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CRUSTAL THICKNESS, HEAT FLOW, ARC MAGMATISM, AND TECTONICS OF MEXICO - PRELIMINARY REPORT

J. URRUTIA-FUCUGAUCHI*

RESUMEN

Se presentan mapas preliminares de espesor cortical y de flujo térmico y una discusión breve sobre la estructura cortical, tectónica y provincias magmáticas en México. Las isopacas siguen aproximadamente la línea de la costa en el margen Pacífico y en el Golfo de México. La corteza es más gruesa ($\gtrsim$ 40 km) en la porción central-sur del Altiplano y en la porción central-este de la Faja Volcánica Trans-Mexicana. El flujo térmico es generalmente mayor que 1.5 UFT, excepto sobre los terrenos Precámbricos-Paleozoicos del sur de México y en la porción norte de la planicie costera del Golfo de México (~ 1.0 UFT). Se observan valores altos de flujo térmico en la Sierra Madre Occidental y en la Faja Volcánica Trans-Mexicana, las cuales representan provincias magmáticas del Mesozoico-Cenozoico Temprano y del Cenozoico, respectivamente.

ABSTRACT

Preliminary crustal thickness and heat flow maps of Mexico are presented. Isopachs roughly follow the coastline of the western margin and the shape of the Gulf of Mexico in the east. Crust is thicker ($\gtrsim$ 40 km) beneath the central-southern portion of the Altiplano and the central-eastern portion of the Trans-Mexican Volcanic Belt. Heat flow is generally higher than 1.5 HFU, except for the Precambrian Paleozoic terranes of southern Mexico and the northern portion of the Gulf of Mexico plain (~1HFU). High heat flow (> 2HFU) is observed inthe Sierra Madre Occidental and the Trans-Mexican Volcanic Belt, which represent Mesozoic-early Cenozoic and Late Cenozoic magmatic arcs, respectively.

* *Laboratorio de Paleomagnetismo y Geofísica Nuclear, Instituto de Geofísica, UNAM, Delegación Coyoacán 04510, D. F., MEXICO.*

INTRODUCTION

Studies of crustal thickness and heat flow have long proved valuable in regional tectonic investigations (*e.g.* Woollard, 1966; Prodehl, 1970; Sass *et al.*, 1971; Lachenbruch and Sass, 1977, 1978), and their importance in understanding deep-seated processes in the Earth's interior has been emphasized in plate tectonics. The purpose of this report is to present an up-to-date compilation of crustal thickness and heat flow data for Mexico and briefly discuss their tectonic implications. It should be mentioned that the relatively low number of results available and the uneven geographic distribution limit any firm discussion of the implications of the data. The main reasons for presenting this report are: (1) these data are necessary for several investigations (mainly tectonic study of the area) and no previous complete compilations were available; (2) the maps given may serve to focus the attention on critical areas in which there are no measurements yet; and (3) this compilation may serve as a starting-point for discussion of the tectonics of Mexico.

DATA

Crustal thickness is taken from reported seismic refraction and surface-wave studies. The quality of data presentarion in the original reports is variable. The source data have not been re-interpreted and only in the case where assignation points were not reported, an approximate location is here provided (*i.e.* in surface-wave and un-reversed refraction studies). Data points are given in Fig. 1a. Results were manually contoured and later superimposed on a simplified tectonic map (Fig. 1b).

Crustal thickness estimates based on geochemical polarity indexes (*i.e.* K_2O - contents at a given SiO_2-level-crustal thickness relationship; Condie, 1976) were calculated and compared with the 'seismic' crustal thickness data (Fig. 1a and b). The results agree well, and since most of Mexico is covered by magmatic arc-related igneous rocks 'geochemical' estimates may be used to complement the results. There is however, considerable debate concerning the accuracy and even validity of 'geochemical' estimates of crustal thickness, and they have been used only as complementary second-order data.

Heat flow is taken from reported measurements. The number of results on land is still low, mainly from the work of D. L. Smith and coworkers in northern Mexico (Smith, 1974; Smith *et al.*, 1979), and from the work of D. D. Blackwell and co-

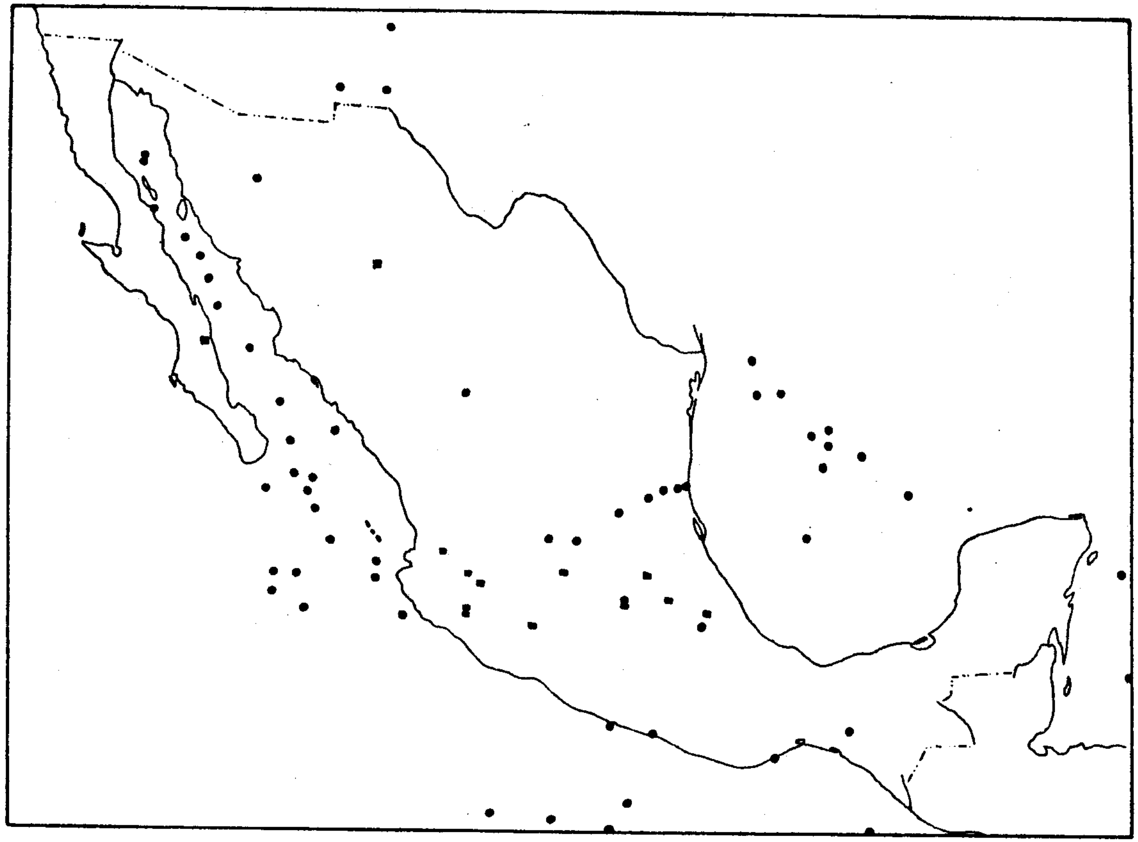
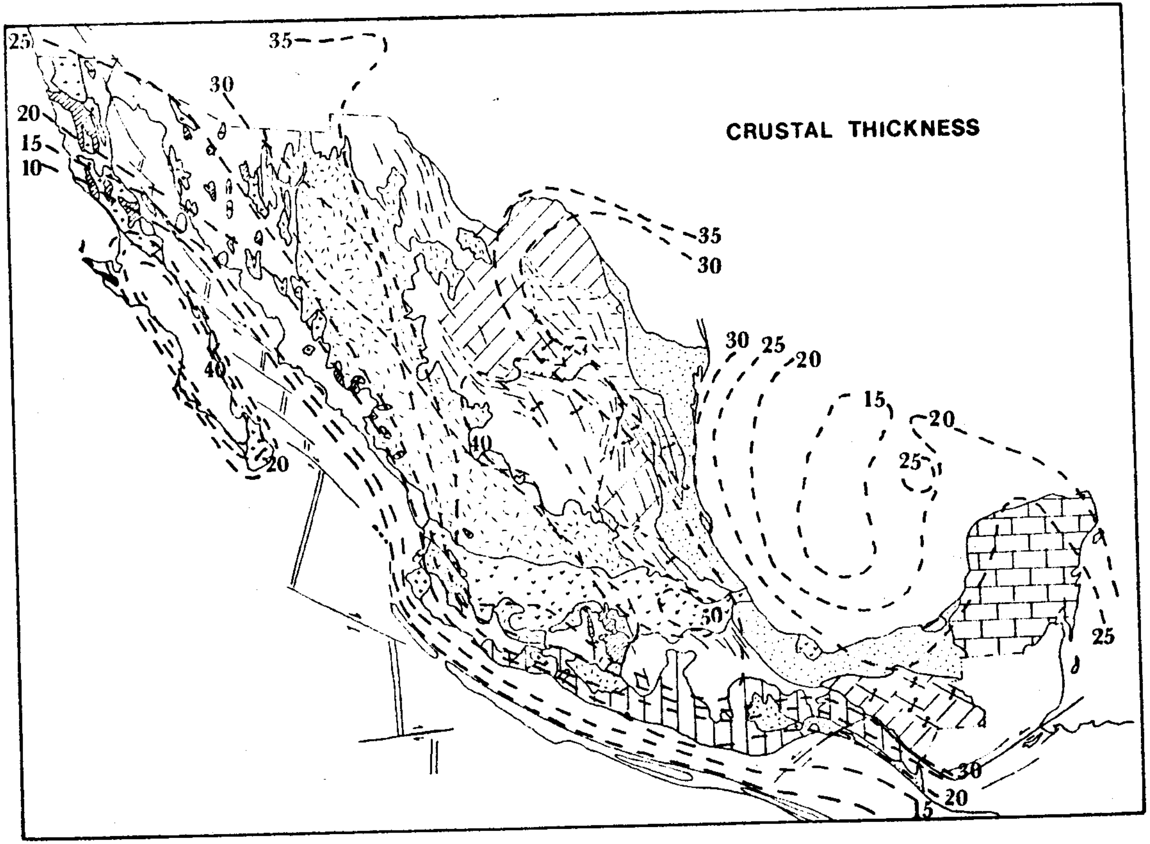


Fig. 1. (a) Summary of crustal thickness data for Mexico. Data derived from seismic refraction and surface-wave studies are indicated by ● and complementary data derived from geochemical measurements are indicated by ■



1b

(b) Preliminary crustal thickness map of Mexico. Isopachs are in kilometers. Simplified tectonic map used for comparison is modified after Tardy (1980).

workers (Blackwell *et al.*, 1977) in southern-central Mexico (Fig. 2a). Results were manually countered and later superimposed on a simplified tectonic map (Fig. 2b). Some heat flow measurements at sea were also incorporated in the maps. The heat flow data set has been complemented with estimates derived from helium isotopic data on hydrothermal fluids. The estimates are based on the relationship reported by Polyak *et al.* (1979) between the $^3He/^4He$ ratios in hydrothermal fluids with measured heat flow. A discussion of this relationship is beyond the scope of this report and one may only mention that the results are apparently in good agreement. If the relationship is supported by further data, it may permit to increase the number of heat flow estimates for areas covered by magmatic manifestations. For the time being, the 'helium' estimates are used only as complementary data.

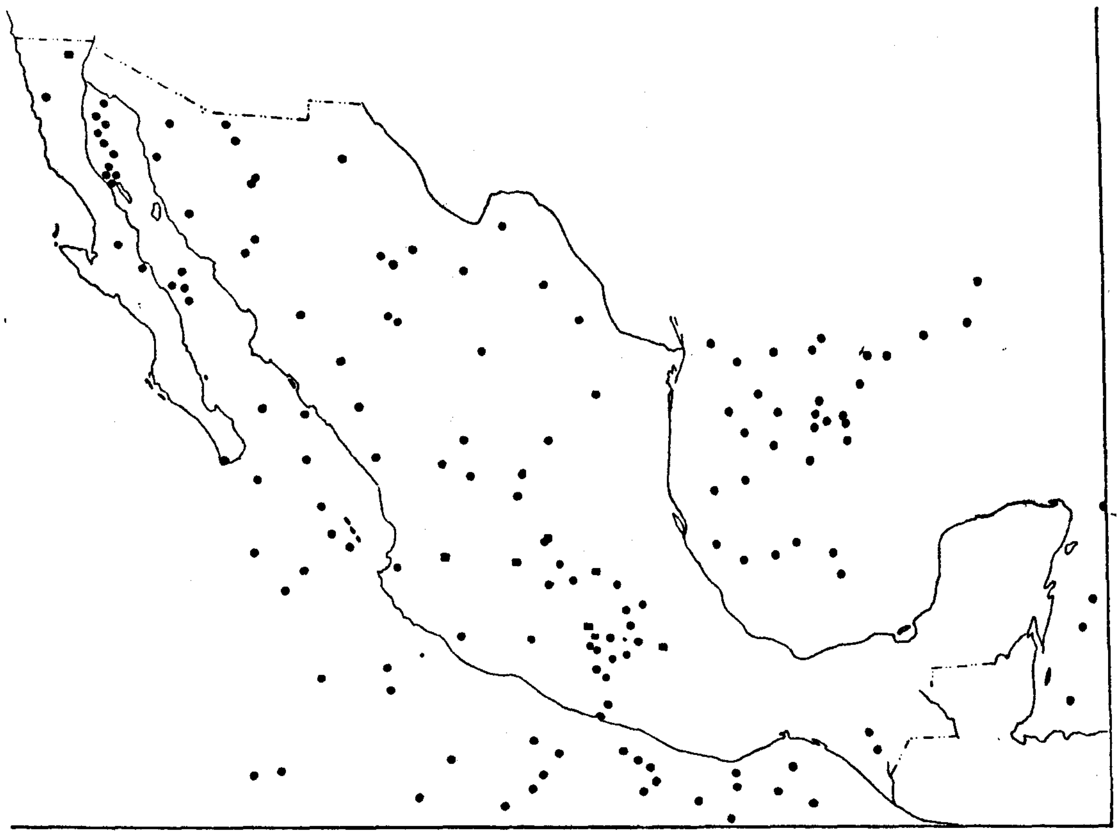
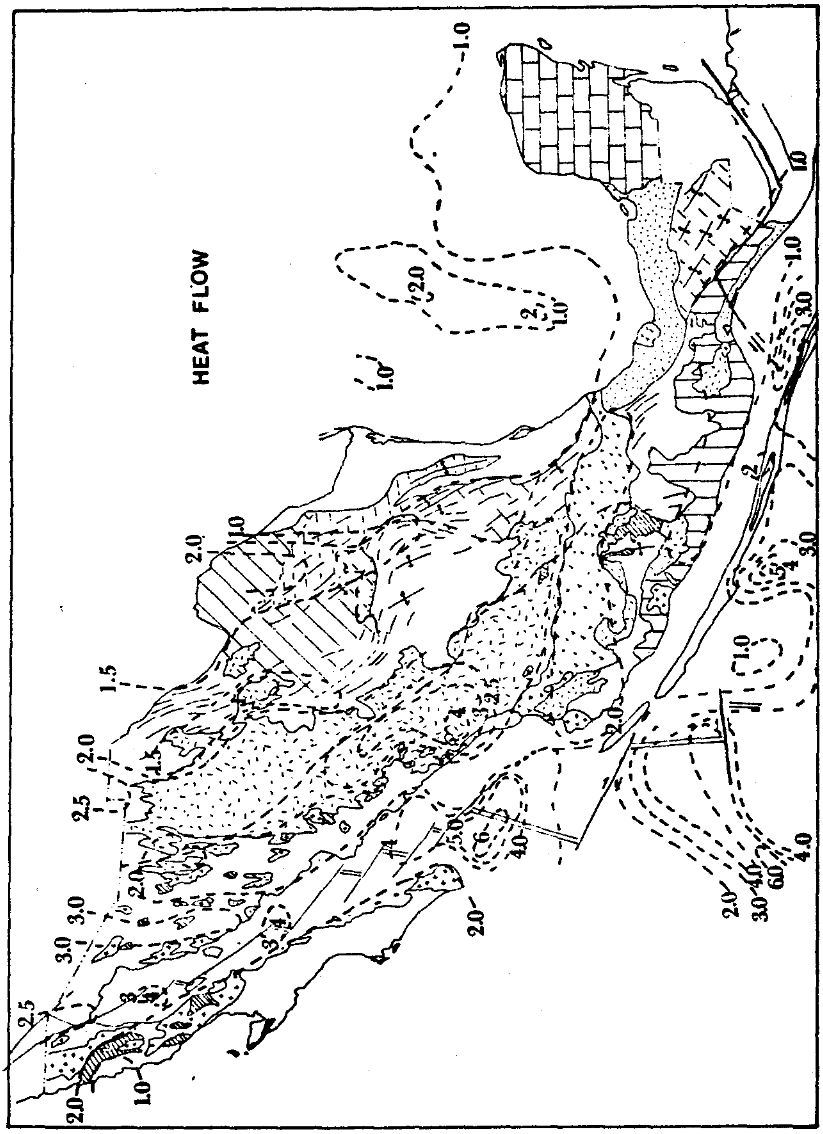


Fig. 2. (a) Summary of heat flow data for Mexico. Data derived from direct measurements are indicated by ●; and complementary data derived from helium isotopic data are indicated by ■.



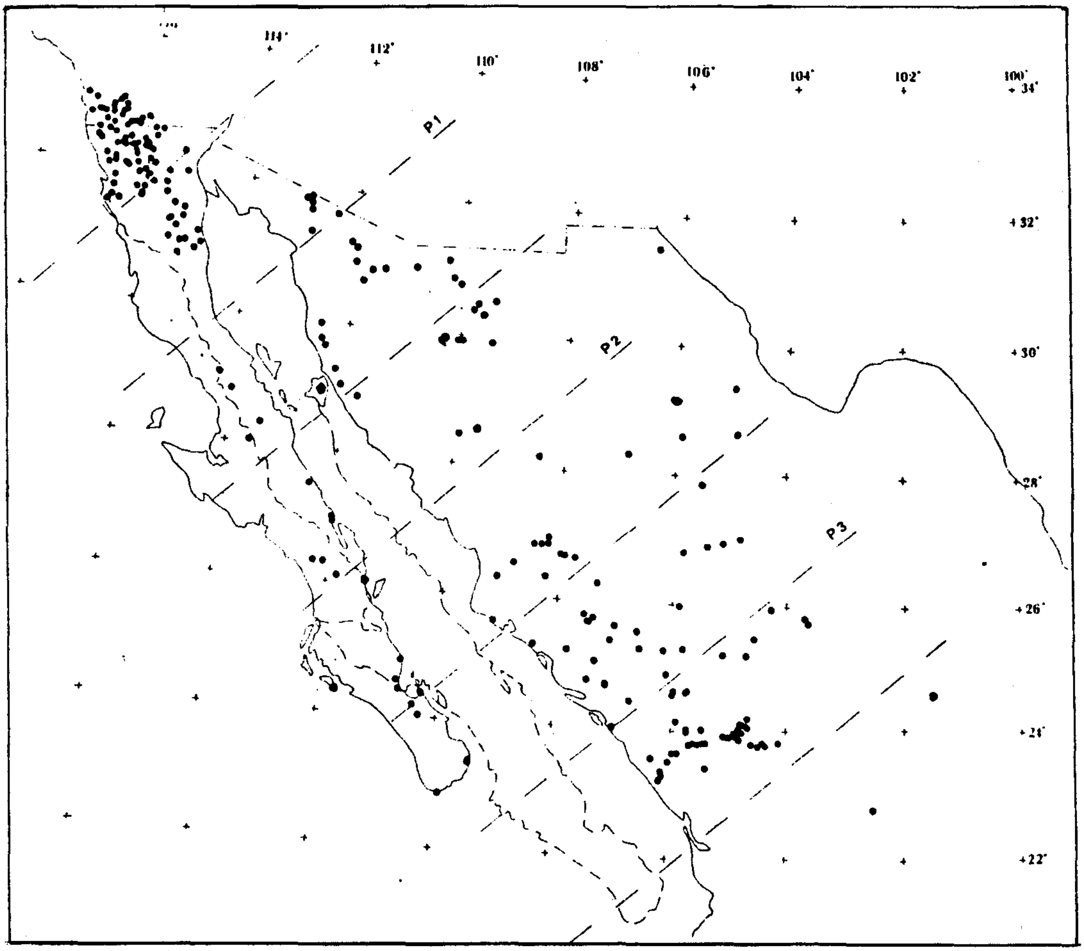
(b) Preliminary heat flow map of Mexico. Contours are in HFU. Simplified tectonic map used for comparison is modified after Tardy (1980).

DISCUSSION

The crustal thickness map (Fig. 1b) presents a simple pattern with isopachs following the coastline of most of the western margin with an apparently steeper gradient in southern Mexico. The crust is thicker ($\gtrsim$40 km) beneath the central-southern portion of the Mexican Altiplano (or central plateau) and the central-eastern portion of the Trans-Mexican Volcanic Belt. The isopachs then follow the general shape of the Gulf of Mexico.

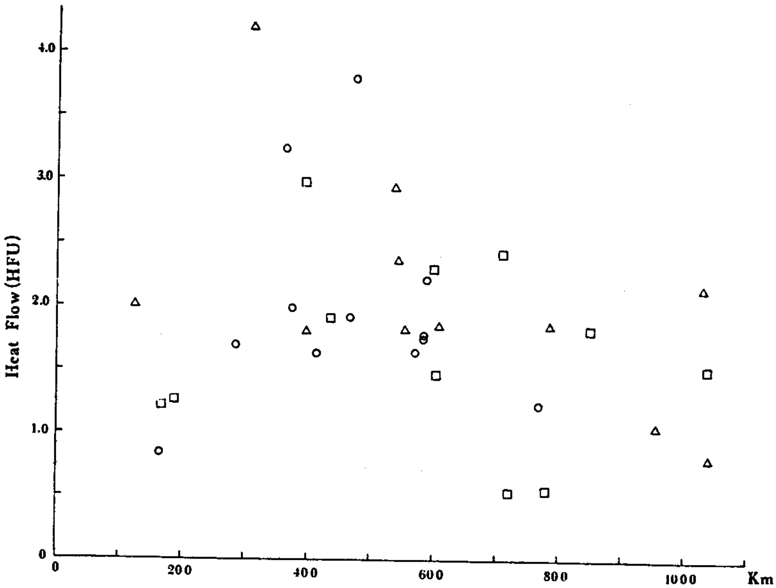
The heat flow map (Fig. 2b) presents also a relatively simple pattern which correlates with major tectonic provinces. Heat flow on land is generally higher than 1.5 HFU (1 HFU = 1μcal/cm^{2}s = 41.8 mW/m^2) with values ranging from 0.54 to 4.18 HFU, which is characteristic of young provinces (Sclater *et al.*, 1981). Historical and present-day volcanic activity is concentrated in the Trans-Mexican Volcanic Belt for which there are just a few measurements available. The highest values are observed in a portion of the Sierra Madre Occidental, a large ignimbritic province of Tertiary age. Plate subduction beneath northwestern Mexico apparently occurred during the late Mesozoic and early Cenozoic (Atwater, 1970), which resulted in the formation of a wide magmatic arc (wider than 1 000 km). In a regional view, the average heat flow is higher in the Trans-Mexican Volcanic Belt, slightly lower in the Sierra Madre Occidental, and lower in the southern part of Mexico.

In the southwestern United States, heat flow is apparently related to plate subduction during the Mesozoic and early Cenozoic (Lachenbruch and Sass, 1978), and areas of high heat flow such as back-arc extension associated with the late-stages of subduction, including the subduction of the spreading center. In northern Mexico, an active extension is observed in the Gulf of California. Heat flow is high in some basins such as Guaymas and Farallon (in places higher than 10 HFU; Lawver and Williams, 1979). Spreading in the Gulf may serve as a vent for release of heat accumulation; so that the possible continuation of the Basin and Range Province into Mexico appears cooler and narrowing (Smith, 1974). The pattern of heat flow (Fig. 3b) across the northwestern Mexico margin (Fig. 3a) seems more complex than that observed in other presently active magmatic arcs (*e.g.* Watanabe *et al.*, 1977), and may reflect the effects of several distinct magmatic episodes and/or differences in the radioactive heat generation distribution. Radioactive heat generation presents an apparent systematic variation across the margin (Fig. 3c), for which Smith *et al.* (1979) suggest three possible explanations: *(1)* chemical variation in magmas; *(2)* crustal thickness variations (Fig. 1b) and *(3)* differential uplift and erosion which

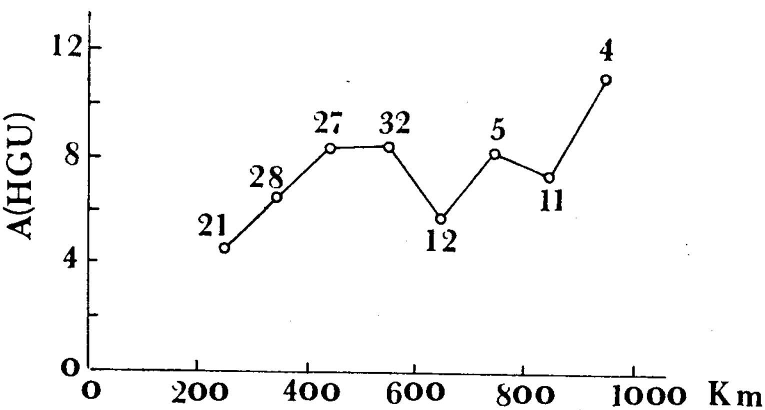


3a

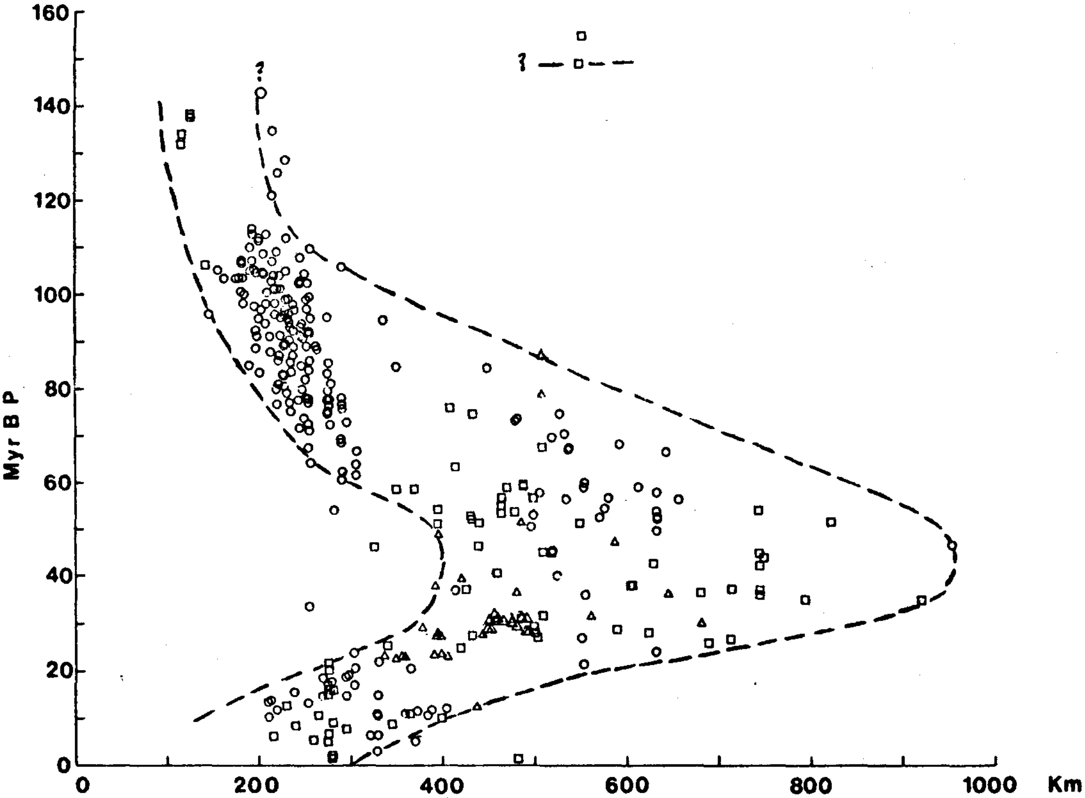
Fig. 3. (a) Simplified schematic tectonic map of northwestern Mexico showing location of profiles.
(b) Distribution of heat flow with distance normal to paleo-trench for three profiles.
(c) Distribution of radioactive heat generation data with distance normal to paleo-trench (after Smith *et al.*, 1979).
(d) Distribution of radiometric dates on magmatic arc-related igneous rocks with distance normal to paleotrench for the same three profiles as in (b).


4.0
3.0
2.0
1.0
0
Heat Flow (HFU)
0
200
400
600
800
1000
Km

3b


12
8
4
0
A(HGU)
21
28
27
32
12
5
11
4
0
200
400
600
800
1000
Km

3c



3d

have removed portions of the crust with higher heat-generating elements. Arc magmatic activity seems to have varied with time, with the loci of activity being at first displaced laterally away from the trench and finally towards it (Urrutia-Fucugauchi, 1978, 1982a, b). This lateral variation can be seen from the distribution of radiometric dates from arc-related igneous rocks with distance normal to the axis of paleo-trench (Fig. 3d). This lateral variation of magmatic activity may well explain the apparently complex heat flow pattern (Fig. 3b). The heat flow distribution reflects the effects of the evolution in time of the subduction zone-magmatic arc and the variation of radioactive heat generation.

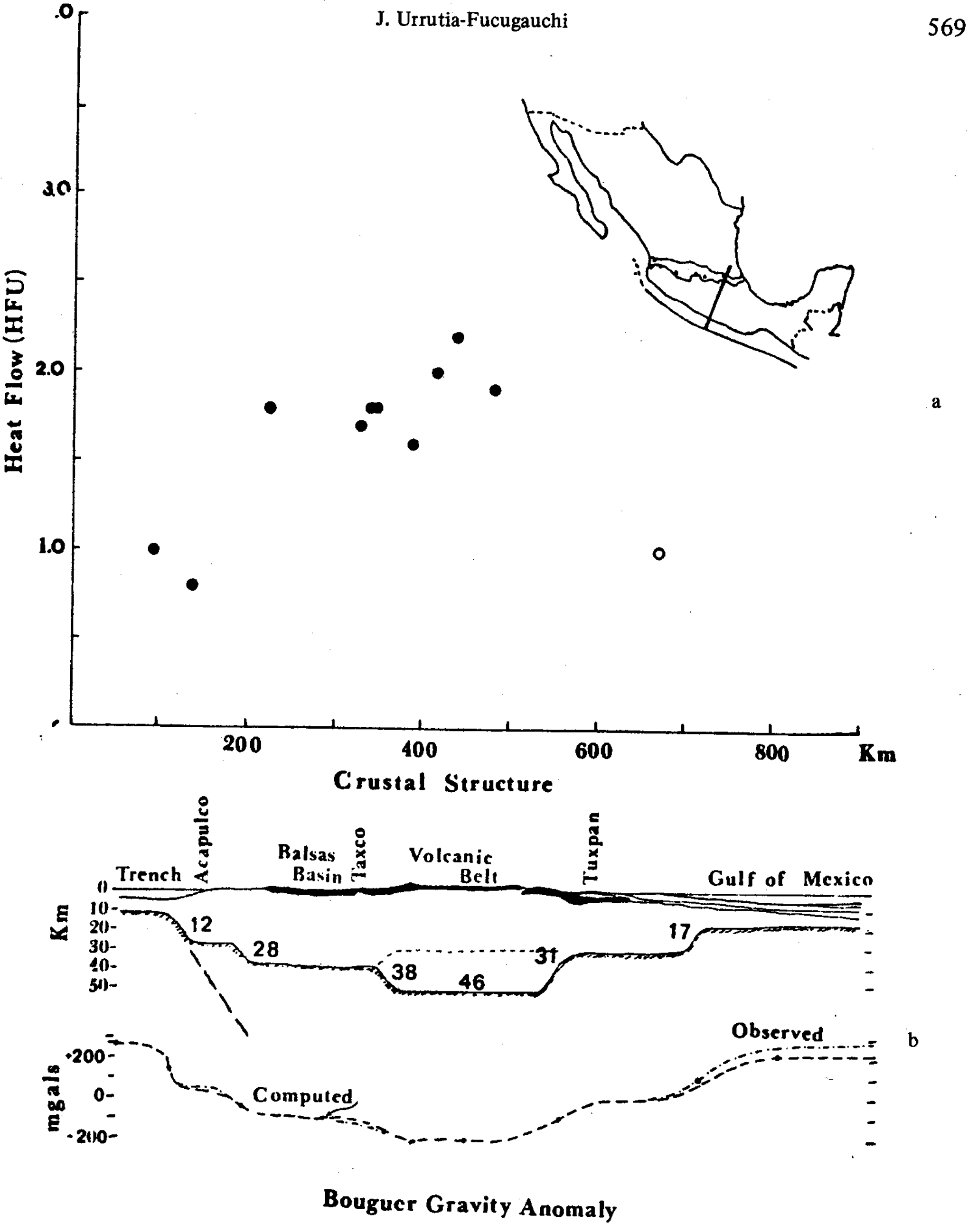


Fig. 4 (a) Variation of heat flow with distance normal to Middle America Trench. Location of profile is given in the inset.

(b) Corresponding inferred crustal structure for southern-central Mexico as inferred from interpretation of gravity anomalies also shown (after Woollard and Monges-Caldera, 1956). Compare with crustal thickness map of Fig. 1b.

The heat flow pattern and structure in southern Mexico (Fig. 4), an active subduction zone-magmatic arc system, seem more simple than those observed for the northwestern Mexico system, and in closer agreement with what is expected for active continental margins. Heat flow increases from about 1 HFU close to the coast (in metamorphic terrane of Precambrian-Paleozoic age) up to 2 HFU in the volcanic belt (radiometric dates range from the late Oligocene to Recent, including present-

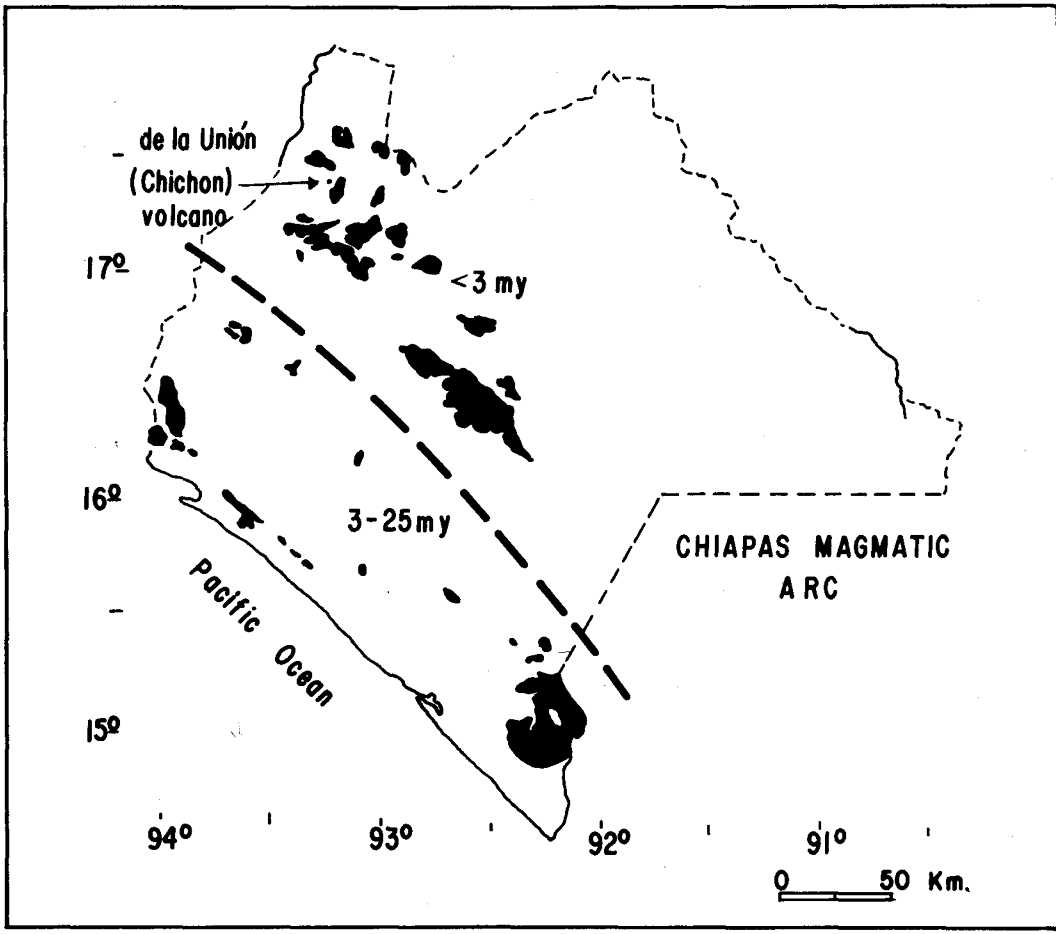
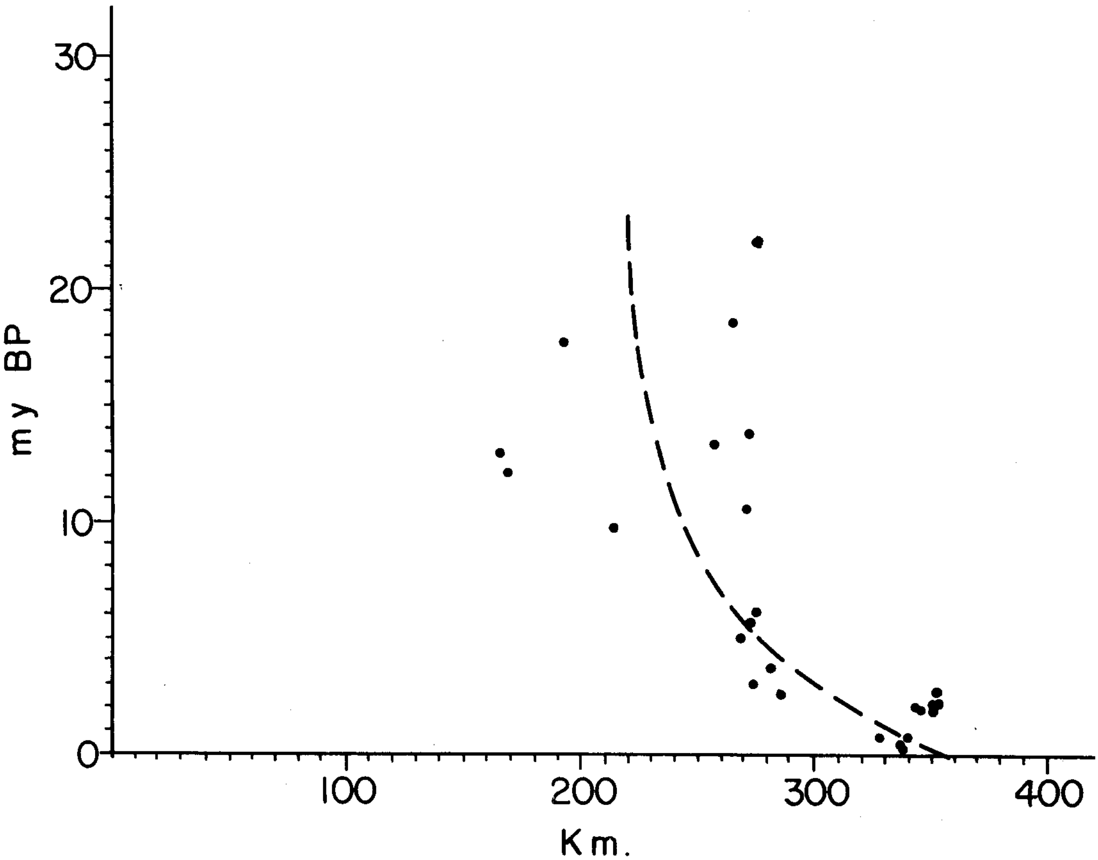


Fig. 5. (a) Distribution of exposures of Cenozoic igneous rocks in southern Mexico with approximate ranges of available radiometric dates (data from Damon and Montesinos, 1978).
(b) Distribution of radiometric dates with distance normal to the Middle America Trench (note inclusion of the Chichonal 1982 eruption).

day volcanic activity), and then decreases to about 1 HFU towards the Gulf of Mexico margin. The high heat flow (>2 HFU) reflects the effects of conductive heat transfer and mass transfer through hot material via mantle convection behind the subduction zone, and the ascending magmas (McKenzie and Sclater, 1968).

A similar situation (Urrutia-Fucugauchi, 1982a) may also be present in the Chiapas volcanic arc (Fig. 5), in which the Chichonal (or de la Union) volcano reassumed activity on April, 1982. An interesting characteristic of the radiometric spatial-temporal distribution (Fig. 5) is the lateral migration of activity away from the trench since the Miocene, which was also observed for the early stages of evolution in the northwestern Mexico margin (Fig. 3d).



5b

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The complete data used in constructing the heat flow and crustal thickness maps can be obtained from the author on request.

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