Cent. Eur. J. Geosci. • 1(3) • 2009 • 291-302
DOI: 10.2478/v10085-009-0024-5

VERSITA

Central European Journal of **Geosciences**

The Carpathian Mountain range and the enclosed interior

Review Article

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Received 20 May 2009; accepted 5 July 2009

Abstract: The baffling duality of the Carpathian Mountain Range and the Basin it surrounds is briefly discussed. The various attempts at solving the nature of this duality, including plate tectonics with its micro-plates are mentioned. The component ranges of the Carpathians and the structural belts are given, followed by the discussion of the Carpathian Basin System, the Interior, consisting of the Great Hungarian Plain, Transdanubia, the two groups of Central Mountains, also the Apuseni (Bihar) Mountains and the Banat Contact Belt. Economic ore deposits are featured in the relevant sections.

Keywords: Carpathian Mountain range • Carpathian basin system • interior

1. History

The Carpathian Mountain Range, itself having quite a complex composition and structure, forms an inseparable unit with the enclosed interior area made up of a large lowland and some smaller mountain ranges of varying origins. There is something baffling about the incongruous nature of the component parts and about the duality of the two: the interior area of the Carpathian Basin, encompassed by the Carpathian Mountain Arc, the two forming one single whole in their present situation of the geological Holocene. The Carpathian Range constitutes an arcuate, almost semicircular asymmetrical fold-mountain chain of Alpidic (Upper Cretaceous to Cainozoic) orogenic age, with nappe (decken) structure. The Carpathian Basin, the Interior has a curiously complex geological history regarding its basement and basin filling. Megatectonically the whole Carpathian Region is a minute fraction of the very large Eurasian Plate, bordered in the south by the African Plate. The geography, morphology, geology and tectonic evolution of the Interior, the Carpathian Basin, renders it a wonderfully homogeneous geographical and economic unit of a uniquely concentric structure, with mineral deposits in the peripheral ring of the Carpathian Mountains enclosing the largely flat plains of great agricultural richness combined with some smaller mountain ranges of considerable importance industrially and agriculturally. This unique situation has been well made use of for thousands of years in human history. A sustainable future for the available natural resources is dealt with by environmentalists of recent years [1].

It was realized prior to the advent of plate tectonics, beginning in the early 1960s, that the concepts of the origin and evolution of this Carpathian region, the Carpathian Basin System, was a staggeringly complex area. Geologists again and again attempted to explain and harmonize

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all the component factors involved in its complex geological history. Several working hypotheses, including some theories of mountain building and crustal movements have been advanced over the last two centuries. The area of the interior has been called almost everything: Tisia, median mass, Zwischengebirge, internal depression, internide, intermontane platform, trough, Pannonian Median Massif, geotumor and mantle diapir.

Earlier two working hypotheses were developed by geographers, one by A. Rehman [2] of Poland and one by J. Hunfalvy [3] of Hungary. In the late 19th and early 20th centuries a geographical-geological trend evolved, represented by Prinz, Jankó and Cholnoky of Hungary as well as few other scholars: Klimaszewski, Martonne, Sawicki, Teisseyre and Uhlig. There were also some pioneers, like Staszic, Beudant and the two Englishmen: Amsted and Townson. Before World War I two geological syntheses of the Carpathian Basin were prepared: one by Lóczy sen. and one by Uhlig in his book of 1903, still referred to at present. Between the two World Wars two eminent syntheses of the geology of the Carpathian Region appeared: one by K. Telegdi Roth and one by F. Pávai Vajna. In the post-war period e.g. F. Szentes became important: he recognized the fact that the morphologically homogeneous Carpathian Mountain Range is nevertheless geotectonically heterogeneous and the various structural components have been fused together by the flysch deposition. Only about a decade before the advent of the plate-tectonic working hypothesis, a comprehensive geo-tectonic synthesis was published in 1953 by Hans Stille [4].

The eminent Estonian geologist D. Andrusov [5] while dealing with the problems of Carpathian tectonics, came to the following conclusions: (1) the Carpathian foredeep lies partly on pre-Triassic basement in the Northern Carpathians, forming the outer zone on Polish territory and partly on the flysch-basement in the Eastern Carpathians, where it forms the inner zone; (2) the Carpathian flysch zone lies on pre-Triassic and partly Jurassic basement, forming a broad rim with depths to a maximum of 8000 m; the crystalline Mesozoic part of the Eastern Carpathians must have subsided under the formations of the flysch towards the northwest.

The geosynclinal history of the flysch belt in the Western Carpathians was investigated in some detail by two well-known Polish geologists, K. Birkenmajer [6] and M. Ksiazkiewicz [7, 8]. They considered the problem of the source areas of the flysch sediments from tectonic and palaeogeographic aspects. Ksiazkiewicz distinguished six main tectonic units and showed that thick sandy complexes influenced the development of nappes and overthrusts. Ksiazkiewicz also maintained that the Carpathian Flysch Geosyncline must have been initiated in Late Liassic times. The Flysch deposits were folded during Early Miocene, followed by a weaker folding phase in the Early Tortonian (Late Miocene).

L. Stegena [9] attempted to explain the geological evolution and tectonics of the whole Carpathian Basin in terms of plate tectonics almost at the time of its birth. He has pointed out that the earth's crust is thinner here on the average; only 23-26 km, whereas the normal continental thickness is 33 km and that of a geosyncline 60-80 km; basin subsidence and the thinning of the crust are in genetic relationship: the thinning of the crust must have caused the sinking.

G. Szénás [10] already after the appearance of the plate tectonic hypothesis, produced a controversial work entitled *Evolution and Structure of the Carpathian Basin,* which proved to be a quite novel work and ahead of its time. He has pointed out that the Carpathian Basin consists of a geosyncline and platform frame within a span of 800 km and within this area there are all the possible geotectonic units of the earth's crust, except the oceans and the Archean shields. He contends that there has been no rigid central mass ("internida", "Pannonian Massif", "Tisia") in the basin. "On the contrary: a mass defect exists" in the crust of this area, because "the crust of the basin is thinner than usual". Because of tensional stresses and rupturing, its bottom disappeared and the area subsided to form a basin. However, we cannot account for the disappearance of ca. 500,000 km^3 of crustal material. "In spite of its perfect closedness, this basin is not an intermontane basin, but a basin that separates two independent mountain systems: the Alpine-Dinarid and the much younger Carpathian (Flysch) range". So "the Carpathian Basin cannot properly be included into any unit of the geotectonical classification".

Trunkó [11, 12] was mainly restricted to the present political boundaries of Hungary: treating the Great Hungarian Plain, the Transdanubian Central Mountains, the Tisia Unit and part of the Northeastern Mountains of the Interior, but not the Carpathian Mountains. He presented an admirable plate tectonic synthesis of the Interior of the Carpathian Basin System in his above work of 1996.

In the early 1960s the plate tectonic hypothesis appeared on the geological scene, an entirely new and unifying working hypothesis which could explain large-scale shifting of crustal segments of regional size, moving of platelets (microplates) becomes feasible and does not necessitate the existence of an internide, a crystalline massif in the basement of the Interior: the basement is actually built up from the surrounding mountains further extending into the basement centre, "the basement is the sunken continuation of the mountains on the fringes" [12]. The unusual thinness of the crust beneath the basin system might be explained by the mantle updoming, "geotumor". Nappe-stacking in overthrusts, subductions in fault lines provide new explanations in plate tectonics. It may also be able to assume and explain the presence of a number of ancient subductions of Cretaceous and younger (Tertiary) age, subsequent to a period of shallow marine conditions since the Middle Triassic. Plate rotation may provide a satisfactory explanation of some of the peculiarities of Mesozoic palaeogeography in the Carpathian area. Subduction with slab detachment has also been examined [13]. Rock sequences could travel on top of lithospheric plates, in form of platelets (small parts of the enormously large Eurasian Plate). The way the Transdanubian Central Mountains moved to the east over a distance of several 100 km after leaving their original environment, are only explicable in terms of plate tectonics. A "mosaic-like puzzle" of microplates of different origin emerges, whose configuration of the geological Recent was reached in the Early or Middle Miocene latest, according to Trunkó [12], i.e. about 15 million years ago. The local tectonic units within the Carpathian Basin are composed of the (1) Austro-Alpine Unit at the western edge; (2) the Northwestern (Slovakian, Vepor) Unit; (3) the SW and NE Central Mountains, delimited by the Mid-Hungarian fault zone, further SE followed by (4) the Tisza Unit of Southern Transdanubia, the entire area of the Great Hungarian Plain and the Transylvanian Central Mountains (Muntii Apuseni).

Despite reservations and criticisms, more and more geologists began to subscribe to the plate tectonic idea. Szádeczky-Kardoss [14] of Hungary assumed the existence of a rising current in the magma layer below the Carpathian Basin, which would explain the subcrustal erosion, the subsidence above it, as well as the volcanicity and the high heat flow; what is more: the contraction on top of the descending current branches and gravitational forces may even explain the Carpathian mountain-building process itself. Radulescu and Sandulescu [15] of Roumania feature two intracontinental basins in the Interior, with oceanic-type floor (active from the Triassic to the Cretaceous), formed by the splitting from the southern margins of the large Eurasian Plate. Wein [16, 17] of Hungary contributed with a pioneering synthesis, based on post-World War II results of research based especially on the evidence sifted from the core-material of more than 6000 deep drillings. From these data a seemingly inexplicable tectonic picture emerges: a curious juxtaposition of (1) North-Alpidic and South-Alpidic stratigraphic-tectonic types; (2) nearshore and offshore facies types. This suggests to him the existence of two tectonic halves within the Carpathian Region: the Pannonian partial microplate, cut in two parts by the Central Hungarian Lineament (the above Mid-Hungarian fault zone). Bodzay [18], following Wein [19], divides the Carpathian Region into two halves, NW- and SE-halves.

Among the Polish geologists: Birkenmajer [6], Ksiazkiewicz [7], Sikora [20], Swidzinski [21] and Unrug [22] contributed considerably to the study of the Outer Belt (the so-called Flysch Belt) of the Western Carpathians, elucidating its overall structure. Ksiazkiewicz [7] contends that the Flysch Belt may not have been deposited on the oceanic crust, but rather: might have been formed on the continental crust caused by spreading and subduction of the oceanic floor, when an active accretion zone prevailed in the Dinaric area during the Jurassic and Early Cretaceous. He also seems to assume the existence of two microplates.

F. Horváth et al [23] contend that the Carpathian Basin, as part of the Alpidic orogenic system, was superimposed on former Alpidic terranes and formed as a result of extensional collapse of the Alpidic orogenic wedge grown too thick, extruding at the same time towards the subducting Carpathian micro-plate.

2. The Carpathian Mountain range

In the form of an imposing arc, roughly a half circle, it extends from the Vienna Basin in the west and ends on the Lower Danube, at Orsova. Its length is 1600 km, its width varies from 60 km in the NE to 225 km in the N (Figures 1, 2) It begins in the west with the Little Carpathians (max. height about 700 m) and the White Carpathians (ca. 1000 m), as rounded, worn down hills. The greatest height of the Carpathians is reached in the High Tatra (Gerlachovsky Peak, 2663 m). The same degree of Alpine appearance is reached again only in the Southern (Meridional) Carpathians (Negoj Peak, 2544 m).

In pre-plate tectonic terms the orogenic folding movement is considered to have come from the S and SW, extending towards the N, pressing against ancient plateaus in southern Poland. From a simplified geomorphological point of view, the Carpathians are made up of two folding zones and the so-called "rear-land" (following Hans Stille's analysis, [4]). The Carpathian Mountain Range consists of the Western Carpathians, Northeastern Carpathians, Eastern Carpathians and the Southern Carpathians.

Western Carpathians consist of a crystalline Inner Zone and a sedimentary Outer Zone of large sandstone and limestone sequences.

Inner Belt ("Internides") of crystalline rocks, begins in the west from the Vienna Basin (Hainburg Mtn.) in the form of the geologically complex Little Carpathians (highest point: 768 m) composed mainly of crystalline rocks (Figure 1).

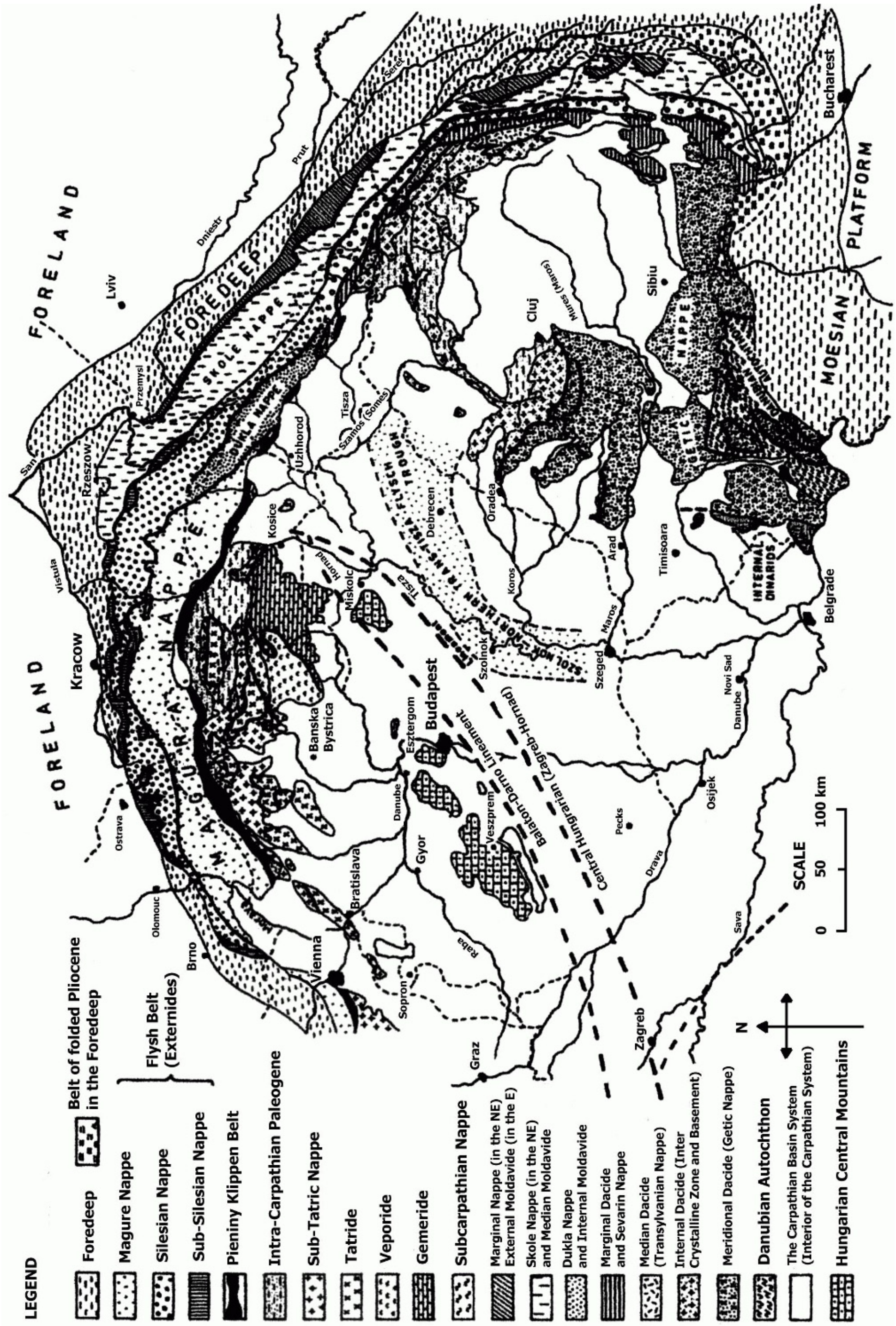

Figure 1. Tectonic map of the Carpathians Region, showing the main tectonic units (based on [25–28]).

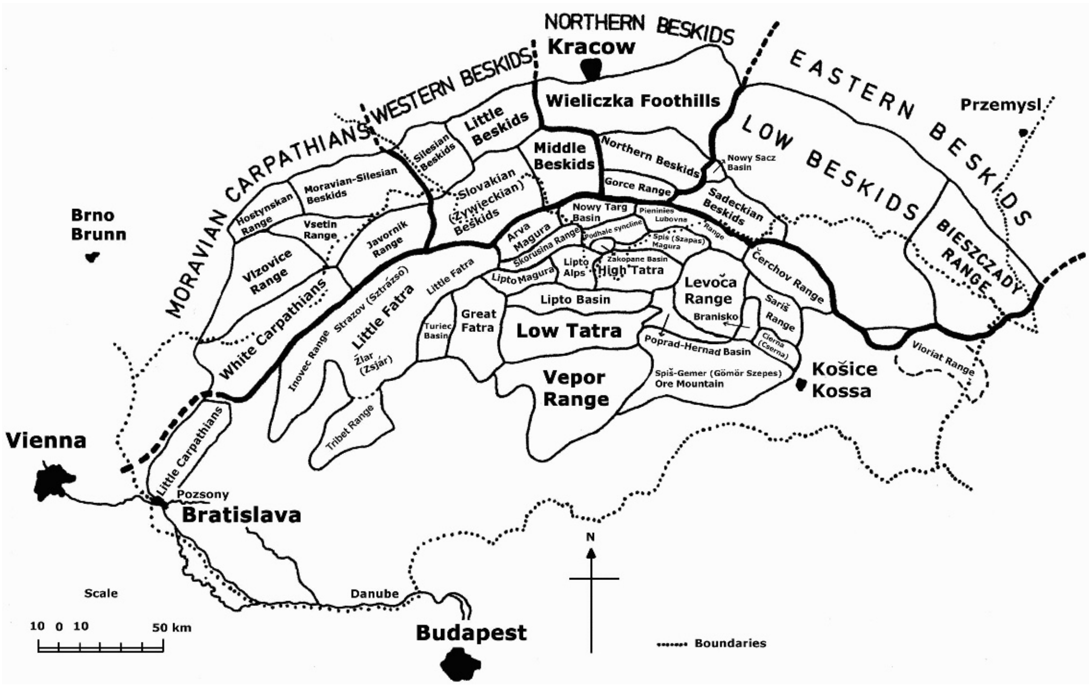

Figure 2. 2 Sketch map showing the position of the various component geomorphological units in the Northern Carpathians (after [43]).

The ancient crystalline masses: granites, gneisses and schists of the Inner Belt (much older than the Carpathian Diastrophism) were "embedded" as "windows", "foreign bodies" or "kernels" in the folded strata of the more recently formed Carpathians. This Inner Belt continues across the Vág (Vah) River valley in the form of the Little (Velká) Fatra Range, Great (Malá) Fatra and the Lipto Magura. Finally the highest part of the Inner Belt: the High (Vysoke)- and Low (Nizke)- Tatra Ranges are reached and disappears in the worn down Branyisko Mtn. There are also several intermontane basins: Zakopane, Lipto, Nowy Satz, Nowy Targ (Neumarkt) and Poprad-Hernad (Hornadska Kotlina) Basins. The inner belt is tectonically strongly disturbed [29] with numerous faults and it is cut or intruded by volcanic and dyke rocks on massive scale, appearing in every section of the Carpathian Arc, not only in the Northern Carpathians, forming Europe's largest **volcanic mountains**, composed of rhyolites, trachytes, dacites, andesites, basalts, porphyritic rocks and volcanic tuffs. These volcanic rocks constitute the *Ostrovski Mtn.,* the *Gömör-Szepes Ore Mtns. (Slovenské Rudohorie),* the *Eperjes-Tokaj Mtn. (Slanské Pohorie* and *Zemplén Range*) and *Vihorlát*; then they continue appearing in the Northeastern Carpathians (now in the Ukraine) in the form of *Szinyák, Borló, Avas, Kőhát, Gutin, Lápos* and *Cibles* volcanic cones. They also appear in the volcanic ranges of the Eastern Carpathians in form of the *Kelemen-, Gyergyó-, Görgény-* and *Hargita Ranges* (the last mentioned reaching the height of 1798 m). The above mentioned Gömör-Szepes Ore Mtns. were submerged during the Mesozoic Era, with the resulting limestone plateaus, after the subsequent uplift of the area, containing the famous ice-cave of *Dobsina* and the limestone cave system of *Aggtelek* (now partly in Slovakian and partly Hungarian territory). The latter is part of the **Inner Northern Montaneland,** geologically independent of the Northern Carpathians, comprising the northern internal volcanic belt: the *Volcanic Ore Mtn Complex* (the Selmec Ore Mtn or Štiavnické Pohorie, the Körmöc Range or Kremnické Pohorie, the Polyána or Polana Range and the Osztrovszky Range, among others). They are well-known for their gold-silver mining with centuries of history. The volcanicity with a rhyolite-andesite-basalt association began in the Eocene, reaching its climax in the Miocene, similarly as in the Pilis and Börzsöny Ranges and the Cserhát Hills further south in the Northeast Hungarian Central Mountains. The so-called *Gemer (Gömör) – Torna Karst (Slovensky Kras)* is an elongated (70 km long) karstic plateau, composed almost entirely of Triassic sedimentary sequences; the best known parts are the Torna Plateau

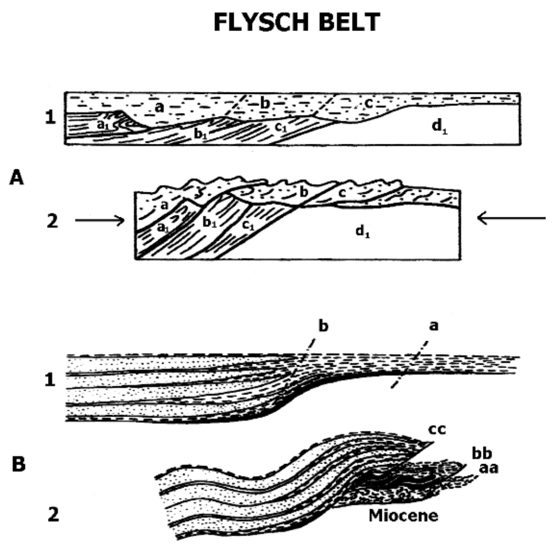

Figure 3. Flysch Belt in the Northern Carpathians (after [8]); A- Origin of the flysh nappes: 1 before compression, 2 formation of tectonic units after compression. B- B - Origin of Godula and Cieszyn Nappes: 1 sedimentary basin before the compression, 2 formation of tectonic units after the compression, showing the overthrusts; bb Cieszyn Nappe over aa Sub-Silesian Nappe, cc Godula Nappe over bb Cieszyn Nappe.

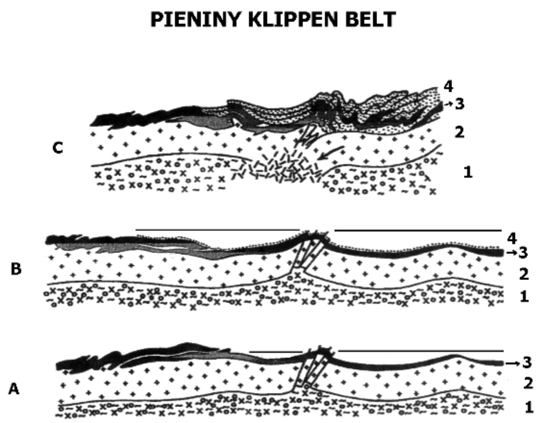

Figure 4. Pieniny Clippen Belt, showing its origin (after [8]): a - end of the Cretaceous, b - transgression during the Palaeogene, c - Late Tertiary folding: 1 substratum of the crust, 2 crust composed of metamorphic and plutonic rocks, 3 Mesozoic sequence, 4 Palaeogene sequence.

(Turnianska Planina), the Szilice Plateau (Silická Planina) with the famous Aggtelek Caves, the Jelsava (Jolsva) area with iron ore and the limestone area of Rimaszombat (Rimavská Sobota). The intermontane basins include the Ipel (Ipoly) Basin and the Borsod (Salgótarján) Basin.

Outer Belt ("Externides") of sandstone and flysch: enormously thick sequences of fine-grained sandstones, extending well into Poland, including the *Carpathian Sandstone* and the *Carpathian Flysch* (Figure 3), mainly of Miocene age (ca. 15 million years old), together with some limestone cliffs, such as the *Pienines* (Pieniny Klippen Belt) NE of the High Tatra, which are mostly of Late Cretaceous age (Figure 4). The Outer Belt begins with the White Carpathians and the Moravian Carpathians, then further north the Western and Northern Beskids and beyond the High Tatra the Eastern Beskids. There are the dolomitic Choch Range (1613 m) and the Prošepny Range within the sandstone belt. As a result of the nature and direction of the folding, the general tendency of the bedding sequence for the strata is to be older inwardly and younger outwardly from the basin as shown by a section through the Northern Carpathians. The structure of the outer zone was complicated by faulting, overthrust folding and even nappes, e.g. the *Magura nappe,* a low-angle shear thrust trending towards NE. The marked dislocation plane in the Great Fatra is regarded as a tectonic surface of the *Krizna nappe* overthust from the south over the "envelope" of the crystalline core mountain. The isolated limestone cliffs are remnants of overthrust folds, providing ideally rugged sites for picturesque mediaeval castles, like the *Arva Castle*. The *salt deposits of Wieliczka* at the northern boundary of the Carpathian foredeep have been mined since the 11th century (first mentioned in 1044); the salt formation is of Tertiary age, infilling of an embayment surrounded by Eocene sandstone units in the west and east, and by marine sandstone of early Miocene age in the north; the size of the salt deposit is estimated as being 3800 m long (in W to E direction), 1200 m wide (N to S), 50 m thick and at a depth of 280 m. *Oil fields* occur in the Galician region of eastern Poland, situated on the northern slopes of the Bieszczady Range and in the Eastern Beskids; they have the oil fields of e.g. Grabownica, Weglowka, Czarnorzeki, Boryslaw, in total about 100 oil-producing sites in the two western belts alone. Many of them produce natural gas as well. The oil and gas fields occur in a Cretaceous and Eocene reservoir rock sequence of the Carpathian flysch (mainly a northern strip of flysch facies sandstone and shale units of Palaeocene to Middle Eocene age). The main oil-producing horizon of the reservoir rock is in the oil fields of Grabownica (14 km NW of Sanok) and Weglowka (10 km N of Krosno) in the Galician region. The local structure is characterized by a large recumbent fold, overturned towards the NE. The tectonics of the Low Beskids are quite complicated, with the western part belonging to the Magura Nappe, the middle part to the Dukla Zone and the eastern part to the Silesian Nappe.

Northeastern Carpathians are much simpler morphologically and in geological composition and structure than the Northern Carpathians (Figure 1). This range is composed simply of two belts: sandstone and a volcanic belt (mentioned above) made up of long-extinguished, worn down volcanic "cones", like Szinyák, Gutin and Lápos. The limestone and crystalline belts almost disappear here. The sandstone belt is attractively represented in the Eastern Beskids and the Maramaros Alps with the Maramaros Basin containing rich salt deposits, over 1 million q per year (1912) near the town Máramarossziget (Sighet) at Aknaszlatina (380,000 q/a, Aknasugatag (200,000 q/a and Rónaszék (Costiui) where the large salt mines have been mined since 1498 AD (flooded in 1766; also having a picturesque subterranean lake).

Eastern Carpathian Range forms the eastern boundary of Transylvania (now in Roumania) (Figure 1). It extends in the north from the Radna (Rodnei) Pass as far south as the peak Királykő (2241 m) in the Persány (Persani) Range (Jurassic limestone and conglomerate beds overlying crystalline schists). The sandstone and limestone belts are well developed, but the crystalline belt is not so well represented. However, there are a number of important volcanic ranges. The sandstone belt does not form the watershed for the historic Transylvanian border, and the rivers cut through attractive, narrow gorge-like valleys; this belt becomes more composite towards the south, breaking up into several branches: the Bereck Range, the Bodok Range, the Barót (Baraoltului) Range (with the Bucsecs Cliff of conglomerate) and the Persány (Persani) Range. The limestone belt clings onto the sandstone belt, and the crystalline belt forms the watershed. The most massive part of the belt is the Gyergyó Range and the belt ends in the Csik (Ciuc) Alps in the south. The volcanic belt begins in the north in form of the Kelemen (Calimani) Alps and continues southwards in the Görgény (Gurghiului) Alps and the Hargita Range. The Radna (Rodnei) Alps form a Variscian massive, which became glaciated during the Pleistocene. The volcanic belt ends with the Lapos Range in the south. The intermontane basins are represented by the Gyergyó-, Felcsik-, Háromszék-, and Brassó (Brasov) Basins. The historic Transylvanian border ran from the watershed somewhat further to the east.

Southern (Meridional) Carpathians or Transylvanian Alps consist mainly of crystalline schists (Figure 1). The folding began earlier than the other parts of the Carpathian Mountain Range; it was part of an ancient Variscian massive in form of two belts and they were strongly deformed during Jurassic, Cretaceous and Tertiary times in form of folding and overthrusting. One belt contains the Fogaras Alps (Negoj, 2544 m, second highest peak in the entire Carpathian Range), the Szeben Alps, the Lotru Range, the Pojana Rusca, the Kudzsir Alps, Semenik, Szárkő-Godjan and partly the Krassó-Szörény (Banat) Ore Mtn. The other belt consists of the Pareng-Retyezát- and Vulkan Ranges. At higher elevations most of the component ranges were strongly glaciated during the Pleistocene. There are numerous synclinal depressions as well as tarns of glacial origin, such as the Zenoga- and Bulea- lakes. The crystalline masses are covered by Mesozoic sandstones and limestones and also by some karstic units. There are some small local basins like the Zsil (Jiul) Basin, also called Petrozsény (Petroseni) Basin, with rich black-coal seams, the Hátszeg Basin and also the Temes Basin.

3. The Carpathian basin system – the interior

The Interior is the area surrounded by the Carpathian Mountain Range. It is composed of flatland areas and smaller mountains and hills. The Palaeo-Alpidic and Meso-Alpidic sedimentary cycles are overlain by 6000 m thick Miocene and Pliocene sequences, surrounded half way by the Carpathian Mountain Arc. The largest lowland area is the Great Hungarian Plain situated in the centre of the Basin; a smaller one is the Little Hungarian Plain near the western edge of the Basin and some smaller local basins in Transdanubia. So it is in reality a set of basins, blocks of crust, differentially subsided. The subsidence might have been an isostatic consequence (compensation) of the destruction of the bottom of the crust below the Basin [10]. This came about because the subduction of the lithopheric plate created an active mantle diapir, which eroded the bottom of the crust. The basin subsidence must have been related to the subduction, during which this thinned-out crust subsided isostatically mainly during the Miocene, gradually easing off in Pliocene-Pleistocene times, leading to the formation of the Carpathian Basin System, the Interior.

The Carpathian Interior is much more than just a Late Tertiary Basin Complex. Paradoxical as it may seem, it is more of a massif then a basin. During most of its history it was an emergent area of ancient rocks. The ancient floor shows up through a thick carpet of Neogene sediment in the Transylvanian Central Mountains, as well as a row of Mesozoic hills forming a central crumple, running NE-SW and a further group of low mountains in the S (the Mecsek Mtn.).

Demonstrated by deep seismic soundings, the Carpathian Basin System has an unusually thin crust beneath it (mainly the lower part of the crust): about 8-10 km, compared with the Northern Carpathian belt with its normal crustal thickness, 30-35 km. In the Outer (Flysch) Belt it increases to 40-65 km. In comparison, the thickness of the Bohemian Massif is 40-48 km, the Russian Platform: 35-40 km and below geosynclinal mountains: 60-80 km. Actually, the thickness of the crust in the Carpathian Basin System seems to be about 27-28 km, as shown by György Hetényi and Zoltán Bus [30].

The geothermal gradient is extraordinarily high in the Interior, reaching even 100°C/km. Both the geo-temperatures and the heat flow values demonstrate clearly that the Interior exhibits a marked geothermal high. In fact this region is actually a geothermal "hot spot" (see A. Ádám et. al., [31]) and the geothermal high is well developed even in the upper mantle of the Carpathian area. The main hot-water reservoir is the Late Pliocene (Pannonian) sandstone-siltstone sequence.

The mountains and hills of the Interior are genetically quite distinct and separate from the inner components of the Northern Carpathians. They are grouped in the following way under the collective name of *Inner Northern Montaneland*: (i) the Volcanic Ore Mtn. Complex south of the Northern Carpathians and (ii) the Northeast Hungarian Central Mountains: a series of fault-bloc mountains, covered by old volcanic rocks: the Börzsöny Mtn, the Cserhát-, Mátra- and Bükk Mountains.

The *Volcanic Ore Mountain Complex* (now in Slovakia) comprises the Štiavnic (Selmec) Ore Mountain famous for its gold mining since ancient times and the Kremnica (Körmöc) Range, also the Gemer-Torna Karst area and the Ipel (Ipoly)- and Salgótarján Basins. The Ore Mountains of Štiavnic area, mining for gold and silver ores was quite intensive prior to 1600 AD with more than 400 mine shafts and it is known that the gold mining yielded richly during the reign of King Matthias Corvinus of Hungary. In 1763 Queen Maria Theresa founded a Mining Academy here, the second in the world. Iron-ore deposits are situated at Lubietova (Libetbánya) among the oldest mines of historic Hungary, and at Rudabánya 32 km NNW of Miskolc, containing 39% Fe in the form of limonite, haematite and siderite, with a thickness of 10 m for the ore body.

The *Northeast Hungarian Central Mountains* constitute a volcanic belt made up of Miocene andesites. Extending towards NE from Budapest and the Danube Bend, they include the Börzsöny Range and Cserhát Range (originally fault-block ranges that became covered by lava flows of andesite and tuff), the Mátra Mountain (where the volcanicity began in the Eocene, D. Karátson et al., [32]). The S-wave velocity structure below the Mátra Mountain was studied by Z. Bus [30]. The ore deposit of Recsk has mining for gold (174 kg in 1937), silver and copper. The very complex Bükk Mountain is made up of a basement of crystalline (igneous) rocks, Late Palaeozoic sediments and a large Triassic sequence of mainly limestones (all folded by the Alpidic Orogeny), also a karst plateau and Miocene lava flows of rhyolite and andesite. Tectonically the Bükk Mtn. is quite anomalous, with the main tectonic axis being an anticlinal structure; it may have been shifted from further north to its present position nappe-like. Northeast of the Bükk Mtn. east of the Sajó and Hernád Rivers stretches almost northwards the Eperjes (Prešov) – Tokaj Mountain Range (Slanské Pohorie – Zemplén Mountain): a series of long-extinct worn-down volcanoes of Mediterranean age (Lower to Mid-Miocene in marine facies), composed largely of andesite and rhyolite with their tuffs. The andesitic Mount Tokaj (516 m) is the southernmost part of this volcanic series. On the western slopes of the Tokaj Range is Telkibánya with worked-out gold-, silver- and iron mines [33].

The *Transdanubian (Pannonian) Central Mountains* are composed of the Bakony- and Vértes Mountains N of Lake Balaton and further NE the Gerecse Range and the Velence Range, while immediately NW of Budapest are the Danube Bend Mountains, including the Buda Hills. The *Bakony Mountain* is a dissected, plateau-like fault-block mountain (result of step faulting): a crystalline core, covered by younger sedimentary sequences, mainly limestones, gently tilted; directly north of Lake Balaton is the Balaton Upland. There are many fossils, like species of *Daonella, Rhynchonella, Posidonia, Encrinus, Balatonites, Paraceratites, Paratrachyceras, Halobia, Lima, Megalodus* in famous sites like near Balatonfüred and the Sándorhegy Limestone. There is also a rich *Nummulites* fauna in the Bakony Mtn. (Tibor Kecskeméti, [34, 35]). The Bakony Mtn. is rich in minerals: bauxite and manganese ores and brown coal. The *Vértes Mountain* is bounded on all sides by fault planes and separated from the Bakony Mtn. by the Mór Graben, the result of transverse faulting; geologically and tectonically similar to the Bakony Mtn. The *Tatabánya Basin* is well-known for its brown-coal mining, the *Gerecse Range* is composed of limestones and dolomites, while the *Velence Range* is a granite batholith, the *Pilis Range* is partly volcanic, partly composed of limestones. The *Buda Hills* are made up of Triassic dolomites, Eocene limestone and Oligocene sandstone, a typical fault-block mountain range [16, 36]. Southern Transdanubia has the geologically anomalous *Mecsek Mountain* north of the town of Pécs and the Villány- and Bán Ranges south of the town. The Mecsek Mtn. is a combination of a relict mountain of old crystalline rocks with a superimposed fault-block mountain of Permian to Cretaceous sediments, largely carbonates, including the Liassic coal deposits and some Neogene volcanics.

The western area of Transdanubia includes the *Little Hungarian Plain* (250 km from SW to NE and about 80 to 100 km wide) with Lake Fertő (Neusiedler See) east of Sopron and environs, and branches like Csallóköz, Szigetköz, Rábaköz and the swampy lowland of the Hanság. The *Drava-Sava Interfluve* is still further south.

The *Eastern Foothills of the Alps* form the junction between the Interior of the Carpathian Basin and the eastern end of the European Alps. It is called Burgenland (now in Austria, but it was part of historic Hungary). Brennberg, 8 km SW of Sopron has a brown-coal (lignite) deposit, with 4 to 10 m thick seams, has been mined since 1759.

Great Hungarian Plain is the largest lowland area of the Carpathian Basin System, taking up one fifth of the total realm: 220 km wide (N – S) and 440 km long (E – W) and below 200 m a.s.l., on average: 100 m a.s.l., with a general tendency to slope from north to south and the southern boundary being the lowest. Its greatest tributary is the River Tisza: it cuts through the middle of the Great Plain (in Hung.: Alföld) in a mostly N-S direction; its length is ca. 1300 km. The boundary of the Great Plain is sharply delineated in the northeast of the Interior by a system of fracture zones along the edge of the volcanic masses of Vihorlát, Szinyák and Borló; a clear-cut boundary is afforded also in the west by the N-S-running section of the Danube. Regionally the Great Plain is made up of the following subregions: the narrow *northern marginal area* of alluvial fans; the *Danube-Tisza Interfluve* with drift-sand and alkali-soil areas, the southern portion having a rich loess soil cover of great thickness, also the western *Kalocsa Terrace*, in the south the Ferenc Canal and in the SE-corner the Titel Plateau; the *Upper Trans-Tisza Region*, comprising the alluvial fan of the Nyirség, the Szatmár Flats, the Ecsed Moor, the Bodrog-Tisza Interfluve and the Szolnok Flysch Trough; the *Middle Trans-Tisza Region*, which comprises the interfluve formed by the three branches of the Kőrös River of Holocene deposits; and the *Lower Trans-Tisza Region* between the Maros River and the Lower Danube, with a large loess plateau and further south alluvial flood plains, also the Béga and Teréz Canals and the Deliblát Sand Dunes. Of the detrital cones the largest is that of the Maros River.

Originally the surface of the Great Plain was composed of, and evenly covered by, the yellowish *loess,* accumulated from blown dust, providing a rich agricultural soil, especially suitable for growing wheat; in several areas the loess deposits became covered up by sand washed over it from the river beds in the Danube-Tisza Interfluve, the Nyirség and the Deliblát "puszta". In human times the courses of the rivers have been regulated, artesian wells have been bored and the adobe houses were exchanged for brick houses.

The evolution of the basin character of the Great Plain began in Middle Miocene times, in the Helvetian Age, in a few areas somewhat later during the Tortonian Age. Large marginal fracture zone began to appear peripherally, along which the basement began to sink, bringing about the extensive deposition of Miocene sediments. The subsidence was strongest near the northern and northeastern marginal areas. The marginal fracturing led to the volcanic eruptive phase, extruding vast masses of volcanic rocks, thus forming the inner peripheral volcanic belt of the Carpathians. In Late Miocene – Early Plioceme times, beginning about 11 million years ago, during the so-called *Pannonian Age*, the sinking of the basin floor began to accelerate, as inferred by the large thicknesses of Pannonian deposits, homogeneous and rather monotonous sedimentation on a large scale. The many-sided facies sedimentation is well demonstrated by the numerous formations below the Great Plain, as shown in a cross-section through the Great Hungarian Plain by Gy. Juhász [37]: below the Quaternary are the Zagyva Formation, Törtel Formation, Algyő Formation (representing slope facies) and Szolnok Formation (representing distal and proximal turbidite facies); in the NW corner of the Plain, below Verpelét also the basal marls of the Nagykörû Formation. The Újfalu Formation represents delta front and shoreface facies, while Nagyalföld Formation represents delta plain and alluvial facies. The Endrőd Formation represents the deep basin facies. As pointed out by Ádám and Kis [38] there must have been an upwelling of the asthenosphere below the Békés Basin (graben) by the extensional forces during the Miocene (about 15 m/y ago), leading to the evolution of all the deep basins in the Carpathian Interior, with sediment thickness of ca. 7 km.

This was the time of the depositional process in an inland sea, the *Pannonian Sea*. The thickness of the Pannonian sequence is estimated to be over 4000 m beneath the Great Plain according to A. Rónai [39] and B. Molnár [40]; e.g. in the bore of Hódmezővásárhely it was shown to be 4080 m.

4. Transylvanian Central Mountains (Bihar Mountain Complex), (Apuseni Mountains)

The Transylvanian Central Mountains situated in the western part of Transylvania, constitutes a heterogeneous group of mountain ranges, somewhat enigmatic in its composition and in its tectonic position within the Interior of the Basin System. It is also referred to as the *Bihar Mountain Complex* in a wide sense: the Bihar Mountain in a strict sense forms the central, axial range of the entire complex of mountains, surrounded by a number of ranges: the Padurea Craiului (Királyerdő) Range, Muntii Codru

(Bél Mountain), the Zaránd Mountain, the Gyalu Alps and Muntii Metaliferi (Transylvanian Ore Mountains); the northern continuations are the Muntii Plopiž (Réz Mountain), Muntii Meses (Meszes Range), Muntii Faget (Bükk Range), the Deala Simleu Silvaniei (Szilágysomlyó Hills) and Muntii Tica and Preluca (Ilosva Downs). There are some important rivers issuing from these ranges of the Bihar Mountain Complex: the triple Kőrös (Crižul) River with its three branches (Fast, Black and White Kőrös), in the south the large Murež (Maros) River, in the north the Somež (Szamos) River; the Kraszna River issues from the Meszes Range, the Berettyó River from the Réz Mountain. There are numerous mineral springs, the better-known are: Baile Episcope (Püspökfürdő), Lunca Sprie (Lankás), Beius (Belényes), Tinca (Tenke) and Tamaseu (Paptamási).

The Bihar Mountain Complex is an important source for timber, hydro-electric power and metallic ore minerals: aluminum, iron, copper, gold and silver. The so-called *gold quadrilateral* falls completely within the gently folded *Transylvanian Ore Mountain*, with famous and ancient gold-mining settlements: Abrudbánya, Sacarimb (Nagyág) and Rosia Montana (Verespatak). The Bihar Mountain Complex is surrounded by a number of larger towns at its foot, important culturally, commercially, educationally and ecclesiastically: Oradea (Nagyvárad), Cluj Napoca (Kolozsvár), Aiud (Nagyenyed) and Alba Julia (Gyulafehérvár).

Geologically the Bihar Mountain Complex is made up of diverse mountain types, with one common characteristic shared by all the elements: they all possess an ancient crystalline basement, over which in some cases a fault-block mountain is superimposed in the form of a cover of much younger sedimentary sequences and/or volcanics, i.e. a crystalline core with a sedimentary cover (Bruchschollengebirge). It is extensively faulted and broken into many fragments; the result is a most involved stratigraphic and structural situation. Since the whole mountain complex is surrounded by plains, both in the west and in the east, it rises like an island from the more or less flat surroundings within the Carpathian Basin Complex. Geologically it may also be called an "island mountain" (Germ.: Inselberg, Inselgebirge), composed of a cover of fault-block mountain over the top of worn-down ancient massive relicts, residuals. To the northeast of the Mountain Complex is Stille's *Szamos Lineament*, oriented NW – SE. Most of the component mountain ranges are made up of Archaean to Early Proterozoic metamorphic rocks, like the Bihar Mountain s.s., the Réz Mtn., the Meszes Range, the Silágysomlyó Range, the Bükk Range and the Ilosva Downs; The Zaránd Mtns. in addition to metamorphics has also igneous intrusions and it is flanked by the very complex Transylvanian Ore Mountains. Szepesházy [41] after extensive first-hand study of deep-drilling material, came to the conclusion that the basement of the Carpathian Basin System does not resemble the basement of the neighbouring platform areas, but rather that of the mobile belt of the Carpathian Mountain Arc itself. This similarity is mainly lithological and stratigraphic, though it is also accompanied by structural analogies. According to his working hypothesis it is possible that the Late Cretaceous overthrusts and nappes of the Bihar Mountain Complex (Muntii Apuseni) and those of the mobile Maramaros Belt of Neogene age are extended westward deep below the surface of at least the eastern half of the Great Hungarian Plain. Szepesházy's [42] hypothesis is in agreement with the plate tectonic picture of the Interior basement.

5. Transylvanian Basin

Geomorphologically this basin of some 20,000 km^2 area is a relatively high plateau with an average altitude of 400 m, sloping towards the west; hence the rivers Somež (Szamos), Murež (Maros) and Tirnava (Küküllő) have a westward drainage, strongly dissecting the plateau. The northern, somewhat treeless and waterless part is called Campia (Mezőség), a country of rolling hills of ca. 5200 km^2, a rich agricultural land: the grain storehouse of Transylvania. North of this lies the so-called Somež (Szamos) Plateau.

The Transylvanian Basin is a Neogene area of subsidence; it consist of some Eocene and Oligocene beds, but the main strata are of Miocene and Pliocene age; on the surface the Late Miocene Sarmatian (5 to 10 m.y. old) and the Pliocene Pannonian (3-5 m.y. old) sequences predominate. The complete sequence of Tertiary deposits represents the gradual shallowing of the Pannonian Sea. In contrast to the main central part of the Interior, this plateau region did not undergo any appreciable sinking during the Tertiary Period and all these sequences were later on gently folded into N-S-running flat anticlines and synclines. The evolution of the basin had its beginnings in the Carboniferous-Permian Variscian Orogeny, then in the Kimmerian Orogeny and finally in the Alpidic Orogeny. The basement of the basin consists of crystalline rocks and Mesozoic deposits, which constitute the bottom of the Transylvanian Basin.

Economically important are the natural gas occurrence and the large salt deposits.

6. Banat Mountain group

Geologically this group of mountains contrasts sharply with the Southern Carpathians, because it constitutes a heterogeneous group of ranges, dominated by Jurasic and Cretaceouss limestones occurring in a long and economically important contact belt, the Banat Ore Mountain (Banat Contact Belt). The neighbouring members of this mountain group consist of metamorphic and igneous rocks in contrast. The component members of the group are: the Banat Ore Mountain, the Plesuva (Szemenik) Range, the Almás Range and the Lokva Range.

Banat Ore Mountain (Banat Contact Belt) formerly referred to as the Krassó-Szörény Ore Mountain, runs almost in N-S direction for nearly 80 km, separated from the Szemenik Range by the Berzava River and the Menižul (Ménes) Creek. The main ridge stretches from the Poganožul (Pogányos) Creek in the north through Krassóvár, Anina (Stájerlakanina), Oraviþa (Oravicabánya) and Sasca Montana (Szászkabánya) in the south as far as the Néra River. The highest point of the Banat Ore Mountain is the Plesiva peak (1144 m), while the mean altitude is maintained between 500 and 1000 m a.s.l.

The Banat Contact Belt occurs in the form of graben (trough, the "Banat Trough" between two N-S-oriented structural lines, the Oravica Lineament forming the western boundary. W of the Contact Belt there are several metamorphic and igneous mountainous areas, such as the Buzias Hills of mainly Pannonian beds, the Aranyos Range (Mtii Aries) of granitic rocks, the Dognácska Range (Muntii Dognecea) with old crystalline rocks in the west and epimetamorphic rocks of the greenschist facies (mainly sericite schists) in the eastern half, the westernmost Versec Range with the highest point (641 m) 10 km E of Vršac (Versec), composed of metamorphic rocks, mainly mica-schists, paragneisses and phyllites, and the Lokva Range, made up of epimetamorphic schists, phyllites and quartzites.

The Banat Ore Mountain is rich in two economically important mineral deposits: (1) Iron ore, mined at Vaskő, Dognácska, Újmoldova and Resiþa (Resicabánya). (2) Black coal, mined at Stájerlakanina and Resicabánya. Resicabánya is the centre of the mining and steel industry of the Banat Ore Mountain region, because of the fortunate situation of the iron-ore mines situated near the coal deposits. In the 19th century it was this fortunate situation which prompted the development of heavy industry by the Austro-Hungarian State Railway Company, with furnaces, iron and steel foundry, rolling mills, tool factories and machine works. Since then, under Roumanian rule, the heavy industry continues to flourish. There is also some mining for gold, copper and lead ores at Ciclova (Csiklófalu) and manganese ore at Delinesti (Delényes).

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