Observations on the Glacial History of Livingston Island[1]

K. R. EVERETT[2]

ABSTRACT. Livingston Island, one of the South Shetland Islands, Antarctica, has recorded at least three glacial events. During the oldest event all areas of the island below 200 m. were covered by an expanded island ice cap. At that time Livingston Island ice probably joined that of adjacent islands. A second, less extensive event, is recorded by deposits of both the inland ice cap and cirque glaciers. Between these two glacial events a higher stand of sea level produced beaches and terraces at 10.6 m. to 12 m. above the present sea level. Following the second glacial event a higher sea level produced beaches 6.1 m. above the present sea level. A third, minor and probably relatively recent glacial event is recorded by push moraines in some cirques from which the ice has now receded.

RÉSUMÉ. *Observations sur l'histoire glaciaire de l'île de Livingston.* L'une des Shetland du Sud, en Antarctique, l'île de Livingston a vu au moins trois événements glaciaires. Au cours du plus ancien, toute l'île en bas de la cote 200 m a été recouverte par une calotte insulaire. A ce moment-là, la glace de Livingston rejoignait probablement celle des îles adjacentes. Un second événement moins étendu est enregistré à la fois dans les dépôts de la calotte et dans ceux de glaciers de cirque. Entre ces deux événements, un niveau marin plus élevé a produit des plages et des terrasses entre 10,6 et 12 m au-dessus du niveau marin actuel. Après le second événement, une nouvelle remontée du niveau marin a produit des plages à 6,1 m au-dessus du niveau actuel. Un troisième événement glaciaire, mineur et relativement récent, est enregistré dans les moraines de poussée de certains cirques dont la glace est maintenant disparue.

РЕЗЮМЕ. *Хронология оледенения на о. Ливингстона.* Остров Ливингстона (Южные Шетландские острова, Антарктика) подвергался оледенению по крайней мере три раза. Во время первого оледенения все отметки ниже 200 м были покрыты льдом и о. Ливингстона, по всей вероятности, был соединен сушей с соседними островами. Второе и менее обширное оледенение представлено на острове отложениями, свидетельствующими о наличии ледников континентального и циркового типа. В межледниковый период более высокий уровень моря привел к образованию намывных террас на высоте 10,6 - 12 м над современным морским уровнем. Третье, незначительное и очевидно сравнительно недавнее оледенение представлено моренами напора в ряде цирков, к настоящему времени уже не содержащих льда.

INTRODUCTION

The observations recorded here are the result of pedologic field investigations carried out in the South Shetland Islands (Fig. 1) during the 1968-69 austral summer.

Because of the nearly complete ice cover on the South Shetland Islands and nearby Antarctic Peninsula (Fig. 1), there is little opportunity to study deposits

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[1]Contribution No. 178 of the Institute of Polar Studies, The Ohio State University.
[2]Institute of Polar Studies, The Ohio State University.

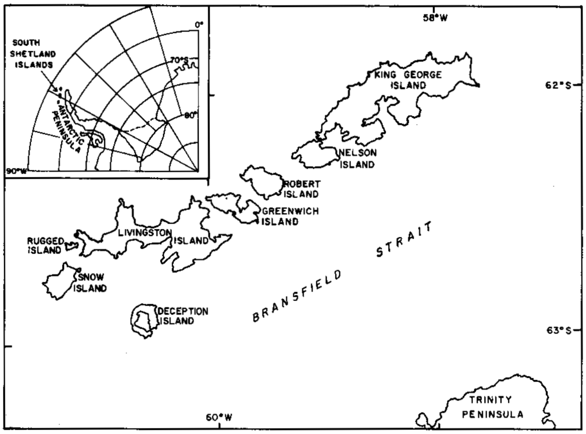

FIG. 1. Location of the South Shetland Islands.

of present or past glaciers. The work of Nichols (1960) in the Marguerite Bay area and his summary of Antarctic glacial geology (1964), the work of the British Antarctic Survey as summarized by Adie (1964), and Hobbs' observations (1968), the survey by Araya and Hervé (1966) and Mercer's (1962) survey of southern hemisphere glaciation probably are representative of the published glacial geologic information on the area. Most of these reports deal with sea-level changes as recorded by raised beaches. No chronology of glacial events of the area has been published.

Most of the observations recorded here are from Livingston Island, second largest of the South Shetland Islands. Like most of the islands of the South Shetland group Livingston Island (Fig. 2) is relatively low and mostly ice-covered over much of its length. The most conspicuous topographic features of the island are the high ice-covered peaks of the Mount Friesland massif on the east end of the island. Mount Friesland itself reaches 1,600 m., while the remainder of the massif generally exceeds 600 m. The maximum general elevation of the island ice cap is 350 m. (Hobbs, 1968). Two sizeable ice-free areas occur on the island which bear at least fragmentary testimony to the island's glacial history. The first

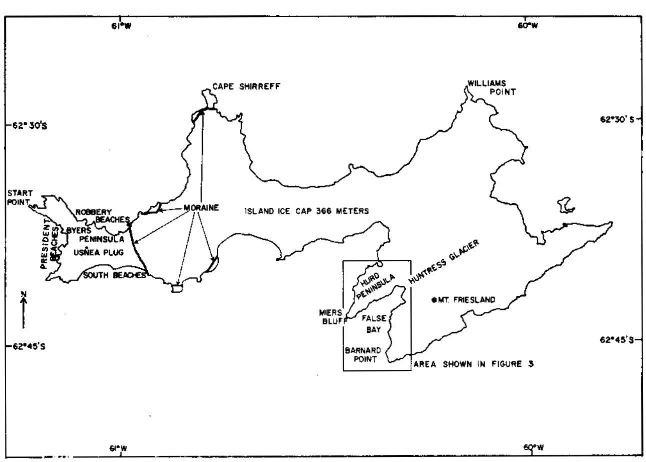

FIG. 2. Generalized map of Livingston Island showing significant geographic locations and area covered in Fig. 3. (From Research Department Foreign Office Map Misc. 66, 3rd edition 1962, and Hobbs 1968.)

and perhaps most important is the False Bay area. Here the close association between glacial deposits and elevated beaches, as well as the preservation of glacial features, provides an opportunity to determine the sequence of more recent glacial events.

False Bay is a fault-controlled (Hobbs 1968) northeast-trending indentation of the southwest coast of Livingston Island. Huntress Glacier, an actively calving outlet of the central ice cap, flows southwestward into False Bay (Fig. 2). Imposing horn peaks flank the bay on either side. Those on the southeast are largely composed of tonalite (Hobbs 1968). Their elevations increase to the east and their summits are ice-covered. The mountains flanking the northwest side of the bay (Hurd Peninsula) are composed of flysch-type deposits and are not as high (350 m.) as those across the bay.

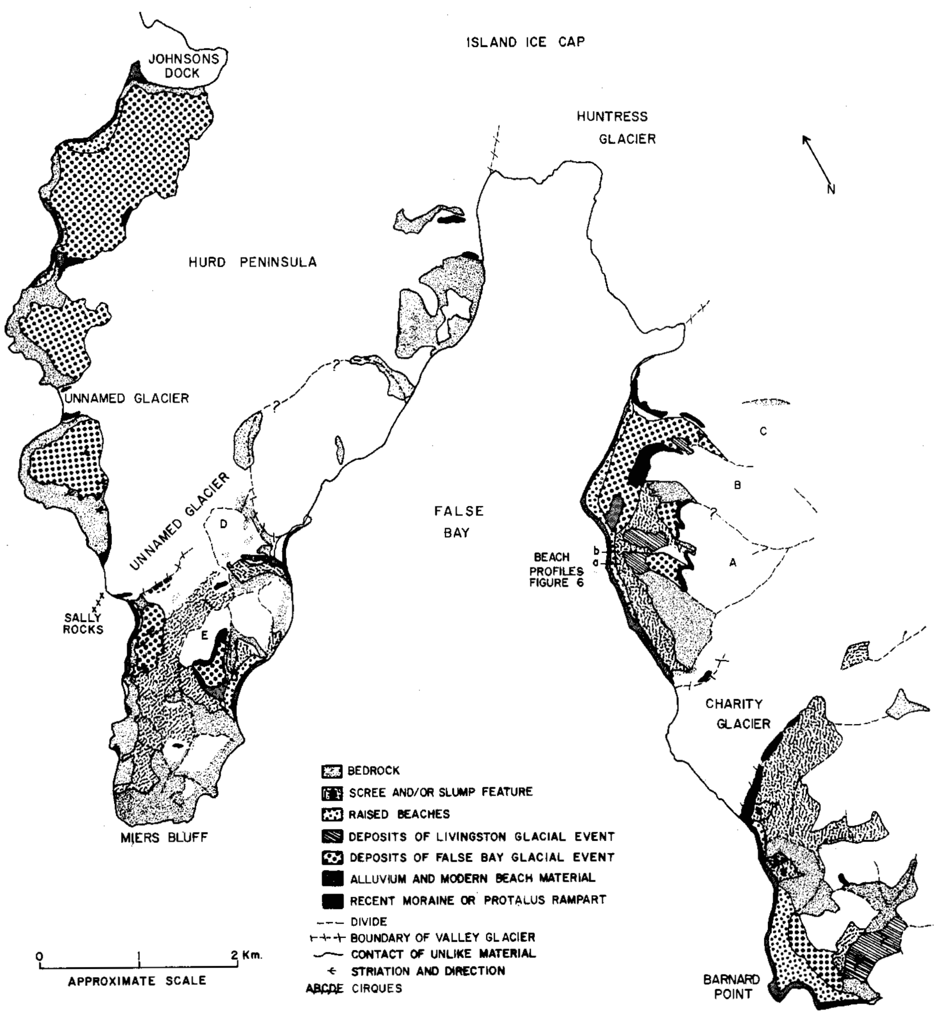

FIG. 3. Generalized map of the False Bay-Hurd Peninsula area of Livingston Island showing distribution of glacial deposits and related features.

Small glaciers flow from cirques toward the bay from both flanking mountain ranges. Cirques farthest to the southwest (Fig. 3) are empty or occupied by small, probably inactive, ice masses. Eastward toward Huntress Glacier, ice flows from the cirques and reaches or nearly reaches the bay. Approximately 2.5 km. northeast of Miers Bluff a small outlet glacier reaches tidewater and separates the ice-free coast and adjacent uplands of Hurd Peninsula from a similar region north to Johnsons Dock. In like manner the Charity Glacier (Fig. 3) separates the pyramidal peaks, cirques and numerous elevated beaches of Barnard Point from False Bay proper. Hobbs (1968) has described the beaches of Barnard Point.

Byers Peninsula, the second and largest ice-free area, has a low (82 m.) central upland with subdued relief. However, several volcanic plugs dominate the inland terrain. Surrounding the central upland on three sides is a complex series of raised beaches, glacial pediments and/or strand flats. The ice-free portion of the peninsula is separated from the inland ice-cap on the east by continuous, multiple-crested end moraines.

The more resistant rock types of the central upland and the andesitic lavas of the Start Point peninsula (Hobbs 1968) have been sculptured into stoss and lee topography. The relative relief may exceed 150 m.

GLACIAL GEOLOGY

Livingston glacial event

Deposits and features related to three distinct glacial events were identified in the False Bay area of Livingston Island. The oldest and least well documented of these is termed the Livingston event. Subsequent events are termed False Bay and Post-False Bay. Evidence for a thicker and more extensive ice cover on Livingston Island consists of rock-cut benches between 180 m. and 190 m. above sea level on the mountains which flank False Bay on the southeast (Fig. 3). Some benches are covered with sandy till or angular tonalite blocks. The benches occur nearly 60 m. below the level of the cirques and are clearly unrelated to compositional differences in the tonalite.

Benches or shoulders occur on Hurd Peninsula (Miers Bluff area) between 150 m. and 180 m. Glacial grooves, striations, and ice-sculptured features (roches moutonnées) are developed between 120 m. and 180 m. in this area.

The pattern of grooves and striations indicates that the ice moved through the cols between the cirques, and thus must have emanated from the island ice cap and not from local cirque glaciers. However, these features cannot, with certainty, be related to the Livingston glacial event. Most reliance is placed on high-level ice-sculptured bedrock.

The only deposits which are considered to be clearly related to the Livingston glacial event are sandy till on benches between 150 m. and 180 m., and scree composed of subrounded tonalite blocks, also on benches. This scree is at least quasi-stable at an angle of repose of 32 degrees.

It is quite likely that ice of the Livingston glacial event moved across Byers Peninsula producing its ice-sculptured surface (Fig. 4). Small patches of gravel in some of the depressions may be related to the Livingston ice.

FIG. 4. Stoss and lee topography. Start Point peninsula, Livingston Island. View to the northwest from Usnea Plug, 26 February 1969.

Ice at the maximum extent of the Livingston glacial event probably completely covered Livingston Island leaving only elevations above 180 m. protruding as nunataks. This includes most, if not all, horn peaks in this area. In view of the present apparently rapid production of talus and scree the horn peaks could have been produced rapidly after the Livingston event and thus could have been overtopped by ice of this event. In any case at this time ice on Livingston Island probably joined that of Rugged Island and perhaps Snow Island to the south (Fig. 1). A partial, perhaps floating, connection existed with Greenwich, Robert and Nelson Islands to the north. The formation of such an inter-island ice cap would require only a moderate thickening of the island ice caps, perhaps about 100 m., for that on Livingston Island. This estimate is based on Weertman's (1964) equations for the expansion of a nonequilibrium ice cap.

Following the Livingston event maximum the ice retreated at least as far as its present position and perhaps much farther. This retreat most probably constituted an interstadial period in which a higher relative sea level cut the well-developed rock terrace or produced beaches in the False Bay area and on the Byers Peninsula at 10 m. to 10.6 m. A constructional beach at 12 m. to 13 m. is probably also related to the wave-cut rock bench (Fig. 5). Beaches between 10 m. and

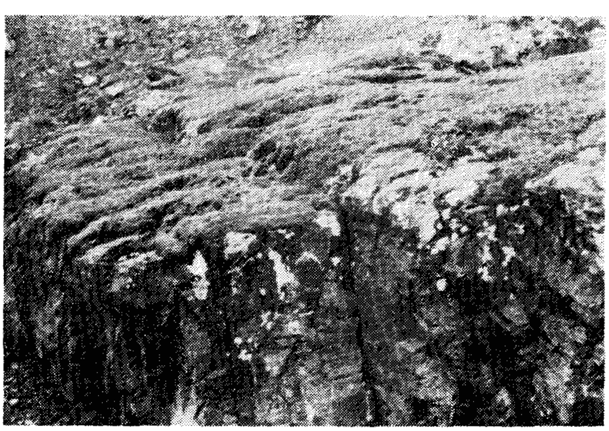

FIG. 5. Wave-cut bedrock terrace (beach IV), Hurd Peninsula, Livingston Island.

12 m. a.s.l. are of regional significance having been measured on Robert Island (Fig. 1). Adie (1964) cited beaches and platforms between 9 m. and 12 m. a.s.l. on Laurie Island (60°44′S., 44°37′W.).

At False Bay two beaches, at 12 m. to 13 m. and at 9 m., have been designated as beaches V and IV (Fig. 6). Both beaches trimmed the base of the slopes parallel to the bay for an indeterminate distance. Remnants of beach IV occur almost to Charity Glacier. However, along this coast beach V and most of beach IV have been buried by active scree. At their exposures at the mouth of False Bay neither beach has been overridden by the old quasi-stable scree, but to the north, toward Huntress Glacier the beaches are covered by a mudflow and glacial deposits. Both cut and depositional elements of these beaches, particularly beach IV, have well-rounded (wave-rounded) cobbles, mostly tonalite. On Byers Peninsula the 10.6 m. beach is a conspicuous element of the raised beach complex.

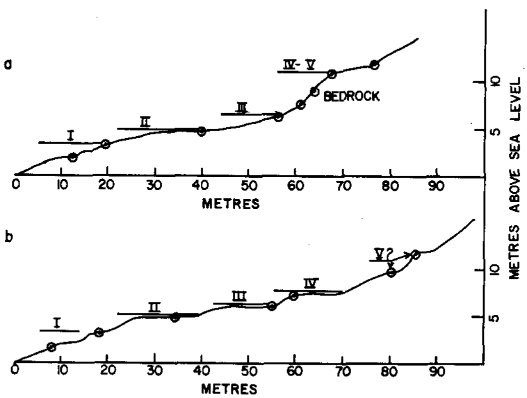

FIG. 6. Profiles of elevated beach sequence, False Bay, Livingston Island. See Fig. 3 for approximate locations. Vertical exaggeration 2X.

False Bay glacial event

After the cutting of beach IV a resurgence of glaciation occurred. There was a general expansion of the island ice cap but it remained much smaller than during the Livingston event. Cirque glaciers advanced markedly, however. The amount of cirque activity increased inland along both Hurd Peninsula and the Barnard Point peninsula. On the southeast side of False Bay, ice in Cirque A (Fig. 3), which may actually be two separate cirques, pushed through a shallow saddle and extended down-slope to an elevation somewhat below 180 m. Another arm of ice from this cirque extended out and around a 180 m. "Livingston" bench. Thus some deposits of the Livingston event were not disturbed by the False Bay push. Ice from Cirque B (Fig. 3) extended out onto a rocky shelf through a broader and deeper valley than ice of Cirque A. Ice from Cirque B was forced to turn sharply southward by a tongue from a still larger glacier in Cirque C. This glacier at present reaches the coast and during the maximum of the False Bay glacial event may have been tributary to some ice of Huntress Glacier.

Deposits of the False Bay event ice advance are abundant. The morainal material in front of glacier B was formed at the junction of glaciers B and C. A prominent ridge deposited on the mountain wall south of the present end moraine of glacier B was probably formed by till and terminal moraine material of the north arm of glacier A which avalanched between glacier B and the rock wall. The deposit does not appear to have been washed. Subsequent sliding and avalanching of till deposited on the mountain side has, in part, covered small recessional boulder moraines of glacier B as well as part of the valley wall terrace. This probably occurred very shortly after recession and in some cases may have been on snow or stagnant ice as the deposit is highly pitted, suggesting ablation. These deposits bury the projected extension of beaches V and IV.

Beach III (6.1 m.) (Fig. 6) is a multi-crested depositional beach. It was probably built just after the maximum of the False Bay event on morainal deposits of that event. These deposits formed a shoal in the Bay which forced long-shore currents to swing bayward. Progressive rise of land level or perhaps a lowering of sea level resulted in numerous arcuate beach ridges (15 over a distance of 99 m.). Three prominent closed depressions behind beach III are believed to mark former positions of detached blocks of ice from the recently withdrawn glacier of the False Bay event.

On the portion of Hurd Peninsula north of the first unnamed glacier (Fig. 3), ice of the False Bay event left a thin, calcareous till over a surface of low relief about 137 m. above sea level. These deposits extend to the very edge of the sea cliffs. For some distance back from the sea cliffs the till is leached to 40 cm. or more and overlain by 30 cm. of wind-blown and/or inwashed scoria. Toward the ice front the scoria deposit thins to 15 cm. and the depth of leaching decreases to only 30 cm. In addition to ground moraine deposits are numerous roches moutonnées with plucked lee faces.

Many of the steeper slopes in the area ($>15°$) have patterned till-derived scree. Summits above 150 m. have been glacially shaped (roche moutonnée forms); however, they lack striations and calcareous till, and are covered instead with angular gravel-sized rocks and talus produced *in situ*. These upland surfaces were shaped by ice of the Livingston glacial event but remained as nunataks extending 12 m. to 30 m. above the level of ice of the False Bay event.

A similar, though poorly documented, series of events occurred south of the first glacier (Fig. 3) in the Miers Bluff area. Here, after retreat of the Livingston event ice and the cutting of the 10.6 m. platform, ice of the False Bay glacial event advanced across the area. It appears to have moved across cols (between 122 m. and 152 m.) and into at least one cirque basin facing False Bay. Ice from the island ice cap definitely invaded the more north-easterly of the cirques and probably reached sea level. The col at the head of the other cirque was probably not breached. Ice appears to have flowed from one of the southwest-facing cirques and from an expanded glacier which now reaches tidewater near Sally Rocks (Fig. 3). These masses moved across the relatively flat uplands behind the sea cliffs. The cirque-derived ice flowed through a small saddle and over the sea cliffs. Ice derived from the expanded glacier near Sally Rocks crossed the upland obliquely and was probably joined by ice from a small, high, west-facing cirque. Once joined, the mass spilled over the sea cliffs onto the 10.6 m. platform and into the sea. In many cases the platform was either modified or destroyed. The directions of ice movement on the upland are indicated by striations and sculptured bedrock.

As stated earlier, at the maximum of the False Bay glacial event, ice from the island ice cap probably breached the cols and flowed into the most north-easterly of the cirques facing False Bay on the west (Cirque D, Fig. 3). This ice may have scoured and striated the bedrock ridge just to the north of the stream and deposited gray calcareous till in the valley bottom. Because of the pre-False Bay event configuration of the cirque valley, ice movement was directed against, and oversteepened, the southwest wall of the valley. It also left lateral moraines against the wall. During the retreat phase of False Bay glacial event the ice in the cirque may have stagnated after the inland ice receded below the level of the col. Lateral moraine material and debris derived from rock chute action appear to have slid at different times against the stagnant ice and produced the prominent lobate forms along the valley wall. This material partially buries the valley bottom clay till moraine. The height of the lobate debris decreases regularly down-valley. Similar deposits are lacking on the opposite valley wall.

The glacial events recorded in the other prominent cirque were not directly influenced by ice of the island ice cap (cirque was not joined by ice cap ice). The cirque glacier reached nearly to sea level before withdrawal to the first prominent moraine (Fig. 3). Several slight readvances in the form of push moraines are recorded on the outer moraine. After these minor fluctuations the ice retreated steadily and stagnated.

Byers Peninsula was little affected by ice of the False Bay event. It is likely that the large moraine ridge that crosses the peninsula (Fig. 2) represents in part deposits of the False Bay advance, as do perhaps similar moraines at Cape Shirreff and Williams Point.

Post-False Bay Time

It was pointed out earlier that a depositional beach (beach III, 6.1 m. a.s.l.) was being built on the southeast side of False Bay at about the time recession of ice of the False Bay event began. Similar beaches (6.1 m.) or beach sets (6.1 m. to 7.9 m.) occur across the bay and intermittently from Miers Bluff to Johnsons Dock (Fig. 3) and along much of the coast of Byers Peninsula. A regional occurrence of constructional beaches between 6.1 m. and 7.9 m. a.s.l. is suggestive of higher sea level. A lower raised beach is developed at 4.5 m. a.s.l. (beach II). This beach is nearly as extensive as the modern beach and may receive flying debris (driftwood and kelp) during severe storms.

Beaches between 3.6 m. and 4.5 m. a.s.l. are not well developed between Miers Bluff and Johnsons Dock. Occasionally a wave-cut notch occurs at 3.6 m. and a beach at similar elevation occurs intermittently on Byers Peninsula.

Shortly after the construction of beach II (3.6 m. to 4.5 m.), or perhaps in part contemporaneous with it, a small readvance of the cirque glaciers occurred. On the southeast side of False Bay small push moraines were built. Ice from Cirque B (Fig. 3) produced a prominent end moraine (ice-cored) which reached the valley floor and covered some of the recessional deposits of the False Bay event. Glaciers farther to the northeast probably reached False Bay. On Hurd Peninsula the resurgence is marked in the more southerly cirque (Cirque E) by a very coarse boulder moraine (push moraine?) which contains little calcareous clay material. The glacier near Sally Rocks left only a boulder line to mark its lateral readvance. However, terminally, it deposited a moraine of calcareous till over both the 6.1 m. and 4.5 m. beaches. Recession from the push moraines amounts generally to about 6.1 m. The freshness and unleached character of the moraines suggest that they are quite recent. A lichen line occurs at the base of a prominent volcanic neck, Usnea Plug, on Byers Peninsula, indicating at least 4.5 m. of recent snowbank recession. Prominent protalus ramparts in west-facing cirques on Hurd Peninsula may have developed at this period and at least one may still be sporadically active.

A modern 1.5 m. beach and 3 m. storm beach occur around the island. The storm beach is marked by the farthest inland occurrence of rhyolitic pumice. These beaches are in many cases being built at the foot of the modern glaciers. Just north of Cirque D on Hurd Peninsula a small outlet glacier of the inland ice is depositing morainal material on the 6.1 m. beach and may still be at its most advanced position since the False Bay glacial event.

Other Raised Beaches

The elevated beaches described in the previous sections are all clearly related to glacial events on Livingston Island or regionally as the distribution of the 10.6 m. and 6.1 m. beaches suggests. On Livingston Island and other islands of the South Shetland group (Fig. 1) beaches and terraces have been recorded from 15 m. to 89 m. a.s.l. (Adie 1964; Araya and Hervé 1966). The local or regional significance of these beaches is not clear. However two significant groups of levels do occur, one between 21 m. and 30 m. a.s.l. and the other between 40 m. and 58 m. a.s.l. These may represent high sea-level stands whose uniformity of height has been lost because of local isostatic rebound.

On Livingston Island a prominent beach occurs at 17 m. to 18 m. a.s.l. between Cirques D and E (Fig. 3). This beach appears to represent a favourable wave focus in addition to higher sea level. A prominent surface between 46 m. and 65 m. a.s.l. occurs on Hurd Peninsula south of Sally Rocks (Fig. 3). Wave-rounded cobbles were found above 46 m. a.s.l., one at 137 m. a.s.l. The surface was covered by ice during both Livingston and False Bay glacial events and the cobbles are believed to have weathered from a thin local conglomeratic zone and were redistributed by the ice. In the region of President Beaches on Byers Peninsula, landward from a well-developed 10.6 m. beach, a scarp rises to 28 m. and grades gently inland (3° to 4°) to 34 m. The beach tread terminates against a dissected scarp beyond which lies the relatively undissected upland (82 m.) developed on volcanic tuffs. Headward stream erosion has not yet completely breached the 28 m. to 34 m. level. This conspicuous level may represent a strand flat related to the Livingston glacial event. The 82 m. upland may well represent a marine planed surface.

CONCLUSIONS

Evidence, largely from Livingston Island, suggests that this island and probably the South Shetland group in general, have recorded at least two significant glacial events. The first, or Livingston glacial event, was probably a full-bodied event in which all island areas below at least 200 m. were covered by ice. The expanded ice cap of Livingston Island probably joined similar expanded ice caps on the smaller islands to the west and east. The 10.6 m. to 12 m. raised beach, which is so well-developed on Livingston Island and occurs generally throughout the region, is considered to represent an interstadial period following the Livingston event. A younger, less extensive although better documented event, is termed the False Bay event. At this time the inland ice expanded into some cirques, moved through cols between others and across narrow upland areas. In some cases the advancing ice reached the sea cliffs and destroyed portions of the 10.6 m. beach. Ice of the False Bay event probably had little effect over most of Byers Peninsula but produced some prominent moraines. Ice from the adjacent islands probably did not join that of Livingston Island at that time.

The regional occurrence of a 6.1 m. beach suggests a higher sea level strand following recession of the ice of False Bay event. Numerous other beach levels of no regional significance indicate isostatic readjustment as well.

A small relatively recent advance of both cirque glaciers and the inland ice is recorded by push moraines from which the ice has now receded. Photographic comparisons indicate little or no change in the margin of Huntress Glacier since 1958. This is probably applicable generally to the inland ice.

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