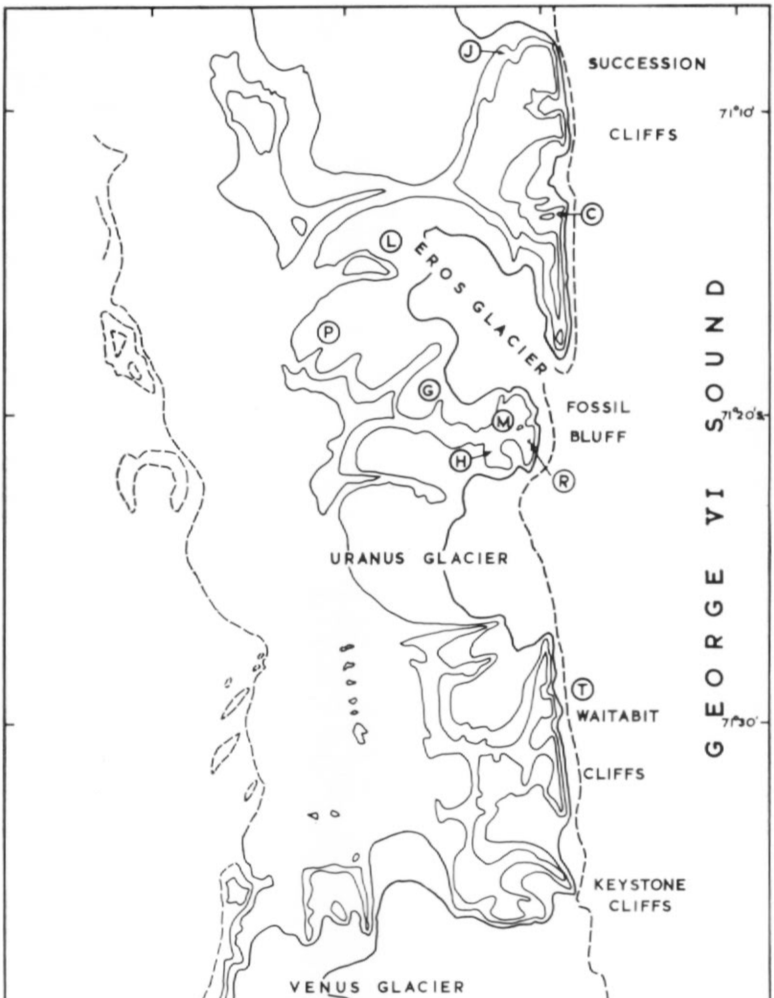

Fig. 1. A map of part of south-eastern Alexander Island showing the localities referred to in the text.

A number of pebble deposits appearing in section as small lenses about 1–2 m. wide and less than 1 m. thick have been recorded by Taylor (1966, p. 63) from localities H, G and L, and by the author from locality T (Waitabit Cliffs) (Horne, 1969). These are interpreted as material filling narrow washout channels.

Venus Glacier area

Within the deltaic facies sequence of the Venus Glacier area (Horne, 1969) conglomerates occur in two distinct environments. The inner deltaic conglomerates are composed of reworked indigenous mudstone clasts (Horne, 1969), whereas conglomerates with extraneous clasts

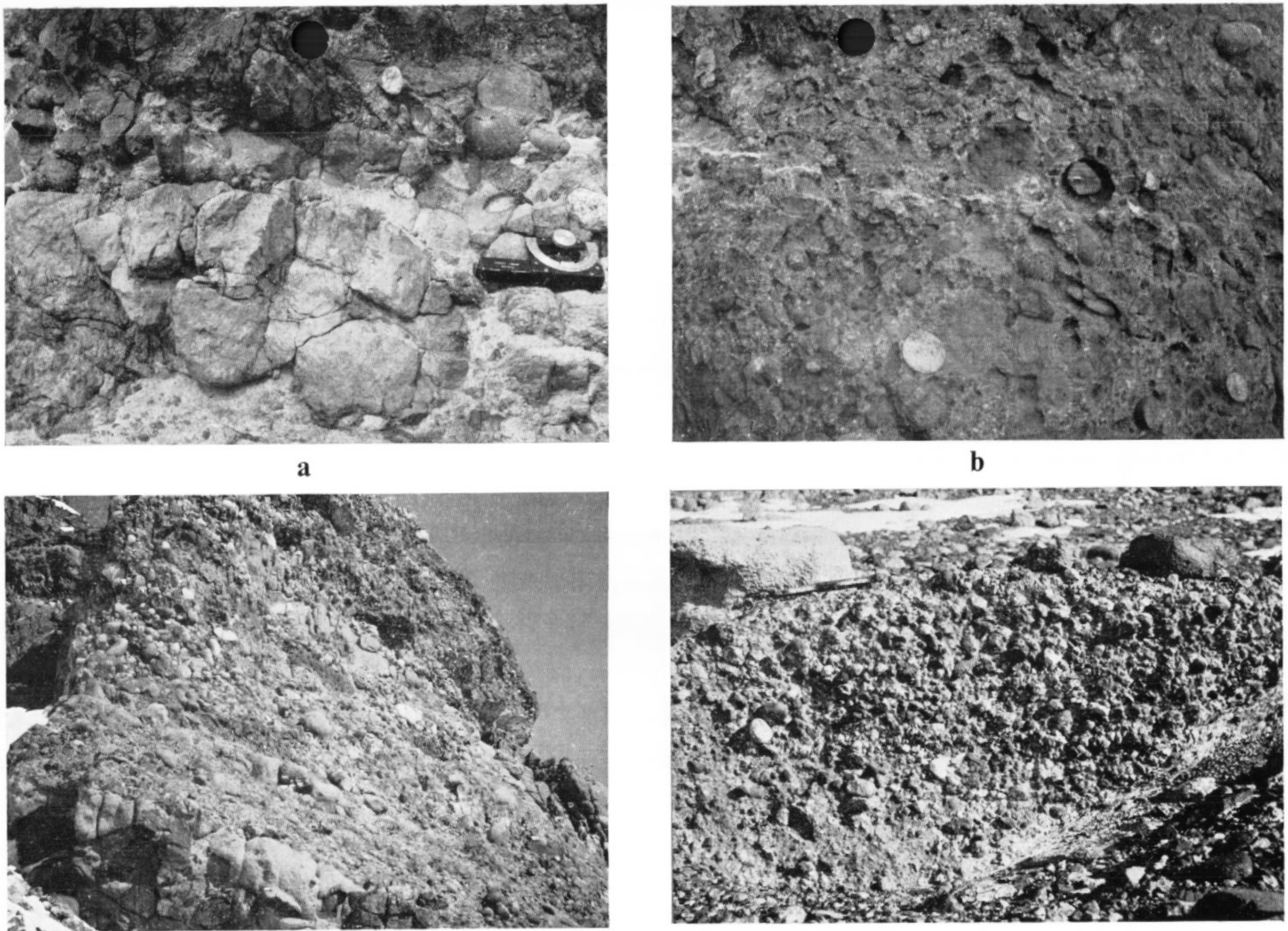

Fig. 2. a. The conglomerate at locality M enclosing a large calcareous sandstone concretion. The tube of the Abney level is 13 cm. long. (Photograph by B. J. Taylor.)
b. The same conglomerate horizon at locality M illustrating the high content of matrix. (Photograph by B. J. Taylor.)
c. The coarse phase of the conglomerate at locality J. The section shown in the photograph is approximately 30 m. thick. (Photograph by B. J. Taylor.)
d. A finer-grained facies of the conglomerate at locality J. The chisel is 12 cm. long. (Photograph by B. J. Taylor.)

are restricted to the outer deltaic environment (Horne, 1968*a*, fig. 6a and b, 1969). In this deltaic environment, where deposition proceeded from active fluvial, marine and tidal currents, the conglomerates generally lack extensive sandy matrices and frequently show an imbricate texture. Irregular sandstone lenses, often with cross-lamination, are common within the conglomerate masses.

The conglomerates recorded by Adie (1958) from the most southerly and probably youngest outcrops in the Corner Cliffs and Stephenson Nunatak area are about 230 m. thick and are associated with fossil trees and thin coal seams. This facies sequence may represent the final infilling of the trough.

In addition to their concentration in these conglomerate beds, isolated pebbles occur in mudstone and sandstone horizons throughout the succession.

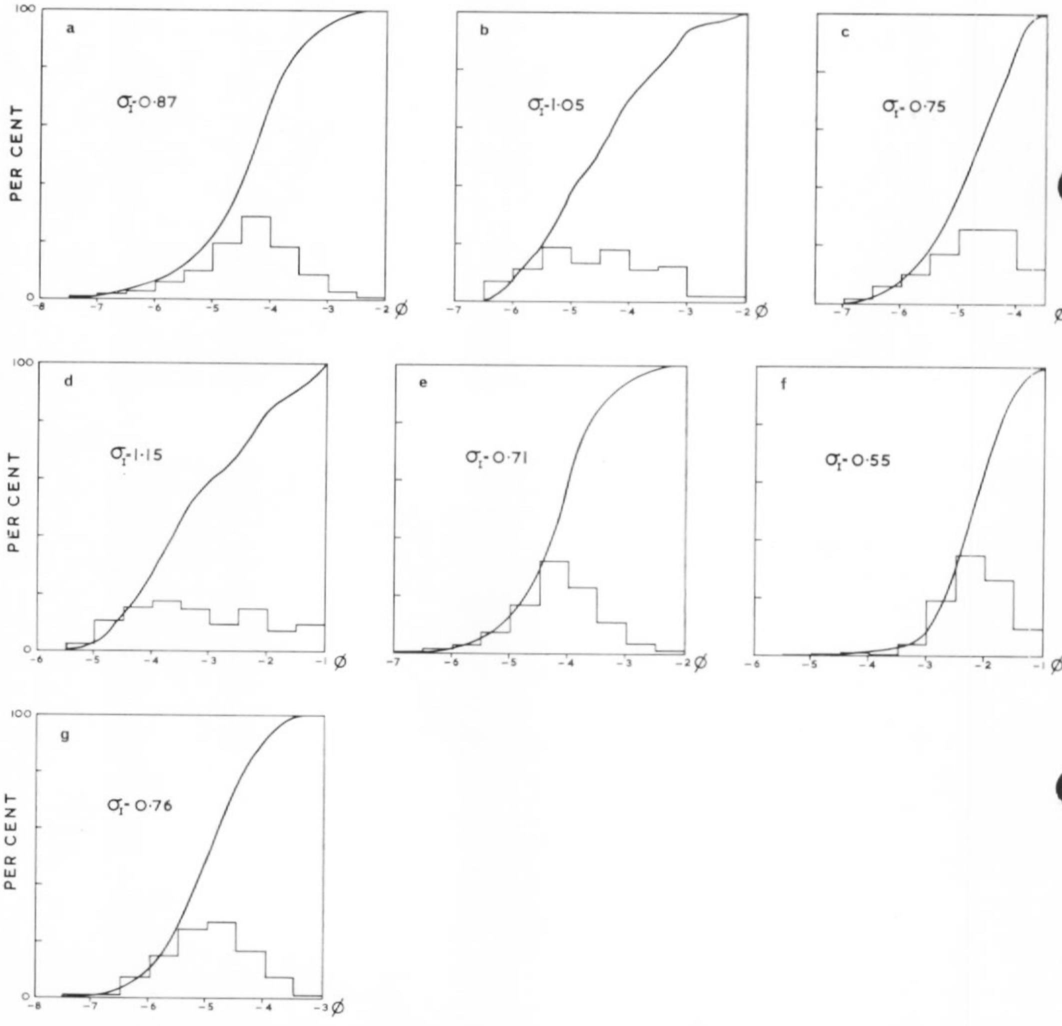

Fig. 3. Partial size analyses in the form of cumulative curves for the conglomerates of south-eastern Alexander Island.
a. Locality H, sample H1 (103 pebbles).
b. Locality H, sample H2 (137 pebbles).
c. Locality P (244 pebbles).
d. Locality R, sample R1 (205 pebbles).
e. Locality R, sample R2 (683 pebbles).
f. Locality M (1,392 pebbles).
g. Locality G (148 pebbles).

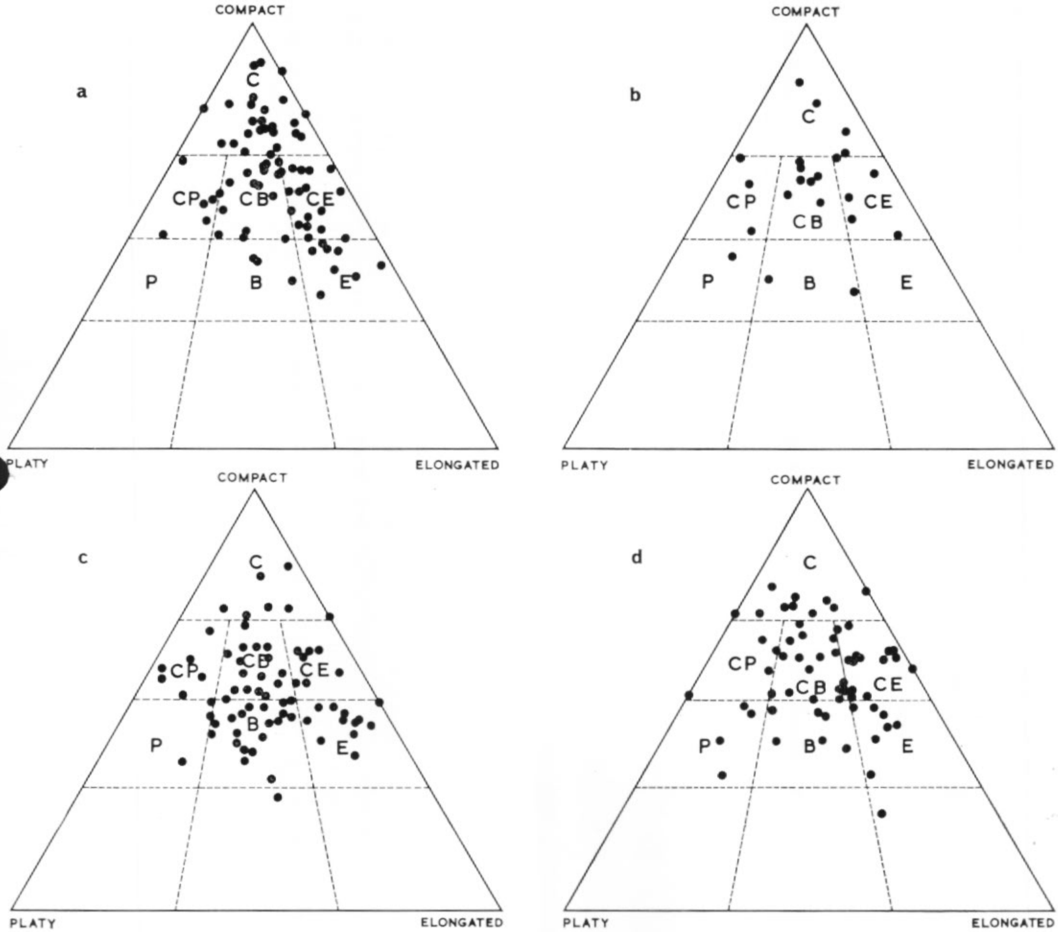

Fig. 4. The morphology of pebbles from the conglomerates in terms of a form triangle (Sneed and Folk, 1958).
a. Localities M and R (74 pebbles).
b. Locality H, sample H2 (22 pebbles).
c. Locality G (72 pebbles).
d. Locality P (62 pebbles).

Pebbly mudstones

The outer shelf conglomerates of upper Venus Glacier (KG.78, 80, 81 and 82; Fig. 1) may represent the source of the pebbles in the pebbly mudstones (KG.83 and 85) derived by mobilization of the shelf-edge deposits and their mass flowage and mixing on the scarp at the shelf edge. These diamictites occur in a narrow but distinct palaeogeographical zone marking this shelf edge. The general structure and palaeogeographical significance of these deposits have already been described (Horne, 1968*a*) and only their pebble fraction will be discussed here.

Size Distribution

Partial size-distribution analyses for bulk samples of seven conglomerate outcrops are given in Fig 3. These analyses are all open-ended towards the finer grades of the sediments which are essentially bimodal. They therefore show the distribution of the coarser mode, the second finer mode generally lying in the sand or fine gravel grades. The exception to this is the pebbly mudstone from locality P whose finer mode lies in the clay or fine silt grades.

Roundness

The roundness of the pebbles shows distinct variation between the conglomerates sampled (Figs. 2 and 5). Although the range of samples is limited, roundness (estimated visually by comparison with the charts of Krumbein (1941)) is more pronounced in the deltaic facies conglomerates of the Venus Glacier area and in the conglomerates from localities M and Q (average roundness = 0·7) of suggested inshore or littoral facies. In this case, roundness may have been enhanced by abrasion *in situ*. The conglomerates of locality G (average roundness = 0·5) and the pebbly mudstone from locality P (average roundness = 0·6), which are considered to have been deposited farther from the shoreline in a deeper-water shelf environment, have lower roundness figures due possibly to their rapid emplacement out of range of current or wave action.

Sphericity

In order to determine the variation of form and sphericity between the conglomerates sampled, 230 pebbles were remeasured by the author. Because of the limited amount of material available, the samples are quite small despite the measurement of all the unbroken pebbles coarser than $-4\ \phi$. The results are illustrated in Fig. 4 in terms of a form triangle (Sneed and Folk, 1958), and in Fig. 5. Due to the small size of the available samples, only very general observations on the form and sphericity of the pebbles are justified.

In the samples from localities M and Q, most of the pebbles fall in the compact, compact-elongate and elongate classes, the minority being represented by compact-bladed and compact-platy forms. The mean maximum projection sphericity is 0·8, the highest among the samples

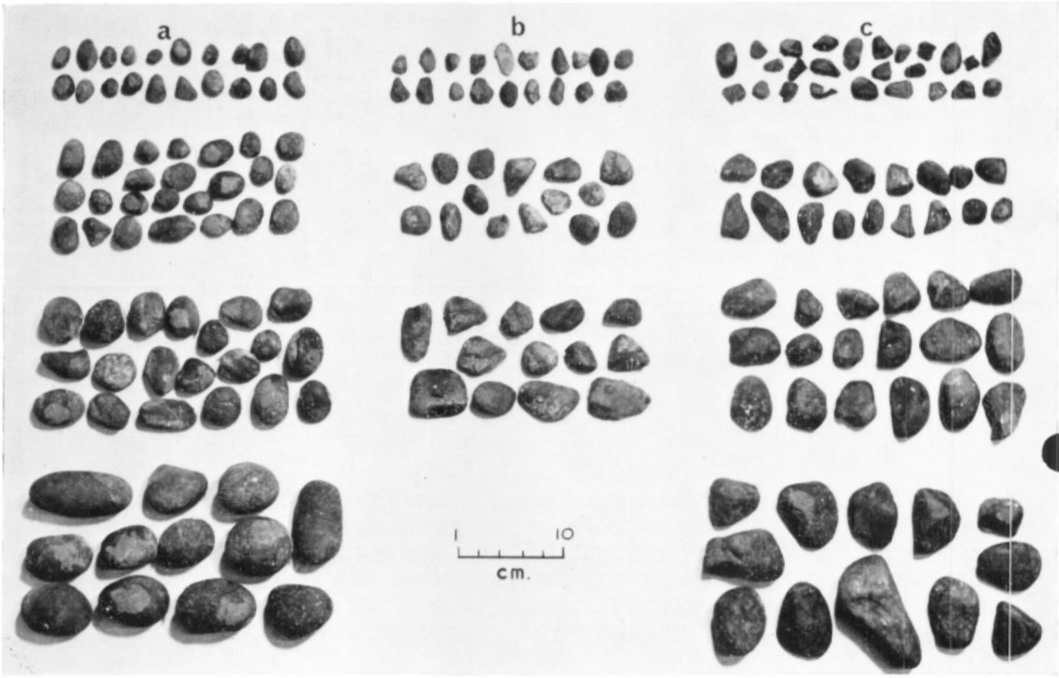

Fig. 5. The roundness and sphericity of certain fractions of the conglomerates of Alexander Island.
a. Localities M and Q; size classes $-6{\cdot}0$ to $-5{\cdot}5\phi$, $-5{\cdot}5$ to $-5{\cdot}0\phi$, $-5{\cdot}0$ to $-4{\cdot}5\phi$ and $-4{\cdot}5$ to $-4{\cdot}0\phi$; average sphericity = 0·80; average roundness = 0·70.
b. Locality P; size classes $-5{\cdot}5$ to $-5{\cdot}0\phi$, $-5{\cdot}0$ to $-4{\cdot}5\phi$ and $-4{\cdot}5$ to $-4{\cdot}0\phi$; average sphericity = 0·73; average roundness = 0·60.
c. Locality G; size classes $-6{\cdot}0$ to $-5{\cdot}5\phi$, $-5{\cdot}5$ to $-5{\cdot}0\phi$, $-5{\cdot}0$ to $-4{\cdot}5\phi$ and $-4{\cdot}5$ to $-4{\cdot}0\phi$; average sphericity = 0·71; average roundness = 0·50.

studied. The bulk of the pebbles from the pebbly mudstone at locality P lie in the compact-bladed, compact-elongate, bladed and elongate fields, the mean sphericity being 0·73. The pebbles from locality G are concentrated in the compact-bladed, bladed and elongate classes, and they have the lowest mean sphericity (0·71) of all the localities sampled. Only a small number of pebbles suitable for measurement was available from the pebble lens (sample H1) at locality H. These show a fairly wide scatter but they are concentrated in the compact, compact-bladed and compact-elongate fields. The mean sphericity is 0·77.

Petrology and Provenance

The palaeogeographic evidence from the Alexander Island sediments consistently indicates that the detrital material was derived from the east (Taylor, 1966, p. 131; Horne, 1969), and it has been concluded on the basis of stratigraphy, palaeogeography and sandstone petrology that the igneous and metamorphic complex of Palmer Land represents the degraded source area of the Alexander Island Cretaceous sediments. The observations on the general petrology of this area by Procter (1959), Ayling (1966), J. F. Pagella, K. D. Holmes and the author have already been briefly discussed in relation to sandstone petrology and they must now be reviewed in the light of the petrological evidence from the conglomerates.

Petrology of the pebbles

The pebbles from all the localities studied can be divided into four compositional groups whose proportional representation in seven conglomerate horizons in Alexander Island is shown in Table I. The analyses of samples from localities P, M and Q, G, H1 and H2 are based on a laboratory study of the bulk samples and numerous thin sections. Those for stations KG.82 and 85 are based only on field counts and fewer thin sections.

Table I. Percentage pebble composition of seven conglomerates from Alexander Island

		Locality						
		P	M and R	G	H (Sample 1)	H (Sample 2)	KG.82	KG.85
Number of pebbles		145	497	119	19	46	460	370
Rock type (per cent)	Volcanic	67·6	82·9	82·3	26·3	26·1	36·9	27·0
	Plutonic	17·2	3·4	6·7	52·6	63·0	48·5	60·8
	Hypabyssal	13·1	11·9	10·9	15·8	8·7	10·9	7·6
	Metasedimentary	2·1	1·8	—	5·3	2·2	3·7	4·6

Pebbles of volcanic material. Included in this dominant group are a wide range of volcanic rocks, both lavas and tuffs. They appear to be largely andesitic in composition but more acid forms are in evidence. Texturally, they are tuffs, possibly welded in part, with dominant lithic and minor vitric and crystal fractions, and plagioclase-porphyries and quartz-plagioclase-porphyries.

Pebbles of plutonic material. This fraction of the assemblage is represented by medium-grained massive or weakly foliated crystalline rocks which are largely adamellitic and less commonly granodioritic, dioritic and granitic in composition. Their texture is only rarely magmatic but it frequently approaches that of a porphyroblastic gneiss. These gneissose adamellites have suffered intense deformation particularly of the quartz, which is strongly strained and fragmented. Potash metasomatism, possibly associated with the deformation, has led to the development of large potash feldspar crystals. The ferromagnesian mineral of these plutonic rocks is exclusively biotite, often deformed and "bleached" and showing varying degrees of chloritization.

Pebbles of sedimentary or metasedimentary origin. Among the 800 pebbles examined petrologically in the laboratory there are less than 20 which form a small but significant group of older sediments, metasediments and quartzose schists of probable sedimentary origin. The least metamorphosed specimens may be termed indurated lithic sandstones of quartzose or quartzo-feldspathic mineralogy. Increasing degrees of recrystallization can be detected in others and a number are foliated quartz-mica-schists. It is probable that they were derived from a continuous progressively metamorphosed sequence, although there is no direct evidence for this among the isolated pebbles.

Pebbles of hypabyssal material. The fourth group includes holocrystalline equigranular and porphyritic igneous rocks derived from dykes, sills and other small intrusive bodies.

Provenance

In an earlier paper (Horne, 1968*b*) it was concluded that the sandstones in the Alexander Island Cretaceous sequence were derived from an easterly source area composed very approximately of 33 per cent granodioritic to dioritic plutonic rocks, 17 per cent granitic rocks, 33 per cent volcanic rocks and 17 per cent *para*metamorphic rocks. The degraded remnant of this source area is represented by Palmer Land, which is at present composed of four main rock groups corresponding well with the above interpretation and with the pebble composition groups.

The most extensive is a series of volcanic rocks of the rhyolite–andesite–basalt association. Andesitic tuffs predominate and can be related in some cases to distinct eruptive centres. Such a volcanic assemblage is directly reflected in the volcanic pebbles of the conglomerates. The second is a less extensive suite of plutonic intrusions which is largely intermediate in composition. Granodiorites predominate and they are associated with minor granites, adamellites and diorites. Gabbros are locally important. Large areas of these plutonic rocks, particularly their marginal facies, have been strongly deformed and metasomatized. The striking similarity between the rocks of this plutonic complex and the plutonic pebbles in the conglomerates is one of the strongest indications that the pebbles were derived from eroded parts of this complex. The third group is of sediments, metasediments and higher-grade metamorphic rocks including mica-schists and gneisses, in part at least, of sedimentary origin. In the Lurabee Glacier area and other parts of north-east Palmer Land a thick sequence of sediments and volcanic rocks shows a progressive westwards increase of regional metamorphic grade from largely unmetamorphosed sediments on the east coast through greenschist facies to higher grades represented by quartz-mica-schists and gneisses towards the centre of the plateau (personal communication from K. D. Holmes). These high-grade metamorphic rocks grade into the foliated marginal facies of the granodioritic batholiths of the central plateau. The lower-grade part of this sequence is an obvious source for the range of metasedimentary rock types among the pebbles. A widespread group of dykes, including porphyritic micro-granodiorites, augite-andesites, dolerites, and quartz-porphyries and quartz-plagioclase-porphyries, represents the source of the hypabyssal fraction of the pebble population.

The proportional representation of the various source-rock types in a particular size range of a conglomerate depends primarily on the abundance of the rock type in the source area, its structural properties such as jointing, cleavage and general fracturing, which determine the importance of the rock as a source of composite fragments as opposed to discrete mineral grains, and its degree of resistance to weathering.

Among the 1,650 pebbles studied compositionally, clasts of volcanic rocks are slightly over-represented in relation to their present abundance in the proposed source area. This is explained in part by the combination of chemical and physical stability with the close-jointed and fractured structure common in lavas and tuffs, and also by the preferential erosion of high-level volcanic cover. Clasts of crystalline plutonic rocks and dyke rocks are present in broadly the same proportion as they occur in the source area. Pebbles of metamorphosed sedimentary rocks are very scarce and they are almost exclusively of quartz-rich metasediments. The less stable schistose and foliated micaceous schists and gneisses were not recorded, although they are present in the source area.

The structural state of the source rocks and their resistance to breakage also controls the relationship between size and composition among the pebbles. A distinct regular variation in composition between fractions at $\phi/2$ intervals is evident (Fig. 6) despite the limited range of the samples. The proportion of pebbles of plutonic origin increases with increasing size and the content of volcanic pebbles correspondingly decreases with increasing size. The proportion of hypabyssal pebbles shows a weak increase with increasing size.

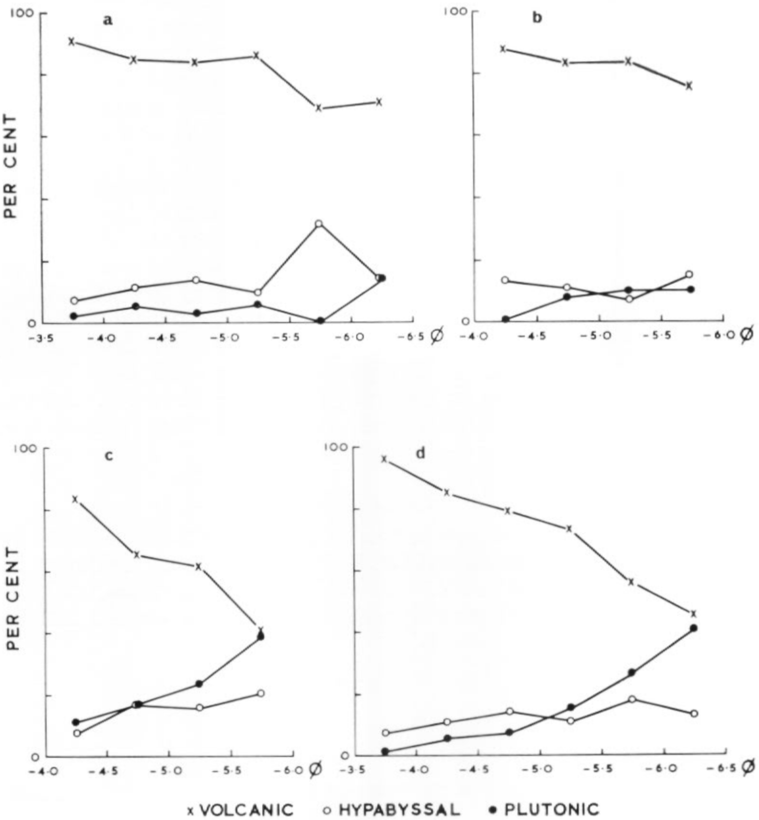

Fig. 6. The relationship between composition and size for the conglomerate pebbles.
a. Localities M and R.
b. Locality P.
c. Locality G.
d. Total of all localities.

Conclusions

In general, the evidence of the composition of the conglomerate pebbles strongly supports the conclusions regarding the source-area composition deduced from the mineralogy of the sandstones (Horne, 1968*b*).

The inference that the plutonic igneous composition of the source area, which supplied the bulk of the quartz, plagioclase and potash feldspar, was broadly 17 per cent of granitic rocks and 33 per cent of granodioritic to dioritic rocks requires some modification. The predominance of adamellitic pebbles suggests that rocks of this composition may have been at least as common in the source area during the erosion phase as granitic or granodioritic types. The proportions of quartz, potash feldspar and plagioclase in most of the specimens analysed (Horne, 1968*b*, fig. 2b) are precisely equivalent to a predominantly adamellitic source.

During the Cretaceous phase of erosion, therefore, the source area was composed of a marginal sequence of low-grade, regionally metamorphosed metasediments and metavolcanic rocks, grading through low-grade schists into high-grade schists and gneisses in the core of the geanticline which is now represented by the degraded Palmer Land. This complex was intruded by a series of synorogenic and late orogenic plutonic rocks, predominantly adamellitic but including granites, granodiorites, diorites and gabbros. The bulk of these plutonic rocks were highly deformed and metasomatized, and are essentially gneissic in texture particularly at their margins. Also important was a widespread sequence of lavas and tuffs and related dykes which probably had been extruded for some time before the Cretaceous; on erosion they yielded material largely in the pebble grade and after disaggregation in the clay grade. Syndepositional volcanic activity of andesitic composition is believed to have occurred intermittently both in this source area and also to the west of the trough. This volcanicity supplied large amounts of andesitic fragments to the sandstones by erosion of the weakly lithified pyroclastic deposits and finer-grade material to the mudstones both by weathering and erosion, and by direct airborne emplacement.

The phenoclasts of the conglomerates were derived from the indurated, non-foliated quartzose metasediments, part of the intermediate plutonic rocks, the well-jointed lavas and welded tuffs, and from the dykes associated with these volcanic and plutonic rocks. The less stable, high-grade metamorphic rocks such as mica-schists, the bulk of the granites, adamellites and diorites, and the syndepositional andesitic tuffs yielded the detritus of sand grade as deduced from sandstone petrology (Horne, 1968*b*). However, the clay- and silt-grade material appears to have been derived from the weathering of consolidated lavas and tuffs, and very largely from syngenetic andesitic lavas and pyroclastic deposits both by weathering and transport, and by direct precipitation into the trough from ash clouds. In addition, the plutonic rocks and higher-grade micaceous metamorphic rocks would have yielded some material in this size range.

Acknowledgements

I wish to thank Professor F. W. Shotton for making available the facilities of the Department of Geology, University of Birmingham, and Dr. R. J. Adie for guidance during the preparation of the paper. I am greatly indebted to Dr. B. J. Taylor, for the specimen collections on which the paper is based, and for much helpful discussion and advice. Thanks are due also to Dr. M. R. A. Thomson for the loan of material.

MS. received 20 February 1969

REFERENCES

Adie, R. J. 1958. Geological investigations in the Falkland Islands Dependencies since 1940. *Polar Rec.*, **9**, No. 58, 3–17.

Ayling, M. E. 1966. *The geology of the "St. Valentine's" area, and related observations in the Batterbee Mountains, Palmer Land.* M.Sc. thesis, University of Birmingham, 119 pp. [Unpublished.]

Horne, R. R. 1968*a*. Slump-shear structures and mass-flow deposits in the Cretaceous sediments of south-eastern Alexander Island. *British Antarctic Survey Bulletin*, No. 17, 13–20.

———. 1968*b*. Petrology and provenance of the Cretaceous sediments of south-eastern Alexander Island. *British Antarctic Survey Bulletin*, No. 17, 73–82.

———. 1969. Sedimentology and palaeogeography of the Lower Cretaceous depositional trough of south-eastern Alexander Island. *British Antarctic Survey Bulletin*, No. 22.

Krumbein, W. C. 1941. Measurement and geological significance of shape and roundness of sedimentary particles. *J. sedim. Petrol.*, **11**, No. 2, 64–72.

Procter, N. A. A. 1959. The geology of northern Marguerite Bay and the Mount Edgell area. *Falkland Islands Dependencies Survey Preliminary Geological Report*, No. 4, 18 pp. [Unpublished.]

Sneed, E. D. *and* R. L. Folk. 1958. Pebbles in the lower Colorado River, Texas: a study in particle morphogenesis. *J. Geol.*, **66**, No. 2, 114–50.

Taylor, B. J. 1966. *The stratigraphy and palaeontology of the Aptian of the central east coast of Alexander Island.* Ph.D. thesis, University of Birmingham, 245 pp. [Unpublished.]