NATURAL ENVIRONMENT

Geophysics

Geodynamics

Alpine, Carpathian and Dinaric mountain belts surround the Pannonian (Carpathian) Basin, of Neogene through Quaternary in age. The Cenozoic evolution of the Alpine-Pannonian region is primarily controlled by the northward drift and collision of the Adriatic promontory with Europe, producing a net convergence of at least 500 km in the Alps. Adria has been pushed towards the north by the African plate even if it was not always tightly attached to Africa.

A most pronounced expression of this collision has been the Late Oligocene to Early Miocene eastward extrusion of an Alpine orogenic wedge, called the ALCAPA (Alps-Carpathians-Pannonian) terrane. There is a second unit in the substrata of the Pannonian Basin called the Tisza-Dacia terrane. It is generally accepted that the Tisza-Dacia terrane rifted apart from the European margin of the Mesozoic Tethys during the Late Jurassic, and this rifting led to the formation of a marine basin, where the Alpine-Carpathian flysch complexes were deposited. The two terranes became juxtaposed during the Late Oligocene and formed the substrata of the later Pannonian Basin.

The Pannonian Basin and its surroundings are characterised by a polyphase deformation history with a sequence of distinct structural episodes. There is a good knowledge of the principal kinematic features, i.e. the location of major fault zones, the timing and the amount of deformation. A rapid and dramatic change in tectonic style started in the Early Miocene (Eggenburgian through Karpatian) that initiated the formation of the Pannonian Basin. This process culminated in the Middle Miocene (Badenian) and was coeval with a large-scale tectonic transport of the external flysch nappes towards the foreland of the Carpathian arc.

The large-scale lateral extrusion of the ALCAPA and Tisza-Dacia terranes took place from the Early Miocene towards an eastern, unconstrained margin of the Carpathian flysch basin. Lateral extrusion is a crustal-scale process including extensional collapse of the brittle upper crust and ductile flow of the lower crust. Extruding crustal wedges are typically bounded by conjugate sets of strike-slip faults, facilitating an orogen-parallel direction of displacement.

Kinematic data and numerical modelling suggest the predominant role of Carpathian subduction facilitating extrusion and large-scale lithospheric extension in the Pannonian Basin. Continuous roll-back of the subducting plate along the contemporaneous Carpathian arc exerted trench pull forces on the upper plate. The overriding plate in a subduction zone tends to passively follow the retreating hinge of the downgoing lithosphere. This induced tensional stresses and the eastward extension of the ALCAPA and Tisza-Dacia terranes.

Tension in the ALCAPA and Tisza-Dacia terranes caused about 50% to 120% crustal, and mantle lithosphere extension of nearly an order of magnitude higher. Occasionally, extension was concentrated in discrete zones where pull-apart basins developed. Heterogeneous extension is reflected by the variation of pre-Neogene basement depth and crustal thickness. Elevated basement blocks separate deep sub-basins where thickness of the Neogene-Quaternary sedimentary rocks can reach 6 to 7 km. Such irregular basement morphology is mainly the result of strain localisation along pre-existing crustal weakness zones inherited from Late Cretaceous thrust and nappe tectonics.

Thickness of the present crystalline crust varies between 22 and 32 km as a consequence of the extension of the originally overthickened orogenic wedge (*Figure 13*). Estimated thickness of the orogenic crustal wedge was between 40 and 45 km. The remarkable crustal and lithospheric

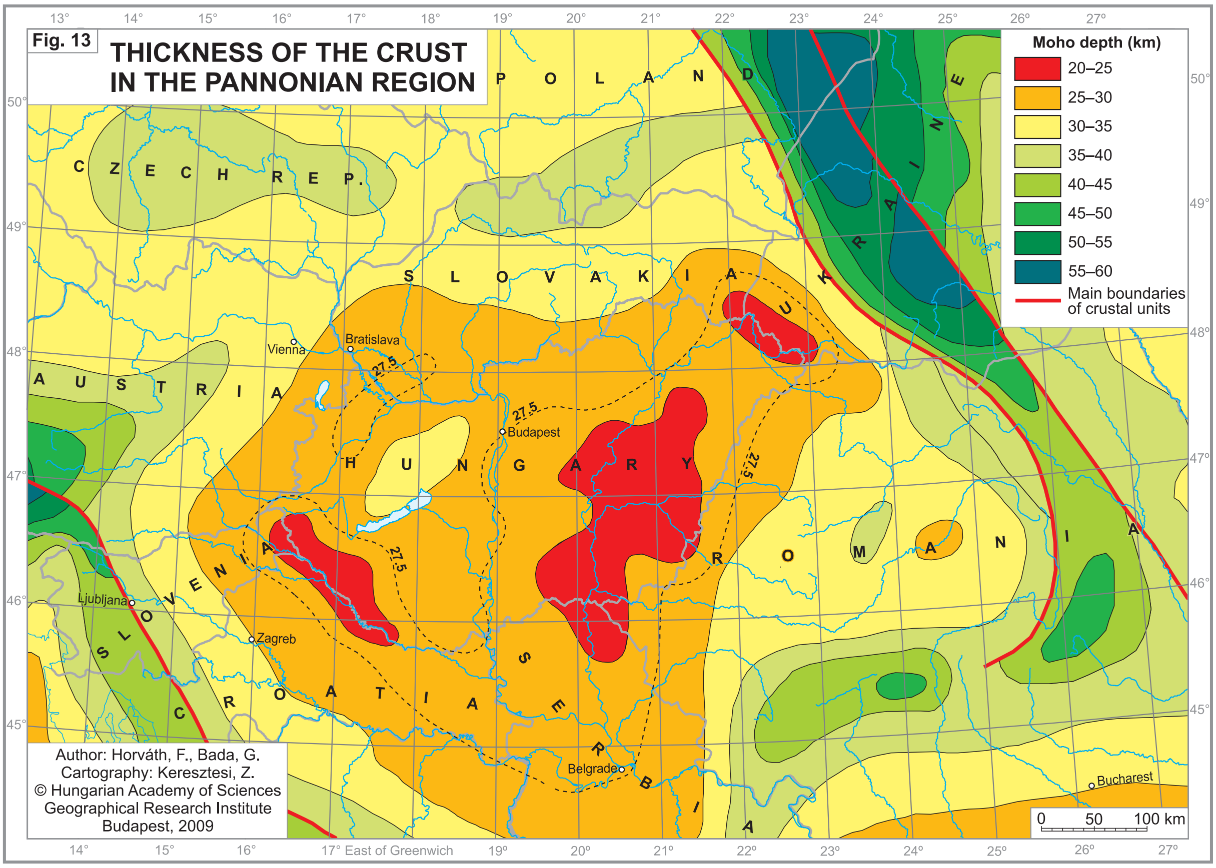


Fig. 13 THICKNESS OF THE CRUST IN THE PANNONIAN REGION

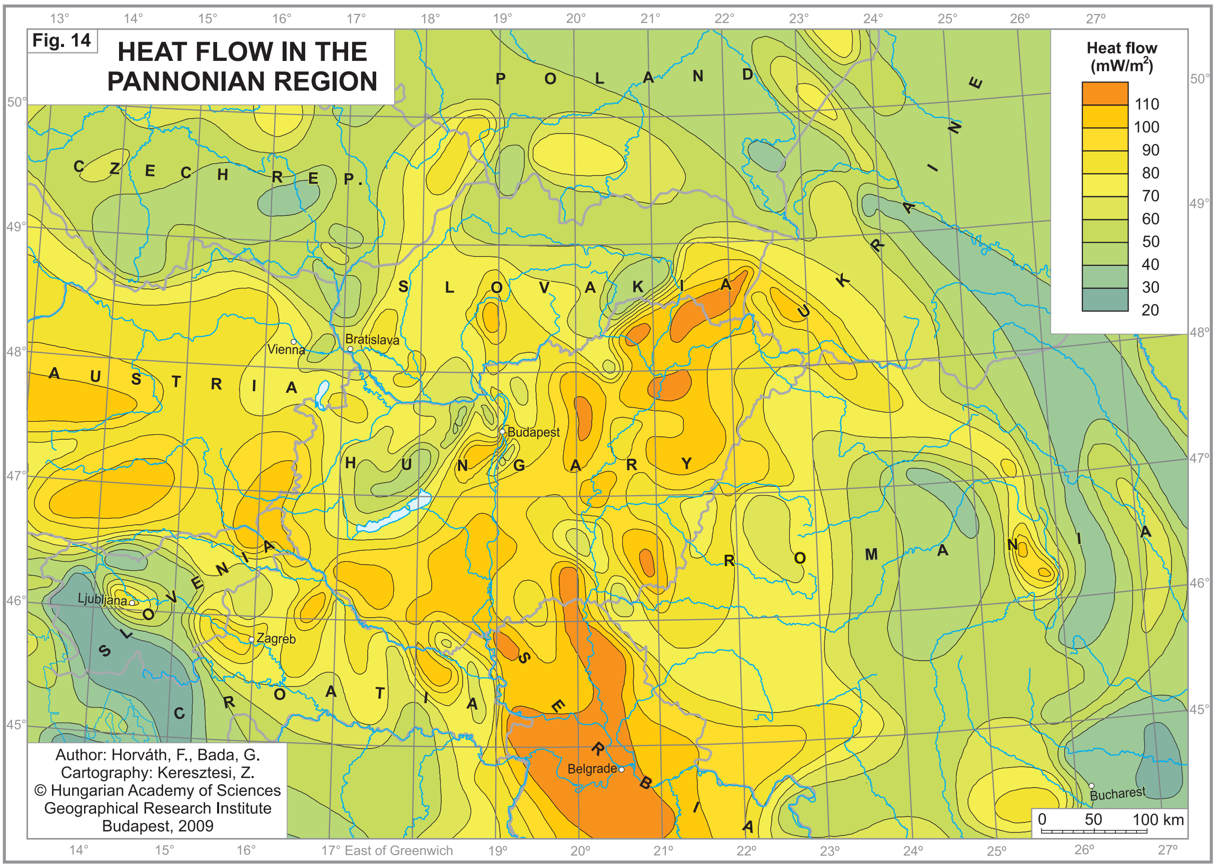
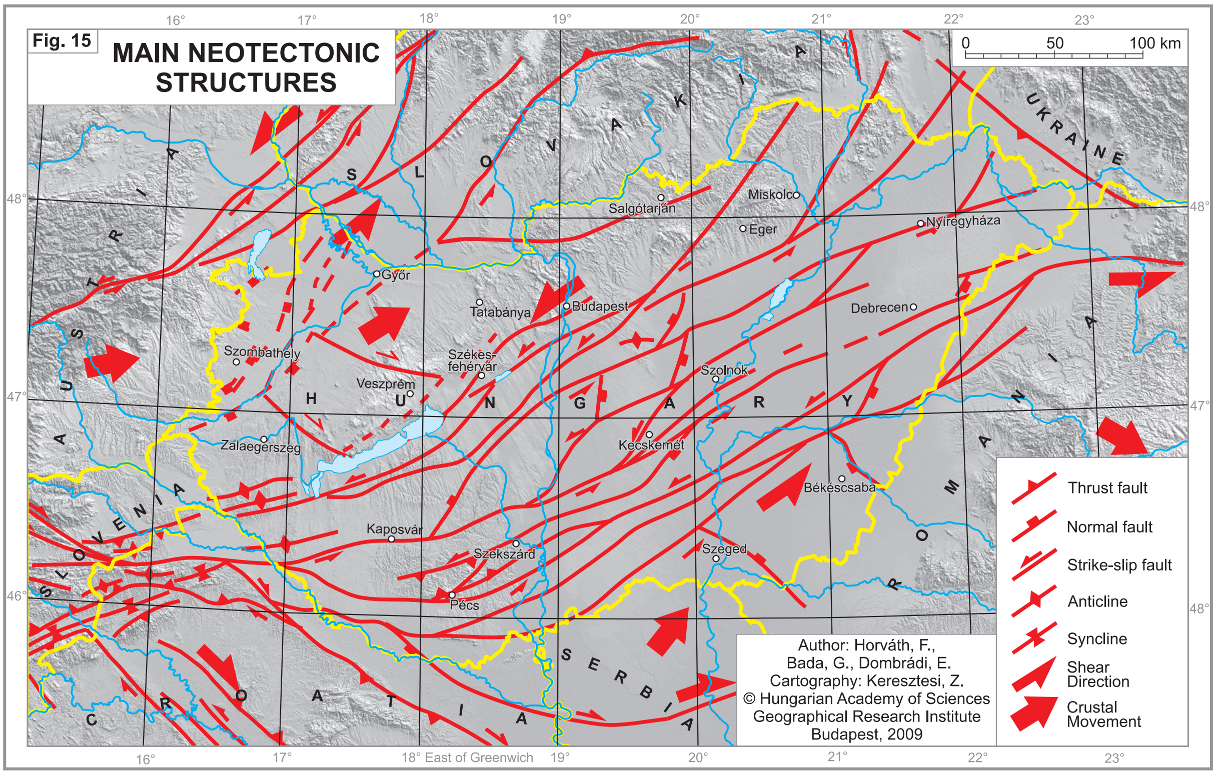


Fig. 14 HEAT FLOW IN THE PANNONIAN REGION

attenuation and asthenospheric updoming during the Middle Miocene resulted in an elevated heat flow of the Pannonian Basin (*Figure 14*). Its present value varies from 80 to 120 mW/m^2, which is about 50 to 100% higher than the continental average.

The recent history of the Pannonian Basin has been characterised by a neotectonic phase. Contemporary stress data, seismicity pattern, Quaternary uplift and subsidence history, surface evolution and young basin-scale deformations indicate that the Pannonian Basin is in the period of structural inversion. Present-day boundary conditions include active collision along the Alps-Dinarides belt (Adria-push), continuing eastward extrusion of ALCAPA, and Tisza-Dacia crustal wedges and their collision with the Eastern Carpathians. The basin system has become completely landlocked and constrained from all directions by a rigid continental frame since the late Pliocene. This has led to a gradual increase in horizontal stress resulting in multi-scale folding and fault reactivation, predominantly in the form of strike-slips and thrusts.

Figure 15 shows the main neotectonic structures of Hungary. It is largely based on a previously published neotectonic map (http://geophysics.elte.hu/atlas/geodin_atlas.htm), compiled in the framework of the geodynamic atlas of the entire Pannonian Basin and its surroundings. The vast geological and geophysical dataset utilised in this project was complemented by newly acquired data as well as available structural and neotectonic information from Hungary and the neighbouring countries. Thus, the updated structural interpretation reflects a synthesis of data from various sources and our present-day knowledge of the neotectonic behaviour of the Hungarian part of the Pannonian Basin.

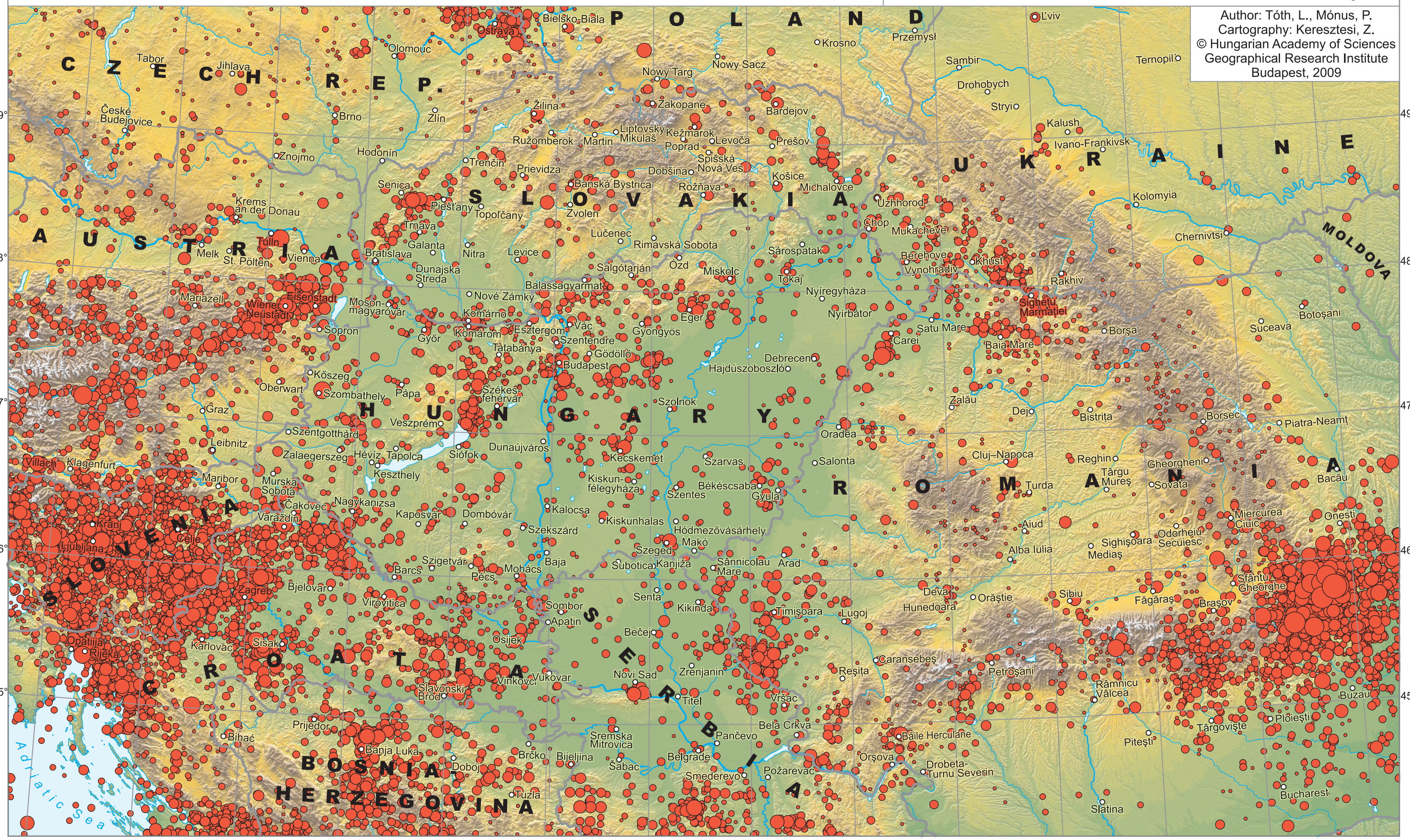


Earthquakes

The Pannonian Basin region is situated in the territory between the Mediterranean area, which is seismically one of the most active regions in the world, and the East European Platform which can be treated as nearly aseismic. At first blush, the earthquake epicenter distribu-

Fig. 16

EARTHQUAKES IN THE AREA OF THE PANNONIAN BASIN
(456–2007)



tion map suggests that there are significantly more earthquakes in the Carpathian and Dinaric tectonic belt than within the Pannonian Basin. Within the basin there also appear to be significant differences in seismicity among different geographical domains. Along the western edge of the basin and in the Eastern Alps and Dinarides some well defined zones of seismic activity can be recognised. Within the Dinaric area, seismic lineaments can be observed running parallel to the Adriatic coast. These are connected by the very active north-east–south-west trending Medvednica zone near Zagreb. A linear seismic source zone in the Eastern Alps, the Mur–Mürz–Žilina line, strikes north-east into the southern Vienna Basin and extends as far as the Little Carpathians.

The seismicity of the Vrancea region in the south-east Carpathians is characterised by an amazingly narrow epicentral region, which is confined to about 20x60 km, where strong M>6 earthquakes occur quite frequently (*Figure 16*).

Seismicity in the Pannonian Basin is more moderate compared to the peripherals and, at first glance, the distribution of earthquake epicenters shows a rather scattered pattern. It is particularly difficult to decide whether the epicenters occur at isolated places or along elongated zones. However, at several individual locations earthquakes occur repeatedly. For example, near Eger (47.9 N; 20.4 E) at least sixteen earthquakes with more than fifty significant aftershocks occurred within a time interval of some 70 years. The Komárom and Mór areas (47.4–47.8 N; 18.2 E), Jászberény (47.5 N; 20.0 E), Kecskemét (46.9 N; 19.7 E) and Dunaharaszti (47.4 N; 19.0 E) also produced significant activity over a certain, but limited period of time.

Moderate seismicity does not necessarily equate to a moderate size of earthquakes: reports of major earthquakes often refer to heavy building damage, liquefaction (e.g. 1763 Komárom earthquake, M 6.2; 1911 Kecskemét earthquake, M 5.6) and sometimes the possibility of fault rupture (e.g. 1834 Érmellék earthquake, M 6.2). These observations indicate that magnitude 6.0–6.5 earthquakes are possible but infrequent in the Pannonian Basin.

Several authors have illustrated the difficulty in constructing any meaningful geographical pattern of epicentral distribution when the statistical significance of the data is so low. Using only historical and early instrumental data, it has been very challenging to find a strong correlation between known tectonic structures and earthquakes. The recent high quality earthquake observations and locations may gradually change this situation. Comparison of historical seismicity with recent events shows that the recent earthquakes, in general, lie near to clusters of historical activity. Only a few events are exceptions, in that they appear to be unassociated with historical activity. However, clusters of stronger present day activity have been detected in the north-eastern part of the Transdanubian Mountains, close to the north-eastern coast of Lake Balaton and at the Danube Bend near Budapest.

Distribution of focal depths suggests three depth provinces where most of the events have taken place. Shallow depth within the top 20 km of the earth's crust is almost exclusive in the whole region except the Vrancea zone in the Eastern Carpathians. In the Pannonian Basin area, the majority of events occur primarily between 6 and 15 km below ground level. The earthquakes of the Vrancea region are characterised by intermediate depth seismicity. Strong earthquakes occur either in the domains of 70–110 km or 125–160 km depth.