GEOPHYSICAL TRANSACTIONS 1993
Vol. 37. No. 4. pp. 243-251

FORMATION OF THE CRUST-MANTLE BOUNDARY IN THE PREVIOUS UPPER MANTLE

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Structural units extending over the present crust-mantle boundary are to be seen on the Pannonian Geotraverse deep seismic section [POSGAY et al. 1990]. Studying these units one can conclude that the present crust-mantle boundary lies in the previous upper mantle. During the depth-ward drift of this boundary the fabric of the depth range of the crust-mantle boundary was not destroyed thus it can be studied on the seismic section.

It can be assumed that the above appearance can be linked with the formation of the Pannonian Basin. Due to tensile stress in the lithosphere, partial melting resulted from the intrusions penetrating into the crust-mantle boundary and from the elevated asthenosphere. The melted material settled down in nearly horizontal bodies. The position of the new crust-mantle boundary is assumed on the basis of the lowest reflection having outstanding amplitude obtained from these bodies.

The repetition of the described process can be supposed on the basis of the boundaries below each other.

Keywords: Mohorovičić discontinuity, basin development, Pannonian Geotraverse, upper mantle reflections

1. Introduction

Results of seismic measurements along the Pannonian Geotraverse [POSGAY et al. 1991a] show that the crust-mantle boundary moved towards the depth during the development of the lithosphere. Certain parts of the section allow us to conclude that the present crust-mantle boundary lies in a domain that previously belonged to the upper mantle.

The novelty of the assumption accounts for studying whether it is in accordance with the facts and theories described in the literature. There are

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Manuscript received: 10 November, 1991

references [MATTHEWS and the BIRPS Group 1990, LIE et al. 1990] that mention those three or four places where a continuously reflecting layer from the upper mantle has been able to be determined. Apart from the Pannonian Basin, all the other determinations have been obtained by offshore measurements [BREWER et al. 1983, CLOWES et al. 1987, LIE et al. 1990]. It is likely that the good penetration results are due to utilizing 2-10 Hz frequency domain [POSGAY et al. 1990]. The low frequency experiments [DOHR, FUCHS 1967] ceased probably because at the time of the 1961-64 measurements there was not yet adequate computer processing facilities for enhancing reflections and suppressing surface waves. At the time of computerized geophysical measurements, however, low frequency measurements lost their importance as vibroseis measurements are easier to carry out in densely populated or industrialized areas.

2. Interpretation of reflecting horizons obtained from the vicinity of the crust-mantle boundary

The enclosure shows the 110 km long part of the seismic profile measured along the Pannonian Geotraverse. After true-amplitude recovery the strongest amplitudes were marked with violescent colours, then red-pink-yellow-green-blue colours were used to differentiate the amplitudes. Light blue marked the smallest amplitudes [POSGAY et al. 1991a]. The continuous black lines indicate the assumed deep fault structure zones, upthrusting and piling up fractures in the depth domain of the crust-mantle boundary, the bottom of the Neogene basement and the crust-mantle boundary in accordance with the assumption that constitutes the basis of the interpretation.

In general the crust-mantle boundary coincides with the deepest lower crustal reflecting horizons over the domain of the upper mantle that seems to be transparent when the usual frequency band is involved [MOONEY, BRAILE 1989]. If low frequencies are applied, reflecting layers can be determined in the upper mantle as well. These layers usually appear as weaker amplitudes than those coming from the crust. In that case the deepest reflections having relatively stronger amplitude with short interruptions can be marked as the crust-mantle boundary. Such reflection series often have a characteristic difference from that of reflections observed in its surroundings [POSGAY et al. 1981]; the horizon of these series can more precisely be followed: its amplitude is higher, its dip is smaller it 'strikes through' the background reflection picture. The overall impression is the following: a previous fabric can be concluded from the background, the traces of which have already been dimmed by now, and the assumably present crust-mantle boundary is a younger formation than the 'background'.

The crust-mantle boundary on the Pannonian Geotraverse seismic section has been marked on the basis of the above mentioned principles, and this boundary correlates well with the boundary having 8.1 km/s velocity previously determined mainly by refraction and wide angle reflection measurements [POSGAY et al. 1991b].

The following conclusion can be drawn from the picture appearing in the depth domain of the crust-mantle boundary in the vicinity of upthrusts [POSGAY et al. 1991a, POSGAY, SZENTGYÖRGYI 1991]: both the crust-mantle boundary before the upthrusts and the boundaries having been formed since then give reflections. The highly reflecting layer at the 84 profile km around 8.4 s rising from south can be interpreted as an upthrusted, previous crust-mantle boundary. Under the assumed thrust plane to the left from the 8.8 s of 84 profile km there is a layer which is similarly highly reflecting; this layer was probably the continuation of the upper layer before the overthrust. The nearly horizontal reflection series starting to the right, on the southern side of the upthrust plane may indicate the present crust-mantle boundary. The reflection picture is very similar to those in the vicinity of the assumed thrust plane south of the 8.8 s region of the 99 profile km.

Assuming that the wave picture between 8 and 8.5 s of the 66 profile km reflects a structure similar to that which more clearly can be seen around 8.4 s of 84 profile km, a faster movement of the crust-mantle boundary towards the depth along the northern side of the strike-slip zone can be concluded. The horizontal reflection appearing markedly at 8.7-8.8 s of 59 profile km may be the residue of the crust-mantle boundary after upthrusting. The 'present boundary' can be concluded at 9.5-9.6 s and a just forming surface at 10.3-10.4 s. This conclusion is backed by the fact that the reflection series at 9.5-9.6 s can better be followed and has stronger amplitudes.

This reflection series intersects reflecting horizons that have seismic characteristics similar to those horizons — located beneath the presumed recent crust-mantle boundary — south of the main wrench fault zone, between 90 and 100 profile kms at 9.8-10.3 seconds.

According to the outlined assumption the recent crust-mantle boundary can be found both to the north and south of the main wrench fault zone, in a depth range that previously belonged to the upper mantle. It follows from this conception that in the northern region the boundary crosses such horizons that presumably are below the present boundary, south of the major structural line. Consequently the boundary moved downward on both sides of the main fault zone although its subsidence might have been stronger on the north side of the zone. Fractured structure and tectonic stress seem to be more increased in the northern part. Possibly a relationship may be sought between the considerably fractured feature and the faster downward shifting of the crust-mantle boundary.

3. Formation and drift of the crust–mantle boundary

The crust of the Earth is a density differentiation product of the mantle. This process is still going on even today and the crust displays a thickening tendency [MEISSNER 1986]. Detectable reflecting lower boundary of the young crust coming into being on oceanic ridges can be formed as a result of intrusions penetrating into the base of the crust from the mantle during a period of about 100 000 years [BARTON 1986], and its thickening trend is similar to those of older crust segments. On the basis of data collected about the crusts of the Earth and the Moon, Meissner inferred that the crust's thickness can be evaluated by the formula:

$$z = 25 \log t - 32$$

(z is given in km). As tectonic events disturb greatly the crust structure, t (given in million years) represents the tectono-thermal age of the crust. It must be reckoned from the last tectonic event resulting in metamorphosis in almost the whole depth range of the crust [MEISSNER et al. 1987]. The formula given above is not valid for intensive tectonic belts: regions of mountain systems and rifts. During their formations 'anomalous' crustal thickening beneath the mountains and crustal thinning in rift zones and also in intramontane basins occurred. In both cases significant time (presumably of the order of 10^7–10^8 my.) is necessary for the thickness anomaly to regress [MEISSNER et al. 1987, MCKENZIE 1978] and to get 'into accordance' with its tectono-thermal age. The above formula shows the tendency of this process. Conditions of the crustal formation cause the standard deviation of data [MOONEY, BRAILE 1989].

One interpretation of the thickening tendency — by MEISSNER [1986] — suggests that more material gets into the crust from the mantle (e.g. as intrusions) than from the crust into the mantle (e.g. by means of subduction).

Examples supporting the variability of the crust-mantle boundary even by seismic profiles can be found in the literature. New crust-mantle boundaries can take form through complex crust-mantle structures [POSGAY et al. 1981, BROWN et al. 1986, KLEMPERER et al. 1986, BARTON 1986, HALL et al. 1990]. On published sections there are dipping reflecting horizons through which the reflections of the crust-mantle boundary pass nearly horizontally. Thus a similar characteristic visible on the Pannonian Geotraverse seismic profile cannot be regarded as a particular and unique occurrence. On the seismic section in the upper and lower vicinity of the boundary, observable parts — from which piling up, upthrust, strike-slip and a more ductile transition zone in the lower lithosphere can be concluded according to the above assumption — should be supported by supplementary information making the novel attempt in interpretation reasonable.

Velocity data from the depth range of the crust-mantle boundary may offer a basis for interpreting this region's formation. Along the shores of Norway on the bottom of the continental crust ZEHNDER et al. [1990], during their reflection and refraction studies, specified a 'layer' of 0–3 km thickness and 7.5 km/s velocity which 'could represent a region of melt liberation and underplating that accompanied the Jurassic phase of extension'. SMITHSON [1989] considering a layer approximately 3 km thick having a seismic velocity of 7.4–7.8 km/s located on the bottom of the crust, in the area of Basin and Range, assumes that it 'could consist of a residuum from partial melting or a cumulate zone from crustal underplating' while with regard to the crust–mantle boundary 'the Moho zone is strongly layered and discontinuous because of intershearing of mantle and crustal rocks or because of intrusion of basaltic melt from the mantle along the mantle–crust transition'.

Velocity analysis in the Pannonian Basin area suggests a 5–7 km thick sequence on the bottom of the crust, characterized by 7.2–7.7 km/s seismic velocity [POSGAY 1975, POSGAY et al. 1980, 1981].

Relying on the results of the Pannonian Geotraverse PGT-1 seismic profile an interpretation can be given having the following new feature: the moments associated with the formation of the Pannonian Basin [STEGENA 1967, HORVÁTH et al. 1988, ROYDEN, DÖVÉNYI 1988] are assumed to have played a great part in the development of the crust's lower sequence with 7.2–7.7 km/s seismic velocity. During the stretching of the lithosphere in the initial phase — that can be characterized by block fractures, subsidence and uplifting of the asthenosphere [MCKENZIE 1978] — basaltic intrusions penetrating into the lower crust [GRIFFIN, O'REILLY 1986] increased the velocity of this sequence. The pushing up of more acid melt parts into upper region of the crust might have contributed to the velocity increase [FOUNTAIN 1986].

The plasticity difference between the lower crust and the uppermost domain of the mantle could have been reduced as a result of the heating effect of intrusions penetrating into the crustal bottom [FOUNTAIN 1989]. This process probably promoted the intrusions intruding into the mentioned uppermost mantle region also. Assuming basaltic intrusions [DAWSON 1987] their penetration might have decreased the velocity of the depth range in question thus forming a 'layer' of the upper mantle the velocity of which can be regarded as a transition between the crust and the mantle (e.g. 7.7 km/s on the area of the Pannonian Basin, 7.4–8.1 km/s in the Basin and Range province; [SMITHSON 1989, MOONEY, BRAILE 1989]).

It can be assumed that the observable piling up structures at the depth range of the crust–mantle boundary occurred in the course of Eocene–Oligocene strike-slip movement [POSGAY, SZENTGYÖRGYI 1991], viz. they are older than the extension structures [HORVÁTH et al. 1988]. Since these older structures are clearly visible on the seismic section, presumably the intrusion process, the developed heating effect and also the metamorphosis pervaded only partially this depth range. This hypothesis is reinforced by the theoretical studies of FURLONG, FOUNTAIN [1986] according to which relatively smaller amounts of intrusions (with smaller heat content) are formed from shallow asthenosphere than from a deeper position. Partial melting as a result of the heating effect might have affected only those parts of rock components having lower melting point. The rock-frame could mostly preserve the earlier structure of the depth range (which is verifiable seismically) but because of the partial melting it could become so permeable in smaller domains that arrangement of melt parts into horizontal bodies was possible owing to gravitational and thermal fields. They jointly constitute the new reflecting crust-mantle boundary whose depth cannot differ essentially from the basic/ultrabasic boundary detectable by the refraction method. During the extension period both deformations and intrusion (also volcanic) activities are likely to be divided into several time phases.

Repetition of the described phenomena can be assumed. 'Crust-mantle boundaries' forming in this way are probably situated under each other as, because of the deepening of the asthenosphere and thermal decrease of the lithosphere, isotherms moved towards the depth. On the basis of seismic results [POSGAY et al. 1981, 1986, 1991a] it can be supposed that some deep faults pass transversely the whole lithosphere or a significant part of it. Taking into consideration the elevated position of the asthenosphere during the extension period, further the repeated reactivating of the faulting [POSGAY, SZENTGYÖRGYI 1991] it is likely that these fractures played a great part in the outlined processes. It could give a reason for the fact that on strongly tectonized parts of the section the displacement of the crust-mantle boundary towards the depth might have been greater than the average.

4. Discussion/Conclusions

The composition and structure of the crust-mantle boundary may depend on the geological history of the lithosphere [HALE, THOMPSON 1982]. On the basis of deep seismic investigations along the Pannonian Geotraverse the interpretation of displacement of the boundary towards the depth beneath the studied part of the Great Hungarian Plain seems to be reasonable. Presumably the recent crust-mantle boundary is situated in the former (before the basin formation) upper mantle. From locations of reflecting horizons that correspond to the earlier crust-mantle boundary and from the neighbouring structural elements, piling up and upthrust can be concluded. The recent boundary is assumed to extend beneath the former boundary/boundaries. Its formation may be connected with the evolution of Pannonian basins. In this time range the lithosphere could have had a main extension of approximately EW direction [ROYDEN 1988] which is almost perpendicular to the Pannonian Geotraverse.

Acknowledgements

I am deeply inbebted to the Board of the Hungarian National Foundation for Scientific Research (OTKA) and to the management of the Central Office of Geology (KFH) for their spiritual and material contributions to these investigations. I am also grateful to my colleagues for their help in data acquisition, computer processing, interpretation and in the realization of this paper.

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A KÉREG-KÖPENY HATÁR KIALAKULÁSA A KORÁBBI FELSŐKÖPENYBEN

POSGAY Károly

A Pannon Geotraverz szeizmikus szelvényén a kéreg-köpeny határon átnyúló szerkezeti elemek láthatók [POSGAY et al. 1990]. Vizsgálatukból arra lehet következtetni, hogy a jelenlegi kéreg-köpeny határ a korábbbi felsőköpenyben helyezkedik el. E határfelület mélység felé történő vándorlásakor a kéreg-köpeny határ mélységtartományának szerkezete nem semmisült meg, az a szeizmikus szelvényeken tanulmányozható.

Feltételezhető, hogy a fenti kép a Pannon-medence kialakulásával hozható összefüggésbe. A litoszféra extenziós igénybevétele következtében a kéreg-köpeny határtartományba hatoló intrúziók és a kis mélységben elhelyezkedő asztenoszféra hatására részleges olvadás következett be. Ezek együtteséről kapott legalsó, kiemelkedő amplitúdójú reflexió alapján valószínűsíthető az új kéreg-köpeny határ.

A leírt folyamat ismétlődését lehet feltételezni az egymás alatt megfigyelhető határokból.

ОБРАЗОВАНИЕ ГРАНИЦЫ КОРА-МАНТИЯ ВНУТРИ ДРЕВНЕЙ ВЕРХНЕЙ МАНТИИ

Карой ПОЖГАИ

На сейсмическом разрезе Паннонского Геотраверса наблюдаются структурные элементы, пересекающие границу кора-мантия [POSGAY et al. 1990]. Предпологается, что современная граница кора-мантия находится внутри древней верхней мантии. При перемещении вниз этой границы не уничтожились ранее существующие структуры в окрестности границы кора-мантия, поэтому их можно исследовать по сейсмическим разрезам.

Можно предпологать, что выявленная ситуация связана с происхождением Паннонского бассейна. Под влиянием интрузий, внедрявщихся в граничную область кора-мантия вследствие экстенсионной загрузки литосферы, а также неглубокого расположения астеносферы, произошло частичное расплавление. Расположение новой границы кора-мантия, вероятно, прослеживается по самым глубоким сейсмическим отражениям большой амплитуды от данного комплекса. Судя по выявленным друг под другом границам, предпологается, что описанный процесс повторялся несколько раз.