INTER-UNION COMMISSION ON GEODYNAMICS

# REPORT OF WORKING GROUP 4 MEETING IN ICELAND

16-20 July 1973

VOL. II

APPENDIX IV

Reviews and bibliographies submitted by WG 4 members
(partial list)

October 1973

NATIONAL ENERGY AUTHORITY

Reykjavík, Iceland

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## IV.2a Magmatic and Metamorphic Processes at Constructive Plate Margins

by I.G. Gass

Models concerning the magmatic and metamorphic processes active at constructive margins can be produced by correlating geophysical measurements at sea with the examination of dredged rocks and the study of rare terrestrial representatives of oceanic lithosphere such as the Troodos Massif, Cyprus, the Semail Complex, Oman and the Macquarie Island in the South Pacific.

Heat flow[1], seismic[2,3], magnetic[4,5], and petrographic[6,7] data suggest that the zone of eruption at oceanic ridge axes is very narrow, certainly less than 25 km, and probably less than 5 km; the formation of most oceanic crust must therefore be restricted to a narrow strip along ocean ridge (rise) axes.

Experimental evidence[8,9] indicates that spreading axis magmas equilibrate at low pressures in near surface storage reservoirs before eruption. It has therefore been postulated[10] that mantle material beneath spreading axes rises rapidly from 1-200 km depth along a narrow planar zone and that near the surface the liquid phase of a partly fused mantle separates from the solid refactories to form a discrete magma body.

As sea-floor spreading continues melts from this elongate chamber beneath the axes of oceanic ridges are extruded to form pillow lavas and injected as dykes. The magma in the storage chamber is continually being replenished as spreading and extrusion continue and the liquid left in the chamber crystallizes as it moves away from the axial zone of high heat flow. On cooling, crystallization occurs with the precipitation first of chromite and olivine and then of clinopyroxene and plagioclase. Thus, as spreading continues a layered plutonic sequence of basal dunites overlain, in turn, by peridotites, olivine gabbros, gabbros and finally trondjemites as formed[10,11,12,13].

The model for the oceanic lithosphere of:

| | | Thickness | Seismic layers |
|---|---|---|---|
| Sediments | | | 1 |
| Pillow Lavas | | 0.5 km | 2 |
| Sheeted Dyke Complex | | 1.0 km | 3 |
| Layered Plutonic Sequence | Trondjemites | 0.5-1.0 km | 3 |
| | Gabbros | | |
| | Olivine Gabbros | | |
| | Peridotites | | |
| | Dunites | | |
| Depleted mantle | | | 4 |

is not only in keeping with oceanographic geophysical and dredge sample evidence but is that found on terrestrial analogues of oceanic lithosphere such as the Troodos Massif, Cyprus[12,13,14,15], the Semail Complex, Oman[16] and Macquarie Island[17].

In many cases dredge specimens from oceanic rises have been metamorphosed to the greenschist or zeolite facies[18,19,20]. Recent studies on the Troodos Massif[21] and on ophiolite complexes elsewhere[22] strongly suggest that this metamorphic imprint is imposed upon the oceanic crust close to the spreading axis where the thermal gradient is in the order of 150-350°C $km^{-1}$. The metamorphic process envisaged is the downward movement of sea water from the ocean/ocean floor interface through the still hot sequence of pillow lavas and dykes. During their passage these waters empoverish the oceanic crust in light rare earths and transition metals which, when the waters come back to the surface of the oceanic crust, reacts with the ocean water to precipitate, in particular, the heavy metals[23]. Many of the massive cupriferous sulphid deposits associated with basic igneous terranes[24] are believed to have been formed in this way.


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## IV.2b Within-plate Magmatism and the Development of Transcontinental Rifting

by I.G. Gass

The corollary of plate tectonics is that some continents now separated by oceanic crust were once contiguous. This poses the question - why did the supercontinents split where they did when they did ?

In the plate tectonic model a lithospheric plate in a continental setting consists of some 35 km of sialic crust underlain by about twice that thickness of upper mantle[12]. The plate lies on top of the asthenosphere, which is here accepted as a zone of partial fusion of mantle peridotite, and the boundary between the two is thermally unstable.

The basic contention is that a continental plate some 100 km thick would not split unless it was first weakened in some way[3]. Significant attenuation of the lithosphere could only be produced by the upward movement of the lithosphere/asthenosphere boundary and this in turn necessitates elevation of the thermal gradient to allow upward pertubation of the asthenosphere. It has been suggested that when this happens there are two consequences:

1. An updoming of the Earth's surface to compensate for the downward movement of phase boundaries in an elevated thermal regieme[4].

2. The extensive production of magma which finds easy egress to the surface through profound fractures in the updomed brittle lithosphere.

A study of Mesozoic to Recent volcanism on the bevelled erosional peneplains of Africa has suggested that there were two major periods of magmatic activity; between 100-200 m.y. ago and between 0-25 m.y. ago[5]. In the late Tertiary episode alkali volcanism is nearly always associated with uplift. Areas of isolated uplift and volcanism are numerous in northern Africa are secondary features following primary updoming[3]. Four overlapping domal structures have been recognised and in the case of the Red Sea and Afro-Arabian domes transcontinental fracture systems have widened con-commitant with the production of new ocean floor in the Red Sea and Gulf of Aden.

The tentative proposal arising from these studies is that when the lithosphere is thinned by the upward movement of the lithosphere/asthenosphere boundary, transcontinental fractures can occur if the usually circular areas of uplift overlap to produce an elongate zone of weakness. This model is currently being tested with respect to the Red Sea and Gulf of Aden. Others[8,9], noting the abundance of matching half domal structures along the west coast of Africa and the east coast of South America, have postulated a similar mechanism for the Africa/America split in the Mesozoic and the formation of the protoatlantic.

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## IV.2c Tectonics and Magmatism of the Red Sea

by I.G. Gass

Geophysical evidence[1,2,3], suggests that oceanic lithosphere exists beneath the Red Sea. Seismic data show P-wave velocities of ca. 6.9 km $s^{-1}$ for basement underlying a 4 km thick sequence of evaporites. This velocity, typical of oceanic layer 3, ceases at about 50 km from the shore where it is replaced by velocities more typical of sialic crust.

Although geophysical evidence for Red Sea oceanic lithosphere is extensive and convincing it is augmented by relatively sparse geological data. Dredge samples of oceanic basalt are few and altered[4] and basaltic volcanic islands, characteristic of the oceanic environment, only occur in the southern most part of the Red Sea[5]. The northern most volcanic island, Jebel at Tair, has geochemical features of an oceanic island such as Hawaii[6], whereas the islands of the Zubair Group are petrochemically transitional on the classification of Yoder and Tilley. Both these island groups lie within the Red Sea axial trough and their structures lie parallel to its trend at those latitudes. In contrast, the islands of the southern most Zukur-Hanish Group are strongly alkalic and lie along a north easterly trend which does not continue into either Arabia or Ethiopia; this volcanism, it has been suggested, lies along a ´leaky´ transform fault within the Red Sea oceanic lithosphere[5].

The structural situation at the southern end of the Red Sea is complicated by the presence of the Danakil platelet[3,7,8] and the presence of extremely thick

Recent sediments in the area where the median trough looses its bathymetric identity. Spreading seems to have occurred in the Afar depression where magnetic linear anomalies have a Red Sea trend. However, to the south of the Afar, in the area west of the Gulf of Tdjura, a Gulf of Aden orientation is evident.[9]

Within this complex situation the tectonic/magmatic relations are far from clear. There is however some evidence that a thermal eminence underlies the Red Sea and that a mesospheric thermal plume may be present. The situation is somewhat analagous to Iceland on the Mid-Atlantic Ridge[10] and investigations are in progress on light rare earth distribution to evaluate this proposal.

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## IV.3 PUBLICATIONS AND RESEARCH PROJECTS RELEVANT TO THE ETHIOPIAN RIFT AND THE AFAR TRIANGLE, 1969-1973

by P. Gouin, Geophysical Observatory, P.O.Box 1176, Addis Ababa, Ethiopia

I GEODESY

a) Publications

Brander, L., 1971, "Imperial College (London) Mekometer survey in Ethiopia" (a short outline). Bull. Geophys. Obs., AA, 13, 120.

Mohr, P.A., 1973, "Ethiopian Rift Geodimeter Studies". Bull. Geophys. Obs., AA, 14, 1-92.

b) Projects

Crustal deformation studies

1. CNRS - IGNF first-order geodetic project in T.F.A.I. No details available to the author at present.

Contact: Dr. J.C. Ruegg, Field party leader, CNRS
Institut de Physique du Globe,
11, Quai St. Bernard, Tour 14,
Paris V. France.

2. Imperial College (London) Mekometer survey. In December 1969, 2 networks of geodetic stations were established by J. Brander and M. Lasserre: the first in the rift proper near volcano Fantale and the other, across a fault near Serdo in central Afar. Claimed accuracy: 0.1 mm over 3 km. The stations have not yet been re-occupied.

Contact: Prof. R.G. Mason,
Imperial College of Science and Technology,
University of London.

3. Smithsonian Astrophysical Observatory project. Since 1969, a network of 81 geodimeter stations has been established and measured across the main Ethiopian rift. Some of these have been re-occupied once or twice. Details and results are given in Bull. of Geophys. Obs., AA, 14, 1973.

Contact: Dr. Paul A. Mohr,
Smithsonian Astrophysical Observatory,
Cambridge, Mass. U.S.A.

Heat Flow Measurements

The project calls for heat flow measurements both in the Rift valley and outside the rift. The program has not started yet.

Contact: Ken Williamson, and Jame Wheildon
Imperial College, London.

Satellite Geodesy

The Smithsonian Astrophysical Observatory has been operating a Baker-Nunn satellite tracking station at Debre Zeit, Ethiopia, since 1967. In 1972, a 25 Mw CNES laser system has been added; started operating in May 1973. This is a joint project with H.S.I.U.

Contact: Dr. Michael Pearlman,
Smithsonian Astrophysical Observatory,
60 Garden St., Cambridge, Mass. U.S.A.

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### a) Publications

Abbate, E. and M. Sagri, 1969, "Dati e considerazioni sul margine orientale dell´ altipiano etiopico nella provincia del Tigrai e del Wollo". Boll. Soc. Geol. Ital., 88, 489-497.

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Weaver, S. D., J. S. C. Sceal and I. L. Gibson, 1972, "Trace elements data relevant to the origin of trackytic and pantellerite lavas in the East African rift system". Contr. Mineral. Petrol., 36, 181-194.

Wiesner, K., 1970, "Vergleichende Besbachtungen au Geologie und Tektonik in Eritrea und Harar (Athiopien)". Geol. Rdsch. Dtsch., 59, 391-408.

b) Projects

CNRS-CNR project in Afar

Geological and volcanic survey of Afar. Joint project CNRS (France) and CNR (Italy). Started in 1968; end unknown.

Contact: Dr. H. Faure, R.C.P. 181,
CNRS,
Laboratorie de Geologie,
Bellevue, France.

Prof. G. Marinelli,
CNR,
Dip. di Sc. della Terra,
Pisa, Italy.

Danakil Alps Geological Survey

Project of the Geol. Dept. of H.S.I. University. Started in March 1973.

Contact: Prof. Russel Black,
Dept. of Geology,
Haile Sellassie I University,
P. O. Box 1176, Addis Ababa.

Omo River Geological Project

Geological, geochemical and tectonic survey of 83,000 square kilometers on either sides of the Omo river in the Provinces of Sidamo, Gomu Gofa, Kaffa and Illubabor. Therefore covers the southern end of the Ethiopian rift and the northern end of the Rudolf rift.

Joint Ethiopia-Canada project.
Duration: 2 years
Canadian Team Leader: Dr. A. Davidson.

Miocene Granits

Study of the Miocene Granits in Afar.

Geology Dept., H.S.I. University, AA.

Ethiopian rift margin in Arussi

Structural and volcanological mapping of Mts Badda and Kakka (Arussi province). Petrochemical lab. studies.

Contact: Eric Potter,
Dept. of Geology,
State University of Oregon.

## III GEOPHYSICS

### a) Publications

Allan, T. D., 1970, "Magnetic and Gravity fields over the Red Sea". Phil. Trans. Roy. Soc., London, A 267, 153-180.

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Dakin, F. M., (in prep.) "Distribution and characteristics of earthquake sequences in Ethiopia and TFAI.

Dakin, F. M., P. Gouin and R. C. Searle, 1971, "The 1969 Earthquake in Serdo, Ethiopia". Bull. Geophys. Obs., AA, 13, 19-56.

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Fairhead, D. and R. W. Girdler, 1971, "The Seismicity of Africa". Geophys. J. Roy. Astr. Soc., 24, 271-301.

Fairhead, J.D. & Girdler, R.W. 1972. The seismicity of the East African rift system. Tectonophysics 15, 115-122.

Girdler, R. W., 1970a, "An aeromagnetic survey of the Junction of the Red Sea, Gulf of Aden and Ethiopian rifts : a preliminary report". Phil. Trans. Roy. Soc., London, A 267, 359-368.

Girdler, R. W., 1970b, "A Review of the Red Sea Heat Flow". Phil. Trans. Roy. Soc., London, A 267, 191-203.

Girdler, R. W. and S. Hall, 1972, "An Aeromagnetic Survey of the Afar triangle, Ethiopia". Tectonophysics, 15 (1/2), 53.

Gouin, P., 1970a, "Gravity and Seismic data on Afar and surrounding areas". Phil. Proc. Roy Soc., London, A 267, 339-358.

Gouin, P., 1970b, "Evaluating seismic activity in Ethiopia". Zede, 4, 5-9, Addis Ababa.

Gouin, P., (in prep.) "Catalog of Ethiopian and TFAI earthquakes (1400 to 1973) and seismic risk map of Ethiopia".

Greinwald, S., 1971, "Magneto-Telluric measurements in Eastern Ethiopia". Bull. Geophys. Obs., AA, 13, 125.

Gumper, F. and P. W. Pomeroy, 1970, "Seismic wave velocities and Earth Structure of the African continent". Bull. Seism. Soc. Am., 60, 651-668.

Knopoff, L. N. and J. W. Schlue, 1972, "Rayleigh wave phase velocities for thepath Addis Ababa-Nairobi". Tectonophysics, 15 (1/2), 157-164.

Lepine, J. C., J. C. Ruegg and L. Steinmetz, 1972. "Seismic profiles in the Djibuti area". Tectonophysics, 15 (1/2), 59-64.

Maasha, N., and P. Molnar, 1972, "Earthquake fault parameters and tectonics in Africa". J. Geophys. Res., 77, 5731-5743.

Mahdi, M.S., 1971, "Geophysical Work in Oil Prospection in Ethiopia". Bull. Geophys. Obs., AA, 13, 122.

Makris, J., H. Menzel, J. Zimmermann, K. P. Bonjer, K. Fuchs and A. J. Wohlenberg, 1969, "Crustal and Upper Mantle structure of the Ethiopian Rift derived from seismic and gravity data". Z. Geophys., 36, 387-391.

Makris, J., N. Menzel, and J. Zimmermann, 1972, "A preliminary interpretation of the gravity field of Afar, northeast Ethiopia". Tectonophysics, 15 (1/2), 31-39.

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Mohr, P. A., 1969, "Relationships between Middle East and African earthquakes". Nature, 223, 516-518.

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Peter, G., and O. E. DeWald, 1969, "Geophysical reconnaissance in the Gulf of Tadjura". Geol. Soc., Amer. Bull., 80, 2313-2316.

Roberts, D. G. and R. B. Whitmarsh, 1969, "A bathymetric and magnetic survey in the Gulf of Tadjura". Earth. Planet. Sci. Letters, 5, 253-258.

Schaeffer, R. M. 1970. Palaeomagnetic study on Ethiopian volcanic samples, in : (H. Illies & St. Mueller eds.) Graben problems, 283-285. Schweizerbart, Stuttgart.

Searle, R. C. and P. Gouin, 1971a, "Notes on the Gravity Survey of Central Afar". Bull. Geophys. Obs., AA, 13, 57-72.

Searle, R. C. and P. Gouin, 1971b, "An analysis of some local earthquake phases originating near the Afar Triple junction". Bull. Seism. Soc. Amer., 61, 1061-1071.

Searle, R. C. and P. Gouin, 1972a, "Local Earthquake Phases observed at Addis Ababa". Tectonophysics, 15 (1/2) 55-57.

Searle, R. C. and P. Gouin, 1972b, "A gravity Survey of the Central Part of the Ethiopian Rift Valley". Tectonophysics, 15 (1/2), 41-52.

Tarling, D.H., Sanver, M., Hutchings, A. M. J. 1970. (D.H.T. only). Palaeomagnetism and the origin of the Red Sea and Gulf of Aden. Phil. Trans. R. Soc. London, 264A, 219-226.

Zimmermann, J. and J. Makris, 1971, "Gravity Survey of southern Afar, Ethiopia". (A progress report and 9 maps) (Restricted) Ministry of Mines, Addis Ababa.

b) Projects

Crustal Studies Project

1. Geomagnetic Deep sounding project

Thirty field magnetometers were operated by Dr. Porath and C. Simmons from the Univ. of Texas at Dallas (U.S.A.) from Dec. 1970 to April 1971. The instruments were arranged (1) along a NS profile to study the spatial dependence of the magnetic variations due to the equatorial electrojet and (2) along several other profiles across the Ethiopian rift and southern Afar to map the electrical conductivity anomalies in the Earth´s crust and upper mantle.

Reduction of the data was delayed by the accidental death of Dr. Porath and the departure of Dr. A. Dziewonski from U.T.D.

Contact: Prof. Anton Hales,
Univ. of Texas at Dallas,
Box 30365, Dallas, Texas, 75230, U.S.A.

2. Magneto-Telluric measurements in Afar from January to May 1971.

A project of the Institut fuer Augewandte Geophysik. Description is given in 33 Jahr. der D.G.G., 5-10 March 1973, p. 5.40. Results to be presented at the Symp. on Afar at Clausthal Univ., in April 1974.

Contact: Dr. A. Berktold,
Inst. für Augewandte Geophysik.,
8 München 2, Theresienstr. 41/TV Block C,
Germany.

3. Seismic deep soundings in Afar and in the Ethiopian rift.

Project of the German Research Group for Explosion seismology. January 1972.

Five 150-250 km long profiles were observed in Ethiopia: 3 in Afar, one in the rift and one reference-profile on the Ethiopian Plateau.

Preliminary results were presented at the meeting of the German Grol. Öoc. in Gottingen (D.G.G. Jahrestagung, 33, p. 5.37 p. 5.37, March 1973); final results will be presented at the Symposium on Afar, at Clausthal Univ. in April 1974.

Contact: Prof. H. Berckhemer, Chairman of the
planning group 'Afar-seismic',
Inst. für Met. und Geophysik,
6 Frankfurt am Main
Feldbergstrasse 47, Germany.

Gravity surveys

1. Haile Sellassie I Univ. - Geophys. Obs. project.

Project started in 1960 by running exploratory profiles throughout Ethiopia to obtain the picture of the background gravity field (cf: Gouin, 1970a). Lately main efforts concentrated on dense network in northern sector of the main Ethiopian rift, i.e. from 7° N to the S.E. corner of Afar. Results are partially published.

Contact: Prof. P. Gouin and Dr. R. C. Searle,
Geophysical Observatory,
Haile Sellassie I University,
P.O.Box 1176, AA.

2. University of Newcastle-upon-Tyne.

Mr. Marsden has been establishing a dense network of gravity stations in the southern sector of the rift, south of 7° N. This is a Ph.D. research project.

Contact: Geoffrey Marsden, School of Physics,
University of Newcastle-upon-Tyne,
NE1 7RU, England.

3. University of Hamburg project.

Started in 1969. Dense network of stations both in Afar and TFAI plus background reference profiles over the plateaus. Preliminary results have already been published (cf: Makris et al., 1969, 1970, 1972). More complete interpretation will be presented at the Symp. at Clausthal. Univ. in April 1974.

Contacts (for the Ethiopian sector):
Dr. Jannis Makris,
Inst. für Geophysik,
Universitat Hamburg,
2 Hamburg 13, Bindustrasse 22, Germany.

(for TFAI sector):
Dr. Makris - ibid
Dr. A. LeBras,
Labo. de Tectonophysique,
Univ. de Paris, VI, France.

<u>Seismicity of the Lower Awash Valley</u>

Part of a development feasibility program of the Lower Awash Valley. Calls for 4 field seismic stations to be located in the Tendaho region (Central Afar).

Contractors are Gibb & Partners.
Sub-contractor for the seismic survey: Univ. of Durham.

Seismicity of Ethiopia

Up-grading of the station AAE (H.S.I.U.)
Project of adding magnetic recording system to the present photographic system to save the traces of local events.

Project of adding a small network of satellite stations near Addis Ababa.

Contact: Pierre Gouin, Director,
Geophysical Observatory, HSIU
P. O. Box 1176, Addis Ababa, Ethiopia.

Seismicity of TFAI and surrounding area

CNRS RCP180 seismic stations network in TFAI. Started in 1972 with 3 stations located at Djibuti, Tadjura and Arta. Two more stations should be operating by the end of 1973 at Obock and lake Asal.

Contact: Dr. R. C. Ruegg,
Institut de Physique du Globe,
4 Place Jussiew, Tour 14,
75230 Paris CEDEX 05, France.

## IV RADIOMETRIC DATING

### a) Publications

Brown, F.H., 1969. Observations on the stratigraphy and radiometric ages of the "Omo Beds", lower Omo basin, southern Ethiopia. Quaternaria II, 7-14.

Brown, F. H. and K. R. Lajoie, 1971, "Radiometric Ages determinations of Pliocene/Pleistocene Formations in the lower Omo Basin, Ethiopia". Nature, 229, 483-485.

Butzer, K.W. (& G.L. Isaac, J.L. Richardson, C. Washbourn-Kamau), 1972. Radiocarbon dating of East African lake levels Science 145, 1069-1076.

Faure, H., C. Roubet, H. Tazieff, et al., 1969, "Age des calcaires coralliens pleistocenes et neotectonique de l'Afar, Ethiopie". Ann. Fac. Sci. Clermont-Ferrand, Geol. et Miner., fasc. 19, 17-18.

Fitch, F. J. and J. A. Miller, 1969, "Age determinations on Feldspar from the lower Omo Basin". Nature, 222, 1143.

Kreuzer, H., P. Müller, W. Haue and H. Lenz, 1969, "Radiometrisch Alterbestimmung an Gestinen der Danakil-Senke und ihrer Umbebung (Nordathiopien)". Geol. J., 88, 83-86.

Lalou, C., H. van Nguyen, H. Faure and L. Moreisa, 1970, "Datation par la methode uranium-thorium des hautsniveaux de coraux de la depression de l'Afar, Ethiopie". Rev. Geogr. Phys. et Geol. Dyn., 12, 3-8.

Lemoigne, Y. and J. Beauchamp, (in press, 1973), "Paleofloral dating of volcanics in Ethiopia". Bull. Geophys. Obs., AA, 15.

Megrue, G. H., E. Norton and D. W. Strangway, 1972, "Tectonic history of the Ethiopian Rift as deduced by K-Ar Ages and Paleomagnetic Measurements of basaltic dikes". J. Geophys. Res., 77, 5744-5754.

Morton, W. H., and D. C. Rex, (in press, 1973), "Age of Mount Yerer". Bull. Geophys. Obs., AA, 15.

Page, N., M. Taieb and H. Faure, 1971, "Liste des ages radiometriques d'Ethiopie". VII Congr. Panafric. Preh. et d'et. du Quatern. Addis Ababa.

Rex, D. C., I. L. Gibson and F. M. Dakin, 1971, "Age of Ethiopian Flood Basalts succession". Nature, 230, 131.

Roubet, C., H. Tazieff, V. H. Nguyen, G. Delibrias, C. Lalou, H. Faure, 1969, "Age des calcaires coralliens pleistocenes et neotectoniques de l'Afar". Ann. Fac. Sci. Univ. Clermont-Ferrand, 41, fasc. 19, 17-18.

Weeh, H. & Giegengack, R. 1979, Uranium-series ages of corals from the Red Sea. Nature 226, 155-156.

b) Projects

Radiometric dating of the Trap series

1. Radiometric dating of Trap series of Afar and of the Addis Ababa regions.

D. C. Rex, University of Leeds,
Geology Dept., Haile Sellassie I University, AA.

2. Radiometric and Geochemical Study of the Trap formations in Ethiopia. (9 profiles)

P. Jones (Ph.D. research) Univ. of Leeds.

V TECTONICS

a) Publications

Abdel-Gawad, M., 1970, "Interpretation of satellite photography of the Red Sea and Gulf of Aden". Trans. Phil. Roy. Soc., London, A 267, 23-40.

Baker, B. H., 1970, "The structural pattern of the Africo-Arabial rift system in relation to plate tectonics". Phil. Trans. Roy. Soc., London, A 267, 383-391.

Bannert, D., 1972, "Afar Tectonics Analysed from Space Photographs". Amer. Ass. of Petrol. Geol. Bull., 56, 903-915.

Bannert, D., and E. Y. Kedar, 1971, "Plate tectonics in the Red Sea region as inferred from space photography". NASA Tech. Note D-6261, 16 pp.

Barberi, F., S. Borsi, G. Ferrara, G. Marinelli and J. Varet, 1970, "Relationship between Tectonics and Magmatology of Northern Afar depression". Phil. Trans. Roy. Soc., London, A 267, 293-311.

Barberi, F., H. Tazieff and J. Varet, 1972, "Volcanism in Afar depression: its tectonic and magmatic significance". Tectonophysics, 15 (1/2), 19-29.

Black, R., W. H. Morton and J. Varet, 1972, "New Data on Afar Tectonics". Nature Physical Science, 240, 170-173.

Burek, P. J., 1970, "Paleomagnetic evidence for an anticlockwise rotation of the Danakil Alps, Ethiopia". EOS (A.G.U.), 51, 271 (abstract only).

Burek, P. J., 1971, "Plattentektoniche Probleme in Bereich Arabiens und der Afar-Senke". (Doctoral dissertation) Karlsruhe Univ.

Fairhead, J. D., and R. W. Girdler, 1969, "How far does the rift system extend through Africa?". Nature, 221, 1018-1020.

Faure, H., C. Roubet, H. Tazieff, et al., 1969, "Ages des calcaires coralliens pleistocenes et neotectonique de l'Afar, Ethiopie". Ann. Fac. Sci., Clermont-Ferrand, Geol. et Miner., fasc. 19, 17-18.

Fisher, R. L., E. T. Bence et al., 1972, "Deep-sea drilling project in dodoland, leg 24", Geotimes, Sept. 1972, 17-21.

Frazier, S. B., 1970, "Adjacent structures of Ethiopia: portion of the Red Sea coast including Dahlak Kebir Island and the Gulf of Zula". Phil. Trans. Roy. Soc., London, A 267, 131-141.

Freund, R., 1970, "Plate tectonics of the Red Sea and East Africa". Nature, 228, 453.

Gass, I. G., 1970, "Tectonic and magmatic evolution of the Afro-Arabian dome". in Clifford, T. N. and I. G. Gass, eds., 'African magmatism and tectonics,' pp. 285-300.

Gass, I. G., 1972, Proposals concerning the variation of volcanic products and processes within the oceanic environment. Phil. Trans. R. Soc. London 271A, 131-140.

Gass, I. G., 1973, "The Red Sea depression - causes and consequences". in Tarling, D. H. and S. K. Runcorn, eds., 'Continental drift, sea-floor spreading and plate tectonics: implications for the Earth Sciences.' London.

Gibson, I. L., 1969, The structure and volcanic geology of an axial portion of the main Ethiopian rift. Tectonophysics 8, 561-565. (read at I.U.G.G. symposium, Switzerland, 1967).

Gibson, I. L. and H. Tazieff, 1970, "The structure of Afar and the northern part of the Ethiopian Rift". Phil. Trans. Roy. Soc., London, A 267, 331-338.

Girdler, R. W., and B. W. Daracott, 1972, "Review of African Poles". Comment. Earth Sci., Geophysics, 2, 131-138.

Hutchinson, R. W., and G. G. Engels, 1970, "Tectonic significance of regional geology evaporite lithofacies in northeastern Ethiopia". Phil. Trans. Roy. Soc., London, A 267, 313-329.

Hutchinson, R. W., and G. G. Engels, 1972, "Tectonic evolution in the southern Red Sea and its posiible significance to older rifted continental margins". Geol. Soc. Amer. Bull., 83, 2989-3002.

Lowell, J. D. and G. J. Genik, 1972, "Sea-Floor spreading and Structural Evolution of the Southern Red Sea". Amer. Ass. of Petrol. Geol. Bull., 56, 247-259.

Maasha, N., and P. Molnar, 1972, "Earthquake fault parameters and tectonics in Africa". J. Geophys. Res., 77, 5731-5743.

McKenzie, D. P. and W. J. Morgan, 1969, "Evolution of Triple Junctions". Nature, 224, 125-133.

McKenzie, D. P., D. Davies and P. Molnar, 1970, "Plate Tectonics of the Red Sea and East Africa". Nature, 226, 243-248.

Megrue, G. H., E. Norton and D. W. Strangway, 1972, "Tectonic history of the Ethiopian Rift as deduced by K-Ar Ages and Paleomagnetic Measurements by basaltic dikes". J. Geophys. Res., 77, 5744-5754.

Mohr, P. A., 1970c, "Plate Tectonics of the Red Sea and East Africa". (reply to McKenzie et al.) Nature, 228, 547-548.

Mohr, P. A., 1970d, "The Afar Triple Junction and Sea Floor Spreading". J. Geophys. Res., 75, 7340-7352.

Mohr, P. A., 1970e, "Volcanic composition in relation to tectonics in the Ethiopian rift system: a preliminary investigation". Bull. Volc., 34, fasc. 1., 141-157.

Mohr, P. A., 1971c, "Outline Tectonics of Ethiopia". Tectonics of Africa, UNESCO, 447-458.

Mohr, P. A., 1971d, "The Ethiopian Triple-Rift Junction in terms of Plate Tectonics". Bull. Geophys. Obs., AA, 13, 1-18.

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Mohr, P. A., 1971f, "Ethiopian Tertiary dyke swarms". Smithsonian Astrophys., Spec. Rep., no. 339, 88 pp.

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Mohr, P. A., 1972c, "ERTS-1 Imagery of Eastern Africa: a first look at the geological structure of selected areas". Smithsonian Astrophysical Observatory, Special Report 347.

Mohr, P. A., (in press, 1973), "Structural elements of the Afar margins: data from ERTS-1 imagery". Bull. Geophys. Obs., AA, 15.

Peter, G. and O. E. DeWald, 1969, "Geophysical reconnaissance in the Gulf of Tadjura". Geol. Soc. Amer. Bull., 80, 2313-2316.

Picard, L., 1969, "On Afro-Arabian graben tectonics". Geologische Rundschau, 22, bd. 59, 337-381.

Piper, J. D. A., 1973, Fine structure of en echelon ridge axes and crustal deformation at constructive plate boundaries. Bull. Geol. Soc. Amer., 84, 931-938.

Rognon, P. and F. Gasse, 1972, "Neotectonique des depots lacustres de l´Holocene inferieur du graben de Dobi (Afar, Ethiopie)". C. R. somm. Soc. geol. Fr., 208-212.

Ross, D. A., R. B. Whitmarsh et al., 1972, "Deep Sea drilling project in the Red Sea", Geotimes, 17, 24-26.

Ross, D. A., R. B. whitmarsh, et al., 1973, "Red Sea Drillings". Science, 179, 377-380.

Ross, D. A. and J. Schlee, (in prep.), "Shallow structure and geologic development of the southern Red Sea".

Roubet, C., H. Tazieff, V. H. Nguyen, G. Delibrias, C. Lalou and H. Faure, 1969, "Age des calcaires coralliens pleistocenes et neotectonique de l'Afar". Ann. Fac. Sc., Univ. Clermont-Ferrand, 41, fasc. 19, 17-18.

Schilling, J. C., 1973, "Afar Mantle Plume: rare earth evidence". Nature Phys. Sci., 242, 2-5.

Searle, R. C. 1970, "Lateral extension in the East African Rift Valleys". Nature, 227, 267-268.

Searle, R. C., (submitted for publication), "The role of lithospheric attenuation in the development of the Afro-Arabian rift system.

Searle, R. C. and P. Gouin, 1972b, "A Gravity survey of the central part of the Ethiopian Rift Valley". Tectonophysics, 15 (1/2), 41-52.

Taieb, M., 1969a, "Les depots quaternaires de la vallee de l'Aouache et leurs relations avec la neotectonique cassante du rift (Ethiopie)". Actes du Congres de l'INQUA, Paris.

Taieb, M., 1970, "Stratigraphie du Quaternaire de la vallee de l'Aouache et ses rapports avec la tectonique". Bull. Ass. Seneg. Et. qual. Quest. Afric., Dakar, 25, 47-52.

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Tazieff, H., 1969, "Tectonique de l'Afar septentrional". C. R. Acad. Sci., D 268, 2030-2033.

Tazieff, H., 1970, "Tectonics of Northern Afar (or Danakil) rift". Intern. U.M.P., Sc. Rep. no. 27, 280-316.

Tazieff, H. and J. Varet, 1969, "Petrographie et tectonique de l'Afar Septentrional (Ethiopie)". Ann. Fac. Sc., Univ. Clermont-Ferrand (5ª Coll. de Geol. Afr., 54).

Tazieff, H., (& J. Varet) 1969, Signification tectonique et magmatique de l'Afar septentrional (Ethiopie). Rev. Geogr. Phys. Geol. Dynam. 11, 429-450.

Tazieff, H., J. Varet, F. Barberi and G. Siglia, 1972, "Tectonic significance of the Afar (or Danakil) depression", Nature, 235, 144-147.

Tazieff, H., 1973, About air and space photo interpretations of Afar.Trans. Am. Geophys. Un. (EOS) 54, 470 (abstract).

Wiesner, K., 1970, "Vergleichende Beobachtungen au Geologie und Tektonik in Eritrea und Hararw (Athiopien)". Geol. Rdsch Drsch., 59, 391-408.

b) Projects

Rift Margin

Tectonic map of the Rift margin between Addis Ababa and Nazareth. Scale 1:50,000 or 1:100,000.

Geology Department, HSIU.

Satellite mapping

Mapping of structural lineaments in Ethiopia from ERTS-1 imagery. (7 sheets at scale 1:1 million).

## VI VOLCANOLOGY

### a) Publications

Augustithis, S.S., 1971, Mantle fragments in basalts (on the origin and significance of "olivine in basalts). Bull. Geol. Soc. Greece 8, 93-101.

Barberi, F. & Varet J., 1970, (F.B., S. Borsi, G. Ferrara, G. Marinelli, J.V.) Relations between tectonics and magmatology in the northern Danakil depression (Ethiopia). Phil. Trans. R. Soc. London, A, 267, 293-311.

Barberi, F. and J. Varet, 1971, "The Erta-Ale volcanic range, Ethiopia". Bull. Volc.

Barberi, F., Borsi, S., Ferrara, G., Marinelli, G., Santacrole, R., Tazieff, H., & Varet, J., 1972, Evolution of the Danakil Depression (Afar, Ethiopia) in light of radiometric age determinations. J. Geol. 80, 720-729.

Barberi, F., and J. Varet, 1971 (M. Treuil, M. Billhot, J.V., F.B.) Distribution of nickel, copper and zinc in the volcanic series of Era´Ale, Ethiopia. Contr. Min. Pet. 30, 84-94.

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## IV.4.a SOME RESULTS OF GEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS IN THE KENYA RIFT VALLEY, 1968-1973.

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A seminar on the East African Rift System held in Nairobi in 1965 emphasised the need for more comprehensive geological and geophysical studies of the classic Gregory Rift Valley. Some indication of the interest which has been focussed on the Kenya rift since that meeting can be gained from the lengthy bibliography now being compiled covering the period 1968 to 1973 (earlier references are listed in Dosaj & Walsh, 1970. The wealth of new information published during the last five years makes it impossible to summarise adequately in a few pages the present state of knowledge, and the brief account that follows will do no more than illustrate some of the achievements and high-light a few of the problems and controversies.

### (1) GEOLOGICAL INVESTIGATIONS

### (a) Rift volcanics

The general sequence, distribution and composition of the volcanics have been summarised in several recent accounts (e.g. Williams, 1969, 1970, 1972; King, 1970; King & Chapman, 1972). Other reviews have dealt more specifically with isotopic age determinations (Bishop et al., 1969; Baker et al., 1971; Fairhead et al., 1972; Logatchev et al., 1972).

In most general accounts an attempt has been made to subdivide the volcanics into extensive 'plateau' formations erupted from fissures or numerous small centres, and more localised products of major central volcanoes. All the volcanics are characteristically alkaline, but range from strongly alkaline nephelinites and phonolites to more mildly alkaline members of a basalt-trachyte series.

Miocene volcanism produced alkali basalts in the proto-rift zone in northern and central Kenya, and also large nephelinite-phonolite-carbonatite volcanoes of western Kenya (King et al., 1972). Eruption of late Miocene flood phonolites coincided with strong uplift of the Kenya dome and was followed by an important phase of rift faulting. Pliocene activity took place along the length of the developing rift. Widespread mid-Pliocene basalts were more or less restricted to the rift floor, but Plio-Pleistocene trachytic lavas and ignimbrites erupted from a down-faulted portion of the Kenya dome overflowed locally on to the marginal plateaus. Extensive rhyolitic lavas and ignimbrites in the northern part of the rift have not yet been investigated in detail but are provisionally assigned to the Pliocene. The numerous Pliocene central volcanoes show a considerable diversity of composition. Large trachytic shield volcanoes dominate the northern and central parts of the rift, but nephelinites and phonolites are prominent at several Pliocene centres in southern Kenya. Late Quaternary activity in the rift floor was largely associated with a string of caldera volcanoes which are predominantly trachytic, and stands in marked oontrast to widespread basaltic volcanism in multicentre fields east of the rift.

An important relationship between chemical composition and stratigraphic position has been demonstrated in lavas of the northern part of the rift (King & Chapman, 1972) where both felsic and mafic volcanics show a decrease in silica undersaturation with time. A chemical distinction between Miocene basalts and phonolites and the younger volcanics of a basalt-mugearite-trachyte suite corresponds to a major episode of rift faulting. There is also some evidence

Williams, 1972) that post-Miocene basalts of the rift floor are less undersaturated than basalts erupted outside the rift. This is probably related to shallower melting under the rift zone, but it should be stressed that lavas with distinct tholeiitic tendencies have not been located in Kenya.

One of the outstanding petrogenetic problems concerns the origin of enormous volumes of trachytic and phonolitic volcanics (Williams, 1970; Baker et al., 1972). The apparent scarcity of flood lavas with compositions between basalt and phonolite or basalt and oversaturated trachyte led to hypotheses invoking partial melting in the mantle or lower crust rather than fractional crystallisation or crustal assimilation. But recent work in the northern part of the rift (King & Chapman, 1972) has shown that, although felsic lavas are as abundant as basalts, the proportion of intermediate rocks has been underestimated and it is concluded that fractional crystallisation cannot be ruled out as the chief process involved in the production of mugearites and trachytes from a basaltic parent. Trace-element distribution patterns in rocks of trachytic and pantelleritic volcanoes are also taken to support a concept of crystal fractionation from a basic parent magma despite the great preponderance of salic lavas over basalts. It is suggested that the central volcanoes developed above high-level salic magma chambers situated over a regional basaltic reservoir (Sceal & Weaver, 1971 ; Weaver et al., 1972). In much the same way, a complex differentiation process involving concentration of volatiles in cupolas high in the crust is envisaged to explain the derivation of intermediate and acid rocks of Silali caldera volcano where a distinct basalt-trachyte bimodality has been demonstrated (McCall & Hornung, 1972). A study of obsidians from the central part of the rift (Macdonald et al. 1970) left the question of the ultimate derivation of felsic liquids unsolved, but showed that a simple crystal-liquid equilibrium process is inadequate to explain the derivation of peralkaline rhyolite from trachyte ; an alkalibearing vapour phase is invoked.

(b) Sediments

Numerous K/Ar age determinations are now available from western Kenya and eastern Uganda where sediments interbedded with Miocene volcanics have yielded mammalian assemblages including hominoid remains (Bishop et al., 1969; Van Couvering & Miller, 1969; Bishop 1971, 1972).

In the Tugen Hills, west of Lake Baringo, Miocene to Quaternary volcanics and sediments attain a thickness of about 3000 m. Important discoveries of fossiliferous formations have been followed up by detailed work (Bishop & Chapman, 1970; Bishop et al., 1971) which has resulted in the bridging of a gap in the fossil mammal record in Africa south of the Sahara between 4 and 14 m.y. Many mammalian assemblages formerly regarded as Pleistocene have come from reliably dated Pliocene sediments, in some cases 7 m.y. old.

Equally important are the numerous discoveries of fossiliferous sediments in the Lake Rudolf basin (Howell, 1968, 1969; Butzer & Thurber, 1969; Arambourg et al., 1969; Brown, 1972; Patterson et al., 1970; Maglio, 1970, 1971, 1972; Behrensmeyer, 1970; Leaky, 1970, 1971; Leakey et al., 1970). These sediments provide a link between the Pliocene deposits of the Tugen Hills and the well known hominid-bearing beds of Olduvai Gorge in northern Tanzania.

(c) Structural evolution of the Kenya rift

The structural history of the Kenya rift can be summarised as follows (Baker & Wohlenberg, 1971; Baker et al., 1972):

(i) Upwarping of the Kenya-Uganda border region (nephelinite volcanoes) and downwarping and faulting of the Turkana depression in the mid-Tertiary (followed by eruption of basalts in northern Kenya).

(ii) Uplift of central Kenya in the late Miocene (flood phonolites).

(iii) Major faulting in early Pliocene (followed by eruption of mid-Pliocene basalts and trachytes).

(iv) Major uplift and faulting in central Kenya in the late Pliocene and early Pleistocene (trachytes and ignimbrites).

(v) Grid faulting of the rift floor in early Pleistocene (trachytic caldera volcanoes).

(2) GEOPHYSICAL INVESTIGATIONS

Teleseismic P wave delays and dispersion of Rayleigh waves along paths between Nairobi and Addis Ababa indicate a low velocity zone in the upper mantle beneath the Kenya rift (Fairhead & Girdler, 1971; Long et al., 1972 ; Knopoff & Schlue, 1972). Bouguer gravity profiles across the East African plateau, which show substantial negative values with even more marked lows at the rifts also demonstrate the existence of an anomalous zone that is shallowest beneath the rifts (Sowerbutts, 1969 ; Girdler et al., 1969). The negative Bouguer anomaly across the Kenya rift has superimposed on it on axial gravity high (Searle, 1970 ; Khan & Mansfield, 1971 ; Darracott et al., 1972) which is considered to be due to an intrusion of basic material reaching to within 2 or 3 km of the surface, or to a broader zone of dyke injection (Searle, 1970 ; Baker & Wohlenberg, 1971). A reversed seismic refraction line in the northern part of the Kenya rift showed that material with high P-wave velocity (6.4 km/sec) overlies a layer with velocity 7.5 km/sec at a depth of about 20 km (Griffiths et al., 1971 ; Griffiths, 1972) but, like the airmagnetic surveys carried out farther south (Wohlenberg & Bhatt, 1972), failed to provide clear supporting evidence for an axial basic intrusion to shallow depth.

## CONTACTS, GEOLOGICAL AND GEOPHYSICAL PROJECTS, KENYA RIFT

Enquiries regarding ongoing and recent projects in Kenya, and formalities connected with proposed projects, could most usefully be addressed to the following:

(1) General geology; permits for field research and export of rock specimens

The Commissioner,
Mines & Geological Department,
Ministry of Natural Resources,
P.O.Box 30009,
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(2) Volcanism; stratigraphy; tectonics

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Dr. M.J. LeBas,
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(b) Reading-Lancaster project (central rift)

Dr. D.K. Bailey,
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University of Reading,
Whiteknights,
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Department of Environmental Sciences,
University of Lancaster,
Bailrigg,
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(c) Oregon project (south-eastern part of rift)

Prof. B.H. Baker,
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(3) <u>Sedimentology; palaeontology</u>

(a) Permits for collection and export of fossils. Enquiries regarding all areas, particularly Lake Rudolf basin (numerous participants)

Mr. R.E.F. Leakey,
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## IV. 5b INFORMATION ON RESEARCHES IN THE BAIKAL RIFT ZONE

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Prof. Florensov requested me to inform W.G. 4 members on the main aims and arrangements that are in progress in connection with Baikal rift zone study, which proceeds under the supervision of the Baikal Rift Commission headed by Prof. Florensov and of which I am a member. The commission includes representatives of several institutions of the Academy of Sciences and Ministry of Geology of the USSR. Its activity is mainly a responsibility of Institute of the Earth´s Crust (Siberian Division of Academy of Sciences) and essentially involves discussion of scientific results and the coordination of future plans. It also produces new recommendations on further investigations. The commission was established in 1966 as part of the former "Upper Mantle Project" and remains active as a regional body of the National Commission on Geodynamics.

The researches now under way for the period 1971-75 are as follows:

1. History of volcanicity and the building up of basalt plateaus and volcanoes. There are a number of volcanic occurrences widely dispersed within the Baikal rift area; at the moment most of them are adequately studied. The main purpose for 1973-74 is to study the basalt plateau and central volcanoes of the Udokan range area, the easternmost and an isolated province of volcanic activity. The map of the prevolcanic (pre-Miocene) erosion surface has been compiled for the southwestern part of the rift zone. On the basis of this map we have reached the conclusion that the most extensive basalt outpourings took place within zones of subsidence superimposed on a huge pre-Miocene updoming.

Petrochemistry of volcanic rocks is under thorough study, with special attention to ultramafic nodules. Amongst the latter, only spinel lherzolites have so far been determined. We plan to start (1974) some experimental work on natural basalt melts under high pressure. The most difficult problem of regional volcanology remains the relation of volcanicity to neotectonic movements and to pre-Cambrian basement structures. This is of great importance since in continental rifts young magmas are the most impressive manifestations of what goes on under the earth's crust.

2. Geomorphic history and development of erosion surfaces, for a better understanding of the tectonic evolution of the Sayan-Baikalian domal uplift and its series of sharply expressed, axial grabens. So far we have succeeded in determining three ancient erosion surfaces that are in good accordance with disconformities and thick layers of weathered rocks within sedimentary infill in big depressions of the Baikal system. An attempt will be made to compile a neotectonic map in 1975, and the date on erosion surfaces will serve as a helpful source of information. We intend to choose as a base level the widespread late Paleocene-early Eocene erosion surface that in some respects closely resembles L. King's pre-Miocene or African surface in Africa.

3. Correlation between neotectonic and basement structures. This question isn't a new one, but it still remains unclear because of complex interrelations between new and old structures in areas under review. The Baikal rift zone has a total length of about 2500 kms, and along its strike young structural elements mostly (especially at the south-eastern edge of the Siberian platform) inherit direction of basement structures (old deep faults, metamorphic belts and so forth). Nevertheless

in some places they are in discordance, crossing at various angles. This matter will become more understandable after a comparison of neotectonic and tectonic maps has been made.

4. Detailed study of faults and fissures to understand the tectonic and physical conditions of faulting which formed the Baikal rift zone. The next aim is to develop a genetic classification of faults and ruptures that took part in rifting. In the course of rifting both rejuvenation of old faults and formation of new faults has occurred. An empirical correlation is found between a rupture's length on the surface and the depth to which a rupture penetrates the earth's crust. Because most earthquake hypocentres in the Baikal area usually lie between c. 5 and c. 25 km depth, we believe that recent faulting originates in the depth interval mentioned. So it may be thought that in general the deeper the foci the longer the ruptures at the surface.

5. In progress is analysis of the local gravity field and isostatic anomalies. Preliminary results suggest that subsidence of rift depression blocks comes not merely from simple extension of the earth's crust. Also important may be subsidence due to increasing density of the lower crust from upper mantle material injection and metamorphism.

6. Because of the active nature of the Baikal rift system, a great amount of new seismic data has recently been collected. There have been found some differences in focal mechanism of separate groups of earthquakes. This fact leads to the conclusion that each group of earthquakes characterizes different blocks of the earth's crust. It is worth mentioning that microearthquake distribution within the Baikal graben proper shows a

connection with longitudinal faults as well as with transverse ones. Therefore the earth's crust underneath the Baikal graben is divided into several blocks by a series of faults that may be compared with transcurrent faults of the mid-ocean ridges.

7. Deep seismic sounding. At the moment some new data are available for a transverse profile extending from the Siberian platform to the moderately mobile Transbaikalia mountain area. According to these data the earth's crust underneath Baikal graben is somewhat thinner (36-39 km) in comparison to adjacent areas (c. 45 km). Towards the Siberian platform the Moho discontinuity declines rather more steeply than towards the Transbaikalia area (The latter was strongly activated during Mesozoic times). The low velocity layer (7.6 - 7.8 km/sec for P-waves) is approximately 20-25 kms in thickness under the Baikal graben. Its extension to the west is limited by the Siberian platform margin and to the east it goes well beyond the structural and geomorphic boundary of the Baikal domal uplift. In other words, the low-velocity layer is not limited to the area of the Baikal rift zone proper.

   Crustal thickness measurements have been made by the jumping profiling method. Crustal thickness changes from, for example, 38 to 48 kms within comparatively short distances (some tens of kms) have been detected. These observations only partially correspond to the surface neotectonic structure of the rift zone, and this problem remains under study.

8. Heat flow measurements have been made in some grabens and neighbouring mountain ranges. As a rule, heat flow value in grabens is 1,5 - 2,5 times as much as in adjacent uplifts. Some local positive anomalies have been registered close to boundary faults of grabens.

Perhaps the main cause of such anomalies lies in additional heat transfer by underground water along big faults. An attempt is being made to resolve a pattern of correlation between heat flow values, seismic activity and density of faults. It seems that all three components at some places are in fact in direct correlation.

9. Magneto-telluric sounding of the earth's crust and the upper mantle. Three layers of high electrical conductivity have been discovered between the surface and 200 km depth. All layers are found to dip away from the rift zone axis. In the direction of the Siberian platform they dip more steeply than towards the Transbaikalia area. It seems that the uppermost layer of high electrical conductivity rises up underneath the Baikal graben to 25-30 kms depth and therefore penetrates the lower part of the earth's crust.

Results of Baikal rift zone study are described in recently published monographs as well as in a number of journal papers. Almost all of them are written in Russian. A collective report on undertakings during 1971-72 is in press and will be published soon. The Baikal Rift Commission has decided to prepare a comprehensive monograph on scientific activities in the Baikal rift area for the period 1971-1975. There is an intention to organize a W.G.4 meeting or an international symposium on rifting processes in Irkutsk in 1975, but no final decision has yet been reached. The commission will inform the chairman and members of W.G.4 about this matter at a later date.

## IV.6a REVIEW AND BIBLIOGRAPHY OF INDIAN OCEAN RIFTS*

by L.N. Rykunov.

Geological, geophysical and geochemical knowledge of the Indian Ocean is more limited in comparison with the Atlantic and Pacific Oceans. Nevertheless interesting and important data have been obtained during the last ten - fifteen years. The programmes of the International Indian Ocean Expedition (IIOE, 1959 - 1965) and Upper Mantle Project (1962 - 1970) were very productive in this respect. Obtained data allow us to describe the main features of the Mid-Ocean Ridge System in the Indian Ocean and to formulate future work.

The results of researches carried out in accordance with coordinated programmes include general maps, monographs and preceedings. The following publications can be mentioned: " Geology of ocean and sea floors ", (1964). Topographic maps of the Indian Ocean floor (Kanaev, 1967 ; Heezen and Tharp, 1964,1965,1966), papers concerning geological and geophysical ivestigations of the Northwest Indian Ocean (Phil. Trans. R. Soc. London, 1966), "The World Rift System " (Geol. Surv. Canada, 1967), " Earth´s crust and upper mantle of oceans" (Belousov, 1968), volume 4 of "The Sea" (Interscience Publishers, 1971), papers concerning the petrology of igneous and metamorphic rocks of the ocean´s floor, (Phil. Trans. R. Soc. London, 1971), "The Structure of the Mid-Ocean rift zone of the Indian Ocean and its place in the World Rift System" (Vinogradov et al, 1969), "Investigations into problems of oceanic rift zones" (in "Nauka", 1972) and "Atlas of Geology and Geophysics

* A review of earlier data has been given by Yentsch (1962).

of IIOE" (in accordance with decision of Intergovernment Oceanographic Commission of UNESCO in 1965, chief editor - Udintsev G.B.) now in press. This will summarise all available data on the Indian Ocean. "When published, this atlas will provide a substantial foundation on which to build new theories about the structure and origin of the Indian Ocean, and against which to test old hypotheses" (Laughton et al , 1971).

Basic geomorphological, geological and geophysical data have been obtained during expeditions on ships of several countries. The most remarkable results concerning the rift zones have been obtained from cruises of "Vitjaz" (1959 - 1960, 1960 - 1961, 1962, 1964 - 1965, 1967 ), "Academik Kurchatov" (1967) - USSR; "Owen" (1961 - 1962, 1962 - 1963)," "Discovery" (1962, 1963, 1964) - UK ; "Argo" and "Malita" (expedition "Monsoon", 1960 - 1961), "Argo" and "Horizon" (expedition "Lusiad", 1962 - 1963), "Argo" (expedition "Dodo", 1964), "Atlantis", "Konrad","Pioneer", "Bird", "Chain", "Vega", "Vema" - USA ; "Meteor" (1964 - 1965) - BRD ; "Umitaka Maru" (1962 - 1963) - Japan, and others.

The study of floor relief, sediments, hard rocks ; magnetic and gravity survey ; deep seismic sounding, heat flow measurements have been included in the programmes of these expeditions, covering many regions of the Indian Ocean.

## GEOMORPHOLOGY

Existing information about bathymetry of mid-Ocean ridges in the Indian Ocean is summarised in generalized maps ("The Indian Ocean", 1965 ; Heezen and Tharp, 1964, 1965, 1966 ; Laughton, 1966 ; Laughton et al, 1971) and in more detailed maps for a few regions. The Carlsberg Ridge and the Central Indian Ridge have been better studied than other parts of the mid-Ocean ridge system ("Bathymetric, magnetic and gravity ...", 1963, 1966 ; Bathymetric and magnetic results ...", 1964 ; Matthews, 1963 ; Zatonsky, 1964 ; Heezen and Nafe, 1964 ; Belousov, 1965 ; Kanaev and Marova, 1965 ; Matthews et al. 1965 ; Matthews, 1966 ; 1967 ; Kanaev, 1967, 1972 ; Udintcev, 1968 ; Kanaev and Mikhailov, 1969, 1972 ; Cann and Vine, 1966 ; Matthews et al., 1967 ; Udintcev, 1972 ; Fisher et al, 1971 ).

Limited data about the Southeast and the Southwest Indian ridges are contained in Ewing and Heezen, 1960 ; Fisher, 1964 ; 1967; Bunce et al., 1966 ; and Udintcev ; 1967.

During the past four years the eastern part of the unexplored Southeast Indian ridge has been studied by "Eltanin" expedition (1969-1971) (Hages and Conolly, 1972). The Southwest Indian ridge is now the least well-known of the Indian ridges.

The geomorphological features of the Indian Mid-Ocean ridges resemble mid-Atlantic ridge features as a whole. But it has been established that the structure of the Indian Ocean is more complicated and some features of it are unique. The northern part of the Central Indian ridge shows sharp discordance of topographic and structural trends with trends of the major ridge axis. The junction area between the three Indian Ocean ridges shows extremely irregular topography, with multi-fracture zones from the Southeast and Southwest ridges.

There are very few regions for which there exist detailed topographic maps of the Indian Ocean ridges. It would be reasonable to begin detailed geomorphological study by selecting polygons covering the most interesting areas of Indian Ocean rifts.

## MAGNETIC ANOMALIES

Magnetic anomalies were investigated by the expeditions named above. The principal aim of these investigations was to map the magnetic lineations, to resolve any connection with topography and geophysical parameters of the regions, to locate the magnetic bodies, etc. The sea-floor spreading hypothesis has been used as basis for interpretation of the observed data.

The results of magnetic measurements concerning all branches of the mid-Ocean ridge system in the Indian Ocean are contained in the review "The structure of the Indian Ocean" (Laughton et al, 1971), in the paper of Le Pichon and Heirtzler (1968) and in the comprehensive synthesis of McKenzie and Sclater (1971).

Magnetic data for the Indian Ocean ridge system are included in: Bathymetric, magnetic and gravity ... , 1963,1966; Bathymetric and magnetic results ... , 1964 ; Raff, 1964 ; Engel and Fisher, 1965 ; Matthews et al., 1965 ; Matthews, 1966 ; Cann and Vine, 1966 ; von Herzen and Vacquier, 1966 ; Vine, 1966 ; Schlich and Patriat, 1967 ; Matthews, 1967 ; Fisher, 1967 ; Fisher et al., 1968 ; Schlich and Patriat, 1968 ; Fisher et al, 1971 ; Weissel and Hages, 1972.

The compiled magnetic data show that very few regions yet covered systematically: northern part of the Arabian sea, small sectors of the Carlsberg ridge, regions near Prince Edward Island.

The magnetic profiling reveals the presence of the characteristic worldwide system of oceanic magnetic lineations in the Indian Ocean. But correct correlation of the magnetic anomalies invites further detailed magnetic surveys in the Indian Ocean.

## HEAT FLOW

The number of the heat flow measurements in the Indian Ocean is relatively large. But the sites of measurements are distributed very unevenly along the ridge system (Langseth and Taylor, 1967 ; Popova et al, 1972). Better distribution of heat-flow measurements is required, especially for the sparsely covered Southwest ridge.

A comprehensive review of available data on heat flow activity is given by von Herzen and Sclater for the IIOE Atlas (Laughton et al, 1971). Heat flow values are presented in: Lee and Uyeda, 1965 ; von Herzen and Langseth, 1967 ; von Herzen and Lee, 1969 ; Popova et al 1972).

Heat flow in the rift zones is very variable. But statistical summarizing of numerous available measurements demonstrates the higher heat flow along the axial zones of ridges. The existence of more complicated distribution of heat flow (minimum heat flow in the central parts of rifts, and maximum near the flanks) has been demonstrated (Vinogradov et al, 1969 ; Popova et al, 1972 ; Anderson, 1972 ; Laughton et al, 1971).

Interpretation of heat flow data is very important for establishment of a lithospheric model. But obtaining of more data with necessary accuracy demands the essential improvement of the methods of heat flow measurement and careful selection of more sites for these measurements (see especially "Understanding the mid-Atlantic ridge", 1972).

## SEISMIC INVESTIGATIONS

The distribution of seismic polygons and profiles in the Indian Ocean is shown on the generalized maps of Shor et al (1969), Neprochnov et al (1972) and Laughton et al (1971).

Information about the deep structure of rift zones is extremely limited. The structure of flanks of ridges in the instance of the northern part of the Central Indian Ridge is described by Francis and Shor (1966). Typical oceanic sections have been obtained.

The most detailed data about deep structure of axial parts of the mid-Ocean ridges (the Carlsberg and the Central Indian ridges) are presented in publications summarising the results of "Vitjaz" and "Kurchatov" expeditions (1964-1965, 1967) (Udintsev, 1966 ; Neprochnov et al, 1967 ; Neprochnov et al, 1969 ; Vinogradov et al, 1969 ; Magnitsky et al, 1970 ; Neprochnov and Rykounov 1970 ; Neprochnov et al, 1972). The multiprofile system of observation including long profiles (≃100 km), a large number of fixed recording stations, and automatic bottom seismographs have been used during this work. It has given new information about deep structure of complicated regions. Thus it has found an upper mantle discontinuity with unusually high seismic velocity. It has yielded estimates of the vertical velocity gradient and established the structure of the region.

The realisation of detailed seismic observations on the polygons and long range profiles, covering the most interesting rift sectors and adjacent regions, is strictly indispensable for the improvement of fundamental knowledge and understanding.

Seismic reflexion profiling results concerning the mid-Ocean ridges in the Indian Ocean are included in Ewing et al, 1969 ; Udintsev and Kogan, 1972; Neprochnov et al, 1972 ; Vinogradov et al, 1969 ; Neprochnov and Kholorov, 1970.

## SEISMICITY

Teleseismic data, for differing time intervals, have been used to compile maps by Sykes and Landisman, 1964 ; Stover, 1966 ; Barazangi and Dorman, 1969 ; and Sykes, 1970.

The position of earthquake epicentres is basic evidence for mapping the rifts and fracture zones. Study of the seismic focal mechanism and fault plane solutions are a second important contribution of seismology to understanding of mid-Ocean ridges. The results of teleseismic study of focal mechanisms of some Indian Ocean earthquakes are discussed in Misharina, 1967 ; and Banghar and Sykes, 1969.

The first attempts have been made to use networks of bottom seismographs for high precision location of small and microearthquakes (including the estimation of the foci depths), for study of focal mechanisms, magnitudes, temporal distributions, aftershock activity, swarms of earthquakes etc. (Rykounov, 1969; Rykounov and Sedov, 1972 ; Rykounov et al - unpublished works of 1972).

## CONCLUSION AND RECOMMENDATIONS

My bibliography lists information which can be used for referring to the present status of knowledge of the Indian Ocean ridges. More comprehensive data will be published soon in the International Indian Ocean Expedition Atlas (IIOE Atlas). These new data will provide an excellent base for working out a new and improved programme of Indian Ocean Studies.

My brief review shows that:

a) The Indian Ocean is the most complicated and least understood of the world's major oceans.

b) There are very few regions which are covered by detailed geophysical surveys. The distribution of these regions along the ridges is extremely irregular.

c) Regions with unique features (as well as the regions of more or less typical rift structure) can now be identified in the mid-Ocean ridges system of the Indian Ocean. These regions include triple junctions, complicated equatorial parts of ridge, zones in the western and eastern branches of the ridge system, and a zone of transition between the Southwest Indian ridge and southern part of the mid-Atlantic ridge.

The following recommendation can be suggested. It would be useful to identify the special international polygons in the mid-Ocean ridge system of the Indian Ocean, covering the rift areas which are the most interesting and important for understanding of rifting. This will concentrate the efforts of countries taking part in studies of the Indian Ocean and help to provide more representive data and a more systematic growth of knowledge.

A group of competent scientists should identify the regions for the initial investigations. Some of such regions for example can adjoin existing polygons where English, Soviet and American geophysical surveys have already been carried out (the Carlsberg ridge, the Central Indian ridge) or can be situated in essentially new parts of the ridge. Working Group 4 should ask the editors of IIEO Atlas to supply it with these special recommendations.

The principal directions of mid-Ocean ridge studies are also discussed in the comprehensive programme "Understanding the mid-Atlantic ridge", published by the National Academy of Sciences (USA) in 1972. Practically all the programmes of investigations recommended there can be applied to the Indian Ocean ridge system.

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# IV.5a MAJOR PROGRAMS OF SOME SOVIET SCIENTIFIC INSTITUTES RELEVANT TO THE GEODYNAMICS OF OCEANIC AND CONTINENTAL RIFTS.

by L.N. Rykunov

## I. Major problems and directions of investigations.

- Crustal structure and geophysical properties of the rift zones.
- Upper mantle structure beneath the rift zones.
- Transition zones between rifts and adjacent regions.
- Connections between recent ground movements and rift zone structure.
- Geological history of rifting.

Participating Institutions - Institute of Physics of the Earth (IPE) Bolchaya Gruzinskaya 10, Moscow;
Institute of Oceanology (IO) Moscow;
Geological Institute (GI) Pyzhevsky Per. 7, Moscow;
Geochemical Institute (Geoch.I) Vorobyevskoyeschosse, Moscow;
Moscow State University (MSU) B-234, Moscow;
Institute of Geology and Geophysics (IGG) P.O.Box 90, Novosibirsk ;
Institute of the Earth´s crust (IEC) 664033 Irkutsk ;
Eastsiberian Geophysical Trust (EGT) 664003 Irkutsk ;
Institute of Volcanology (IV), Petropavlovsk, Kamchatka.

## II. Regional investigations

1. Investigations of rift zones of the Indian Ocean.

- Studies of crustal and upper mantle structure and seismicity (Neprochnov Y.P. - IO Rykunov L.N. MSU)

- Studies of the magnetic field (Mirlin E.G. - IO).
- Studies of magnetic properties of the rocks (Pechersky D.M. - IPE)
- Geochemical and petrologic investigations (Dmitriev L.V.- Geoch I, Udintsev G.B. - IO)
- Geological study (Udintsev G.B. - IO)

2. Investigations of rift zones near Iceland.
(V.V. Belousov, S.M. Zverev - IPE, G.B. Udintsev - IO).
- Studies of deep structure to clarify the nature of connections between Iceland and adjacent oceanic regions (S.M. Zverev - IPE, G.B. Udintsev - IO)
- Studies of microseismicity and its relation with tectonics. (S.M. Zverev - IPE)
- Geological, volcanological, geothermic and hydro-chemical investigations (V.V. Belousov - IPE)
- Geochemical and petrologic studies (V.I. Gerasimovsky, L.V. Dmitriev - Geoch. I)
- Geophysical survey of the ocean regions adjacent to Iceland (G.B. Udintsev, V.F. Kanaev - IO)

3. Investigations of the Baikal rift (N.A. Florensov - IEC)
- Deep seismic sounding (N.N. Pusyrev - IGG)
- Magneto-telluric sounding along the DSS profiles (V.V. Mandelbaum - EGT)
- Studies of surface crustal deformation using geomorphological and geodetic methods (D.V. Lopatin - IEC)
- Studies of geodynamics, geokinematics and morphology of the faults in the rift zones (S.I. Sherman - IEC)
- Numerical estimation of recent tectonic movements by geodetic methods (E.E. Fotiadi - IGG)
- Detailed studies of seismicity of the rift zones (V.N. Gaysky - IGG)

4. Investigations of the Kamchatka rifts (S.A. Fedotov)

IV.6.b Note on French oceanographic researches in the Indian Ocean. (compiled from information supplied by R. Schlich).

The attached map summarises the tracks which have been run by the ship 'Gallieni' since 1967.

Our priorities for future work between Kerguelen Is. and Africa are:

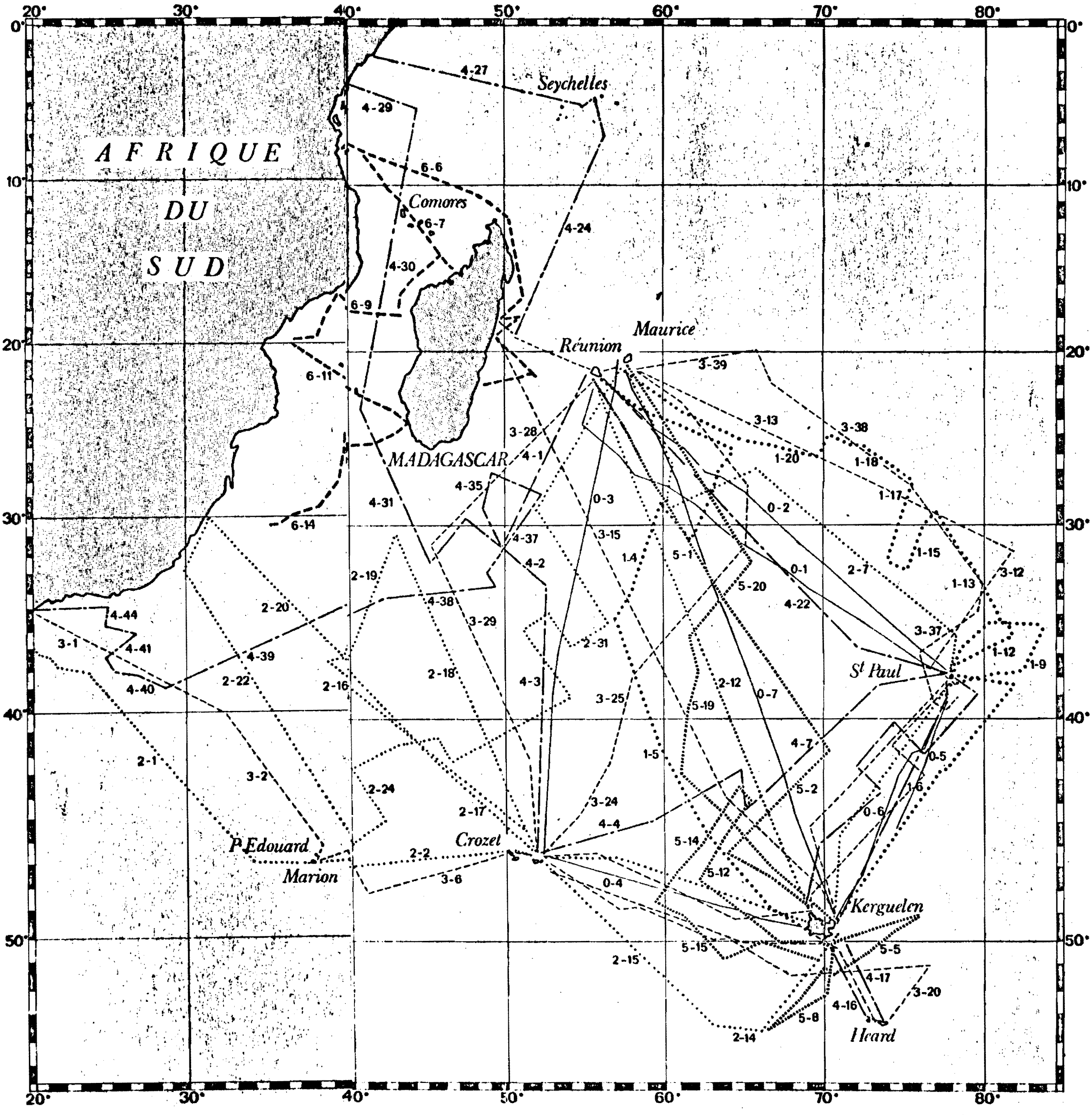
(i) The origin and age of the Crozet, Madagascar, Mascarenes, Mozambique and Somali basins.

(ii) the relationships of these basins to adjacent plateaux and for continental margin: Kerguellen Lena, Crozet, Agulhas, Madagascar and Mozambique.

(iii) to study the area south of Crozet and Kerguelen Is. to better understand the separation of Africa and Antarctica.

(iv) the nature of the triple junction near Rodriguez Is.

(v) relationship of the African rift system with the Mozambique Channel.




CAMPAGNES OCEANOGRAPHIQUES DU GALLIENI
DANS L'OCEAN INDIEN
1967 — 1972

## IV.9 Rifting in Iceland; Relevant Geodetic Research

by R.W. Decker, Dept. of Earth Sciences, Dartmouth College,
Hanover, NH 03755, U.S.A.

Geodetic experiments designed to detect ground surface movements in Iceland were started in 1938 by Niemczyk and continued by Gerke and Pelzer during 1964 to 1969 (Das Unternehmen Erdmantel, 1972). The German group established a triangulation net across the rift zone near Mývatn in the north of Iceland in 1938. Remeasurement in 1964-1965 showed changes of the intermediate points from 0 to 4 meters in a westward direction relative to the two end points on the west and east sides of the rift zone. The two end points were arbitrarily held fixed so no net movement across the entire triangulation net was allowed. Portions of the northern rift showed apparent contraction of 5 to 10 mm/km-yr. A geodimeter survey was made over part of the triangulation net in 1965 and remeasured in 1968. This also showed apparent contraction of 14 mm/km-yr. Creep meters of invar wire were installed in 5 fissures in 1967 but showed no change to 1969. A level line across the rift zone in the north of Iceland was also established in 1938 and remeasured in 1965 to 1967. Points in the rift zone showed subsidence of 5 to 10 mm/yr. The German group also established a geodimeter net in the Thingvallavatn area in 1967 but have not yet remeasured these lines. Eysteinn Tryggvason (1968, 1970, 1973) established several very high precision level lines in Iceland during 1965 to 1972 in the Thingvallavatn, Myvatn, and Reykjanes areas. The level line across the north end of Thingvallavatn shows a yearly subsidence of 1 mm whereas subsidence of a few cm has occurred on one of the Reykjanes level lines apparently related to an earthquake displacement.

R. Mason of Imperial College, London (personal communication) established horizontal measurement nets in the Thingvallavatn and Reykjanes areas during 1967-1972. No movements have been detected near Thingvallavatn, but a trend of left-lateral strike-slip motion of about 1 cm has been observed on the NE-SW fractures of the Reykjanes Peninsula.

Decker, Páll Einarsson, and Mohr (1971) established geodimeter profiles across the western and eastern rifts in southern Iceland during 1966 to 1973. No measureable changes have occurred at Thingvallavatn (the western rift). Small but measureable extensions of 6 to 7 cm over a distance of 10 km in the eastern rift occurred between 1967 and 1970, possibly during the 1970 eruption of Hekla volcano.

The fact that small contractions, extensions, and horizontal shear motions have been detected by the various groups is not surprising. Most of the horizontal deformations are small and just barely exceed the precision of the measuring techniques. Even if they are all real deformations, it is well known that a deviatoric stress field produces different strains in various directions to the stress axes. It will probably take several years before a consistent stress pattern emerges from the geodetic research in Iceland.

Geodetic techniques for measuring small ground surface deformations have been recently reviewed by Decker and Kinoshita (Unesco, 1971) and recommendations for additional geodetic research in Iceland have been made in the mid-Atlantic Ridge Program (National Academy of Sciences, 1972).

Finally, I would like to ask for help in expanding this brief review of geodetic research in Iceland to a more comprehensive review of ongoing geodetic studies in all the world's rift zones. Please send me the names and addresses of persons studying these problems so that a more comprehensive report can be prepared for the next meeting of working group 4.

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IV.11

## GEOPHYSICAL INVESTIGATIONS IN ZAMBIA

(Professor H.N. Pollack)

| Subject | Investigating Organization | Scope | Status |
|---|---|---|---|
| Gravimetry | Geological Survey of Zambia Universities of Zambia and Michigan. | Nationwide reconnaissance, some detailed studies of certain tectonic elements. | Reconnaissance (  1000 stations) to be completed 1973; detailed studies of Tanganyika-Mweru rift juncture and west central seismic zone underway. |
| Airborne magnetic survey | Geological Survey of Zambia. | Nationwide reconnaissance. | Western province completed 1973, completion of other areas expected 1974. |
| Seismology | University of Zambia | Local seismicity, crustal structure | Two stations of tripartite network installed, local travel times being assembled. |
| Heat flow | Universities of Michigan and Zambia. | Nationwide heat flow survey. | Heat flow determinations in progress in 30 boreholes, representing 12 regions in the central African plateau. Preliminary results expected early 1974. |