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ABSTRACT

The general concurrence of volcanoes and geothermal fields along plate margins is an established fact. The different types of plate boundaries, however, give rise to variations in the geological settings of volcanic and geothermal areas, both with regard to the heat flow pattern and the lithology and thickness of the crust through which magma and geothermal fluids must penetrate.

At a constructive plate boundary, like in Iceland, the entirely igneous crust ages and the heat flow decreases symmetrically away from the boundary. Active volcanoes and steam fields are confined to a 20-50 km broad zone along the boundary, and are controlled by magmatic activity in the 10 km or so thick crust. Low temperature hydrothermal activity is much more widespread; its heat source is the regional heat flow, but the distribution of the hydrothermal fields is controlled by the lithology and structure of the volcanic strata. All geothermal reservoir rocks are of a volcanic origin, although some may be reworked.

At a destructive plate boundary, like that of the Mediterranean, the crust is of a very variable character comprising metamorphic, sedimentary, and igneous rocks, the two former normally being much older than the boundary itself. The heat flow pattern is very asymmetrical across the boundary. Active volcanoes and geothermal fields are spread over a several 100 km broad zone and are controlled by tectonic and magmatic activity in the 30 km or so thick crust. The geothermal reservoir rocks are most commonly metamorphic or sedimentary.

A comparison of geothermal prospecting data from type localities in Iceland and the Mediterranean shows that the interpretation of data is much more complicated at the destructive plate margins due to the structural complexities, the highly variable lithology and the greater thickness of the crust.

1. INTRODUCTION

It has long been known that earthquake epicenters, volcanoes, and geothermal fields are not randomly distributed over the Earth's surface, but are mostly concentrated in fairly narrow, interconnecting active zones. According to the plate tectonics theory these zones are boundaries of crustal plates.

The different types of plate boundaries give rise to great variations in the geological settings of volcanic and geothermal areas, both with regard to the heat flow pattern and the lithology, structure, and thickness of the crust through which magma and geothermal fluids must penetrate. It is apparent that in an attempt to compare geothermal activity in Iceland and the Mediterranean area one must start by comparing the plate boundaries in the two areas.

Iceland lies astride a spreading ridge, the Mid-Atlantic Ridge, a constructive plate boundary. The Mediterranean area is situated on a destructive plate boundary of the Eurasian and African plates, which consists of a complex network of microplates. The discussion in the paper will be focussed on Iceland and Italy as type localities representing the two types of plate boundaries.

2. ICELAND - GEOTHERMAL ACTIVITY AT A CONSTRUCTIVE PLATE BOUNDARY

The average crustal thickness at an ocean ridge is 10 km (Brune, 1969). The oceanic crust is mostly composed of basaltic rocks, extrusives in the upper part, but mafic intrusives become predominant in the lower part.

Iceland lies astride the Mid-Atlantic Ridge. The crustal thickness is variable from 8-15 km, and the crustal structure is known in a considerable detail from geological and seismic surveys (e.g. Pàlmason and Saemundsson, 1974). The crust is formed almost entirely of igneous rocks. The uppermost 2-3 km are composed of subaerial lavas and much subordinate airborne tuffs in the Tertiary provinces, but of subaerial lavas intercalated (at intervals corresponding to glaciations) with morainic horizons and thick, elongated piles of subglacial hyaloclastites in the Quaternary provinces. Each eruptive unit is fed by a dyke, and consequently the dyke intensity increases with depth in the crust. The lower part of the crust probably consists mostly of very low porosity impermeable intrusions. This layer (the oceanic layer, V_p=6.5 km/s) may form a base to water circulation in the crust.

Active ocean ridges are characterized by a wide scatter of heat flow values (1-8 H.F.U., according to Brune, 1969). With increasing distance symmetrically away from the ridge crest the scatter diminishes and the mean heat flow falls until it reaches an average level for the oceans.

The regional heat flow in Iceland is very high (Fig.1). A heat flow profile (Fig.2) across the Reykjanes-Langjökull volcanic zone (which is a direct continuation of the Mid-Atlantic Ridge) shows a fairly regular trend towards higher values near the zone. The data quoted in Fig. 1 and Fig. 2 (Palmason, 1973) are all from boreholes outside the active volcanic zones and outside known geothermal fields.

Active volcanoes and high temperature areas (Bödvarsson, 1961) in Iceland are confined to the active zones of rifting and volcanism that run through the country (e.g. Palmason and Saemundsson, 1974). The high temperature areas are thought to draw heat from both the very high regional heat flow in the volcanic zones and from local accumulations of igneous intrusions cooling at a shallow depth in the crust. The low temperature areas are, on the other hand, thought to draw heat from the regional heat flow. All the geothermal reservoir rocks are of a volcanic origin, although some may be reworked volcanics (Fridleifsson, 1975).

3. ITALY - GEOTHERMAL ACTIVITY AT A DESTRUCTIVE PLATE BOUNDARY

The crustal thickness at a destructive plate boundary is highly variable, but figures of 30 km and 55 km for island arcs and alpine regions respectively (Brune, 1969) give an indication of the range. The crust is generally of a very variable character comprising metamorphic, sedimentary and igneous rocks in the upper part, but the lower part is generally considered to be mostly of mafic intrusives.

The southern part of the Italian peninsula has been compared with an island arc structure (e.g. Loddo and Mongelli, 1974); the African plate is considered to be wedged under the Eurasian plate along a Benioff zone dipping from the Ionian Sea under Calabria. The Tyrrhenian Sea is considered to represent a marginal basin. The crustal thickness is highly variable with depths to the Moho ranging from 20 km in the Tyrrhenian Sea to 40 km in the Ionian Sea and the NE-part of the Italian peninsula (Morelli et al, 1967). The author is not aware of any detailed analyses of the crustal structure on a regional basis. A tentative crustal section from the Ionian Sea to the Tyrrhenian Sea (Barberi et al, 1973) indicates a typical continental crust underneath the Calabrian arc with the mafic intrusion layer at a depth of some 30 km, but the same layer is shown at a depth of only 3 km under the Tyrrhenian abyssal plain (marginal basin). It is thus evident that the variations in thickness of the crustal rocks that can be looked on as potentially permeable are very great from one area to another.

Oceanic trenches have characteristically abnormally low heat flow (less than 1 H.F.U.), but a short distance away, in the adjacent island arc, the heat flow is high (2-4 H.F.U.). The heat flow pattern is very asymmetrical across the island arcs.

The regional heat flow in Italy is highly variable (Fig.3). The Appenine chain continuing in the Calabria divides the Italian Peninsula into two heat flow regions, the western with high and the eastern with low or normal heat flow (Mongelli and Loddo, 1974).

Active volcanoes are mostly confined to the southern Tyrrheninan Sea, but geothermal steam fields as well as Quaternary volcanoes reach considerably further north. The heat source to the steam fields appears to be Upper Tertiary and Quaternary intrusions, which have intruded metamorphic and sedimentary rocks of Mesozonic and Cainozoic age (e.g. Calami et al, 1970). The relatively young magmatism is thus superimposed on a relatively old continental crust, which in most instances has suffered some tectonic deformation prior to the emplacement of the intrusions. Low temperature thermal springs are much more widely distributed than the steam fields, and probably draw heat from the regional heat flow.

4. DISCUSSION

The distribution and intensity of hydrothermal activity in Iceland is apparently mainly controlled by three factors:

1. The regional heat flow.
2. Local heat flow anomalies due to shallow level intrusions in the active volcanic zones.
3. The lithology and structure of the essentially volcanic strata, which are in turn critically dependant on the chemical composition of the eruptives, the environmental conditions during eruption, and the tectonic history of the area.

In Iceland the regional heat flow, the local heat flow anomalies and the geothermal reservoir rocks can be considered of the same geological age. The geothermal activity in Iceland may therefore be regarded as a steady state process at a constructive plate boundary.

The distribution and intensity of hydrothermal activity in Italy is apparently mainly controlled by two factors:

1. Local heat flow anomalies due to shallow level intrusions.
2. The lithology and structure of the relatively "mature" crust, which serves as a host rock to the late arriving intrusions and as reservoir rocks to the geothermal systems.

The regional heat flow is considerably lower in Italy than in Iceland, and is therefore probably less important as a controlling factor.

The reservoir rocks in Italy are in most cases much older than the intrusions. They have been subject to complicated geological processes prior to the superimposition of the new heat sources (intrusions).

Similar methods are applied in geothermal prospecting in Iceland and Italy, i.e. a combination of geological, geophysical and geochemical surveys. The interpretation of the geophysical data is, however, in many instances more complicated in the Italian fields, as there is a much higher number of unknown variables in the thick and relatively heterogeneous crust as compared to the thin and relatively homogeneous crust in Iceland. Similarly the interpretation of geochemical data is more complicated. The mineral content of geothermal water is generally much higher in Italy (Baldi et al, 1973) than in Iceland (Arnorsson, 1974). This is probably due to the greater heterogeneity of the rocks leached by the thermal water in Italy. It is apparent that a detailed knowledge of crustal structure and the geological history of potential geothermal fields is of a fundamental importance in both Iceland and Italy, but probably more so in the latter area.

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HEAT FLOW (H.F.U) IN ICELAND

Modified from Pálmason, 1973

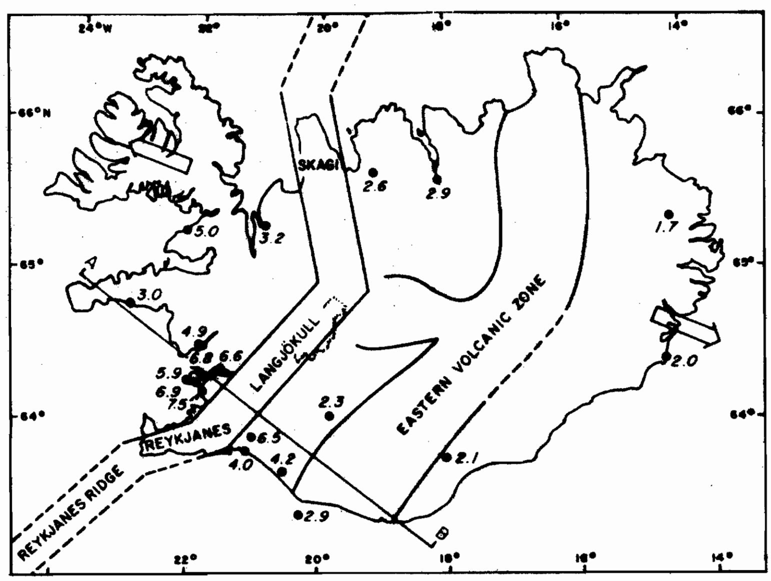

Fig. 1. Regional heat flow in Iceland. All the measurements are made in drillholes outside the active volcanic zones and outside known geothermal fields. Line A-B indicates the heat flow profile of Fig. 2. The two main active volcanic zones in Iceland are shown schematically. The arrows indicate the assumed directions of plate motion.

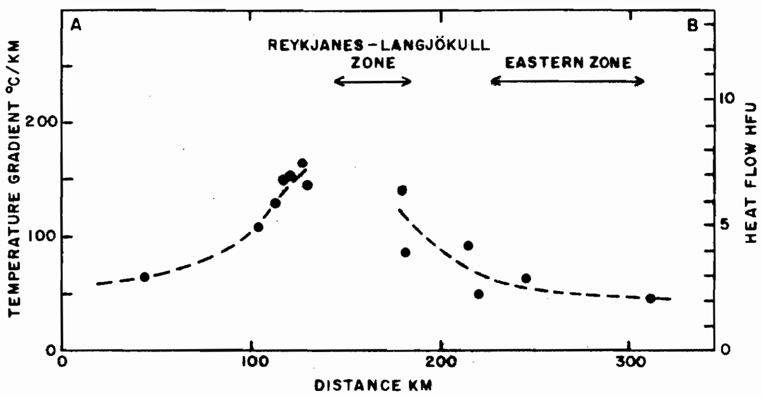

Fig. 2. Heat flow profile across the Reykjanes-Langjökull volcanic zone, which is a direct continuation of the crest zone of the Mid-Atlantic Ridge. The location of the profile is shown in Fig. 1. (From Palmason, 1973).

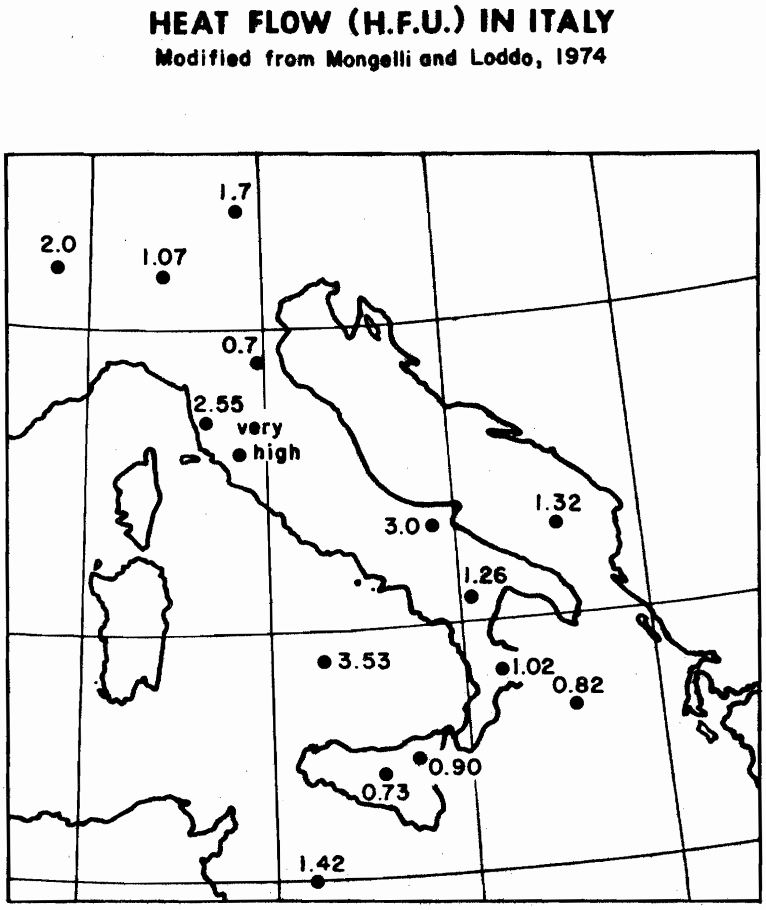

Fig. 3. Heat flow in Italy. Most data points represent mean values from several heat flow stations.