by János Haas¹, and Géza Hámor²

Geological garden in the neighborhood of Budapest, Hungary

1 Geological Research Group of the Hungarian Academy of Sciences, Eötvös Loránd University, 1088, Múzeum krt. 4/a, Budapest, Hungary.
2 Eötvös Loránd University, Department of Regional Geology, 1143 Stefánia str. 14, Budapest, Hungary.

Introduction

More than a hundred million year history of the Mesozoic evolution of the Tethys is recorded in the layers of the Kálvária (Calvary) Hill at Tata, a town 70 km northwest of Budapest, between the Gerecse and Vértes Mountains. On the ruins of a medieval church, located on the top of a projecting cliff, a chapel as well as calvary monuments were built in the 18th century lending the name of the hill.

Kálvária Hill is a small fault-bonded Mesozoic horst. It is surrounded by Oligocene fluvial formations and deposits of the Late Miocene Pannonian Lake. Hot spring activity since the Ice Age has led to formation of caves within the horst and patches of travertine in the surrounding area. All these geological phenomena together with prehistoric chert pits are visible in a tiny area, in the central part of a picturesque baroque town, in the neighborhood of many historical sites and the famous Fényes spa with its karst-water springs.

The outcropping Mesozoic sequences and well-preserved fossils in Tata have been studied by a number of scientists since the 19th century. For the initiative of Professor Elemér Vadász, the geologically most valuable parts of the Kálvária Hill have been declared to be a Geological Conservation Area already in 1958. In the subsequent decade, under the leadership of Professor József Fülöp and thanks to the financial support and work of the staff of the Hungarian Geological Institute, step-by-step development of the protected area led to the establishment of a geological park, the germ of the present-day one, in 1969. In the meantime, a comprehensive research on the geology of the region was carried out, resulting in the publication of a monograph written by Fülöp about geology of the Kálvária Hill, in 1975. Since the 1970s, simultaneously with abandonment of the quarries, the territory of the garden has remarkably increased. It has been enriched by an exhibition of the most characteristic rock types (46 monoliths were set up) and mineral raw materials of the country and more than 600 valuable plant species. The developments were significantly supported by the Bureau of Nature Conservation between 1994–1995. As a result of all these efforts, an attractive park showing harmony of the rocks and plants came into being in the place of the previously existing dirty and dusty quarries.

At present, the geological park, extending to an area of 2.8 hectares is under auspices of the Eötvös Loránd University, Budapest. It serves the interest of the scholars, students and tourists and it is a base of vocational training, culture and education.

Historical background

In 1797, in his travelogue on Hungary, English traveler Robert Townson characterized Tata as a town built on red marble.

In 1859, Austrian geologist Karl Peters was the first to publish descriptions of scientific value on the "red marble" of Tata and also mentioned Megalodus-bearing Dachsteinkalk. At the same time, Franz Hauer reported new ammonite species from the Liassic limestone.

In 1906, the famous Hungarian geologist Lajos Lóczy sr. was the first to recognize the gray crinoidal limestone as an independent formation and determined its Cretaceous age. He supposed a steep, rocky coast existing here at the time of deposition of the crinoidal limestone unconformably overlying the Jurassic sequence.

Nándor Koch's work "*Geological conditions of the Kálvária Hill at Tata*" (1909) was the first comprehensive treatise on this area. Relying on very rich fossil assemblages, he proposed a detailed stratigraphic subdivision for the Jurassic succession. Based on fossils, he assigned the gray crinoidal limestone to the Lower Neocomian. Later on, Somogyi (1914) re-evaluated the fauna and placed it into the Aptian Stage.

In 1975 (1976 in English), József Fülöp summarized the litho- and biostratigraphy of the Mesozoic formations of the Kálvária Hill and the surrounding region in a richly illustrated monograph. In another work, in 1973, he also described the prehistoric chert pits and the unearthed archeological findings. Professor Fülöp continued the detailed study of the area until his unexpected death in 1994.

In the last decades, focusing on some special hitherto unsolved problems, the study of the exposed sections continued. Cyclicity of the Dachstein Limestone and nature of the Triassic-Jurassic boundary were studied in detail (Haas, 1995). A repeated collection of ammonites, other molluscs and brachiopods, and revision of the previously collected fauna were carried out to determine the range of the gap between the Triassic and basal Jurassic strata (Pálffy, 1997). Based on studies of the rich ammonite fauna in the condensed basal layer of the gray crinoidal limestone, a revised chronostratigraphic evaluation was proposed (Szives, 1999). Further studies on the Jurassic neptunian dikes and diagenesis of the Triassic and Jurassic formations are underway.

Geological setting

Tata is located in the northeastern part of the Transdanubian Range traversing western Hungary (Transdanubia) in NE–SW direction (Figure 1). The Transdanubian Range shows a mega-synclinal structure, which came into existence in the Mid-Cretaceous as a result of the Alpine orogenic movements. The Tata horst is located in the axial zone of the syncline where the youngest Mesozoic formations have been preserved. Mountains of the Transdanubian Range are separated by Tertiary transversal faults of northwest-southeast trend, as a rule. The small Tata block is situated between two larger mountains: the Vértes and the Gerecse. East of the horst, a segmented graben-system filled by a 300–500 m-thick Eocene-Oligocene series occurs. To the west, towards the Kisalföld (Little Plain) along a series of faults, the Mesozoic basement subsided, reaching a depth of 6–7 km and covered by Neogene sequences.

As to the development of the Mesozoic formations of the Tata block, they reflect an intermediate setting of the area. In the Late Triassic, a predominant part of the Transdanubian Range belonged to the huge marginal carbonate platform of the Tethys (Dachstein platform-system). Disintegration of this platform initiated at the end of Triassic, leading to the drowning of the platform, just at the Triassic-

Figure 1 A) Location of Tata within the Transdanubian Range, Hungary; B) Pre-Tertiary geological map showing the geological setting of the Mesozoic horst at Tata.

Jurassic boundary in the NE part of the TR, while the platform survived in its SW part.

In Tata, the platform evolution came to an end at the Tr/J boundary and features of the predominantly ammonitico rosso-type Jurassic succession show close genetic relationships with those in the NE part of the Transdanubian Range (Gerecse Mts.). In contrast, the Lower Cretaceous sequences show closer affinity with those in the SW part of the range (Bakony Mts.).

In the neighborhood of the Tata horsts, the Eocene formations have been lost due to intense denudation prior to the Oligocene. The Oligocene is represented by a fluvial succession of remarkable thickness. In the Late Miocene (Pannonian Stage in the Pannonian Basin), shallow lacustrine, gravely, sandy sediments containing a characteristic Congeria fauna were laid down. During the Quaternary, sedimentary sequences of varied lithology were formed. Based on Pleistocene pollens, which were found in fine sand and variegated clay fissure-fills, the horst may have been uplifted to reach its present-day altitude in the middle Pleistocene. It was followed by travertine deposition along the faults. In travertine beds, Paleolithic tools and bones of coeval animals were found at the foot of the Kálvária Hill.

Late Triassic carbonate platform and its drowning at the Tr/J boundary

The Upper Triassic (Rhaetian) Dachstein Limestone is the oldest formation exposed on the Kálvária Hill (Figure 2). The outcropping beds provide a superb example of the cyclic peritidal inner platform deposits. They show every characteristic of the Lofer cycles described by Fischer (1964) from the type locality of the Dachstein Limestone in the Northern Calcareous Alps. The meter-scale cycles reflect probably high frequency sea-level oscillation triggered by orbital forcing (precession cycle).

In the northwestern part of the protected area, four and a half cycle are exposed on the steep wall of a former quarry (Figure 3). A disconformity surface occurs at the base of the cycles, as a rule. Few decimeter thick stromatolitic layers with desiccation phenomena overlie it. Rip-ups of microbial mat origin and tiny black pebbles are common. The thin basal layers are followed by a thicker subtidal one, containing plenty of Megalodonts, embedded usually in life

Figure 2 Lithology and stratigraphy of the Mesozoic succession exposed on the Kálvária Hill, Tata.

position. In the topmost part of the cycles, the tidal flat facies, punctuated by subaerial erosion surfaces, returns. The uppermost cycle of the Dachstein Limestone is truncated. The very sharp and surprisingly flat truncation surface commonly cut the Megalodonts, suggesting that the erosion affected already lithified deposits. Solution cavities and moldic pores of Megalodonts in the topmost layer are filled by marine sediments of the overlying lowermost Jurassic layers. Although the truncation horizon appears to be parallel with the bedding planes of the Dachstein Limestone, detailed measurements of the sections revealed that in reality a very low angle angular unconformity does exist (Haas, 1995).

Based on the previously described characteristics, the following scenario can be reconstructed for the Tr/J boundary interval. At the

Figure 3 Triassic-Jurassic boundary section under the Calvary monument.

very end of the Rhaetian started the disruption of the Dachstein platform. Due to sea level drop at the end of the Triassic, the slightly tilted blocks were probably affected by subaerial erosion. Rising sea level in the earliest Hettangian led to inundation and hence the hard bottom was affected by submarine bioerosion. Biotic crisis after the massive extinction at the Tr/J boundary may have contributed to the drowning of the former carbonate platform and the long lasting lag-time during the Early to early Middle Hettangian.

A well-developed network of neptunian dikes cuts the Dachstein Limestone and the lowermost Jurassic beds. Pink wackestone or mudstone fills the fissures, originating from the overlying Jurassic sequence and also contains pieces of the host rock (Figure 4). Width of the dikes may reach 20–30 cm. Formation of neptunian dikes was connected to the extensional tectonics, leading to disintegration of the Dachstein platform during the Early Jurassic.

Figure 4 Neptunian dike with Liassic fissure fill crosscuts the Dachstein Limestone. Fragments of the host rock are also visible in the red micritic matrix.

Continuous Mediterranean Jurassic succession

A complete, gently dipping Liassic succession is exposed in a single continuous section in the part of the conservation area, whereas the Dogger and Malm layers are visible in the upper terrace of the park. So, walking in the park, the visitor may get an impression of a typical Mediterranean Jurassic sequence. Stratigraphic subdivision of the 43 m-thick sequence is presented in Figure 2.

The basal layer of the Jurassic series is pinkish crinoidal limestone, 30–40 cm in thickness. It is overlain by a 20–30 cm-thick oncoidal bed, containing microbially encrusted fossils, predominantly ammonites and brachiopods. Concurrent occurrence of *Alsatites* s.l. and *Paracaloceras*?, found in the oncoidal bed, refers to an interval from the upper part of the Middle Hettangian to the lower part of the Upper Hettangian (Pálffy, 1997).

The basal beds are overlain by about 10 m-thick, light pink, thick-bedded limestones (Pisznice Limestone). Along with scattered crinoid ossicles, benthic foraminifera are also common. In these

beds, dm-size lens-shaped filled cavities occur, parallel with the bedding. They are filled by bioclastic wackestone and mudstone internal sediment below, while the upper part of the cavity is lined by fibrous calcite and filled by drusy spar.

The 4 m-thick middle member of the Pisznice Limestone is made up of well-bedded, somewhat darker pink limestone with brachiopod and lenses of crinoid sand. It is overlain by about 6 m-thick red limestones, showing features of the "ammonitico rosso". Uneven, commonly stylolitic bedding planes punctuate it. The layers are rich in brachiopods and ammonites. Tubular casts of burrowing organisms, perpendicular to the bedding planes, are abundant. Based on ammonites, this member was classed to the Upper Sinemurian (Géczy in Fülöp, 1975).

The next unit of the Liassic series is made up of red crinoidal limestone of Pliensbachian age. It is characterized by an intensely bioturbated structure (Figure 5) and a rich shallow marine microfoss-

Figure 5 Pliensbachian red, intensively bioturbated, crinoidal limestone.

sil assemblage with crinoids, benthic foraminifera, sponge spicules and ostracodes.

The basic change in the microbiofacies in the overlying less than 1 m-thick Toarcian marl layer suggests a sudden deepening. Instead of the benthic elements along with ammonites, pelagic *Bositra* valves and radiolarians become prevailing. It is covered by red nodular limestone (Tölgyhát Limestone) in a thickness of 5 m. Fe-Mn oxide nodules, 1–2 cm in diameter are common. Chondrites-type trace fossils occur on the bedding planes. Based on the rich ammonite fauna, the age of this unit is Aalenian-Bajocian (Fülöp, 1975). A half-meter thick alldapic crinoidite bed and an even thinner *Bositra coquina* layer end the Tölgyhát Limestone.

The Bathonian-Callovian interval is represented by a 1 m-thick, strongly condensed radiolarian chert bed. In this time interval, the sedimentary basin may have got below the CCD, reaching the maximum depth in the Jurassic. On the other hand, slump structures in the chert bed indicate an articulated bottom topography.

The whole Malm succession is very condensed and its total thickness is not more than a few meters. The Oxfordian is represented by a grain-supported breccia bed, which can be interpreted as a toe-of-slope deposit. The Kimmeridgean is red nodular limestone locally with smaller or larger lithoclasts and slump structures. The sequence is punctuated by Fe-Mn coated hard grounds with plenty of

Figure 6 Fe-Mn coated hard ground with plenty of ammonites in Kimmeridgean red nodular limestone.

ammonites. The ammonite-pavement is one of the main attractions of the geological garden. Moreover, the hard ground is segmented by neptunian dikes indicating renewal of the extensional tectonic movements in the Late Tithonian-Berriasian interval (Figure 6). The Tithonian-Berriasian sequence is not thicker than 1.5 m. It is made up of light gray and lilac-reddish *Calpionella* wackestone, rich in ammonites and brachiopods.

Type locality of the Cretaceous Tata Limestone

In the Aptian, the whole Transdanubian Range was affected by intense tectonic movements of the Alpine orogeny. It was resulted in the formation of the mega-syncline structure of the whole structural unit, folding and imbrication. In the southwestern part of the Transdanubian Range, in the deepest axial part of the newly formed syncline, the marine sedimentation was continuous. In contrast, a larger part of the Transdanubian Range was uplifted and it was affected by erosion. This area became inundated again during the Middle Aptian to Early Albian when gray crinoidal limestone was formed on a shallow ramp. Fülöp (1975) named this limestone Tata Limestone because basal beds of the formation contained a rich ammonite fauna on the Kálvária Hill. Based on the ammonite assemblage, Fülöp classed the basal beds to the Upper Aptian (Clansayan Substage). A recent revision of the fauna has revealed that it is actually a mixed assemblage containing elements of five Aptian and one Lower Albian ammonite zones (Szives, 1999). Thus a long lasting submarine lag period can be assumed without any significant sediment deposition but with accumulation of mega-fossils in the small depressions of the uneven erosion surface. The rough erosion surface (Figure 7) is coated by a 1–2 cm-thick, brownish-yellow stromatolitic crust and in a lot of cases the mega-fossils are also encrusted. In the very spectacular basal layers, chert, sandstone and quartz pebbles and smaller clasts of the underlying Jurassic carbonates also occur. Above the basal beds, a few meter thick crinoidal limestone is exposed in the protected area showing typical features of the Tata Formation.

Other geological sightseeing

Along with the Mesozoic marine sequences, the main attraction of the Kálvária Hill, other spectacular geological phenomena are also

Figure 7 Basal layers of the Aptian Tata Limestone overlaps the uneven erosion surface of the Malm formations. Shelter building of the prehistoric chert pit is visible on the background.

visible in the geological park. In the western part of the protected area, a Late Miocene (Pannonian) abrasion surface occurs on the top of the Liassic formations, locally with etching figures of bivalves *Congerina*.

On a large unearthed rock-surface, in the upper terrace of the garden, a network of the Tertiary faults is perfectly exposed. Lateral displacements of the thin and distinctive Middle to Upper Jurassic layers are easily recognizable even for the nonprofessional visitors. A normal fault separates the upper and the lower terrace of the garden. Here, the mirror of the fault with striae and a brecciated fault zone are exposed and an explanatory board provides information on the mechanism of the faulting for the visitors.

Along some faults, smaller or larger solution cavities are visible in the Triassic-Jurassic limestones. In 1972, a hydrothermal cave was discovered under the surface of the Kálvária Hill, 10–16 m below the lower terrace level. Measured length of the cave is 175 m. Etched molds of *Megalodonts* cover the wall, locally. Opening of the *Megalodus* Cave for the tourists is one of our plans for the future development.

Prehistoric chert mine

In 1965, in the course of geological study of the Bathonian–Callovian chert bed, Fülöp and his co-workers encountered traces of prehistoric chert mining. In the subsequent years, together with archaeologists L. Vértes, V. Dobosi, and paleontologists M. Kretzoi and L. Bécsy, they unearthed several chert pits, and numerous tools of mining. They also found traces of a fireplace, with bones of the consumed animals (progenitors of cattle and goat, deer and 17 other genera) and pieces of a jar. However, workshop for tool making has not been encountered on the Kálvária Hill or in the surrounding area for the time being.

Excavation of the chert was started in the Neolithic and continued also in the Copper Age. According to the findings, the prehistoric miners used pick-axes, made mainly of stag-horn, stone hammers and choppers.

Perspectives

The geological park is open for the visitors every day from April to October. It plays an important role in the higher education. Students of 30–40 secondary and elementary schools and 6–7000 tourists come to see it, yearly.

Further development of the protected park is planned for the coming years. Completing of the monolith collection is under way. As a result, a wider spectrum of the characteristic rock types of the country is going to be visible in the garden. Establishment of a multi-function monitoring station for measuring and registration of meteorological data, environmental conditions and level of the karstic-water table can also be found among our plans.

The geological park at Tata invites the geoscientists and nature-lovers of the world to show them an example of land reclamation, which made possible the presentation of geological sightseeing in harmony with the nature and history of the region.

References

- Fülöp, J., 1973, Funde des prähistorischen Silexgrubenbaues am Kálvária-Hügel von Tata. - *Acta Arch. Acad. Sci. Hung.*, 25, 4–25.
 Fülöp, J., 1975, Tatai mezozoós alaphegység-rögök (The Mesozoic basement horst blocks of Tata). - *Geol. Hung. Ser. Geol.*, 16, 228 p. (in Hungarian).
 Fülöp, J., 1976, The Mesozoic basement horst blocks of Tata. - *Geol. Hung. Ser. Geol.*, 16, 228 p.

János Haas, Research Professor, is Head of the Geological Research Group of the Hungarian Academy of Sciences. He started his career in mineral assessment and geological mapping at the Hungarian Geological Survey in 1972. Till 1994 he worked as a Division Director at the Hungarian Geological Survey and leader of the National Key-Section Project as well as several projects of applied geology. Since 1994 he teaches at the Eötvös Loránd University, Budapest. His main fields of research are Mesozoic stratigraphy and sedimentology. He is President of the Hungarian Geological Commission, Editor-in-Chief of *Acta Geologica Hungarica* and Editor of the new edition of the *Geology of Hungary* (2001).

- Haas, J., 1995, Az Északi Gerecse felsőtriász karbonát platform képződményei (Upper Triassic platform carbonates of the northern Gerecse Mts.). - *Földt. Közl.*, 125/3–4, 259–293 (in Hungarian with English abstract).
 Koch, N., 1909, Die geologischen Verhältnisse des Kalvarienhügels von Tata. - *Földt. Közl.*, 39/5, 285–307.
 Lóczy, L. 1906, Geológiai megfigyelések a tatai Kálvária-hegyen (Geologic observations on the Kálvária Hill, Tata). - *Földt. Közl.*, 36, 206–207 (in Hungarian).
 Pálffy, J., 1997, Age of the Jurassic basal layers in the Kálvária Hill, Tata. - Manuscript, Hung. Mus. Nat. Hist., Budapest (in Hungarian).
 Peters, K., 1859, Geologische Studien aus Ungarn. II. Die Umgebung von Visegrád, Gran, Totis und Zsámbék. - *Jahrb. Geol. Reichanst.*, 10, 4.
 Somogyi, K., 1914, Das Neokom des Gerecsegebirges. - *Jahrb. Ung. Geol. Anst.*, 22/5, 295–370.
 Szives, O., 1999, Ammonite biostratigraphy of the Tata Limestone Formation (Aptian–Lower Albian), Hungary. - *Acta Geol. Hung.*, 42/4, 401–411.
 Towson, R., 1797, Travels in Hungary, with a short account of Vienna in the year 1793. - London.

Géza Hámor is a Professor of Regional Geology, Eötvös Loránd University, Budapest, Director of the Geological Nature Conservation Area and Open-Air Geological Museum Tata. He started his career in geological mapping and regional geology at the Hungarian Geological Survey. Between 1979 and 1991 he was Director of the Survey. He is Honorary Member of the Geological Societies of Hungary, Poland and Austria. His main fields of research are Tertiary stratigraphy, palaeoreconstruction and mineral assessment. Since 1978 he has been a member of the Executive Board of the Regional Committee on Mediterranean Neogene Stratigraphy. He was Editor-in-Chief of the *Neogene Palaeogeographic Atlas of Central and Eastern Europe*. He is co-author of the *Geology of Hungary* (2001).

THE JORDEN RIFT VALLEY

by A. Horowitz

2001
 25 cm, 748 pp., hardback,
 ISBN 90 5809 351 4
 EUR 160.00/\$ 160.00

A.A. Balkema Publisher
 evenis@swets.nl
 www.balkema.nl

Storms in Space

by John W. Freeman

October 2001
 Hardback, 139 pages
 ISBN: 0 521 66038 6
 £18.95 (US\$27.95)

Cambridge University Press
<http://www.cup.org>

CAMBRIDGE
 UNIVERSITY PRESS