ENGINEERING-GEOLOGICAL TEST ON SETTLEMENTS WITH CELLAR DIFFICULTIES

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Abstract

From the middle of sixties more and more reports were published on cellar difficulties that in unexpected time and places caused problems in our historical towns as Eger, Pécs and Budapest. At present, we can report not only on the damages, but also on the preventive engineering-geological research and activity that with a significant central support bring forth safety in the endangered towns and villages.

Commencement of the complex engineering-geological examinations

The rapid development of urbanization commenced in Hungary in the sixties. The law on construction control was issued in 1964 prescribing the completion of a *general arrangement* plan for the future area utilization of settlements.

In the evaluation of the settlement characteristics the detailed examination of the ambient's superficial, geological, groundwater, slope, flood and drainage conditions of the vaulted areas and recovery places of utilizable raw-materials is a very important task. Within this, the analysis of the engineering-geological conditions helping or hindering the development of settlement is an emphasized task.

In our country, this complex examination completed with revelation observation, soil test and analytical evaluation is done in the form of engineering-geological mapping.

The engineering-geological mapping in 1966 commenced with surveying areas having priority in the development plan in the region of Balaton and Budapest. From 1968 on, however, the examinations were focussed on towns endangered by cellar collapse — Eger, Pécs, Szekszárd, Szentendre — and on smaller settlements as Nagymaros, Ostoros, Noszvaj, Novaj (Fig. 1).

The detailed engineering-geological mapping of the settlements in large towns is under process by the professional supervision and financial support of the Central Geological Authority, with uniform principles on a scale of 1: 10 000 in downtowns and smaller settlements on scale 1: 5 000 and recently on 1: 4.000.

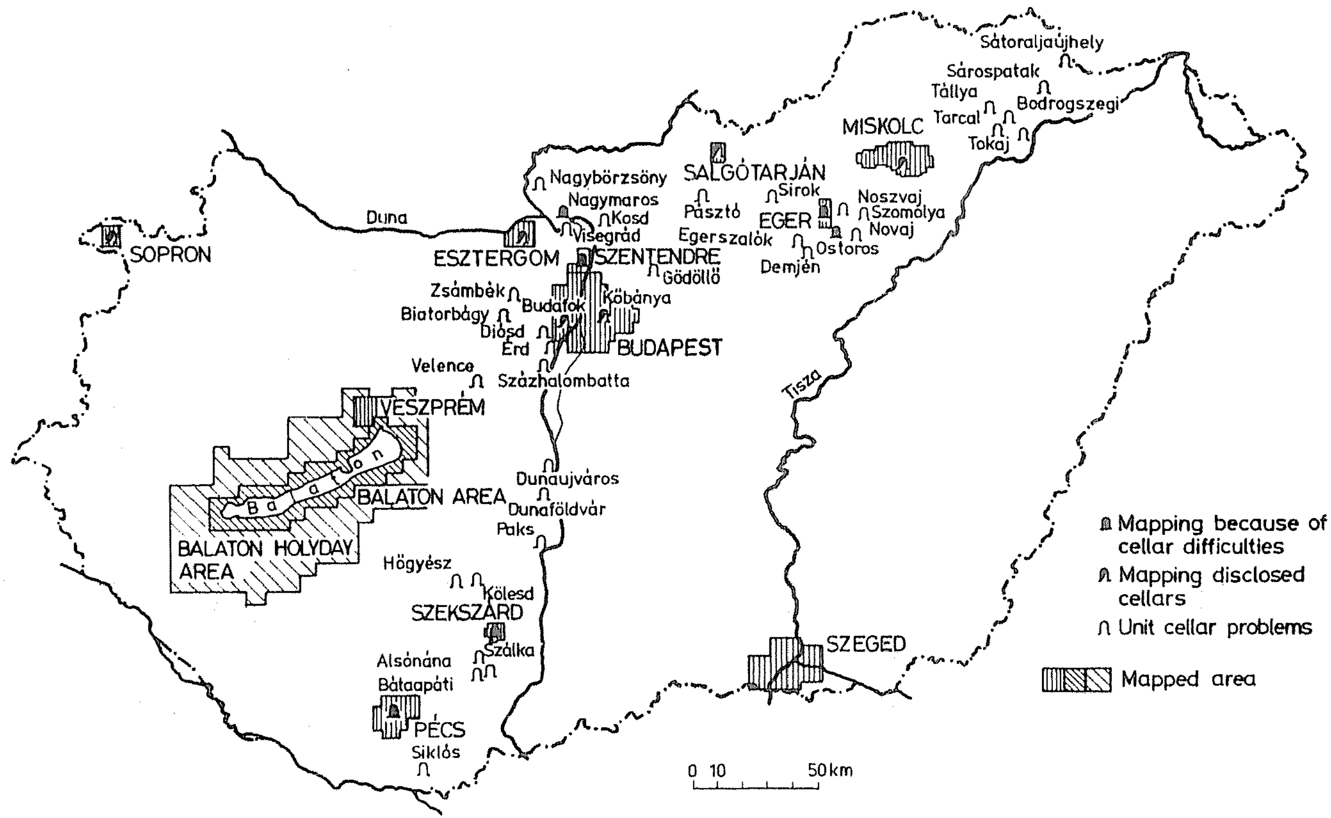

Fig. 1. The engineering-geological mapping and cellar difficulties in Hungary

Exploration of cellar network

The exploration and examination of cellar networks is a complex problem partly with engineering-geological tasks.

To collect information on the location, the perambulation and the examination of the hollows originated in different ways — caves, mine pits, tunnels, cellars, cave-dwellings, storage places — is the most difficult task. This is

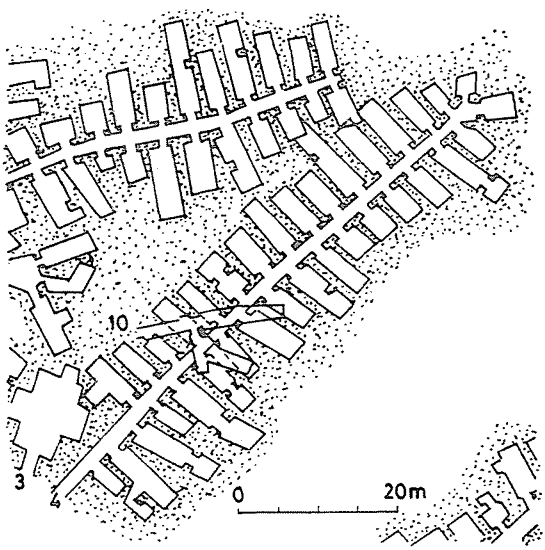

Fig. 2. Finger-like branching from the main gallery cutted to rhyodacit-tuff (Eger)

partly due to the great number of the hollows, partly to their establishing time, condition, proprietary rights and leasing forms.

At registering the cellars, the city council and revenu office registers ensured the initial basis. The accomplishment of the task was complicated by the fact because in certain cases — e.g. in Eger — for registering only one cellar' it was necessary to notify 24—28 renters (Fig. 2).

The utilization and proprietary conditions are important from other aspects as well. Namely, most of the hollows at the time of their creation were located outside the city, on unbuilt grounds. But at present, they are situated under public houses and roads. In Eger e.g. in 669 cellars a total length of 7 010 m run under the road network of the city.

Although, for the maintenance of these cellars there is a law-decree, *this is not suitable to avert these continuously existing dangerous phenomena in such a large number.*

Instrumental detection of unexplored caves

At the preliminary surveying it became obvious that under the cities, there are numerous cellars or caves that are out of use, water loaded or closed with rockburst and their *opening and spatial is unknown.*

According to international experience, there is a real chance of detecting a cavé by geophysical methods, only, when the depth and cross-sectional dimension of the cave are of the same order of magnitude. Since this applies to most of the cases, the idea of making geophysical cave research has arosen.*

Surface measurements

The geophysical measurements on the surface were encumbered by the disturbing effect of traffic, the public works and that the area was built up.

The situation is favourable when above the caves a rupture zone is formed, and its effect is projected to the surface.

At the *seismic-smallrefractional* measurements the effect of the cave results in a time increase of the distance-time curve. At the measurements of Eger, only the time retardation was observed being equal in magnitude to the values of surface correction (ms).

With *geoelectric* method we can achieve good results mainly at the measurement of so-called infinitely resistant i.e. not-collapsed water free caves. With detailed sectioning no characteristic anomaly was found (Fig. 3) in these cases.

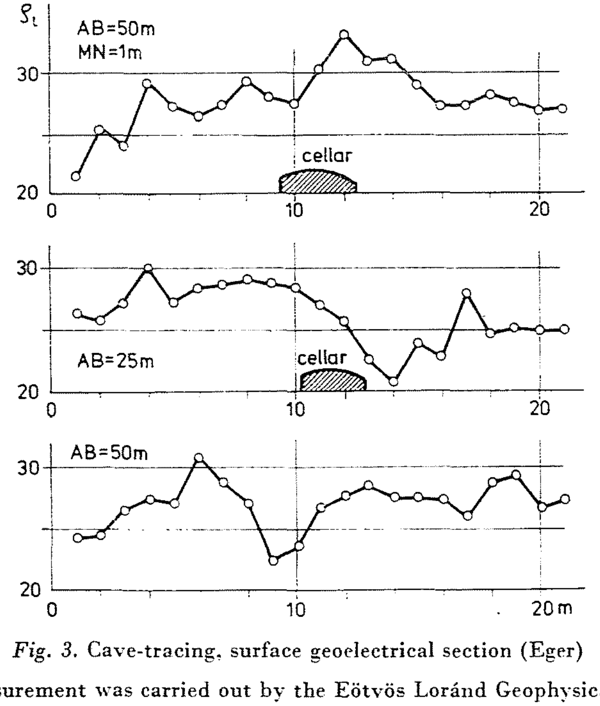

Fig. 3. Cave-tracing, surface geoelectrical section (Eger)

* The measurement was carried out by the Eötvös Loránd Geophysical Institute.

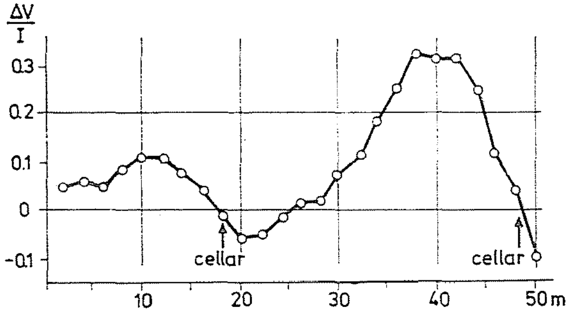

Fig. 4. Caves found by the surface geoelectric differential method

In the framework of a later investigation, by the so-called MAN system probe installation the detection of dry cellars was successful (Fig. 4).

"Transillumination" between the bores

Since the surface measurements carried out in different places with different methods were not successful, we tried instrumental measurements in bores drilled nearby known cellars.

At the *seismic* measurements, the velocity remains low inspite of the varying rock material due to the effect of the caves (Fig. 5).

At the *geoelectric* test with different electrode and probe installation, the effect of caves resulted in a potential drop. With the electrical surveying of the

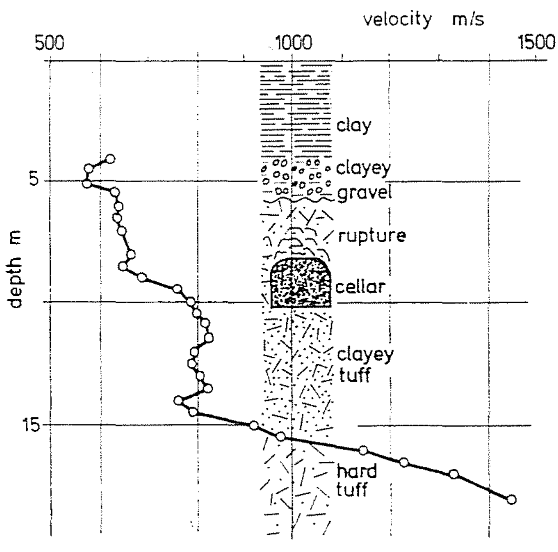

***Fig. 5.* Seismic "transillumination" between the bore holes (Eger)**

bores the caves could be detected by natural potential, specific resistance and by radiology.

The "effective depth" of the measurement, however, is only 1—2 m around the bore.

According to the above mentioned *there is a possibility to detect the cave.* For this method a 6×6 metres drilling network would be needed knowing the section of the cave (average 2.5×2.5 m) and the measurable anomaly. Since its costs are so high and cannot provided in a built-up area, the application of this method was not adopted.

Detection of caves with "destructive" method

The insufficient result of instrumental tests made necessary the application of other expensive methods.

Cave exploration with drilling

The exploration of caves with unknown spatial is rather expensive and involves uncertanties with the traditional bore installation, and it cannot be applied on a built-up area. With relatively small expenses, we achieved quick and reliable result with *horizontal* bores started from known cellar caves (Fig. 6). With the electric drive equipment in a fan shape, 50—100 m long, small diameter bores were drilled, and by these, the cellar network of the area assigned for building site, was reliably explored.

It is obvious, that this method is more complicated and more expensive if the caves are situated in different levels, and it cannot be applied on the level of foundations and public works.

Cave exploration with mining method

In cities struggling with cellar problems, there are many collapsed perilous caves, that should be accessed or explored with precautious measures.

In Eger, e.g. during the mapping of 41 cellars, surveying was accomplished in a total length of 5 104 m with pile-trapezoid or poligon tubbing, and in some cases it was necessary to prepare exploitory tunnels and shafts (Fig. 7).

Next to the strongly ruptured sections there are flooded cellars in great extent. That is why we consider *dewatering* as one of the most important method carried out usually by 800—1200 l/min capacity BIBO pumps. In Eger during the period 1969—71 surveying of 148 waterflooded cellars was accomplished on a total area of 16 800 m^2.

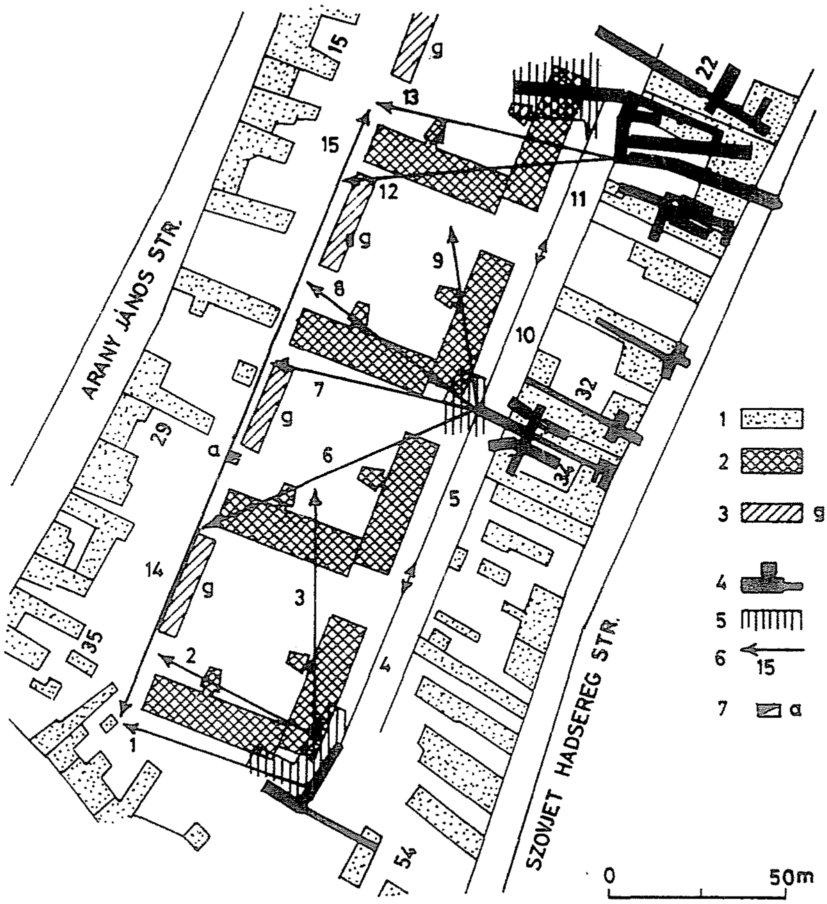

Fig. 6. Cave exploration with horizontal bore holes (Eger)
1-existing appartment house; 2-planned five storied appartment house; 3-planned garage; 4-known, explored cellar; 5-the range of the cellars effect; 6-horizontal exploration bore holes, exploration-shaft

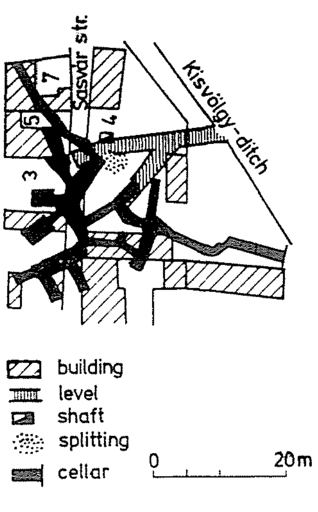

Fig. 7. Sinking hole exploration with| mining method (Eger)
1-appartment house 2-exploration tunnel; 3-exploration shaft; 4-rupture; 5-cellar

Surveying of cellar networks

It is a science historical curiosity that in Eger, surveying of the caves having different purposes interested the engineers already centuries ago.

So, the famous casmete and tunnel system of the castle in 1711 and the surrounding cellars in 1776 were surveyed. On the map of the cellar network belonging to the archdiocese made in the year 1807, the watered branches are also shown (Fig. 8).

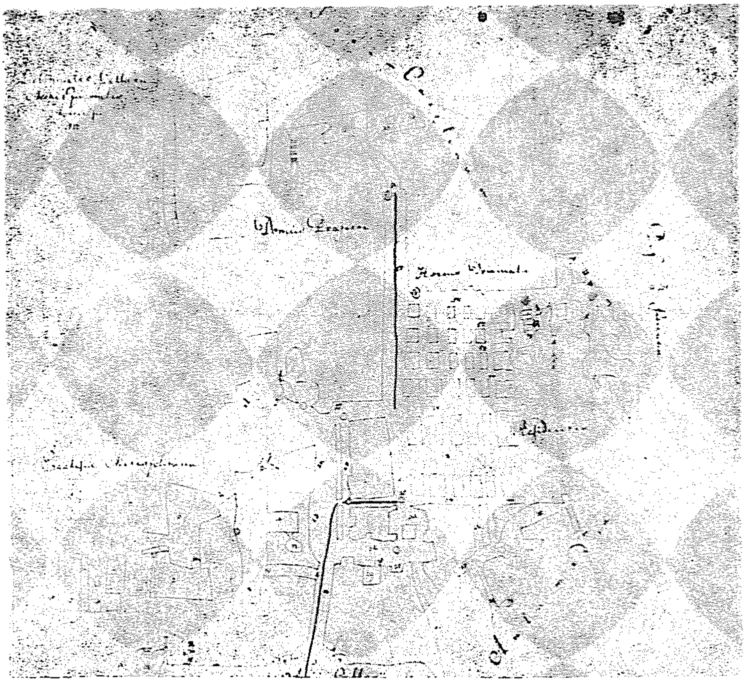

Fig. 8. The surveying of the arcdiocese's cellar of Eger in 1807

The necessity of the exact surveying of the cellar network nowadays is inevitable, and it has got multiple purpose:

- by the longitudinal- and cross-section it determines the position of the underground caves to the related surface constructions,
- provides bases for planning: at stemming and supporting for the volumetric calculations, and also for the exploration of further unknown caves,
- provides information for the future town-planning program, and the actual situation is recorded.

The surveying work commences with the installation of transverse-survey points that with adequate density is started from a bench mark of the Hungarian network.

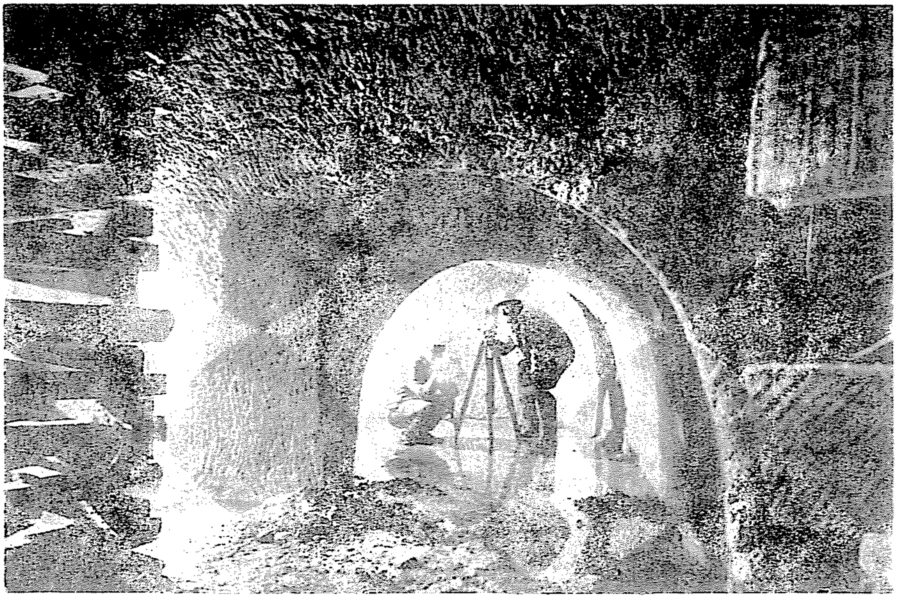

Fig. 9. Surveying of cellar branches

To project the points under the ground is a very difficult task, even in the easily accessible branches (Fig. 9).

On the characteristic points of the cellars the depth of the bottom and roof above the see level is recorded.

The cross-sectioning of regular caves was done by traditional method. In the case of irregular caves the photogrammetrical method was also applied.

The mapping of Eger that is mostly under cut by cellar network was made on the scale of 1: 200. Later, on other settlements scales of 1: 250 and

Table I

Cellar surveying, that was done in the framework of engineering-geological mapping at Eger

Year of surveying	The surveyed cellar	
	pcs	total length, m
1969	463	13 100
1970	565	36 500
1971	470	22 000
1972	103	8 400
1973	197	4 700
1974	104	1 800
Sum:	1 902	86 500

The surveying was accomplished by the Nógrád Geological and Soilmechanical Office.

Table II

Information about the extent of cellar networks

Settlement	Length of cellar network, km
Eger	135
Pécs	55
Szekszárd	14
Szentendre	6
Budapest	
Budafok*	14
Kőbánya**	18
Várhegy***	10
Nagymaros	8
Ostoros	15

* Originally under-ground stone-pit nowdays wine cellar, mushroomcellar, storage place, etc.
** Originally underground stone-pit nowdays cellar network of a brewery
*** Partly natural hotspring cave partly medieval cellar

1: 100 were also applied. The exploration work done in the framework of engineering-geological mapping is remarkable, even in international level (Tables I, II).

The stability problems of cellar networks

The ambient of the cellars being in small depth under the examined cities and villages, should be considered as *stable*, since those caves for decades or even for centuries are stable. The deterioration that happens from time to time and place to place may be due to the recent upset of the balance. Since no new caves were cutted and the pillars were not diminished, the causes of the earlier upset of the balance can be the following:

- by the installation of water supply network the water consumption rapidly increased, but the sewage disposal was not solved: *the groundwater level significantly raised.* Due to the deterioration of the supply network, pipe breakage is more frequent.
- by the development of the city more and more building were built above the caves, due to this the *static load* increased
- by the increasing number of quick and heavy trucks, the static and *dynamic load increased* on the roofs and pillars of the cellars,
- by the changes of the way of life and the economic system, the cellars got out of use, so the maintenance work was neglected, the *construction material worn out, the decay of rock ambient* became gradually more advanced.

The cause of the deterioration, obviously, may be the full or partial coincidence of the above factors.

In settlements struggling with cellar difficulties, the depth, the location and the cross section of the caves are different. But the rock ambient and its condition is also variable.

So, their stability should not be discussed in general, that is why complex investigation is necessary:

- **in the framework of the detailed, uniform research and investigation plan all the morphological, geographical, structural and hydrogeological factors, should be detected which may be the cause of the deterioration,**
- **the arrangement of the cellars, and any other undergrounnd caves and storage places should not be considered separately from the structure — buildings, road — and public works, network, and traffic — of the city.**
- **the social life of the settlement, the technical, economical and any other aspects should be taken into consideration at the order of the work.**

The shape and location of the cellar

The considerable change of the environmental effects should be significant in the deterioration of the condition, because the depth under the surface and location of the collapse is unfavourable.

On the basis of a great number of examinations carried out in different settlements the caves can be classified into three depth categories:

< 5 m *shallow-* or *crust cellar:* they are usually in connection with the structure of the buildings, there are many of them at Pécs and Esztergom,

— 5—10 m *medium depth cellars*, the most frequent and the largest extent cellars, except of Pécs, they are cutted to rocks within supporting structures,

> 10 m *deep cellars:* they have no connection with the buildings, they are cellars, storage places, military passes, or stone-pits cutted into rock.

From the above informations it is obvious that even the depth of the location can cause problems. On the one hand, the soilmechanical exploration bores necessary to the plain foundation, does not indicate the presence of the caves, in some cases, at the start of the earth work unexpected sinking took place. On the other hand, the depth of the location can be unfavourable, because the rock ambient of the cellars is sensitive to the static and dynamic surface loads.

The unfavourable characteristic is worsened by the fact, that — first of all in Eger — the cellars established in different ages are situated above each other sometimes even in *more levels* (Fig. 10). Even the exploration of the deeper level is complicated, because most of them are flooded and some are sunken.

From the point of view of stability the interrelation of the location of the cellars has got primary importance. Namely, the cellars and cellar arms located

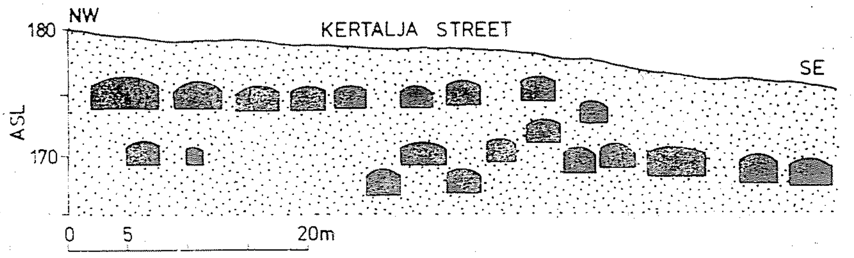

Fig. 10. Tuff-cellars on multiple level situated within the range of effect in Eger

usually on a way, that the stresses and shape transforming forces induced in the ambient of the caves are superposed, i.e. the caves are within the range of the affect — that is why from the point of view of rock mechanics we call it cellar network.

The examined cellar networks by their horizontal plan can be classified to three main types:

- long arm series running beside each other formed by *stripe pillars* (Fig. 11).
- galleries consisting of numerous smaller cellars and arms are running from the main tunnel — essentially also with stripe pillar system (see Fig. 2.)
- hall-like caves, underground stone pits, large episcopal or smaller vine cellars formed with *square pillar* supports.

The *thickness* of the stripe pillars in many cases does not exceed 10 to 20 cm and due to the weathering, drenching and the increased loads they are not stable any more, so the *rupture and brust* of the *pillars* is rather frequent

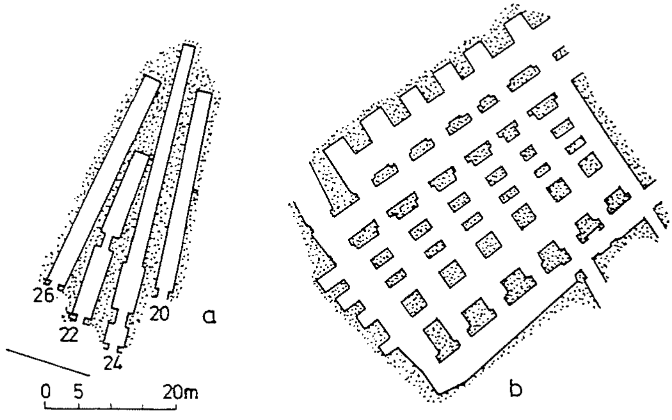

Fig. 11. **Characteristic cellar shapes (Eger)**
a-long cellars with stripe pillars; b-hall-like cellars with quadratic pillars

(Fig. 12). This type of damage, with the simultaneous rupture of more cellars may cause crumbling, that affect the surface to a great extent. At Eger in 1957 on a 35×40 m area at about a 10 000 m^3 there was a rockmass sinking resulting in a 2 to 3 m diameter surface depression.

From the point of view of safety of the cellars and underground caves, their *cross-sectional size* is also of importance. According to the surveying work that was extended to more thousands of caves, the width and internal height of the caves is rather variable.

Classification according to width:

<1 m *narrow:* usually old military passes, tunnels, observation corridors or drainage galleries

1–3 m *average:* cellars, sand exploiting drifts (Pécs)

3–6 m *large:* cellars, vine cellars, cave-dwellings storage places

>6 m *hall-like:* vine cellars, underground limestone pits (Budapest, Kőbánya, Budafok), gravel pits (Eger).

According to height:

<2 m *low:* old tunnels, some cellars

2–3 m *average:* most of the cellars, sand — and gravel pits

>3 m *high:* some cellars, vine cellars, underground limestone pits (Budapest)

The *wide span* in the loosed rock ambient resulted in broken of inadequate strength in many places (Fig. 13). That causes problems especially in Eger where for gravel exploitation they formed large irregular shaped "halls" under the loose limnetic super incumbent without pillar supports.

The rock ambient of the cellars

The deteriorating and movement phenomena developed in the rockambient of the underground caves greatly depend on the *strength characteristic* and *structure* of the *rock ambient*, and similarly on the stratification and fissurance.

At the examined settlements the cellars and caves were cutted to low-strength, easy-cut rocks: riodacit-tuff, andezit-tuff, raw-limestone, loess, coherent sand (Table III).

The rocks within one settlement can be different (Fig. 14).

The underground caves under certain circumstances can keep their stability for long even if they are not supported with artificial structures. In an other case the deterioration of the roof and the fall of the loosed rocks is continued until a natural arch is shaped and with this its state becomes stable.

According to Börger, H. 1954 for the low-strength rock the hight of the rupture (h max) conjugate to the maximum span (l max) knowing the one way

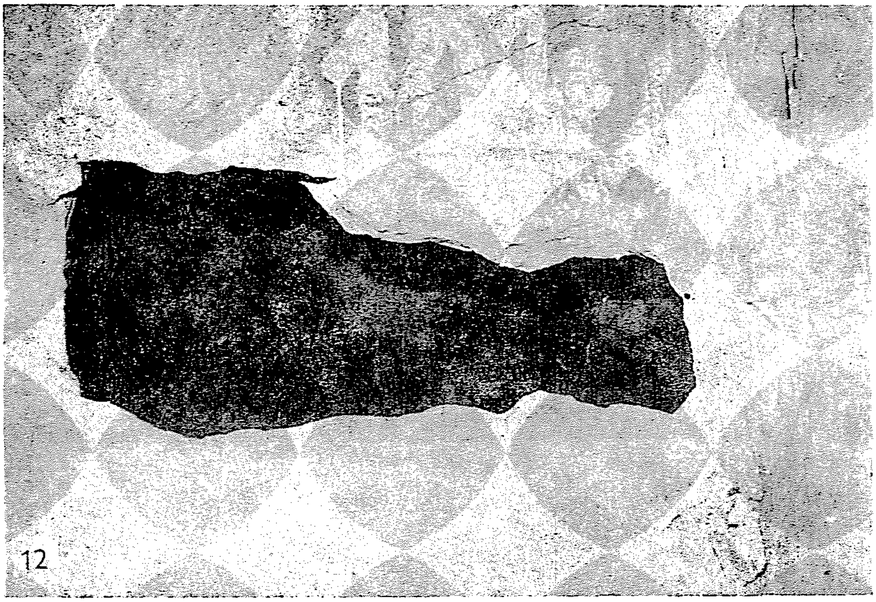

Fig. 12. The rupture of tuff stripe-pillar between cellar-branches (Eger)

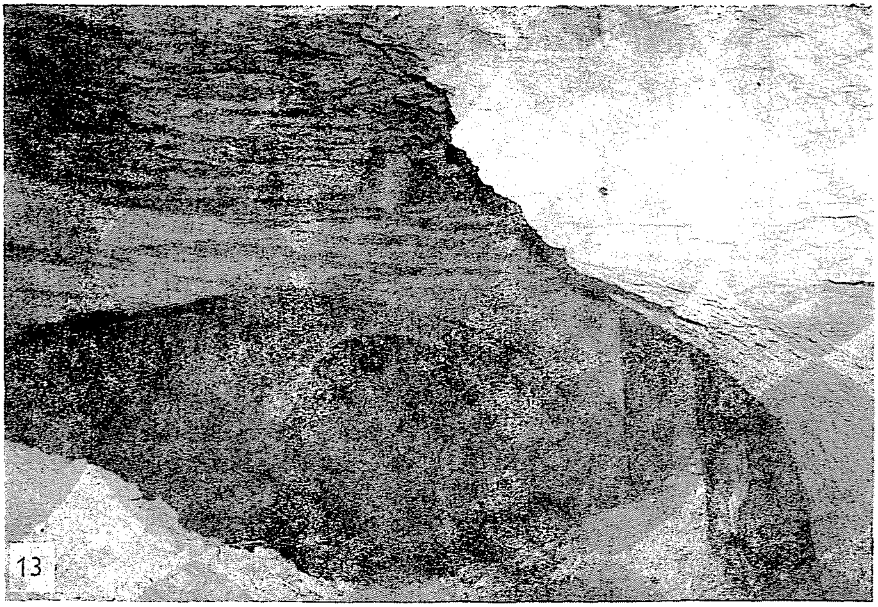

Fig. 13. Sink of a wide-span cellar roof in stratified tuff (Eger)

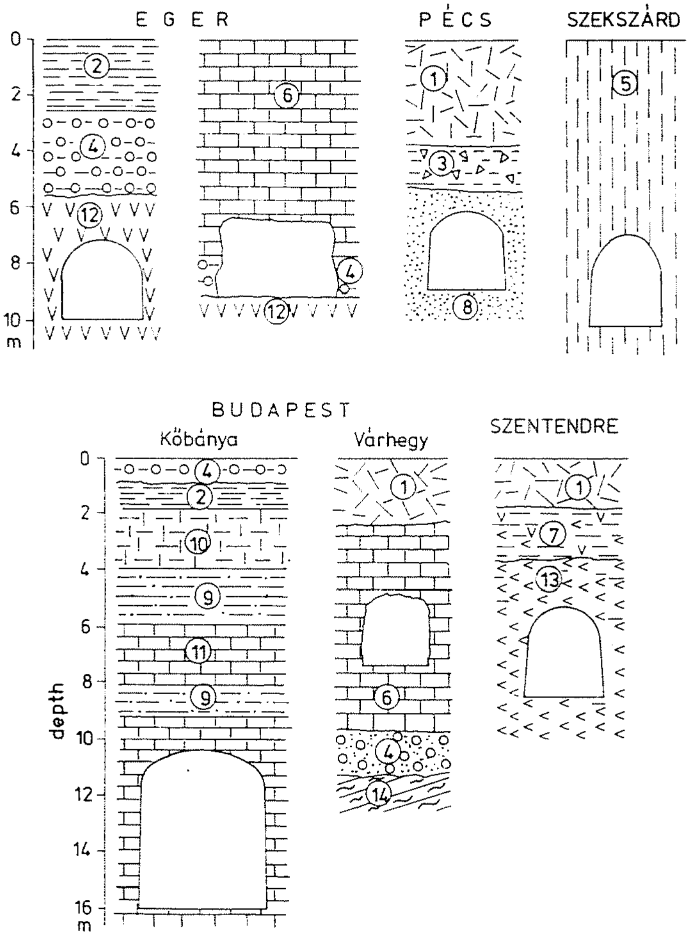

Fig. 14. The geological ambient of the examined cellars and caves:
1-infilling; 2-clay; 3-clayey regolith; 4-clayey sandy gravel; 5-loess; 6-limnetic-stone; 7-tuffy-clay; 8-coherent sand; 9-clay; 10-calciferous clay; 11-rough limestone; 12-rhyodacit-tuff; 13 andezittuff; 14-buda-marl; 2—7 Pleistocene; 8-Pliocene; 9—13 Miocene; 14-Eocene

compressive strength (σ_c), the density (ϱ_1) and the thickness (H) of the superincumbent rock can be given as follows:

$$l \max = \sqrt{\frac{2.96\sigma_c H}{\varrho_l}}$$

$$h \max = 0.63\ H$$

The basis is relating to homogenous and isotropic rocks but it can be applied for given conditions supposing that the parameters are carefully determined (Table IV).

Table III

The characteristic rockambient of the cellar network

Rock	Eger	Pécs	Szekszárd	Szentendre	Budapest Várhegy	Budapest Budafok	Budapest Kőbánya	Nagymaros	Ostoros	Noszvaj	Novaj
Pleistocene											
clay with regolith		◪									
loess			■					■			
limnetic-stone	◪				■						
Pliocene											
coherent sand		■									
Miocene											
coherent sand, marl	□			□							
rhyodacit-tuff	■								■	■	■
andezit-tuff				■				□			
rough limestone						■	■				

■ preveling ◪ frequent □ single

Table IV

The main physical characteristics of the rocks
(average values)

Rock	Density, kg/m³	Compressive strength air-dry, MPa	Compressive strength water saturated MPa	Soaking, m%o	Elasticity modulus, GPa	Pore factor, e	Cohesion, kPa	Internal friction angle, Ø°	Compressibility modulus, MPa
Clayey regolith	2050					0.79	27.5	27	16.0
Loess	1750					0.81	29.8	29	10.2
Limetic Stone									
Eger	2130	16.0	9.5	3.2					
Budapest	2480	25.3	18.6	2.8					
Coherent sand	2050					0.62	28.0	30	15.0
Rough limestone									
Budafok	1620	5.5	4.0	15.0					
Kőbánya	2070	18.0	12.0	10.2					
Rhyodacit floodtuff	1380	7.6	2.2	22.0	0.9				
Rhyodacit tuff	1350	4.9	1.6	21.9	0.6				
Redeposited rhyodacit tuff	1220	3.7	1.1	26.4	0.4				
Rhyodacit dust-tuff	1250	3.0	0.7	33.0	0.2				
Pumice-breccia	1010	2.6	1.1	44.8	0.3				
Andezit-tuff	2290	11.5	8.4	5.6					

It is generally valid that if a cave formed in small depth is arched and thus considered as a stable — the cellars are like that — and its superincumbent rock is stable, its thickness above the highest point of the cave is not less than half of the span ($> 1/2$) then the *maximum rupture will not break through the superincumbent rock*, i.e. the rupture will not affect the surface.

In the examined areas we experienced that the cellars cutted to low-strength rocks, in their original condition are stable. The structure — the loose — pass beside the fissurance and stratification — affects the deterioration volumetrically, break down of the roof takes place in tuff and loess in these places (Figs 15—16). That is why the microtectonical and stratigraphical tests are important.

Variation of the environmental effects

Most of the cellars under the examined cities have been existing since centuries, their deterioration in such a large number happened in the last decades. This may be due to the significant change in the previous state of balance.

On the basis of the soil mechanical tests it should be concluded that in a previously stable cellar ambient, a great extent rupture, sometimes breaking through up to the surface occurs, when, the state of the rocks is fundamentally changed — e.g. drenched — or the superincumbent rock cannot stand the increased static or dynamic surface load, any more.

Knowing the rock ambient of the cellars — vulcanic tuffs, rough-limestone, loess, sand — it is obvious that the *primary factor of the deterioration is the water*.

The rock ambient at most of the cellars is rhiodacit-tuff, having usually high pumice-stone content, that, with its high water absorption and weathering of clay minerals in case of drenching, is getting worser (Fig. 17).

Due to the drenching the *strength of the tuff is reduced to 1/3rd or 1/5th of its original value* (Fig. 18). Under this condition, since the cap of the tuff is of low strength clayey gravel or clay, during arch formation it frequently happens that the *2 to 3 m diameter well-like rupture extends up to the surface* (Figs 19, 20).

Since the primary factor in the deterioration of the cellars is water, at the beginning of the engineering-geological mapping at Eger, we have installed 24 staff gauges with known level. According to the measurement the yearly regime of the cellar water was similar to the characteristics of the underground flow transition. Nevertheless, we have to underline that since the water supply is provided by pipeline-network, the dugg-wells are buried, the ground water is not utilized any more, so its level is arising (Fig. 21). According to information obtained on the part of the city supplied by pipeline network in 1927, on the bottom of the cellars water was found in 1930. In addition to this, due the hilly characteristics the break of the pipeline is rather frequent, and as the sewage

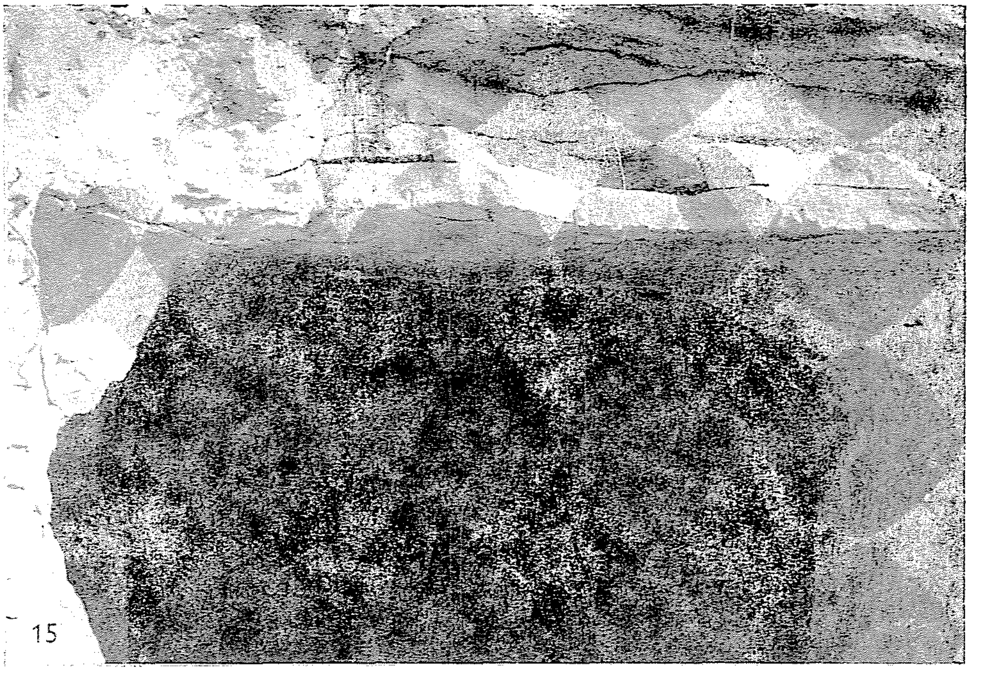

Fig. 15. Roof sunk in rhyodacit dust-tuff

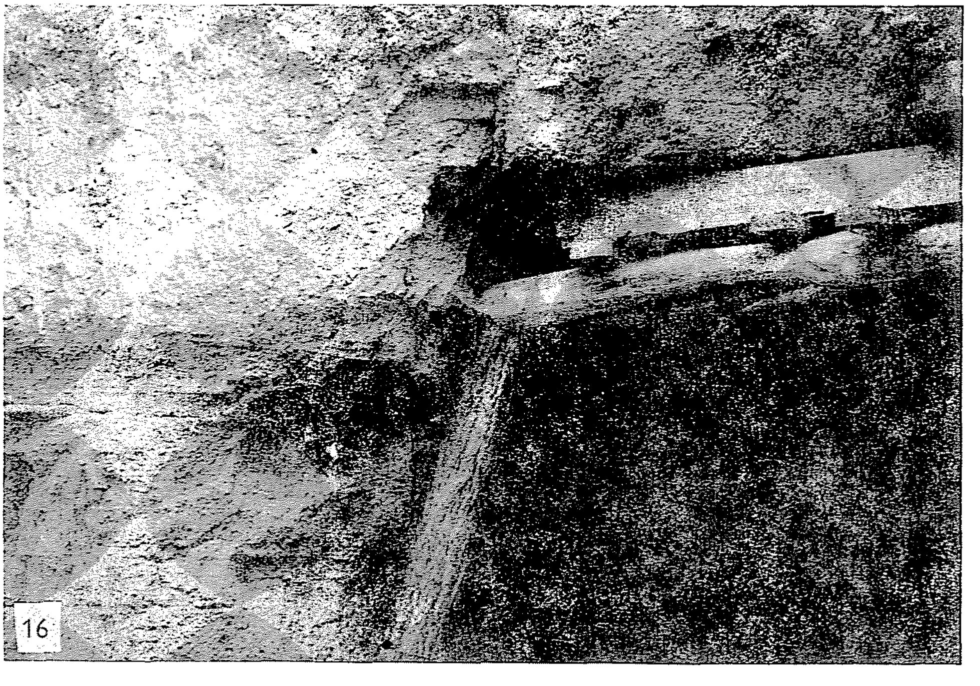

Fig. 16. Roof sunk along fragments of rock bedded into loess (Nagymaros)

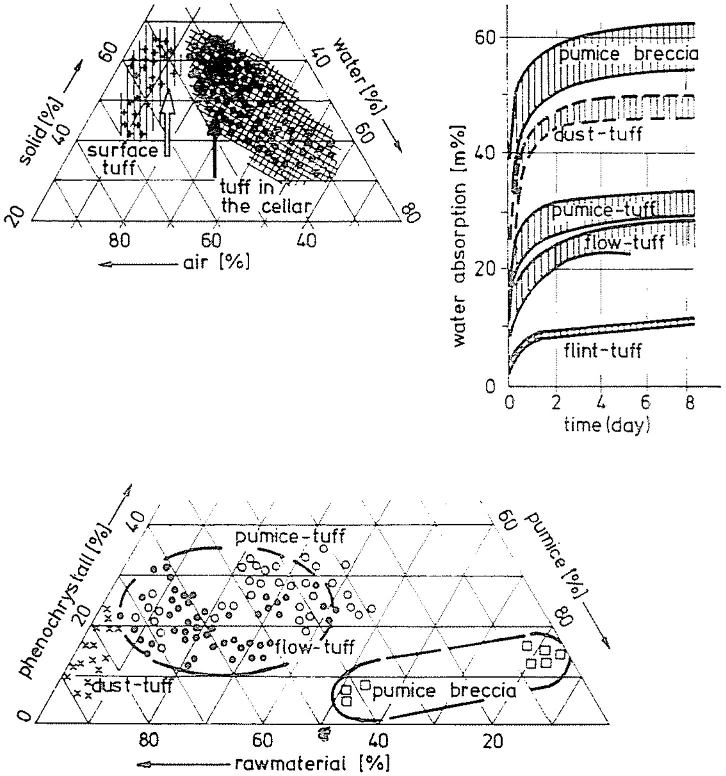

Fig. 17. Composition and soaking of rhyodacit-tuffs (Eger)

network is insufficient the sewage is disposed in cellars that are out of use. In the framework of the cellar survey on an area as large as a block of house, we have applied a total dewatering with 2 m drawdown, but that has solved the problems not longer than for one month.

In the city of a 4 km^2 area as much as three million m^3 water accumulated. For the satisfactory arrangement of the area a 1 000 m^3/d/km^2 continuous water drainage would be necessary.

The cellar waters cause not only stability problems, but from the point of view of public health the degree of their pollution is also not acceptable (Table V). During our investigation the quality of the pipeline water — karst-water — by drenching the tuff for six months, has significantly changed — besides the dissolved lime content the cation concentration increased by 2.6 times, and the value of the water pH changed from 7.3 to 5.9.

The ambient of cellars at Pécs that is Pliocene sand and superficial slide rock clay, regionally is less drenched (Fig. 22). In certain areas, however- "water-hillock" is formed referring to karst-water that according to our tri,

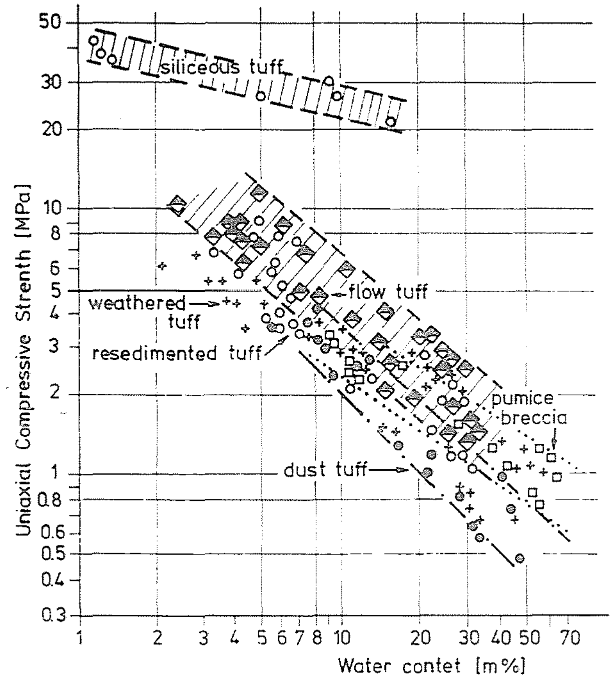

Fig. 18. The decrease of strength of rhyodacit-tuff as effect of water (Eger)

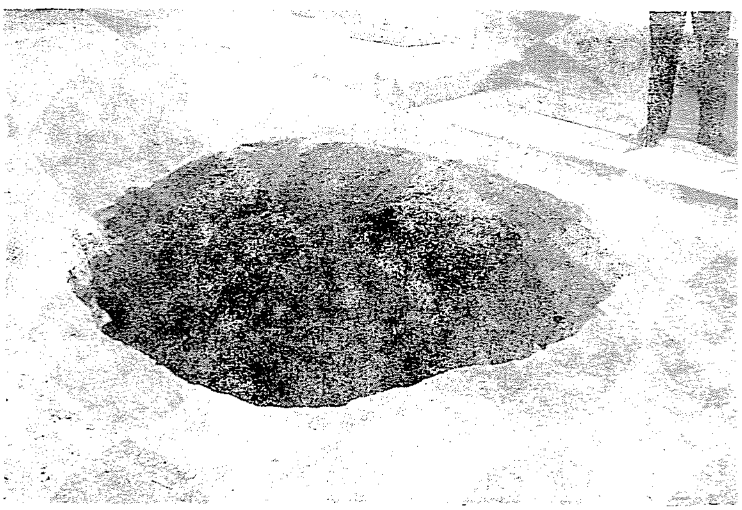

Fig. 19. Well-like rupture up to the surface in rhyodacit-tuff with clay superficial (Eger)

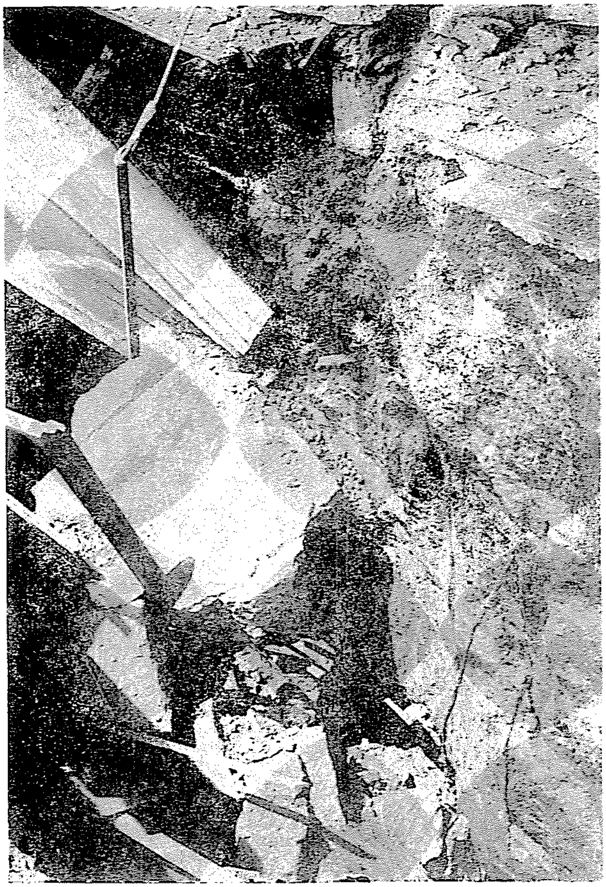

Fig. 20. Vertical rupture with building deterioration

cium tests is originated from the water supply network, and from seepage of the medieval wells and water supply network that are out of use. Here, from the point of view of stability, the streaming water causes problems as it washes away the sand from behind the walls of the cellars.

The stability of the numerous loess cellars with local characteristic is undermined similarly by the periodic *thorough drenching* that is due to the faults of the water supply network (Fig. 23). In this case e.g. Nagymaros, Szekszárd and other settlements an *immediate* sliding occurs (Fig. 24).

In addition to water, locally, the breakdown of the roof of the cellars occurred due to the *dynamic effect of public traffic* and to the increasing dynamic and static effects of several foundation works.

The above listed effects and the related deteriorations prove that the *problem of cellars should not be studied separately*, it is a complex question associated with public works, transportation and the building density.

Fig. 21. Marks of water-flow in a flooded tuff-cellar (Eger)

Table V

The chemical composition of cellarwater of Eger

Elements	Average*, mg/l	Minimum, mg/l	Maximum, mg/l
Na^{+}	166.1	13.8	1075.8
Ca^{++}	227.8	71.6	512.0
Mg^{++}	60.4	16.0	132.0
Cl^{-}	136.8	2.5	435.0
HCO_3^{-}	349.6	83.8	797.0
SO_4^{--}	340.8	65.8	679.0
NO_3^{-}	250.7	3.4	726.0
All solid elements	1572.9	389.0	3740.0
Total hardness	44.3	13.1	102.1
pH	7.1	6.4	7.5

* On the bases of 36 samples taken betwen 1969—1971

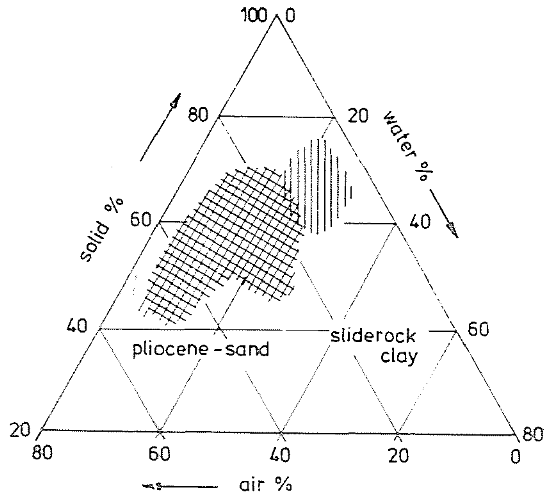

Fig. 22. The phase composition of rock ambient of cellars at Pécs

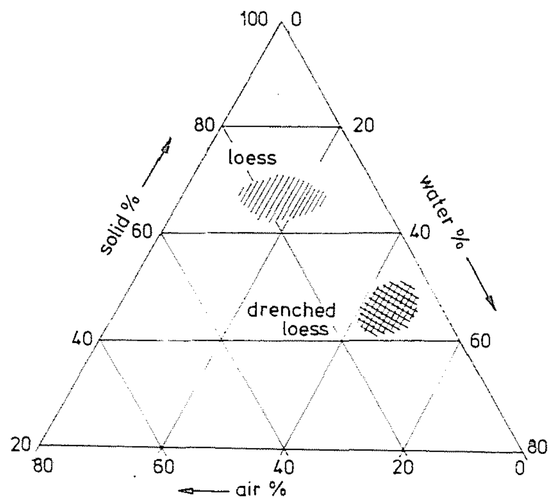

Fig. 23. The variation of phase composition of loess due to drenching (Szekszárd, Nagymaros)

The control of the emergency cases, support works

The cellars and cellar networks under our historical cities and other smaller settlements with their deteriorated state, endanger the safety of the life and economy, the very valuable ancient historical and architectural monuments and the development of the settlement. To bring forth safety in these

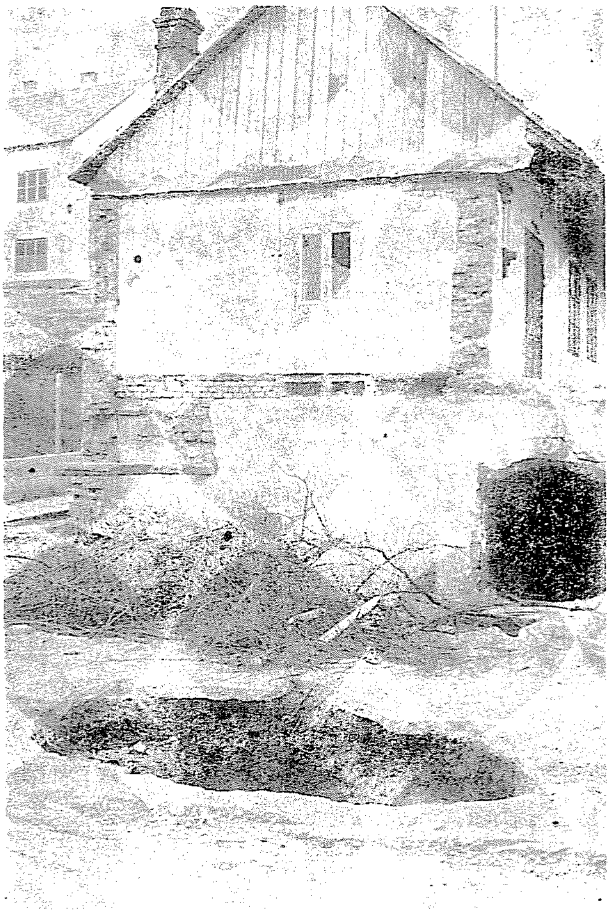

Fig. 24. Cellar rupture ranging up to the surface in loess

settlements a complex and efficient preparation and continuous accomplishment of security works is needed. That was helped by the fact, that in 1974 an Interparlamentary Coordination Committee was formed, that assigned the Surveying and Soil Testing Enterprise as general planning and the Mining Shaft-sinker Enterprise as general contractor firm.

For the accomplishment of this complex task the Government ensured central monetary fund for some five year plan periodes.

The mining characteristical *provisional timber support* — crib, trapesoid or polygon — is applied in case of single sudden breakage, where quick measures has to be made. It is protecting the cellar and the surrounding area for about one to two years.

The advantage of the *permanent support* comparing to the provisional one is that it should be constructed according to plans, and it provides protection for long period. The way of construction, nevertheless, is a function of several conditions. E.g. it is important to decide whether the cave will be maintained or liquidated.

Supporting works with the liquidation of the caves

Most of the cellar networks that are under our historical cities are not utilized any more, their ambient is drenched and in some places is ruptured — the liquidation of those is necessary. The method applied for liquidation is different from place-to-place.

The *backfilling* with *own material* or with *sand* was applied first in the cellar arms near the surface.

In cellars situated in deeper level backfilling with stone-heap, coating mortar and slime-ash was tried out. These methods are more expensive, and due to the difference of ambient characteristics they obstruct the flow of the water, so dewatering must be ensured.

The hydromechanical sand backfilling seems to be efficient, quickly compacted, infilles the space well, and it is not necessary to pump the water out (Fig. 25). The infilling does not disturb the conditions of the water flow.

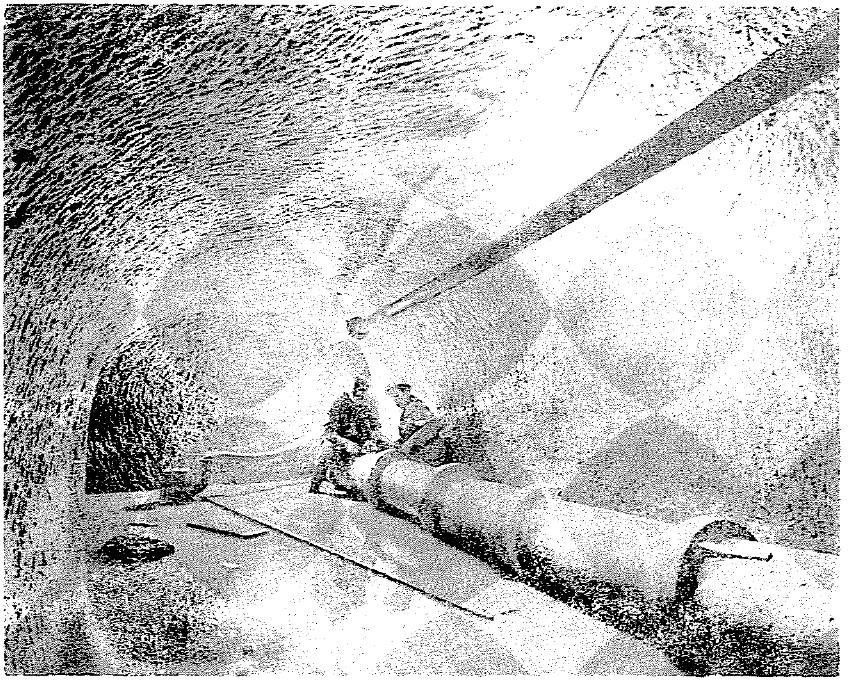

Fig. 25. Hydromechanical sand backfilling at Eger

Supporting with maintaining the caves

The cellar support does not mean that all the caves must be liquidated. Under the settlements there are numerous caves, that before deterioration were utilized, and their further partial utilization can be beneficial. By the supporting works one must make efforts to get the reinforced cellars and underground storage places usable. First of all, regional dewatering, is to be ensured and after that we should select the supporting method which shows a wide variety according to the experience. Previously, the concrete bricklaying — that is common in the mining — was applied, but this is very expensive. In the great extent cellar networks the monolith-concrete method is applied providing attractive, smooth surface.

The *spurt concrete method* is also common in certain places. It is greatly mechanizable, there is no need for shuttering, its strength and loading capacity is better than that of the monolith-concrete. Its disadvantage is that the necessary wall thickness should be achieved by successive layers, and there are great fall-back losses.

At great extent cellar surfaces the *rock screw reinforcement* is applied. It is simple, quickly applicable, the quantity of utilized material is small, and it is important that it does not reduce the cross-section of the cellar. It supports several layers, generally the applied density is 1 pc/m^2 for 0.8 to 1.5 m length. For surface protection wire netting or, in certain cases, spurt concrete should be used.

Regional cellar support

The reinforcement of cellar arms ruptured or deteriorated from the point of view of life-transport- and establishment safety is necessary. The supporting works of the territories undercut by interconnected cellar networks demand high expenses, that is why at the beginning of the work an economical evaluation had to be made (Table VI).

Table VI

Comparison of buildings values and the cost of cellar support in Eger

Type of buildings	Value of the buildings		Cost of cellar exploration planning, construction USD*
	present USD*	reconstructional USD*	
One-two storied century-old building at the Castle-hill	132 980	388 610	135 420
Modern 2—12 storied appartement and public houses	1 689 140	1 770 440	447 920

* On the level of 1972 prices, on the present course 1 USD = 48 HFL

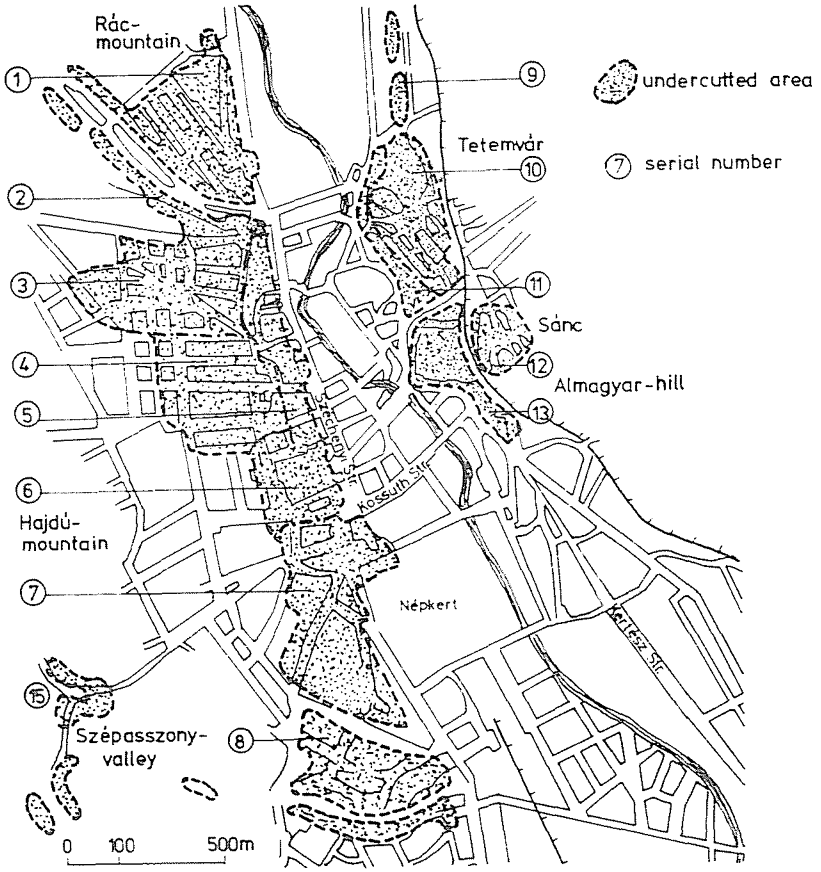

Fig. 26. The undercutted territory of Eger's downtown

As it is clearly seen from the data, inspite of the huge costs, only on economical bases, on areas where the buildings are deteriorated is acceptable, on other places the value of the protected goods is three to four times greater than the costs of cellar supports. Nevertheless, it must be underlined that the major part of the undercutted area belong to the *downtown* and even if not taking into consideration the value of the historical buildings, they should not be liquidated (Fig. 26).

In this type of area at the new constructions, the foundation of building and roads, the safety of public works arise the necessity of pre-planning, and the application of extraordinary constructional methods, that are more expensive and the constructional period is longer (Figs 27—28).

It is resulting from the above that the cellars beneath the cities should be taken into consideration not only from the point of view of exploration and

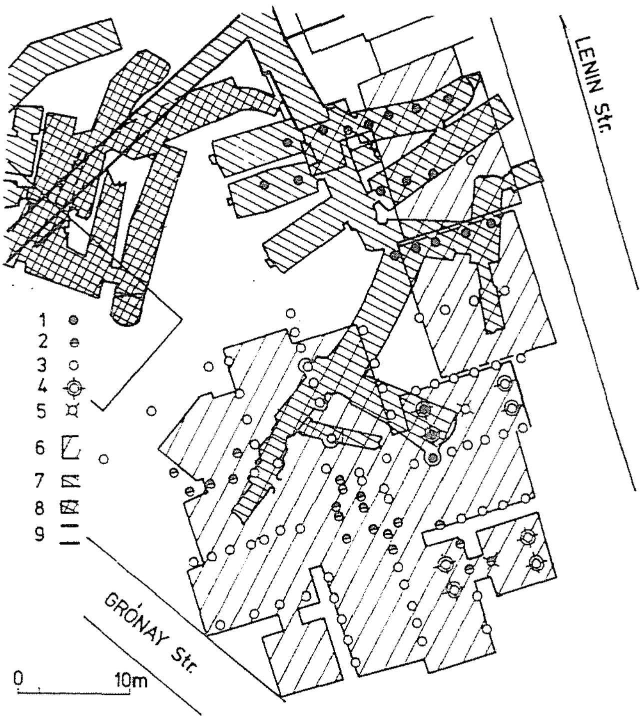

Fig. 27. Pile-foundation of a high building on an undercutted area of Eger (designed by FTV) 1-pile through the cellar; 2-pile driven to an unknown cave; 3—5 any other reinforced concrete drilled pile types; 6-planned building; 7-explored cellar network; 8-backfilled cellar network; 9-cellar branch supported by shaped concrete bricks

supporting works, but they should be handled as part of the city reconstruction plan. Because of these, the moral and technical support of the caves should be done together with the road and public works reconstruction. This attitude is reflected by the result of the most advanced activity that has been performed at Eger (Table VII).

After the expensive supporting works the next important question is the adequate utilization of the caves — that can be traditional as vegetable, fruit, package storage place or according to latest ideas entertaining places, museum, etc.

The settlement historical examination of the caves

Caves causing gravy problems nowadays, played significant role in the economical and occasionally in the military life of the settlements in the historical past That is why in addition to the exploration of construction-geo-

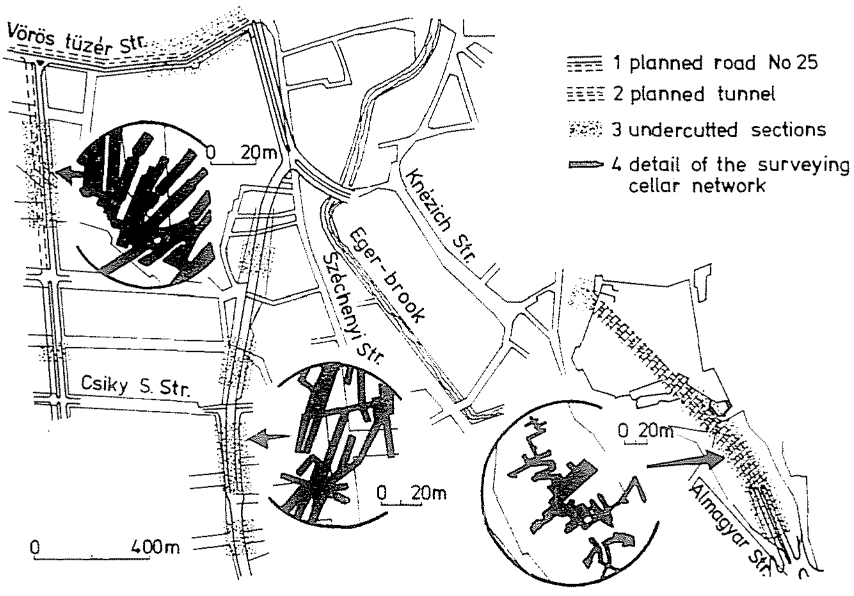

Fig. 28. The planned tracks and undercutted sections of the main traffic road at Eger 1-planned road No 25; 2-planned tunnel; 3-undercutted sections; 4-detail of the surveying cellar network

Table VII

Cellar problems and the result of its solution in Eger

Liquidated	Newly built
105 appartments	11,9 km sewer
21 public offices	10,0 km precipitation canal
6 abutments	
25.4 km (300 pcs) backfilled cellar	0,8 km surface drainage
	18,9 km road reconstruction
	15 abutments
	15,1 km (165 pcs) cellar support

graphical characteristics, the emergency case recording and the solvation of technical problems the settlement historical role of the examined caves have also been studied.

The profession of underground cave — burial vaults, cave dwellings, cellars — cutting preserves its instruments and technics through hundred or even thousand years. Because of this, the faces of cellars, their shape and size cannot provide enough information on the age and circumstances of their formation

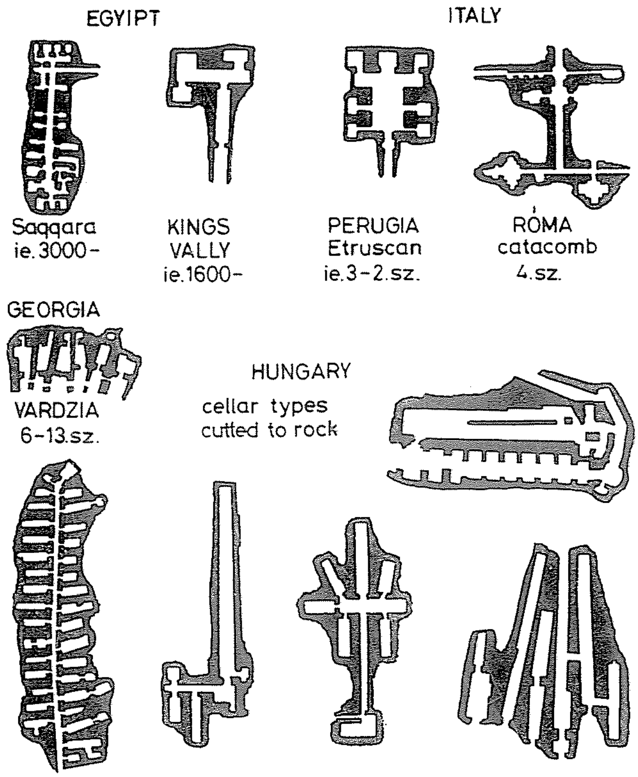

Fig. 29. The plan of underground caves arrangement with international comparison

(Fig. 29). The material of findings of the explored huge cave network — except at Pécs — is very poor. In the territory of Pécs, the first townlike settlement — Sopiane — numerous Early Christian brick covered burial vaults were found. Nevertheless, we are not convinced that they are originated from the Roman time.

From the 13th—15th centuries — partly verified with written documents — we know more cellars cutted to rocks in Buda, Eger, Esztergom, Pécs. Connected to these, there are tunnel-like narrow arms mostly formed in the 16th century, at the time of our struggling against Turks.

In Hungary, most of the cellars were formed after the Turkish rule in the 18th—19th century. At certain settlements — Eger, Szentendre, Szekszárd, Ostoros, Nagymaros — the cellars are the *architectural memories* of the vine monoculture, at that time basis of the economic development. Among them there are some — first of all at the Eger region — containing artistical sculptures deserving protection as historical monuments (Fig. 30).

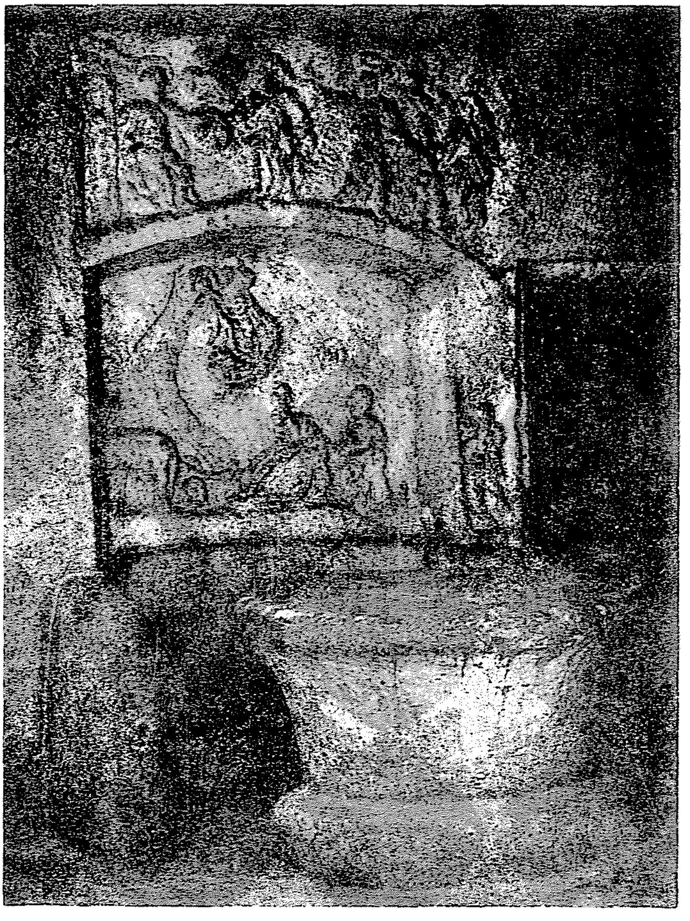

Fig. 30. A cellar, cutted to tuff with relief

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