RAISED MARINE AND GLACIAL FEATURES OF THE COOPER BAY–WIRIK BAY AREA, SOUTH GEORGIA

By P. Stone

Abstract. A series of raised beaches and wave-cut platforms up to 11 m. a.s.l. are described from part of the south-eastern coast of South Georgia. Complexes of moraine ridges in front of glacier snouts can be subdivided into three groups on the basis of relative size, degree of consolidation and vegetation cover. The glacier positions marked by these ridges probably correlate with glacial maxima described from the Cumberland Bay area of South Georgia at *c.* 5,500 yr. B.P. (Clapperton, 1971), *c.* 1875 and *c.* 1929 A.D. (Smith, 1960). The highest raised features, at 8·5 m. a.s.l., may represent outwash plains deposited during the first of these advances and graded to sea-level; beaches formed between the two more recent glacial maxima contain whaling relics from the 1904–25 period and range up to 2·5 m. a.s.l. Very recent retreat of Twitcher Glacier has caused periodic lowering of the water level in an adjoining ice-dammed lake with the result that previous higher shorelines are now abandoned around its perimeter. Annual retreat of two glaciers is suggested by the regularity of the most recent moraine ridges. Rapid surface ablation has in places led to the formation of abundant dirt cones and perched boulders.

THE snow-covered mountains and extensive glaciers of South Georgia contrast with its relatively northern latitude of 54°S. The island is situated south of the Antarctic Convergence and the climate throughout the year is generally cold and damp with the average temperature only just above freezing point and the total annual precipitation well in excess of 1,000 mm.

The oldest landscape features are possible dissected planation surfaces described from the accordance of mountain summits (Gregory, 1915; Clapperton, 1971) and, around the coast, a pediment-like lowland area. This was first attributed to marine erosion (Gregory, 1915) but the action of ice was stressed later by Holtedahl (1929), who described the area as a foreland formed by the action of a piedmont glacier. This lowland area has since become generally known as the *coastal foreland* (e.g. Clapperton, 1971; Stone, 1974). Although it has been scoured by ice during a glaciation of ice-cap proportions extending well beyond the present coastline (Clapperton, 1971), the origin of the coastal foreland may have been earlier with marine erosion or subaerial slope retreat playing a part. An *ice-cap stage* in the glacial history of South Georgia has been tentatively dated as at least 10,000 yr. B.P. (Clapperton, 1971). The subsequent interstadial was then terminated approximately 5,500 yr. B.P. by a stage of extensive *valley-glacier* advance and, in historical times, two more limited phases of advance have been recognized (Smith, 1960; Clapperton, 1971). Large glaciers, fed from the permanent snowfields in the mountains, still occupy the majority of the valleys and some terminate in the sea with spectacular ice cliffs up to 30 m. high. The foreland areas generally end in steep sea cliffs with wave-cut platforms below them, whereas in the more sheltered bays raised beaches are commonly developed. These are evidence of the relative fall in sea-level as isostatic re-adjustment followed deglaciation.

This paper records observations and measurements made around Cooper Bay (lat. 54°47′S., long. 35°48′W.) and Wirik Bay (lat. 54°45′S., long. 35°51′W.) (Fig. 1) during the 1973–74 summer field season.

Raised Marine Features

A series of raised beaches is developed in Iris Bay, Wirik Bay and Cooper Bay (Table I) but their heights above sea-level do not fall into well-defined groups. Behind the modern storm ridge there is usually a level area with only a very sparse covering of peat or vegetation. This area varies from 1·5 to 3 m. a.s.l. with the higher levels generally occurring along the more exposed sections of coast. It is not uncommon for modern storm ridges to be higher than the levels behind them and it is probable that these areas are the result of progradation or the progressive development of storm ridges. As such, they are related to present sea-level and are "relict" beaches rather than true raised beaches. The movement of seals is causing the active erosion of peat and tussock grass in these areas.

Included in these "relict" beaches are large numbers of seal and whale bones, and, at one locality in Wirik Bay at 2·5 m. a.s.l., a large quantity of whale bones was found together with

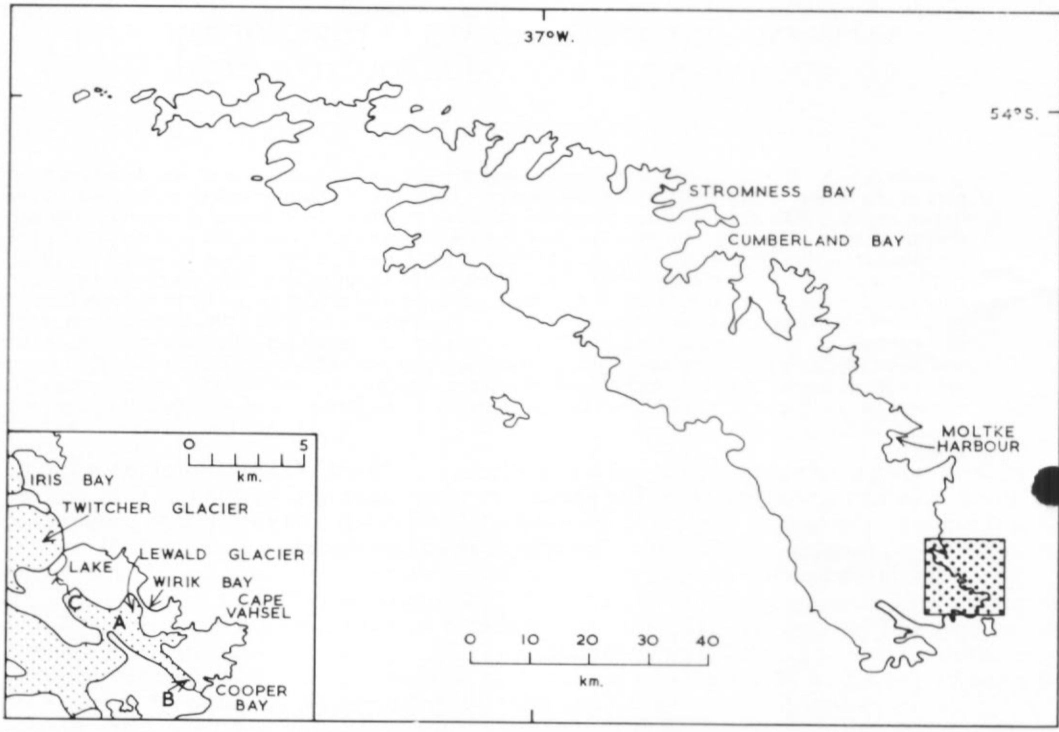

Fig. 1. Map of South Georgia showing the area discussed in the text (stippled and inset). Locations A, B and C on the inset map are referred to in the text; glaciers are stippled.

TABLE I. SUMMARY OF RAISED BEACH DATA

Locality		*Height above sea-level* (m.)								
		SL	1	2	3	4	5	6	7	8
Iris Bay				2·5	3·5				7·0	8·5
Wirik Bay	North			2·5*						
	South			2·5*	3·5		5·0			
Cooper Bay	North		1·5*	2·5	3·5					
			1·5–2·0*		3·0–3·5					
	Central		1·5*		3·5					
			1·5*	2·5–3·0						
			1·5–2·0*		3·5–4·0					
	South		1·5*							
				2·0–2·5		4·5				

* "Relict" beaches probably formed by progradation.

the remains of a harpoon. This carcass is probably that of a whale which was killed at sea but not recovered. The modern whaling industry did not start at South Georgia until 1904, and by the mid 1920's eye-witness accounts (e.g. Ommanney, 1938; Hardy, 1967) show that harpoons with spring-loaded barbs were in general use. The harpoon found in Wirik Bay is an earlier pattern with solid barbs and this suggests that the dead whale was washed ashore between 1904 and 1925. The bones and harpoon were firmly embedded in beach material, indicating that there was active accumulation on what is now the 2·5 m. "relict" beach during at least part of the 1904–25 period.

A second beach level frequently occurs between 2·5 and 4·5 m. a.s.l., and this is covered by a much more extensive development of peat and tussock grass, although in places this has also been eroded by the movement of seals. In the north of Cooper Bay, a raised beach at 3·5 m. a.s.l. is backed by an old cliff line and relict sea stacks (Fig. 2).

Fig. 2. An old cliff line and relict sea stacks behind the 3·5 m. raised beach in the north of Cooper Bay. The cliffs are 6·5 m. high.

Higher raised beaches were observed at 5 m. a.s.l. in Wirik Bay and as a widespread level at 7–8·5 m. a.s.l. farther north in Iris Bay. These two beaches are covered by up to 15 cm. of peat and tussock grass. Behind the 3·5 m. raised beach, in central Cooper Bay the ground surface rises steeply to 10 m. a.s.l. and then slopes more gently inland as an extensive outwash plain. At the time of its deposition, this plain may have been continuous with a beach but no definite beach deposits have been identified at that level.

Levelling of the raised beaches was carried out during late December 1973 and in January and February 1974; it was related to the mean sea-level observed locally during that period. This procedure resulted in a levelling base approximately 0·5 m. below the debris line at high-water mark, except on more exposed beaches where it increased to 1 m. Unfortunately, there are no authoritative figures for tidal variation in the Cooper Bay–Wirik Bay area but a comparison can be made with the official estimates for Moltke Harbour (Hydrographic Department, 1973) 35 km. to the north-west (Fig. 1). There, the tidal variation during January and February ranged from 0·6 to 1·1 m., which is in agreement with the figure of approximately 1 m. observed to the south-east. Any error in the positioning of mean sea-level is therefore likely to be small but the obvious difficulties in accurately fixing a levelling base increase the uncertainties of raised beach correlation over even a short distance. However, it does seem that the raised and "relict" beaches in the Cooper Bay–Wirik Bay area do not fall into such well-defined groups as have been described from other areas of South Georgia (Clapperton, 1971; Stone, 1974).

A wave-cut platform, ranging from sea-level up to approximately 2 m. a.s.l., is present on all stretches of exposed coastline. A higher, relict wave-cut platform is probably represented by the extensive surface at 10–11 m. a.s.l. which forms the top of the sea cliffs behind the raised beaches of northern Cooper Bay (Fig. 2). South of Wirik Bay, an uneven platform at 120–150 m. a.s.l. forms the surface of the headlands (Fig. 3). This may be an extension of the coastal foreland which on the north-eastern coast of South Georgia ranges in height from 20 to 150 m. a.s.l., with a tendency for its elevation to increase southward (Stone, 1974). The levels south of Wirik Bay would continue this trend but the surface of these headlands is very much more broken and irregular than farther north.

Fig. 3. Coastal cirques and a possible relict coastal foreland; looking north-west from Cape Vahsel towards Wirik Bay.

Cirques have cut down into the possible coastal foreland at several localities, one of the best examples affecting the headlands south of Wirik Bay (Fig. 3). A curious feature of this cirque is the line of small caves cut into well-consolidated till on the southern inner flank of the hollow. The local topography eliminates an origin through stream action, and on South Georgia there are no burrowing animals capable of producing excavations of that size. These caves are situated along a horizontal line and it seems most likely that this is the site of a former shoreline, perhaps of a lake which once occupied the cirque. However, the possible shoreline is at 35 m. a.s.l. and, since wave-cut rock platforms up to 50 m. a.s.l. have been described from other parts of South Georgia (Adie, 1964; Stone, 1974), the possibility of marine erosion cannot be ruled out.

Glacial Features

The centre of the glacier system in the Cooper Bay–Wirik Bay area (A on Fig. 1) is about 2 km. south-west of Wirik Bay. Ice flowing into this area from cols to the north-west and south-east merges and flows north-eastward as Lewald Glacier. The area centred on locality A at the head of Lewald Glacier is a wide shallow depression in the ice which fills with several centimetres of slushy melt water in mid-summer to form a supraglacial lake.

Cooper Bay

The south-eastern glacier snout (B on Fig. 1) was situated 500 m. inland in early February 1974. The snout itself sloped fairly steeply and was incised by several deep, supraglacial stream channels with the main subglacial outflow in the extreme south. An extensive moraine system occupies the area between the glacier and the sea, and the moraine ridges can be easily subdivided into three groups.

11 low, sinuous and rather irregular ridges are present within 100 m. of the glacier snout. These ridges are composed of fresh unconsolidated debris, which probably accumulated as a result of melting out from the ice and sliding down the sloping glacier snout. This process is certainly active in the formation of the present terminal ridge and there is no evidence that the moraine has been pushed into position. There is no lichen cover on boulders incorporated in these 11 ridges and the first vegetation, comprising small cushions of moss, isolated grasses and patches of *Acaena*, was observed 80 m. in front of the ice.

A more prominent and continuous moraine ridge crosses the valley 100 m. from the glacier. This ridge is composed of consolidated material and covered with a sparse growth of tussock grass among which are a number of disused penguin nests. Five smaller and more irregular ridges occupy the succeeding 70 m., with an increasing vegetation cover, before a much larger continuous ridge is encountered 170 m. in front of the glacier. This well-consolidated ridge rises to a height of 4 m. and supports a cover of up to 3 cm. of peat and tussock grass with exposed boulders partly overgrown by lichen.

Large, mature moraine ridges, covered by up to 30 cm. of peat and tussock grass, occur 250 m. from the glacier. There is a continuous series of five larger ridges for the remaining 220 m. down to the edge of the raised beach area behind the modern beach. They are much bigger features than the ridges closer to the glacier and they rise to a height of 15 m. Abandoned melt-water channels are present beside and between these large ridges, and the extensive outwash plain in central Cooper Bay may have formed during this glacial phase.

The five very large moraine ridges farthest from the glacier snout in Cooper Bay can be readily correlated with the group 3 moraines described from Stromness and Cumberland Bays (Clapperton, 1971) (Table II). These were considered to have resulted from a phase of glacial advance which reached its maximum approximately 5,500 yr. ago. The Cooper Bay moraines show at least five recessional phases of this valley-glacier stage, followed by a period of more steady retreat. The other two continuous and more prominent moraine ridges may correlate with glacial maxima around 1929 and 1875 (Smith, 1960) with which Clapperton associated his group 1 and 2 moraines. The moraine ridges described here are correlated with moraine groups 1–3 described by Clapperton (1971, p. 9–12) and so will also be comparable to moraine groups 4–2 on the map accompanying his report.

Wirik Bay

Lewald Glacier (Fig. 1) forms the north-eastern branch of the glacier system and flows down towards Wirik Bay. This glacier is very wide in relation to its length and its snout is now separated from the sea by an area of raised beach and, in the centre, by a rock cliff up to 5 m. high. The most recent moraines, 15 low and unconsolidated ridges, occupy the 15 m. between the rock cliff and the ice front, the central part of which is covered by a thick layer of supraglacial debris. These ridges have a very fresh appearance, are completely unvegetated and suggest recent, possibly seasonal, retreat of the glacier resulting in the annual formation of the moraine ridges.

Southward of the glacier snout, a series of moraine ridges occupies a lateral position but two groups can be clearly recognized. Four small and two larger ridges lie 12–20 m. in advance

TABLE II. SUMMARY OF THE COOPER BAY AND WIRIK BAY MORAINE SYSTEMS

Cooper Bay	*Wirik Bay*	*Possible age*	*Correlation with Clapperton (1971)*
11 small ridges	Centre of snout 15 small ridges		Group 1
	15	*c.* 1958	
	South side of snout		
Low continuous ridge	Four small and two larger ridges		
100*	20	*c.* 1929 (Smith, 1960)	
Five small ridges	"Relict" beach at 2·5 m. a.s.l. containing harpoon and whale bones		Group 2
Continuous ridge 4 m. high	Large isolated ridge		
170	35	*c.* 1875 (Smith, 1960)	
	Beach		Group 3
	approx. 45		
	Sea		
250			
Five large ridges up to 15 m. high			
470		*c.* 5,500 yr. B.P. (Clapperton, 1971)	
Raised beach deposits			
500			
Sea			

* Distance from the glacier snout is given in metres.

of the snout; they increase in size away from the glacier so that the outermost ridge is 2 m. high. This ridge is well consolidated and contains a large number of well-rounded pebbles and an elephant seal bone which must have been picked up as the ice advanced across an area of beach deposits. Immediately in front of the 2 m. high outer ridge is the 2·5 m. raised beach on which the harpoon was found. Since this beach was probably formed during the 1904–25 period, the glacial advance may correlate with the suggested 1929 advance phase (Smith, 1960). The moraine ridges of this group have retained a sharp crest but they are overgrown by tussock grass in places. Surrounded by the 2·5 m. raised beach, and clearly pre-dating it, is a much more massive moraine ridge rising to a height of 7–8 m. above the beach. This ridge is situated approximately 35 m. in front of the glacier snout and has a thick covering of tussock grass. Its shape is rather degraded and this moraine may represent the *c.* 1875 advance phase (Smith, 1960). The thicker tussock covering of the Wirik Bay moraines, in comparison to their chronological equivalents at Cooper Bay, is probably due to their situation only a few metres above sea-level.

South side of Twitcher Glacier

The small glacier flowing north-west towards Twitcher Glacier (C on Fig. 1) occupies a sheltered valley with a northerly aspect. As a result, surface ablation is considerable and a large volume of supraglacial melt water floods across the ice or is channelled into gullies up to 1 m. deep. These frequently lead into moulins and running water can invariably be seen at the bottom of crevasses. The ice surface is dotted with large numbers of dirt cones (Fig. 4) and perched boulders, and pock-marked by holes where rock fragments have melted into the ice.

Fig. 4. Dirt cones on a small glacier with moraine stripes at its snout indicating possible annual retreat. Twitcher Glacier and an old ice-dammed lake are in the background.

There seems to be a critical size limit for the fragments producing positive and negative features, since only boulders with a diameter > 12 cm. were observed capping ice pillars. Smaller rock fragments tend to melt into the ice but, when the ice surface is covered by a mass of fine-grained material, dirt cones develop. The material forming the cover of dirt cones has been shown experimentally (Drewry, 1972) to fall into the 0·6–5 mm. diameter range. The dirt cones show only down-slope linear development and the majority are irregularly dispersed. None of the ice cores inside the dirt cones examined had a cleft top indicative of a crevasse origin (Swithinbank, 1950) and they were probably initiated by fine outwash debris deposited on the ice. The highest residual mound of ice, associated with either dirt cones or perched blocks, was 60 cm. high and the majority showed close similarity of height in the 25–40 cm. range. According to Drewry (1972), the height of a dirt cone is a function of its basal area and the thickness of its debris cover, with the growth of cones proceeding at a rate of up to 50 per cent of the ablation rate. The uniformity in size of the dirt cones in this area may indicate that they are of a similar age, and it is possible that they form annually. If this is the case, the annual surface ablation of this glacier may be in excess of 1 m. The cover of outwash debris is probably deposited during the spring thaw and rapid ablation would proceed during the summer. If more than one generation of cones is present, a multi-modal size distribution would be expected, but this was not seen. It therefore seems likely that, in this locality, the full cycle of cone development and decay occurs each year.

At the snout of the glacier a large terminal ridge of fresh moraine partly covers a *roche moutonnée*. The glacier side of this ridge is striped by a series of subsidiary ridges (Fig. 4) which may indicate annual retreat of the ice.

Approximately 1·5 km. north-west of glacier C is Twitcher Glacier (Fig. 1) with a large lake adjacent to its margin (Fig. 5). The lake is filled by a stream flowing from the south and by melt water from Twitcher Glacier. The glacier dams the lake in places and some of the drainage may still be subglacial, but the main outflow is now in the extreme north-east over a 30 m. cliff into the sea immediately beside the glacier snout (Fig. 5). The map prepared by the

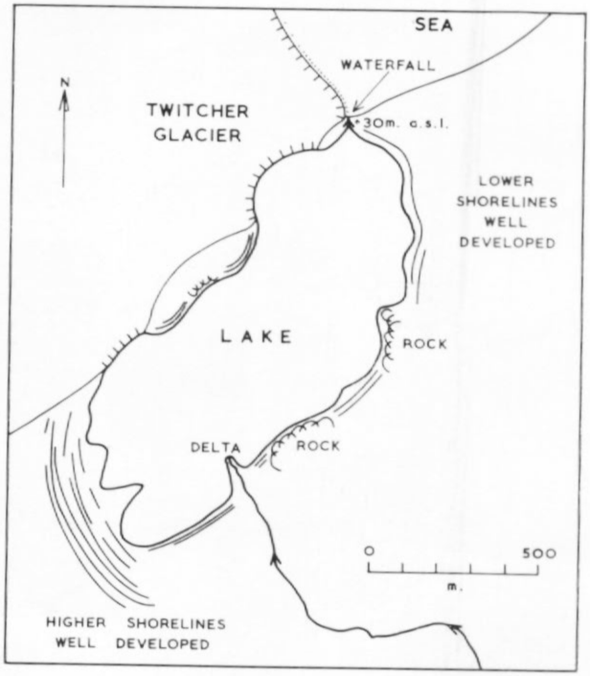

Fig. 5. Map of the Twitcher Glacier ice-dammed lake with the position of the old shorelines surrounding it shown diagrammatically.

South Georgia Survey Expeditions of 1951–57 (D.O.S. 610, 1958) shows the lake to be completely ice-dammed with the snout of Twitcher Glacier 1 km. farther east. However, at about the same time the British South Georgia Expedition of 1954 made a sketch map showing the lake and the glacier snout to be very close together (Sutton, 1957). Sutton described the lake as "... a huge hidden lake, dammed at its seaward end by a narrow tongue of ice and land ..." and, although he made no comment on the drainage situation in the north-eastern corner, it seems likely that at that time the lake was completely ice-dammed.

Old shorelines up to 60 m. a.w.l. are preserved around the sides of the lake (Fig. 5). At least 12 levels were recorded but the upper ten are rather degraded, cut by scree runs and partly overgrown by moss and grasses. They are best developed on the western side of the lake. In contrast, the lowest two levels, at 4·5 and 11 m. a.w.l., are very fresh, free from vegetation and rarely cut by torrent gullies. The lowest terrace (Fig. 6) is over 7 m. wide in places, varies in height from 4 to 5·5 m. a.w.l. and slopes gently towards the lake. The second shoreline, at 11 m. a.w.l., is only marginally more degraded than the lowest terrace and supports isolated grasses and occasional cushions of moss. Where rock cliffs form the sides of the lake, there is a very clear undercut ledge, corresponding in height to the 11 m. shoreline, which suggests that the water level of the lake was static at this point for some considerable time. On the southern side of the lake the main inflowing stream has built up a large delta. This situation has clearly occurred previously as the stream has cut down through older deltaic deposits, associated with the 4·5 and 11 m. shorelines, to expose large-scale cross bedding in unconsolidated outwash material.

From the available evidence it seems likely that the lake level in the mid 1950's corresponded to the 11 m. shoreline, with the snout of Twitcher Glacier in a slightly more advanced position than at present. Shortly after this, glacial retreat allowed the lake level to fall to the 4·5 m. shoreline, and continuing retreat finally removed the ice dam from the lake during the past few years. It is certainly difficult to envisage the extensive shoreline feature, shown in Fig. 6, forming in less than 10–15 years. The ten higher terraces are probably very much older than

Fig. 6. An abandoned shoreline terrace 4·5 m. above the south side of the Twitcher Glacier ice-dammed lake.

the lower two and they apparently correlate with much more advanced glacier positions. However, they clearly demonstrate that Twitcher Glacier has been separated for a considerable time from the small glacier flowing north-westward towards it.

Shorelines around ice-dammed lakes have been correlated with glacier retreat elsewhere in South Georgia (Brook, 1971; Clapperton, 1971) but these lakes remain completely ice-dammed and may drain periodically. The Twitcher Glacier lake may still not have reached its base level, since the remaining stretch of ice dam may block a lower potential drainage channel. There is no evidence for rapid changes in water level as shown by the Hindle Glacier ice-dammed lake (Stone, 1975) 25 km. to the north-west.

A shingle beach is now forming along the base of the southern part of the Twitcher Glacier snout but the northern part of the snout still appears to be afloat.

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