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GEOLOGICAL CONDITIONS OF NORTH EAST ATTICA (ATHENS, GREECE) WITH REGARDS THE SELECTIONS OF A LANDFILL SOIL LINER AND A LANDFILL SITE.

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ABSTRACT

Modern selection procedures involve landfills that depend upon a combination of engineering systems and low permeability natural occurring strata. Geological, hydrogeological, geotechnical and environmental criteria, play the key role to landfill design and selection. In north east Attica the intensely folded geologic formations determine groundwater movement and migration of the pollutants. Lack of low permeability strata, tectonic activity together with the requirement to keep waste contained until is inert make the use of a soil liner necessary, regardless of where the landfill will be located. Geotechnical properties of the proposed liner were found satisfactory. Sites proposed for further in situ investigation offer solutions with minnimum environmental risks.

Key words: landfill selection, soil liner, geology of Attica, Greece.

RESUMEN

Los procedimientos de seleción modernos implican rellenos antrópicos que dependen a su vez de una combinación de sistemas de ingeniería y la presecia de estratos de materiales de baja permeabilidad. Los criterios geológicos, hidrogeológicos, geotécnicos y ambientales juegan un papel clave en el diseño y selección de los rellenos antrópicos. En el noreste de Attica, la presencia de formaciones geológicas intensamente plegadas implica movimientos de agua subterránea y la consiguiente posibilidad de migración de contaminantes. La ausencia de estratos de baja permeabilidad y la actividad tectónica, todo ello unido a la necesidad de mantener aislados los residuos hasta que sean inertes, hace necesario el uso de capas impermeabilizantes, independientemente del lugar donde vaya a situarse el relleno. Las propriedades geotécnicas de las capas propuestas fueron satisfactorias. Los lugares propuestos para nuevas investigaciones in situ ofrecen soluciones con mínimos riesgos ambientales.

Palabras clave: Geología de Attica-Grecia, capas impermeabilizantes, rellenos antrópicos

INTRODUCTION

The problem of waste management in Athens is becoming increasingly acute as existing landfills that do not conform with environmental standards will close in the next few years. The only operational waste disposal site is situated at Ano Liosia approximately 12 km north west of Athens. The site has already exceeded the initial planned operational life and will close in the next few years. An old waste disposal site at Schisto, situated west of Athens is known to contribute to the pollution of groundwater.

Climatologic conditions that dominate in Athens (low rainfall, no freeze) together with availability of low cost land, offer a very strong advantage to disposal by landfilling which is considered the most effective solution. New landfill sites around Athens are necessary and both local and central authorities have now recognised the imperative nature of the problem. Two new sites north and west of the city are planned. The final landfill site for North East Attica will accept domestic (household) wastes of three transfer stations and the neighbouring villages. The expected weight of wastes, the landfill should be able to accept, is 1335 ton/day total, according to the responsible waste authorities.

The major morphological feature of NE Attica is Marathonas Lake which supplies Athens with drinking water. We can therefore understand, the importance of the lake and the need to remain, at any cost, free from pollution caused by the proposed landfill in NE Attica.

GEOLOGY OF ATTICA

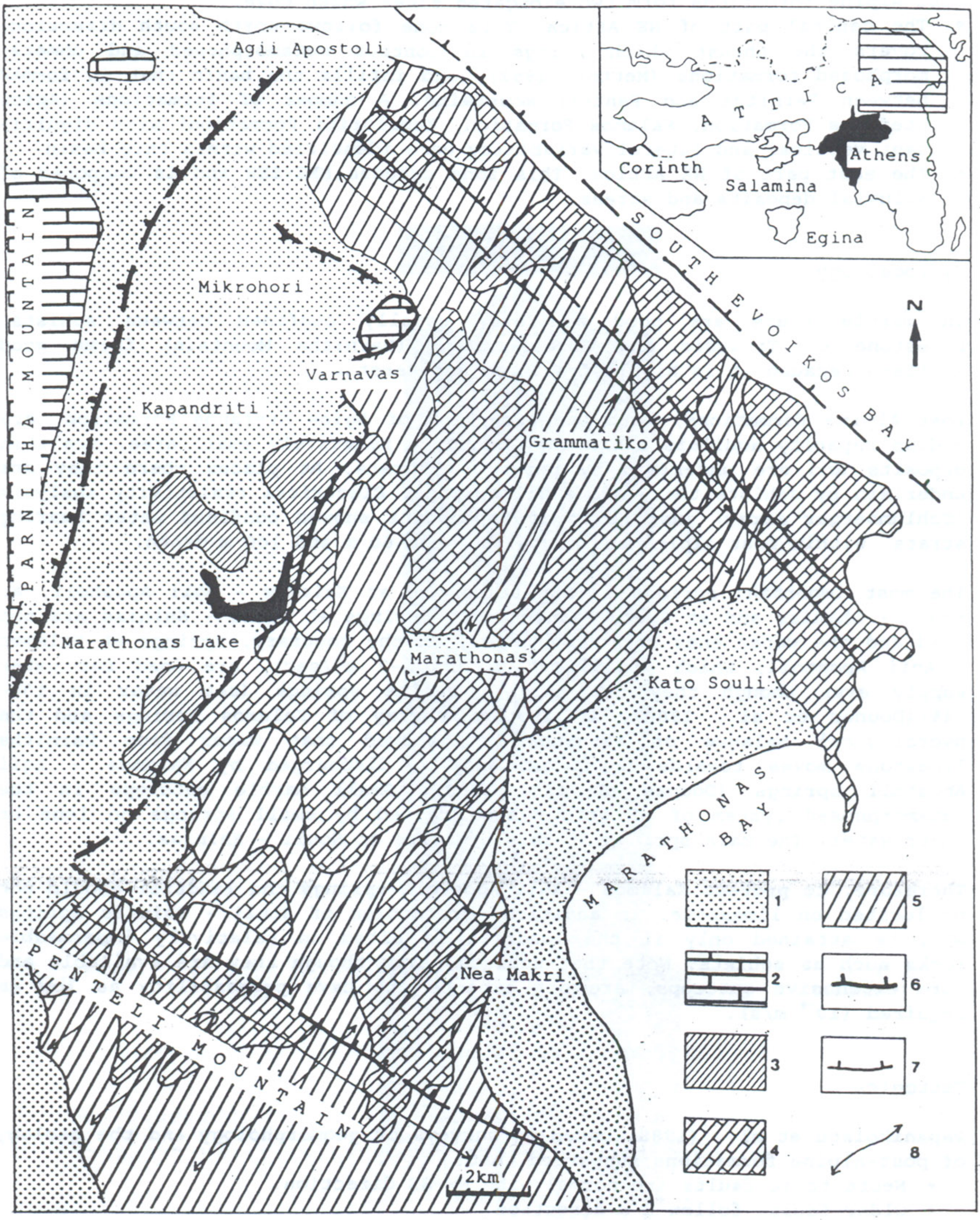
Geology

NE Attica is composed of metamorphosed and unmetamorphosed rocks (Fig. 1). Unmetamorphosed rocks occupy the west part of the study area, mainly Parnitha mountain, and are overthrusted on metamorphosed rocks which form the east part of the region even though the opposite has been observed locally (Dounas et al., 1979). The thrust follows a N - S general direction and is covered with post alpine formations.

A recent survey (Lozios, 1993) on metamorphosed rocks (Penteli Mt.), concluded that the region of NE Attica belongs to the relative autochthonous of "NE Attica Unit" and the allochthonous "Agios Georgios Unit". NE Attica unit covers most of the area of interest. The basic materials are marble, schists, quartzofeldspathic gneissose and metabasic rocks. The later two rock types form a metavolcanosedimentary sequence. "Agios Georgios" Unit is a mesozoic, HP/LT (blueschist) metamorhosed unit not important for landfill site selection because it forms only limited outcrops.

Marbles, from a stratigraphic point of view, overlie schists and are in normal contact with them. There is no large scale continuity between marbles which means that potential migration of the pollutants will be confined. Transition beds between schists and marbles comprise sipoline marbles and interbedded horizons of marbles and schists. If marbles of the transition beds are in hydraulic continuity they can provide routes for the escape of the pollutants.

Large scale isoclinal folds of NNW-SSE direction dominate in metamorhosed rocks of NE Attica. This feature is of great hydrogeological importance because it determines the large scale movement of the pollutants, i.e pollutants would percolate down the marbles and flow on the surface between marble and schists. Marble is therefore unacceptable and the thickness of schist outcrops must be investigated prior to landfill development. The landfill should be lined because intense folding may have resulted to thin schist beds and hydraulic continuity between marble horizons at depth.



1. Post Alpine Formations (undivided), 2. Unmetamorphosed Alpine Formations, 3. Schists with marble intercalations (Agios Georgios Unit), 4. Marble of the relative autochthonous unit of NE Attica, 5. Schist and occasional gneiss with few marble intercalations (NE Attica Unit), 6. Thrust, 7. Fault, 8. Fold axes

Fig. 1 Simplified Geologic map of NE Attica (Lozios 1993).

Post Alpine formations form two elongated zones which cover:

- The central part of NE Attica. This zone follows north south direction, covers the thrust which brings in contact metamorphosed and unmetamorphosed formations (Mettos, 1992), and infills the basin that is formed between Parnitha and Penteli mountains. A number of formations (Agios Stefanos Formation, Kalamos Formation, Kapandriti Formation) with significant vertical and lateral variability were identified within this basin.
- The east part of NE Attica. This zone extends NNE-SSW and is composed of alluvial deposits and screes.

Hydrogeology

In marble there are good aquifers, usually confined between schists. Limestone of Triassic and Jurassic age (Parnitha Mountain) forms good aquifers because it is highly fractured and karstic.

Post Alpine Formations, with the exception of Agios Stefanos Formation, are medium capacity aquifers since they occupy a relatively small area, are thin deposits and are underlain by permeable strata. At places where they are underlain by schists there are small springs. Electrical resistivity analysis (Schlumberger array) just north of Kapandriti showed confined water bearing strata, within post alpine sediments, between 60 m and 100 m depth.

The most important springs in NE Attica are at Kalamos - Agii Apostoli, at Souli - Shinias and at South Parnitha Mt. Springs at Souli - Shinias are not used and the water ends up into the sea. On the contrary, springs at Kalamos - Agii Apostoli, which yield most water (1-2 m^3/sec), are used for water supply even though they are karstic saline springs (sea water is 10%-14%)(Dounas et al., 1980). An isotope survey of Kalamos springs and the hydrological balance of Parnitha Mt. showed that water from Parnitha limestone moves towards northeast and is discharged by Kalamos - Agii Apostoli springs (Dounas et al., 1980). Small marble outcrops in the metamorphosed system of NE Attica are drained by small springs on land or under water. The main springs of this type are at Souli - Shinias.

Therefore, to protect Kalamos - Agii Apostoli springs the landfill should not be located on limestone. In addition, protection of Souli - Shinias springs will be attained only if the landfill is sited on relatively impermeable rocks such as schists. Note that schists, even though they are available and form extenssive outcrops, are not expected to have permeability as low as required (10^{-9} m/s).

Tectonics

Papanikolaou et al., (1988) based on surveys of geomorphology and the geology of post-alpine formations supported that:

- Neotectonic faults are normal with NW-SE direction.
- Older faults follow E-W direction.
- There are complicated movements but the overall tendency is rotation of NE Attica around a horizontal E-W axis which results in uplift of the area.
- Faults were activated during Pliocene and they are still active today.

Note that, faults in NE Attica, even though they are active from a geological point of view, have not given major earthquakes i.e. they are not seismic

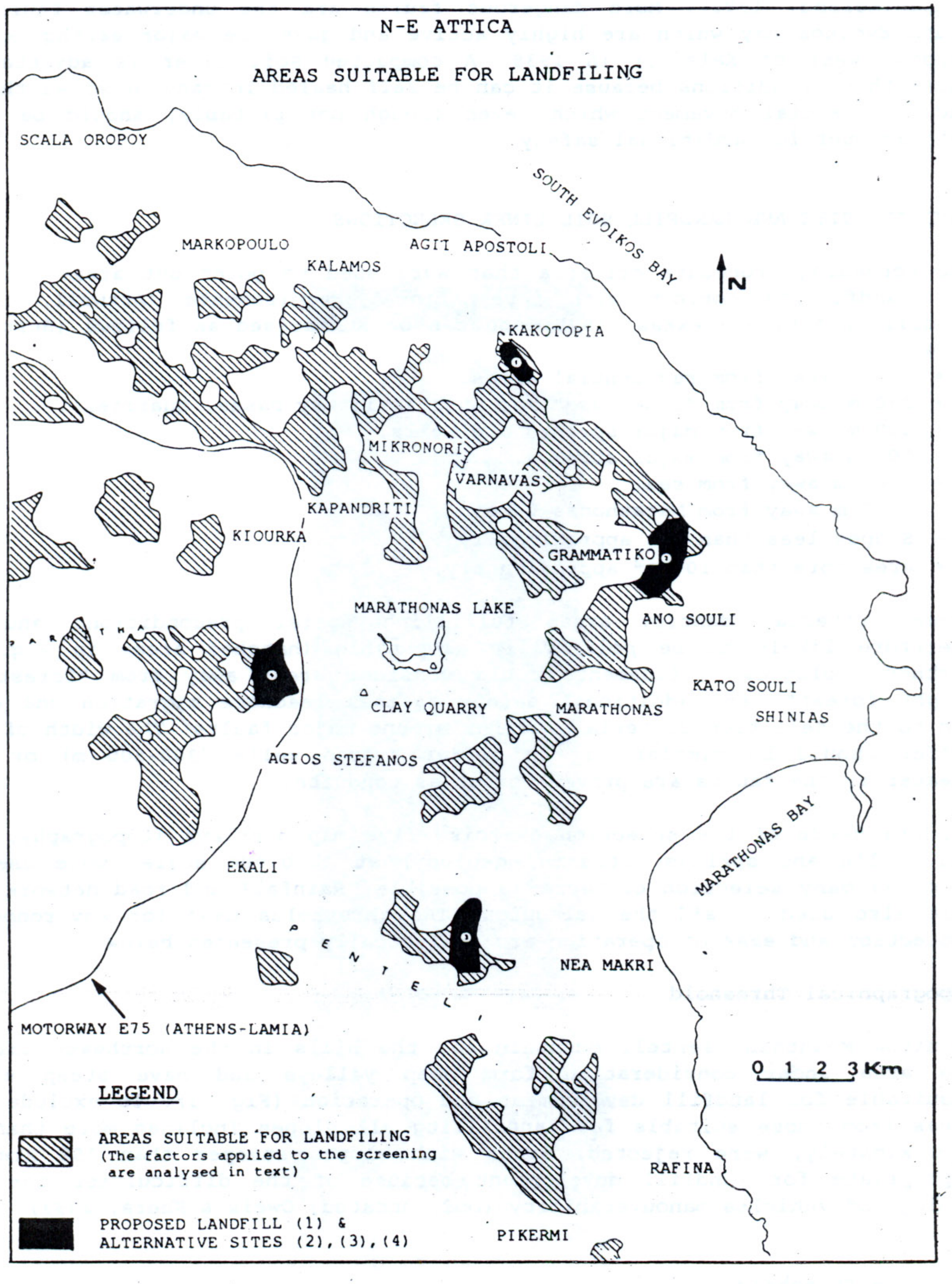


Fig. 2 Areas Suitable for Landfilling (hatched) and Sites proposed for detailed in situ investigation (black).

500 m wide around residential areas was rejected. A buffer 250 m wide around the "other use" map unit was also rejected.

Wells and Springs Thresholds

Registered wells up to 1988 together with springs are shown in Fig. 5. Most of the wells are located in residential areas and are shallow wells used for irrigation. Near the villages of Varnavas, Grammatiko and Kapandriti there are some deep wells which exploit aquifers within the Post Alpine Formations.

Sites closer than 300 m to major springs and wells were rejected. This distance is set by East Attica Authorities as the minimum distance between wells. Note that this distance is not a standard but it is used at this stage of the study to help the screening procedure. Detailed hydrogeological survey at the selected sites to define the travel time to potential targets will be needed to assess the pollution susceptibility of wells and springs (NRA, 1992).

Stream Threshold

For the screening procedure a buffer of 500 m around the major streams (Fig. 6) was used to reflect the greater sensitivity of surface water compared to groundwater. Note that, like the buffer around springs and wells, this distance is not a standard but it is used to help screening. Minor streams have only seasonal flow and were not specially protected.

The distance away from sea and Marathonas lake that was used for the selection was 3 km. Such a long distance was selected because of the importance of Marathonas lake and the attractiveness of sea at NE Attica.

Access

The road network map of NE Attica can be seen in fig. 7. The motorway can be used to access the landfill even though it suffers from heavy traffic. NE Attica in general, has easy access to any site suitable for landfilling. However, by-passes will be needed to avoid small villages. The railroad which essentially follows the same route with the motorway can also be used for transportation of the waste without causing extra traffic.

Rainfall

High rainfall areas were excluded from the areas suitable for landfilling mainly due to limitations of topography. The remaining land accepts essentially the same rainfall with some differences, not adequate to influence the landfill selection, at the hilly terrain north of the area under consideration (Fig. 8).

A characteristic of the rainfall in Greece is that it is concentrated in short but intense events. Concentrated rainfall means that water infiltrating into the site is minimum which in turn means minimum leachate production. Problems such as flash flooding and slope erosion (e.g. material placed for lining) can, however, result from heavy rainfall events.

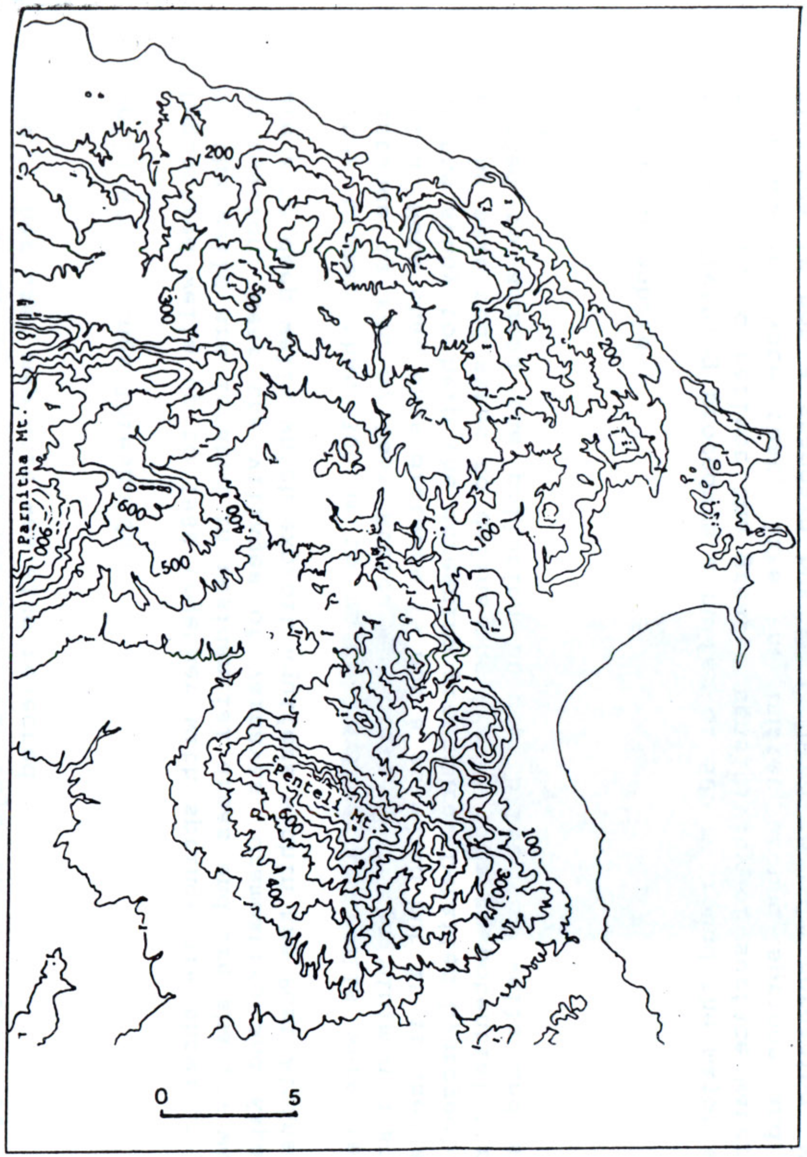


Fig. 3 Topography

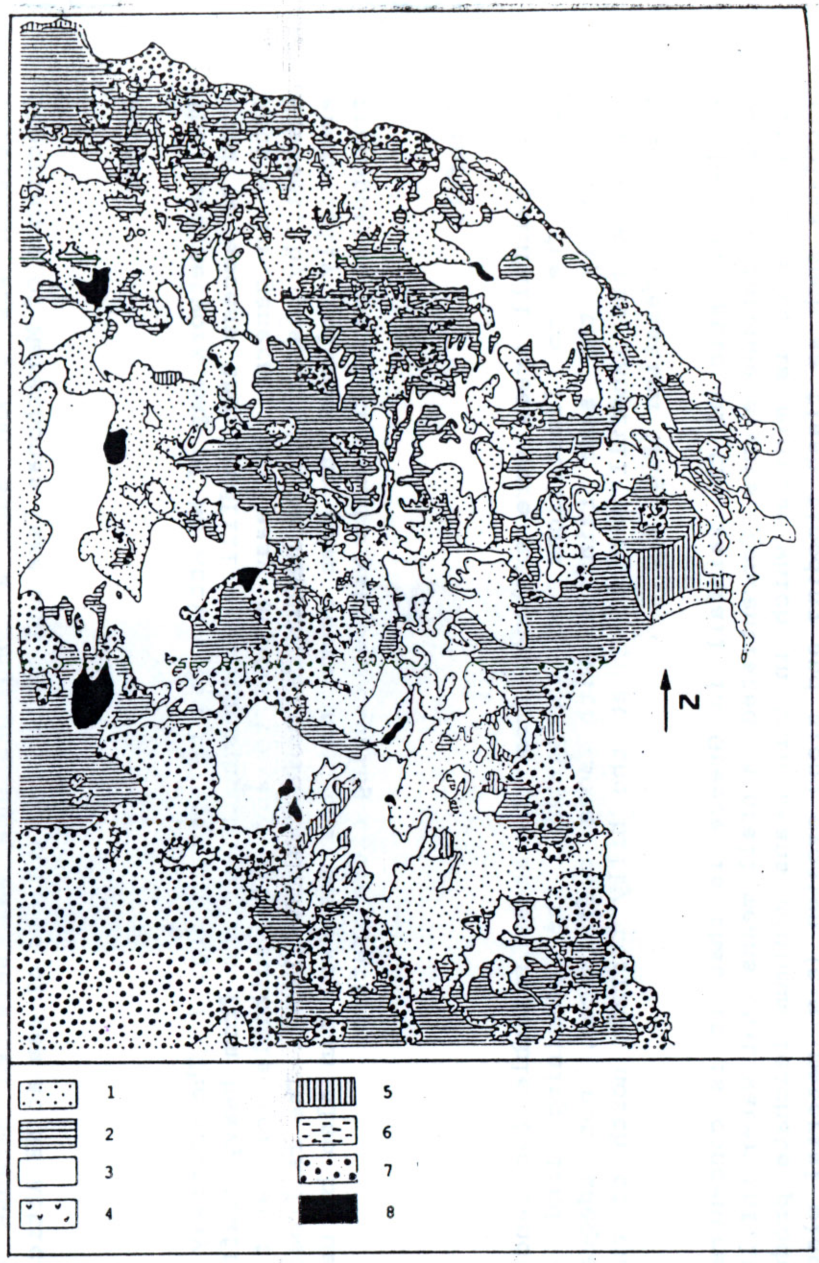


Fig. 4 Land Use map (1. Forest, 2. Agriculture land, 3. Light Forest, 4. Scrubbs, 5. Infertile land, 6. Pasture, 7. Residential areas, 8. Other Uses)

Geological - Geotechnical Criteria

Geological criteria, to identify areas with impermeable bedrock or soils, were applied to prioritise areas within the "*politically acceptable*" zones defined above. Sites 2 and 3 (Fig. 2) lie completely on schists and Site 4 lies on Agios Stefanos Formation (red silty clays of Miocene age). All sites were selected in valleys to reduce visibility. Site 1, which was identified by the responsible authorities, is partly on schists and partly on marbles. The fact that no permeable formation is present at Sites 2, 3 and 4, and that they have good access, offers them a strong advantage against Site 1. Further investigation including detailed mapping, boreholes, in situ and laboratory tests, are nessecary to establish the hydrogeology and the geotechnical properties of the materials (Cooper, 1991). Other low permeability materials like metaflysch (Agios Georgios Unit) are not suitable due to their limited outcrops. Unmetamorphosed formations of Parnitha mountain were not used because they comprise mainly limestones and flysch type rocks which have only limited outcrops and form aquifers and springs that need to be protected.

To investigate the suitability for a soil liner or filters, the materials present on Site 1, which is in a valley typical for NE Attica weathering conditions, were tested in the laboratory (Table 1) and the conclusions may be safely extrapolated to all sites on schists in NE Attica. Particle size distribution analysis of the materials on the slopes (1) showed very low clay content (12%) and high sand content (51%) which indicate materials unsuitable for liners. Field permeability of such soil is expected to be high, due to high sand content, and is increased even more by root and worm holes. If this site is finally selected soils that cover the valley slopes can be used to infill the valley bottom and make it accessible to equipment. Soils that were found on the valley bottom (2) can not be used for construction of filters since they are mainly silty sands and not clean sands or gravel which are required for this purpose.

	SOIL TYPE	MOISTURE CONTENT	LL	PL	PI	CLAY CONTENT	SAND CONTENT	ACTIVITY
		%	%	%	%	%	%	
(1)	VERY SANDY SILTY CLAY	7.6	33	21	12	12	51	1
(2)	SILTY CLAYEY SAND	1.4	-	-	-	6	68	-

Table 1. Summary of laboratory test results for the soils present at Site 1.

A slope instability mechanism that acts on site is creep. A clear indication of creep is the shape of tree trunks, which are not straight but show a curvature near their base. The potential mechanism is creeping of the upper weathered mantle which comes essentially from schist, over the unweathered and more competent rock. Heavy rainfall or earthquakes can trigger bigger landslides of the weathered mantle. Slope angles as high as 70° are produced by the intense downcutting of the torrents, but they are not stable in the long term if soils or adverse discontinuity orientations are present.

Rresence of marble on Site 1 may lead to pollution of the neighbouring area. Pollution of Marathonas Lake, South Evoikos Bay or Kalamos - Agii Apostoli Springs is not anticipated given the geology of the area. Pollution of the springs at Shinias is possible but not anticipated because of the distance between the landfill and the springs. Detailed hydrogeological investigation is necessary to confirm the conclusions of this preliminary stage.

Problems for site development and operation are expected because of the steep slopes (19° average) of the valley. Minor slope stability problems (creep of the upper weathered mantle and shallow slides) can be dealt with by removing the potential to landslip material and grading the slopes. The cost of such works will have to be considered. The major advantages of Site 1 is that leachate collection is relatively easy due to the natural sloping of the site (5° towards north), and that it does not face opposition from the local community.

SUITABILITY OF AGIOS STEFANOS FORMATION CLAYS FOR LINING A LANDFILL SITE

A compacted soil liner should be used as was pointed out by the geological, hydrogeological and tectonic conditions. Agios Stefanos Formation red silty sandy clays are potential for lining or siting a waste disposal facility. The advantages of Agios Stefanos clays for use as liner, are:

- There is already a quarry which produces material for brickworks. This will minimise development cost and will speed up operations, since opening of a new quarry is not necessary. In addition, environmental impact will be minimum.
- The quarry is situated at the "centre" of NE Attica (Fig. 2).
- It is the only quarry in such formation.

To investigate the geotechnical properties of the clays, large undisturbed blocks were taken back to the laboratory and sub-samples were extracted using driven samplers. Natural moisture content was preserved. The tests that were executed are: Index tests (liquid limit, plastic limit, natural moisture content), Particle Size Distribution, Oedometer test, Shear box test, Standard Proctor test.

Table 2 and the points below summarise the laboratory test results:

- Average index properties are: LL=31%, PL=16% and PI=15%.
- Cohesion is 0.3 kg/m^2 and angle of internal friction is 25°
- Coefficient of volume compressibility is 0.1 m^2/MN.
- Optimum moisture content is 14%

The main conclusions that can be drawn from the tests are:

- Strength is adequate to secure slope stability even in steep landfill slopes.
- The coefficient of volume compressibility shows low compressibility and therefore no settlement problems are anticipated.
- The soil falls above the A-line in the Casagrande Plasticity Chart (group CL - Inorganic clays, silty clays, sandy clays of low plasticity). This is advantageous for use as lining.
- Plasticity index is lower than 40% which shows that soils are not susceptible to cracking when drying.
- Samples have high clay content (25-28%), high sand content (24%) and are well graded which is advantageous because it reduces porosity and therefore permeability.
- Optimum moisture content (14%) is easy to achieve by adding a specified amount of water. Natural moisture content of 17% that was found in tests is greater than usual because samples were taken near the natural small pond. Such high moisture content is not representative of Agios Stefanos clays.

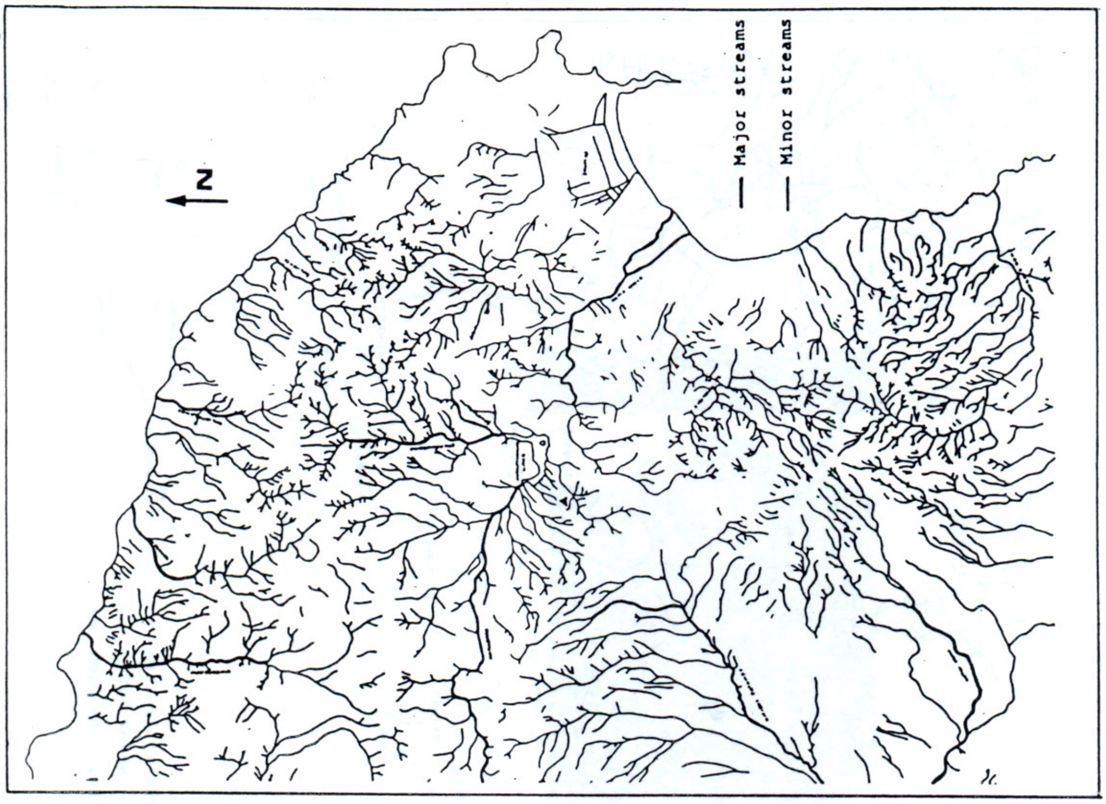


Fig. 6 Drainage

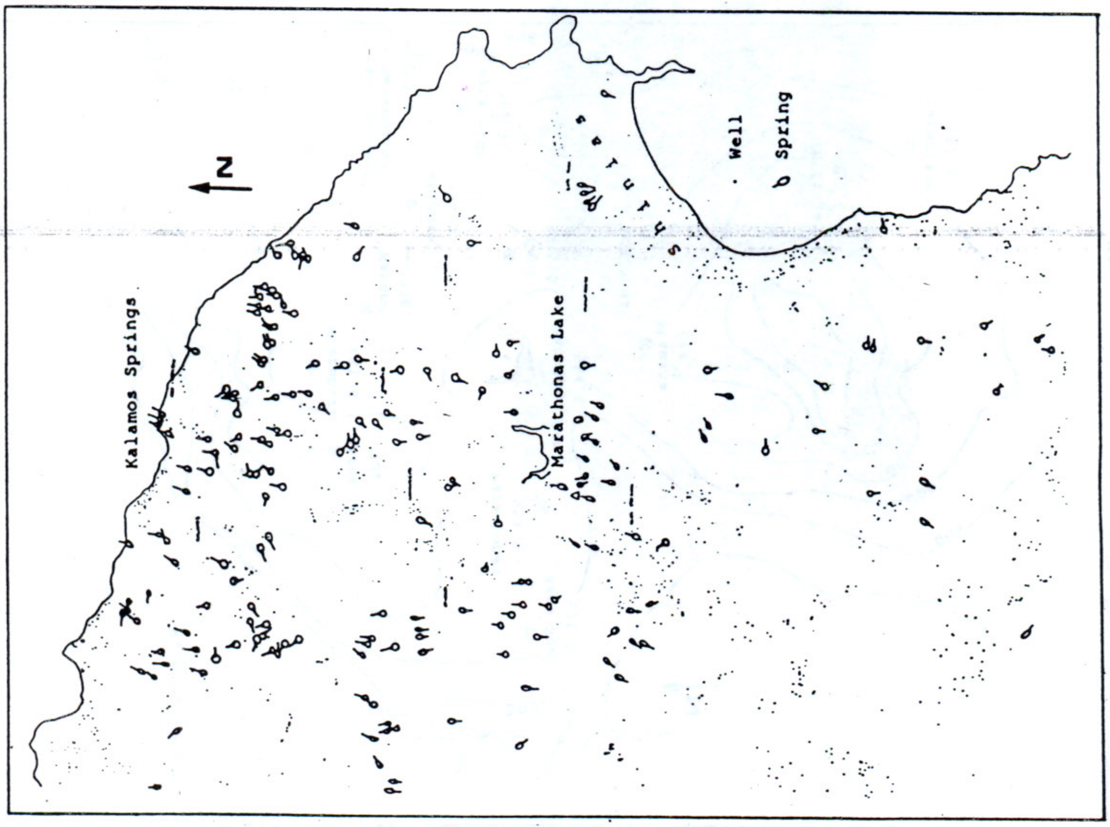


Fig. 5 Wells and Springs

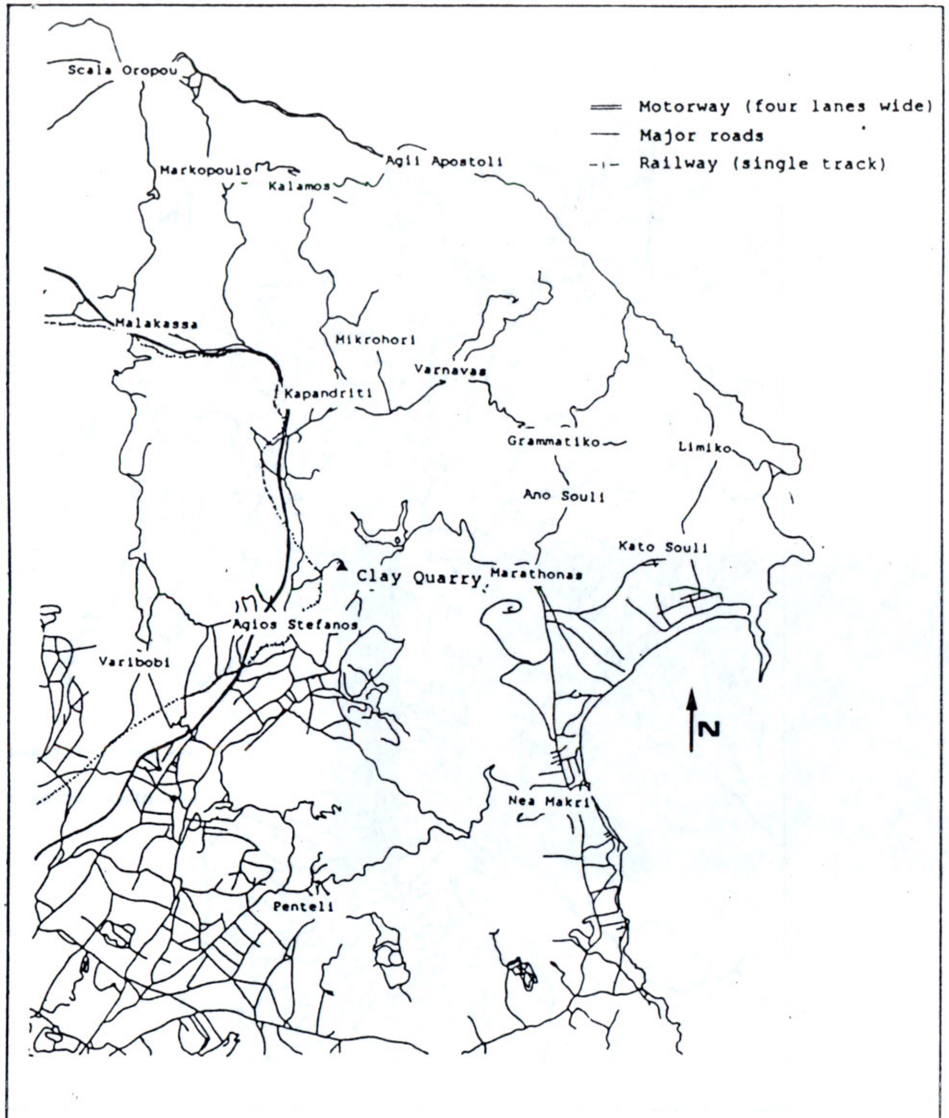


Fig. 7 Major Road Network

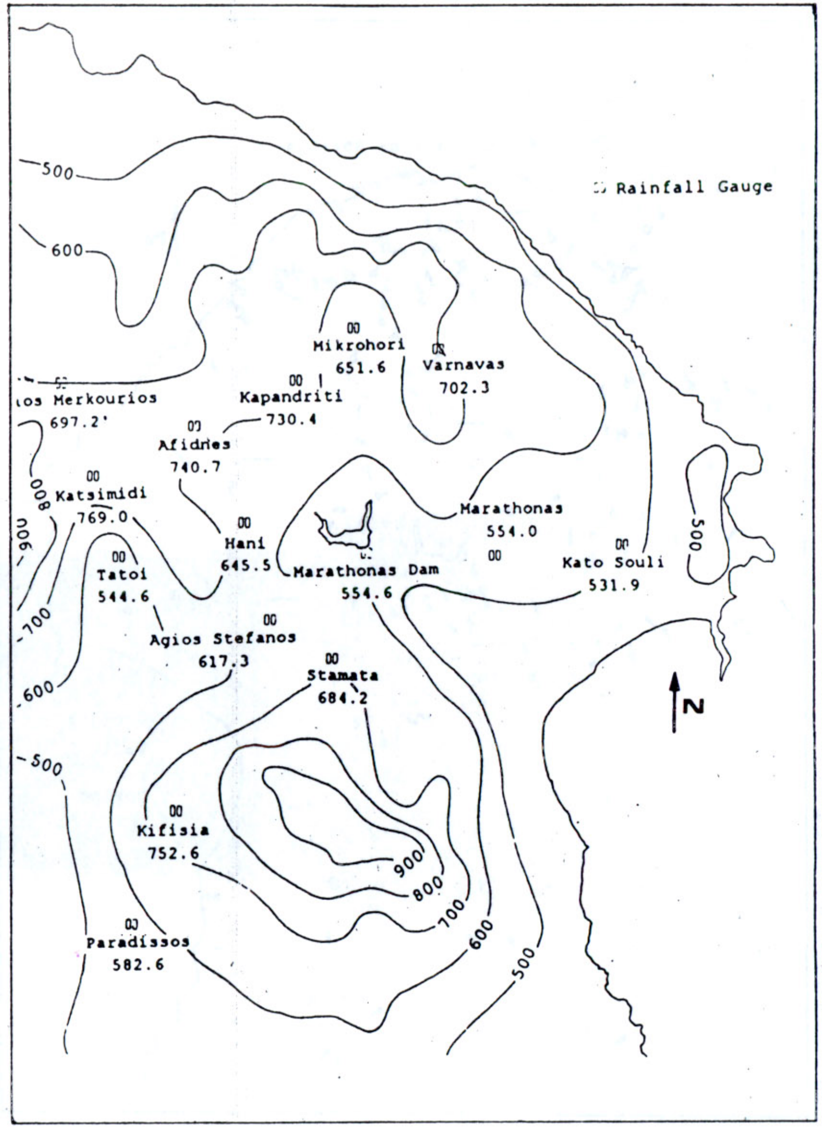


Fig. 8 Rainfall (isohyets in mm). Rainfall station data from Dounas et al. 1980 & Water authority.

SOIL TYPE	Moist cont.	LL	PL	PI	Clay cont	Act.	c	Φ	m_v	Cv	d_{dmax}	m_{opt}
		%	%	%	%		kg/m^2	deg	(m^2/MN)	(m^2/s)	kg/m^3	%
silty sandy clay	16,9	36	15	21	28	0,75	0,3	25	0,1	$2,4\ 10^{-9}$		
silty sandy clay	17,0	26	17	9	25	0,36						
silty sandy clay											1845	14.0

Act. = Activity, c = Cohesion, Φ = angle of internal friction, m_v = Coefficient of volume compressibility, Cv = Coefficient of Consolidation, d_{dmax} = maximum dry density, m_{opt} = optimum moisture content.

Table 2. Summary of laboratory test results of the Agios Stefanos Formation clays, which are proposed for use as liner.

As a conclusion silty clays of Agios Stefanos Formation have geotechnical properties (strength, compressibility) that are suitable for lining a landfill site. However, permeability is expected to be at the order of 10^{-7} m/sec, which is not suitable for a liner (NWWDO, 1988; Hoeks & Agelink, 1982). Therefore, use of a composite liner would be better for NE Attica landfill. Mixing with bentonite which can be easily obtained in Greece is an alternative solution to improve the permeability of the liner.

CONCLUSIONS

Study of geological and hydrogeological conditions helps landfill selection techniques move towards environmental protection. In NE Attica large scale movement of groundwater and pollutant migration is determined by isoclinal folding. Neither shcists nor Agios Stefanos clays are appropriate for siting a landfill without additional lining, even though they have the lowest available permeability.

Environmental protection requirements, geological conditions (lack of low permeability strata) and tectonic activity (risk of an earthquake) make the use of a compacted soil liner, which has low permability and is resistant to movement, necessary regardless of the location of the final landfill site. Geotechnical investigation of materials appropriate for lining (Agios Stefanos Formation Clays) has given good geotechnical properties (strength, compressibility) and satisfactory slope stability of the possible liner on the natural slopes.

Alternative sites are good solutions because they are closer to Athens than Site 1, and most important because they are situated completely on suitable materials. All sites must be investigated further to establish the hydrogeology and the geotechnical properties.

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