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ENGINEERING GEOLOGICAL SURVEY OF RÓZSADOMB AREA, BUDAPEST, HUNGARY[1]

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Abstract

Late Triassic platform and extensional basinal sediments and Eocene shallow self carbonates are mainly covered by Oligocene clays, Pleistocene-Holocene slope sediments in the Rózsadomb area. Eocene carbonates are the host rocks of the extended (25 km) cave system, which passages are primarily tectonically controlled. The fractures and joints of the three major tectonic phases were enlarged by ascending thermal waters in the Plio-Pleistocene period. The presence of near surface cave passages raises special problems: hazards of cave collapse, especially when the cover beds are fractured Eocene marls; pollution of karst and related thermal water system from failure of sewer system or cesspits via fissures and cave passages. Damages in built environment are mainly related to landslides of the soaked clayey slope sediments, since in the deeper zones the 'solid' carbonate rocks are stable. The major trigger mechanism of the landslides is the precipitation combined with slope instability (human activity). To reduce the risk of landslides, damages and contaminations the reconstruction and extension of sewer system; the stricter regulations of human impact (control of townplanning regulations); the extension of protection zones and the exploration of the unknown cave system would be necessary.

Keywords: engineering geology, petrophysics, stratigraphy, facies analysis, tectonics and cave system.

Introduction

Budapest is often called as the city of spas, bathes and caves. This special geological and hydrogeological setting determined the development of the city from the Roman times onward. Furthermore this unique heritage raises special problems and has become the cornerstone of geological research (SZABÓ, 1858, SCHRÉTER, 1919, JASKÓ, 1936, KOVÁCS and MÜLLER, 1980, SZENTIRMAI et al., 1986, SZÖRÉNYI, 1986, KRAUS, 1982, 1990, FORD and TAKÁCS-BOLNER, 1991, NÁDOR, 1992). Rózsadomb area is one of the most favourable and valuable building areas of Budapest

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with an extended cave system of 25 km in length underneath. Due to the increased building activity slope failures, landslides and cave collapses became more frequent endangering the natural and built environment. This paper outlines the geological conditions of the region emphasizing the importance of classical geological, engineering geological, structural geological and petrophysical studies in the prediction of hazards and in the protection of natural and human environment.

1. Research Methods

In the first phase of the research the documentations of former drillings, reports as well as laboratory analyses were collected. The geological mapping, profiling and sample collection formed the major of the field studies. Topographic maps and aerial photomosaic maps were used in the mapping as well as in the assessment of anthropogenic-geomorphological interactions and in the evaluation vegetation cover versus built in areas. The subsurface geology was studied in caves and in the form of core materials of current drillings.

The samples were described in petrological, sedimentological and microtectonical point of view. The mineralogical analyses of samples included XRD (X–ray diffractometry) and thermal analyses (Derivatograph) (161 samples). For petrological, microfacies and carbonate diagenesis studies 192 thin sections were prepared. The data evaluation of the 896 tectonic measurements included compilation of stereograms and rose-diagrams showing the orientation of different structures (fissures and faults), tectonic features (riedel fractures, pull-apart basins, en-echelon faults, stress fields, fault displacements and strikes of joints and faults, respectively).

Petrophysical tests were carried out according to standards of building stone materials. Furthermore sampling methods and sample groups were also chosen conform to these standards. The core, the outcrop and cave samples (727 samples) were analyzed for the determination of mass distribution and water content, rebound, longitudinal ultrasonic velocity, compression strength, petrophysical modulus of elasticity, Poisson ratio, tensile strength, rheology and creep, colour of the rock types. Joint pattern analysis of 620 m core was described by using of the IAEG (1981) joint systematization (Polyhedral blocks, Po ratio; Tabular blocks, Ta; Prismatic blocks, Pr; Equidimensional blocks, Eq; Rhomboidal blocks, Rh type). RQD (Rock Quality Designation) values of rock bodies were also measured.

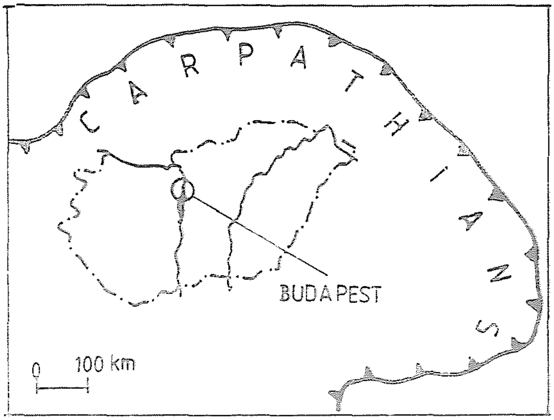

Fig. 1. Setting of the study area in Hungary

2. Geological Setting

The investigated area, so-called Rózsadomb, is 10 km^2, and is situated in the middle and eastern part of the Buda Mountains (*Fig. 1*).

Similarly to the Buda Mountains, the central massif of the investigated area is also built up of karstified Triassic and Eocene rocks (WEIN 1977). The major part is covered by vegetation, or urbanized areas. The five most important caves in a total length of about 25 km (Pál-völgy, Mátyás-hegy, Szemlő-hegy, Ferenc-hegy and József-hegy caves) are found on the area (*Fig. 2*).

3. Geological and Petrophysical Description of Major Rock Types

3.1. Late Triassic

Hauptdolomit (Main Dolomite) Formation.

Surface outcrops of Hauptdolomit are found at isolated cliffs, which are mainly parts of natural conservation areas, therefore they are subordinate in terms of engineering geology.

The Hauptdolomit Formation is partly covered by Mátyáshegy Formation and they are partly interfingering (*Fig. 3*). It is a white, at some places yellowish, grey, micritic, microsparitic dolomite. The original bedding is hardly visible. In some places on the surface reddish and yellowish clayey, laminated intercalations are present. Autoclastic clast supported breccias are also common.

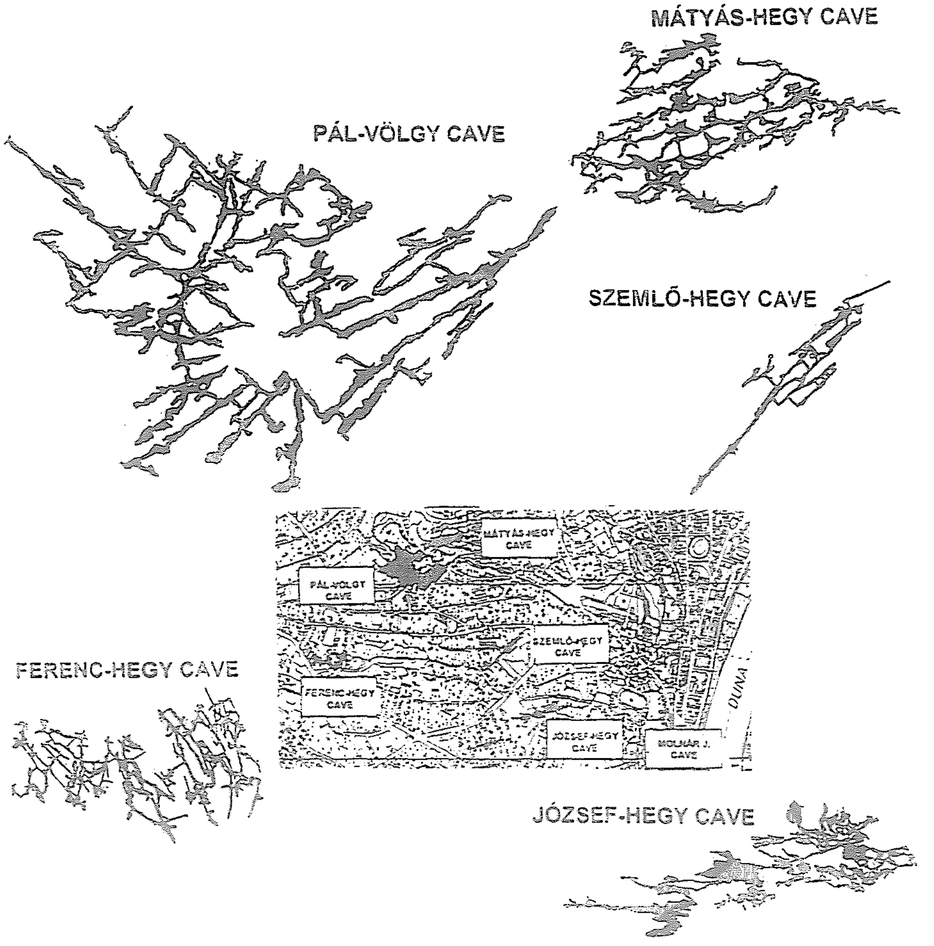

Fig. 2. The setting of the five largest caves on Rózsadomb and their plan view

As a result of dolomitization and later thermal alteration the depositional texture, the peloidic, microoncoidic and laminated algal-cyanobacterial crusts is hardly visible.

Intercrystalline porosity of the micritic, microsparitic dolomite is subordinate. Micro fracture pattern, brecciated zones and the hydrothermally altered pulverized zones determine basically the porosity of the formation.

Mátyáshegy Formation

The rocks of Mátyáshegy Formation only occur in small patches in quarries (in natural preservation area), in caves (Erdőhát-út cave, Mátyás-hegy cave, József-hegy cave, Kis-Hideglyuk cave) and in borehole Vérhalom tér

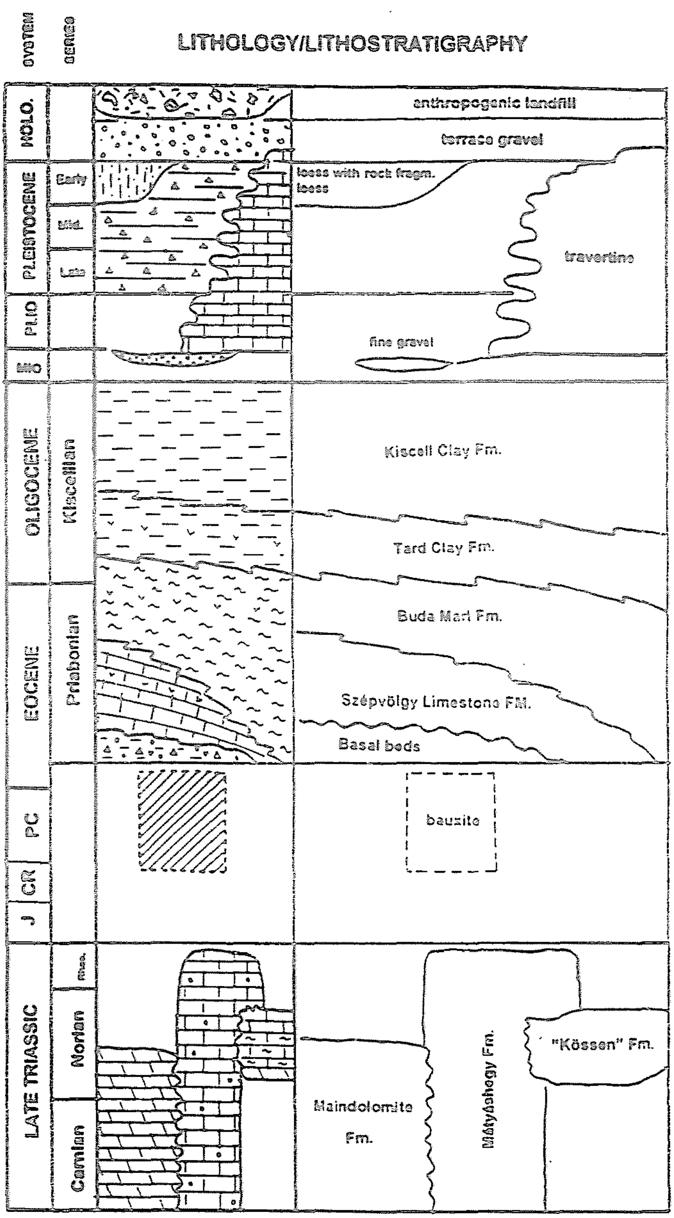

Fig. 3. Lithostratigraphic chart of Rózsadomb area

Table 1

Petrophysical material characteristics of the rock types (data in V%, pure density Mg/m^3)

Sample group	Apparent porosity	Clay minerals	Quartz+ Plagioclase	Pirite+ limonite	Calcite	Dolomite	Organic materials	Specific density
				FRESH WATER LIMESTONE				
Jh-1	3.45				100			2.750
				TARD CLAY				
Kp-1/1	19.58	24.1	18.2	1.6	53.3	2.30	0.4	2.698
L-VII/3	15.43	37.0	21.5	2.6	34.2	3.00	1.8	2.68
				BUDA MARL				
Vh-1/1	7.53	11.9	13.2		73.3	1.7		2.691
L-VII/4	10.52	26.0	18.3	0.6	55.0	0.2		2.681
L-VII/5	10.77	26.7	17.7	1.0	53.0	1.6		2.689
L-VII/6	10.05	14.1	18.9	0.6	64.1	2.4		2.698
Kp-1/2	14.04	26.5	18.1	0.8	52.1	2.6		2.687
Fh-1	11.38	17.6	3.8		78.6			2.688
Fh-2	9.36	12.4	3.1		84.5			2.695
Fh-3	11.38	16.2	4.0		79.8			2.690
Mh-4	14.16							
				SZÉPVÖLGY LIMESTONE				
Vh-1/2	5.62	4.5	8.1		83.6	3.8		2.705
Vh-1/3	3.71	1.1	5.6		93.4			0.706
L-VII/7	7.90	22.4	21.5	9	52.9	2.3		2.691
L-VII/9	3.60							
Mh-2	3.88							
Mh-3	8.92							
				MÁTYÁSHEGY FORMATION				
Vh-1/5	1.83	5.2	7.2	0.3	85.5	1.90		2.780
Vh-1/6	2.37	4.7	8.2	0.8	85.6	0.70		2.714
Mh-1	2.55							
				KÖSSEN FORMATION				
Vh-1/7	5.55	12.1	13.0	0.5	39.2	35.2		2.745
Vh-1/8	8.23	25.3	16.5	1.2		54.8	2.1	2.738
Vh-1/9	5.24	3.5	7.1	0.1	61.0	28.3		2.742
Vh-1/10	6.83	7.3	25.3	0.7	6.1	60.6		2.785

Table 2
Mass distribution parameters of the rock types

Sample group	Apparent density air dry (kg/m^3)	Apparent density saturated (kg/m^3)	Water content (V%)	Water absorption (V%)	Ultrasonic sound velocity air dry (km/s)	Ultrasonic sound velocity saturated (km/s)	Duroskop's rebound ratio air dry	Duroskop's rebound ratio saturated
FRESH WATER LIMESTONE								
Jh–1	2498	2524	0.36	3.09	5.808	6.025	40.3	45.3
TARD CLAY								
Kp–1/1	2219	2232	1.29	18.29	2.300	1.789	22.3	27.3
L–VII/3	2343	2362	1.88	13.55	2.552	2.388	27.6	17.1
BUDA MARL								
Vh–1/1	2440	2509	0.67	6.89	4.177	4.303	33.6	36.1
L–VII/4	2436	2533	0.78	9.74	4.312	4.251	38.6	35.4
L–VII/5	2409	2508	0.91	9.86	4.294	4.186	35.4	38.8
L–VII/6	2409	2502	0.74	9.31	4.293	4.141	39.7	44.4
Kp–1/2	2322	2457	0.51	13.53	3.544	3.110	30.2	29.9
Fh–1	2406	2497	2.28	9.10	3.973	4.093	33.2	33.8
Fh–2	2453	2526	2.11	7.25	3.356	3.800	31.2	31.6
Fh–3	2434	2519	2.83	8.55	2.734	3.366	20.0	23.3
Mh–4	2237	2366	1.31	12.85	3.465	3.139	25.4	24.1
SZÉPVÖLGY LIMESTONE								
Vh–1/2	2521	2573	0.42	5.20	5.435	5.450	38.2	42.3
Vh–1/3	2567	2601	0.16	3.45	6.181	6.244	42.4	50.1
L–VII/7	2466	2540	0.51	7.39	4.791	4.705	38.6	45.5
L–VII/9	2595	2626	0.45	3.15	5.913	5.771	44.6	45.2
Mh–2	2587	2621	0.46	3.42	5.708	5.685	41.4	48.8
Mh–3	2416	2499	0.66	8.26	4.404	4.359	33.7	38.4
MÁTYÁSHEGY FORMATION								
Vh–1/5	2651	2665	0.46	1.37	5.608	6.021	43.1	51.6
Vh–1/6	2624	2643	0.44	1.93	5.864	6.076	44.8	51.6
Mh–1	2632	2651	0.66	1.89	5.452	5.670	43.1	47.8
KÖSSEN FORMATION								
Vh–1/7	2566	2615	0.70	4.85	5.214	5.418	45.4	50.7
Vh–1/8	2513	2586	0.94	7.29	4.786	4.921	42.0	46.6
Vh–1/9	2561	2608	0.53	4.71	5.390	5.494	44.7	52.2
Vh–1/10	2595	2653	0.42	5.81	5.493	5.548	44.7	51.5

Table 3
Strength parameters of the rock types

Sample group	Compressive strength air dry (MPa)	Compressive strength saturated (MPa)	Tensile strength air dry (MPa)	Tensile strength saturated (MPa)	Young's modulus air dry (GPa)	Young's modulus saturated (GPa)	Poisson's ratio air dry	Poisson's ratio saturated
FRESH WATER LIMESTONE								
Jh–1	48.55	30.8	4.52	4.31	24.84	19.61	0.202	0.246
TARD CLAY								
Kp–1/1	30.5	9.9	2.77	0.39	3.8	0.6	0.17	0.33
L–VII/3	27.3	13.2	2.89	0.13	4.6	3.1	0.10	0.43
BUDA MARL								
Vh–1/1	57.6	46.4	5.66	4.13	15.8	13.6	0.23	0.27
L–VII/4	66.1	47.1	5.26	3.30	20.0	15.6	0.25	0.21
L–VII/5	61.4	40.7	5.20	3.14	18.0	14.1	0.23	0.29
L–VII/6	57.7	42.4	6.40	3.06	18.1	15.9	0.21	0.26
Kp–1/2	46.9	24.6	3.99	1.96	11.1	5.9	0.22	0.32
Fh–1	63.3	36.3	5.27	2.64	15.2	10.3	0.38	
Fh–2	68.8	36.0	6.79	2.78	10.3	7.3		
Fh–3	35.5	13.0	4.11	1.50	4.2	2.40	0.32	0.24
Mh–4	30.9	16.9	3.68	1.35	8.99	5.30		
SZÉPVÖLGY LIMESTONE								
Vh–1/2	75.1	66.9	6.13	4.10	29.9	28.1	0.20	0.28
Vh–1/3	95.1	91.6	6.02	5.64	45.4	44.3	0.29	0.29
L–VII/7	88.4	65.1	6.58	5.21	26.2	19.6	0.20	0.22
L–VII/9	98.5	91.6	5.51	6.42	38.4	37.4	0.22	0.20
Mh–2	159.1	141.4	6.26	7.42	42.2	40.4	0.24	0.32
Mh–3	69.3	43.2	5.51	4.62	20.6	17.4	0.21	0.34
MÁTYÁSHEGY FORMATION								
Vh–1/5	116.0	92.8	7.61	7.41	37.2	33.8	0.29	0.29
Vh–1/6	74.7	91.2	6.94	7.55	33.7	40.4	0.31	0.33
Mh–1	98.3	74.6	9.44	5.07	32.4	28.0	0.16	0.28
KÖSSEN FORMATION								
Vh–1/7	65.2	41.8	5.44	5.57	29.3	28.1	0.2	0.33
Vh–1/8	40.4	33.1	5.25	2.73	26.5	13.5	0.28	0.36
Vh–1/9	74.8	50.4	6.31	4.33	34.1	26.8	0.25	0.25
Vh–1/10	66.8	59.7	7.10	4.36	37.9	31.3	0.28	0.25

(Vh–1) (*Fig. 4*). This pale brown limestone is well stratified. The texture is micritic mudstone (wackestone). It occasionally recrystallized to microsparite. The fauna is mainly composed of pelagic, recrystallized bioclasts as radiolarians, furthermore it contains echinoderms, forams and ostracods. Disseminated pyrite occurs. The silica occurs in the rock as a form of both chert pebbles, angular clasts (max. 30 cm in diameter) and silicified zones. The predominantly dolomitic type has a microsparitic texture due to the progressive dolomitization. Bioclasts are partly recrystallized, and only a few echinoid fragments and relict micritic peloids can be observed in the thin sections.

The porosity is very reduced (based on water absorption it is between 1.4–2.5%). In altered zones and along unfilled fractures (Melocco quarry) the porosity can exceed this. But this secondary porosity is genetically related to tectonics and the superimposed karstification.

Table 4
Rheological petrophysical material characteristics

Rock type	Basic-deformation ε_0 L ‰ air dry	Basic-deformation ε_0 L ‰ saturated	Rheological constant (r) 1/h air dry	Rheological constant (r) 1/h saturated
Fresh water limestone	0.018	0.055	4.25	2.57
Buda Marl	0.060	0.266	4.40	3.45
Szépvölgy Limestone	0.056	0.052	2.22	2.12
Mátyáshegy Formation	0.014	0.033	1.70	1.23
Kössen Formation	0.099	0.113	2.05	3.97

The petrophysical properties of the rock are shown on *Table 1–5*. The apparent density and ultrasound velocity of this rock do not show significant increase with depth. Its properties correlate well with the other Triassic compact limestones (*Fig. 5*). It has a Po and Rh jointing system near to the surface and in deeper zones, respectively. Distances of jointing surfaces are varied between 10–15 cm, while RQD value is 65–75.

'Kössen' Formation

There is no currently exposed outcrop of the formation in the Buda Mountains, but borehole Vérhalom tér Vh–1 explored it (*Fig. 4*). The upper part of the core material represents a slope debris with platform derived limestone clasts. Meanwhile the major rock type is a dark grey laminated mudstone/wackestone, which is rich in organic matter and contains pelagic microfossils (radiolarians) and some plant remnants. Larger bioclasts are found in intercalations. The graded, intraclast bioclast packstone/floatstone microfacies of these light grey intercalations are markedly

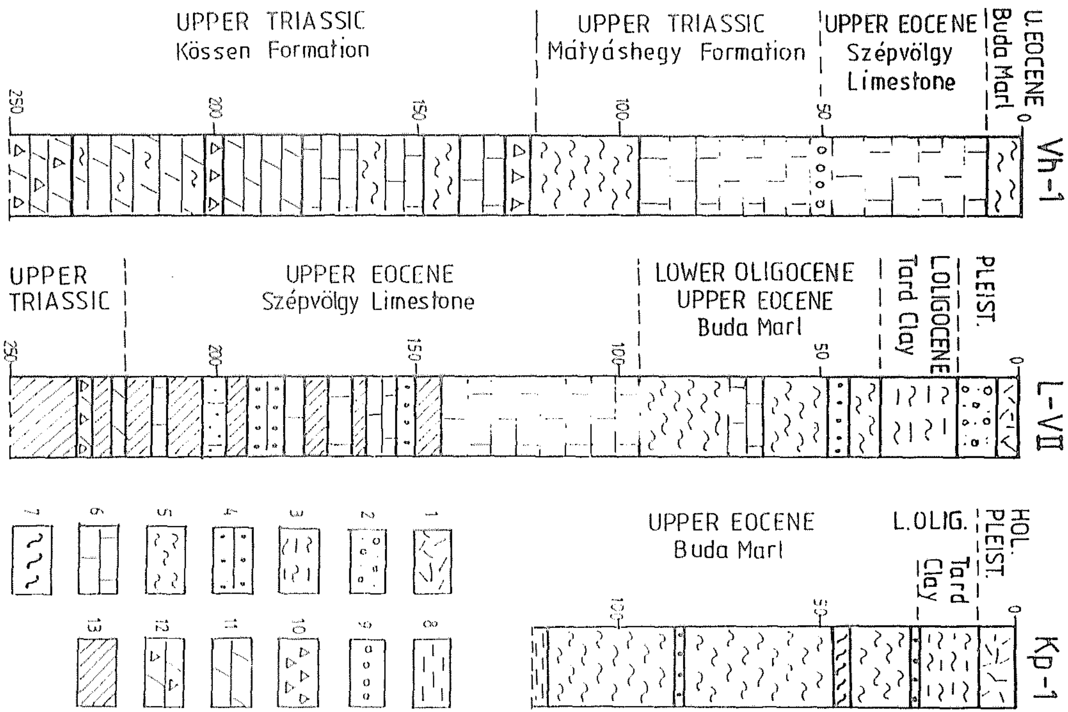

Fig. 4. Lithological and lithostratigraphical log of three recent boreholes of Rózsadomb area (Vérhalom tér Vh-1, Lukács fürdő L-VII and Kapy utca Kp-1) 1. soil and landfill 2. gravel and sandy gravel 3. claymarl 4. sandstone 5. marl 6. limestone 7. slumps 8. clay 9. basal conglomeratum 10. breccia 11. dolomite 12. dolomite breccia 13. no data

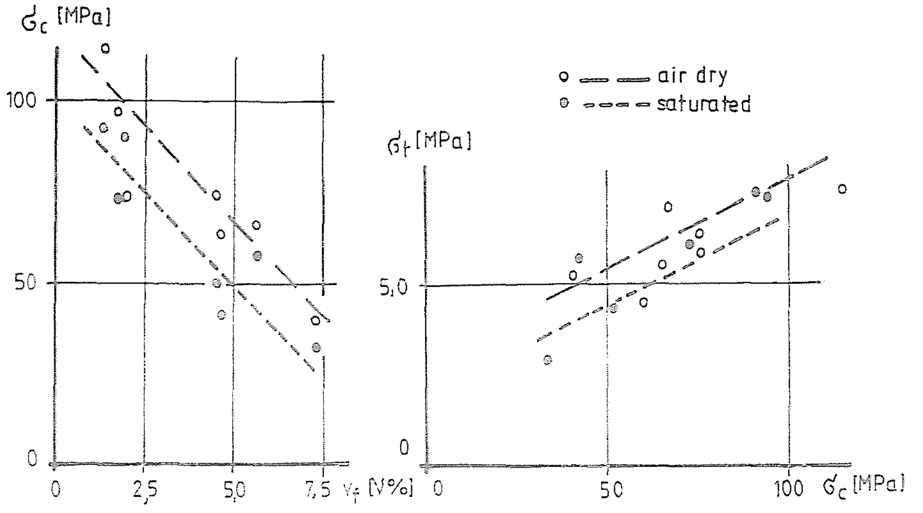

Fig. 5. The relation of compressive strength to water absorption and compressive strength versus tensile strength (Mátyáshegy Formation, 'Kössen' Formation)

different form the mud supported ones of the host rock, i.e they are redeposited ones. The lower part of the section becomes progressively dolomitized downward. Synsedimentary tectonic features as extensional microfaults, and sediment filled dykes are very common (*Fig. 6*).

The porosity (4.0–7.3 V%) is related to the lamination of the rock. The lower, dolomitic part shows an increased porosity due to dolomitization and brecciation. In this zone open or dolomite powder filled fractures are frequent, therefore the rock does not behave as an aquiclude.

Petrophysical properties are shown on *Tables 1–5*. The rocks of Mátyáshegy Formation and 'Kössen' Formation are very sensitive to the influence of water. The compact limestones with saturation lose their compressive strength very rapidly. It can already be recognized even in the case of minimal saturation, which exceeds 1 V%. The measure of decrease may be quite the same in both, air-dry and water-saturated petrophysical states (*Fig. 5*).

The fact that the water saturation causes the proportional deterioration of strength properties is shown at the *Fig. 5* presenting the connection between tensile and compressive strengths.

Its joint system is of Po type and the distance of the jointing surfaces is about 15 cm, while RQD value is between 50–75.

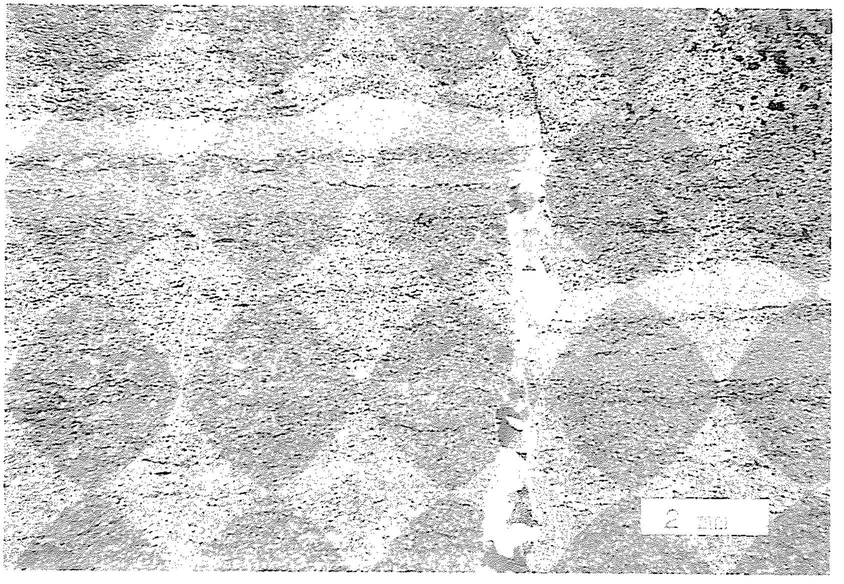

Fig. 6. Microfault which is partly filled with sparitic calcite in laminated microbioclastic wackestone (thin section photograph, Upper Triassic, Vh–1 borehole, 137.8 m, +N)

3.2. Eocene

Basal Conglomerate, Basal Breccia, Triassic-Eocene Contact

Layers of basal conglomerate and breccia can be found in the surroundings of Triassic outcrops and were exposed in boreholes (Vérhalom tér Vh–1 and Lukács-fürdő L–VII) (see *Fig. 4*). It is thick bedded, consisting predominantly of local clasts (Triassic dolomite, limestone and chert), with subordinate extraclasts (altered volcanites, quartzite) (FODOR and KÁZMÉR 1989) (see *Fig. 3*). It contains large blocks of the Szépvölgy Limestone occasionally. The Basal Conglomerate in Vérhalom tér (Vh–1) borehole is well cemented by micrite. Its porosity is 2.5 V% based on water absorption and water content. On the surface breccias, which overlay Triassic strata, have more significant porosity.

Szépvölgy Limestone Formation

Its outcrops are found in tectonically elevated blocks, which were quarried in several places in the past decades. It forms stable rocky surroundings for foundation and structural construction. It was also recovered by several

Fig. 7. Well cemented Discocyclina-Nummulites floatstone microfacies of Eocene Szépvölgy Limestone (thin section photograph, Vh–1 borehole, 21.8 m, +N)

boreholes (see *Fig. 4*). This is the major host rock of the extended cave system (see *Fig. 2* and *Fig. 3*).

The limestone is light grey or yellow if altered. It is thick bedded and its main components are forams (Nummulites, Discocyclina) (*Fig. 7*) and corallinacea algae, bryozoans and echinoids and their sand sized fragments. Planctonic fossils (globigerinids and radiolarians) are less frequent. The microfacies analysis well documented the deepening upward character of the formation, showing a transition from shallower microfacies types (Corallinacea, Nummulites, Discocyclina, echinodermata packstone, coral boundstone and echinodermata grainstone-packstone) toward the deeper facies zones of (Discocyclina, Nummulites floatstone-wackestone). The latter one clearly indicate the redepositional processes. Synsedimentary listric faults were recognized in Pál-völgy cave (N–S).

The present porosity of the different Eocene limestones is inverse to that of the depositional one. Namely the well sorted calcarenites had a larger depositional pore size, than the foraminifera floatstones, but as a result of cementation and infilling of inter-granular pores the original porosity pattern was changed. The greater porosity of micrite supported rocks is related to clayey solutional surfaces resulting 7 % porosity, which is well over the 3–5 % of the cemented calcarenites. Porosity of the altered spongy rocks found on the cave walls, may increase significantly (12–33 V%).

The petrophysical properties of the rock are shown on *Table 1–5*. The surface-near variations of this limestone show a lower apparent density. With increasing overburden these values are in the range of compact limestones. Variation of apparent density and ultrasound velocity may be observed depending on the depth (*Fig. 8*). The compact limestones from 30 m depth have already an apparent density of 2.6 Mg/m^3.

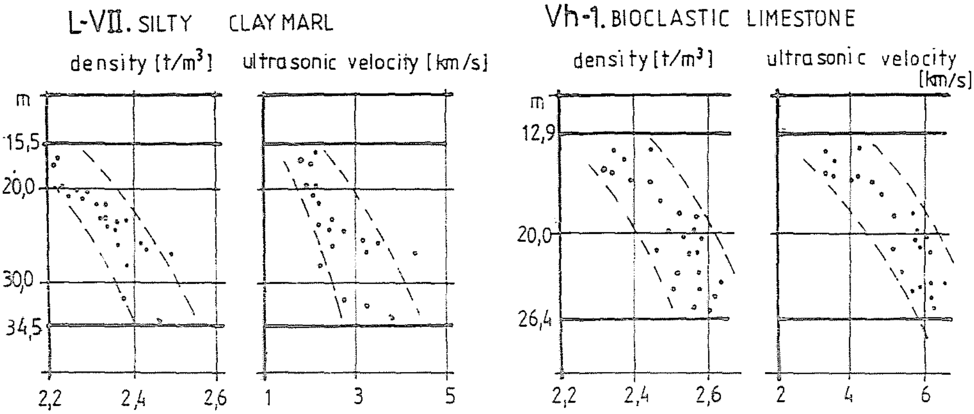

Fig. 8. The apparent density and ultrasonic sound velocity as a function of depth, Tard Clay and Szépvölgy Limestone

The saturation water-content of the rock type is high enough in comparison to other similar limestones, perhaps due to the cemented bioclasts of various sizes. With decreasing saturation primarily the strength parameters measured in a water-saturated state increase. *Fig. 9* shows the interdependence of compressive strength and saturation water-content, proving, that the compressive strength of rock types with low saturation capacity may be hardly influenced by water. The interdependence between compressive and tensile strength shows only in a water-saturated state an unambiguous regression. An increasing compressive strength results an important increase of the tensile strength (*Fig. 9*), too.

Jointing system near to the surface and fault zones is of Po type, while in the subsurface zones it is Rh type. Average distances of jointing surfaces are 15–20 cm. RQD value is between 5–50, depending on the fracturation.

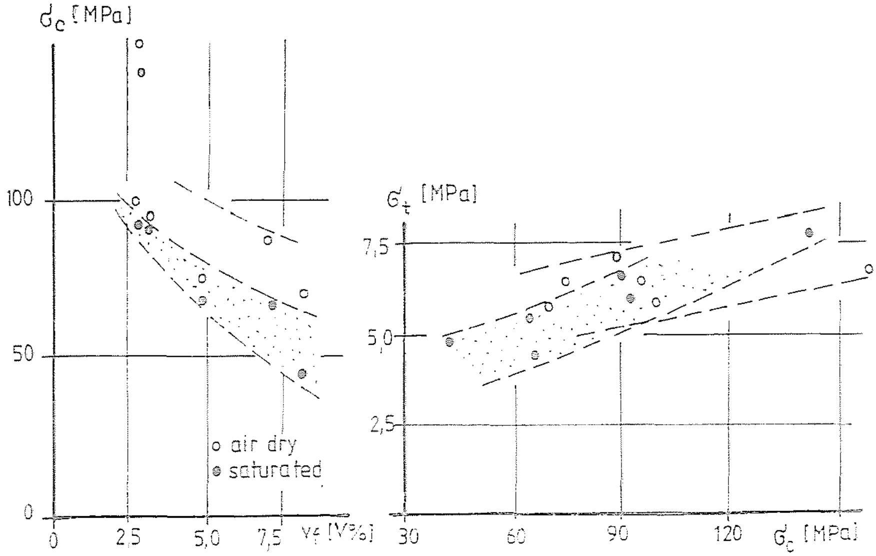

Fig. 9. Compressive strength as a function of water absorption (to the left) and compressive strength versus tensile strength (to the right) (Szépvölgy Limestone)

3.3. Eocene-Oligocene

Buda Marl Formation

The formation covers the greatest part of the Rózsadomb area (see *Fig. 3*). It is exposed by caves and boreholes as well (see *Fig. 4*). The rocks are yellow on the surface, and grey in the cores. It is well bedded. It contains variable amount of clay (10–30%) and carbonate (50–80%) material and a small amount of angular quartz grains. Intercalations of thin often graded siliciclastic layers and volcanic sands occur. Calcareous turbidite beds with redeposited bioclasts of shallower water origin are common. The Globigerina wackestone microfacies represents an open and deeper outer shelf formation (KÁZMÉR, 1985) while the Bryozoan packstone-floatstone (*Fig. 10*) indicates a shallower outer shelf environment with frequent turbidite events. Slumps are also relatively frequent in the sequences (see Kp-1 borehole 44.0–45.7 m in *Fig. 4*).

Its porosity is higher than that of the limestone with values ranging between 8–13 V%. This recent porosity is related to bedding parallel solution seams and intercalations. Meanwhile the significant permeability is merely attributable to the open fractures, which were observable both in the surface outcrops and in the caves. The altered marls of caves and bore-

Fig. 10. Large bioclasts in clayey Bryozoan wackestone. Note the presence of quartz grains and pyrite (thin section photograph, Buda Marl, L–VII 97.3 m, +N)

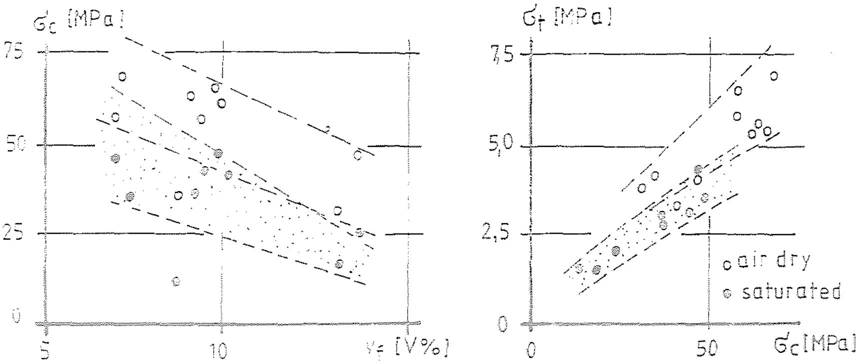

Fig. 11. Compressive strength as a function of water absorption and compressive strength versus tensile strength (Buda Marl)

holes (Kp–1 borehole) also demonstrate a major increase in porosity similarly to altered limestones.

Petrophysical parameters of the rock are shown on *Tables 1–5*.

The apparent density is depending on the clay content of the matrix and the frequency of bioclasts. Thus it appears to be less dependent on depth, but the differences following the stratification are observable. The porosity of greater pore sizes causes a low density, appearing also in the modest values of the ultrasonic sound velocity. With the increase of water absorption the strength properties become worse, which is well documented by the increase of compressive strength with decreasing water absorption (*Fig. 11*).

The rock types of the Buda Marl are very sensitive to water. The function shown at *Fig. 11* represents well that for tensile and compressive strength the behaviour-marking points take separate fields for air-dry and for water-saturated specimens.

The surface-close, altered layers of the Buda Marl can be represented by soil physical parameters, in an engineering geological evaluation. The identification parameters of the yellow, altered, argillaceous, debris-bearing marl are:

apparent density (kg/m^3)	2050±107
liquid limit (%)	58.6±10.5
plastic index (%)	31.3±8.1
index of consistency	1.25±0.17
void ratio	0.62±0.18

strength parameters:

compressibility modulus (MPa)	13.3±7.7
coefficient of friction (tgΦ)	0.328±0.107
cohesion (kPa)	111.1±56.2

Jointing system of the surface-close Buda Marl is of Pr, while in the cores it is of Eq type. Distances of discontinuity surfaces are 5 and 10 cm.

Its good natural stability decreases, when it is contacted with water. Rheological investigations showed a very slow creep. Foundation pits and deep garages often expose it. Previously it was quarried, the more solid beds are still used in the area.

Oligocene Clays (Tard and Kiscell Clay)

In the elevated zones it only occurs in smaller patches on the surface and covers larger areas in morphologically deeper valleys. Tard Clay evolves from the underlying marl with the gradual decrease in carbonate content. Typically it is a grey and rhythmically laminated clay. Synsedimentary slump structures are common. The rock is rich in organic matter and in pyrite.

These clays are generally considered to be significant aquicludes. However in some outcrops it contained micro fractures, perpendicular to the lamination. These may have served as minor conduits. They become importantly plastic through water absorption. The surface-near layers of the rock type show a less important apparent density. This density increases with depth in a very important manner to the limit state, equal to the compactness, which is adequate to the self-weight loading. This change may be followed through the changes of ultrasonic sound velocity, too (*Fig. 8*).

The surface-close, altered types of the Oligocene clay may be evaluated by soil physical parameters. The identification parameters of the yellowish-grey clayey type are:

apparent density (kg/m^3)	2020±100
liquid limit (%)	58.3±8.6
plastic index (%)	32.5±7.2
index of consistency	1.17±0.12
void ratio	0.66±0.11

strength parameters:

modulus of compressibility (MPa)	12.5±4.0
coefficient of friction ($tg\Phi$)	0.321±0.107
cohesion (kPa)	132.6±64.6

Tard and Kiscell Clays were quarried from the mid 1800's at several sites, which changed the natural environment in the area. Carrying capacity and stability of the clayey marls and clays are good in natural conditions, but they are sensitive to water. When they are soaking wet, they are movement prone.

3.4. Quaternary

Freshwater Limestone

It occurs in small isolated patches and serves as an important indicator of ascending thermal springs and related cave occurrences (KRIVÁN. 1986). They are found in three morphological levels (90–100, 160–190 and 200–230 m asl.) representing the uplift of the region and the related downward shift of thermal springs. The limestone is a greyish yellow, well cemented macroporous type. In the bedded types, the pores are parallel with the stratification. The pores are only partly filled by yellowish micrite or sparitic calcite, they are mostly open.

Petrophysical properties of the rock are shown on *Tables 1–4*. The massive types were quarried in the past and the part of the blocks were removed or dissected. At Rókus Hill the blocks slid down on the slope, where the underlying clay has soaked. Nowadays the dissected blocks rather impede building earthworks, than form stable basements. Travertines have an important role in the prediction of unknown cave passages.

Fig. 12. Atectonically folded blocks of Eocene Buda Marl due to Pleistocene frost induced creeping

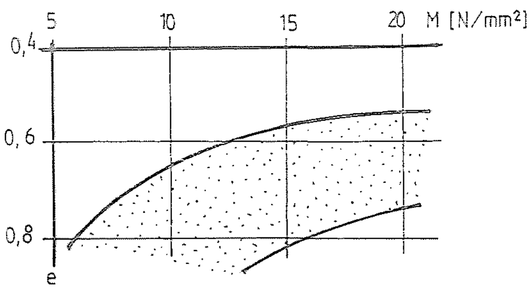

Fig. 13. Correlation of compressibility modulus (M) and void ratio (e) (Pleistocene-Holocene clay)

Clay, Clay with Marl and Limestone Debris (Regolith)

The largest part of the differentiated surface is covered by clays of different origin, marls, clays with slope debris or silt (regolith) of Pleistocene-Holocene period. They are generally 0.5–2 m thick (rarely 10 m), yellow or brownish yellow layers. They are considered to be the altered, loose weathered products of Buda Marl on the western slopes or Kiscell and Tard Clay on southern and eastern slopes of Rózsadomb and can be treated as soils in the engineering practice. Presence of atectonically folded and displaced blocks of marl of variable size is common (*Fig. 12*). As a result of the tundra frost slow creeping characterizes the area (KRIVÁN, 1986). This, especially on the western part, where the bedrock is impermeable clay, causes stability problems in buildings. The clay content and its composition is very variable therefore its mechanical properties also vary:

compressibility modulus (MPa)	12.0±4.8
coefficient of friction (tgΦ)	0.348±0.119
cohesion (kPa)	81.2±58.2

The variation of the modulus of compression takes a very large interval, but shows well that the more compact, more consolidated variations are susceptible to a less important settlement (*Fig. 13*).

The near surface layers of Buda Marl, Tard and Kiscell Clay often become loose as a result of freezing and dissolution, and it is difficult to differentiate them from the unaltered bedrocks. Nevertheless it would be important in solving engineering geological problems, because these heterogeneous layers, which have already lost their original structure and stability are prone to movements, sensitive to water and often serve as the base levels of foundations. It frequently contains laminated marly detritus, but m^3 size blocks may also occur. Besides its heterogeneous structure, water sensitivity can cause problems.

Loess, Loess with Slope Debris

At present this 3 to 5 m thick wind-blown sediment is rarely exposed on the area because of the common building cover. It may overlie Buda Marl, Kiscell Clay and travertines as well. It does not possess the original, macroporous texture, but it is usually atypical since it is clayey and contains marl clasts as well as other slope detritus. However, its vertical permeability is still good. When the underlying clays soak, it can be dangerous for stability.

Terrace Gravel

The lowermost terrace of Danube (terrace I) is an elevated zone of the present flood plain. This is a wide area on Pest side, and can also be well recognized on the foothills at Buda side. Due to urbanization this level was filled up with debris and levelled. On the area this urban landfill forms an elevated zone in a thickness of a few metres. These coarse sands and gravels of fluvial origin are important aquifers.

Anthropogenic Landfill

At the eastern and south-southeastern foot of the Rózsadomb large territories are found, where the thickness of the human landfill exceeds 2 metres. In Melocco quarry the landfill is much thicker (5–10 metres) and composed of clay and detritus of building materials and slag. The highly heterogeneous landfill, concerning its porosity, solidity and thickness, causes problems in civil engineering works. It can also cause environmental contamination, because the polluting materials may spread over by the ground water and karst water system.

4. Structural Geology

4.1. Description of the Major Structures

The oldest tectonic phase in Buda Mountains is the Late Triassic synsedimentary extensional phase, which was first recorded here in the basin sediments of Vérhalom tér (Vh–1) cores (see *Fig. 6*). This phase was followed by the folding of Triassic cherty limestones and dolomites. These folds can be explained by a Middle Cretaceous deformation.

In the geomorphologically elevated Ferenc Hill displacement zone (Balogh Cliffs, Ferenc Hill, Szemlő Hill) the Triassic carbonates and Eocene limestone were laterally displaced relative to each other.

The dip directions of Eocene carbonates are variable. Their general dip is to the SE but on the basis of different dip directions several synclines and anticlines with NE–SW directed axes can be detected. The angle of the dip varies between 6° and 40°–60°.

Besides the recorded synsedimentary folds in the cores further folded beds have not been found neither in the Szépvölgy Limestone nor in the Buda Marl. Complex and variable dip directions are characteristic features of the displacement zones.

The microtectonic measurements of the outcrops and caves have shown that multiphase faults, dextral and sinistral strike-slips, reverse faults and low-angle faults are detectable on the area. The structural elements of the five major caves are shown on a series of maps, see one example on *Fig. 14*.

Significant jointing, fractures, fissures generally have steep dips and have an important role in cave collapse and also may be dangerous for buildings. Thus structural properties have an important role in engineering geological questions.

The frequent rejuvenation of faults and the often controversial displacements are evidenced from the different orientations and superimposed

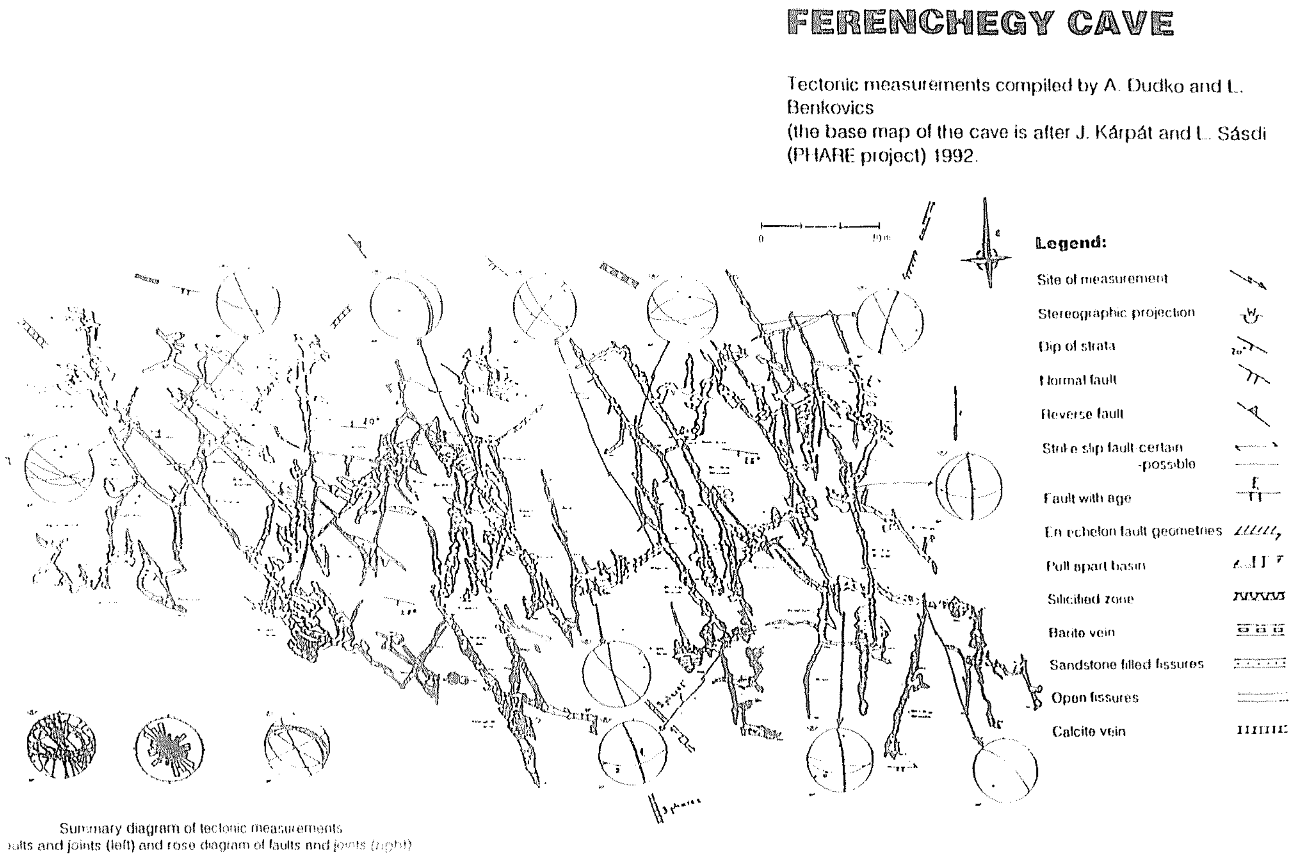

Fig. 14. Tectonic measurements of Ferenc-hegy cave showing the major tectonic structures

lineations on the same fault plane (Kis-Hideglyuk cave, Mátyás-hegy cave, József-hegy cave).

In Kis-Hideglyuk cave a dextral slickenside was overgrown by calcite on a fault plane on which an oblique sinistral slickenside was observed. The calculated compression (NE–SW direction) of the later lineations is contrary to that of the dextral one, i.e. it refers to a younger, second phase displacement. The karstic infilling of fractures, calcite, barite fissure fillings and the siliceous zones signify that all the fractures became open, i.e. the deformation stress field changed in that time.

In the zone of Ferenc Hill and Szemlő Hill, which we call 'Ferenc Hill strike-slip' zone, we also recorded dextral displacements. From the west (from Balogh Cliffs) to Ferenc Hill the distribution of rocks show a 'right-directed step', i.e. the zone of Balogh Cliff and Ferenc Hill is considered to be a push-up structure. Within this zone block motions with different scale displacements were recorded.

After this dextral displacement, a sinistral pull-apart structure could have developed in a NW–SE extensional regime, which resulted the formation of the perpendicular faults. The silicification took place along these altered zones and furthermore the ascending thermal waters could dissolve the cave rooms along these faults.

In the region of Mátyás Hill and Pál-völgy the fractures also suggest a multiple phase deformation but the control of bedding planes appears to be important, too, meanwhile the major controlling factor is still the dextral strike slip. The passages in Pál-völgy cave are arranged in two directions in accordance with the fault geometry; in the NW part of the cave they are mainly NW–SE-directed, while in the SE part the ENE–SSW-directed passages are dominant. Thus in this region it was also the tectonics, what has the major role in the preformation of cave passages.

We could identify the third deformation phase in several caves and outcrops (Apáthy Cliffs, Bimbó út, Pál-völgy quarry, Szemlő-hegy cave, etc.), and especially in the fracture zone of Lukács fürdő.

4.2. Tectonic Phases

With the structural analysis of Rózsadomb area we clarified the major tectonic phases which reflect multiple displacements with the rejuvenation of some of the faults. The present structure is mainly characterized by strike-slips rather than by faults. The most significant structure is the Ferenc Hill dextral strike-slip zone with a very complex built up. In this zone both the compressional (push-up) and the extensional (pull-apart) structures are present, furthermore at its eastern part we also recognized signs of sinistral displacements.

The structural elements of the multiphase displacements and especially the pull-apart related tension fractures had an influence on the formation of caves (*Fig. 15*). It is well documented in three major caves, in Ferenc Hill, József Hill and in Szemlő-hegy caves. The most important bedding control can be detected in Pál-völgy and in Mátyás-hegy caves (*Fig. 15*). The NNW–SSE directed fault system of Lukács fürdő and Molnár János cave is related to the latest tectonic phase according to its direction, although we cannot entirely exclude the rejuvenation of older faults.

To date the tectonic phases we have to take into account the regional structures as well. In the first phase the compressional (FODOR et al., 1991, 1992) and extensional faults and fractures were formed in the Late Eocene – Early Miocene. The second phase in the Miocene was characterized not only by ESE–WNW-directed extension but related compression, too. In the Quaternary the differential uplift resulted the rejuvenation of faults (E–W margin faults, gravitational slides) and the formation of faults in a N–S compressional regime (*Fig. 16*).

5. Geological Evolution

The Upper Triassic carbonates represent three major facies types which are considered to have been isopic and heteropic ones: 1) dolomitized platform carbonates (Hauptdolomit), 2) open shallow self; cherty limestones and dolomitized limestones with pelagic and redeposited, platform derived, bioclasts (Mátyáshegy Formation) and 3) a periodically euxinic basin; laminated marls with intercalating thin distal calcareous turbidites. The sedimentation in the basin reflects a strong tectonic control, i.e. synsedimentary extensional faults (domino faults, listric faults, micro reverse faults), the sediment filled extensional cracks and large platform derived clasts of the slope breccia suggest a basin setting with relatively steep margins (*Fig. 17*). There is no known evidence of younger Mesozoic sequences since the Triassic was followed by a long subaerial erosional phase. In the geological record it is documented by the karstified surfaces and overlying bauxitic clays.

The transgressive deepening upward Eocene sequence starts with a coastal (breccia) to marine (conglomerate) series (FODOR and KÁZMÉR, 1989). The following limestone (Szépvölgy Limestone) represents a shallow subtidal deposit with isolated shoal bars (bioclast grainstones/packstones) back shoal Corallinacea algae sands and slightly deeper Nummulites-Discocyclina wackestones/floatstones. In the deeper facies zones marls

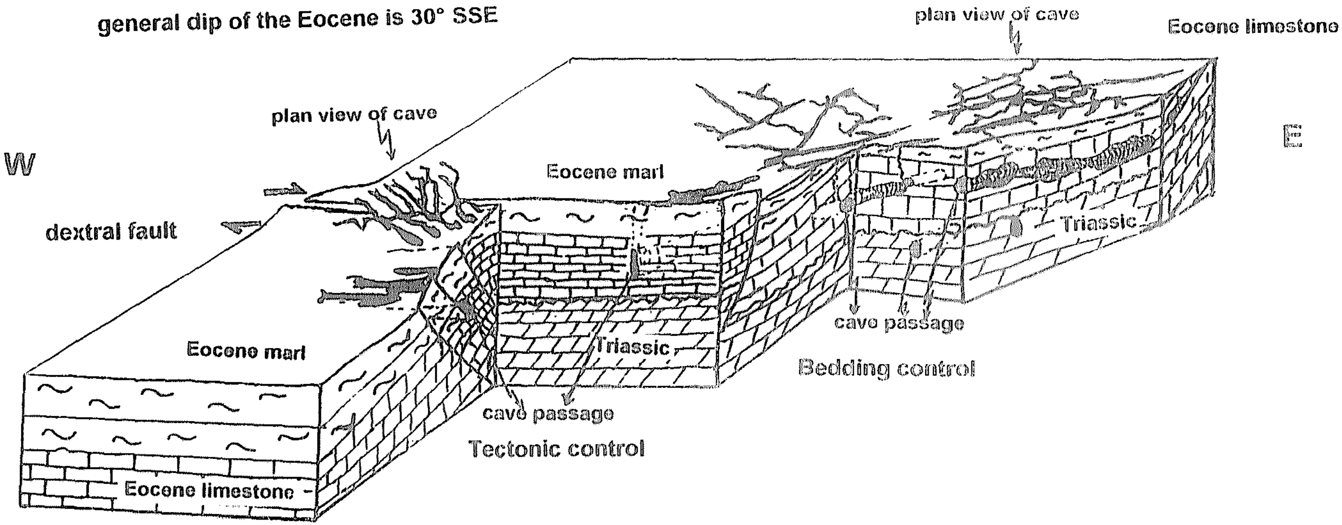

Fig. 15. Simplified 3D model of the cave system showing the tectonic and bedding control of cave formation

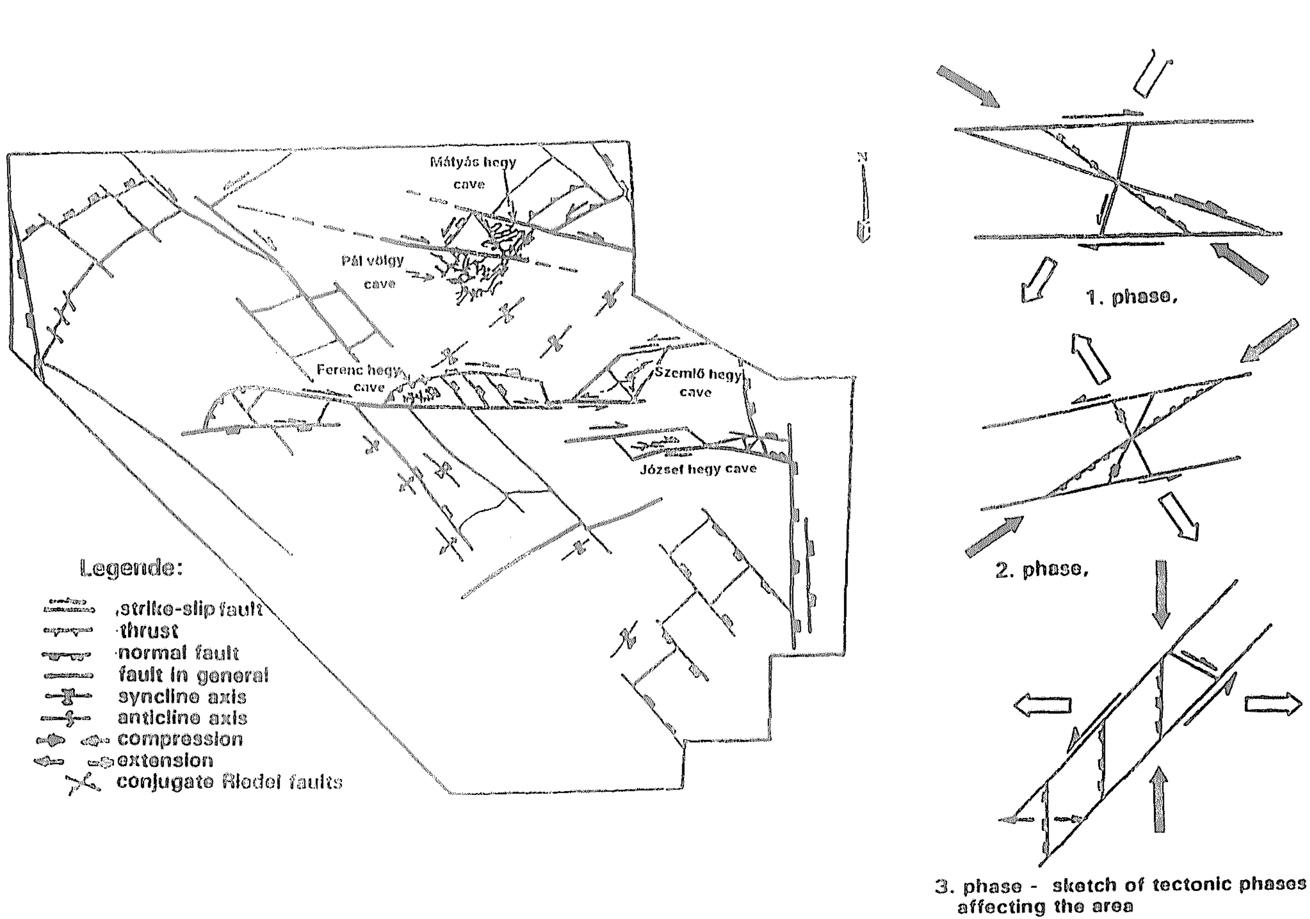

Fig. 16. Structural sketch of the Rózsadomb area and the major tectonic phases (BENKOVICS, DUDKÓ)

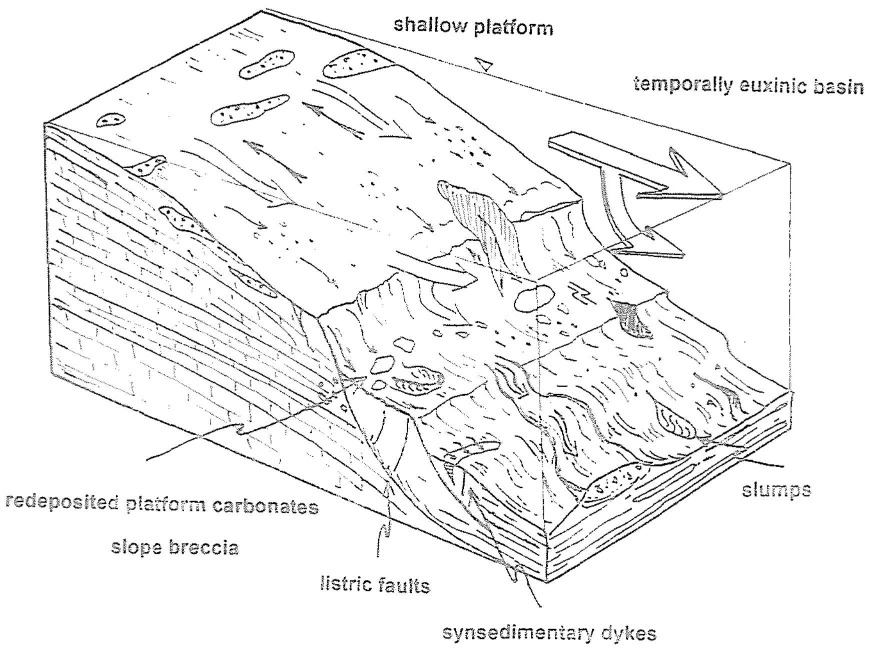

Fig. 17. Summary diagram of Late Triassic facies zones and related synsedimentary tectonics

with benthic and pelagic bioclasts were formed (Buda Marl). Slumps and the redeposited shallower bioclasts (Nummulites) mark the dynamics of the depositional environment as well as reflect the synsedimentary tectonism (*Fig. 18*). With decreasing carbonate input the Oligocene clays (Tard and Kiscell Clay) evolves from the Eocene corresponding to the restriction of the depositional environment. The periodic euxinity is well documented by the occurrence of organic rich, pyritized clays. From the Miocene onward the area was uplifted and only minor sedimentation occurred. In the Plio-Pleistocene the increased thermal activity and water discharge is marked by the occurrences of fresh water limestones of spring origin. This was the major phase of cave formation dissolution which still continues at present in a decelerated way. Pleistocene glaciation is documented by loess and solifluctional features while post glacial and present terrain formation is related to fluvial (Danube) and neotectonic process.

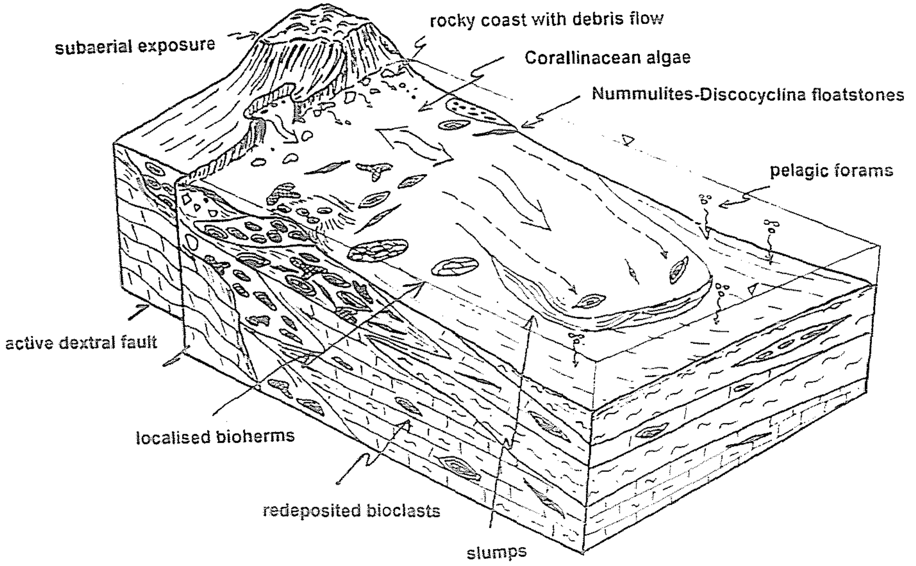

Fig. 18. Summary diagram of Late Eocene facies zones, related synsedimentary tectonics and early paleokarst

6. Porosity Evolution and Karstification

Primary porosity of the Triassic rocks was minor. Combined fracture pattern of different tectonic phases created its secondary porosity, which are significant permeable pathways. During the early phases of karstification related to the Triassic-Eocene unconformity, older fractures were solutionally enhanced and cavities were dissolved, total porosity of the system increased. Sediments of the Late-Eocene transgression and shallow burial diagenesis decreased previous permeability of the Triassic carbonates. Fractures and cavities were mainly cemented, infilled, or collapsed. Total porosity of the Triassic karst system decreased during this phase.

The primary porosity of Upper Eocene shallow marine carbonates was already cemented in an early diagenetic stage (see *Fig. 7* and *Fig. 10*). However, Late-Eocene syntectonic fractures may have created conduits. During Oligocene burial (200–300 m thick clay cover), permeability of Triassic-Eocene carbonates decreased significantly (burial cementation, pressure solution related porosity decrease). Meanwhile extensional tectonics during the deposition of Kiscell Clay created combined fracture pattern, which possibly was an important conduit system for thermal fluids.

Most important phase of porosity evolution of Triassic-Eocene carbonates in the area took place in the Plio-Pleistocene. As a result of mixing of descending cold karst waters and the ascending thermal waters in the spring zone caves were formed (MÜLLER and SÁRVÁRY, 1977, KOVÁCS and MÜLLER, 1980, MÜLLER, 1989). These solutional processes in the meteoric, mixing and deep zones resulted significant enlargement of the fractures and the development of hydrothermal caves (see *Fig. 2*). Besides the cave morphology the speleothemes also suggest thermal origin (NÁDOR 1992). Botryoids and bunches of gypsum crystals are the nicest examples of that origin. Furthermore the present cave morphology also shows the signs of recent karstic processes, which is well documented by the formation of stalagmites and stalactites. The cave passages are mainly tectonic controlled although in some caves they follow the general SE dip of Eocene carbonates (see *Fig. 15*). There can be found a correlation between the caves and the different levels of freshwater limestones, i.e. caves and base levels of karstic discharge (springs) (SCHEUER and SCHWEITZER, 1973, 1988).

From the four major phases of karst evolution (Triassic-Eocene unconformity; Eocene early palaeokarst; high temperature Oligo-Miocene thermal karst; and Plio-Pleistocene low temperature karst) the Pliocene-Pleistocene phase had the major role in the formation of cave system of Buda Mountains.

7. Petrophysical Evaluation

7.1. Role of the Petrophysical Parameters in the Description of the Rock Types

The rocky surroundings of the buildings and technical constructions as a rock mass in interaction with these structures may be characterized by their petrophysical and soil physical properties. The evaluation of the interaction and through it the prediction of the estimable behaviour may be connected with the space elements of the surroundings, being aware of several material properties and material characteristics.

In the engineering geological model-based evaluation system of the rocky surroundings the basis is given by the three-phases rock model, in which the solid, liquid and gaseous material is continuum-like filling of the rock's space. The actual properties are determined by the actual petrophysical state of the rock (GÁLOS and KERTÉSZ 1990).

The underground cavities must be considered as separate space elements, where the behaviour types may be governed by the dynamic interaction of cavity and surroundings.

7.2. Petrophysical Evaluation of the Rock Types

The changes of phase-relations in a three-phases rock model appear in a different manner, because above the hydrostatic pressure in the pore-water a structural change may also occur in some rock-forming minerals, mainly in clay minerals. The saturated petrophysical state takes place as a result of the saturation process. In *Fig. 19* the saturation curves of the Buda Marl and the Szépvölgy Limestone show the characteristics of the process. The saturation process of marls can be a very long one, similarly to the compact limestones, although there are differences in the porosity system and the rock forming minerals.

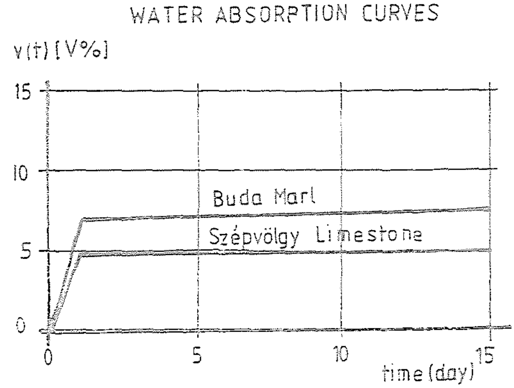

Fig. 19. Water absorption curves of Eocene carbonates

The rock types of the Buda Marl are exceptionally sensitive to water. *Fig. 20* shows the sensitivity factor of the uniaxial compression strength versus apparent porosity. The apparent porosity of these porose rocks is 5–15 V%, and its compressive strength falls at 10 V% porosity to its half/third value.

The apparent porosity of the rock types of Szépvölgy Limestone may be less high, the test results give an apparent porosity of 10 V%. *Fig. 20* representing the water sensitivity proves that the compressive strength of rocks of about 5 V% apparent porosity does hardly present a decrease; the sensitivity factor being 0.9–1.0. The greater porosity results in an important property-change: the sensitivity factor of strength parameters decrease to 0.7–0.5.

The scale of property changes due to water is a very important factor while evaluating the behaviour of rocks from rocky surroundings of natural caves. The deteriorations due to saturation of rock types result a decrease of original strength properties and may start local failures in the vicinity.

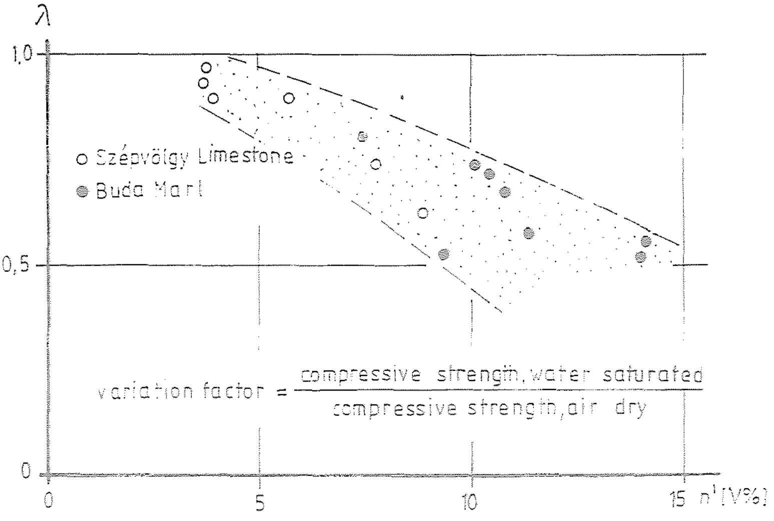

Fig. 20. Variation factor of compressive strength versus apparent porosity

The rheological behaviour of the rock types may be represented by the rheological parameters. The creep tests, executed on a constant stress level represent the whole process on our diagram, starting from the initial state (*Table 4*).

The basic deformation as well as the rheological constants of the Buda Marl rock types are enough high, showing a creep process of long durability. These rock types are susceptible to an important deformation. This phenomenon is related to high clay minerals content.

7.3. Petrophysical Characterization with Joint Values

The jointing parameters of the rock types may be seen for each sample group from the drilling core evaluation (*Table 5*).

In the knowledge of the jointing parameters the classification of the rock bodies becomes possible by the Q factor of Barton, as well as by the RMR value of Bieniawski. Barton's Q factor divides a parameter being a product of the RQD value, the fissure roughness, and the effect of water moving in them with the product of parameters characterizing the number of fissure groups, the displacement of them and the impact of the weakened zones.

Following the *Table 5* the Q values are: Tard Clay 9, (medium blocky, stratified), Buda Marl 24 (strong, stratified, disfoliating), Szépvölgy Limestone 45, (strong, homogeneous, lightly fractured), rock types of the Mátyáshegy and Kössen Formation 142–125 (strong, massive). The Q value represents 4–10 when 'medium', 10–40 when 'good', 40–100 when 'very good' and over 100 when 'extremely good' quality for a rock body (IAEG 1981).

8. Engineering Geological Evaluation

As it was shown in the geological description most formations are considered to be as stable ones (*Tables 1–5*), although the topmost layers are often less favourable in the sense of stability.

8.1. Groundwater System

Geological and morphological conditions determined groundwater patterns, subsurface water mainly occurs at the eastern, southern and western margins of the area. Continuous groundwater is mainly characteristic at the former fluvial plain along the Danube, where sandy sequences with pebbles store water. On the other areas groundwater occurrence is related to the clayey layers of Tard and Kiscell Clays and Buda Marl. There it can have a significant sulphate content especially next to the Tard Clay. Those areas, where there is no subsurface groundwater are built up of karstified rocks, or rocks with open fissures, where infiltrating waters feed directly the karst water.

8.2. Geology of the Building Areas

When we qualify the building areas besides the natural conditions, appropriate execution of the buildings, presence of public utilities (water, sewer, roads) and their technical condition, their probable breakdown are also important factors to be considered.

In the Rózsadomb area on gentle slopes and in the valleys one- or two-storey buildings, their outbuildings, garages and retaining walls have their foundations in the near-surface loose, weathered, or redeposited rocks. Because of the improper foundations, a lot of retaining walls, enclosures and outbuildings cracked and sank.

Morphological conditions have an important role in the road hazards. Freezing hazards of roads related to the decreased stability of the underlying layers, and the presence of clays. Pleistocene or Oligocene clays or weathered parts of the Buda Marl are partly composed of swelling clays. Furthermore in most cases the roads are the main drainage lines during rains. Besides the aging of pavements the insufficient compaction of communal pipelines and the cavity-formation due to seepage can cause damages.

8.3. Slope Stability

The geological buildup and the morphology make susceptible several slopes to mass movements, after an initiating impact, as wetting or excavation occurs. The first engineering geological investigations of this area were begun in the 60'ies from this point of view. In 1973, during a general overview on mass movements a general and regional analysis were carried out in Budapest.

In 1986, the Municipal Council of Budapest in its regulations 5/1986 BVSZ (in the Budapest Regulation of Townplanning), delineated the landslide-hazardous zones and published the regulation for building activity (*Fig. 21*).

On the basis of this, constructional activities can only be carried out on landslide-hazardous areas on the basis of special geotechnical survey.

This current study showed that the previous deteriorations were repaired in several cases, but some new fissures were also observed on retaining walls and masonries. The overwhelming part, the several years old, unprepared deteriorations were still observable and can be related to creep processes (see *Fig. 12*, *Fig. 22*).

From the beginning of the seventies, a shortage in precipitation is characteristic, which resulted a relative stability of slopes. Meanwhile with an increase of precipitation we can expect the renewing of landslide activity.

8.4. Cavity Problems

Several caves have been discovered since the thirties, especially as a result of building activities.

The József-hegy cave was discovered in 1984 during the constructional works of a housing estate, i.e. in the foundation pit. The protection of the natural value, and the security of the planned settlement required detailed engineering geological investigations (SZENTIRMAI et al, 1986, SZÖRÉNYI, 1986).

These analyses gave the basis for a temporary building rule (1986), dividing the Rózsadomb area into 3 building areas (*Fig. 23*).

The greatest part of the caves are found in Szépvölgy Limestone, but some of the passages are stretching up to the Bryozoan and Buda Marl Formation in several tens of metres (*Fig. 24*). The cave passages

Fig. 21. Hazards of landslides and the damage of buildings in Rózsadomb

Fig. 22. Landslide and following creep displaced and fractured concrete seats at 'Vasas' sports ground

are tectonically preformed and they have a labyrinth-like ground-plan (see *Fig. 2*).

The Buda Marl, which often forms the cover beds of caves was formerly considered as a strong, quite impervious rock. As a result of our detailed investigations, it was only proved that the air-dry compressive strength of the marls is high (*Table 3*), meanwhile there is remarkable decrease in strength due to water absorption. An additional fact is that these well bedded rocks are very fractured (see *Fig. 12*).

Previous investigations analyzed the possibilities of predicting different cavity failures, and proved, that predictions are only valid for artificial openings and not for the natural cavities. A stability survey of the natural cavities must be – similarly to the mass movements – executed by individual investigations. This is the only way to determine the method of intervention, the necessity of the lining structures and their position.

In spite of the disadvantageous conditions the buildings are very rarely damaged as a result of cave collapse or cave failure (*Fig. 25*).

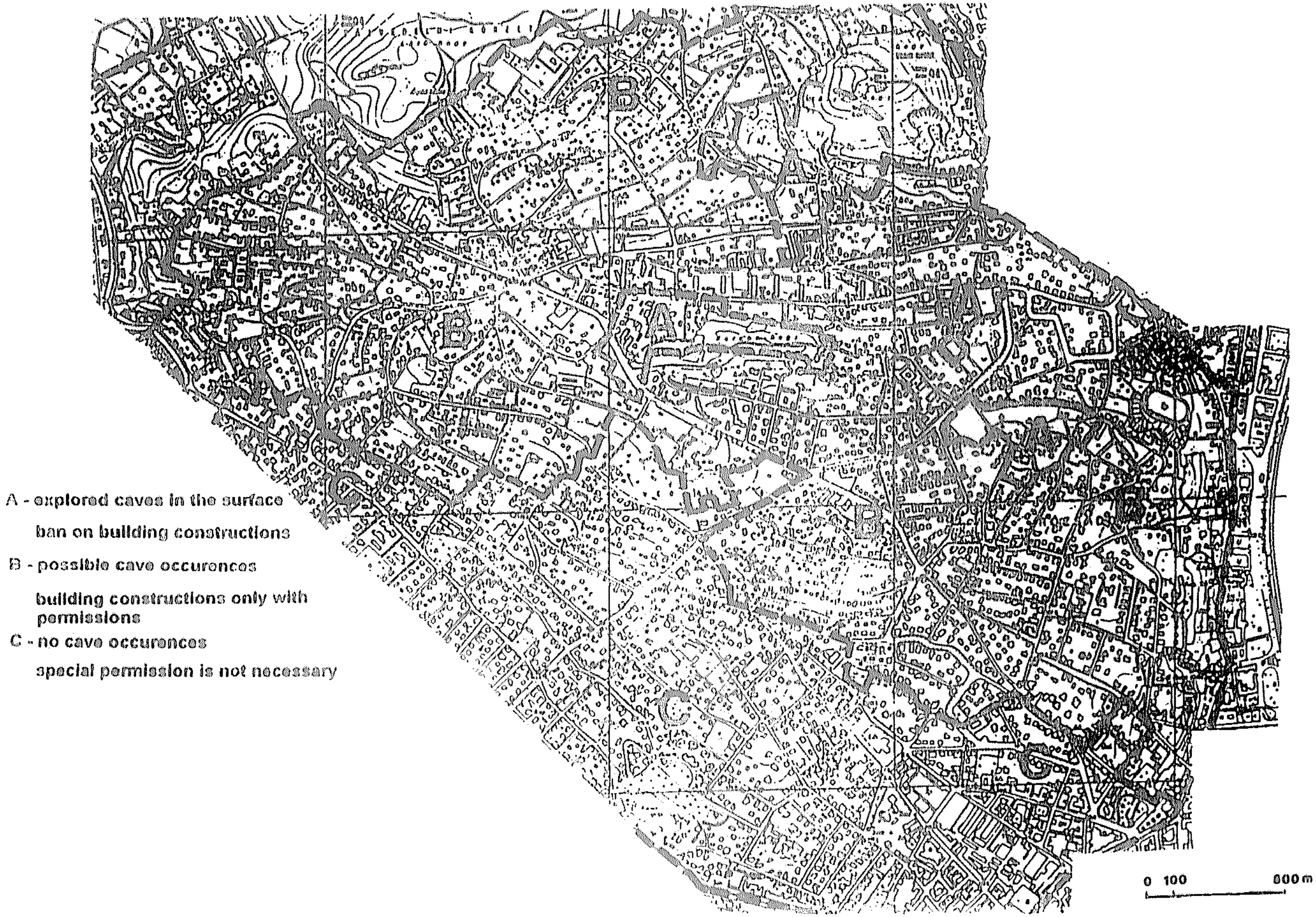

Fig. 23. Protecting zones and possibilities of building constructions in the area of Rózsadomb

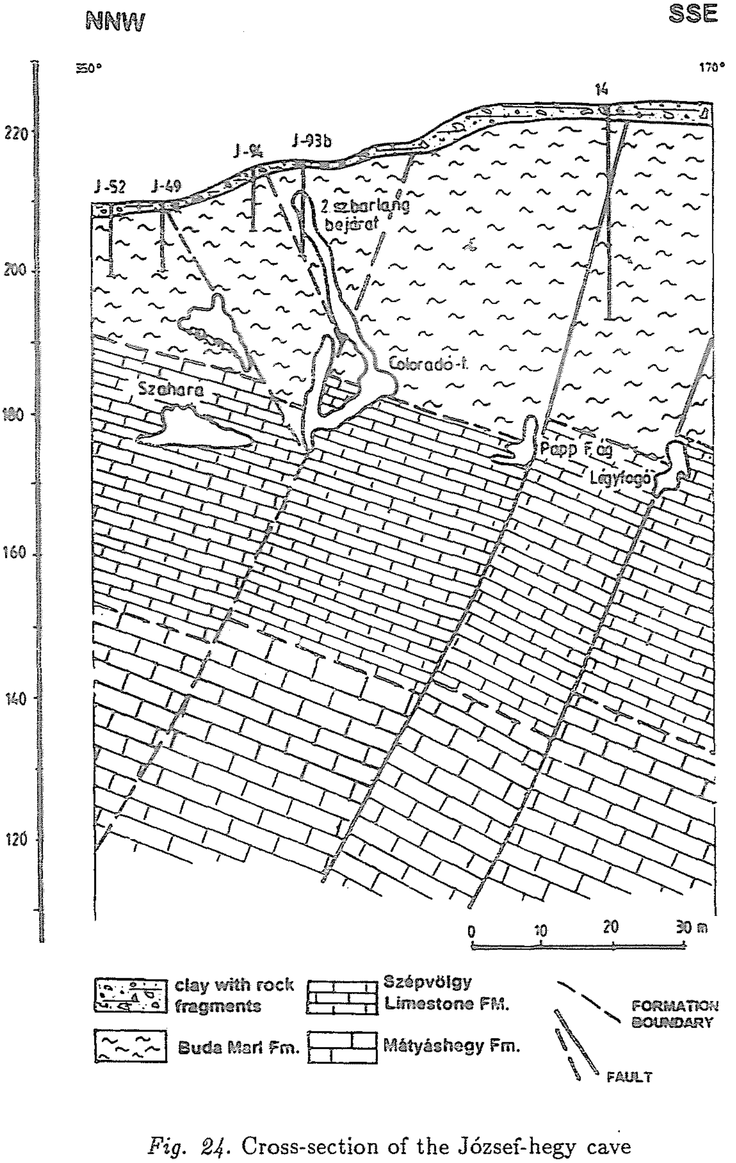

Fig. 24. Cross-section of the József-hegy cave

8.5. The Expected Behaviour of the Built Environment, Necessary Interventions

The expected behaviour of the built environment can be evaluated by a common interactive investigation of rocky surroundings and the technical

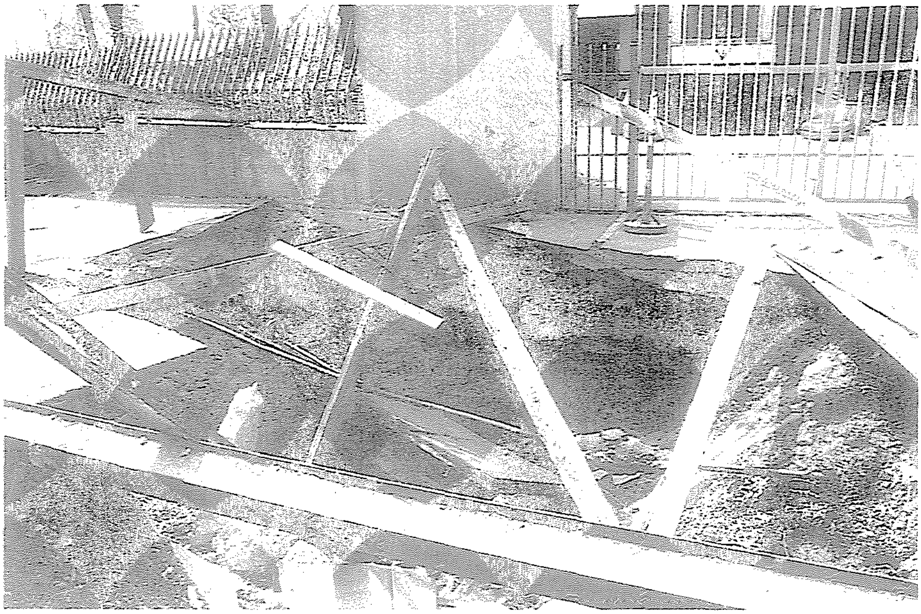

Fig. 25. Cave collapse damaged pavement near József-hegy cave

constructions. The knowledge of geological conditions and their suitable utilization requires an action plan in techniques and economics, which includes two types of actions since 1986:

* obligatory

* recommended

Since landslides are still active at several sites it is necessary to take into consideration, especially after rainy periods, the requirements of BVSZ 35, which includes the geotechnical control of the foundation design as well as a prohibition of seepage.

Among the proposed actions, the state survey of caves and cavities as well as the complex evaluation of their position and stability were underlined. A basic condition for these works is the knowledge of geological conditions, a detailed investigation of dynamic processes and a system-like management.

The greatest damaging agent of natural values and surface constructions is related to failures of the water and sewage pipelines. The leaking water causes the soaking of the near surface layers.

At those areas, where the Buda Marl layers are close to surface and covered by volume-variable (expanding) clays, the pipelines must be regularly controlled for their impermeability. A relatively modest infiltration may also be a critical one, because the suffocation provokes a very quick deterioration.

For the contamination of the caves, besides the sewer leakage, local seepage of outlet water plays the determining role. As supported by the infiltration tests even tens of metres of Buda Marl do not assure a complete protection. It is very regrettable that in spite of the regulations nearly 700 cesspits were still in function in the second half of the eighties. Some of those are found in the protecting zones of thermal springs (*Fig. 26*).

8.6. Human Impact

As archaeological investigations prove, the territory was already inhabited before the historic times, but the human actions were not able to change the landscape. Among the small quarries, furnishing local building material, some were well developed about the millenium (1896) supplying stone material for the great constructions in Budapest. These quarries had already changed the natural landscape. The settling down and consequently the building constructions in the area continued between the two world wars. In the valleys and on gentle slopes housing estates were built in row of 4–6 floors, with brick masonry, high roofs and cellars. On the elevated zones of Rózsadomb and Pasarét villa-like buildings were built of 1–2 floors, but not all of them were provided with cellars. The drinking-water system has been completed on the greatest part of Rózsadomb, but the sewer system is still incomplete. As a result of this at some places the outlet water can directly penetrate into the joint system of the rocks and further down into the cave system. It is especially fast when the host rock of the caves is on the surface.

At the Rózsadomb and the Pasarét territory in the second half of the sixties an intensive settling down started, which is characterized by few storey buildings despite the opposing regulations of BVSZ. According to this regulation a maximum of 15 % building-in is possible, with free standing town houses.

The built-in versus natural area of Rózsadomb (about 10 km^2) can be calculated from the digital evaluation of aerial photographs :

	green	built in	road pavement
1972	83%	16%	1%
1992	80 %	19%	1%

The built-in percentage seems to be medium because the villas have gardens, but these data prove, that the permitted rate was exceeded. The changes can have drastic effects at several places, from environmental protectional point of view.

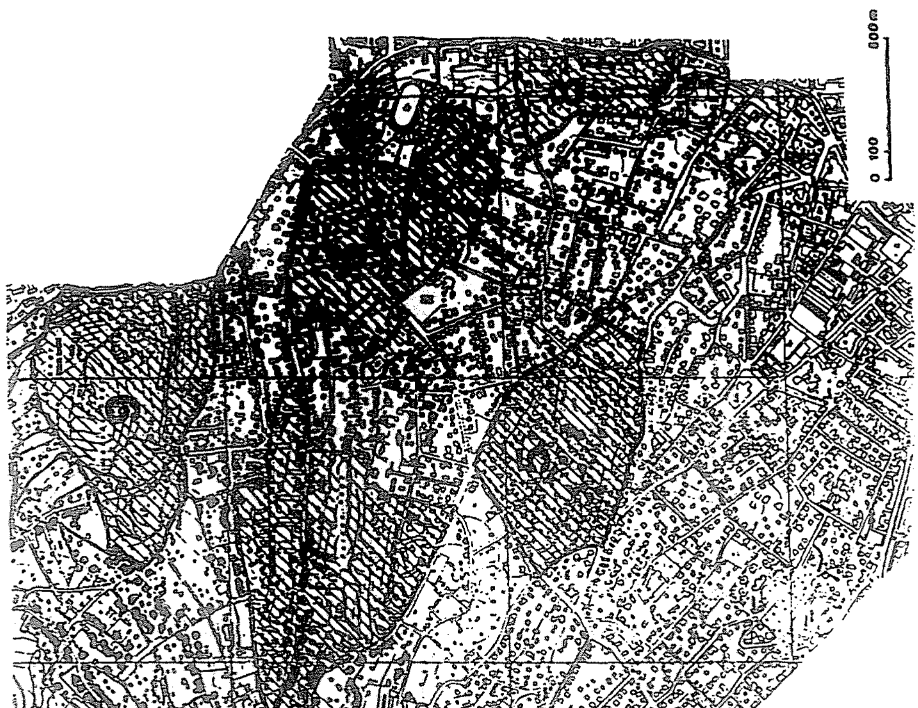

Fig. 26. Hydrogeological protecting zones of Rózsadomb thermal springs and the occurrence of cesspits

This territory is very important for the metropolis, since several natural 'treasures' are found here. Some of them are in the interest of national and international tourism.

Conclusions and Discussions

1. Late Triassic carbonates represent three major facies zones including laminated euxinic carbonates of an extensional basin origin (synsedimentary faults and sediment filled dykes).
2. Eocene carbonates, the host rocks of caves, were deposited in a deepening upward sequence and they reflect a dynamic regime characterized by shallow subtidal carbonate sands, slumps and outer shelf calcareous turbidites.
3. Oligocene clays covered the carbonates providing a relatively impermeable seal for upward migrating fluids.
4. Tectonic zones are preferential pathways of ascending thermal and descending cold waters and had a leading role in preformation of the extended (25 km) Plio-Pleistocene cave system.
5. Three major tectonic phases lead to the formation of fracture and joint systems: Late Eocene – Early Miocene compressional, Miocene extensional and Quaternary – Recent extensional one.
6. 'Ferenc-hegy' dextral strike-slip zone is the most significant megastructure of Rózsadomb area.
7. Petrophysical tests and joint pattern analyses showed that the Eocene marl cannot be considered as an aquiclude and as a geological barrier for contaminated waters especially because it also contains cave passages.
8. The petrophysical properties of rock masses are primarily controlled by joint pattern and frequency. Consequently the solid and compact limestones and marls in tectonic zones and near to the surface show a significant decrease in durability and an increased deformation. Similar trends were recognized in rheological properties.
9. The weathered and creeping near surface zones of Eocene marls and Oligocene clays can cause damages in built environment especially in case of shallow foundations.
10. The arid periods lead to a temporal decrease in landslide activity, which can be dramatically changed in rainy seasons. Lacking of risk reducing measurements it is necessary to follow the strict building regulations.
11. The cave system has not been entirely explored therefore it would be required to test the region with geophysical methods and further

drillings. Meanwhile it is essential to extend the protection zones of thermal springs and caves since the sewer system is far not complete on the area.

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