Marine and fluviatile terraces and colluvial fans reflecting quaternary climatic changes, Gough Island, South Atlantic

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Evidence for former sea levels at +3 to +4m, +12 to +15 m, +30 m, +55 m, +75 m, -23 m and -50 m is presented. A high plateau (c. 700 m) attributed to possible marine planation is a structural feature. The +3 to +4 m bench is provisionally dated as Eemian, the +12 to +15 and +30 m as Middle Pleistocene, and the +55 m terrace as late Early Pleistocene. Gravel and boulders abutting the +75 m terrace are severely weathered suggesting a still earlier age. The benches below present sea level are considered to have been cut during the last glacial period.

Cut-and-fill terraces flanking the two largest rivers, and rubble fans from tributary valleys in one, indicate a former much colder period with intense frost weathering (dry: fill). It was succeeded by a period of much higher rainfall than to-day (cut). The fill stage is correlated with the last glacial maximum (peak c. 18 000 yr B.P.) and the cut with a 'pluvial' around 13 000 - 17 000 years ago. A subsequent drier period in the Holocene, marked by small-size gravel capped by transported turf, was followed in turn by downcutting during the ensuing, and still prevailing, wetter period.

Getuienis van vorige seevlakke op hoogtes van +3 tot +4 m, +12 tot +15 m, +30 m, +55 m, +75 m, -23 m en -50 m word voorgelê. 'n Hoogliggende plato (c. 700 m), voorheen aan moontlike mariene planering toegeskryf, is 'n strukturele verskynsel. Die +3 tot +4 m bank word voorlopig as van Eemiese ouderdom, die +12 tot +15 en die +30 m as Middel-Pleistoseen, en die +55 m terras as laat Vroeë Pleistoseen beskou. Gruis en rolblokke wat teen die +75 m terras rus is erg verweerd wat 'n nog vroeër ouderdom aandui. Die banke benede huidige seevlak is bes moontlik tydens die laaste glasiale tydperk ingesny.

Sny-en-vulterrasse langs die twee grootste riviere, en puinwaaiers vanuit sytakke in die een, is aanduidings van 'n baie kouer periode met intensiewe rypverwering (droog: opvul). Dié periode is deur een met baie hoër reënval as die huidige opgevolg (insny). Die opvulstadium is met die laaste glasiale maksimum (spitstyd c. 18 000 jr gelede) en die insnystadium met 'n 'pluviale' om en by 13 000 - 17 000 jr gelede gekorreleer. 'n Volgende droër tydperk tydens die Holoseen, gekenmerk deur afsetting van kleingruis waarop vervoerde turf lê, is deur insnyding tydens 'n daaropvolgende natter periode, wat tans heers, opgevolg.

Introduction

Gough Island (*c.* 40°20'S, 9°54'W) lies in the South Atlantic about a third of the way from the southern tip of Africa to Patagonia; its

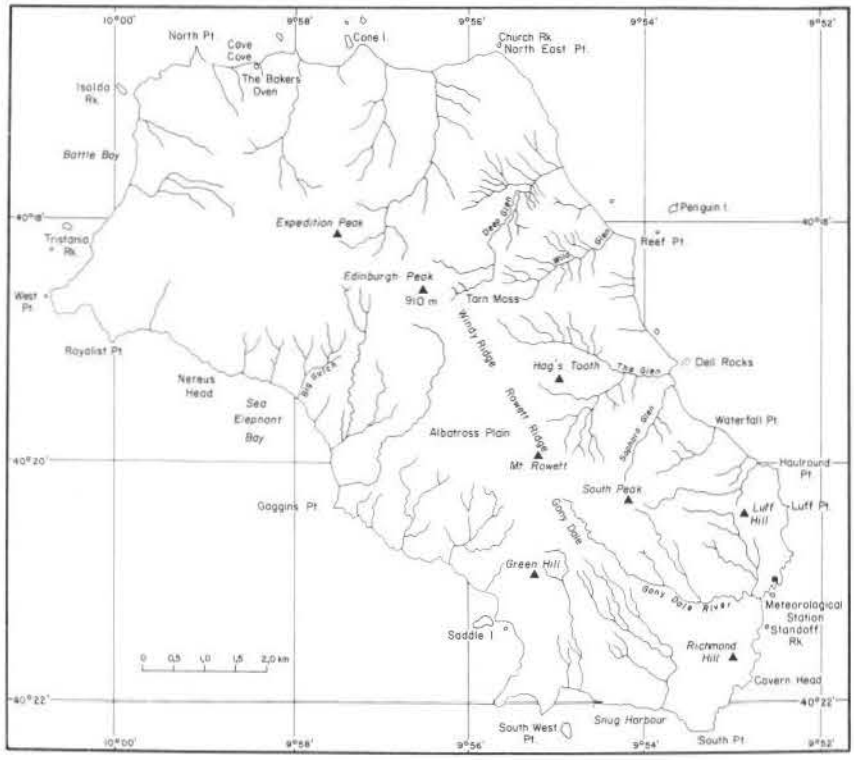

Fig. 1. Map of Gough Island based on airphotos, the South African Hydrographic Map (1969) and Ollier's (1984) topographic map.

nearest neighbour, the better-known Tristan da Cunha, is 340 km to the north-north-west. The island, 13,3 km long and 4,6 to 8,2 km wide, is mountainous and highly dissected, the highest point (Edinburgh Peak) reaching 910 m (Fig. 1). Cliffs up to 300 m high form virtually the whole coast; beaches are few and small. The island is the upper part of a large volcano - the exposed basaltic and trachytic successions range in age from 2,5 to 0,1 Ma (Maund et al. 1988). Its tectonic and structural evolution has been discussed by Chevallier (1987).

A system of radial rivers has incised deep valleys, termed 'glens' by the pioneer mappers (Heaney & Holdgate 1957). Only two, The Glen and its close neighbour Sophora Glen, enter the sea at anything like grade (Le Maitre 1960). The others cascade down the cliffs or, as is the case with the largest, the Gony Dale River, plunge over falls very near their mouths. Heaney & Holdgate (1957) considered that the deep erosion of the glens was due to rejuvenation of the incising streams as a result of a recent uplift of the order of 60 to 90 m, but did not present further evidence. They also suggested that the extensive plateaux in the central part of the island lying at 550 and 610 m 'may indicate a former uplift of much greater magnitude'.

During a visit in November 1985 the lower parts of the valleys of the Gony Dale River and The Glen were investigated and about three-quarters of the coastline inspected from boats. Evidence was obtained for former higher and lower sea levels and for a period of intense cold, followed by one of much higher rainfall than at present.

Elevated marine benches and terraces

Remnants of elevated wave-cut benches and terraces, cliff notches, sea caves and arches occur along the coast. Elevations given are mostly estimates and the +3 to +4 m and the +12 to +15 m groupings could prove an over-simplification.

+3 -4 m

Benches at this elevation are common, attaining widths of up to about 30 m. They are generally strewn with large, angular blocks from cliff falls mixed with subangular to subrounded boulders, which together protect the terraces and the backing cliffs from stormwave attack. Good examples can be seen north and south of Transvaal Bay; another is the narrow (10-20 m) raised beach extending from the mouth of The Glen to opposite Dell Rocks.

When the coast from Transvaal Bay to Cone Island off the north coast was studied from the crayfish catcher *Tristania II*, well-defined benches at this elevation were noted south-east of Gaggins Point and up to and past West Point. Off North Point there is also a prominent wave-cut platform at about 3-4 m with a corresponding notch in the cliffs. Around the Point in Cave Cove is the Bakers Oven, a small sea cave whose floor lies about four metres above the sea. Notches in the sea cliffs at equivalent elevations were noted both on the main island and on some sea stacks, notably Tristania and Isolda Rocks.

+12-15 m

Although remnants of benches at this elevation are not rare they are much less frequent than those at +3-4 m. Heany & Holdgate (1957) reported that 'patches of what may be a raised beach' lie to the south of The Glen. Ollier (1984) briefly noted the same feature as the most recent of his 'phases of volcanic and erosional events', giving the elevation as 'a few metres above sea level'. The bench is marked on the nautical chart (South African Hydrographic Office 1969) as a 'Raised Beach' extending 0,9 km south-east from Waterfall Point. When inspected close up from an inflatable dinghy, its elevation, which is constant along its whole length, was estimated to be about 15 m. The bench, which is some 10 to 20 m wide, was clearly cut in solid lava and does not follow any plane of weakness in the cliff. It is covered by boulders and cobbles; a pot-hole, several metres across, near the south-eastern end connects with a partly drowned sea cave.

A remnant at the tip of a small promontory about halfway between Standoff Rock in Transvaal Bay and Cavern Head was accessible from the dinghy. Its surface is strongly eroded in places and local deep box-work weathering indicates extended subaerial exposure. Where the bench links with the cliff there is a well-developed undercut largely filled with rounded boulders up to about 0,7 m across. They are weathered at the surface, causing the more resistant larger phenocrysts to protrude.

+30-35 m

Isolda Rock near North Point, which rises to 91 m, is perforated by a large arch, the floor of which is about a third of the way up the stack. There are other features at this elevation (e.g. at South West Point) that could not be identified in the time available with any degree of probability.

+50-55 m

The Meteorological Station was built near the north-eastern edge of an extensive marine terrace that slopes gently seawards. It is blanketed by turf and peat but its rock surface is exposed in a southerly flowing tributary of the Gony Dale River, hereinafter referred to informally as the 'Water Supply Creek', as it is tapped for the Station (Fig. 2). Levelling showed that the surficial turf

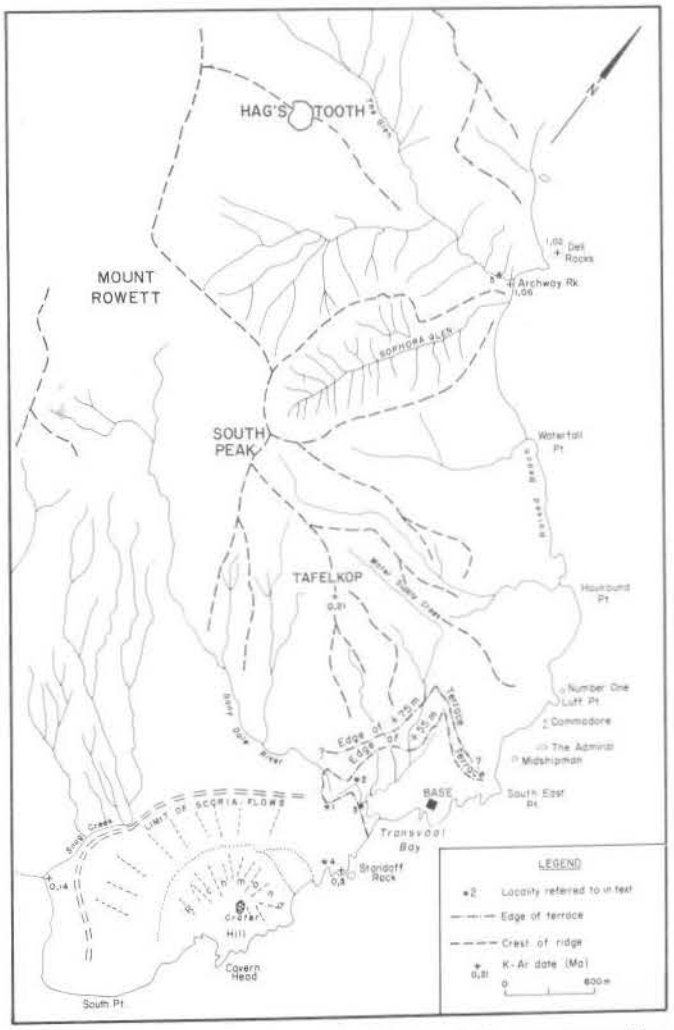

Fig. 2. Map of eastern part of Gough Island showing drainage systems and the +55 m and +75 m terraces traced from an airphoto mosaic. 1. Landslide. 2,3. Exposures of gravel. 4. Cave. 5. Debris fan.

cover hereabouts is around eight metres thick. This agrees with the depths (max. 9,1 m) to which the steel pipes supporting the main building at the Station had to be driven before impenetrable material was struck (pers. comm. Mr. E. Bamford, P.W.D., Cape Town). Ground level at the building, from a nearby bench mark, is 53 m, which gives an elevation of about 44 m for the seaward edge of the rock surface of the terrace. This is confirmed by an altitude of 45 m established for the top of weathered scoria struck in an excavation 80 m to the north-east.

To the west, immediately across the Gony Dale River, there are well-preserved cliffs, considered to be former sea cliffs, associated with the terrace. They are undercut at several places at elevations of about 55 m (Fig. 2, *c.* 50 m NE of locality 1). These undercuts, which have sub-horizontal roofs, were carved into a sheet of trachyte that dips north-eastwards at low angles. Most of them are partially or completely hidden by dense vegetation, accumulations of plant remains, and turf and rocks that have tumbled over the cliff edge. In one that was readily accessible, the walls are smooth and turn back and forth at abrupt angles of almost 90°. This is a feature in keeping with waves attacking the cliff more or less at right angles. The undercuts could not have been shaped in this manner by river erosion.

Immediately up river there is a landslide scar clearly visible from the Meteorological Station. It is on a very steeply sloping part of the south bank adjacent to the undercut cliffs (Fig. 2, locality 1). It exposes two old boulder beds, the lower and younger of which extends from about 4,5 m above the river (lower contact not visible) to about 11 m (Fig. 3). At this elevation the outcrop of the boulder bed is stepped back at a level corresponding to the bottoms of the undercuts, i.e. an altitude of 55 m. The bed consists of very well-rounded pebbles and cobbles, with boulders up to about 0,4 m in diameter. The interstices are filled by apparently well-sorted coarse sand. Gravel, with boulders, identical in appearance was encountered at an elevation of about 50 m on the other side of the river (Fig. 2, locality 2). How far this gravel deposit extends and whether it continues down to river level could not be established due to obscuring turf and the dense vegetation.

About 0,2 km from its mouth the Gony Dale River has cut a narrow gorge through the north-easterly dipping trachyte sheet that forms the top of the undercut cliff previously described. Massive gravel, with well-developed weathering crusts, is exposed in the near-vertical cliff (Fig. 2, locality 3) as part of the northern sidewall

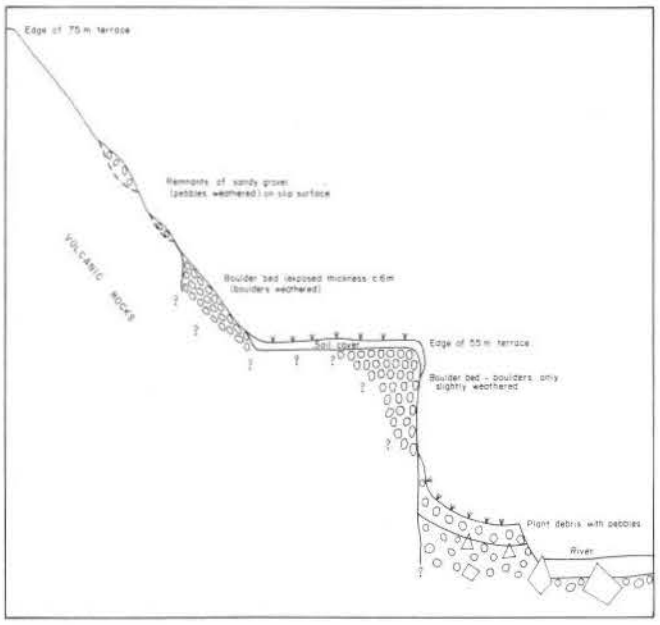

Fig. 3. Schematic section at the landslide, south bank, Gony Dale River. (Locality 1, Fig. 2).

of the gorge. This gravel and that of the two other exposures are considered to be remnants of a deposit that once filled the now fairly steeply sloping lower part of the Gony Dale Valley. Unlike riverine gravels that usually contain sandy and even clayey layers, sometimes as a succession of layers of different average clast size, these Gony Dale gravels do not vary appreciably in the size distribution of the clasts throughout. It is concluded that they accumulated in the submerged valley of the Gony Dale River under a uniform marine depositional regime while the 55 m terrace was being cut by wave action during a transgression.

Huge pot-holes are exposed near the seaward edge of the terrace where the peat blanket is absent. One, near the fuel tanks at the Meteorological Station and some 30 m from the edge of the sea-cliff, is 7 m across and extends down to below a severely eroded remnant of the +12 to +15 m bench - an undercut in the cliff links it to the sea. The pot-holes are undoubtedly of marine origin - there is no evidence for a former river channel or channels.

+75 m

At the landslide (Fig. 2, locality 1) a bed of strongly consolidated well-rounded gravel and cobbles, with boulders, is exposed intermittently from the +55 m level for about 20 m up to the edge of a plain (Fig. 3). Unlike the lower bed, the component clasts are severely weathered suggesting an appreciably greater age. No other exposures of gravel at this altitude were encountered, but clear indications of a step were noted on the air photo. The probable margin of the terrace where it is cut into the lower slopes of the South Peak range is shown on Figure 2. To the south of the Gony Dale River its extent is unknown as it disappears under the Richmond Hill volcanics. A cave near the seaward edge (Fig. 2, locality 4) is ascribed to marine erosion.

It must be stressed that the approximately 75 m elevation is for the top of the gravel exposed in the landslide; the elevation of the inner edge could not be determined - it could well be 10 m or more higher.

High-level surfaces

From the air, the remarkably flat, extensive, peat-blanketed surfaces of Tarn Moss (*c.* 655-755 m), Albatross Plain (*c.* 550 m) and the still lower Gony Dale Plain are very striking features. Heaney & Holdgate (1957) and Holdgate (1958) suggested that the higher two had been planed off by the sea. They were thus listed by Nunn (1984) in his review of evidence for Late Tertiary shorelines on South Atlantic coasts as of possible Late Tertiary age. During helicopter flights it was clear that a thick, near-horizontal sheet of lava demarcates the north-eastern edge of Tarn Moss, forming the top of the high cliffs, which strongly suggested that the surface is a structural feature. Chevallier (1987) interpreted it as a caldera closing the basaltic stage and infilled by later volcanics. The top sheet, a flow from the Edinburgh Peak eruptive centre, has recently been dated at 0,20 ± 0,04 Ma (Maund *et al.* 1988) which completely excludes a Late Tertiary or even an Early Pleistocene age for the surfaces.

Submerged terraces

The high arch in the very narrow (2-3 m at the top) promontory next to the cliff-top crane at the Station is a spectacular coastal feature. According to Dr Norbert Klages (pers. commun. Nov. 1985) who scuba dived below the arch, it continues down at its full width to 17 m below sea level where a pile of boulders some 5-6 m thick lies on solid rock. The arch, thus, must have been cut when the sea was some 23 m lower than now. The other well-known arch on the island, Archway Rock at the mouth of The Glen, also continues down far below present sea level - how far is not known.

Between South East Point and Luff Point, about a kilometre north-north-east of the Station (Fig. 2) there is a prominent cluster

of sea-stacks, the highest rising to 52 m. Dr Klages found that the almost vertical sides of the lowest stack, The Midshipman (10,7 m), continue down to a depth of 50 m to a flattish sea bed.

Other evidence for sea levels lower than now is the presence of many partially submerged caves at the bottoms of the girdling cliffs - they are particularly noticeable between Transvaal Bay and Waterfall Point.

Probable ages of the benches and terraces

The island rises from *c.* 38 Ma-year-old oceanic crust (Le Roex 1985) far from plate junctions and thus qualifies as a good 'measuring rod' for 'shifts' in the level of the surrounding sea (Ladd 1962). Furthermore, there are no signs of tectonic disturbance of the coast or of the +55 m terrace. Accordingly, although sea-level changes relative to the land are dependent on a host of variables, and long-range correlations based solely on altimetric grounds are hazardous, evidence from other South Atlantic shores considered to bear on the dating of the former higher and lower sea levels on Gough Island will, nevertheless, be assessed.

The lower benches

According to the CLIMAP group (1984) the beaches of oxygen isotope substage 5e (*c.* 120 000 yr B.P. - Eem Interglacial) that are known and dated throughout the world, range between 2 and 7 m above present sea levels. On the nearest continental shores to Gough Island, those of southern Africa, benches and beaches at +2 to +5 m have been reported from Cabinda (Davies 1962), the Cape west coast (Hendey & Cooke 1985), and the southern and eastern Cape Province (Marker 1984, 1987) - but radiometric dates are lacking. The +3 to +4 m benches on Gough Island are thus provisionally assigned to the Eemian Interglacial.

It should be noted that until very recently an Eemian age was generally given to benches and beaches lying between +6 and +9 m along the South African coast (e.g. Tankard 1976b, Davies 1980). More recent work has shown that they are appreciably older. Hendey & Cooke (1985) on good palaeontological evidence have dated the +7 to +8 m sea level on the Cape west coast as Early Pleistocene and consider that the Eemian beach was at +4 to +5 m. At Hondeklip Bay, also on the west coast, Kensley & Pether (1986) concluded that the +5 m beach is Late Pleistocene and the +8 m one Middle Pleistocene. From a study of coastal caves in the southern Cape, Hendey & Volman (1986) on various evidence concluded that the +6 to +8 m beaches are Early Pleistocene.

The +12 to +15 m bench on Gough Island may be coeval with the +15 m 'erosion feature', considered to be of Middle Quaternary age, reported by Almeida (1961) from the very isolated Trinidade Island east of Rio de Janeiro. Terraces at about this elevation are widely distributed in the eastern and southern Cape Province (Marker 1984, 1987), and Davies (1959) reported a beach lying at +13 to +16 m in the vicinity of Swakopmund in Namibia. On the Namaqualand coast of the western Cape Province, beaches at +17 to +21 m and +29 to +34 m were dated as Middle Pleistocene by Carrington & Kensley (1969). Subsequently, also on palaeontological evidence, Kensley & Pether (1986) placed the '30-m complex' in the Early Pleistocene. On archaeological grounds, Davies (1973) suggested a Mindel-Riss (Holsteinian) Interglacial age for +30 m terraces in the western Cape Province and in Namibia; he also reported 'beach remains' at +30 m near Moçamedes in Angola (Davies 1962).

As recently as 1984 Marker noted that 'extremely little dating is available for benches from 60 m altitude to below present sea level'. Since then, although not yet confirmed by radiometric dating, the recent palaeontological studies indicate that in southern Africa, terraces at present levels above the Eemian beaches and up to about 30 m date back to Middle Pleistocene. The +12 to +15 m bench between Standoff Rock and Cavern Head which is cut in lavas for which a date of 0,3 Ma has been given (see following section) could well be upper Middle Pleistocene.

Table 1
Reported ± 55 m terraces on South and central Atlantic islands and flanking continents

Locality	Elevation (m)	Reported age	Reference
Canary Islands	55	Pliocene or Early Pleistocene	Lecointre *et al* 1967*
Cape Verde Islands	50-60	Early Pleistocene	Serralheiro 1967*
Netherlands Antilles	46-54	Early Pleistocene	Alexander 1961*
Falklands	69	Early to Middle Pleistocene	Adie 1953*
South Georgia	50	Late Pliocene	Stone 1974*
Venezuela	61	Early Pleistocene	Weisbord 1969*
Brazil	50-60	Pleistocene	Bigarella & Andrade 1965*
Argentina (Patagonia)	60-75	?	Darwin 1842*
Tierra del Fuego	50	?	Halle 1910*
Ghana	50	Early Pleistocene	Gregory 1962*
Sierra Leone	50	?	Gregory 1962*
South Africa			
Alexander Bay	46	?	Keyser 1972
Namaqualand	45-50	Early Pleistocene	Carrington & Kensley 1969
South coast	60	?	Marker 1987
Eastern Cape Province	58-80	?	Marker 1984
Southern Africa			
Transkei, Natal and KwaZulu	60	Pleistocene (Cromerian Interglacial)	Davies 1970

* *Cited by Nunn 1984.*

The +55 m terrace

Terraces corresponding closely in altitude to the +55 m terrace on Gough Island have been recorded from the African and South American Atlantic coasts and from several islands (Table 1). Early Pleistocene ages have generally been assigned, but apparently no substantiating radiometric dating has been done. On palaeontological evidence a 'transgression complex' at 45-50 m on the Namaqualand coast has been assigned to the Early Pleistocene (Carrington & Kensley 1969), and an age as old as Late Pliocene has even been suggested for the +50 m beach in the Hondeklip Bay area (Kensley & Pether 1986). It is significant that Fleming & Roberts (1973) from consideration of sea-floor-spreading data concluded that the 'basal Pleistocene sea surface would have been 50-60 m above present'. However, two published K-Ar dates for lavas stated to have been collected a the Meteorological Station, which is situated on the seaward edge of the +55 m terrace, contradict an Early Pleistocene age. The first, by I. McDougall of 'trachyte from near the Meteorological Station and part of the Richmond Hill flow' is 0,18 ± 0,01 Ma (Ollier 1984). The assigning of the locality was affected by a draughting error (letter from Prof Ollier, 14 April 1987) on his topographic map, which placed the Station on the south side of the Gony Dale River instead of 0,4 km to the north, on the other side of the river. That the sample was from a Richmond Hill flow is also clearly stated in an earlier report (Wace & Ollier 1975). The second date of a sample 'from the Meteorological base', 0,30 Ma, was given by Le Roex (1985) and again by Maund *et al.* (1988). In a letter of 16 June 1988, Dr le Roex informed us that the sample 'was taken from the southern end of Transvaal Bay, from cliffs behind Standoff Rock'. The locality is thus also south of the Gony Dale River (Fig. 1) and the date does not reflect the age of the rocks on which the +55 m terrace was cut.

Chevallier (1987), presumably on the assumption that Le Roex's cited date was of a rock from the immediate vicinity of the Station, and from K-Ar dates of samples collected from 'Tafelkop' and 'W end of Tafelkop' (Fig. 2), both 0,21 ± 0,02-0,03 (dates given in Maund *et al.* 1988), showed on his geological map the area extending eastwards from South Peak to the sea, which includes the +55 m terrace, are being covered by trachytic flows emanating from Tafelkop. However, the eastern slopes of Tafelkop and of the South Peak range most clearly expose a subhorizontal succession predominantly of scoria.

Maund *et al.* (1988) who based their revised stratigraphy on radiometric dating ('We also present new high-precision K-Ar dates upon which we have based the revised stratigraphy'), also placed the rocks cut by the +55 m terrace in their trachyte extrusives unit (mean age *c.* 0,2 Ma). Le Maitre (1960) and Ollier (1984), on geological grounds, showed them falling in their older (Lower Trachytes) and oldest (Basic agglomerates) units, respectively. Chevallier (1987) and Maund *et al.* (1988) considered that the earlier workers had been misled by the trachyte generally occurring 'at a lower topographic level ... giving the illusion that these salic lavas are stratigraphically older'. Our considered opinion is that the volcanic successions planed by the +55 m terrace are substantially older than the Richmond Hill and Tafelkop lavas.

The four investigations of the geology of Gough Island have led to four quite widely differing geological maps and stratigraphic columns (Table 2). We in our 3-weeks stay made no attempt to produce yet another geological map, even of the relatively small area shown on Figure 2, as our prime purpose was to study riverine terraces.

The +75 m terrace

Wave-cut and depositional features at this elevation have been reported from the west coast of southern Africa and other localities around the south and central parts of the Atlantic Ocean. Ages from Late Tertiary to Early Pleistocene have been ascribed (Table 3). Admittedly the altimetric correspondence of several of them to a former +75 m sea level may well be quite fortuitous, due to crustal movements such are known to have affected the higher marine terraces on sections of the Cape west coast (e.g. Tankard 1976a) and Angola (Davies 1962).

As has been noted, the boulders and gravel abutting the +75 m terrace on Gough Island, and cut by the +55 m transgression (Fig. 3) are severely weathered, to a very much greater extent than those on the +55 m terrace. As chemical weathering under cold conditions, such as have generally prevailed on the island, is a very slow process, it is accordingly considered that the terrace was cut during the Early Pleistocene.

Submerged terraces

Flights of terraces at depths of 10 to 60 m have been reported from the vicinity of the mouth of the Orange River (De Decker 1987). A sea level of -20 to -25 m has been inferred by Fleming (1976) for a relict wave-cut platform off Cape Point, and a former

Table 2
Stratigraphic columns proposed for Gough Island

Le Maitre (1960)	Ollier (1984)	Chevallier (1987)	Maund *et al.* (1988 with K/Ar ages (Ma)	
		Slope detritus		
Upper basalts	Edinburgh Peak basalts	Terminal trachy-basalt	Edinburgh Peak basalts	0,13-0.20
Upper trachytes (including plugs)	Upper trachytes	Trachytic pumice (Trachytic domes and plugs)	Trachyte extrusives (Trachyte plugs)	0,12-0,30 0,47-0,84
	(Tarn Moss Erosion Surface)	Trachytic flows (Extensive erosion) (Caldera formed)	(Major erosion)	
Middle basalts	Rowett basalts	Upper basaltic sequence	Rowett basalts (including plugs)	0,52-0,56
Lower trachytes	Lower trachytes	Lower basaltic sequence	Glen basalts	0,52-1,06
Lower basalts	Basic agglomerates (with lava)	Basal phreato-magmatic episode	Reef Point basalts	2,55

Table 3
Reported ± 75 m terraces on South and central Atlantic islands and flanking continents

Locality	Elevation (m)	Reported age	Reference
Cape Verde Islands	80-100	Early Pleistocene	Serralheiro 1967*
Netherlands Antilles	70	?	Alexander 1961*, Bowen 1964*
Brazil	80-100	Pleistocene	Bigarella & Andrade 1965*
Cameroon	73	Early Pleistocene	Hori 1977*
Ghana	75	Late Tertiary (?)	Hilton 1966*
Sierra Leone	76	Late Tertiary	Gregory 1962*
Angola	80, 90	?	Davies 1959
South Africa			
Alexander Bay	64-84	Early Pleistocene	Keyser 1972
Namaqualand	75-90	Basal Pleistocene	Carrington & Kensley 1969

* Cited by Nunn 1984.

sea level of -55 m was deduced by Orme (1976) for the incision of the now submerged extensions of Natal estuaries. These lower sea levels (many more examples could have been cited) with which the -23 m and -50 m indications on Gough Island may well correlate, have generally been ascribed to the last glacial period (e.g. Orme 1976). The -23 m bevel may, however, be Early Holocene.

During periods of low sea level the streams on the island must have been rejuvenated and there is no need to postulate uplift (Heaney & Holdgate 1957).

River terraces and alluvial fans as indicators of Late Pleistocene and Holocene climatic changes

The Glen

The mouth of The Glen, only some 50 m wide between near-vertical cliffs, is blocked by a contemporary beach wall of well-rounded boulders and pebbles with some very large angular blocks. From the nature of the boulder-filled bed of the river near the mouth, it is evident that the stream had, in the past, adjusted to a lower sea level than at present. It is now undersized and forced to meander around very steep fans issuing from similarly steep-sided valleys, which merge with gravel and boulders which choke the river bed. This fill is mostly angular and subangular, plus many very large angular blocks several metres in diameter. The fans consist of angular, unsorted debris, containing blocks more than a metre across - the predominant size being 0,4 - 0,5 m.

A good example of these fans was studied. It is about 200 m inland from The Glen mouth issuing from the second ravine on the north side (Fig. 2, locality 5). The fan is covered by dense plant growth, except where this has been destroyed by a colony of rockhoppers, resulting in the exposure of the underlying fanglomerate. No rock debris is being added to the fan under current climatic conditions. Subsequent to formation of the fan, the steepness of which rules out any significant solifluction processes during the last stages of its growth, a much wetter period led to channels being eroded between the sides of the fan and the near-vertical walls of the ravine. The eastern (sea side) channel must later have been abandoned in favour of the western. The latter is a 'mini ravine', about three metres wide and several metres deep. The waterflow must have been strong enough to remove a considerable amount of fan debris. This was also the period when the flow of The Glen River increased considerably and it dug its present 2,0-2,5 m deep channel into the boulder fill of its bed. Now the water flow in the 'mini ravine' is very much reduced and in a less steep part, behind a huge lava block, a flood plain has developed on which two meandering 0,3 and 0,1 m wide channels are maintained.

It is concluded that a progressively colder and drier climate led to the choking of The Glen valley with angular debris, including large blocks. Eventually lateral transport ceased along the then channelless flood plain, and frost-shattered rock fragments accumulated in fans which slowly built up across the fill of the main valley. Subsequently, debris production ceased and strong water flow resumed, eroding deep channels into the fill of the main and side valleys. At present, water flow is very much reduced, but when the river is in full flood it inundates the previously built-up flood plain leaving vegetable matter, sand and fine gravel.

It is suggested that the frost-debris terrace and fan-formation period could well be coeval with the last glacial maximum that is generally considered to have peaked at *c.* 18 000 yr B.P. The subsequent period of much higher rainfall than the present, some 4 000 mm p.a., may well equate with the wet period that, from the evidence from palaeolakes in the northern Cape Province and Botswana, fell between about 13 000 and 17 000 yr B.P. (Kent & Gribnitz 1985).

The Gony Dale River system

The Gony Dale River enters the sea in a gravel and boulder-choked little bay, some 50 m wide, between high cliffs recessed for about 100 m inland. Two, two-metre-high waterfalls mark where the river drops into the bay out of a six-metre-wide gorge, the exit of which is blocked by a huge angular rock that forced the river to cut a narrow passage round it. Upstream of the gorge, the main waterfall on the river (*c.* 15 m high) has formed a small amphitheatre into which the Water Supply Creek also drops. Above the waterfall the main stream runs for about 100 m in a narrow gorge, over a bed of trachyte, with only a few boulders and some gravel in deeper water on the side. The bedrock is full of pot-holes and remnants of pot-holes, and the sides of the gorge are marked by strong lateral scour.

Higher up, the Gony Dale River flows for the most part over exceptionally well-rounded pebble and boulder gravel, mixed with angular debris with blocks up to several metres in size. Similar material forms the bed of the Water Supply Creek (Fig. 4) all the way up to the inner edge of the 50-55 m terrace at the foothills of South Peak, save for a few places where lava is exposed. It is considered that the creek could not have produced such well-rounded clasts during such short transport. The rounded clasts cannot represent the unweathered cores of weathered-out lava blocks, for where rock is exposed in gullies and cliffs of the South

Peak range, it is solid and unweathered. Furthermore, the sides of the narrow gorge cut by the creek in the foothills are deeply weathered to soft clayey material, confirming the general impression that at present, and in the immediate past, the creek has had little erosive force. The well-rounded gravel and boulders in the river beds are readily distinguished from the blocky, angular debris that has been produced from the cliffs of the South Peak range by frost weathering, and it is concluded that the rounding is to be attributed to wave action at the time of the cutting of the 50-55 m terrace.

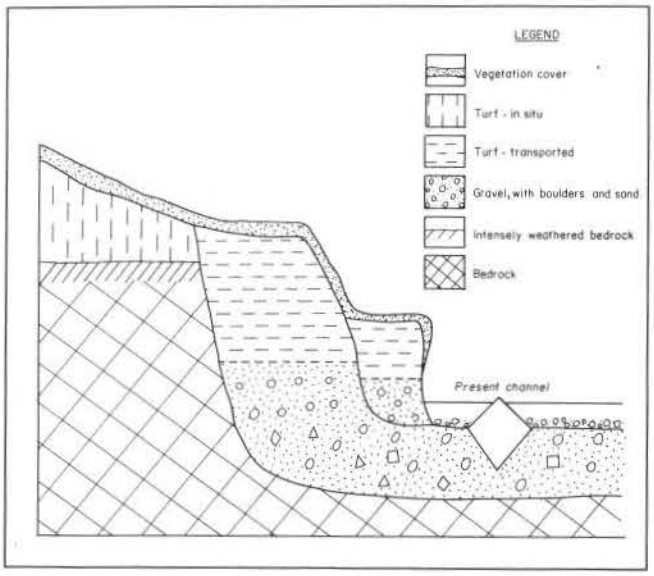

Fig. 4. Schematic section, east bank, Water Supply Creek illustrating cut-and-fill terraces.

As regards more recent events, the lower courses of both the Gony Dale River and the Water Supply Creek are flanked on both banks by two clearly defined cut-and-fill terraces (Fig. 4). The deposits on the higher terrace begin with a bed, generally over two metres thick, of sub-angular boulders, large angular blocks, and well-rounded gravel all embedded in sand. This bed, which is thougt to be coeval (e.g. *c* 18 000 yr B.P.) with the main channel fill and the fan formation in The Glen, is overlain by up to about half a metre of predominantly well-rounded gravel and sand. Thereafter, the often more than 10-m-wide channel accumulated up to four metres of transported, structureless black turf, locally mixed with sand and a few pebbles. This indicates that effective water transport must have almost completely ceased and the black turf blanketing the +55 m terrace was exposed to erosion - signalling a prolonged dry period.

Thereafter, renewed erosion in the Holocene dug a channel right down through the gravel to where large angular blocks and occasional protruding bedrock prevented further deepening. Limited lateral erosion ensued. Subsequently transporting power decreased and up to a metre of gravel and sand began to choke the channels. Then up to 1,5 m of transported black turf was deposited indicating a second, less prolonged, dry period. Finally, a renewed increase in precipitation led to the digging of the present channels and to the proliferation of the dense vegetation cover which prevents any noticeable erosion of the black turf. The high-water mark (plant debris caught in overhanging vegetation) after major storms shows that the surface of the lower terrace does get inundated, but no turf is at present being transported or deposited.

Save for the transported turf which, in The Glen, is largely absent as there are no turf-covered plains to supply the material, the sequences indicate the same rhythm in the two river systems - one of Upper Pleistocene and the other of Holocene age.

Note on underground drainage systems

As this paper deals with two of the principal components of the radial drainage of the island, it may be noted that there are also at least two underground drainage systems. A little west of Big Gulch on the west coast (Fig. 1), ground water issues strongly from the bottom of a thick sheet of lava and falls some 80 m down the cliff face into the sea. According to Captain Warren, Master of the *Tristania II*, who pointed it out, the fall, unlike the many other sea-cliff falls, has not been known to dry up. Another fall, issuing from a sea-cliff near West Point, is also a discharge of ground water but Captain Warren has known it to weaken and virtually dry up, presumably because its infiltration catchment is more restricted that that supplying the permanent waterfall.

Conclusions

1. The +3 to +4 m wave-cut bench is probably of Eemian age (*c*. 120 000 yr B.P.).
2. The +12 to +15 m bench is pre-Eem and, with the +30 m, dates back to the Middle Pleistocene.
3. The +55 m terrace, which is shown to be represented around the South and central Atlantic, is probably late Early Pleistocene. Judging by the severe weathering of the gravel and boulders lying on it, the +75 m terrace is appreciably older.
4. The lower stands of the sea at -23 m and -50 m are correlated with the last (Würm/Weichselian) glaciation.
5. The progressively colder and drier climate during the last glacial maximum (centered around 18 000 yr B.P.) led to the choking of the channels of the Gony Dale and The Glen river systems with frost-riven debris in the lower reaches of the Gony Dale mixed with an element of gravel of the +55 m marine terrace. Then followed a period of much higher rainfall than at present.
6. A dry period during the Holocene, marked in the Gony Dale River catchment by deposition of small-size gravel capped by transported turf, was followed by downcutting during the ensuing and still prevailing wetter period.
7. No features due to glaciation were observed.

Recommendations

It is hoped that the work reported here, based on a stay of only three weeks will be followed up by others. Levelling to determine more accurately the elevations of the benches and terraces is desirable, as are studies of other rivers and of the now-submerged erosional features. Detailed geological mapping of the island, supplemented by further radiometric age determinations, especially of the lavas underlying the +55 m terrace is warranted.

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