COMPILATION OF HEAT FLOW IN EAST ASIA

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Introduction

Recently fairly large amount of heat flow data in East Asia have been accumulated to allow us to compile those data using a computer. Earlier compilations of heat flow data in East Asia have been made either of marine heat flow data only (Anderson, 1978), or not containing recently obtained data (CGMW, 1982). Therefore, we think it worthwhile to undertake at this time a computerized filing and mapping of heat flow data in this region.

Compilation Method and Data Sources

Firstly, heat flow data from published reports have been stored as a file on a personal computer system. We prefer to use the international format of heat flow data compilation. Data of one heat flow station is given by one line of a data file. Although additional unpublished heat flow stations are also included here, the number of heat flow stations is approximately 1000. A few other utility programs, such as data displaying routines, are also accompanied (Nagao, this Symposium). There are three major categories of data source: 1) standard deep sea measument technique employed for marginal sea stations, 2) mineral exploration holes or water wells used for on-land measurements, and 3) numerous industrial temperature data collected from oil and gas exploration wells in sedimentary basins, offshore and onshore. The marine heat flow data in the Pacific and Indian Oceans in this work are taken from the 1983 heat flow data compilation by the International Heat Flow Commission. On-land heat flow data together with offshore deep well data in sedimentary basins have been collected since late 1970s in cooperation with national institutes of Thailand, Malaysia, Indonesia, the Philippines, Papua New Guinea, and Taiwan. In addition, heat flow data on the mainland China, which have been obtained recently are also included but on-land heat flow data of the Asian part of the Soviet Union are not included in this compilation.

Fig.1 shows a part of our computer generated heat flow map in Mercator Projection for the southern half of the region we are now working on. Values of heat flow are represented by the size of the circles. A map of averaged heat flow values by latitude-longitude grid mesh can also be produced, which is not included here due to space limitation. In the last part of this paper, tectonic implications are discussed based on our new heat flow map.

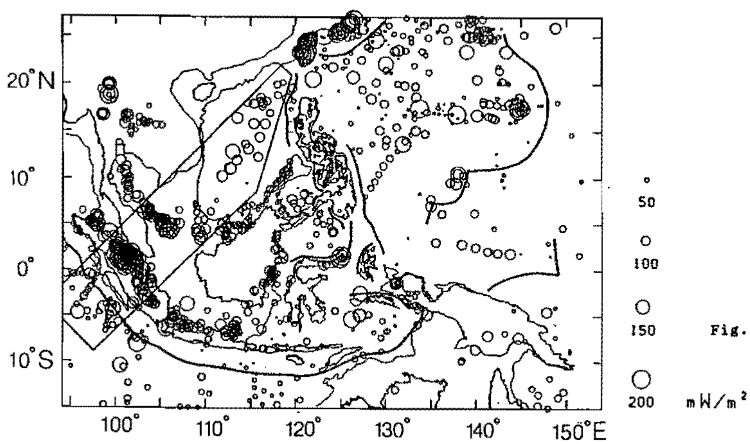

Fig.1. Heat flow map of Southeast Asia. 200 m iso-depths and trenches are shown by thin and thick lines.

Discussions

Various types of crust have been known to exist within the region: from the the very deep Philippine Trench accompanied with the actively subducting Philippine Sea Plate to the old continental crust of Eurasia. Below we are discussing them with special reference to heat flow data.

(A) Continental Part

On the Asian part of the Eurasia Continent, China is one of the most intensively studied countries in terms of heat flow (Wang et al.,1981; Wang et al., 1985; Shen et al.,1985). It has been revealed in these papers that rather high average heat flow data in North China are related to the reactivation of old blocks since Mesozoic and that the anomalously high values in Tibet may be due to the processes associated with the colliding Indian Ocean Plate against Eurasia. Heat flow data in Korea, obtained in a early work (Mizutani et al,1970), indicate higher than normal average values on the southern part of the penensula.

In Thailand heat flow stations are also populated rather densely. Heat flow data in Thailand summarized by Thienprasert and Raksaskulwong (1984) showed that the thermal state of the territory is in harmony with its geological setting: low heat flow in the older, eastern part and anomalously high in the western part of Thailand, where low level seismicity exists. A recent publication by the Geological Survey of Japan (1987) has included these heat flow results by contour lines. Apart from Thailand, on-land heat flow determination on continental blocks of Southeast Asia has been attempted at one site only in peninsular Malaysia. In Burma, Cambodia, Laos and Vietnam no measurement of heat flow has been made yet.

(B) On-land Heat Flow Data of East Asian Islands

There are already many detailed discussions on the heat flow data on the Japanese Islands, therefore in this paper island arcs in Asia other than Japan are reviewed. First, on the Philippine Islands, a few on-land type measurements were made. Apparently low heat flow values, except for one site, have been reported by Watanabe et al(1982). But because very high potential of geothermal resources, associated with young or active volcanoes, are known on this island arc, there might be a possibility that true heat flows from depths are masked by superficial groundwater effect at most of the measuring sites.

Heat flow data on the island of Taiwan were summarized in Lee and Cheng(1986) and the anomalously average high values as well as many local extreme values were presented. There have been only a few attempt to get on-land heat flow data on the New Guinea Island and its vicinity, but the number of observed heat flow data are very small in these areas to be used for meaningful discussions.

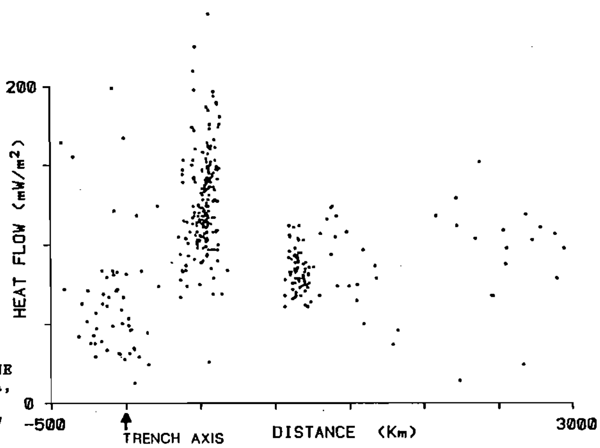

Fig.2 Heat flow variation along SW-NE transect passing through Sumatra, Sunda Shelf and South China Sea. Each dot represent one heat flow station.

(C) Marginal Seas

There have been many different views of the origin of marginal seas. According to a recent paper by Lee and McCabe(1987), three of the marginal seas in East Asia might be a trapped piece of Cretaceous to Eocene oceanic crust. The heat flow values of the Banda, Sulu and Celebes Seas are interpreted by them to be evidence of normal crust of Cretaceous to Eocene age, rather than the "back-arc type" crust. In contrast, another recent hypothesis by Miyashiro (1987) on the origin of those seas considers a very large scale migration of one Hot Region, to explain the evolutionary histories of the whole western Pacific marginal seas. To the east of the three major marginal basins, South China Sea, Celebes Sea, and Sulu Sea, there is a N-S trending belt of plate interactions, consisting of many islands (Weissel,1980). Heat flow pattern within this belt is not yet clearly defined, as mentioned in (B).

In the Andaman Sea, very high heat flow results are regarded to reflect the present opening of the sea floor (Eguchi et al., 1979). In the Banda Sea, a new measurement resulted in extremely high heat flow (Van Gool et al., 1987) but there are also conflicting results by Bowin et al.(1980) showing anomalously low average heat flow in the same area. The heat flow distribution of the South China Sea has been explained as the consequence of sea floor spreading in late Oligocene to early Miocene. There still remain problems of the origin of the South China Sea, particularly in connection with the above two new hypotheses.

(D) Continental Shelves

A large number of exploration wells have been drilled for oil and gas in East Asia. In the case of Southeast Asia, geothermal gradient data were compiled by the Southeast Asia Petroleum Exploration Society and Indonesian Petroleum Association in 1977. Estimated formation temperatures for individual wells with the Horner's extrapolation were listed, using a set of the bottom hole temperature data taken from successive loggings of the well. If we know the thermal conductivity distributions along those wells, heat flow values can be obtained. An early study by this approach was made by Matsubayashi and Uyeda(1979) for some wells in Malay Basin and off Sabah, East Malaysia. In Indonesia, very detailed work has been made by Vacquier and his co-workers (Vacquier, 1985). Recently a heat flow data compilation in Indonesia based on those results has been published(IPA, 1987). In Malaysia also, detailed works have been made using this kind of deep wells (Matsubayashi and Uyeda,1979; Wan-Yusoff, 1985) and it was pointed out that the temperature structure is quite anomalous below the continental shelf of the southern part of the Gulf of Thailand betweeen Malay Peninsula and the South China Sea.

In order to visualize these observations, plots of heat flow values against distance along transects were constructed. For example, if we examine the heat flow data in a SW-NE belt passing through Central Sumatra, Sunda Shelf and South China Sea (shown by thick rectangle in Fig.1), higher than normal heat flow values over the whole area is evident, except for southeast of the volcanic front of Sumatra, and extremely high values at Central Sumatra are also remarked (Fig.2). From the viewpoint of crustal structure, the shelf area is not an oceanic basin but rather like the Basin and Range of the western United States, with the same feature of thinner than normal crust and anomalously high heat flow.

Our new version of heat flow compilation in East Asia is the most up-to-date and is a very useful tool to study the thermal state of this important region, where the Eurasian, Indian Ocean-Australian, Pacific and Philippine Sea Plates are colliding with each other hence very complicated geological evolution has been and is now in progress. Although density of measuring sites is not yet so high as in Europe or North America, heat flow distribution in scale of hundred kilometers has become clearer than earlier works in this region. It seems apparent from this work that on the major shelves in the region there still remain vast areas where heat flow studies have not been applied. In particular, there are vast offshore areas of potential interest adjacent to the continent, namely the shelves of the East and South China Seas where very little is known about crustal temperature distribution.

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