# TECHNICOGEOLOGICAL OBSERVATIONS IN THE ANCIENT DELPHI AREA (GREECE)

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Summary

The ancient Delphi area represents one of the most important archaeological sites of the historical times of Greece (7th cent. B.C.), in which the most famous oracle of the ancient world had been established. The major area is covered by neritic limestones of Jurassic - Upper Cretaceous age and the flysch formation of Paleocene age which belongs to the "Parnassos" geotectonic unit. Post alpine formations, mainly talus cones, scree and alluvial deposits, cover the major area of the archaeological site. A great number of faults and fault zones cross the limestones and the flysch formation. Some of them are characterized as active faults and they seem to be connected with the seismic activity of the area, since the ancient times. The main technicogeological problem in the area is the rockfalls which are the result of the very intense morphological slopes, of the great number of faults, joints and other discontinuities and their geometry and of the flow of ground water. A detailed tectonic analysis of all these discontinuities is necessary for separating the areas according to their probability for rockfalls, as well as finding the appropriate way to control them. Creep, subsidence and landslides also have been observed, mainly in the flysch and the post alpine formations, as a result of the kind of soils, the water capacity, the morphological slopes and the human activities. The detailed study of the geomechanical properties of the soils, the study of the flow of the ground water and the determination of the thickness of the post alpine formations and the depth of the basement, are the necessary works which have to be done for preventing and controlling these phaenomena.

## 1. INTRODUCTION

As it is well known, a great number of archaeological sites of historical times exist in Greece. A lot of technicogeological problems, can be observed in these areas, as a result of their physicogeographical, geological, neotectonical and seismical conditions and of the human activities since the erection processes as well.

In this presentation, some of the technicogeological problems of the ancient Delphi area will be presented. These results represent the first phase of a bigger research project under the auspices of the Ministry of Culture and Civilisation of Greece.

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* This paper was presented by S.LOZIOS

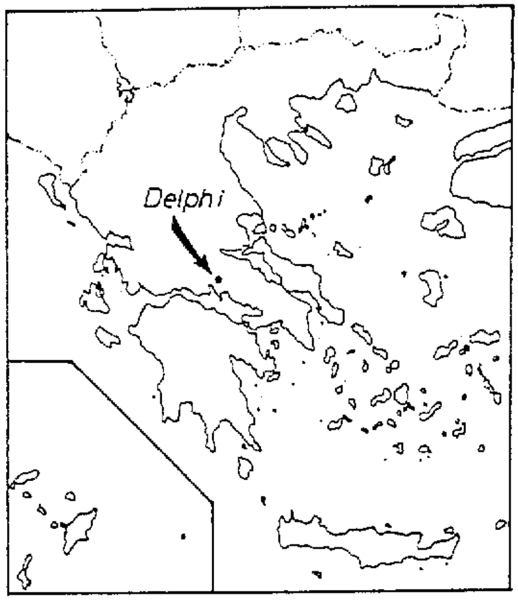


Fig.1 Geographical situation of the area.

The ancient town of Delphi (fig.1), is located 250km west of the city of Athens, in the southern slopes of Parnassos mountain and in the northern border of the Corinthian gulf. It represents one of the most important archaeological sites in Greece, in which the most famous oracle of the ancient world was established.

In the geological map of fig.2, two types of formations, the post - alpine and the alpine, can be distinguished in the major area.

The post - alpine formations are mainly represented by screes and talus cones which cover the major part of the archaeological site. There is a very close relationship between these formations and i) the very intense morphological slopes and ii) the successive reactivations of the Arachova - Delphi fault zone in the northern border of the archaeological site (fig.2 and 3). Four generations of screes can be distinguished (fig.3).

The first one is mainly represented by compact breccias and conglomerates with calcitic matrix.

The second one is represented by breccias and conglomerates cemented with a pelitic material.

The third generation consists of polymict unconsolidated material, including big blocks or fragments of limestones.

The fourth generation is the result of the relative recent rockfalls and it is represented by big blocks of limestones (from 0.5 up to $10m^3$).

The thickness of the post alpine formations differs from place to place, depending on the Palaeomorphology of the basement. So, in the northern part of the archaeological site (fig.2), it seems to be small (up to 2m), as it is proved by the very often basement outcrops. In the contrary, in the southern part it seems to be greater but it does not exceed the 15m.

The alpine formations belong to the "Parnassos" geotectonic unit and they are represented (fig.2), by the flysch formation (alternations of sandstones, marls and pelites) of Paleocene age and neritic and medium bedded limestones of Jurassic - Cretaceous age.

The alpine tectonism is characterized by a large scale overturned isoclinal fold structure (fig.4), resulting the younger formation of flysch to underlie the older limestones in the northern part of the archaeological site. The contact between the limestones and the flysch formation in some cases is normal whereas in some others is an upthrust (due to the alpine tectonism). A great number of upthrusts and reverse faults can be also observed within the calcareous rock mass.

The neotectonic macrostructure of the area is characterized by the existence of first order macroblocks, horsts and grabens, which are separated by fault zones like the first order Arachova - Delphi active fault zone which separates the tectonic mega horst of "Parnassos" mountain to the North from the tectonic graben of "Itea" to the South (fig.5).

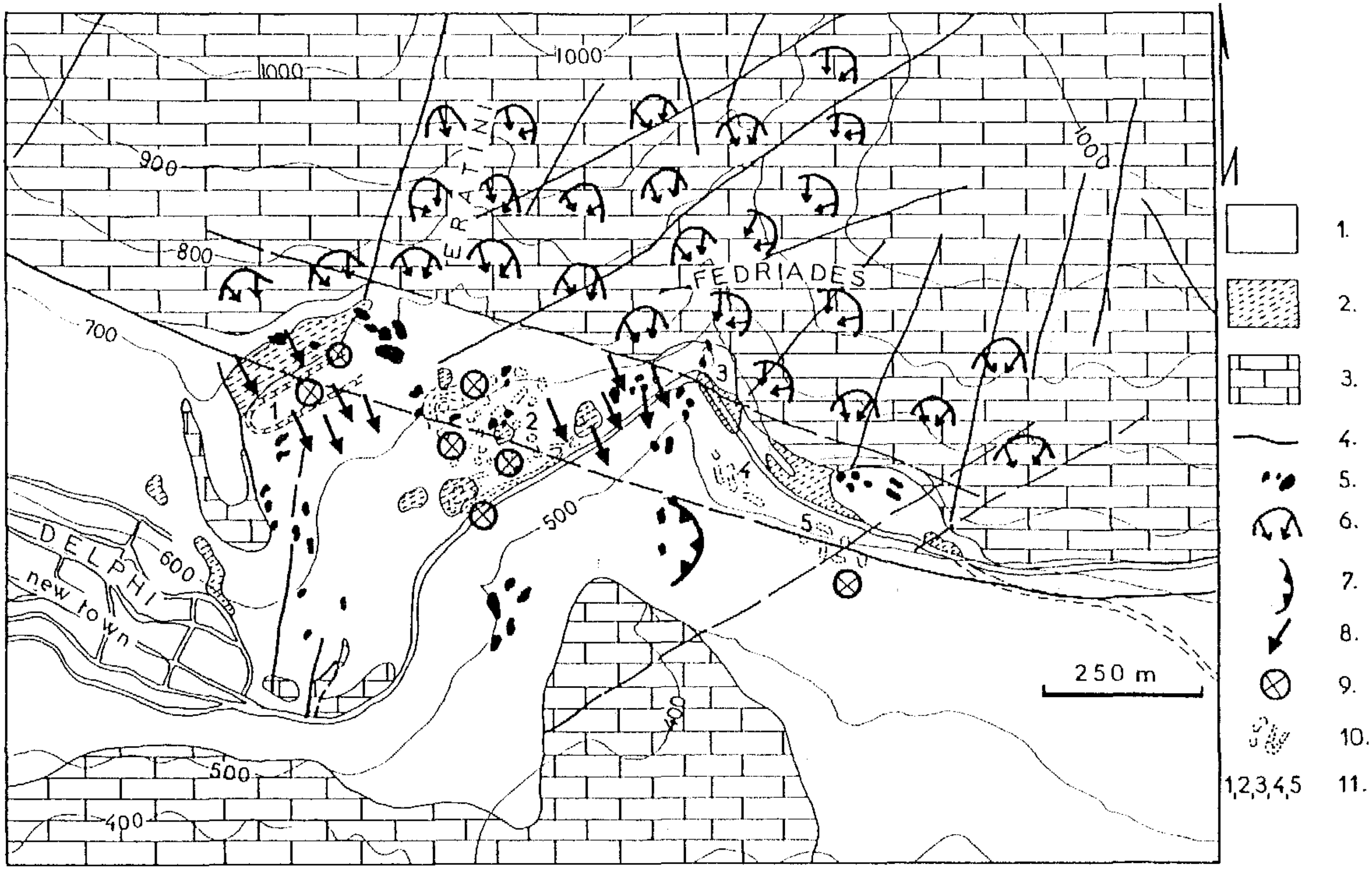


Fig.2 Map of technicogeological data. 1.Scree, 2.Flysch, 3.Limestones, 4.Fault, 5.Rockfalls 6.Dangerous areas for rockfalls, 7.Landslides, 8.Creep, 9.Subsidence, 10.Archaeological sites, 11. (1)Stadium, (2)Apollo Sanctuary, (3)Kastalia spring (4)Gymnasion, (5)Tholos.

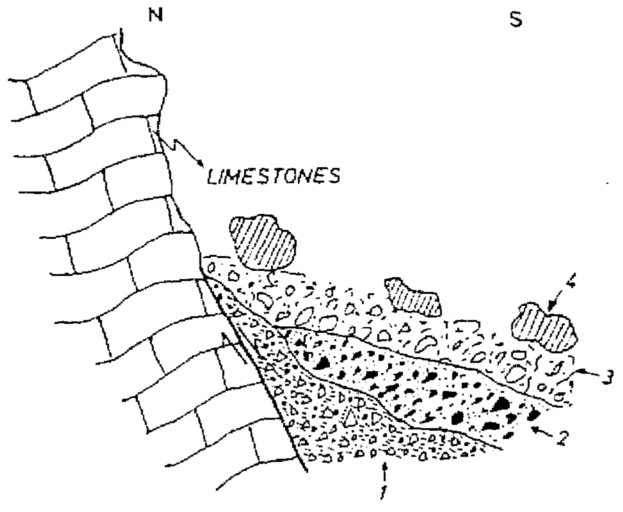


Fig.3 The four generations of scree in the area of Delphi.

A great number of second or smaller order faults and fault zones cross the alpine and post alpine formations. Some of them can be characterized as non - active faults and some others as active. The latter seem to be connected with the seismic activity which has been occured in the area since the ancient times. In the first case the fault surfaces can be convexe or concave when they are small and wavy when they are big. In some places, a lot of slickensides have been observed (fig.6) In the contrary, the active fault surfaces of the area, are almost plane and cross the non - active ones. They are usually accompanied by a zone of "loosing material", a zone of "cataclastic rock" (fig.7). This type of fault surfaces are mainly reactivated during an earthquake.

The hydrogeological conditions of the area are defined and controlled by the alpine and post alpine structure. In fig.8, the flow of the groundwater in the calcareous mass within the discontinuities (faults, joints,...etc.) and the karsts, is presented. Along the contact between the limestones and the flysch formation a lot of springs can be observed and they are characterized like typical "contact" or "overflow" karstic spings. The flow of the surface water, in the major area, take place along the Fedriades torrent to the east and the Eratini torrent to the west. A lot of destructions have been caused during the periods of very intense rainfalls

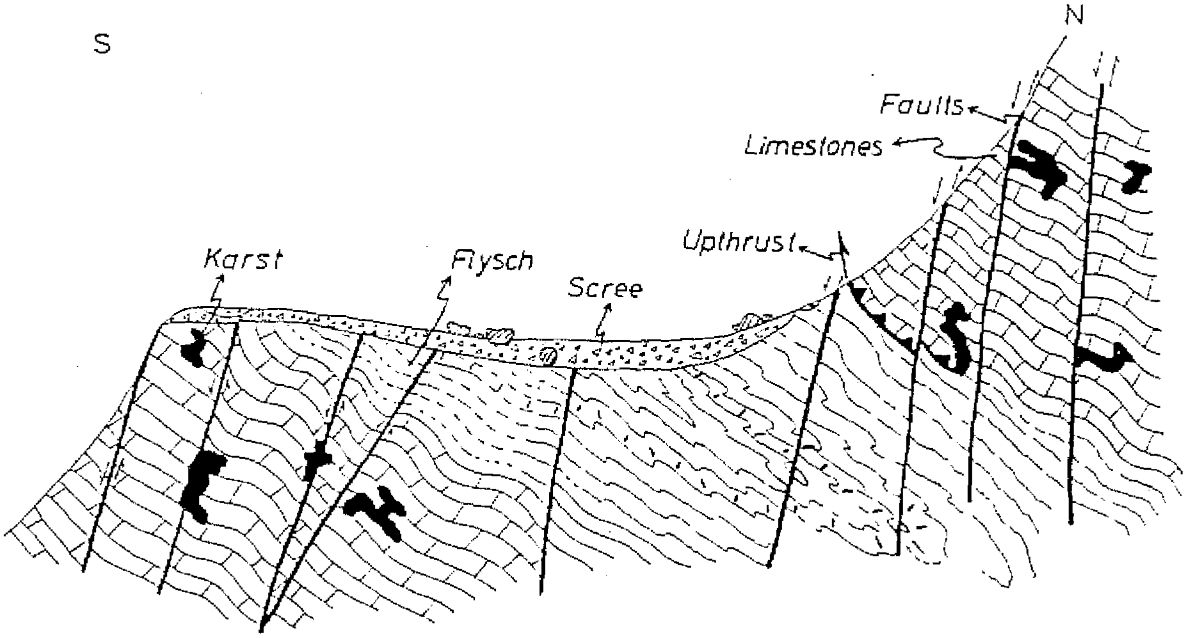


Fig.4 Schematic geological cross section.

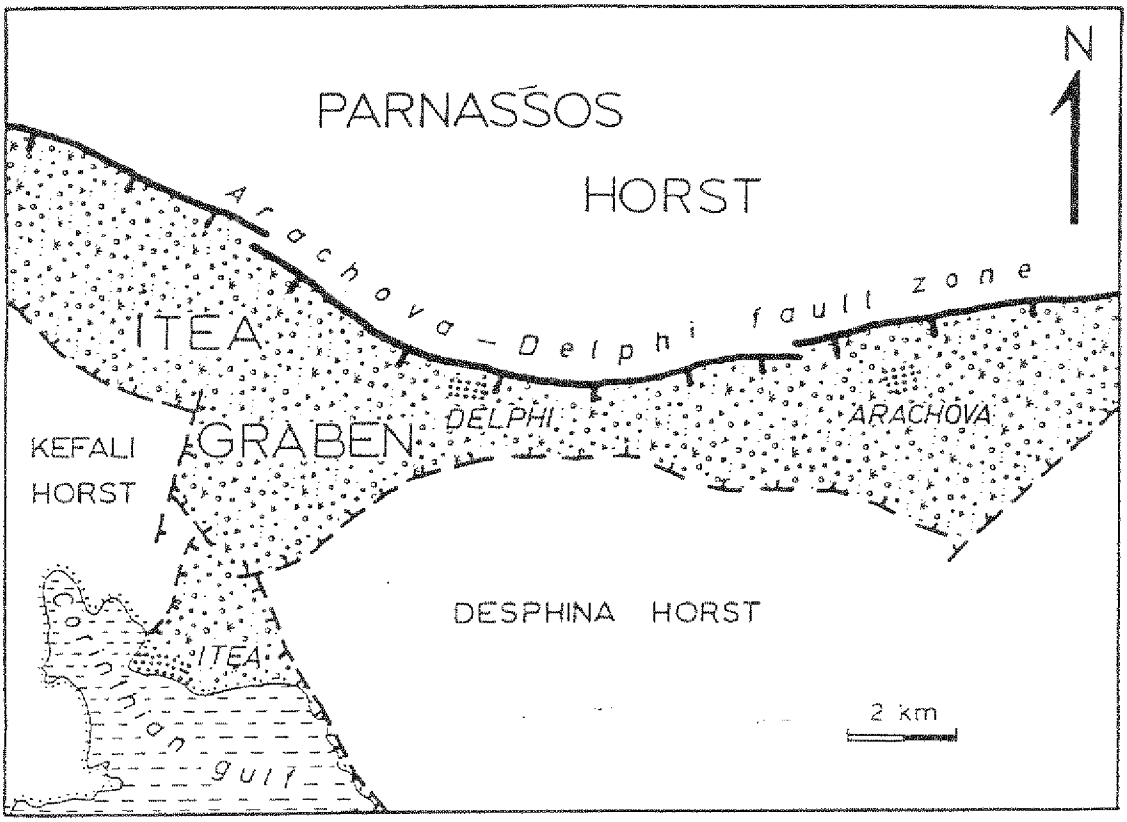


Fig.5 The neotectonic macrostructure of the major area.

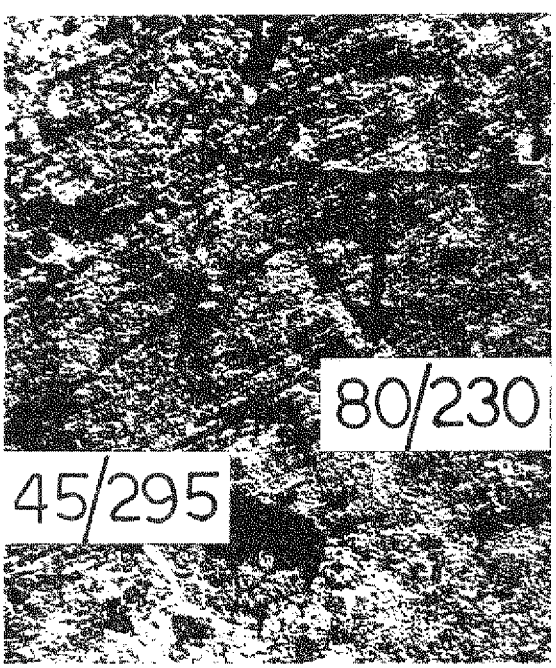


Fig.6 A non active fault surface in which one set of slickensides can be observed.

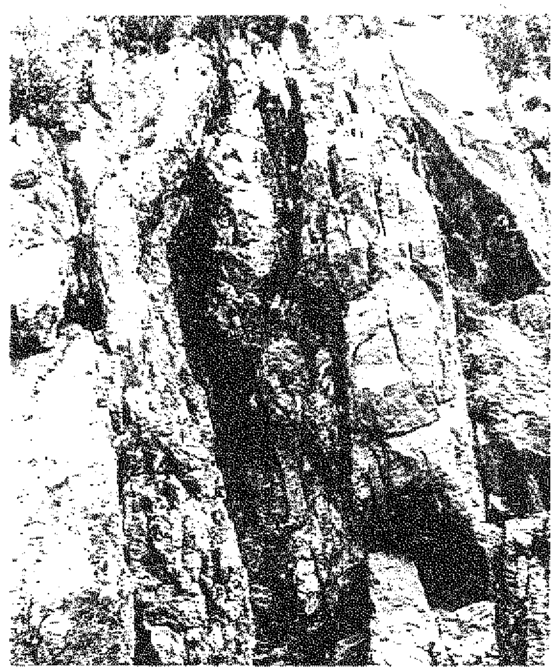

Fig.7 A typical active fault zone.

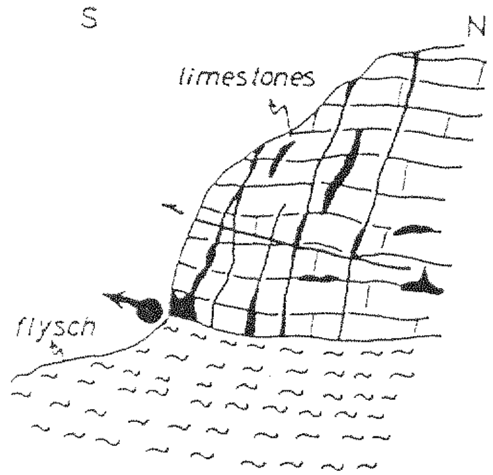


Fig.8 The flow of the groundwater within the limestones and the creation of the "contact" or "overflow" springs.

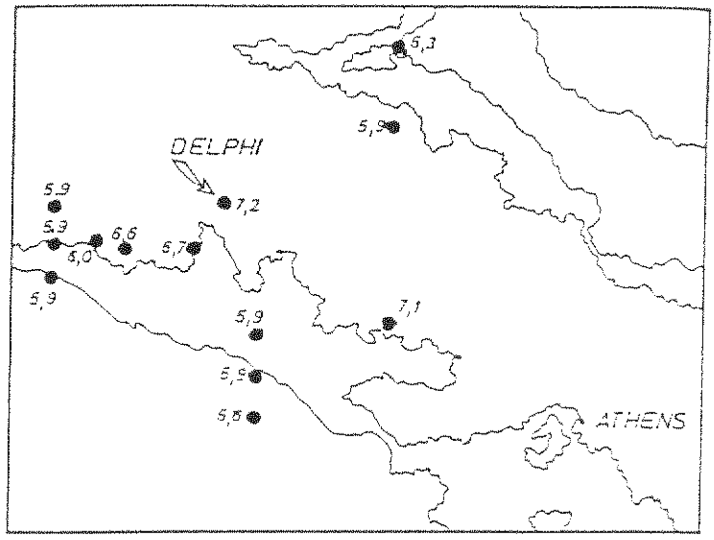


Fig.9 The earthquakes of the major area with M>5 up to 1985.

(like 1935), by the violent flow of the surface water.

The seismic activity of the major area seems to be very high since the ancient times, as we can see in fig.9 where the epicenters of the earthquakes with a M>5 up to 1985, are presented. The ancient town of Delphi was totally destroyed by the earthquakes of 600 B.C. ($I_o$=VIII-X).

The probability for the occurence of shallow earthquake with $M_s>6$ in the period 1986 - 2006 is $0.80<p<1.00$ (PAPAIOANNOU 1986).

The expected macroseismic intensity for a design period of 80 years is VIII-IX (PAPAIOANNOU 1986).

The expected ground acceleration, with a probability 63% of not been exceeded in the next 50 years, is 250-275 cm/sec$^2$, (MAKROPOULOS 1986).

## 2. TECHNICOGEOLOGICAL OBSERVATIONS

The technicogeological problems of the narrow, as well as of the major area of the archaeological site of Delphi are rockfalls, subsidence and creep phaenomena and landslides.

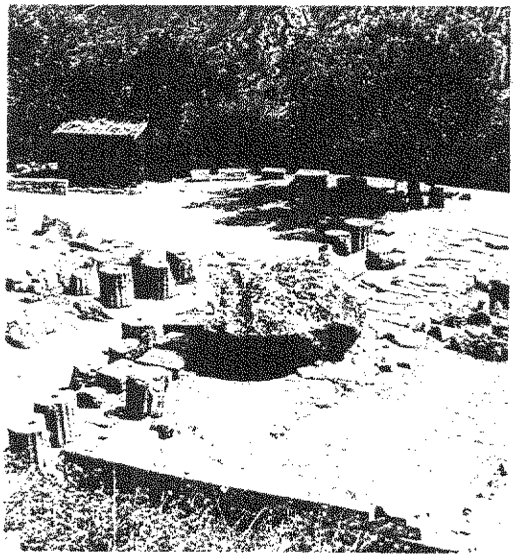

Fig.10 Rockfalls in the area of the archaeological site.

The rockfalls represent the main technicogeological problem of the area (fig.10). A great number of "big blocks" exist, as a result of the relative recent rockfalls. This problem was existing since the historical and pre - historical times as it is proved by the fact that the southern wall of the sanctuary of Apollo is built on a big fallen block of limestones (fig.11), as well as by the presence of big blocks of limestones within the 2nd and 3rd generation of scree which consist the basement of some ancient constructions.

The density and the presence of rockfalls phaenomena varies from period to period, as it is shown by the study of the "stratigraphy" of the scree generations and of the recent

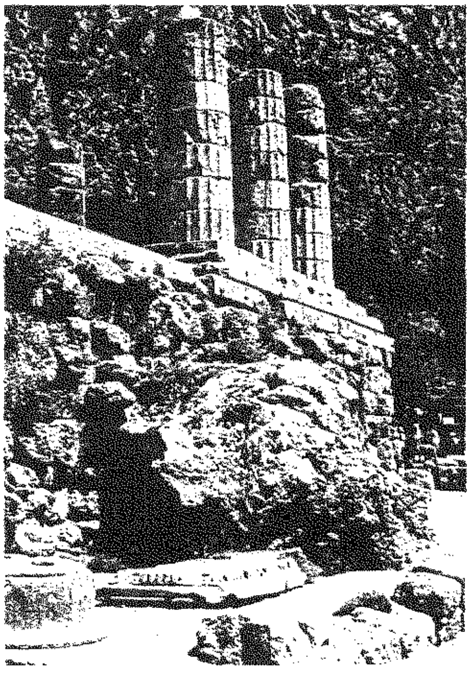

Fig.11 The southern wall of the sanctuary of Apollo which is built on a fallen block of limestone.

rockfalls; during 1980 e.g. the rockfalls were very often and common phaenomena, due to tectonic (high seismic activity), or other causes (hydrogeological or meteorological).

The products of the rockfalls processes are represented mainly by fragments or blocks of limestones, from 10cm up to 10m, and rarely by blocks of flysch. They cover the major part of the archaeological site and the surrounding area, mainly along the scarp of the contact between the limestones and the flysch, (fig.2).

The very intense morphological slopes of the calcareous mass, in the northern border of the archaeological site, (as a result of the differential errosion between the limestones and the flysch as well as of the vertical component of the displacement along the Arachova - Delphi fault zone), and the great number of discontinuities, that cross the limestones separating the rock mass in bigger or smaller blocks, in combination with their geometrical features (density, size, dip and dip direction,...etc.), represent some of the major factors and causes which will define the dangerous areas for rockfalls, (fig.12).

In some areas, the density of the discontinuities (faults, fractures, joints, upthrusts, bedding,...etc.), is so great, that the whole "mass" is fractured in small pieces, giving to the limestone the image of a gigantic mass, more or less "loose". All these surfaces cross and break the whole area to big rhomboeder shaped blocks, which represent an enormous tectonic macrobreccia, very dangerous of course, for rockfalls (fig.13).

The density of the discontinuities is usually great, in the case where a lot of joints,in an en echelon arrangement, are observed between successive upthrust surfaces, as it occurs near the tectonic contact between the limestones and the flysch formation.

The hydrogeological and climatological conditions of the area (flow of the groundwater, pore pressure, solution and errosion, decreasing of friction coefficient, intense rainfalls, temperature fluctuations,...etc), are also favorable factors for rockfalls.

A very detailed tectonic analysis and mapping has been done in some places for preventing and controlling the rockfalls phaenomena. Elements were taken into consideration during this analysis, like the orientation, the frequency, the density and the size of the discontinuities, if they are continuous or not, if they are open and filled up with loose material, the value and the weight of the separated blocks, the area of the probable failure surfaces,...etc.

As it was proved, the first order tectonic structures (faults and fault zones, megajoints, upthrust surfaces,...etc), that cross the limestones, separate the whole calcareous mass in big blocks. The geometrical features of the discontinuities differs from macroblock to macroblock, so some of them are dangerous (more or less), for rockfalls and some others not, (fig.14).

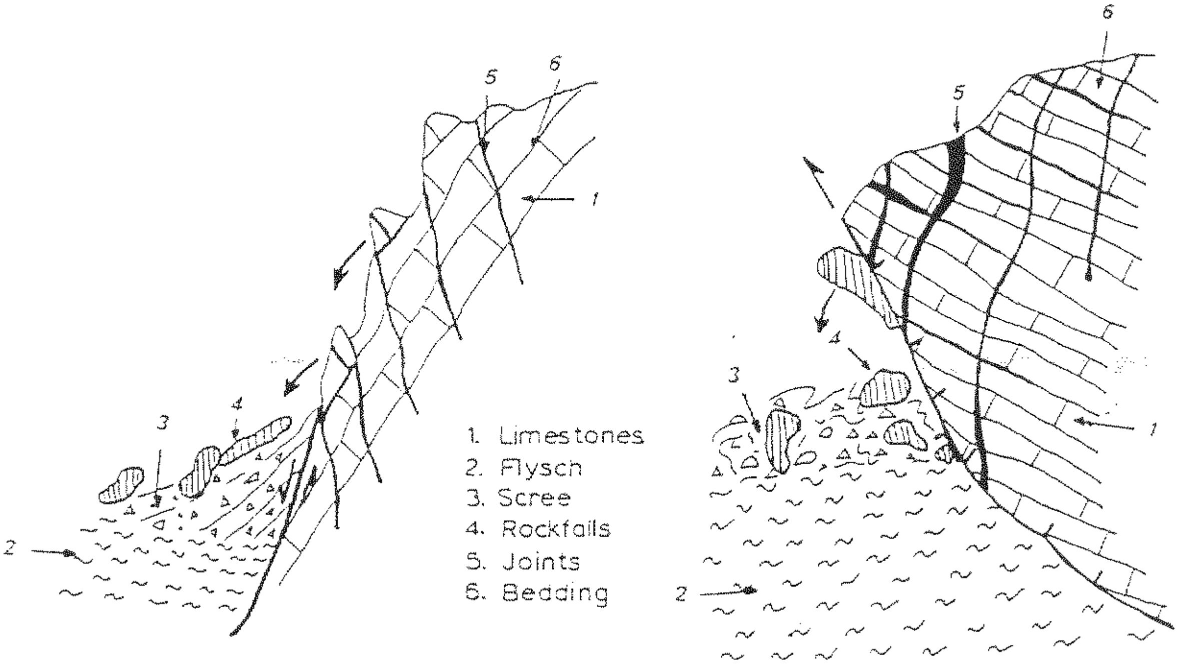


Fig.12 The very intense morphological slopes and the great number of discontinuities represent some of the most important factors for the creation of rockfalls along the contact, between the limestones and the flysch formation, which can be a fault or an upthrust.

Fig.13 The great number of discontinuities gives to the limestones the image of a tectonic macrobreccia, dangerous for rockfalls.

The engineers, taking into consideration also some other important factors (like the coefficient of internal friction, the geomechanical features of the filling material, the safety factor, the cohesion, the seismic load coefficient,...etc.), have proposed some solutions for concrete sites, like the Fedriades area, where the rockfalls destroy and close the road from Arachona to Itea (fig.15) (MONOKROUSOS - PAPADAKIS 1985). Generally the problem of the rockfalls in the area of Delphi, in some cases is very complex and complicated, because the density of the failure surfaces is so great that it is very difficult to control all of them. In addition to this, the existence of active fault zones that could be reactivated during future earthquakes and the almost vertical slopes, make aimless and disadvandageous the control efforts.

The creep and the subsidence are also common phaenomena in the area of the archaeological site.