INTER-UNION COMMISSION ON GEODYNAMICS

REPORT OF WORKING GROUP 4 MEETING IN ICELAND

16-20 July 1973

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1. Introduction

Working Group 4 met in Iceland from 16-20 July 1973, under the chairmanship of Dr. Gudmundur Pálmason. The meeting was attended by eight of the fifteen Working Group members (appendix I). The chairman had previously appointed Dr. Paul Mohr as secretary for the meeting.

Travel expenses of some WG 4 members were supported by a grant from ICG and the Royal Society of London for which thanks were expressed. The Working Group is most grateful to the sponsoring Icelandic organisations for facilities and hospitality extended throughout the meeting. Particular appreciation was expressed concerning the excellent field excursions arranged and led by Dr. Kristján Saemundsson, during and after the meeting. Dr. Saemundsson was invited to sit in on the Working Group sessions.

Following a general discussion of the aims of WG 4, a series of lectures was given by members and invited scientists on the geodynamics of Iceland (appendix II). This was followed by reviews by each WG member, covering his particular field of competence (appendix III). It was noted that the absence of many WG 4 members caused a marked inbalance in favour of continental rifts, an imbalance which the Group attempted to keep in mind during its subsequent deliberations and decisions. It was also noted that, amongst oceanic rifts, the mid-Atlantic rift had been the subject of some extensive recommendations in "Understanding the mid-Atlantic Ridge" (National Academy of Sciences, Washington, D.C., 1972).

2. General Statement

The Working Group has resisted suggestions that it be subdivided into continental and oceanic rift study groups. The concept of discussion within unity is preferred.

The precise function of the Working Group received attention, and it was decided to be:

(i) Keeping abreast of researches relevant to rifts, bearing in mind that the primary function of the Group is an advisory one.

(ii) making recommendations to assist on-going and future studies, directed especially to those fields where there are gaps in present knowledge and understanding.

(iii) sponsoring of symposia on various aspects of rifts.

The existence of older, now inactive rifts (eg. Oslo graben) was recognised, but it was decided to restrict Working Group involvement to active rifts. Nevertheless, a liaison or the setting up of study groups with scientists working on palaeo-rifts is to be encouraged.

Future meetings of WG 4 were discussed. It was agreed that concurrence with the IUGG General Assembly in Grenoble (August 1975) would be desirable. Furthermore, that the meeting might be extended by then transfering the venue to Irkutsk: Dr. Logatchev stated that the Soviet Baikal Rift Commission would almost certainly look with approval on a 1975 Lake Baikal meeting for WG 4.

Proposals for a 16th member to fill the Working Group were deferred.

The Group recommended that the present report be submitted to the ICG, together with the appendices, for approval and publication. Noting that the bibliographies, compiled with some labour, would become obsolescent in a year or so, it was also recommended that these be published quickly, and widely distributed.

3. Recommendations.

3.1 GEOLOGY

The mantle processes which cause crustal rifting can be studied by their effect on the surface of the Earth, and also by investigations of volcanic rocks derived from the interior.

Generally, rifting is associated with contemporaneous crustal uplift. This initiates erosion and sedimentation which occur concurrently with volcanism.

Although rifting and uplift are related in time and space, there are few data concerning the precise rate and magnitude of these processes. Information can be obtained from detailed geomorphological analysis of uplifted surfaces and the development of rift structures, account being taken of the additive processes of volcanism. Our ultimate aim is to elucidate the nature of the primary thermal and mechanical processes causing these, within the Earth.

In a continental setting the rift pattern is related, in part, to the upper crustal tectonic fabric, the tectonic stress pattern often making use of pre-existing lines or zones of weakness. It seems probable therefore that although the detailed location of rift zones within the upper, brittle carapace of the Earth's crust may be controlled by palaeo-sutures, these do not explain the regional disposition of the rift system.

Some continents were once contiguous and the possibility has been proposed that continental rift systems develop into major constructive margins. The development of existing continental rifts should be examined as possible initial stages of drifting and sea-floor spreading.

The spectacular development of volcanic activity that is commonly associated with rifting has been and is the subject of considerable attention. It is of primary importance that the historical relationship between tectonic setting, composition and volume of these eruptives be more precisely studied.

For convenience we accept the two fold division of rifts into oceanic and continental, noting that little is known about behind- and within-arc rifts and their relation to subduction processes.

Recommendations.

1. We urge that quantitative measurement of subsidence and uplift be undertaken to evaluate rates of vertical movements. The volume of material eroded from elevated areas and deposited within the developing rift zones should then be estimated. These measurements should

be made for all stages in the development of rift systems so that the episodic or continuing nature of rifting and uplift can be assessed. Discrimination is required between the vertical movement due to isostatic readjustment and to thermal processes. Such investigations would provide information concerning the viscosity of the asthenosphere. We note that measurements of this type have started in the Rheingraben, and urge their continuance there and their initiation elsewhere.

2. We note the need for more radiometric dating of volcanic rocks carefully chosen with regard to their stratigraphic position. Re-assessment of the quantities and compositions of volcanic materials in time and space is required.

3. Completion of systematic mapping of all rift structures and studies of present and past stress fields from investigations of dyke orientations, microtectonic structures and fabric analysis are encouraged. Correlation of physiographic, volcanic and tectonic information is required so that the underlying geodynamic causes can be studied.

4. Concerning the development of oceanic from continental rifts we urge the continuing investigation of the Gulf of Aden, Red Sea and Afar regions, paying attention to the respective roles of downwarping and fracturing in the formation of new continental margins.

5. We support the continuance and expansion of deep sea drilling and dredging programs related to oceanic rifts. Further geochemical investigations are desirable, including analysis of cores from layer 2. Such work may give information on possible "hot spots".

6. We recommend the detailed study of all sub-aerial exposures of oceanic lithosphere, so that the magmatic and metamorphic processes operating beneath oceanic rift zones can be evaluated. Metamorphic zoning in the neighbourhood of spreading centres should be further investigated. The formation of massive sulphide deposits is probably related to this metamorphism and merits further study.

7. The study of laboratory and finite element modelling of rifts and transforms is to be encouraged.

8. In the continental setting we suggest that one rift sector be subjected to a complete spectrum of scientific investigations, and follow the U.M.C. Nairobi (1965) meeting in suggesting that the Kenya rift is the most suitable contender.

3.2 SATELLITE IMAGERY.

Status. The potentialities of satellite imagery for aiding regional geological and structural mapping were first revealed by photographs taken by astronauts on the U.S. Gemini and Apollo missions. These photographs (mostly oblique) have been much used by Earth scientists, though strong cautions have been expressed on the need for extensive ground control.

A systematic coverage of many land areas of the Earth, by vertical multi-spectral scanning, started with NASA's ERTS-1 satellite in July 1972. Colour composites can be constructed from three spectral bands: green, red and near infra-red. The images are generally reproduced at a scale of 1:1 million, and each image covers an area of 180x180 km^2. Resolution can be as good as 50 m, more typically 150 m.

ERTS-1 imagery is already being used for unified regional mapping of the structural lineaments and gross lithological boundaries associated with the African rift system. Some of the lineaments can be identified with feature already recognised on the ground ; others cannot, and further ground surveys will be required. Similarly, interpretation of ERTS-1 imagery of Iceland is now in progress.

Recommendations.

1. That structural lineaments be systematically mapped from existing ERTS-1 imagery at a scale of 1:1 million, and where possible co-ordinated with ground surveys.

2. That proposals be made that ERTS-B (launching date, 1976) will image all continental rifts: East Africa, the Gulf of Aden and Red Sea margins, the Gulf of Suez and Aqaba, the Dead Sea rift, the western European grabens, the Baikal graben and its possible extensions, the inter-arc grabens (eg. New Zealand; Sumatra; Central America).

3. Projects requiring a greater resolution than possible with ERTS satellites should consider proposals to the NASA SKYLAB satellite experiments.

Possible additional uses of satellites:

1. Infra-red sensing of thermal areas.
2. Measuring intercontinental distances.

3.3 GEOTHERMY.

New lithosphere is generated at diverging plate boundaries by intrusion of igneous material. This process gives rise to high heat flow, and at the surface, extrusive volcanism and hydrothermal activity are frequently observed. Away from the boundary the heat transport is by conduction.

It is of importance for an understanding of the mechanism of crustal generation to know the magnitude of the various modes of heat transport and their areal distribution. For this purpose measurements of surface heat flow are needed as well as estimates of the volume productivity of extrusive volcanism. Heat transport to the surface by hydrothermal activity may be a significant part of the total heat budget and this should therefore be estimated in some detail.

The economic importance of heat transport studies of rift zones stems from the occurence of the majority of the world's geothermal resources in the rift and island arc zones. These geothermal resources are becoming of increasing importance in many areas in providing a relatively cheap and pollution-free form of energy.

Ocean-bottom heat flow measurements show a large scatter in the axial zones of the mid-ocean ridges, which is presumably due to various disturbances, for example the movement of water in the heavily fractured crust. This is shown very clearly by the available borehole temperature data from Iceland. Deep boreholes into layer 2 of the oceanic crust near ridge axes would provide a good opportunity for comparing the crustal temperature field in the oceanic ridges with similar measurements made on land ridge segments.

Magnetotelluric soundings also offer promising possibilities for obtaining information on upper mantle temperatures in rift zones and complement surface heat-flow measurements, by giving fairly reliable temperature estimates at depths of a few tens of kilometers.

Recommendations.

1. It is recommended that countries with rift zone studies on their program make special efforts to collect crustal temperature data from any existing boreholes in or near rift areas.

2. It is recommended that geothermal profiles consisting of a number of boreholes of suitable depth be placed across the land rift zones, in order to detect heat flow variations associated with the mechanism of crustal generation. Such geothermal profiles could advantageously be combined with exploration programs for geothermal resources.

3. It is recommended that special attention be given to the study of palaeogeothermics in rifted regions.

4. It is recommended that special efforts be made to obtain reliable crustal temperature data from deep boreholes to be drilled into the oceanic crust near the mid-ocean ridge crests and arc system rifts.

5. It is recommended that magnetotelluric soundings be undertaken in rift areas and that they be combined with heat flow measurements to obtain lower crustal- and upper mantle temperature data.

3.4 GEOMAGNETISM.

The concept that the World Rift System represents spreading margins of diverging lithospheric plates was greatly strengthened by the discovery and interpretation of the linear magnetic anomalies of bilateral symmetry about and parallel to the oceanic rift axes. Because so many conclusions on the rate and kinematics of plate motions are based on these magnetic anomalies, it is difficult to overemphasize the importance of understanding their source and pattern. The following investigations are suggested:

1. Comparative studies of the source and pattern of mid-Atlantic Ridge magnetic anomalies, and the magnetic anomalies of Iceland. Iceland is unique in that it is apparently crossed by an oceanic rift system, and thereby provides an above-water field laboratory for magnetic studies.

2. Review magnetic anomaly patterns with regard to the possibility of intermittent spreading. This suggestion has recently been made to explain the Red Sea magnetic anomaly pattern.

3. The acquisition of additional near-bottom oceanic magnetic profiles to observe and interpret short-wavelength components of the magnetic anomalies. Are the boundaries of the magnetic anomaly patterns as regular near the sea floor as their recording at sea level implies ?

4. Additional field and laboratory experiments to determine the source of magnetization in igneous rocks formed along rifting plate margins, and also the processes which appear to cause loss of magnetization away from the rift axes.

5. Attempt to trace the weak magnetic patterns further into the magnetically quiet areas of the sea floor. This may give some insight into the earlier histories of lithospheric plate kinematics.

3.5 GRAVIMETRY.

For a detailed study of the tectonics and crustal structure of rift zones, gravity information is an essential supplement to seismic data.

A vast quantity of surface observations concerning the gravity field over rift zones has already been collected by different agencies, a good proportion of which is not deposited in World Data Centers.

It is therefore suggested:

a) that scientists working in rift zones deposit their gravity data more readily with the Bureau International de Gravimétrie (Paris), including data extending to distances of 200 to 300 km from the rifts.

b) that a gravity map of the rift zones and margins be produced possibly using $(1x1)^{\circ}$ mean values for continents and not more than $(5x5)^{\circ}$ for oceans. Critical gaps in the resulting maps should be filled by selected longitudinal and transverse profiles.

Gravity maps would not only reveal density contrasts in the crust and upper mantle but also possible temperature variations. A longitudinal gravity profile along the axis of rifts could help to locate any discrete hot spots.

Satellite gravity data are now approaching a resolution which will complement the surface data by producing density anomaly information down to a depth of the order of the width of major ridge-rift features.

3.6 SEISMOLOGY.

The Working Group recognises the importance of various techniques involving both exploration and earthquake seismology for investigating the nature of plate boundaries and for testing various hypotheses relating to their evolution.

We particularly recommend:

1) the use of seismic profiler records to examine in detail the thickness of sediments as a function of distance from the axes of mid-ocean ridges with the possibility of discovering pauses in sea floor spreading.

2) the use of seismic profiling to obtain greater penetration in an effort to obtain reflexions below the base of layer 1 in order to understand the structural evolution of the various oceanic layers.

3) attention to the careful location of epicentres and their depth of focus using local arrays and other techniques, and where possible relating the epicentres to topographic and geological features.

4) the more widespread use of ocean bottom seismometers for the furtherance of (3) and for the study of local crustal and earthquake magnitude-frequency studies.

5) the design of experiments (involving both explosion and earthquake seismology) to study the anisotropy of both the lithosphere and asthenosphere.

6) the use of various seismic internal reflexion phases such as P_dP for determining the thickness of the lithosphere especially its variation with distance from the plate boundary (rifts).

7) the design of experiments to test the various hypotheses of mantle convection plumes at or near plate boundaries. These might involve various ray paths from the same event with some of the paths passing through the "hot spot region" and some on either side of it. This could be done using existing records and ray tracing programmes.

The Working Group recognizes that a lot of progress can be made using data collected by such organisations as the I.S.C. Edinburgh, and the W.W.S.S.N. Such organisations should be encouraged and receive support to continue their excellent services. In addition it is recognised that some countries hold valuable array data which can be used to facilitate these studies, and the Working Group strongly recommends that such data should be preserved and made available for future use.

3.7 STRESS AND STRAIN.

Knowledge of the rates and directions of deformation within and near rift zones will help in elucidating the stress fields related to rift dynamics. New techniques of accurate vertical and horizontal deformation measurements are needed. Gravity meters with accuracies of 0.01 milligal can be used to inexpensively and more rapidly measure elevation changes of $\pm$ 5 cm; 2-colour optical-electronic distance measuring devices offer the promise of measuring horizontal strains of 10^{-7}. New ideas on submarine geodetic measurements are required for monitoring oceanic rifts.

Continuous strain measurements, probably with recording tiltmeters, are needed to determine whether rift deformation is continuous or episodic and how much is from creep and how much from rupture.

Geodetic measurements should be complemented with geologic estimates of rates and patterns of deformation wherever possible. Fracture patterns, lineations, orientation of stylolites, deformed spherulites and rates of sedimentation all offer independent geologic checks against the geodetic results. Other direct stress measurements such as hydraulic fracturing, over-coring, and seismic first motion studies are needed to resolve the stress and strain dynamics of rift systems.

Various strength parameters such as viscosity and flexural rigidity of the lithosphere are closely related to stress and strain determinations. Glacial rebound rates are a measure of asthenospheric viscosity, and tidal stresses versus strains offer a way to estimate the Love numbers. Comparison of intercontinental base-line strains with short base-line strains near rift axes may yield some data on intra-plate strains.

The rates of strain in active rift zones are in the range of 10^{-5} to 10^{-7} per year, and to obtain consistent results will probably take several years. Therefore, the sooner investment is made in establishing the needed reference measurements, the sooner meaningful and scientifically productive results will be forthcoming.

3.8. DEEP DRILLING.

The Working Group has discussed the scientific aims of deep drilling in rift areas. These are multidiciplinary projects, which would give very important information regarding the processes taking place in such areas. It is understood that the Deep Sea Drilling Project plans to drill in the mid-Atlantic ridge, and the Working Group would like to recommend three deep drilling projects in three distinct and seemingly very different parts of the World Rift System. These are the Iceland, Baikal and Kenya rifts. The scientific aims of each of these projects is outlined:

Iceland

1. To obtain information on the nature of the seismic boundaries in the crust, in particular the nature of layer 3. The observed seismic velocities in layer 3 (6.3 to 6.7 km/sec) are thought to be appropriate for either metamorphosed basaltic rocks or for intrusive rocks mainly in the form of dykes.

2. To study the physical properties of the rocks cored and especially their magnetization and its variation with depth. The magnetic properties are of particular importance for the interpretation of the magnetic anomalies observed both in Iceland and on the submarine mid-ocean ridges.

3. To obtain deep crustal temperature data from a borehole close to a rift zone. Available heat flow data indicate that a temperature of 400 to 500°C may be found at a depth of 4 km. Such findings would be of great importance for assessing the heat source of the geothermal areas in rift zones, and for understanding low-pressure temperature-controlled metamorphic processes.

4. To compare the above data with similar data from boreholes drilled by the Deep Sea Drilling Project in and near the axis of the mid-Atlantic Ridge system. This would help in deciding to what extent Icelandic data can be applied to the submarine mid-ocean ridge system, and would help to understand why Iceland and its surrounding insular shelf seems to be different in several respects from the typical oceanic ridge, to which it belongs.

Baikal

It is of great importance to obtain new data by deep drilling in the Baikal rift area, in particular:

1) to increase our knowledge of the stratigraphy and thickness of the sedimentary and volcanic infill within the Baikal graben, where the total thickness is estimated from reflexion data to be close to 5 to 6 km. Evidence from boreholes suggests that early Cainozoic sediments might exist at depth.

2) to study physical properties and composition of the rocks.

3) to make heat flow measurements.

Kenya

It would be desirable to choose a site near the centre of the rift where the most complete succession of volcanics and sediments is likely to be found (of the order of 3 to 4 km), and where the nature of the sub-volcanic surface is unknown. The axis of the rift is associated with a maximum Bouguer anomaly and thermal activity, and it is likely that the sialic Precambrian crust is very thin or even non-existent here. Location of the borehole along or near the axis of the positive anomaly will test previous gravity interpretations and provide critical data for reinterpretation of the anomaly.

The volcanic sequence established in the proposed borehole would be compared in detail with the already studied sequences exposed on the rift shoulders. Continuous coring would enable a thorough study of the petrology, mineralogy, chemistry, radiometric ages and physical properties of the rocks.

The borehole would be used to measure temperatures and obtain the heat flow near the centre of the rift.

APPENDIX I

Attending Members of Working Group 4

Chairman:

Gudmundur Pálmason	National Energy Authority Laugavegur 116 Reykjavík, Iceland.

Secretary:

Paul Mohr	Smithsonian Astrophysical Observatory 60 Garden Street Cambridge, Mass. 02138, U.S.A.

Members:

R.W. Decker	Dept. of Earth Sciences Dartmouth College, Hanover, NH 03755, U.S.A.
I.G. Gass	The Open University, Walton Hall, Milton Keynes MK7 6AA, Buckinghamshire, U.K.
R.W. Girdler	School of Physics,The University, Newcastle upon Tyne, NE1 7RU, U.K.
P. Gouin	Geophysical Observatory, Haile Sellassie I University P.O.Box 1176, Addis Ababa, Ethiopia.
J.H. Illies	Geologisches Institut Universität Karlsruhe, Kaiserstrasse 12, 75 Karlsruhe 1, F.R.G.
N.A. Logatchev (for N.A. Florensov)	Institute of the Earth's Crust, Irkutsk 33, U.S.S.R.
K. Saemundsson (for G.E. Sigvaldason)	National Energy Authority, Laugavegur 116, Reykjavík, Iceland.
L.A.J. Williams	Dept.of Environmental Sciences, University of Lancaster, Bailrigg, Lancaster, U.K.

Invited Scientists

Sveinbjörn Björnsson	National Energy Authority Reykjavík, Iceland
Trausti Einarsson	University of Iceland Reykjavík, Iceland
Karl Grönvold	National Energy Authority Reykjavík, Iceland
A. Krasnov	Institute of Geology of Ore Deposits, Petrography,Mineralogy and Geochemistry, Academy of Sciences, Moscow, U.S.S.R.
Leó Kristjánsson	University of Iceland Reykjavík, Iceland
E.E. Milanovsky	Moscow State University Moscow, U.S.S.R.
Sigurður Steinthórsson	University of Iceland Reykjavík, Iceland
R.S. Williams, Jr.	U.S. Geological Survey EROS Program, Washington, D.C. U.S.A.
S.M. Zverev	Institute of the Physics of the Earth, Academy of Sciences, Moscow, U.S.S.R.

APPENDIX II

Reviews of state of knowledge regarding Iceland and neighbourhood.
(Given in Reykjavík on Monday, 16 July 1973)

Kristján Saemundsson:

Geological structure of the zones of rifting and volcanism. Central volcanoes, eruptive fissures. Regional dips of flood basalts. Lenticular units. Age determinations (radiometric). Shifting of the volcanic zones. Tjörnes fracture zone.

Gudmundur Pálmason:

Seismic structure of the crust and upper mantle. Gravity survey of Iceland and insular shelf. Teleseismic P-wave delays, ratio V_p/V_s. Viscosity, electrical conductivity and temperature of upper mantle. Heat flow, regional pattern.

Sveinbjörn Björnsson:

High-temperature geothermal areas. Heat output. Exploration by surface surveys and drilling. The Reykjanes area. Low-temperature areas. Micro-earthquakes, distribution in space and time. Larger earthquakes. Comparison with Reykjanes and Jan Mayen ridges. Westman Islands earthquakes.

S.M.Zverev:

Results of North Atlantic Seismic Project 1972. Some comments on results of Soviet Geodynamics Expedition to Iceland.

Leó Kristjánsson:

Aeromagnetic surveys of Iceland and surrounding shelf. Magnetization of Icelandic basalts. Comparison with Reykjanes Ridge. Magnetic anomalies and central volcanoes. Geomagnetic time scale.

Karl Grönvold:

Distribution of acid rocks in Iceland.
Sr-isotope studies of Icelandic rocks.

Sigurdur Steinthórsson:

Origin of the acid rocks, based on studies of Hekla.
Oxygen isotopes
Trace elements

R.S. Williams, Jr.

Potential usefulness of satellite imagery for the study of rift zones, with particular reference to Iceland.

R.W. Decker:

Rifting in Iceland: relevant geodetic research.

APPENDIX III

Titles of reviews presented by Working Group members

(Given at Laugarvatn, 18 July 1973)

I.G. Gass - Magmatic and metamorphic processes at constructive plate margin as exemplified in the Troodos massif, Cyprus.

- Within-plate magmatism and the development of transcontinental rifting with special reference to the Red Sea.

R.W. Girdler - Geophysical studies of the Gulf of Aden and Red Sea.

P.A. Mohr - Review of the geology of the Horn of Africa.

P. Gouin - On-going geophysical projects in Ethiopia.

L.A.J. Williams - Geology of the Kenya rift.

N.Logatchev - Baikal rift studies.

J.H. Illies - Western European rifts.

E.E. Milanovsky (for L. Rykunov) - Review of Indian Ocean ridge-rift studies.

The written submission of a review by Dr.D.E. Karig, entitled "Island arc trailing edge and crustal extension" was noted, and part is reproduced in Appendix IV.

APPENDIX IV

Reviews and bibliographies submitted by WG 4 members.

1. Iceland in relation to the mid-Atlantic ridge, (summary and conclusions), to be published in Annual Review of Earth and Planetary Sciences, Vol.2, 1974, by Gudmundur Pálmason and Kristján Saemundsson.

2. (a) Magnetic and metamorphic processes at constructive plate margins,
   (b) Within-plate magmatism and the development of transcontinental rifting,
   (c) Tectonics and magmatism of the Red Sea,
   by I.G. Gass

3. Bibliography and list of on-going Earth-science researches in Ethiopia and adjacent areas,
   by P. Gouin

4. (a) Some results of geological and geophysical investigations in the Kenya rift valley, 1968-1973.
   (b) Selected bibliography for the Kenya rift, 1968-1973, and list of on-going researches,
   by L.A.J. Williams.

5. (a) Major programs of some Soviet scientific institutes relevant to the geodynamics of oceanic and continental rifts.
   (b) Information on researches in the Baikal rift zone,
   by N. Logatchev (for Prof. N.A. Florensov)

6. (a) Review and bibliography of Indian Ocean rifts
   by L.N. Rykunov
   (b) Note on French oceanographic researches in the Indian Ocean ,
   by R. Schlich

7. Titles of contents of "Approaches to Taphrogenesis" (a volume concerning the geology and geophysics of the Rhinegraben
by J.H. Illies and K. Fuchs

8. Island arc trailing-edge and crustal extension
by D.E. Karig

9. Rifting in Iceland : relevant geodetic research
by R.W. Decker

<u>Additional documents submitted to WG 4</u>

10. Italian program for Working Group 4
received from Professor Morelli

11. Geophysical investigations in Zambia
received from Professor H.N. Pollack (Univ. Michigan, Ann Arbor, Michigan 48104, U.S.A.)