TEN YEARS OF SOUTH AFRICAN ANTARCTIC EARTH SCIENCE:

SOLID EARTH GEOPHYSICS, OCEANOGRAPHY AND GLACIOLOGY

Introduction

South Africa commenced research in the earth sciences some two years after the close of the International Geophysical Year. Since then, a continuous programme of exploration in the fields of geology, glaciology, solid earth geophysics, and oceanography, and a station observatory programme in seismology have been maintained in the sector longitude 1°W to 6°30′W, latitude 69°S to 74°12′S (fig. 1). The area investigated constitutes part of the Queen Maud Land region of East Antarctica and includes the King Haakon VII Sea, the Fimbul Ice Shelf, the ice-covered mountains of the Ahlmannryggen and Borgmassivet occurring inland from the Princess Martha Coast, and the Kirwanveggen, an escarpment along the edge of the Polar Plateau.

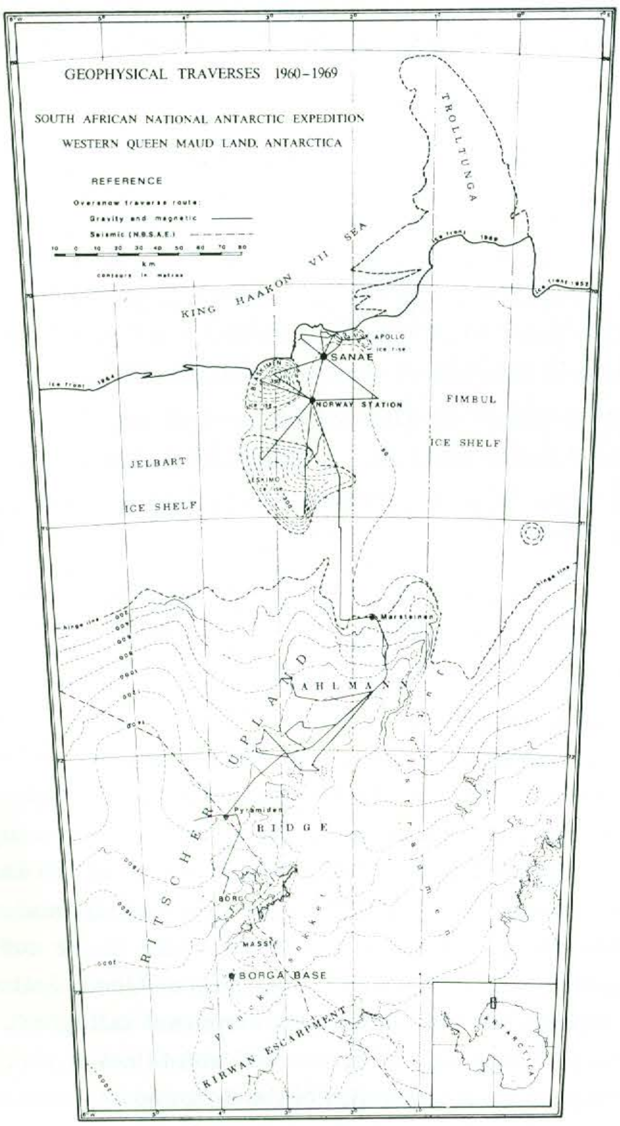

Fig. 1. Map showing routes of oversnow traverse parties and site of Borga Base, Ahlmann Ridge (reproduced from TSO Misc. 4554, Trigonometrical Survey, Pretoria).

(a) *Programme organization*

The Earth Science Programme, as an integral part of the South African National Antarctic Research Programme, is administered by the Geological Survey of the Department of Mines on the advice of the South African Scientific Committee for Antarctic Research (SASCAR). Its long-term objectives have been formulated within the limitations of available logistic support which is provided by the Department of Transport, in accordance with the recommendations of SCAR, the Scientific Committee for Antarctic Research set up during the IGY by the International Council of Scientific Unions (ICSU).

Following an initial period of largely unco-ordinated research, in which various organizations were involved, the Earth Science Programme was re-organized on a permanent basis when an Antarctic Section was established within the Geological Survey. The Chief Geologist of this Section was designated Programme Director and was responsible for the formulation of long-term objectives, direction of field programmes and supervision of data processing. Expedition geologists are attached to the Antarctic Section for contract periods, of approximately $1\frac{1}{2}$ years, comprising 3 to 4 months of pre-expedition training at the Geological Survey in Pretoria, and 13 to 14 months wintering in Antarctica followed by a post-expedition data-processing period of 3 to 12 months. A total of 195 Earch Science Programme reports have been completed during the period under review; most of the data have been published, or are in the press.

(b) *Logistics*

During the first two years, oversnow expeditions were staged from the Norwegian IGY base, Norway Station, and thereafter from the main South African base, Sanae (70°18,5'S, 2°21,5'W), which is about 21 km to the north-east (fig. 1. See also Bulletin No. 29, 1969, pp 62-63). Both these bases are more than 120 km from the nearest rock outcrop and as exploration proceeded further inland, increased support missions over severely crevassed regions were required to establish and maintain supply depots at strategic points in and en route to the mountain areas. It soon became evident that, in spite of the provision of additional tractor support, the method of pre- and post-winter field seasons using Sanae as wintering base greatly reduced the time available for field work during the short summer season. During 1966 the establishment of a subsidiary 4-6 man inland wintering base was therefore proposed in order to extend the scope of exploration activities. This led to the establishment in 1969 of Borga Base (72°58'S, 3°48'W) some 350 km south of Sanae (fig. 1).

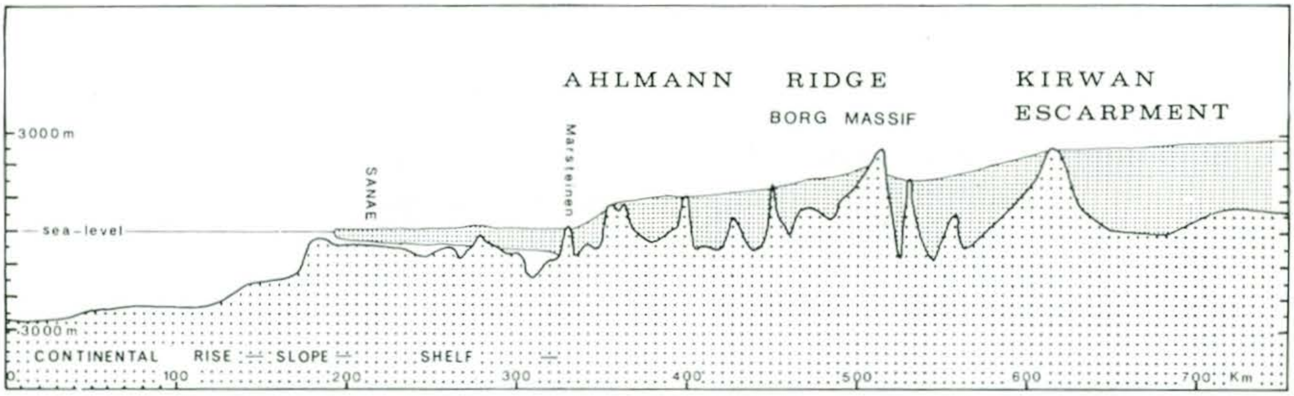

Fig. 2. Composite section along 2°W longitude across the outer edge of the Antarctic Continent and its continental terrace off Princess Martha Coast, Queen Maud Land (reproduced from Neethling 1970).

SUBMARINE AND SUBGLACIAL MORPHOLOGY OF THE PRINCESS MARTHA COAST

A geophysical-glaciological observation programme, supplemented by late winter/autumn ice-shelf traverses, was programmed for both the geological and the support field parties in order to explore the submarine and subglacial features below the ice-shelf and ice-sheet.

The initial reconnaissance, with Sanae as the starting point, embraced more than 800 traverse-kilometres in the period 1962-1968 (fig. 1). Observations of relative gravity, and of vertical and total magnetic field variations were made at more than 360 field stations spaced approximately 3 km apart.

In general it was observed that subglacial rock elevations existing on the continental shelf approximates the east-north-easterly trend of the edge of the continental slope and other prominent lineaments in the Ahlmannryggen.

After the establishment of Borga Base in 1969, the potential range of the traverse operations was greatly extended. The main project planned for this stage is a 2 000 km return traverse to the northernmost turning point of the United States South Pole. This traverse, which should have commenced during 1971, has now, due to logistic considerations, been rescheduled for the summer of 1973/74. The return route has been planned to intersect a Soviet plateau traverse made during 1968. Traverse observations will include radio echo sounding, gravity, magnetics (all elements), astronomical observations for position fixing, glaciological observations, ice flow studies, and collection of snow samples for stable isotope determinations. Major traverse stations will be spaced 80 km apart, with minor ones every 8 km.

Marine Surveys

Oceanographic surveys and observations were made in the King Haakon VII Sea, one of the several marginal seas of the Atlantic-Indian-Antarctic Basin. During 1964, the *R.S.A.* conducted a radar survey of 370 km of ice front from 0° to 5°W. The survey was repeated in 1969 and significant changes were found in the configuration of the ice front. According to United States ESSA satellite photographs, the event is of cartographic and glaciological significance and constitutes a major change in the configuration of the Antarctic ice coastline in these latitudes.

The approaches to the Fimbul Ice Shelf West of 0° have been charted and Bathymetric maps prepared which outline the significant geomorphological submarine and subglacial features of the continental terrace of this part of Antarctica.

Measurements of ocean tidal variations have been made from a substation close to the ice front, and an average peak to peak movement of 0,70 to 1,65 m found. Bottom sediment samples were dredged inshore from the ice front. The dredged deposits comprised mainly poorly-sorted, angular to rounded, sand-sized to pebble-sized, mafic and sedimentary rocks. The bottom sediments represent ice-rafted material transported by floating ice from a source similar to that in the Ahlmannryggen some 150 km to the south.

Pack Ice

The northern limit of pack ice in the South Atlantic between Africa and Queen Maud Land oscillates from latitudes south of Bouvet (56°S) during winter to the King Haakon VII Sea (69°S) during summer. The most sever ice conditions were encountered during the *R.S.A.*'s return journey of her maiden voyage in late summer of 1962. During this time, the *R.S.A.* was beset for more than 5 weeks in close pack only 150 km from Sanae. On the 39th day, while on a steady drift towards the Weddell Sea, she broke loose at 5°W, 68°S and completed the 2 400 km journey to Cape Town in only 12 days.

In the King Haakon VII Sea pack ice usually forms during autumn and breaks up in early spring when dense clouds of frost smoke and ever-widening leads appear as south-easterly winds break the hold of the pack on the ice shelf. The westerly coastal current disperses the floes and ice fragments, and on occasions the region to the west of Trolltunga becomes a polynya with a lead of open water extending from the ice front to the southern limit of close pack beyond the northern horizon. Narrow bands of shore and bay ice usually remain in the more sheltered bukten (bays) in the ice front, to be removed later in summer or, in exceptional cases, to remain intact for several seasons. Large tabular icebergs on their westerly drift towards the Weddell Sea often crash spectacular ice-strewn paths through the pack to collide with the front of the Fimbul Ice Shelf. Icebergs also run aground in shallow water to the north of Blaskimen and Apollo Ice Rises, where they remain for several seasons. During 1968 more than a hundred tabulars, many of them no doubt resulting from the fragmentation of the Trolltunga ice tongue, were reported offshore from Otterbukta.

The Continental Terrace

Figure 2 shows some of the more significant features of the submarine and subglacial morphology that have been determined. These include, a stepped continental rise, which laps onto the foot of the continental slope at a depth of 2 000 m. The continental slope forms the main transition between the continental and oceanic depths. It also defines the edge of the continent and has a break away point at a depth of 400 to 600 m.

The continental shelf is typical of shelves off glaciated regions. There is great diversity of relief. Figure 2 shows clearly where the Fimbul Ice Shelf is grounded to form the Eskimo, Blaskimen and Apollo Ice Rises shown in figure 1.

The origin of the continental shelf off Princess Martha Coast appears to be of the fissured type, i.e. of tectonic origin, formed mainly by block movements.

The Mainland

Subglacial rock elevations indicate a dissected land surface below the ice sheet, with deep ice-filled fjord-like valleys extending for some considerable distances inland. The steep subglacial terrain accentuates to an even greater extent the predominant north-north-easterly lineaments displayed by the surface topography. It delineates Ahlmannryggen as one of the most prominent geographical divides of Queen Maud Land, and Kirwanveggen as a prominent mountain range transecting the divide to the south, and it emphasizes the deep valley of the Pencksokket-Jutulstraumen as a significant negative feature separating regions of contrasting geomorphology and geology.

GLACIOLOGY OF THE WESTERN PART OF THE FIMBUL ICE SHELF

Glaciological research by South African Antarctic Expeditions also constitutes a part-time project associated with the main geological and traverse geophysical investigations. It has, however, been programmed along the lines recommended by the SCAR Working Group on Glaciology within the limitations set by available logistic support and opportunity. Most of the observations were made during the Antarctic winter when the geologists were confined to base. Continuity of surface snow accumulation measurements was provided for by other members of the Expeditions during the absence of the geologists.

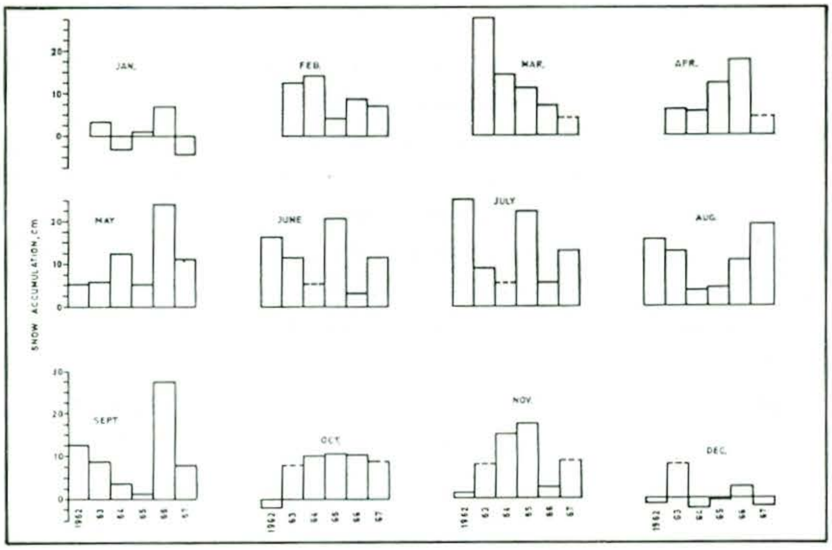

Fig. 3. Variation of monthly snow accumulation determined from small-area, high-frequency network, Sanae, 1962-1967.

Base and traverse glaciological studies were made on the Fimbul Ice Shelf in the vicinity of past and present wintering bases, across nearby ice rises and along the main traverse routes onto the island ice (fig. 1). The mass balance studies commenced at Norway Station (70°30′S, 02°32′W) by the Norwegian IGY expedition were continued by the 1st and 2nd South African Expeditions until 1961. Observations were thereafter extended to Sanae, where they were incorporated in a long-term glaciological project initiated by the 3rd Expedition in 1962. Local projects included a 57-year stratigraphic profile, snow settling studies, density and grain-size profiles, and a study of the variation of tidal movement on a floating ice shelf. Expedition surveyors also observed the absolute movement and strain as well as the changes in elevation of the ice shelf. Additional observations along a 350 km oversnow traverse from Sanae to Borgmassivet (fig. 1) have included the measurements of ice thickness, sampling of snow and ice for isotope ($0^{16}/0^{18}$) determinations; 10-m snow temperatures; and stratigraphic and density profiles utilizing rammsonde soundings, SIPRE-cores and pit observations. Traverse stations were spaced 3 to 9 km apart.

Stake Measurements

The mean annual rate of accumulation of surface snow during the period 1963-1967 around Sanae was 43,9 g $cm^{-2} yr^{-1}$.

Seasonal Variation

The mean variation in monthly snow accumulation indicates that there is a period of ablation during December, a distinct accumulation low during January, and periods of peak accumulation during March, June and July. Although the snowfall during all other months appears to be evenly distributed, there are individual months, from one year to another, when there are large variations in precipitation (fig. 3).

Stratigraphic Observations

The variation in snow accumulation during the period 1912-1960 was established from the interpretation of firm stratigraphy and density measurements made in a 32 m deep composite pit and SIPRE-core profile at Sanae. A temporal variability of 7,4 g cm^{-2} yr^{-1} was found. The mean annual accumulation as worked out by this method is about 11 to 17 per cent lower than those obtained by stake measurements. A long-term increase in snow accumulation was found for the last 50 years, with an eleven-cycle variation reaching a low in 1951 and a high in the early 1960's. A remarkably close agreement was found in mean annual accumulation on the Fimbul and Maudheim Ice Shelves. However, values for Norway Station show a consistantly higher rate than Sanae. A marked difference in wind distribution has also been observed at these two stations, which are a mere 21 km apart. Southerly winds, which are usually associated with snow accumulation have a higher mean velocity and are twice as frequent at Sanae as at Norway Station, whereas westerly winds are six times as frequent at Norway Station. These wind regimes could be the cause of the higher precipitation observed at Norway Station. The relationship between climatology and accumulation has since been investigated and reported in the literature.

Ice Flow Movements

Repeated measurements of movement of the Fimbul Ice Shelf indicated a rate as slow as 30 m yr^{-1}. The predominant direction of movement of the ice shelf itself in the Sanae region is north-north-west. In the hinge area the movement is 62 m yr^{-1}.

SEISMOLOGY: USCGS STATION SNA

The unique position of Antarctica, in the centre of an oceanic hemisphere open to most of the world's belts of seismic activity, means that the seismological stations there can receive earthquake surface and body waves from all directions and distances, as there are no intervening continents to affect either travel times or signal amplitudes. The Antarctic continent itself, mainly as a result of the weighting-down effect of the more than 30 million km^3 ice cap, is essentially an aseismic region with only weak shocks occurring in the coastal zone. In contrast, the circum-Antarctic oceanic region is one of the most active seismic zones on earth.

Sanae Observatory

Instrumentation

A standardized seismograph was installed at Sanae during mid-summer of 1963/64 by personnel of the U.S. Coast and Geodetic Survey (USCGS), and code-named Station SNA in their world-wide seismograph network. The seismograph is a short-period Benioff variable reluctance model, equipped with a 3-drum recorder which allows continuous and simultaneous recording of the vertical, N-S and E-W components of ground displacement.

Preliminary times and phases of stocks are measured at Sanae and then forwarded by telex to USCGS, Washington D.C., via the Geological Survey, Pretoria, which is in technical control of the observatory. Epicentral loci, origin times, focal depths and magnitude determinations are then published in USCGS bulletins and data sheets.

Location

The location of the Sanae observatory is significant in that it is situated a mere 25 km inshore from the breakaway point of the continental shelf. The vault itself is located approximately 450 m above the surface of the continental shelf and in the upper 10 metres of a 350 m thick floating section of the Fimbul Ice Shelf. This siting of the observatory on a floating ice shelf was determined more by logistic than by seismological considerations, the nearest rock outcrop for a more suitable site being more than 120 km distant from Sanae. Although a variety of foreseeable operational problems arose from this unstable foundation, successful recording of short period waves at a magnification of 50 000 has been feasible. Experimental recording of long-period waves at a magnification of 10 was also achieved but this has since been discontinued and the system dismantled. Microseismic activity is intense during summer, particularly during periods of bad weather when open coastal leads prevail a mere 15 km distant from the observatory. In addition, continuous tilting of the seismometers, which are placed directly on individual base plates on a low-density snow floor, has also made frequent and time-consuming relevelling adjustments necessary. Arching of the snow floor has also contributed to this rapid drift in level.

Seismicity

Although the station was inactive for the larger part of 1969, due to technical difficulties, it recorded more than 1 180 shocks during the period 1965-68. Among the major earthquakes recorded at Sanae was the disastrous Alaskan earthquake of 1966. Operation Long Shot, the nuclear explosion during October, 1965, was also recorded. However, most of the other earthquakes originated in the South Atlantic, particularly in the regions of Bouvet Island (54°26′S, 3°24′E). This ice-capped island at the southernmost end of the Mid-Atlantic Ridge comprises the uppermost 800 m of an immense volcano rising more than 5 000 m above the ocean floor. From the distribution of earthquake epicentres in its vicinity, Bouvet Island appears to be located in a particularly active region which, according to USCGS data, shows a number of shocks varying in magnitude from 4,7 to 6 (Richter Scale) per year. The region is considered to represent a juncture of major tectonic features in the earth's crust, and is therefore of considerable interest in problems of sea-floor spreading, plate tectonics and continental drift.

SOURCE

South African Journal of Antarctic Research, No. 2, pp 2-15, 1972; South African Antarctic Earth Science Programme 1959-1969; Solid Earth Geophysics, Oceanography and Glaciology, by D. Neethling, Programme Director, 1965-1970.