… 1. THORIUM, URANIUM AND POTASSIUM CONCENTRATIONS* IN CRYSTALLINE ROCKS OF NEW QUEBEC, CANADA

	Area shown on Fig. 1	Th (p.p.m.)	U (p.p.m.)	K (per cent)	Th/U
…granulite	2	9·8	0·4	2·1	24·5
	4	5·7	0·6	1·8	9·5
	5	4·2	0·5	1·4	8·4
	6	4·1	0·6	1·6	6·8
	8	5·8	0·7	2·1	8·3
	12	8·7	0·8	2·9	10·9
	15	10·7	1·3	2·2	8·2
…Th, U and K …of hornblende …facies of New …*		7·1	0·8	2·1	8·9
…facies	1	10·1	0·9	2·3	11·2
	2	6·6	0·8	2·0	8·2
	3	6·1	0·6	1·6	10·1
	4	7·4	0·9	2·0	8·2
	5	6·3	0·9	2·3	7·0
	6	11·6	0·9	2·1	12·9
	7	11·8	1·4	2·7	8·4
	8	12·3	1·1	2·4	11·2
	9	13·0	1·2	2·9	10·8
	10	10·1	1·1	2·9	9·2
	11	12·9	1·2	2·0	10·8
	12	9·0	1·0	2·7	9·0
	13	4·8	1·0	2·2	4·8
	14	9·2	1·8	2·3	5·1
	15	9·2	2·3	2·8	4·0
…Th, U and K …of amphi… facies of New …*		9·6	1·3	2·4	7·4
…Th, U and K …of all the … of the sample …*		9·2	1·1	2·3	8·4
…tration in …ites (ref. 5)		0·04	0·014	0·086	2·9
…tration in …ntal crust …)		9·6	2·7	2·09	3·6

* The weight of each of the composite samples the radioactive content of … was determined was 450 g. For a general description of the method … see ref. 7. The estimate of errors in individual determinations is as …: Th, ±0·3 p.p.m. or 5 per cent of the amount (whichever is larger); U, … p.p.m. or 5 per cent of the amount present (whichever is larger); K, ± … as metal for amounts greater than 1 per cent.

* Weighted according to the area represented by each analysis.

… in high grade metamorphic rocks to large fluctua… in uranium concentrations, with high ratios being …d to much lower than "normal" uranium content. … have suggested that because of the greater solubility … oxidized uranyl complex ion uranium is easier to … in metamorphic processes. The use of composite …ples in the present investigation undoubtedly irons out … effect of large local fluctuations of this type. There … remains a higher than "normal" overall Th/U ratio … this part of the Shield.

… Th/U ratios in the rocks of New Quebec are lower … general in rocks of amphibolite facies than in rocks of …ulite facies. Heier and Adams[4], who analysed a series … metamorphic rocks ranging from epidote amphibolite … granulite facies, found that if the lowest Th/U … from each metamorphic group are compared, the … ratios decrease with increasing grade of metamor… They concluded that the Th/U ratio may decrease … increasing metamorphism. Data from the present …gation do not appear to support this. We suggest … uranium is more strongly fractionated than thorium … high grade regional metamorphism.

… abundance of thorium in the rocks of New Quebec is …rkably close to the estimate of 9·6 p.p.m. which …r[5] has published for the abundance of this element … crust (Table 1). His estimated crustal average of … p.p.m. for uranium, however, is about twice the …ance in these rocks. Taylor's estimate is based on … and granite averages, but the granitic average …btedly contains a preponderance of analyses of … level magmatic granitic material with a uranium … much greater than that of deep crustal gneisses[6]. …ses such as the ones discussed here may have been …ndly metamorphosed more than once during the …ean. The mineral transformations which occurred … each episode would allow fractionation of elements … as uranium. In addition, such predominantly high … gneisses contain few silicate species with the capacity of incorporating foreign ions into their structures, so that a higher percentage of these ions would be in adsorbed positions from which they could easily be mobilized.

In generalizing about the significance of the chemical composition of the surface crystalline rocks of this area we are faced with one major question. Would most shield areas if eroded to moderate depths (say 5 miles) expose high grade gneisses similar to these? If this is an acceptable assumption, then the bulk of the continental crust is likely to have radioactive element abundances similar to the surface rocks of New Quebec.

We thank A. F. Gregory for helpful advice on this project.

Radiometric measurements made at Rice University were supported by a grant from the Robert A. Welch Foundation.

W. F. FAHRIG
K. E. EADE

Geological Survey of Canada.

J. A. S. ADAMS

Department of Geology,
Rice University,
Houston, Texas.

Received February 13, 1967.

[1] Eade, K. E., Fahrig, W. F., and Maxwell, J. A., *Nature*, 211, 1245 (1966).
[2] Richardson, K. A., and Adams, J. A. S., *Geol. Soc. Amer.*, annual meeting (abstract), 137*A* (1963).
[3] Heier, K. S., *Norsk. Geol. Tidsskr.*, 42, 143 (1962).
[4] Heier, K. S., and Adams, J. A. S., *Geochim. Cosmochim. Acta*, 29, 53 (1965).
[5] Taylor, S. R., *Geochim. Cosmochim. Acta*, 28, 1273 (1964).
[6] Whitfield, J. M., Rogers, J. J. W., and Adams, J. A. S., *Geochim. Cosmochim. Acta*, 17, 248 (1959).
[7] Adams, J. A. S., in *The Natural Radiation Environment* (Univ. Chicago Press).

276 3/95

Origin of Hot Brines in the Red Sea

THE hot, highly saline waters in a limited area at the bottom of the Central Red Sea have attracted much interest since they were reported by Swallow and Crease[1]. More recently, Miller *et al.*[2] have distinguished two deeps, separated by a distance of about 4 km (Fig. 1). The tem-

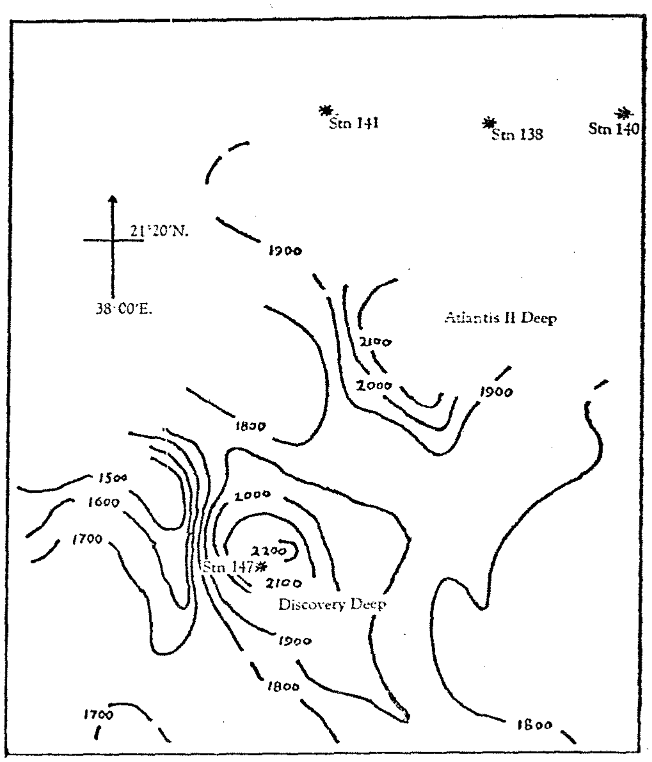

Fig. 1. Map showing station positions (after Swallow and Crease).

perature of the bottom brines in Discovery Deep was approximately 44° C, and that of the bottom brines in Atlantis II Deep was 56° C, though in both cases there are layers of water at intermediate temperatures overlying the hottest bottom water, and below the normal 22° C Red Sea bottom water.

The source of the heat is generally supposed to be geothermal, but it has not been established whether heating occurs gradually as a result of conduction of heat through the sediments to brines *in situ*, or whether a more catastrophic mechanism is involved. Recent measurements of fine temperature structure in the bottom brines of both deeps indicate that the latter mechanism is more probable.

Using a modified form of the Cambridge heat flow apparatus[3] detailed temperature gradients were measured in November 1966. Thermistors were used as the temperature sensitive elements, and position fixing relative to the bottom was achieved using a precision pinger. Relative accuracy of temperatures is ± 0·003° C in Discovery Deep, but less in Atlantis II Deep because of the adverse effects of 56° C temperatures on the electronics. Absolute accuracy is limited by the resistance of plugs in the circuitry, but is better than ± 0·2° C at these temperatures. Temperature gradients are recorded during the raising and lowering of the apparatus. In order to convert the pinger records to distance, it is necessary to know the velocity of sound in the bottom water. A velocity of 1,900 m/sec has been assumed, based on an extrapolation of Horton's formula[4]; the extrapolation is known to be good to ± 20 m/sec at 17° C and 25 per cent salinity by direct measurement in brine reservoirs (Bullard, E., personal communication) so that errors resulting from this uncertainty are probably less than 1 per cent.

The temperature profile for Discovery Deep (Fig. 2) (Stn. 147) shows a gradual decrease in temperature of 0·5° C n the bottom 60 m. This decrease was also observed by Swallow and Crease[1] but was only just measurable within the limits of their accuracy using pressure-corrected unprotected thermometers. The marked decrease in temperature between 76 and 83 m above the bottom suggests layering within the 44° C water. In contrast, the temperatures in Atlantis II Deep are constant to 0·01° C of 56·7° C to within 5 m of the bottom. This was confirmed by three lowerings (Stns. 138, 140, 141).

The colder water at the bottom of Discovery Deep implies that this water cannot have acquired its heat from below because such heating leads to vertical convection, and adiabatic temperature gradients. Atlantis II Deep water, however, is probably being heated in this way, causing almost uniform temperatures throughout the 56° C bottom layer. It appears that Atlantis II Deep water has overflowed into Discovery Deep at some time in the past. The layering at 80 m may be caused by overflowing on different occasions. If this is so, then not only is the source of the hot brines restricted to Atlantis II Deep, but a catastrophic mechanism, for example a submarine volcano, is indicated.

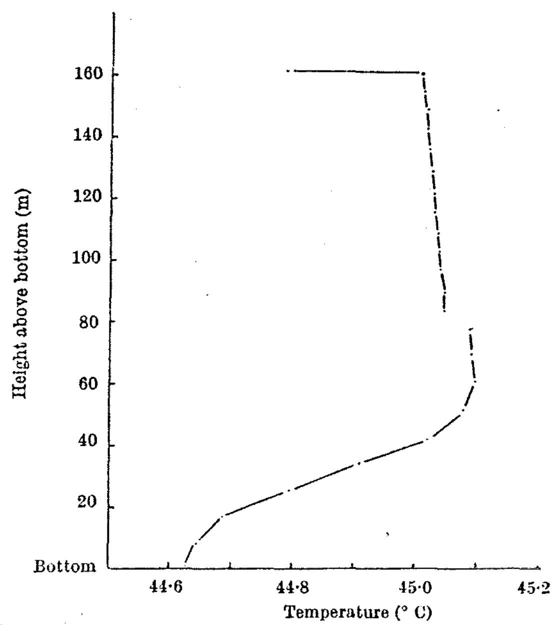

Fig. 2. Discovery Deep temperature profile.

I thank the scientists and crew of the R.V. Chain for help in making these measurements. The work was supported by the Natural Environment Research Council and Shell.

D. T. Pugh

Department of Geodesy and Geophysics,
University of Cambridge.

Received February 13, 1967.

1 Swallow, J. C., and Crease, J., *Nature*, 205, 165 (1965).
2 Miller, A. R., *et al.*, *Geochim. Cosmochim. Acta*, 30, 341 (1966).
3 Lister, C. R. B., *Geophys. J.*, 1, 571 (1963).
4 Horton, J. W., quoted by Vigoureux, P., and Hersey, J. B., in *The Sea* (edit. by Hill, M. N.), 1 (1963).

Unmetamorphosed Volcanic and Sedimentary Xenoliths in the Kimberlites of Sierra Leone

The dominant xenolith types in the kimberlites of the Sefadu area of eastern Sierra Leone are granite, amphibolite and amphibole-schist derived from the wall rocks. Eclogite and dunite xenoliths are only rarely encountered. Small inclusions of a suite of virtually unaltered volcanic rocks and derived sediments for which no counterpart is found in the mapped country rocks of the area are a feature of the kimberlite now exposed by mining at Koidu. I recently collected a series which included undeformed amygdaloidal basalt, clastic basaltic sandstone, fine-grained basic tuff, fragmental andesitic tuff and calcareous tuff. The kimberlites occur in granite emplaced in the Pre-Cambrian Kambui Schists, a strongly metamorphosed schist series of largely volcano-sedimentary parentage[1,2]. The unaltered xenolithic material in the kimberlites is most readily explained as being derived from an overlying sequence of volcanic and associated sedimentary rocks, now removed by erosion.

Approximately 100 miles west of the kimberlite area a series of essentially unmetamorphosed sedimentary rocks with volcanics, the Rokel River Series, outcrops in a long tongue which passes southwards into west central Sierra Leone from the Guinea border. The rocks occurring in the east of this belt, according to Allan[3], are mainly mudstones passing into thin-bedded sandstones and mudstones with thin conglomerate horizons. Laminated arkoses and feldspathic sandstones outcrop locally along the eastern margin where there is visible unconformity on the basement gneisses. In the west, demonstrable lavas and tuffs outcrop and are associated with grey mudstones, siltstones, subgreywackes and rare feldspathic greywackes. Nothing is known of the nature of the western limit of this series. The Rokel River Series is unconformably overlain in the north by the rocks of the Saionya Scarp Series. The precise age of the Rokel River Series is not known but the unconformable relationships indicate an age younger than the basement gneisses and older than the Saionya Scarp Series which, in its northern extension, has been ascribed a Cambro-Ordovician age by French geologists[4].

No precise correlation can be made, but it is possible that the volcano-sedimentary relics preserved as xenoliths in the Koidu kimberlite correspond to the Rokel