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Hot Springs, Geothermal Fields and Plate Tectonics in Japan

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Abstract

Hot springs are, in general, situated in the volcanic belt of a convergent zone and are utilized as indicators of geothermal potential in an area. The locations of hot springs (with temperatures $\geq$ 90°C) in Japan, have been examined to determine the influence that plate underthrusting exerts in determining the locations of these hot springs. This examination shows that hot springs and geothermal fields in Japan are situated in the volcanic areas along the extension of zones which mark discontinuities in plate underthrusting. Measured heat flow in many of these zones is higher than average for volcanic areas. Such zones with higher than average crustal temperatures should be prime targets for comprehensive geothermal exploration programs.

Sugimura and Uyeda (1976) have noted that springs yielding water warmer than 30°C (warm springs) are distributed almost exclusively in the volcanic belt of Japan all along the arc. Springs in volcanic areas confirm three required characteristics for geothermal fields, namely, heat source, rock permeability and ground water availability. If temperature at shallow depth ($<$ 2 km) is high ($>$180°C) in such areas, then geothermal energy can be exploited. Figure 1, however, shows that springs with temperature $\geq$ 90°C (referred to hereafter as hot springs) do not occur all along the volcanic belt. Figure 1 also shows that there are four proven geothermal areas in Japan and the geothermal fields are situated near hot springs in these areas. Although the exact delineation of a geothermal field is based on a comprehensive exploration program, the presence of several hot springs in the vicinity of the geothermal fields suggests that crustal temperatures are high over a wide area in the vicinity of these fields. The discrepancy in the distribution of warm springs, hot springs, and geothermal fields in Japan suggests that high temperatures necessary to exploit geothermal energy may not be prevalent at shallow depths all along the volcanic belt but may result from certain special conditions.

The locations of these hot springs have therefore been examined to identify the influence of the underthrusting process and determine the special conditions in the vicinity of geothermal fields.

Figure 1 suggests that hot springs occur in clusters and are spaced about 100-150 km apart in northern and southwestern Japan. Kelleher et al (1974) noted that the rupture zones of large (Magnitude $\geq$ 7.0) earthquakes in Japan are on an average about 150 km long. It is therefore possible that hot springs may be influenced by the rupture zones of large earthquakes. Mogi (1968) has noted that the after shock zones of great earthquakes (Magnitude $\geq$ 7.7) occur in nonoverlapping units separated by structural discontinuities or transverse zones in the arc. Seno (1977, 1978) divided northern Japan into several provinces on that basis. Figure 1 shows the province boundaries for northern Japan as drawn by Seno and for southern Japan on the basis of data in Mogi (1968).

Figure 1 shows that hot springs are in general situated along the extension of transverse zones or province boundaries. It is interesting to note that southwest Honshu is not volcanic and hot springs occur in only one area, along the extension of zone C, which separates the rupture zones of the 1944 and 1946 earthquakes. This suggests that proper conditions (i.e., fractures, fluids, etc) exist for the development of hot springs along the extension of these zones and the locations of hot springs are therefore influenced by the mechanics of underthrusting.

Available heat flow data in Japan (Figure 2) support this suggestion. Heat flow along the extension of zones A,D,E,I,J,L and M is indeed

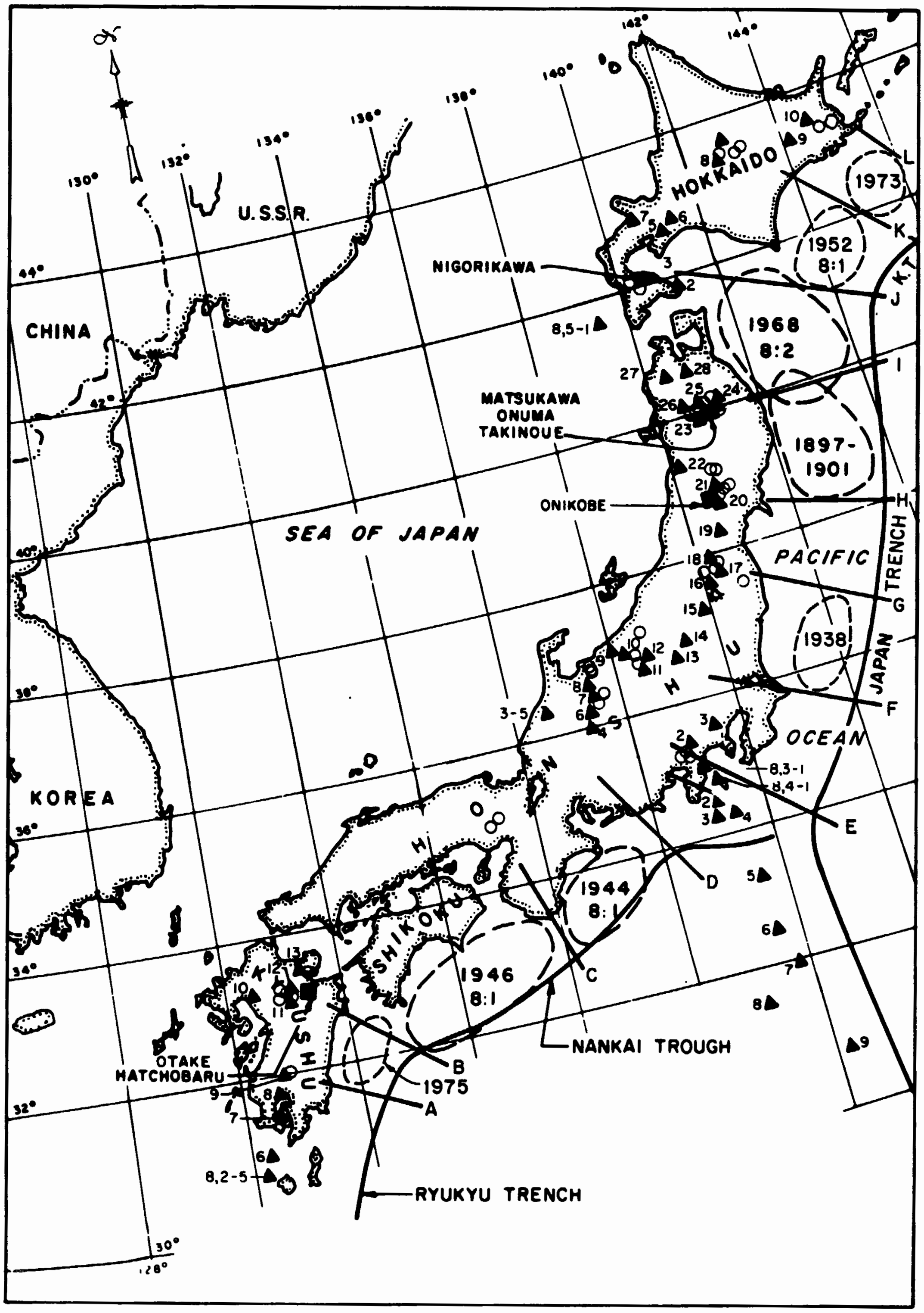

Figure 1 - Hot springs, geothermal fields and plate configuration in Japan. Locations with two or more hot springs (open circles) from Sumi (1975) and geothermal fields (filled squares) from Nakamura (1981). Base map showing volcanoes (filled triangles) and plate boundaries from McCann et al (1979). Rupture zones—of great earthquakes including the year of rupture and earthquake magnitude are from Mogi (1968) and Seno (1977, 1978).

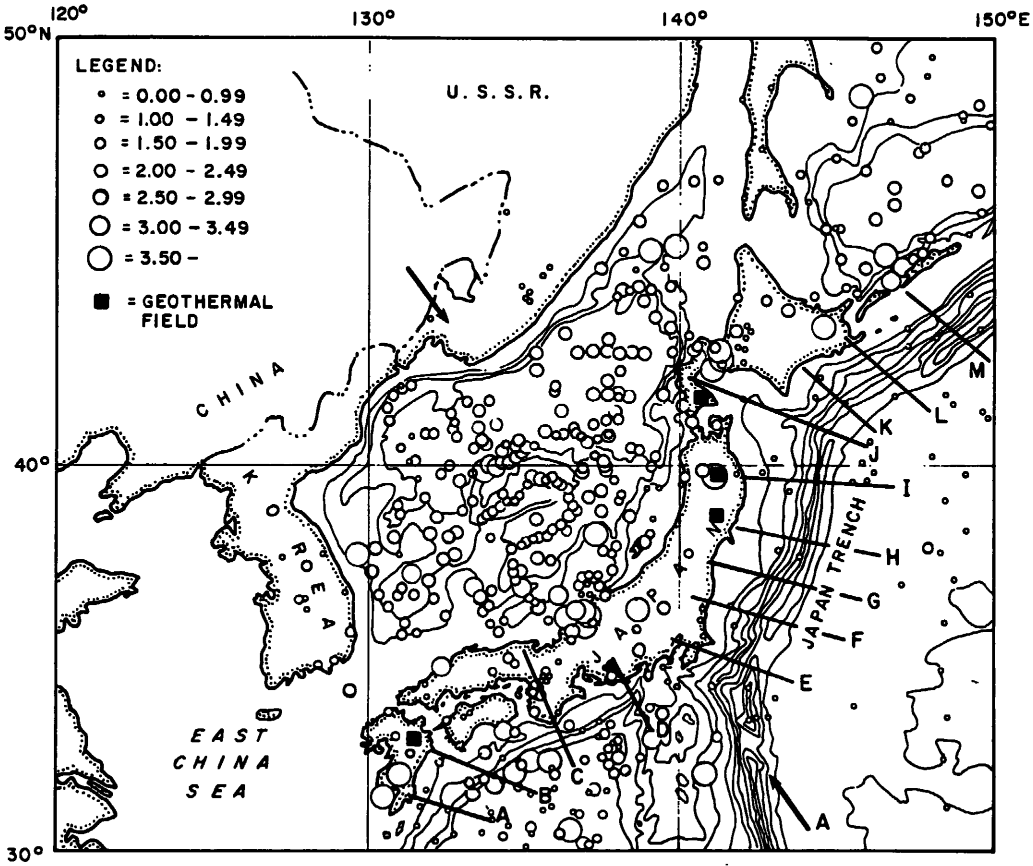

Figure 2 - Heat flow in Japan and vicinity in relation to the location of geothermal fields and transverse zones. Basic heat flow map from Watanabe et al (1977). Locations of geothermal fields (filled squares) from Nakamura. Transverse zones A-L as in Figure 1. Zones L and M outline a block which ruptured in 1973 and ruptured earlier in 1894.

very high ($\gtrsim$3.5 HFU) as compared to the average ($\sim$1.5 HFU) in volcanic areas. Heat flow along the zones D and G is about 1.5-2.5 HFU and along zone C about 1.5-2.0 HFU. There are no volcanoes in southwest Honshu (Figure 1) and in the absence of magma at depth, the heat flow in zone C is compatible with heat flow in other transverse zones in Japan. Heat flow values are not known for zones B, F, H, and K. The high values of heat flow along some of the transverse zones therefore support the observation that shallow crustal temperatures in these zones are higher than normal for volcanic areas. Figure 2 also shows that geothermal fields are located in several of these transverse zones with heat flow$\gtrsim$3.5 HFU.

Acharya (1982 and 1984) examined the locations of geothermal fields in the circum Pacific area and observed that most of the geothermal fields in the circum Pacific area (including Japan) are situated along the extension of zones which mark a break in the lateral continuity of the underthrusting plate. The breaks noted were (i) terminal ends of several plate boundary segments (such as B, D, E and J in Figure 1), and (ii) transverse zones which divide plates into several independent blocks on the basis of rupture zones (such as A, C, F, G, H, I, K and L in Figure 1). Acharya therefore suggested that such transverse zones are favorable areas for the development of a productive geothermal field. One difficulty with testing this hypothesis is that while geothermal fields are indicative of high temperatures at shallow depth, its absence does not mean low crustal temperatures. The expense involved in geothermal exploration is sufficiently high so that only few locations are thoroughly investigated. Hot springs, on the other hand, are abundant in island arcs and temperatures of hot springs can be measured inexpensively. The distribution of hot springs as well as heat flow measurements in Japan indicates that shallow crustal temperatures are indeed high in these transverse zones and therefore such zones can be favorable places for the exploration for geothermal fields.

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