Precambrian Moho offset and tectonic stability of the East European platform from the URSEIS deep seismic profile

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SEISMIC DATA OF THE CARPATHIAN FOREDEEP BASEMENT (ROMANIA)

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Abstract

The Carpathian foredeep is a molasse-bearing depression that formed in front of the folded eastern and southern Carpathians in the Late Miocene. Deep seismic reflection/ refraction profiles as well as gravity and thermal studies carried out in the foredeep area of the southern and eastern Carpathians provide information on the crustal structure of the study region. The variability in the reflectivity pattern and crustal thickness shown by the different sectors of the Carpathian foredeep are due to differences in the structure and lithology as well differences in crustal age (Klemperer, 1987; Wever et al., 1987).

In western part of the southern Carpathian foredeep reflectivity increases with depth and Moho is deliniated by strong reflections at 9-11.5 s two-way travel time (TWT) (30 - 33 km depth). The eastern side of the southern Carpathian foredeep shows a decreasing reflectivity with depth, the crustal base being interpreted at 12-13 s TWT (40-45 km depth) (Raileanu et al., 1994).

The eastern Carpathian foredeep is characterized by an almost transparent upper crust and a layered lower crust down to 13 s TWT (40-45 km depth). The greatest thickness of foredeep rocks is in the eastern Carpathian arc bend (Focsani depression), where Neogene rocks are 8 to 10 km thick.

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1. Introduction

The Carpathian foredeep external to the outer southern and eastern Carpathians is considered to be a typical molasse bearing foredeep that formed coeval with thrusting in the adjacent mountain belt (Royden and Karner, 1984). It is a transition zone between the Carpathians and foreland units and formed as a result of the Savian and Styrian tectonic movements (Burchfiel and Royden, 1982).

The Carpathian foredeep contains mostly Neogene sediments largely derived from the Carpathians, but also with significant contributions of detritus from the more external East - European (Moldavian) and Moesian platforms. Rock types within the foredeep include molassic conglomerates, sandstones and shales and local important evaporite deposits. Folds and small thrusts within the Neogene, Pliocene and even Pleistocene rocks are complicated by salt diapirs which have a variety of complex structural forms (Patrut et al., 1973). Many of these folds contain important oil reserves (Paraschiv, 1979; Burchfiel and Royden, 1982). The foredeep ranges in width from only a few kilometers (~10 km) in the northern part of the eastern Carpathians to more than 100 km at the southern Carpathian bend. The greatest thickness of the foredeep sediments is south of the eastern Carpathian bend (Focsani depression), where the Neogene rocks are probably 8 to 10 km thick. Recently this area has been subsiding at a rate of up to 3mm/yr. (Popescu and Dragoescu, 1986).

This paper synthesizes previous seismic studies carried out in this zone(Radulescu et al., 1977;Radulescu, 1981;Raileanu et al., 1994;Diaconescu M. et al., in press) creating an integrate interpretation of the data. The knowledge of the crustal structure of the Carpathian foredeep in Romania is mainly based on seismic (near-vertical reflection profiling and refraction methods) gravity and thermal data (Andreescu et al., 1989; Andreescu, 1993; Demetrescu and Andreescu, 1994;Diaconescu C. et al., in press).

2. Geological setting

Structurally, the Carpathian foredeep forms a wedge of clastic rocks and evaporites that thickens toward the Carpathians. The inner part of the foredeep has been involved in the folding and thrusting of the foreland belt.

The Carpathian foredeep was deformed during three different orogenic phases. The first stage ended in the Early-Middle Miocene with the uplift of the Carpathian orogen and overthrusting of the flysch zone onto the foredeep deposits.

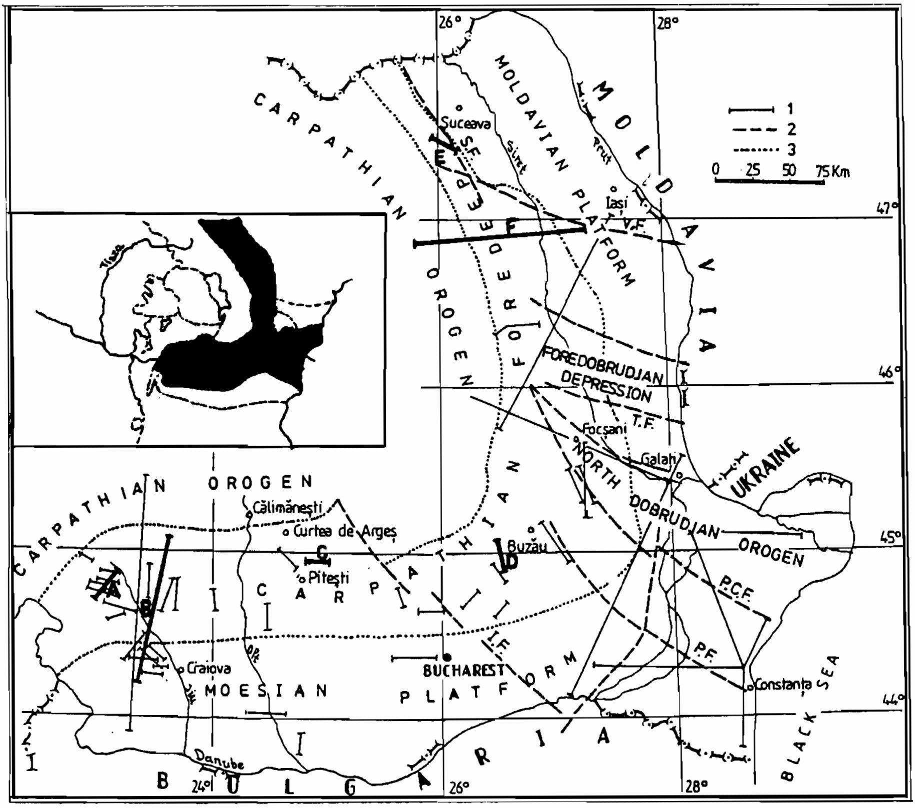

Figure 1. Location map of deep seismic reflection and refraction lines in the Carpathian foredeep and neighbouring areas. 1 - seismic line; 2 - fault; 3 - limit between tectonic units; I.F.-Intramoesian fault; P.F.-Palazu fault; P.C.F.- Peceneaga-Camena fault; T.F.- Trotus Fault; S.F.-Solca fault; V.F.-Vaslui fault.

At the same time, the foredeep deposits together with the Palaeogene flysch were strongly folded. During the Late Miocene (Moldavian orogenic phase) the folded molasse zone overlapped the foreland areas along the Pericarpathian fault. During the Vallachian phase (Neogene-Pleistocene) salt deposits were folded as diapir folds (Mutihac, 1990). The sedimentary basin of the Carpathian foredeep became a separate crustal block in the Early Miocene as a result of the uplift of the Carpathian external flysch.

West of the Intramoesian fault (Fig. 1), the crystalline basement of the Carpathian foredeep is composed of Moesian type basement up to the South Calimanesti fracture, and of folded Hercynian elements of the southern Carpathians (Danubian autochthon)(Visarion et al., 1984). In this area the Moesian-type basement is made up of mesometamorphic schists, that underwent retrograde metamorphis during the Late Protozoic age (0.6-1.0 Ga)(Mutihac, 1990). Granitic, granodioritic and gabbroic Hercynian intrusions pierce the basement (Paraschiv, 1979). The folded Hercynian elements of the Danubian autochthon are composed of crystalline schists with granitic intrusions of pre-Alpine age and a sedimentary cover of pre-Tertiary age .

Between the Intramoesian fault and Peceneaga-Camena fault (Fig. 1), the crystalline basement of the Carpathian foredeep can be subdivided into two different rock types:
1-Rocks metamorphosed to the greenschist facies during the Cadomian period. They crop out in the central Dobrudja and extend west of the Danube between the Peceneaga-Camena and Palazu faults, where they are covered by sediments, (Fig. 1), (Sandulescu, 1984; Visarion et al., 1988 a)
2- Mesometamorphic crystalline schists of Karelian age that extend from the South Dobrudja westward, between the Palazu and Intramoesian faults (Visarion et al., 1988 a). The Intramoesian and Palazu faults are probably Cambrian, but are younger than the oldest strata of the Moesian sedimentary cover (Sandulescu, 1984). The Peceneaga-Camena fault is contemporaneous with the folding of the greenschists, but it was activated by the subsequent orogenic phases (Mutihac, 1990).

The Karelian crystalline basement was affected by tectonic and metamorphic processes at least one more during the recent Cadomian orogeny. The Variscan orogeny significantly affected the sedimentary cover, but had only minor effects on the basement (Sandulescu, 1984).

The greenschist facies basement extends northward, to the Vaslui fault (Fig. 1). North of this fault, the basement of the eastern Carpathian foredeep is composed of schists

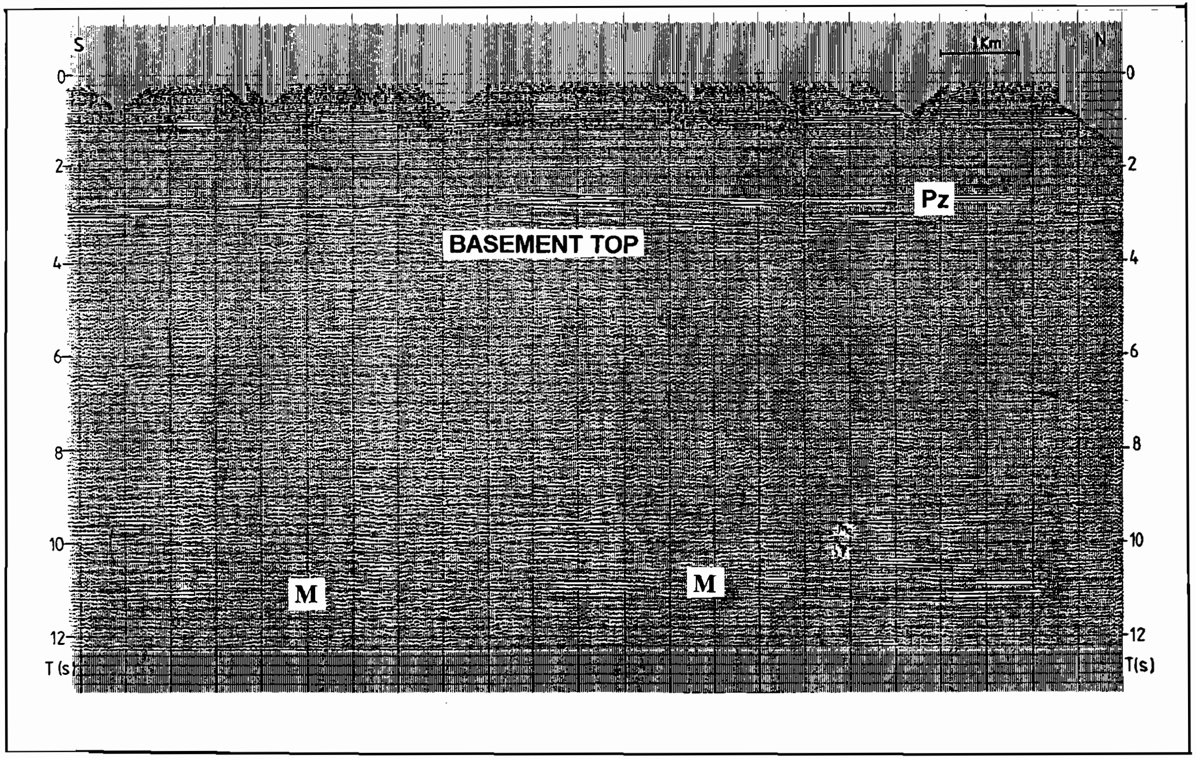

Figure 2. Seismic section of line A (see Figure 1 for location); Pz-Palaeozoic; M-Moho.

of Baikalian age (North Dobrudjan type). In the East-European (Moldavian) platform the Baikalian basement on the west has been overthrust onto Middle Proterozoic basement to the east along the Solca fault (Visarion et al., 1988 b).

3. Geophysical data

Many deep seismic reflection and refraction lines were recorded in the Carpathian foredeep area, most of them in the westernmost zone of the southern Carpathian foredeep and in the eastern Carpathian arc bend region. Using seismic analyses together with other geophysical data (Radulescu et al., 1976; Cornea et al., 1981; Radulescu, 1981; Radulescu, 1988; Enescu et al., 1992), the crust has been divided in different domains, some of them being transitional boundaries.

Line A (see Figure 1 for location) was recorded in the western part of the Carpathian foredeep, in the region with Moesian platform-type basement. The seismic section of this line (Fig. 2) shows a highly reflective sedimentary cover of which the Palaeozoic top (Devonian) is the most prominent horizon, at 2.8-3.0 s two-way travel time (TWT). The top of the crystalline basement does not generate prominent reflections, but a weak reflective horizon at ~ 3.8 s TWT(7-8 km depth), is interpreted to be the base of the sedimentary cover. The depth to the basement was evaluated based on drilling and refraction seismic data (Radulescu et al., 1977; Radulescu et al., 1984). The upper crust seems to be transparent (4.0-8.0 s TWT), possibly as a result of the homogeneity found with granitic intrusions (Brown, 1991), while the upper crustal lacks reflectivity, the lower crust has a strongly layered character (7- 11.5 s TWT). Such a spatial correlation is often cited as evidence for the extensional origin of the deep reflectivity (Brown, 1991). Mafic sills emplaced during the collision delamination could be an important contribution to the enhanced lower crustal reflectivity (Nelson, 1991). The Moho seems to be a transition zone between the crust and mantle (9.0 - 11.5 s TWT), is deliniated by two bands of reflections (Raileanu et al., 1994).

Figure 3 shows a crustal cross section of the line B (see Figure 1 for location) in the same region that was interpreted from reflection/refraction, gravity, geological and thermal data (Andreescu et al., 1989; Diaconescu C. et al., in press). The reflectivity pattern of this region is similar to the reflectivity of Variscan and Caledonian Europe indicating a stable crust (Nelson, 1991) that has not been deformed since Alpine orogeny. The magmatic intrusions that accompanied the orogen were horizontally dispersed as a result of the reduced viscosity caused by the relative high (400 - 500^{o} C) temperatures in the lower crust (Fig. 3) (Wever et al., 1987). The inferred temperature distribution in the crust is based on observe heat flow data (Diaconescu C. et al., in press).

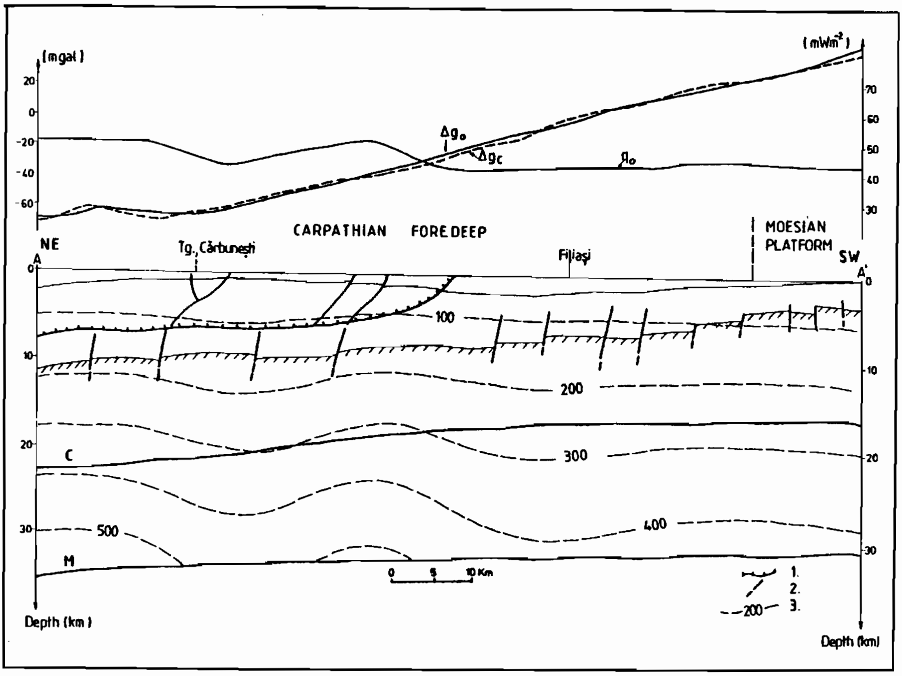

Figure 3. Depth section of line B in Figure 1. Δg_o - observed Bouguer anomaly; Δg_c - computed Bouguer anomaly; q_o - surface heat flow; C-Conrad and M-Moho discontinuities

Line C (Fig. 4) was recorded in the central Carpathian foredeep (Fig. 1). The basement top is interpreted to be at ~ 5.5-6.0 s TWT (~ 10 km depth), close to the bottom of the reflective sedimentary cover. The crust shows a decreasing reflectivity with depth, the upper crust

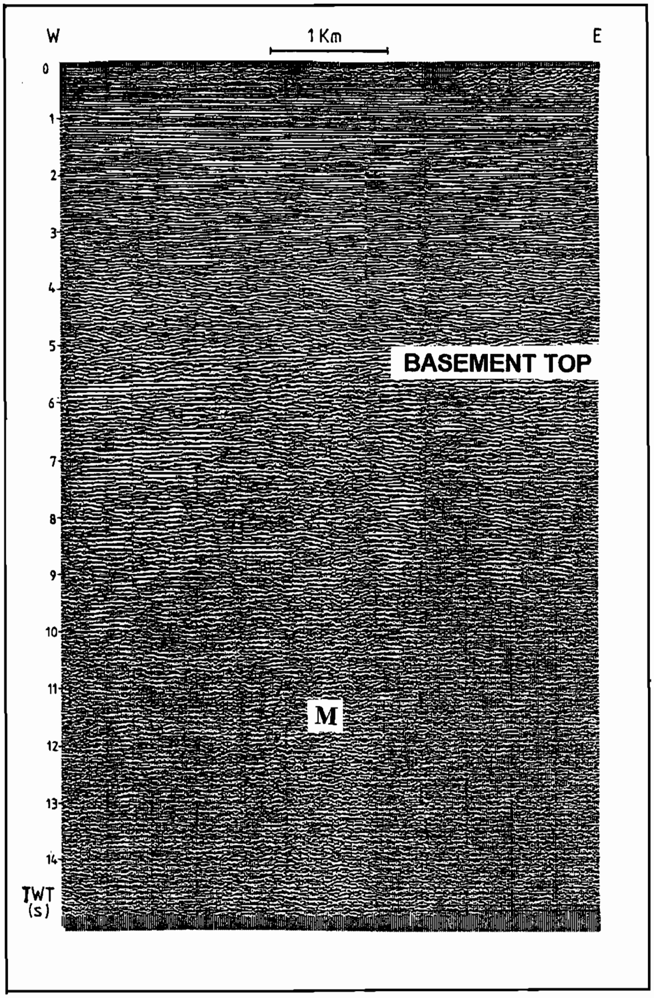

Figure 4. Seismic section of line C (see Figure 1 for location); M-Moho.

contains zones with strong reflections that can be correlated over long distances, alternating with zones void of reflections. At the same time, some short and diverging reflections like seismic 'crocodiles' in southern Germany (Sadowiak et al., 1991) occur in the middle crust (6.0-8.0 s TWT). They are found in compressional belts and may represents different interwedged rocks (Price, 1986).

The base of the crust is characterized by a paucity of reflections, is interpreted to transition to mantle material at ~ 11.6-12.0 s TWT (~36 km depth), with a mean crustal velocity of 6.2 km/s (Enescu et al., 1992).

The line in Figure 5 was recorded in the arc bend zone of the eastern Carpathian foredeep (line D in Figure 1). The top of the basement is interpreted to be at ~ 5.0 s TWT, at the base of the sedimentary cover. Reflections from 6.2-6.8 s TWT delineate the transition zone between the upper and lower crust. The Moho is deliniated by the strong nearly continous reflections from 12.8-13.0 s TWT. The seismic section of line D shows many diffractions mainly produced by fault zones. The reflections dip slightly from S to N, following the deepening of the Moesian platform deposits toward the orogen.

Fig. 6 is a density crustal section across the

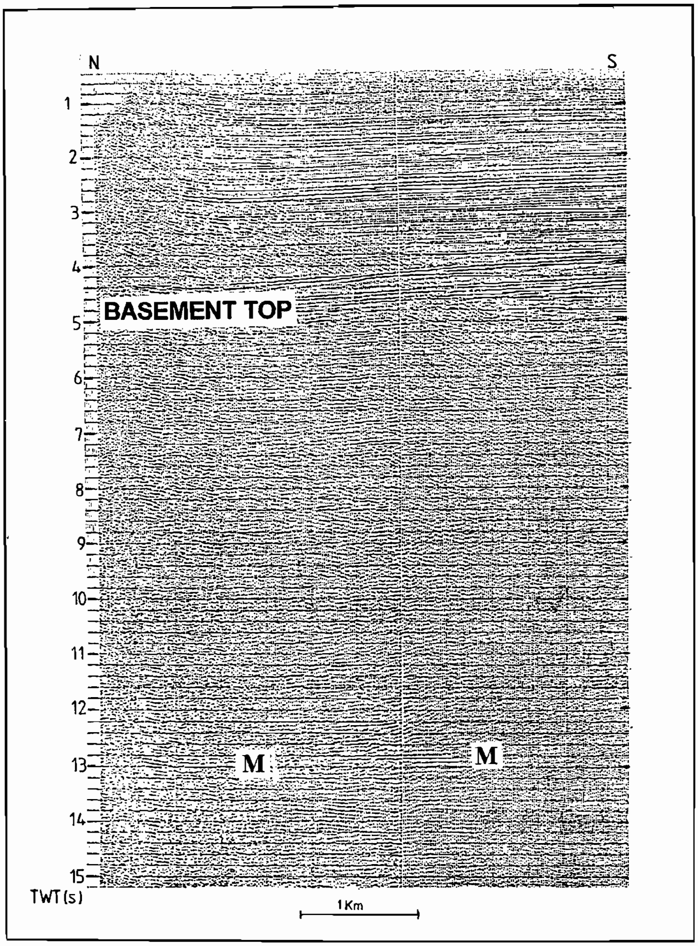

Figure 5. Seismic section of line D (see Figure 1 for location). M-Moho.

eastern Carpathian foredeep along the international profile XI, (Radulescu et al., 1976; Cornea et al., 1981). It shows a gravity low value in the deepest part of the Carpathian foredeep (Focsani depression), that contains Neogene rocks that are 8 to 10 km thick .

Line E (see Figure 1 for location) is situated in the northern part of the eastern Carpathian foredeep, in the transition zone from the Moldavian platform to the eastern Carpathians. The Moldavian platform is the southwestern part of the east European platform, and it consolidated in the Middle-Proterozoic time. Line E crosses the Solca fault that separates two different types of basement: the Moldavian platform-type basement to the east and the Caledonian-Hercynian basement to the west. The Solca fault also separates two different reflectivity patterns (Fig. 7). The surface of the basement is interpreted to be at 2.8 s TWT (~ 6.5 km depth) in the southeastern side of the seismic section and it sinks slightly to the northwest up to the Solca fault. East of the Solca fault there is an increasing reflectivity with depth. The lower crust seems to be layered (between 10.0 and 13.0 s TWT), suggesting a ductile medium. West of the Solca fault, the seismic section has many diffractions, and the reflections are difficult to correlate. The Moho is inferred to be at ~ 42 km depth (Raileanu et al., 1994).

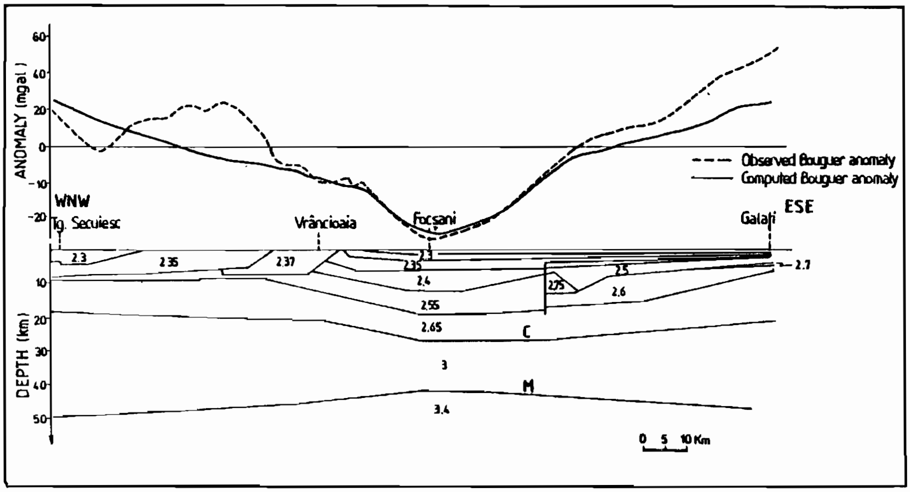

Figure 6. Density crustal section across the Carpathian foredeep arc bend zone (see line XI in Figure 1).

A crustal model across the eastern Carpathian foredeep as interpreted from a refraction line (line F in Figure 1) recorded in the transition area between the Moldavian platform to the Carpathian orogen is presented in Figure 8. It depicts the main crustal domains, as follows: the sedimentary/basement boundary (9-11 km depth), the

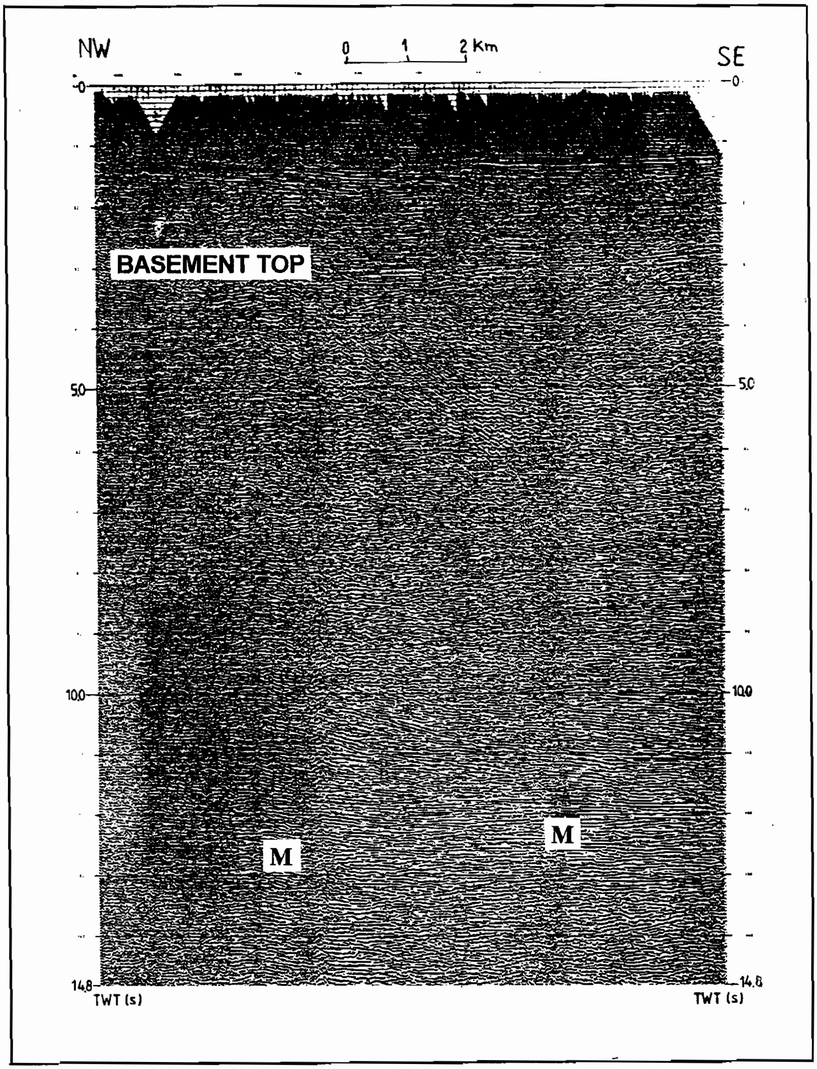

Figure 7. Seismic section of line E (see Figure 1 for location); M-Moho.

upper/lower crust limit (19-22 km depth), the base of the crust (43-50 km depth) and the base of the lithosphere (75-78 km depth) (Pompilian et al., 1993).

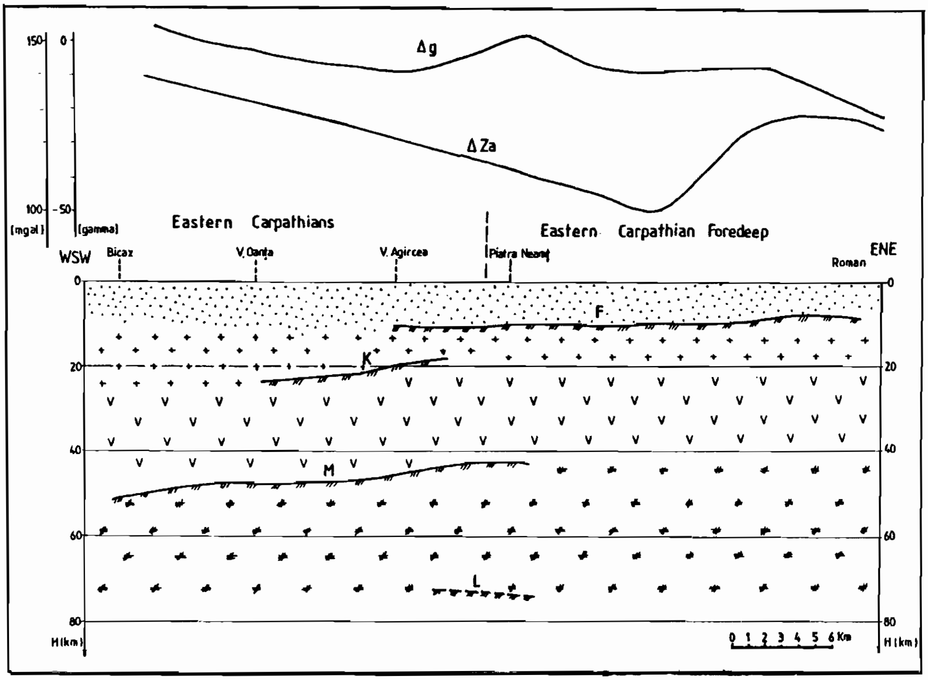

Figure 8. Crustal cross section across the Eastern Carpathian foredeep (F in Figure 1). F-sedimentary/basement boundary; K-Conrad discontinuity; M-Moho; L-lithosphere/asthenosphere boundary; ☐ — sedimentary cover; ☐ — upper crust; ☐ -lower crust; ☐ —subcrustal lithosphere

4. Conclusions

The western part of the southern Carpathian foredeep shows a relatively transparent upper and middle crust with some diffractions and/or some short and dipping reflections that may indicate a brittle medium (Fig. 2). The reflectivity increases with depth and a crust-mantle transition zone with distinct and prominent reflections (at 9.5-11.5 s TWT) has been identified. The temperatures calculated (using heat flow data) for the Moho boundary in this region have values around 400-500^{0} C , suggesting thermal conditions that would induce the development of layering of the lowermost crust. This suggests that the Carpathian foredeep basement was reworked during the Alpine orogeny.

In central and eastern parts of the southern Carpathian foredeep the upper crust shows a pronounced reflectivity that decreases with depth, however the Moho is difficult to distinguish. This reflectivity pattern agrees with the relatively low values of the surface heat flow (35-40 mWm^{-2}) and the low temperatures calculated for the Moho (Andreescu, 1993). The crust thickens from west (~30-33 km) to east and northeast (~40-45 km). Moreover, the lower crust exhibits a thickening in this direction relative to the upper crust, which may explain its lower heat flow values (Demetrescu and Andreescu, 1994).

The eastern Carpathian foredeep formed as a basin with molasse sediments between Early Miocene and Late Pliocene. Although the reflectivity of the eastern Carpathian foredeep crust was poorly investigated, it does show some distinct characteristics. The northern side of the eastern Carpathian foredeep exhibits increasing reflectivity with depth, and the lower crust seems to be layered, suggesting a ductile medium (Wever et al., 1987). The crustal reflectivity of the eastern Carpathian foredeep which is 40 to 42 km thick is consistent with the $400^{0}C$ temperatures at a depth of 20 km (Demetrescu and Andreescu, 1994) that are present in this area.

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