GEOLOGICAL SETTING AND TECTONIC EVOLUTION OF HUNGARY

JÁNOS HAAS¹, GÉZA HAMOR² and LÁSZLÓ KORPÁS³

¹ Hungarian Academy of Sciences–Eötvös Loránd University, Geological Research Group, H–1088 Budapest, Múzeum krt. 4a., Hungary
² Eötvös Loránd University, Department of Regional Geology, H–1143 Budapest, Stefánia út 14., Hungary
³ Geological Institute of Hungary, H–1143 Budapest, Stefánia út 14., Hungary

ABSTRACT

Hungary is located in the central part of the Pannonian Basin filled up with a thick clastic sedimentary cover Neogene to Quaternary in age. Its basement is made up by Paleozoic to Early Tertiary formations representing the Austroalpine–Tatro–Veporic, the Pelso and the Tisza Megaunits, which are separated by major lineaments from each other.

At the end of the Variscan cycle the polymetamorphic complexes of the Tisza Megaunit belonged to the Variscan Foldbelt forming the southern margin of the European plate. Metamorphic formations of the Pelso Megaunit and the Austroalpine nappes may have formed in the Prototethys existed between the Eurasian and African plates. Closure of the Prototethys in the Middle Carboniferous led to accretion of the Variscan Foldbelt. Middle Carboniferous flysch and Late Carboniferous to Middle Permian continental molasse deposits indicate stages of this process. Low to high level gold anomalies were detected in some of the pre–Alpine formations of the Pelso Megaunit.

The Alpine evolution may be characterized by multiphase opening (Permian to Jurassic), closure of the Tethys (Cretaceous to Paleogene) and which was followed by the formation and filling up of the Pannonian Basin (Neogene to Quaternary).

Evolution of the Pannonian Basin (Miocene to Quaternary) was controlled mainly by the formation of the early Inner Carpathian and the late East Carpathian volcanic arcs and back arc rifting. These processes led to the uplift of the Alp–Carpathian Chain and to the collapse of the Pannonian Basin. This stage in evolution was not favorable for Carlin-type gold mineralization, although some sedimentary formations exhibit sporadic gold anomalies near to detection level.
1. INTRODUCTION

Present-day geological setting of the Pannonian Basin, and within it Hungary, is the final result of a complicated and multiple evolutionary history. Complexity of the evolution is the consequence of the peculiar setting of the Pannonian region: it is located in the buffer zone of the European and the African continental plates where a series of ocean openings and continent collisions took place resulting in disruption of the lithosphere. Microplates, lithosphere chunks were formed. During the Alpine tectogenic stage, folding and nappe formation were followed by sizeable displacement of microplates leading to accretion of the mosaic-like basement of the Pannonian Basin. Formation of half-grabens, smaller basins and also the intense magmatic activity can be bound to Miocene orogeny of the Carpathians. In the same time, formation of a rift-type graben system of NW-SE direction (Vardar Graben, HÁMOR 1999) appears to be also of crucial importance. Attenuation of the crust (mantle diapir formation) led to generation of large basins of the Pannonian Basin System which primarily determine the present-day tectonic setting. The Carlin gold potential of Hungary was controlled by this multiphase evolution.

2. TECTONIC SETTING AND MAIN STAGES OF EVOLUTION

Hungary is located in the central part of the Pannonian Basin, thus sedimentary successions filling the young, deep Neogene depressions play a crucial role in the geology of the country (Fig. 1). Basement of the basins is made up by Paleozoic to Early Tertiary formations. Three major tectonic units (megaunits, composite terranes) separated by major faults or fracture zones (lineaments) constitute the pre-Middle Miocene basement of the Hungarian part of the Pannonian Basin (Fig. 2). These are as follows:

- the Austroalpine–Tatro–Veporic Megaunit bounded by the Piennini Klippen Belt on the north and the Rába–Diósgenő–Lubenic–Margecany Line on the south. The Penninic Unit, and above it some parts of the Austroalpine nappe complex, extend over western Hungary, whereas crystalline complexes of the Vepor Unit extend over northern Hungary;
- the Pelso Megaunit (Pelsonia Composite Terrane – Kovács et al. 1996-97) is located south to the above-mentioned megaunit and bounded by the Mid-Hungarian Line on the south. It consist of the Transdanubian Range, the Zagreb–Mid-Transdanubian, the Bükk and the Aggtelek Units, showing Alpine–Dinaridic facies affinity;
- the Tisza Megaunit (Tisia Terrane – Kovács et al. 1996-97) is situated south of the Pelso Megaunit and limited by the Dinaridic Ophiolite Complex on the south and southwest and the Mures Ophiolite Belt on the east. Variscan tectogenesis led to accretion of the Tisza Terrane by the Late Permian. Paleozoic to Middle Jurassic sequences show definite European facies affinity. Differentiation of definite facies zones initiated in the Late Triassic leading to the formation of three facies units: Mecsek, Villány–Bihar and Békés–Kodru Zones, respectively. These are bounded by Alpine thrust sheets.

The Austroalpine–Tatro–Veporic Megaunit moved together with the Pelso Megaunit from the Late Oligocene. The large composite unit, which came into existence on this way, was named as Alcapa Megaunit (Csontos et al. 1992). The Alcapa got into juxtaposition with the Tisza Megaunit in the Early Miocene creating the Pannonian Megaunit, i.e. the basement of the Pannonian Basin.

2.1. Pre–Alpine evolution

Due to polymetamorphic transformation of a significant part of the pre-Variscan formations and lack of fossils in many other cases, paleogeographic reconstruction for the Early Paleozoic interval is particularly difficult. Polymetamorphic complexes of the Tisza Megaunit suffered their first metamorphism perhaps in the Cademian or the Caledonian or the Early Variscan tectogenic phase, however, their meso- to ultrametamorphic transformation occurred certainly during the Variscan phase. According to petrographic and geochemical features of the granitoids of the crystalline complexes, they show affinity to those of the Moldanubicum Zone of the Variscan Orogenic Belt (Buda 1996). It means that the Tisza Megaunit may have belonged to the Variscan Foldbelt which was formed along the southern margin of the European plate during the Middle Carboniferous.

Lower Paleozoic rocks of the Pelso Megaunit and the Austroalpine nappes, which suffered metamorphism of various grades, may have formed in the Prototethys realm, in the foreground of the African plate. First metamorphic transformation of the Lower Paleozoic sedimentary and magmatic rocks of the Lower Austroalpine nappes might have taken place in the Caledonian, or more likely in the Variscan phase. Lower Paleozoic very low- to low-grade metamorphic series in the Upper Austroalpine nappes in the basement of the Little Plain and in the
Fig. 1: Geological sketch of the Pannonian Basin (after Royden and Sandulescu 1988)

Fig. 2: Tectonic scheme of the pre–Tertiary basement of the Pannonian Basin (after Haas et al. 1995)
Abbreviation: MT=Mid–Transdanubia
MIDDLE CARBONIFEROUS ~325 Ma

Fig. 3: Middle Carboniferous (~325 Ma) reconstruction (after Ebner et al. 1991)

LATE PERMIAN ~255 Ma

Fig. 4: Late Permian (~255 Ma) reconstruction (after Haas et al. 1995)

182
Transdanubian Range Unit were transformed in the Variscan phase, whereas series of similar age and metamorphic grade in the Bükk Unit only in the Alpine phase (Lelkesné Felvári et al. 1984, Árkai 1983).

Closure of the Prototethys in the Middle Carboniferous led to accretion of the Pangea supercontinent and consolidation of the Variscan Foldbelt (Meso-Europe – Stille 1924). However, in a relatively narrow zone, the marine sedimentation remained practically continuous from the Early to the Late Paleozoic. The Bükk, Szendrő and Uppony Units belonged to this zone which was not affected by significant tectonic deformations and metamorphism (Fig. 3).

In the Szendrő Unit, carbonate platforms, foreslope and siliciclastic flysch basin formed coevally in the Early Carboniferous. It was exchanged by overlying flysch deposition in the Middle Carboniferous. In the Bükk, the flysch sequence is overlain by a Late Carboniferous shallow marine carbonatic-siliciclastic series. In the Uppony Unit, the Lower to Middle Carboniferous is represented by basin facies, whereas the Upper Carboniferous sandstones and conglomerates are post-tectonic molasse deposits. Upper Carboniferous siliciclastic sequences, occurring in the Transdanubian Range, are typical continental molasse deposits. Siliciclastic, coal-bearing series of similar age are known also in the Slavonian–Drava Unit of the Tisza Megaunit and in the Zemplén Unit which may have formed in a continental foreland basin of the Variscan Foldbelt (Ebner et al. 1991).

In Early to Middle Permian, in the Tisza Megaunit, belonging still to the southern margin of the European plate, continental sedimentation continued in the previously formed molasse basins and initiated in the newly formed rift troughs. Deposition of continental red-beds was punctuated by an intense acidic magmatic activity at the end of the Early Permian, roughly coeval with a significant extension of the area of the continental depositional basins. Similar continental rift system and related sedimentary and magmatic series were formed on the African margin, i.e. in the Southern Alps, and although less pronounced, in the southwestern part of the Transdanubian Range, too. In the Bükk, belonging formerly to the inner zone of the Prototethys, subsequent to a short gap the Alpine evolutionary cycle appears to initiate as early as the base of the Middle Permian with continental–peritidal–shallow marine siliciclastic and dolomitic–evaporitic series. Here, the Upper Permian (Fig. 4) is represented by shallow marine facies akin to that in the Carnic Alps, Southern Karavanks and the northeastern segment of the Transdanubian Range which belonged to the same facies belt.

Geological background for Carlin-type gold mineralization of this stage can be outlined after Korpás et al. (1999) as follows. Ordovician to Late Permian evaporites, platform carbonates, foreslope carbonatic and siliciclastic sediments, molasse and flysch sequences with volcanics were checked in the Transdanubian Range, Bükk, Uppony, Szendrő and Bodva Unit (Figs. 3 and 4). Low level gold anomalies (up to 27 ppb Au) were found in pyrite and organic matter rich sediments of the Tapolcsány and Irota Formations of the Uppony and Szendrő Unit. Low to high level gold anomalies (from some to 2090 ppb Au) were detected in the platform carbonates (Úrhida Limestone, Polgárdi Limestone, Szabadbattyán Limestone) and metaporphosed flyschoid sequences (Balatonfőkajár Quartz Phyllite, Lovas Slate) in the Balatonfő–Velence Hills area of the Transdanubian Range. The latter ones are considered as targets of further explorations.

2.2. Alpine evolution

The Alpine history may be subdivided into the following main stages:

1. Multiphase opening of the Mesozoic Tethys ocean by rifting (Permian–Jurassic);
2. Multiphase closure of the Tethys by subduction and collision resulting in orogenesis, large-scale displacement of the lithosphere blocks between the European and African plates (Cretaceous–Paleogene);
3. Formation and development of the Pannonian Basin (Neogene–Quaternary).

Based on polarity and fitting of the Upper Permian–Triassic facies belts in the various tectonic units, setting of these units prior to the major orogenic dislocations could be reconstructed. Main starting points of the reconstruction are as follows:

- the Transdanubian Range Unit was located between the Southern Alps and the Northern Calcareous Alps (Upper Austroalpine Megaunit);
- the Zagreb–Mid–Transdanubian and the Bükk Units may have situated between the Dinaridic and the Southern Alpine realms;
- position of the Tisza Megaunit can be determined at the margin of the European plate, east to the Tatro-Veporic Megaunit. Within the Tisza Megaunit, the Mecsek Zone was located in the most external position.

Facies pattern, which came into being subsequent to the Late Permian transgression, sufficiently proves the above described setting (Fig. 4). Shallow marine deposits, formed in the inner belt of the Paleotethys Gulf, are known in the Bükk Mts. Marginal evaporitic sabkha–salina facies appear in the Aggttelek Mts. and also in the NE part of the Transdanubian Range. Continental red-beds characterize the developments of the SW part of the Transdanubian Range and the Mecsek and Villány Mts. Main stages of the evolution are summarized below.
2.2.1. Pre-rifting stage (P3–T2)

It is characterized by continuous, moderate but differentiated subsidence. Based on sedimentological features, the following substages can be distinguished:

- continental to shallow marine siliciclastic-carbonatic ramp deposition (P3–T1);
- shallow carbonate ramp–carbonate platform evolution (T2 Anisian).

Features of sequences belonging to this stage are fairly similar to each other as they were formed on the weekly articulated ramp of the Paleotethys Gulf not very far to each other in a tectonically tranquil period (Figs. 4 and 5).

The Carlin gold potential of this stage is considered by Korpás et al. (1999) extremely low. Twenty one formations including Late Permian evaporites, Early Triassic siliciclastic-carbonatic and Middle Triassic carbonate ramp deposits in the Transdanubian Range, Mecsek, Bükk and Bodva Unit were checked. Two of them, the Szentlélek Sandstone (up to 234 ppb Au) in the Bükk Unit and the Rudabánya Iron Ore Formation (with some tens to 630 ppb Au) in the Bodva Unit show anomalous gold values. The Rudabanya Iron Ore was considered as a perspective target for further and more detailed explorations.

2.2.2. Rifting stage (T2)

Rifting is manifested in the disintegration of the carbonate ramps and opening of an oceanic basement (Fig. 5). Consequences of the ocean opening significantly differ depending on the paleo-position of the individual units.

Tholeitic basic-ultrabasic rocks of oceanic crust occur in some nappes of the Aggtelek Unit together with deep-sea shales and radiolarites. Slope sediments of the Szőlősardó Unit and pelagic basin deposits of the Bódva and Torna Units are known in the Aggtelek Mts. (Kovács et al. 1989). The Silice nappe of the Aggtelek Mts. was probably formed on the European shelf of the Tethys, whereas the Bükk Unit may have formed on the African (Apulian) shelf where, as a consequence of rifting, intense volcanism initiated and intraplatform basins came into existence. Similar intermediate to acidic volcanic activity and extensional basin formation characterise also the South Alpine evolution. Although geochemical characteristics of these volcanites show similarities with those of island-arc magmatites, the tectonic evolution suggests rift-related volcanism (Harangi et al. 1996). In the Transdanubian Range, the extensional tectonics are manifested in facies differentiation and synchronous volcanic activity.

Since the area of the Tisza Megaunit belonged to the external zones of the European shelf far from the oceanic basins, evolution of this region was not disturbed by the rifting. Thus, carbonate deposition on ramps and platforms continued in the Tisza Megaunit.

The Ladinian–Lower Carnian Berva Limestone in the Bükk Unit exhibit sporadic low level gold anomalies (less than 25 ppb Au). The volcanic and volcano-sedimentary formations belonging to this stage do not show any sign of gold, consequently they appear to be unfavorable for Carlin-type gold mineralization (Korpás et al. 1999).

2.2.3. Stabilisation of the passive margins (T3)

In the Late Triassic (Fig. 6), cessation of rifting led to filling up of the intraplatform basins. Widely extended carbonate platforms evolved keeping place with the thermal subsidence. Climatically controlled enhanced siliciclastic input characterizes the western Neotethys realm in the Carnian. Initiation of terrigenous siliciclastic input is very conspicuous in the external belt of the European shelf which is represented by the Mecsek Zone where deposition of siliciclastics continued also in the Jurassic.

Increased terrigenous input led to upfilling of the intraplatform basins of the Transdanubian Range, the Aggtelek Mts. and the Bükk Unit.

By the Late Carnian, a levelled topography came into existence on the shelves giving rise to formation of large carbonate platforms, which continued as long as the end of the Triassic or even in the earliest Jurassic (Haas 1988).

A major part of the nineteen checked formations, including platform carbonates and siliciclastics, slope and intraplatform basin deposits were free of gold. The Veszprém Marl, Mátyáshegy Formation, Hautoptolomite and Dachstein Limestone in the Transdanubian Range (less than 25 ppb Au). Gold anomalies ranging between some to 84 ppb Au were detected in the Parád Complex of the Recsk porphyry copper deposit in the Bükk Unit (Korpás et al. 1999). This later one is considered target of further, more detailed explorations.
MIDDLE TRIASSIC ~230 Ma

Fig. 5: Middle Triassic (~230 Ma) reconstruction (after Haas et al. 1995)

LATE TRIASSIC ~215 Ma

Fig. 6: Late Triassic (~215 Ma) reconstruction (after Haas et al. 1995)
Abbreviations: DR=Drauzug, TR=Transdanubian Range, SA=Southern Alps, JU=Julian Alps, SL=Slovenian Basin, MT=Mid-Transdanubia, BO=Bükk. Sampled formations: 16=Mátavashegy Formation, 19=Rezi Dolomite, 20=Kössen Formation, 21=Feketehegy Formation, 23=Vesszős Shale, 51=Fődolomit Formation, 52=Dachstein Limestone
2.2.4 Late rifting stage (J1-Cr)

In the early Jurassic, in connection with the Atlantic opening, a new ocean branch (Ligurian–Penninic ocean) began forming in the region (Fig. 7). Meanwhile, opening of Neotethys still continued. This intense multiple rifting resulted in the disruption and drowning of the former carbonate platforms.

The process began in the Liassic leading to segmentation of the platforms. Highs and grabens came into being in the Transdanubian Range, in the Silice Nappe and the Bükk Unit similar to those in the Southern Alps and in the area of the Austroalpine and Tatro–Veporic Megaunit.

Jurassic ophiolites in the Szarvaskő Nappe of the Bükk Unit can be bound to the opening of the Neotethys (HARANGI et al. 1996) whereas redeposited sediments in the Bükk and Aggtelek Mts. may have accumulated at the toe of the continental slope.

Ophiolites of the Penninic Unit in West–Hungary, formed the basement of the Penninic ocean (KUBOVICS et al. 1990).

In the Transdanubian Range, drowning of the Triassic–earliest Jurassic carbonate platforms, formation of uplifted blocks and grabens refer to rifting (GALÁCZ 1988, VÖRÖS and GALÁCZ 1998). From the Late Liassic to the end of the Jurassic, pelagic deep-sea sedimentation prevailed which continued also in the Early Cretaceous in the SW part of the unit. In contrast, generation of a flysch basin initiated, in the Gerecse area, in the NE part of the unit (Fig. 8), indicating the closure of the Neotethys ocean (HAAS et al. 1990). In the same time, appearance of ophiolitic rock fragments and heavy minerals in the siliciclastic sediments refers to the obduction of the oceanic basement not far from the sedimentary basin (ÁRGYELÁN 1996).

A significant change in the setting of the Tisza Megaunit took place during the Jurassic. As a result of eastward propagation of the Penninic ocean, it began to separate from the southern margin of the European plate in the Middle Jurassic and this process continued also in the Early Cretaceous (HAAS et al. 1990).

Lower Jurassic siliciclastic and coal bearing sequences of the most external Mecsek Zone clearly indicate the vicinity of the continental source areas at the southern margin of the European plate. The rifting may have initiated in the Dogger by opening of pelagic basins with coeval submarine volcanism. This process continued in the Early Cretaceous when large amount of alkali mafic magmatites were formed mainly in the Mecsek Zone (KUBOVICS et al. 1990, HARANGI et al. 1996). The rift-related volcanic activity came into an end in the middle part of the Cretaceous when the whole region was affected by compression.

Estimation of Carlin gold potential of this stage is based on evaluation of 22 formations (KÖRÖS et al. 1999). All investigated siliciclastic, coal bearing and basin formations of the Mecsek Unit were free of gold. Among the pelagic basin and slope deposits showed only the Úrkút Manganese Ore, the Kisgerecse Marl, the Lókűt Radiolarite (Transdanubian Range) and the Bányahegy Radiolarite (Bükk Unit) low gold values, ranging between 2 and 7 ppb Au, slightly above detection level. Ophiolites and related deep sea sediments of the Penninic Unit (Kőszeg Quartz Phyllite, Cák Conglomerate, Velem Calc Phyllite and Felsőcsatár Greenschist) and of the Szarvaskő Nappe in the Bükk Unit (Darnóselye Shale, Darnó Radiolarite and Szarvaskő Basalt) exhibit low gold values (up to 19 ppb Au) with two extremely high values in the Felsőcsatár Greenschist (300 ppb Au) and in the Darnóselye Shale (334 ppb Au). Consequently, formations of the Penninic Unit and the Szarvaskő Nappe will be subjected to further explorations.

2.2.5 Early Tethys subduction and collision stage (J1–Cr)

The step-by-step closure of the Tethys started in the latest Jurassic and continued during the Cretaceous in several stages. It resulted in nappe formation, tectonic deformations, metamorphism as well as disruption and dislocation of lithosphere blocks.

According to classic concepts for tectonics of the Alps, formation of nappe systems and Alpine metamorphism of the lower nappes commenced at the end of the Early Cretaceous (Austrian phase) in connection with closure of the South Penninic ocean (TOLLMANN 1987). Metamorphism of the young Mesozoic formations of the Penninic Unit in West Hungary can be bound to this event (Fig. 8).

The peculiar nappe structure of the Transdanubian Range (ÁDÁM et al. 1985, RUMPLER and HORVÁTH 1988) with its central megasyncline was formed also by the Austrian tectogenesis, during the Aptian. This compressional phase was followed by a transgression-regression cycle in the Albian–Early Cenomanian. Orogenic collapse subsequent to the Pre-Gosau tectogenic phase led to formation of extensional basins and a new transgression-regression cycle during the Senonian (HAAS and CSÁSZÁR 1987).

Collision at the end of Cretaceous (Fig. 9) is marked by regional uplift and slight deformation (Laramian phase). Uppermost Cretaceous alkali basic and ultrabasic dikes in the NE part of the Transdanubian Range may be bound to extensional zones perpendicular to the collision front (KUBOVICS et al. 1990).
**MIDDLE JURASSIC ~170 Ma**

Fig. 7: Middle Jurassic (~170 Ma) reconstruction (after Haas et al. 1990)

- Sampled formations: 37=Kőszeg Quartz Phyllite, 38=Cák Conglomerate, 39=Velem Calc Phyllite, 56=Lőkút Radiolarite, 92=Darnóhegy Shale, 93=Darnó Radiolarite, 94=Szarvaskő Basalt, 95=Bányahegy Radiolarite, 96=Lókovölgy Shale, 97=Mónosbél Formation, 98=Óldalvölgy Formation.

---

**EARLY CRETACEOUS ~120 Ma**

Fig. 8: Early Cretaceous (~120 Ma) reconstruction (after Haas et al. 1990)

- Sampled formation: 40=Felsőcsatár Greenschist.
The main nappe formation in the Bükk Unit took place also probably prior to the Late Cretaceous. However, Upper Cretaceous formations, resting unconformably on the Paleozoic of the Uppony Unit, are folded.

As a consequence of the closure of the Tethys during Late Jurassic—Early Cretaceous (Figs. 7 and 8) the Bükk Unit, which was located on the southern (Dinaridic) shelf, may have approached the Tatro—Veporic Megaunit belonging to the northern (European) shelf. Collision led to obduction and nappe formation.

In the Tisza Megaunit, the first Alpine compression occurred at the end of the Early Cretaceous (Fig. 9). It is indicated by folding and cessation of basalt volcanism too. In the Villány—Bihar Zone, flysch-type sedimentation refers to initiation of nappe forming in the Albian. In the Apuseni Mts., main phase of nappe forming was at the beginning of the Senonian (pre-Gosau phase—IANOVIC et al. 1976). End of Cretaceous tectogenesis is marked by regional uplift which affected even the deep-sea basins.

This stage was considered unfavorable for Carlin type mineralization. The Felsőcsatár Greenschist of the Pannonian Unit was evaluated earlier, while some bauxites and alkali ultrabasites in NE Transdanubian Range proved to be empty (KORPÁS et al. 1999).

2.2.6. Late Tethys subduction and collision stage, formation of the Paratethys basins (E—O)

Process of closure of the Tethys system continued in the Early Eocene and finished at the Eocene/Oligocene boundary. Subduction and subsequent collision of the Adriatic (Apulian) microplate and the European plate resulted in the emergence of the Alpine and Dinaridic ranges. Juxtaposition of Transdanubian Range, Mid-Transdanubian and Bükk Units took place probably during the Eocene (Fig. 10) when, moving eastward, the Transdanubian Range reached, and dragged blocks of the Mid—Transdanubian Unit and pushed forward the Bükk Unit on its front. Calc-alkaline island arc volcanism in the afore-mentioned units marks the relationship of these units in the Late Eocene and Early Oligocene. At this time, they were located along the northern margin of the southern (Slovenian—Bosnian) flysch basin.

A series of basins belonging to the Paratethys, i.e. a remnant basin of the former Tethys ocean came into existence in the Early Oligocene (NAGYMAROSY 1990). These basins include also the Hungarian Paleogene Basin (Fig. 11) which were formed as a consequence of large scale eastward motions of the Pelso Megaunit (ROYDEN and BALDI 1988). The fact, that the North Hungarian Paleogene Basin oversteps the Pelso Unit and continues in the Tatro—Veporic Megaunit (BALDI and BALDINÉ—BEKE 1985), indicates that the two units had come into juxtaposition by this time and moved further eastward together. In the Mecsek Unit of the Tisza Megaunit ("Flysch Belt of the Szolnok Subunit"), marine deposition continued till the end of Oligocene.

Although the carbonate platform formations and its slope deposits, furthermore the siliciclastic delta and prodelta, restricted basin sediments of the Transdanubian Range were affected by hydrothermal overprints in this period, they do not show any sign of gold mineralization. The volcano-plutonic formations of the Paleogene Island Arc, represented by the Nadap Andesite in the Velence Hills of the Transdanubian Range, and Recsk Andesite in the Bükk Unit, can be considered as generators of Carlin-type gold mineralization (KORPÁS et al. 1999).

2.2.7. Pannonian Basin stage (M—Q)

Miocene tectogenesis of the Pannonian Basin was controlled by post-collision effects of the African (Adriatic) and European plates and elastic deformation of the collisional fronts. The Neogene deep basins are located and formed approximately above the "collisional sutures" (HÁMOR 1983, 1984). The cause of rejuvenation is the weakening of stresses which led to formation of a network of tensional troughs and subsequently basins at the crossing of the troughs, as a rule.

Three aspects make this simple model complicated:
- existence and rotation of small fragmented microplates between the large continental plates,
- volcanic masses of "Neogene and superimposed island-arcs" generated by subduction,
- effects of vertical movements of the NW—SE Vardar system during the Miocene.

Evolution of the Pannonian basin took place in four cycles with alternating changes of compressional and tensile intervals and stress fields.

The Savian cycle (26—19 Ma) is characterized by an intense NE-ward piling up of the Alpine systems and up-lifting of the Vardar zone of NW—SE strike, parallel to the collision front (Fig. 12) In this period, displacement and rotation of plate fragments were still probable. Generation of great alluvial depositional systems in W, SW and SE Hungary, graben structures of the Late Egerian—Ottangian marine sedimentary basins in the NE and outflow of fracture-controlled ignimbrites ("lower rhyolite tuff") in the NE and SW may be attributed to this tensional cycle.

188
LATE CRETACEOUS ~65 Ma

Fig. 9: Late Cretaceous (~65 Ma) reconstruction (after Haas et al. 1990)

LATE EOCENE ~ 40 Ma

Fig. 10: Late Eocene (~40 Ma) reconstruction (after Csontos et al. 1992)
Main result of the Styrian cycle (19–15 Ma) was the uplift of the Alps and Carpathians, generation of the southern foredeep of the Alps and collapse of the Dinarides (Fig. 13). At that time the Pelso and Tisza Megaunits already got into juxtaposition and, along dislocation zones of their units the NE–SW oriented Karpatic and Early Badenian pull apart basins came into existence. The compressive forearc basin of the to NE directed subduction-front is marked by explosion maximums of the “middle rhyolite tuff” and by the intermediate andesitic volcanism along the early Inner Carpathian Arc.

In the Leithan cycle (HÁMOR, 1978), during the Late Badenian-Sarmatian-Pannonian s.s.t. (15–6 Ma), took place the last nappe generation in the Alpine–Carpathian–Dinaric system and general uplift of this realm. In the same time, tension in the inner part of the system excepting the isolated midmountains ranges led to collapse of the Pannonian Basin (Fig. 14). On the completely consolidated basement, incipient elements of the present-day orography, i.e. large depressions and isolated mountains came into being at this time. Characteristic tectonic elements are extensional faults shifting in time towards the margin of the basin. Unconformities and onlap geometry are common. The deep basins (1–5 km) came into existence in the Transtisza area, Drava basin and Little Plain (Kisalföld). Uplifting of the Vardar system continued also in this period. Traces of basalt volcanism were encountered on the uplifting range. The late acidic–intermediate volcanism of the East Carpathian Arc migrating to NE and E started in the Late Badenian, reached its paroxism during Sarmatian and practically finished at the end of the Late Pannonian.

In the course of the Rhodanian cycle (6–2.4 Ma), uplifting of the Alpine-Carpathian chain continued, whereas compression characterized the inner regions. Forcing effects from NW and SE enhanced the NW–SE transverse faults causing small displacements and minor folds.

Uplifting of the Pannonian Basin (Fig. 15) took place by continuous progradation of delta systems from the margins towards the centre. At the margin of the isolated mountains, in the inner part of the basin, onlap of the younger formation is usual. Marine connection to SE might have existed through the Al-Duna or Timok trough. Volcanic activity was completed by rifting generated basalts on the Balaton Highland, in the Little Plain, in N Hungary and in the Great Plain during Late Miocene to Quaternary.

Evaluation of Carlin gold potential of this stage is based on geochemical signatures of eight formations (KORPÁS et al. 1999). The Early Badenian Börzsöny and Visegrád Andesite can be considered as the generator of the low-level gold anomalies in the Hauptdolomite and Dachstein Limestone in NE Transdanubian Range. Traces of gold (some ppb Au) were detected in the pyrite and limonite rich basal horizons of some Late Pannonian to Quaternary formations (Transdanubian Range), furthermore in the residual dump deposits of the Rudabánya Iron Ore in the North Hungarian Range.
Fig. 12: Early Miocene (22–20 Ma) reconstruction (HÁMOR 1995)
Fig. 13: End of the Middle Miocene (15.5-14.4 Ma) reconstruction (HAMOR 1995)
Fig. 14: Late Miocene (14.0–10.0 Ma) reconstruction (Hámor 1995)
3. CONCLUSIONS

The Carlin gold potential of Hungary has been evaluated in the frame of multiphase geologic evolution of the region. Our most important considerations will be summarised in the following:

1. Major stages of structure evolution related both to Paleozoic (Variscan) and Mesozoic (Alpine) rifting or subduction may be favorable phases for gold mineralization.

2. Among them the pre-Alpine stages may have of special importance, manifesting in perspective formations which were formed along the paleomargins of the Pelso Unit.

3. Early and late rifting as well as subduction stages of the Alpine cycle may have yielded favorable host formations both in the shelf (Pelso Unit) and oceanic domains (Penninic Unit, Meliata Unit) during Triassic to Middle Jurassic.

4. Subsequent subduction and collision stages during Cretaceous and Paleogene, and the stage of formation of the Pannonian Basin during Neogene to Quaternary are not considered as favorable for Carlin type gold mineralization.

4. REFERENCES


Hámor, G. 1999: Megatectonic and palaeogeographic significance of Vardar system. — Acta Geologica Hungarica, in press


