SOME OBSERVATIONS ON SEA-LEVEL CHANGES IN THE JAMES ROSS ISLAND GROUP

By J. S. BIBBY

THE coastal areas of north-east Graham Land are for the most part composed of high cliffs of rock and ice. These descend below sea-level to great depths, e.g. soundings of more than 400 fathoms (730 m.) were made by R.R.S. *John Biscoe* in Duse Bay and the northern approaches to Prince Gustav Channel during 1960. It is only in a few favourable sites that knowledge of past changes in sea-level can be gleaned. If, during the period of raised beach formation, the occurrence of ice cliffs had been greater than at present, they would have effectively prevented the formation of evidence of epeirogenic uplift. If they had not been present and beaches were formed, then the re-advance of the ice has masked or destroyed such evidence. Indications of sea-level changes have been reported from the James Ross Island group by Croft (1947). Between 1957 and 1960, during a geological survey of these islands, an attempt was made to enlarge the scope of Croft's observations.

Basically, James Ross Island consists of a plinth of soft Cretaceous sediments overlain by a great thickness of mid-Miocene volcanic rocks (James Ross Island Volcanic Group). The plane of the unconformity between the two formations fluctuates in height considerably from one area to another, sometimes lying above and sometimes below sea-level. It has provided a structural weakness which has been exploited by agents of erosion and this has resulted in many cases in the destruction of the overlying volcanic cover and the exposure of the soft Cretaceous sediments. At levels above 100 ft. (30·5 m.) glacial agencies appear to have been responsible. However, between sea-level and 100 ft. (30·5 m.) the nature of the surface material leads to the conclusion that marine erosion has played an active part in the demolition and removal of the volcanic cover. As the land emerged from beneath the sea the Cretaceous sediments were also eroded and this erosion continues at the present day. Where the plane of the unconformity lies below sea-level the coast is formed of vertical cliffs of the volcanic rocks, which appear to be relatively resistant to marine erosion.

The composition of the beach deposits is generally sandy gravel or gravelly sand, and frequent sub-angular blocks of olivine-basalt also occur. The nature of the sand is variable and depends on whether its source was from the sediments or the volcanic rocks. The surface consists of a pavement of small stones with occasional larger blocks. Surfaces of this type are characteristic of the whole area, not only of the raised beaches, and they have been found in many places where marine action could not be a factor in their formation (Fig. 1). In such places the top 10–12 in. (25–31 cm.) of the deposits are often roughly stratified parallel to the surface and it is considered that they are similar to those described from many areas of the world where periglacial processes are active. The deposit thus equates to the "active layer" of Muller (1947) or to the "congeliturbate" of Bryan (1946). The annual freeze–thaw cycles through which the material passes cause the coarser constituents to rise to the surface. This results in a stratification of the deposit, but in a reverse manner to that produced by water sorting which grades from coarse at the base to fine at the top. In the simple case, the nature of the sorting and of the bedding enables the beach deposit to be differentiated from the congeliturbate. Where solifluction processes have disturbed the deposits, or where cryoturbation processes have been at work on deposits of raised beach origin for any length of time confusion can result and it is frequently not possible to differentiate between them with any degree of certainty. Since both the Cretaceous sediments and the Miocene volcanic rocks have a high proportion of rounded and sub-rounded stones the presence of rounded stones in the surface layers cannot be taken as proof of a water-laid origin.

The location and extent of the areas described in the James Ross Island group are shown in Fig. 2; of these the most important is The Naze. Other areas in which indications of changes in sea-level have been found are Bald Head on Trinity Peninsula, on Beak and Eagle Islands, near Madder Cliffs on Joinville Island, and at Welchness on Dundee Island. At the latter area a similar structural condition to that of James Ross Island exists. As far as could

Fig. 1. A rock pavement and the establishment of a drainage system on the Jurassic sediments of Camp Hill. The upper end of the channel in the centre of the photograph terminates at an area of stone polygons.

be ascertained by the author, there is no evidence in the Hope Bay area to substantiate Andersson's (1906) statements on the occurrence of raised beaches.

James Ross Island Group

The Naze

The Naze is a promontory which extends in a northerly direction from the north-east coast of James Ross Island. For convenience of description it is subdivided here into three areas, in each of which evidence referable to sea-level changes can be found. These are Terrapin Hill and Fortress Hill in the south, Dagger Peak and Comb Ridge in the north, and the flat-topped neck of land joining the two, which has an average height of 35 to 40 ft. (10·5 to 12 m.) but rises at each end.

Terrapin Hill and Fortress Hill. In shape Terrapin Hill is a blunt cone which reaches an altitude of 1,750 ft. (535 m.) and is a prominent landmark from Herbert Sound and Erebus and Terror Gulf. It is composed principally of orange-coloured bedded tuffs of the James Ross Island Volcanic Group. Fortress Hill is composed of redder coarse basaltic agglomerates and is separated from Terrapin Hill by a wide valley which slopes to the south-east. At the head of the valley is a col, the north-western side of which slopes steeply down into Herbert Sound.

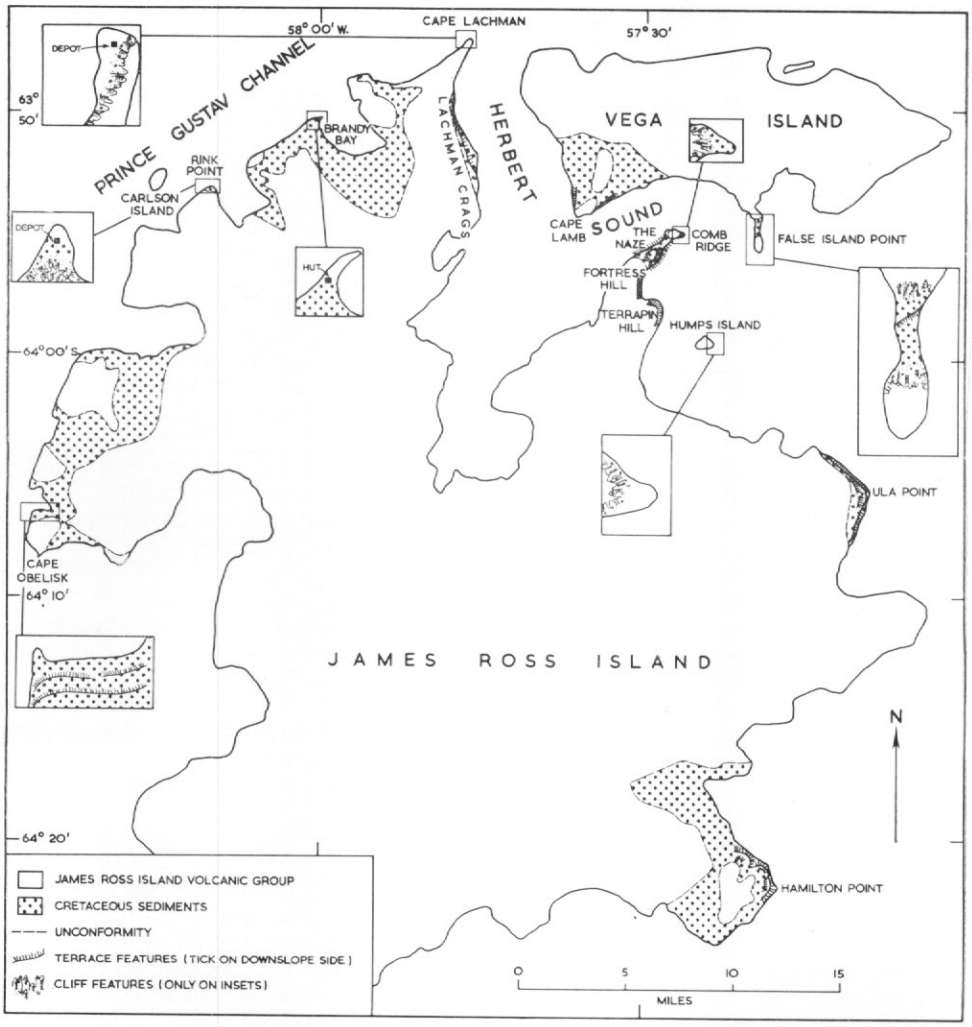

Fig. 2. Sketch map showing the location of sites and their relation to the Cretaceous sediments. Insets of Cape Obelisk and Brandy Bay are from plane-table surveys by J. S. Bibby (1958 and 1959); False Island Point from a sketch map by W. N. Croft (1946); others from sketch maps by J. S. Bibby (1958 and 1959).

The foot of the eastern slopes of these hills is interesting from the point of view of a study of raised beaches. Evidence of these is found in two unconnected areas. Croft (1947, Pt. 2, p. 12) has described the most extensive beach feature as ". . . an area about 300 yd. (275 m.) square rising from about 10 ft. (3 m.) at the sea edge to about 40 ft. (12 m.) where it grades up gradually into the scree slopes of the brown coarse tuff cliffs above". The coastline is undergoing marine erosion which has exposed several sections of sands and gravels. The sandy sections yielded broken shell fragments which were not identifiable. Croft reported finding *Thracia* and *Anatina* in these sections; these were indeed found on the beach surface during 1959 but, since the activities of gulls during the summer season could easily account for this distribution, it is preferable that such occurrences should be discounted.

The smaller beach feature lies to the south of the larger one, has an altitude of 30 ft. (9 m.) above sea-level, but there are no sections exposed. Its nature is determined largely by comparison with other areas and in particular its close correspondence in height.

Gravel sections containing a scant marine fauna are proof of a raised beach in the vicinity of Terrapin and Fortress Hills.

The Naze isthmus. The isthmus connecting the high ground of Fortress Hill with that of Dagger Peak and Comb Ridge provides good evidence of raised beaches. Its average height is between 35 and 40 ft. (10·5 and 12 m.), with a flat top and cliffed sides. Croft (1947) showed that this isthmus is not a tombolo beach but the remnants of a platform of Cretaceous sands and silty sands which had been severely eroded by marine action. The Cretaceous sediments are overlain by sands and gravels of a similar character to those of the Terrapin Hill raised beach and in most places they are capped by 6 to 12 in. (15 to 30 cm.) of solifluction deposits. In the coastal cliffs the contact between the superficial gravels, which vary from 10 to 30 ft. (3 to 9 m.) in thickness, and the underlying Cretaceous rocks was seen in two places. In one of these it is sharp with a bed of nodules between the Cretaceous sands and the current-bedded sands of the raised beach, which are characterized by a high content of olivine-basalt. A fragment of *Gunnarites* sp. was found in one nodule. It was therefore presumed that these nodules had been winnowed out of the Cretaceous beds by marine action, a conclusion also reached by Croft for a different locality. At the second exposure the contact is sharp but no nodules were found.

Near the southern end of the isthmus there are three small lakes. Around and embedded in the ice of these lakes were numerous shells, again probably dropped by gulls. The banks which retain the lakes are almost certainly marine in origin, both from their shape and from the fact that they are cleaner than most of the other gravels seen. A small section shows grading from coarse at the base to fine at the top.

Several sections of the sands and gravels were examined and, as noted by Croft (1947), they contained many broken and a few complete shells. He also reported finding clays in which echinoid spines were embedded, and a whale rib in gravels. Although the latter was seen, the former were not traced; they were probably buried under snow drifts.

On the north side of the lake a bank winds its way across the isthmus from east to west, its summit being at about 30 ft. (9 m.). Another less well-defined bank occurs 200 yd. (185 m.) north of this and raises the height of the isthmus to 50 ft. (15 m.), but this soon decreases again to about 30 ft. (9 m.). It appears that only one beach level is represented at The Naze and that this is slightly higher than 30 ft. (9 m.).

Dagger Peak and Comb Ridge. The north and west sides of Dagger Peak and Comb Ridge are formed by precipitous cliffs, upon which no trace of former beach levels remains. The cliffs rise to 360 ft. (110 m.) in height and Dagger Peak is separated from Comb Ridge by a small col, a noted locality for fossils. The north-eastern tip of the promontory, however, shows very similar features to The Naze isthmus between Fortress Hill and Dagger Peak. Croft (1947) reported seeing the contact between recent sands and gravels and the Cretaceous sands here. At the contact in this section there is also a layer of concretions which were derived from the older rocks.

False Island Point, Vega Island

In many ways False Island Point is physiographically similar to The Naze. Both have isthmuses connecting a terminal higher part to an island. The terminal parts have both been shown on maps as separate islands when their connection was overlooked in bad weather, and False Island Point owes its name to such a mistake.

Croft (1947, Pt. 4) visited False Island Point and stated that the isthmus bears terraces probably due to marine action. No special features mark the 70–80 ft. (21–24 m.) level, which is the approximate height at which scree ends and the sorted surface gravels begin, but the average height of the isthmus at 30–40 ft. (9–12 m.) compares favourably with that at The Naze. Several imperfectly preserved banks are shown in the sketch map accompanying Croft's (1947, Pt. 4) report.

Humps Island

Evidence of raised beaches on Humps Island is very scant. On all occasions when it has been visited a deep snow cover was present. Croft visited the island and reported a low bank

at about 70 ft. (21 m.) above sea-level near the south-west end of the island and extending to the south for a few hundred yards. This height correlates well with the height at which sorting of surface material commences in other areas, but its value as a criterion of sea-level changes is very doubtful.

East coast of James Ross Island

The two principal occurrences of raised beach phenomena are at Ula Point and Hamilton Point (Fig. 2). In addition there are numerous small terrace features at other points on the coast which generally consist of morainic material slightly modified by marine action. The beach features at Ula Point are extensive and show two terraces capped by frost-modified gravels at about 30 and 50 ft. (9 and 15 m.), respectively. The 30 ft. (9 m.) terrace commences near the glacier east of Skep Point and extends past Ula Point as far as Coley Glacier. The 50 ft. (15 m.) terrace is best developed near Ula Point but dies away laterally. No shell remains were found in these gravels, but sections of the poorly-bedded gravel were seen in stream gullies near Ula Point where they were 3 to 4 ft. (0·9 to 1·2 m.) thick.

At Hamilton Point there is an extensive platform of Cretaceous rocks, on the surface of which indistinct banks and terraces occur at several different heights. The lower ones could be attributable to marine action, though above 100 ft. (30·5 m.) large-scale solifluction has occurred and it is probable that the banks here are solifluction lobes. No shells were found in or on the terraces and the sea cliffs were largely obscured by snow drifts, so that no sections could be seen. One small section in a valley north of Hamilton Point seemed to indicate that the lowest levels at least possessed a thin capping of sandy gravel.

Coast east of Lachman Crags

Traces of a raised beach are to be found in a narrow coastal strip extending for about 300 yd. (275 m.). It varies in height between 10 and 20 ft. (3 and 6 m.), and is backed by a bank leading on to the Cretaceous rocks, which form numerous moraine-capped mounds. Some of this material contains erratics derived from Graham Land. Marine shells were found on the surface of the platform, but none were *in situ* in the gravels which cap it.

West coast of James Ross Island

This area is in general not a favourable site for the formation of beach phenomena. The Cretaceous rocks are better cemented and harder than on the east or north coasts of the island, and the plane of the unconformity was either too high or too low for the sea-level changes which occurred. On the south side of the entrance to Brandy Bay there is a feature which rises gradually from 10 ft. (3 m.) at its tip to 30 ft. (9 m.) at its base and appears to be the remains of a spit. The base of the spit is composed of thin sandstones and shales of the bedrock, but its recurved tip is of current-bedded sands and gravels derived from both sedimentary and volcanic rocks. It was undoubtedly formed by longshore drift from south-west to north-east up Prince Gustav Channel at the last halt before the sea attained its present level. This spit is now well above high-water mark and is the site of an Argentine field hut. Similar features, though somewhat smaller and without recurved tips, occur at Rink Point and Cape Lachman (Fig. 3) at heights of 15–20 and 10 ft. (4·5–6 and 3 m.) above sea-level, respectively. These were the sites of depots established by the Falkland Islands Dependencies Survey.

The surfaces of all the features so far described have been modified by frost action and, during summer and warm spells at the end of winter, can turn into quagmires due to the degree of waterlogging of the surface layers. This is a condition admirably suited to intensive frost-sorting and comminution, and thus it is not surprising that at Rink Point and Cape Lachman it was not possible to demonstrate any marine bedding in the deposits.

Separated by some 20 miles (32 km.) from the previous localities is Cape Obelisk. At the cape, rocks of the James Ross Island Volcanic Group form sheer cliffs of over 900 ft. (275 m.) high. To the north of the cape there is a flat spur of ground (Fig. 4) upon which two levels can be detected. The higher is at 80 ft. (24 m.) but it falls to 50–60 ft. (15–18 m.) near its western edge. The lower level varies in height and is sometimes not traceable at all. Both levels

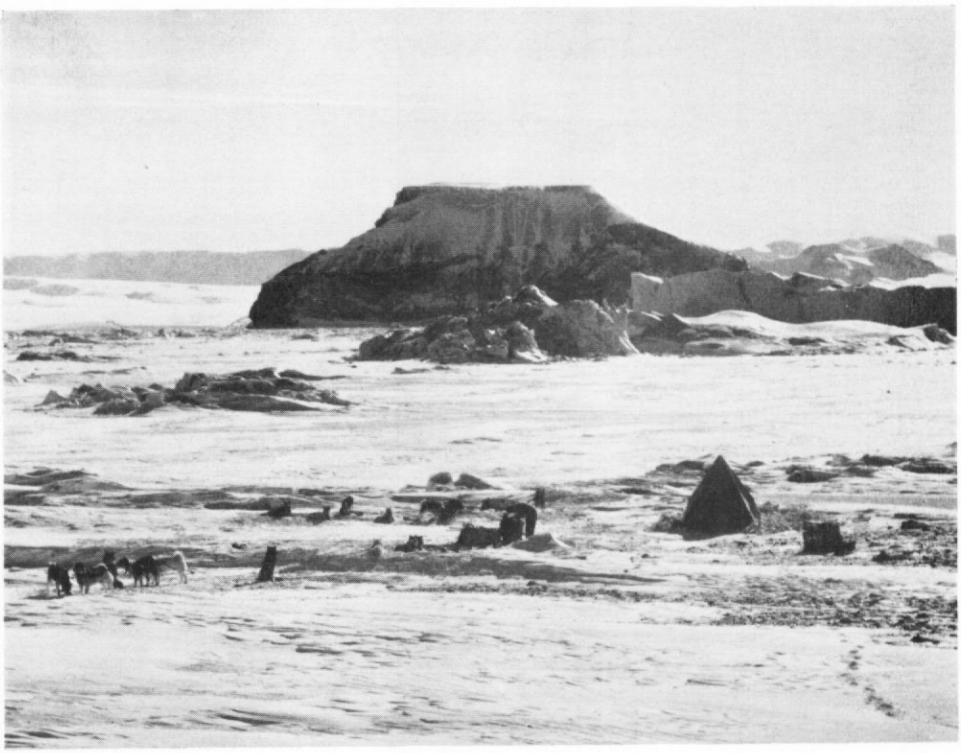

Fig. 3. View from Cape Lachman westwards across Prince Gustav Channel to Red Island. The cliffs of Cape Lachman are similar to those of Red Island though lower in height. The tent and depot are situated on a raised gravel promontory which is at its narrowest here, but to the right of the photograph it becomes more extensive.

are clearly visible in Fig. 4. Shells were not found at any of these localities, but the surface consisted of re-worked Cretaceous sands and gravels mixed with volcanic material, and was very similar in nature to the surfaces at The Naze. The possibility of a glacial outwash origin cannot, however, be discounted.

Other Areas

Bald Head

Two well-marked rock terraces at the west-south-western extremity of Bald Head have been interpreted as raised beach features. A glacial origin has been considered, but this has been discarded for the following reasons:

i. The alignment of the terraces is at right angles to the direction of ice flow as determined from the orientation of glacial striae in the area. This eliminates the possibility of their being glacial platforms of different levels.

ii. Consideration of the nature of the surface deposits. Although they do not show rounding or the presence of recent shell remains (other than those which could be attributed to the activities of gulls), the deposits are well-sorted and not of the irregular variety attributable to drift.

There are two levels, at 20 and 70 ft. (6 and 21 m.) respectively, which cut directly across the structure of the underlying rocks. Discussion about the Long Island area indicates the presence of a similar feature there on the south-west and south sides, which approximates to the 20 ft. (6 m.) level (personal communication from R. M. Koerner). There is no evidence of a higher level.

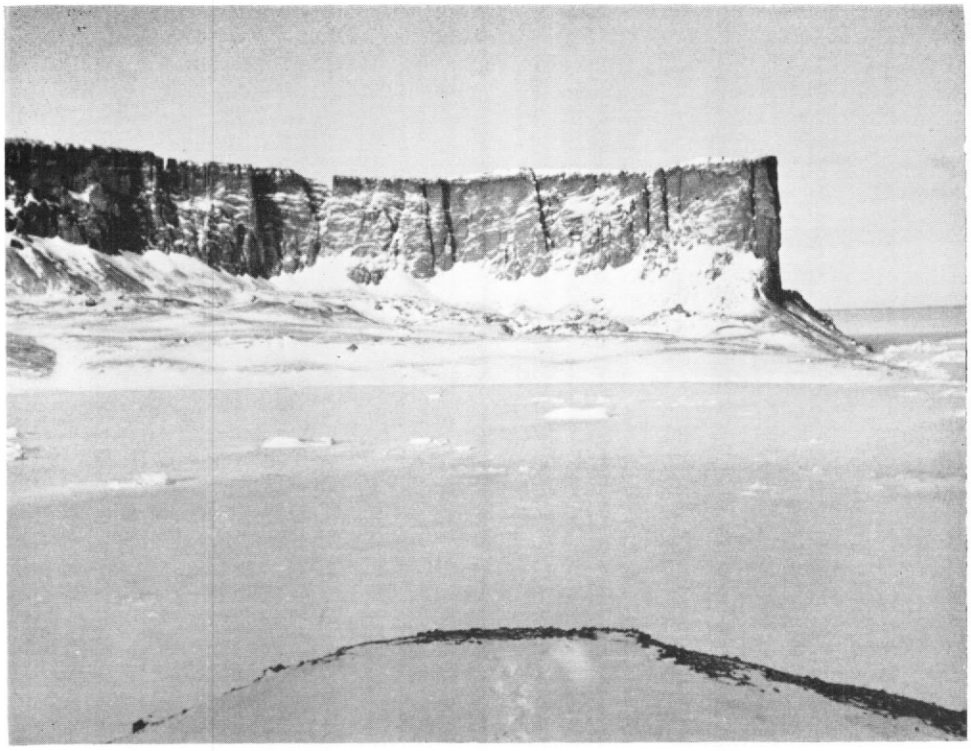

Fig. 4. The mesa-type topography of Cape Obelisk. The cliff is 1,000 ft. (305 m.) high. In the centre of the photograph two platforms can be detected which may be raised shorelines.

Apart from a small area at Botany Bay which is of dubious affinities, no trace of these levels has been seen elsewhere on the mainland. Careful levelling on the col to the north of Bald Head may reveal more information.

Beak and Eagle Islands

On the north-east coast of Beak Island, and the north-east coast of Eagle Island below Scree Peak, are terraces which rise gradually from 15–20 ft. (4·5–6 m.) to 30–40 ft. (9–12 m.). The Beak Island locality was not visited but the one at Eagle Island was examined when a depot was established there by R.R.S. *Shackleton* in 1960. It consisted of a layer of small sub-angular to sub-rounded pieces of basalt on a very coarse dark pebbly sand containing abundant olivine. No shell remains were found during a brief inspection. The beaches of Beak and Eagle Islands were the only examples of beaches cut entirely within rocks of the James Ross Volcanic Group seen during the investigations.

Dundee and Joinville Islands

Croft was of the opinion that strandflat development in the vicinity of Hope Bay and Antarctic Sound is the result of glacial rather than marine peneplanation. In the absence of any criteria other than the flat-topped nature of the features this seems likely.

At Welchness on Dundee Island there is a broad promontory certainly of marine origin. This was viewed from d'Urville Monument on Joinville Island, but it has been visited by both Croft and Adie. Croft (1947, Pt. 10) has described it as "the clearest example in the region of a beach formed from the destruction of glacial moraines which, still only partially wasted, lie along the landward side of the beach".

In plan Welchness is triangular, bounded on two sides by the sea, and of sufficient size to allow Ellsworth to use it as an airstrip from which to start his trans-Antarctic flight. The gravel surface of the beach rises gradually and irregularly to an estimated height of 15–20 ft. (4·5–6 m.) above sea-level. A gently sloping bank leads to a higher part of the beach, which reaches an estimated altitude of 50 ft. (15 m.) near the moraines. No shells were found and no sections through the gravels were seen by Croft. The morainic humps may have Cretaceous outcrops amongst them, as reported by Adie (personal communication).

On Joinville Island, near the landing place at Madder Cliffs, a penguin rookery has been established on a flat at a height between 80 and 100 ft. (24 and 30·5 m.). This is separated by vertical cliffs from a narrow and discontinuous fringe round the coast which has a variable height but does not average more than 20 ft. (6 m.). Several relict sea stacks and at least two storm beaches were found in the penguin rookery at this level. The remainder of the coast here is composed of ice cliffs and no other features were observed.

At one other locality, near Fitzroy Point, a wave-cut notch at 40 ft. (12 m.) is present. No other features attributable to marine action were seen.

Summary

Phenomena which can be interpreted as the remnants of old beach levels have been found at numerous localities in the James Ross Island group. These can be divided into two groups, between 70 and 80 ft. (21 and 24 m.) and between 10 and 30 ft. (3 and 9 m.), and thus indicate the presence of two major beach levels.

Considered individually, very few localities show evidence which is conclusive in itself. Certain similarities, particularly the correspondence in heights between areas which are widely separated, provide a strong case which is further reinforced by correlations from the few localities where marine shells have been found in the gravels and sands. In fact, the major part of the evidence for an 80 ft. (24 m.) marine level is correspondence in height from one locality to another.

Apart from a bank on Humps Island, no structural features have been found at the 80 ft. (24 m.) level, yet the sands and gravels attributable to marine action often grade into scree at approximately this height. Here, due to modification by solifluction and their exceptional thinness, they may be difficult to distinguish from the usual drift cover.

The deposits at The Naze may have been laid down at the time of this 80 ft. (24 m.) sea-level, since Croft was of the opinion that they are deposits formed at the bottom of a shallow sea rather than actual beach deposits. That they have since been carved by marine action on beaches is not, however, in dispute, and it is to this agency that the formation of the banks found at the 30 ft. (9 m.) level are ascribed. These deposits have been derived from several sources. It appears that the sea has been an active agent of erosion and deposition only where the major structural weakness of the unconformity was exposed. In other areas material originally deposited as moraine has been re-worked and levelled, e.g. Humps Island and near Comb Ridge.

During the gradual recession of the sea from the higher level to its present position, there has been an obvious halt at approximately 30 ft. (9 m.) (scanty evidence of intermediate levels at various heights can be traced in individual localities). This was of a sufficient duration to allow small rock terraces to be cut at Bald Head and on Long Island; probably exposures of metamorphic rocks were rather rare at sea-level at this time due to the ice cover. Strong sea currents are known to be present off Bald Head at the present time and sea ice is often slow to form here; open pools and thin ice often persist well into the winter season in many years. The strong currents would materially aid erosion. The formation of the spit deposit at Brandy Bay also occurred at this time.

No correlation between this region and the South Shetland Islands has been attempted here. The beaches which have been examined by the author on King George Island (Bibby, 1961, p. 3) had achieved far better development than any observed in north-east Graham Land with the exception of Welchness on Dundee Island. Croft was of the opinion that these could form a link with the 15 and 50 ft. (4·5 and 15 m.) beaches in the South Shetland Islands. The 10 ft. (3 m.) raised beach of Point Thomas, King George Island, is certainly as well developed as the 15 ft. (4·5 m.) beach on Dundee Island and may indeed be contemporaneous.

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