DEMARCATION OF SABKHA ZONES FROM REMOTE SENSING DATA AND ASSESSMENT OF THEIR ENGINEERING AND ENVIRONMENTAL HAZARDS FOR URBANIZATION

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ABSTRACT

For the last three decades, several urban infrastructures have been constructed on sabkha landforms distributed along the Red Sea and Arabian Gulf. Continuous dynamic changes of sabkhas and unique engineering geological characteristics of sabkha sediments under the prevailing natural conditions mark such sediments challenging foundation-soil for construction. Moreover, increasing human activities after construction enhance the environmental and engineering hazards for the urbanization program.

Monitoring of inhabited former sabkha sites in the Eastern Province of Saudi Arabia indicates that such engineering geological hazards are mainly due to groundwater table rise, and moisture and salt migration from the original sabkha hypersaline to new structures.

This research attempts to assess the utility of remote sensing data in zone mapping and estimates the degree of risks in reclaimed sabkha sites. Data relating to the engineering geological aspects of selected sabkha sites that are experiencing engineering problems are defined. The effect of sabkha sediments and groundwater regime in the spectral reflectance in remote sensing images is reported. Results obtained from the remote sensing data analysis and conventional field investigations are presented.

The research indicates that processing of the remotely sensed multispectral images could be useful in defining and delineating the susceptibility and potential zones of the expected hazards in sabkha landforms before and after the site preparation and constructional activities.

However, the remote sensing technique looks promising for a quick and cost effective approach for prediction and mapping of the engineering and environmental hazards in the arid region.

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COMPATIBILITY OF CLAYS IN DIFFERENT CHEMICAL ENVIRONMENTS -- A REVIEW

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ABSTRACT

The use of clays to retard the movement of different organic and inorganic pollutants from a variety of industrial and domestic sources has gained the popularity in recent years. In order to contain waste and to protect the groundwater from being contaminated, various types of clay liners are being used to provides good barriers against the leachates, and hazardous and toxic compounds. The efficiency of clay is not only because of its low permeability, but also due to its ability to absorb many harmful compounds from the liquid phase which come in contact with it. Moreover, the long-term sustainability of clay structure, in prevailing chemical environment, is only ascertained based on the thorough investigation of clay mineralogy, pore fluid characteristics, organic contents, cation exchange capacity, compressibility, and strength characteristics.

To make sure that clay structure behaves satisfactorily, it is necessary to study the effects of such harsh chemical environments on its properties. This paper briefly presents an overview of a literature survey of various studies on the effects of different chemical regimes on the behavior of clayey soils.

KEYWORDS

Clay; liners; geoenvironment; chemical pollutants; oil contamination; organo-clays.

INTRODUCTION

Engineering properties of a soil depend on the composite effects of several interacting factors. These factors may be divided into two groups: *Compositional factors* and *environmental factors*. Compositional factors determine the potential range of values for any property. They include: Type of materials; Amount of each mineral; Type of adsorbed cation; Shapes and size distribution of particles; and Pore water composition. On the other hand, environmental factors determine the actual value of any property. They include: Water content; Density; Confining pressure; Temperatures; Fabric; and Availability of water, Michell (1993).

Another factor which is not explicitly included above is the type of liquid phase (permanent), other than water, that might exist in the case of contaminated soils, especially clayey soils. The colloidal (fabric/structural stability) and ion exchange properties of clays are dependent on the type of permanent. Reliable assessment of the long-term stability of clay-liquid-electrolyte system is a challenging problem in *geoenvironmental engineering.*

Geoenvironmental engineering is an inter-disciplinary area between geotechnical and environmental engineering. It emerges as a result of the need to study the engineering properties of contaminated soils. Extensive coverage of such soils can be found in Cairney (1993); Schulin, et al. (1993); Petruzzelli and Helfferich (1993); Weyer (1990); Arendt, et al. (1990); Kostecki and Calabrese (1989).

Tremendous efforts have been made in recent years which focus on the study of engineering properties and mechanical behavior of clayey soils related to their fundamental characteristics such as microstructure, mineralogy, chemistry, and surface morphology. These are resulted from the various usage of clay in environmental protection. Such applications include: the use of clay in land reclamation of contaminated soils, and the use of clay as a barrier against contamination transport to protect groundwater. Therefore understanding the behavior of fine grained soils in a prevailing chemical environment over a longer period of time is a matter of interest for both environmental and geotechnical engineers.

Wet clays are chemically active electrolyte-water-solid system. Most of their properties are governed by their microstructure and physico-chemical forces between the particles. The initially attained structure can easily be modified by changing environmental conditions bringing about new particle association, pore sizes and pore fluid characteristics. Subsequently, such changes may affect the ability of soil to withstand effective stresses. Furthermore, mechanical response of a soil to various loading conditions, and its permeability, consistency, and volume change behavior are also affected, Panucku et al. (1990).

Long term contact of contaminants with a soil may influence the long range clay- particle interaction, which is responsible for fabric formation. Such influences may be brought about by a number of factors such as zeta potential, dielectric constant, cation exchange capacity (CEC) and pH of the clay-water system. As a consequence, changes in physical and mechanical factors such as turbidity, particle size distribution, ion concentration, kinetics of water, rate of deposition after fabric formation are also found to occur (Panuckcu et al., 1990).

The consolidation pressures during post-depositional period may not be so high that is sufficient to alter the initially formed fabric. However, these may by sufficient enough to bring any either constructive or destructive change to the particle-to-particle or to the particle-to-contaminant associations. If a contaminant gets in contact with clay during post-depositional period, as in the case with most of natural oil spills and the use of clay as barrier to retard the movement of different contaminants, the chemical changes in the soil may be significant enough to alter physical and mechanical properties.

The subject matter of relating engineering properties and mechanical behavior of clay to their more fundamental characteristics such as microstructure, mineralogy, chemistry and particle surface morophology has gained much attention in recent years. Increased occurrence of soil contamination from different sources has got the attention of not only the environmentalists but also the geotechnical engineers, who are getting more and more involved in this field as contamination poses threat to both physical and mechanical properties of soil. Since clays and colloidal particles are more sensitive to the physico-chemical conditions during depositional and post-depositional changes in the environment, much attention has been focused on these issues.

Clays exposed to environmental stresses, examples of which can be the introduction of various chemicals into the pore fluid, pH, or temperature of the pore fluid, generation of gases through biological or chemical reactions, etc., tend to display changes in their physical properties over time. Introduction of various organic/inorganic ions into the pore fluid influence the colloidal stability of the fine grained soil, Panucku et al. (1990).

The structure of clay minerals has been extensively studied and is reasonably well understood. Gouy-Champan theory of a "diffuse double layer" has been applied to explain clay behavior since 1950s. Subsequent modifications to the theory have been developed, which resulted in a refined definition of ion distribution in the double layer. Based upon the interaction of clay mineral and accompanied diffuse double layer, definitions of different types of soil fabric have evolved. *Flocculated* structures are those in which particles tend to join together, whereas *dispersed* structures are those in which particles tend to move apart. The Gouy-Chapman theory indicates that the tendency towards flocculation is increased by decreasing diffuse double layer and thus a decrease in the interparticle repulsive force. Conversely, the tendency towards dispersion increases as the double layer thickness increases. A flocculated "cardhouse" arrangement of clay particles suggests higher stiffness, brittle mode of deformation and higher permeability due to open fabric and collapsed double layer. Conversely, a dispersed "parallel" arrangement of particles suggests lower stiffness, ductile mode of deformation, and lower permeability due to the swollen double layer.

CHEMICAL ENVIRONMENTS

Before selecting a particular type of clay mineral to retard the movement of a particular type of chemical, it is very essential to know the nature of chemical being encountered. Choice of clay mineral and any necessary treatment made to it should be compatible to the chemical environment over a longer period of time. Therefore, type of chemical, its source and its effects on a particular type of clay mineral is required to be studied before applying it to a real situation. Clays offer good resistance to most of the chemicals' movement both because of its low permeability and its capacity to adsorb many chemicals which come in contact with it. Clays are generally used as a barrier against different compounds leaching from a waste pile. To know the characteristics of the leaching chemicals, type and constituents of the waste itself are necessary to be studied

Types of chemical environments are classified based on the kind of contaminants, as summarized in Fig. 1. Primarily, there are two main categories of waste; liquid and solid. Moreover, waste is subclassified as municipal, industrial, special, and radioactive waste. Domestic sewage falls into the category of domestic liquid waste, whereas domestic solid waste includes refuse from commercial and residential sources. The leachate generated from the solid waste is rich both in organic and inorganic compounds. The usual chemistry of leachate includes compounds of TDS, chlorides, sulfates, hardness, ... etc., Alther (1982). Industrial wastes are divided into four categories: aqueous inorganic; aqueous organic; organic; and sludges, slurries, and solids.

Aqueous inorganic wastes are those in which water is the solvent and the solids are mostly inorganic such as metals, acids, and bases. In aqueous organic waste, water is the solvent and solutes are organic in nature such as woods preserving waste, water based dye waste, ethylene glycol production waste. In the organic waste solvent is an organic fluid, and dissolved solids are organic in nature such as oil based paint wastes, pesticide manufacturing waste, spent motor oil , spent cleaning fluid solvent, etc. Origin of sludges is a water stream when it is dewatered, filtered or treated for solvent recovery. They have low solids contents, and include storage tank bottom sludges, petroleum separator sludges, treatment plant sludges, etc., Alther (1982).

EFFECTS OF OIL CONTAMINATION ON CLAYEY SOILS

Oil falls into the category of organic pollutants. Oil contamination by either spent motor oil or by leaking and damaged underground storage tanks have been reported in the literature with special emphasis on its effect on the geotechnical and physico chemical properties of fine grained soils. Tuncan (1989) studied the effect of fuel oil on the geotechnical and physico chemical properties of marine sediments. Abduljuwad (1996) studied the effect of crude oil contamination on the behavior of a calcareous expansive clay. A review of the results provided by some studies will be presented in the following.

Geotechnical Properties. Shear strength is a variant property of contaminated clay. The shear strength parameters of fine grained sediments consists of void ratio, water content, porosity, electro-chemical interparticle forces or cohesive bonds, and type of contamination. A laboratory testing program was conducted by Panucku et al. (1990) on artificially prepared marine clay specimens. Marine clay produced a significant reduction in shear wave velocity and unit weight; and was observed to retain most of the water. The high water content, low density, and low shear modulus indicate a dispersed or nonflocculated soil matrix upon addition of fuel oil. Results of scanning electron microscopy (SEM) for addition of 20 % fuel oil showed an open loose structure. However, the random orientation of particles and floc formation do not support the deductions made with respect to the dispersion. It appears that the loose structure of the material dominates the mechanical properties rather than the fabric characteristics, in this case. Fuel oil might have acted as a gluing agent to produce the flocs, but it also trapped water that resulted in reduced stiffness.

Another study of oil contamination effects on the shear strength behavior of fine grained marine sediments was carried out by Tuncan (1989). It was concluded that shear strength of fine grained sediments show a decrease with the addition of oil to them. On the whole, it is concluded that addition of fuel oil decreased plasticity index, wet unit weight, specific gravity, permeability and shear strength, but increased water content. The interesting finding was that the permeability was decreased as the shear strength. The lower unit weight of oil-mixed clay supports the formation of a looser structure.

Effect on Physico-Chemical Properties. Surface area of clay particles is a very important property influencing the particle's behavior Tuncan (1989). Cation exchange capacity (CEC) is also an important fundamental property useful in understanding the development of electrical charges between the clay particles and also between clay particles and other substances. Soil organic matter affects significantly the surface area and CEC of clay particles. A laboratory experimental program was launched by Tuncan (1989) to investigate the effect of crude oil contamination on the surface area and CEC of a marine clay. It was concluded from the study that organic matter of marine clay increases with the addition of crude oil, Fig. 2. High specific surface area of clay minerals makes organic matter an important constituent of the particles. Organic matter are often adsorbed onto clay minerals due to electrostatic adsorption and chemical bonding. Organic matter has electrostatic and steric cation retention characteristics.

Crude oil is a petroleum hydrocarbon. The hydrocarbons are mainly carbon and hydrogen, with some other elements such as nitrogen, sulphur, and sodium. The adsorption of high molecular weight components, such as the hydrocarbon chains of crude oil, onto clay surfaces causes wettability to change from water-wet to oil-wet. The adsorption of these components creates an adsorbed layer around the particles. This adsorbed layer is not water soluble, and is not displaced by water, Tuncan (1989). Specific surface area of clay was significantly affected by crude oil contamination, Fig. 3-a. Organic matter coats and agglomerates the clay particles, thereby reducing the specific surface area. The agglomeration causes small particles to come closer to one another resulting in apparent larger particle size. It was observed that the color of crude-oil-mixed clay was brownish and clay flocs can not be crushed easily possibly due to gluing effect of the oil.

Cation exchange phenomenon is important for the fundamental understanding of the differences in the nature and development of electric charges between the clay particles, which affects the flocculation and dispersion processes in clay system. Cations are attached and held onto the surfaces and the edges to preserve electrical neutrality. These cations are exchangeable cations because they can be replaced by cations of another type. Cation exchange capacity (CEC) is a measure of the degree of the isomorphous substitution. This substitution gives a net negative charge to clay particles. CEC decreases with the increasing percentage of crude oil contamination, Fig. 3-b. CEC of clays reduces considerably in the presence of large organic molecules such as crude oil. The molecules may blanket or coat exchange sites, thus inhibiting the measured exchange potential.

Surface charge density is another important characteristics of clays which affects their behavior to surrounding environment. It is obtained by dividing the CEC capacity by the surface area. Crude oil contamination significantly affects the surface charge density of clay, and there is an increasing trend in the surface charge density with the increase in the percentage oil contamination (Fig. 3-c), because specific surface area of oil-mixed clay reduces considerably.

Finally, it is concluded that addition of crude oil to clayey soil decreases the specific surface area of clay (Fig. 4), decreases the CEC, increases organic matter, and increases the surface charge density.

ORGANOBENTONITES-CHEMICAL INTERACTION

Bentonite is a sodium montmorolonite, used as component of landfill liners in municipal and hazardous waste disposal sites, because of its hydrophillic nature. Bentonite mixed with sand or silt swells in the presence of water. This expanding nature enables it to fill effectively the void spaces between larger soil grains. The resulting medium offers a relatively low hydraulic conductivity. Hydraulic conductivity of earth liners composed of 8 to 12% (by weight) bentonite has been reported to range from 10^{-9} to 10^{-8} cm/sec.

Sand and bentonite liners, and soil bentonite slurry walls have two limitations. First, because of its polar mineral surfaces and generally low organic carbon contents, bentonite is not a powerful sorbing medium for nonionic organic contaminants. Therefore, performance of earthen liners containing bentonite layer depends largely on liner's ability to minimize the velocity of percolating water carrying nonionic organic contaminants. Second, the presence of large percentages of miscible organic liquids or non aqueous phase organic liquids (NAPLs), can increase the permeability of sand and bentonite liners by several orders of magnitude relative to the water saturated system, Abdul et al. (1980) and Greens et al. (1983). The reduced polarity of the organic liquids causes dehydration and desiccation of bentonite and a resulting increase in permeability.

Organobentonites are formed by exchanging the quaternary ammonium organic cations for inorganic cations (Na^+,Ca^{2+},H^+) onto the external and internal mineral surfaces of the bentonite. Molecular weight of the quaternary ammonium cation is the major factor on which sorption of nonionic compounds to the surface of bentonite depends. Quaternary ammonium compounds of smaller functional groups (e.g., methyl, ethyl, benzyl groups) offer strong sorption mechanism and is attributed to physical adsorption. When clay is modified by cations of larger functional groups (e.g., 10 to 18 carbon chain functional group) sorption mechanism is not strong enough and is attributed to the solute partition between the aqueous and organic phases. When organically modified bentonites are used as a component of liner system in earthen liners, transport of nonionic organic compounds is significantly hampered.

Smith et al. (1995) studied three kinds of synthetic organobentonites and the sorption of benzene to each of these modified soils. The modified organobentonites were 40 BTEA-bentonite, 40DDTM-bentonite and 40BTEA/40 DDTMA-bentonite. The sorbent denoted by 40BTEA is bentonite with benzyltrimethylammonium (BTEA) cation exchanged on to the bentonite in an amount 40 percent of CEC. DDTMA refers to dedcytrimethylammonium and numbers mentioned with each compound refers to the relative amount of corresponding cation present expressed as a percent of CEC.

Fig. 5 represents the results of batch sorption tests quantifying benzene sorption to the organobentonites. Graph B in the same figure represents the sorption of benzene to the untreated bentonite. Sorption to 40BTEA-bentonite is characterized by distinctly nonlinear isotherm and relatively strong solute uptake. By contrast, benzene sorption to 40 DDTMA- bentonite is characterized by a linear isotherm comparatively and represents lower solute uptake. The magnitude of sorption by 40BTEA /40DDTMA - bentonite is intermediate to benzene sorption to 40BTEA- and 40DDTMA- bentonite. This isotherm is slightly nonlinear at low aqueous benzene concentrations and exhibits mild upward curvature at aqueous benzene concentrations approaching solubility. However, in all three cases, benzene uptake was higher as compared to untreated bentonite.

Organically modified bentonites have been successfully studied as far as removal of nonionic compounds from aqueous solution is concerned. However, geotechnical and strength properties of such soils has not yet been investigated which is an essential parameter for design of liners. Moreover, this study has been carried out using commercially available bentonite. One can extend this work to study the behavior of natural clays with a high value of CEC.

EFFECT OF PORE FLUID CHEMISTRY ON THE PROPERTIES OF CLAYS

In the design and analysis of earthen barriers, not only geotechnical properties of the material used are important to be investigated but also they must have a higher degree of tolerance in the prevailing environmental conditions, so that long term stability of the facility is ensured. For this purpose it is required to study the effects of encountered chemicals on the behavior of the material being used as a barrier.

Acar et al. (1989), uses three types of clays and a variety of chemicals, and conducted various tests to see whether they have any influence on the properties of the soil when mixed with such chemicals. Compositional features of clays and a summary of different chemicals used are presented in Tables 1 and 2, respectively. His findings are summarized below.

Atterberg Limits and Free Swell Tests. It is well established that the engineering properties of clays are dependent on the interaction of the clay particles with the pore fluid. The relative thickness of the diffuse double layer may be related to the square root of the dielectric constant. If the properties of the fluid in the diffuse double layer and around the clay particle are different from those of pure water, and if effective stresses do not restrict the variation in the fabric, the changes in the thickness of this layer will result in rearrangements in the effective pore space contributing to the total flow. Because the extent of repulsive forces is related to the thickness of diffuse double layer and the liquid limit, and free swell tests present a good estimate of this thickness, it was decided to conduct such tests on three clay minerals with organic molding fluids.

Fig. 6 represents the results of the consistency limits, and Fig. 7 represents the results of the free swell test. It was observed that free swell and liquid limit of montmorolonitic clays displayed an increasing trend with an increase in dielectric constant. These clays became nonplastic for fluids with dielectric constant of less than 30. These results were anticipated from the review of the interaction of pore fluid and clay surface. On the other hand, it was observed that different organic fluids induced different responses in the liquid limit and free swell of kaolonite. This mineral was nonplastic to acetone and to contaminants with a dielectric constant less than 3. Nitrobenzeze, phenol and carbonteterachloride with low pH resulted in high liquid limit values.

Effect of Organic Fluid Permeation on the Fabric of Compacted Clay. Five samples of kaolonite compacted at the standard proctor effort at a water content of 38% and a dry density of 76 pcf were identically prepared and tested. Consequently, the initial fabric of these samples was identical. The permeation fluids were acetone, phenol, nitrobenzene and a 0.01 N $CaSO_4$ solution. Six samples of Ca-montmorolonite compacted at the standard proctor effort and molding water content of 60% and a dry density of 62.4 pcf were identically prepared and tested. Table 3 shows the initial and final values of hydraulic conductivity and their ratios. It is found that hydraulic conductivity for kaolonite slightly increased with acetone and phenol but, decreased almost three orders of magnitude with benzene and nitrobenzene.

Results of tests for Ca-montmorolonite indicated that the hydraulic conductivity decreased slightly with nitrobenzene, p-dioxane and phenol. The decrease in hydraulic conductivity of Ca-montrolonite with acetone was almost two orders of magnitude. Full breakthrough was not achieved with acetone, because it took about 20 days to permeate only 0.1 pore volume at such a low hydraulic conductivity. Similarly, the hydraulic conductivity of Ca-montmorolite permeated with benzene first decrease to less than 1×10^{-10} cm/sec. Subsequently, it was not possible to detect any changes in effluent levels for almost 2 months. Consequently, full breakthrough was again not achieved in these tests.

The hydraulic conductivity experiments were duplicated with the specific organic fluids except benzene. Fig. 8 presents the results of hydraulic conductivity tests on compacted Ca-montmorolonite. From these results, it was concluded that a specific trend was not observed between the absolute hydraulic conductivity of the compacted soils and dielectric constant of the organic fluids used in this study. Other factors such as fluid immiscibility, pH, and effective stress should then be considered.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

1. The interaction of clay with different chemicals are numerous both because of a large variety of chemicals available in the surrounding environment and existence of clay over a wider range of mineralogical spectrum.
2. Clay-chemical interaction is the function of many parameters such as type of chemicals, clay mineral on the one side, and other environmental factors such as temperature and pressure on the other side.
3. For a particular type of chemical response may be different for different types of clay minerals.
4. Before using a particular type of clay mineral in a prevailing environmental conditions, its effectiveness should be assessed by a laboratory study.
5. Organically modified bentonites provide a good sorbing medium for nonionic organic pollutants. However, mechanical and geotechnical properties of such modified soils are still unknown, and require further investigation.
6. Rather than using commercially available bentonites in the soil sealing application, attention should be paid to some locally available clay mineral with a high CEC value. Such clays should be studied, both as a sorbing medium for chemicals and as geotechnical material after it has been organically modified.

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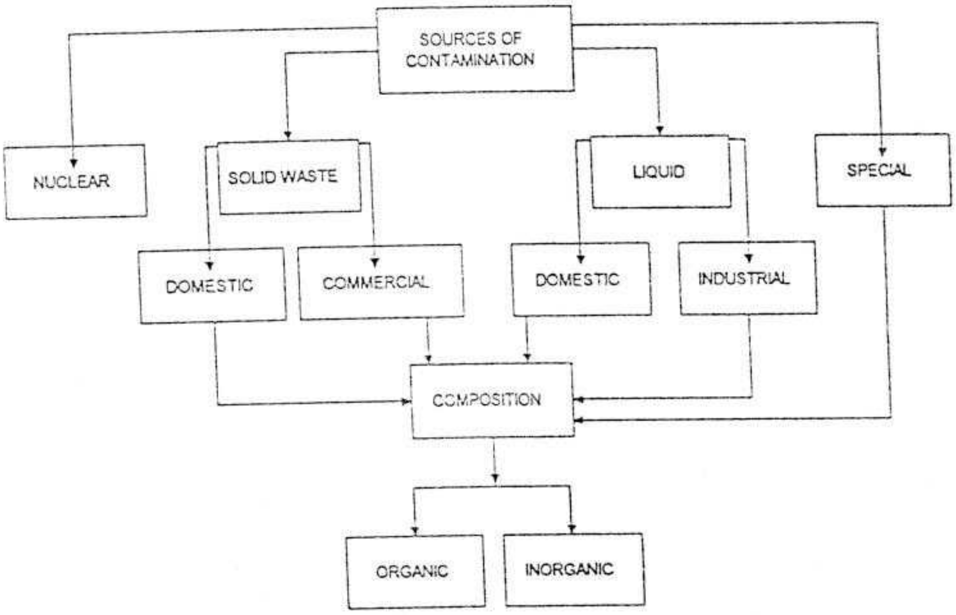

Fig. 1. Classifications of contaminants.

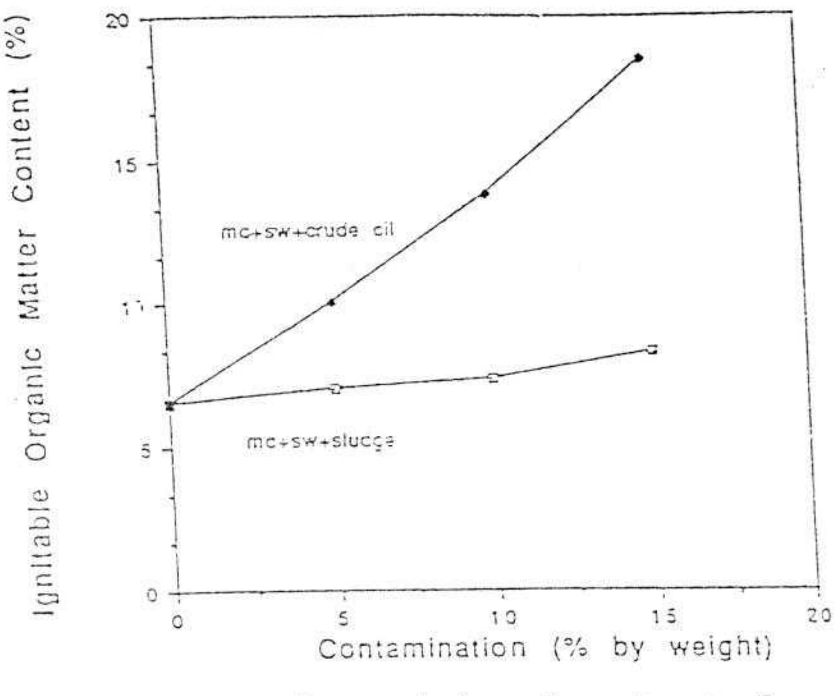

Fig. 2. Relationship between oil contamination and organic matter for marine clay, after (Tuncan 1989).

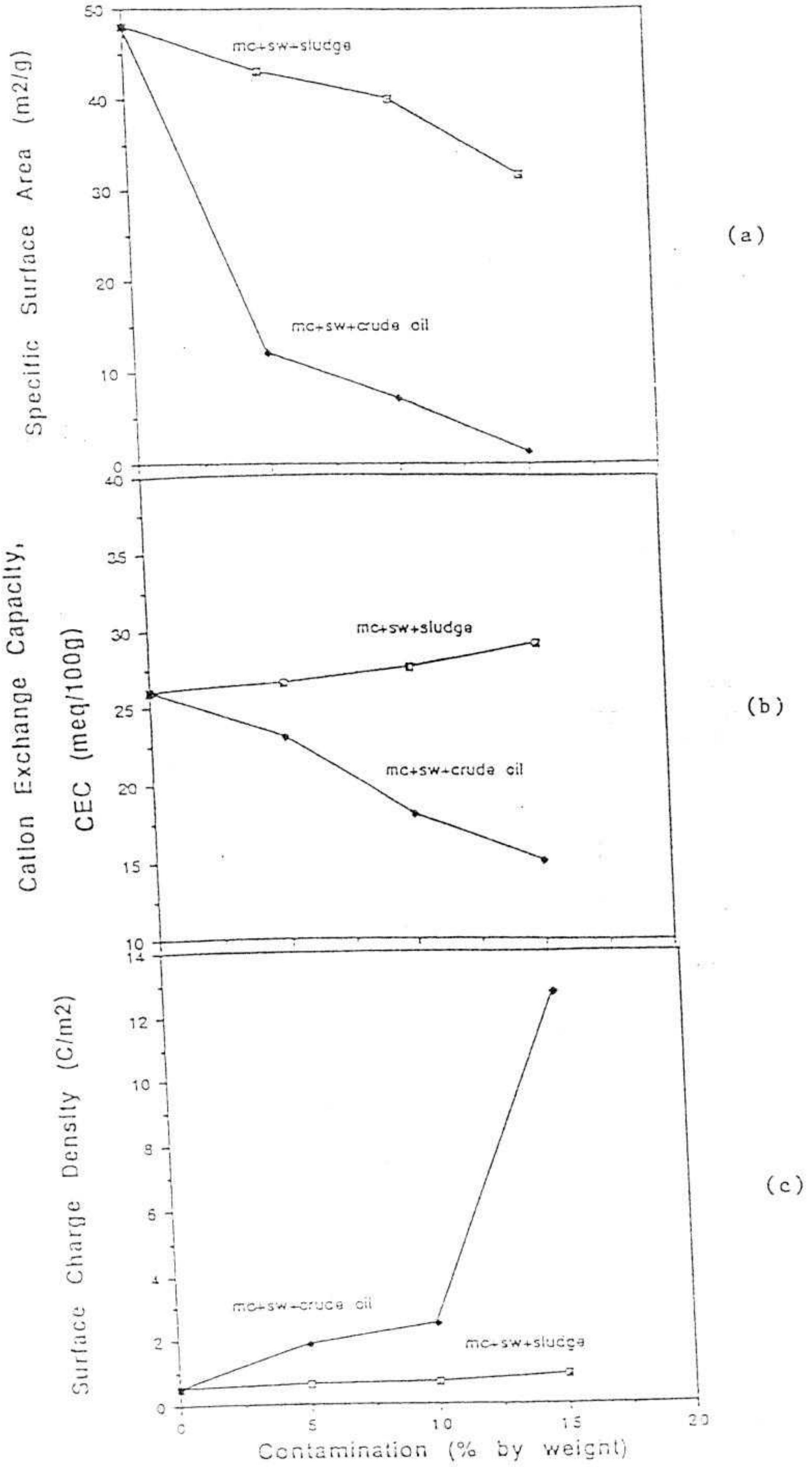

Fig. 3. Relationship between oil contamination and a) specific surface area; b) CEC; c) surface charge density , after (Tuncan 1989)

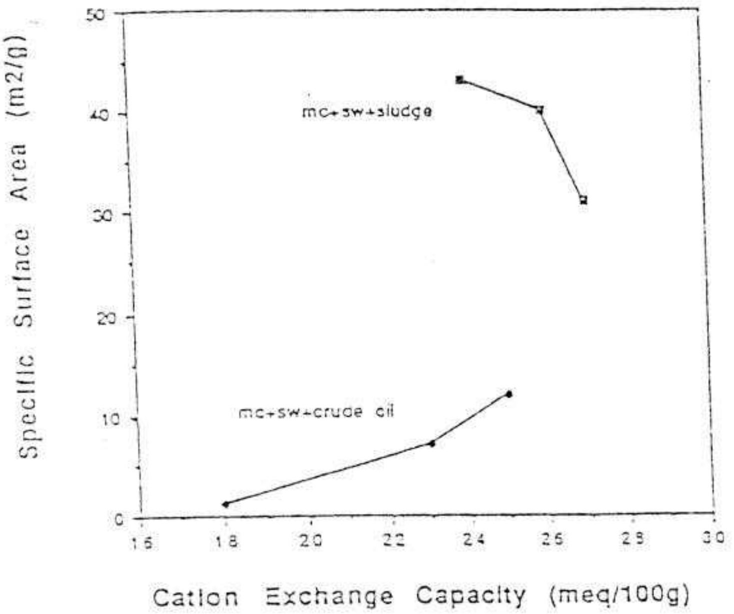

Fig. 4. Relationship between CEC and specific surface area, after (Tuncan 1989)

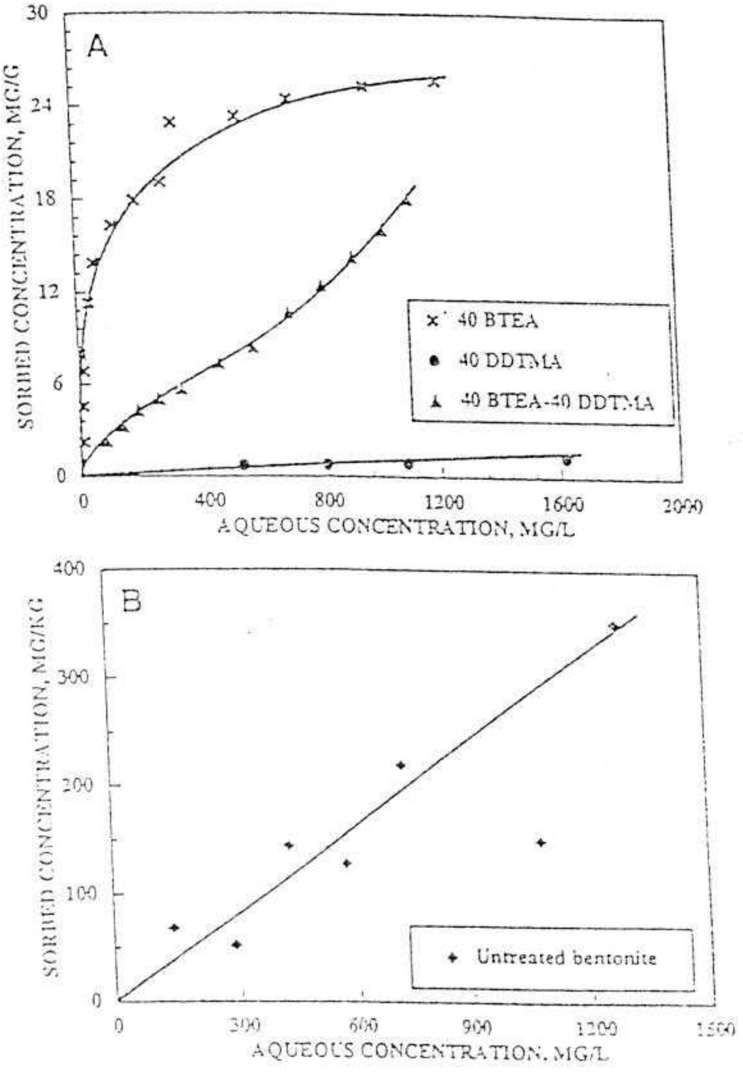

Fig. 5. Sorption of benzene by organobentonites and untreated bentonite, after (Smith et al., 1995).

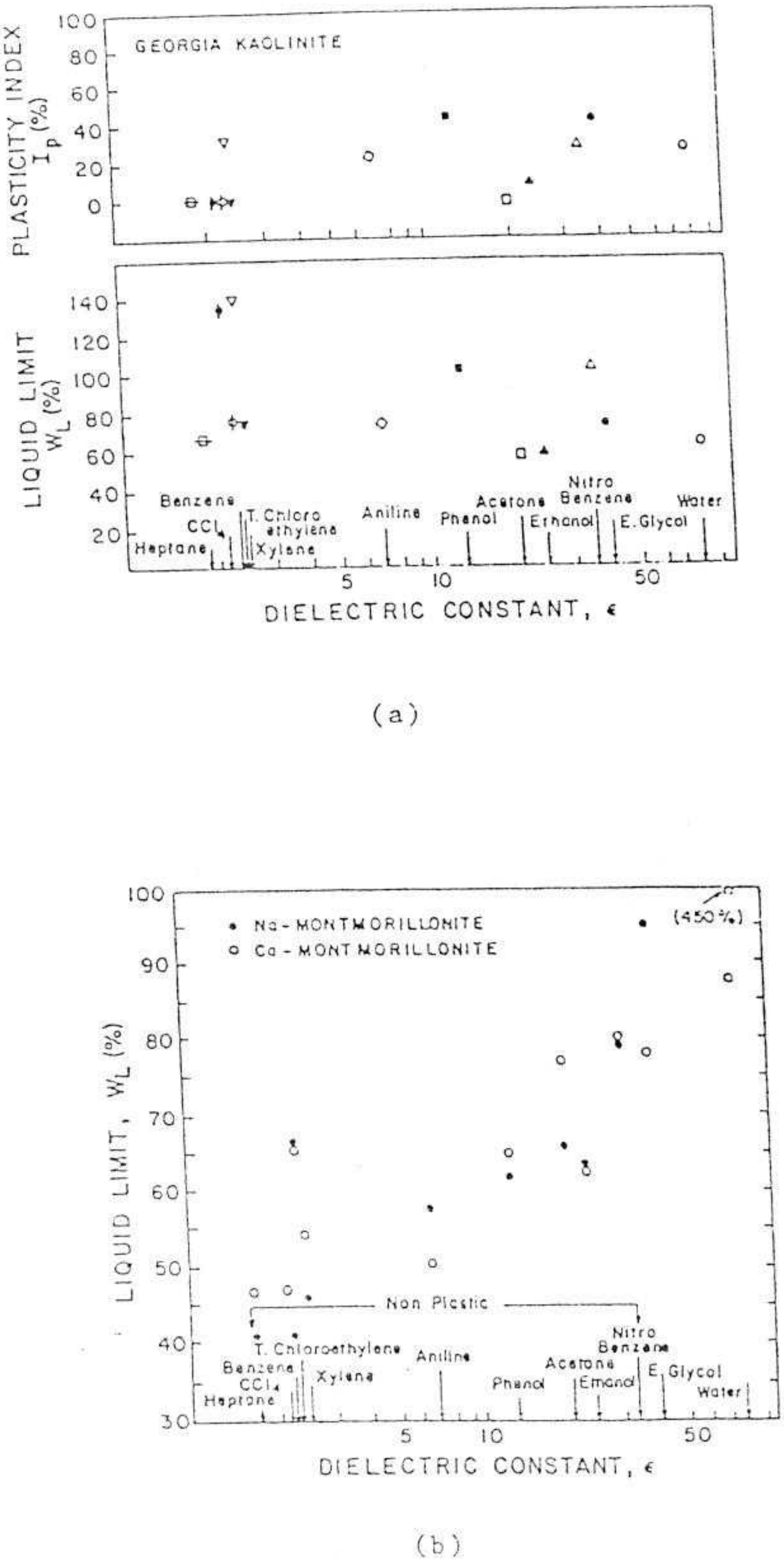

Fig. 6 Effect of organic fluids on the consistency limits of a) georgia kaolinite; b) montmorolonite, after (Acar et al., 1989).

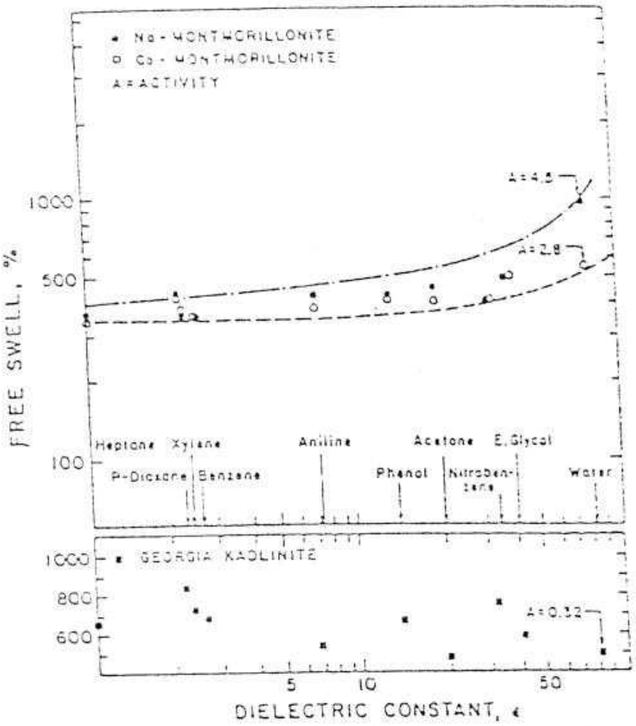

Fig. 7 Effect of organic fluids on free swell of clays, after (Acar et al., 1989).

Table 3 Results of hydraulic conductivity tests, after (Acar, et al., 1989).

Permeant	Hydraulic Conductivity (x 10^{-8} cm/sec)		k_f/k_i
	k_i^*	k_f	
Compacted Kaolinite			
Nitrobenzene 1**	5.60	<0.025	<0.005
Nitrobenzene 2**	5.20	<0.015	<0.005
Acetone 1	5.60	6.00	1.07
Acetone 2	5.00	11.00	2.00
Phenol	6.00	14.00	2.33
Benzene**	5.10	<0.010	<0.0005
Compacted Ca-montmorillonite			
Nitrobenzene 1	0.55	0.45	0.82
Nitrobenzene 2	0.72	0.45	0.63
Acetone 1**	0.72	0.01	<0.01
Acetone 2**	0.70	0.01	<0.01
Phenol 1	0.77	0.21	0.27
Phenol 2	0.48	0.14	0.08
P-Dioxene 1	0.84	0.73	0.87
P-Dioxene 2	0.63	0.52	0.83
Benzene 1**	0.74	stop	<0.01

*initial permeabilities with 0.01 N $CaSO_4$.

**full breakthrough was not achieved due to decrease in hydraulic conductivity to less than 1 × 10^{-10} cm/sec.

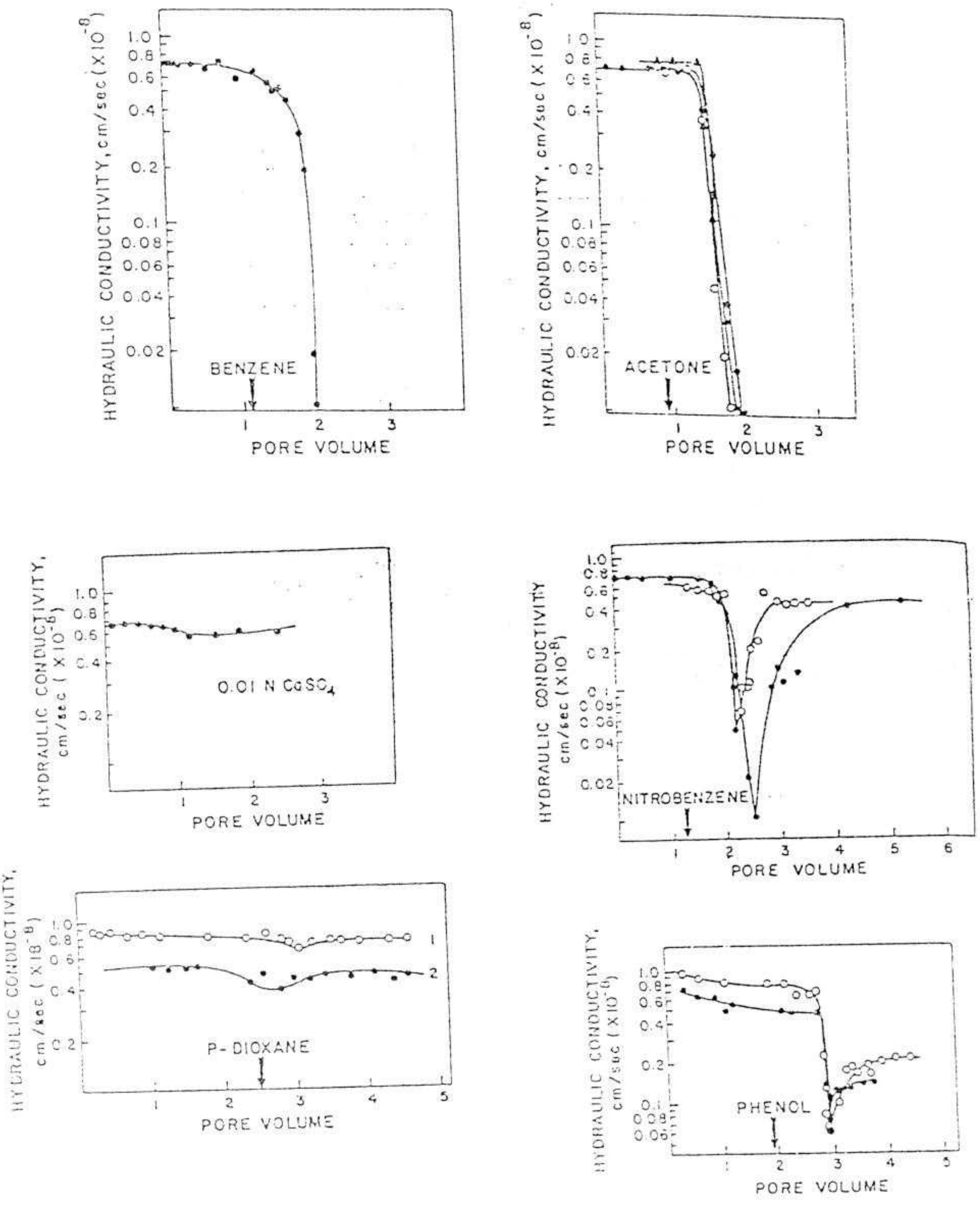

Fig. 8 Hydraulic conductivity of compacted Ca- montmorolonite to different pore fluids, after (Acar et al., 1989).