Conference report

**RRS Shackleton in the Indian and south Atlantic oceans**

D. S. CRONAN

**RRS Shackleton** undertook one of the longest voyages of her career between October 1974 and July 1976. After leaving England, she worked in the equatorial and south Atlantic, prior to rounding the Cape of Good Hope into the Indian Ocean, and then went down to work in the Antarctic. Finally, she undertook some work in the eastern Pacific, before returning home through the Panama Canal. These cruises were not without their moments of excitement, such as the attempted arrest off the Falkland Islands by an Argentinian destroyer. Most of the time, however, **Shackleton** carried out routine work and collected a great deal of valuable material which is being worked on at various centres throughout the country.

The largest single part of **Shackleton**'s voyage was spent in the western Indian Ocean, where she undertook a number of 20–26 day cruises. This region is one which has been visited in the past by British research vessels, most notably by **RRS Discovery** in 1963 and 1967. Some of the work planned for **Shackleton** was to follow up studies made on these two cruises, but the greater part of her work was on the investigation of new problems.

After working with Dr Calvert's group off SW Africa, **Shackleton** sailed for the Gulf of Aden, where the first of the Indian Ocean geophysical cruises, that with Dr Girdler's group, was undertaken. This was followed by geophysical work in the Gulf of Oman, with Dr Matthews' group, and in the northern Arabian Sea, with Dr Whitmarsh's group. Whereas the first half of **Shackleton**'s Indian Ocean work was concerned mainly with geophysics, the second part was devoted principally to geochemical investigations. Following maintenance in Bombay, she sailed to the Carlsberg Ridge and Somali Basin, with the writer's group, to work on manganese nodules and metalliferous sediments. This was followed by work with Dr Chester's group on sediments from the equatorial Central Indian Ocean Ridge and, finally, with Dr Elderfield's group, on sediments from the southern part of the Central Indian Ocean Ridge.

**Shackleton**'s Indian Ocean Cruises represent one of the longest and most comprehensive marine geological programmes that British universities have undertaken. The Marine Studies Group felt that a meeting about one year after the termination of the cruises would provide an ideal opportunity for participants to present their findings and discuss how work resulting from the cruises might best proceed.

*Report of a Marine Studies Group meeting, held in Burlington House, 20 October, 1976.*

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Dredged rocks from seamounts in the northwestern Indian Ocean R. G. Pritchard

The samples examined were dredged from seamounts north of the Seychelles. These seamounts rise from the sea bed at about 5000 m to within about 1000 m of the surface. The samples from dredge haul 1320 were composed of corals encrusted with a mixture of manganese-iron oxyhydroxides and phosphorite. Samples of other dredge hauls (1321, 1323, 1325) also showed some correlation of Ca and P from core to rim indicating possible phosphorite deposits on the outer rims. Phosphorite was confirmed by X.R.D. Major element analysis by X.R.F. using fusion beads, was used to study the variation from core to rim. The most marked changes were the decrease in K₂O and the increase in total Fe₂O₃ with respect to percentage H₂O. If lava cooling and sea water interaction is accepted these rocks must be in the early stages of alteration, the glassy rims being less altered than the interiors. Major elements indicated that the rocks were the product of off-axis volcanism, having much higher Fe/Fe + Mg to TiO₂, SiO₂ and Al₂O₃ ratios than ridge basalts. Study of the vesicle linings by microprobe and X.R.D. showed the ubiquitous clear crystal lining to be a high K-phillipsite but other material in the vesicles has not been definitely identified; possibilities are clay and/or sulphide minerals.

Preliminary observations on ferromanganese oxide deposits from the northwestern Indian Ocean S. A. Moorby & D. S. Cronan

During the course of cruise number 5 of RRS Shackleton's Indian Ocean Expedition in 1975, dredging and coring operations were carried out at various sites on the Carlsberg Ridge and in the Somali Basin. Samples of ferromanganese oxides were recovered from 14 sites. The morphology of the samples was generally very variable. Occasionally, dredge hauls from closely adjacent sites contained samples of different morphology. Morphologically different samples generally differed significantly in chemical composition.

Mn concentrations average about 15 per cent in the deposits. This is very close to the average concentration of Mn in samples from seamounts in other areas of the Indian Ocean. The average concentrations of iron in both Somali Basin samples and samples from the Carlsberg Ridge are similar at 19.4 per cent Fe, which is well above the average Fe concentration of Indian Ocean ferromanganese oxides, but which compares well with Fe values in samples from seamounts and ridges in other parts of the Indian Ocean. Cobalt values in the samples analysed are generally quite high, but values vary quite markedly, even over very small distances. Nickel values are much less variable, especially over small distances. However, Ni values are generally lower than average Indian Ocean Ni concentrations. Copper tends to show a similar pattern to Ni, being enriched in Ni-rich samples, but is much more variable than Ni showing as much as a 3-fold variation even in samples from the same dredge haul. Zinc tends to follow Ni and Pb tends to follow Co. However, both Zn and Pb show much lower overall variations than the elements with which they correlate.

Mineralogically, all the samples analysed consisted largely of α-MnO₂. One sample also contained todorokite. The apparent lack of mineralogical variation means that mineralogy alone does not appear satisfactorily to explain the variation in trace metal concentration in the samples analysed. A full explanation will have to await more detailed chemical and mineralogical work on these samples.

A geophysical study of the western Gulf of Aden R. W. Girdler & P. Styles

During legs 2 and 3 of Cruise 2 of the RRS Shackleton (1975) 16 total intensity magnetic profiles were obtained in the western Gulf of Aden along the direction N.32°21'2° and about 10 km apart. Interpretation of these reveals that there was an early phase of sea floor spreading during the Oligocene followed by a quiet interval, followed by a further phase of spreading over the last 5 million years. The last spreading phase occurred in a different place and in a different direction from the first.

Plate subduction and sediment deformation in the Gulf of Oman R. S. White

The northern Gulf of Oman, off the Makran coast of Iran and Pakistan is an area of compressive sediment deformation resulting from
the northward consumption of the Arabian plate beneath the Eurasian plate. A series of reflection profiles across the Makran continental margin obtained on Leg 3 of the cruise of RRS *Shackleton* in 1976 clearly delineate a sequence of ridges and basins aligned parallel to the coast. Present-day folding appears to be concentrated in the southernmost of these ridges. This frontal fold varies in height along strike from a few metres to over 700 m. The basins between the folds are filled with later-derived sediment which increases in thickness towards the coast until the ridges are completely buried. Consistent back-tilting of the sediment surface in the interfold basins suggests the presence of active northward-dipping thrust faults within the offshore Makran fold belt.

Within the undisturbed abyssal plain to the south of the folded zone the continuous seismic reflection profiles show a prominent horizon which divides the uppermost 3.5 km of flat-bedded strata from sediment layers below which dip gently northwards. The deepest observable reflector is seen as a series of diffraction hyperbolae which dip conformably to the north at about 1° over 4 secs two-way travel time into the sediment. Compressional wave velocities obtained from variable angle reflection and refraction stations indicate that the material lying above the basement has a low velocity and therefore is probably all sedimentary. The material directly below the basement reflector has a P-wave velocity of 4.5 ± 0.2 km secs and is probably volcanic in origin.

**The origin of montmorillonite in some equatorial Indian Ocean ridge sediments**

R. Chester, J. M. Hirst & L. R. Johnson

During 1975 RRS *Shackleton* Indian Ocean Expedition, sediments were collected on two equatorial mid-ocean ridge profiles; one to the north and one to the south of the Vema Trench. A series of soil-sized oceans dusts and a number of surface sea water particulates were also collected.

The collection programme was designed to yield a suite of trans-ridge sediments for detailed geochemical and mineralogical studies. Here, some preliminary data are presented on the clay mineralogy of the <2 μm carbonate-free fractions of the sediments, dusts and surface sea water particulates. The concentrations of the four principal clay minerals, illite, montmorillonite, and (kaolinite + chlorite) were determined by an X-ray technique, and are expressed in terms of a total <2 μm clay sample; i.e. \( I + M + K + C = 100 \) per cent.

The average concentrations of the clay minerals in the top portions of the sediments from the two traverses are: illite, ~23 per cent, montmorillonite ~40 per cent (kaolinite + chlorite) ~37 per cent. In both traverses montmorillonite is the predominant clay mineral and there is some evidence that its concentration increases towards the crestal portions of the ridge.

In contrast to the sediments, illite is the predominant clay mineral in both the soil-sized dusts and the surface sea water particulates from this region of the Indian Ocean. On average, the dusts contain ~63 per cent illite and ~5 per cent montmorillonite, and the sea water particulates ~43 per cent illite and ~14 per cent montmorillonite. Clearly, there is considerably less montmorillonite in the dusts and sea water particulates than in the underlying deep-sea sediments, indicating that a larger proportion of this mineral in the sediments does not have a source on the surrounding land areas. The most probable origin of the 'excess' montmorillonite in the ridge sediments is the in situ alteration of volcanic material on the ocean floor.

**Geochemistry and mineralogy of Mid-Indian Ocean ridge sediments**

J. M. Mcarthur

Sediments collected during the RRS *Shackleton* Cruise 8/75 from the Marie Celeste fracture zone and on and near the Mid-Indian Ocean Ridge (17-20°S, 58-69°E) range in type from siliceous lutite of moderate to low carbonate content, to calcilutile, to siliceous ooze overlain by 1 x 0 em of red clay.

The coarse fraction (>10 μm) mineralogy comprises pyroxene, olivine, rutile, plagioclase (labradorite/andesine) with rare quartz and varying quantities of black, poorly-vesiculated basaltic glass fragments containing vesicles, black, highly vesiculated volcanic ash and sparse brown vesiculated basaltic glass (R.I. ≈ 1.60). Phillipsite crystals and crystal aggregates occur in the lower, reworked, section of one core. In all carbonate cores so far studied there occurs a 4-5 cm layer of clear acidic volcanic glass (R.I. ≈ 1.50) at depths between 35 and 62 cm. This glass constitutes less than
2 per cent of the total sediment and may be derived from Indonesia, whereas the most probable source of the volcanic ash and brown glass is Reunion.

The fine-fraction mineralogy comprises smectite, chlorite, mica, kaolinite, and clastic plagioclase. Smectite appears to increase in abundance towards the ridge crest, and with depth within the sedimentary column, and appears associated with phillipsite, suggesting a possible link with basaltic glass alteration.

Sedimentation rates have been determined on three cores by radiocarbon dating of one of the cores and lateral correlation using the acidic glass horizon. Accumulation rates for Si, Al, Ti, Fe, and Mn, calculated via chemical analysis, are comparable with the lower rates of element accumulations recorded for normal pelagic sedimentation. These findings conflict with the conclusions of previous workers who proposed, on the basis of the indirect evidence of metal/aluminium ratios, that sediments from this area are metalliferous. The present findings indicate that such ratios must be used with caution when discussing excess metals in the marine environment.

**Geochemistry of the sediments on the Namibian continental shelf** S. E. Calvert

The Recent sediments off Namibia (South West Africa), accumulating on a wide and deep shelf platform beneath the highly productive Benguela current, comprise three facies: organic-rich, diatomaceous muds on the inner shelf off Walvis Bay; gravelly and shelly sands on the inner shelf in the northern and southern parts of the area; highly calcereous sands and muds on the central and outer shelf.

The organic-rich muds represent the only Holocene sediment in the area. They are anoxic, contain relatively high concentrations of trace metals together with abundant fish debris and phosphorite. The trace-metal concentrations correlate significantly with the organic-carbon contents, a relationship used previously to argue for the association of metals with organic material in many other sediments. Direct determinations of the metal concentrations of extracted organic fractions from the Namibian sediments have shown that the metals are associated to some extent with the humic and kerogen fractions and also possibly with pyrite.

The phosphorite occurs as unconsolidated laminae and lenses, as friable and cemented concretions and as black ovoid pellets. Uranium disequilibrium dating of the phosphorites shows that only the unconsolidated material is modern, with a $^{34}U/^{238}U$ ratio of 1.16, similar to that in sea water and in the bulk sediment. The other forms of phosphorite have evidently been reworked from older sediment into the modern muds possibly during the Pleistocene periods of fluctuating sea level.

In addition to the large uranium contents of the phosphorites, the reducing sediments also contain relatively high concentrations of this element, emphasizing the importance of anoxic sediments in areas of high organic production as the major sink for uranium in the ocean.