

EVALUATION OF AN ON-SITE SEWAGE DISPOSAL SYSTEM
AT THE LAKE OF THE OZARKS

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SUMMARY

PROJECT: Alternative On-Site Sewage Disposal for the Lake of the Ozarks Region

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This project was carried out in two phases: an evaluation of the water movement in two Ozark soil landscapes and an evaluation of an existing on-site sewage system in the Lake Ozark area. Separate reports are attached for each phase.

In phase I, two hillslope landscapes were monitored for water movement and zones of saturation. Zones of saturation commonly occurred in the summit and shoulder slope positions and were prominent in fall and winter months. Movement appeared to be lateral from summit to shoulder. These zones of saturation could lead to problems with conventional on-site waste disposal systems and should be evaluated in locating disposal systems. Interceptor lines or french drains may be needed to prevent pollution of shallow water.

An aeration device--conventional tile field system was monitored for one year in Phase II. The aeration unit produced a well oxidized effluent low in soluble COD but high in nitrates and phosphates. Considerable denitrification appeared to be occurring in the tile field. Little coliform movement was detected. Good management of the tile field will be necessary to prevent nitrate contamination of shallow groundwater.

PHASE I

Evaluation of An On-site Sewage Disposal
System at the Lake of the Ozarks

EVALUATION OF AN ON-SITE SEWAGE DISPOSAL SYSTEM
AT THE LAKE OF THE OZARKS

by

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ABSTRACT

An aeration device - conventional soil disposal field system was monitored for one year in the Lake of the Ozarks area to assess its treatment efficiency and effect on the water quality of the immediate area. The aeration unit consistently produced a well oxidized effluent (soluble COD=44 mg/L; NO₃-N=22 mg/L; PO₄=6.3 mg/L; SS=14 mg/L). Soil-water samples taken from the tile line and 2 and 5 m down slope indicate that considerable denitrification was occurring but may be decreasing. Little coliform movement was detected. The practice of excavating tile lines into the bedrock was discouraged due to a lack of treatment occurring.

INTRODUCTION

The Lake of the Ozarks region is experiencing rapid growth resulting from the development of lake shore homes and expanding tourism activities. Development is occurring on topography which is characterized by steep slopes, shallow soil depth to bedrock and soil horizons restrictive to water flow (i.e., fragipans). These restrictive soil characteristics make on-site disposal of sewage very difficult, particularly with the conventional septic tank-tile field system. Many of these systems have failed, causing unsightly aesthetic problems and concern for water pollution.

Many residents in the lake area have turned to the individual aeration system coupled to a conventional tile field as a means of providing better waste treatment and environmental protection. Some have questioned whether these systems can provide adequate protection in light of the difficult environmental conditions. The objective of this study was to assess the ability of an aeration-conventional tile line system to treat sewage in the Ozark's soils region and determine the system's affect on the water quality of the immediate area.

PROCEDURES

A small office building (12 people) located in the Lake of the Ozarks area was chosen for the study. The sewage system for the office was being replaced with a new aerator and conventional tile field. This system is typical of ones being used

extensively in the lake area and afforded an opportunity to monitor a system from the very beginning. The treatment plant consisted of a precast concrete unit trucked to and installed on site. The unit contained a single aeration chamber followed by gravity settling before discharging into the tile field.

Common practice in the lake area is to use plastic tubing (10.2 cm diameter) laid in a 0.9 m deep by 0.9 m wide trench. The 0.9 m depth is generally maintained even if that means excavating into the limestone bedrock. This practice is discouraged by the state water pollution regulatory agency but is still commonly used for individual sites. The tile field at the study site consisted of two 13 m long parallel trenches laid across a 26 % slope (Figure 1). Soil at this site is 0.46 m deep and to achieve the 0.9 m depth, the trench was excavated 0.3-0.4 m into the bedrock (Figure 2). Gravel was placed in the trench bottom and the plastic tubing installed by conventional methods.

Soils in this area are generally of the Bardley (very fine, mixed, mesic Typic Paleudalf) series. The entire vertical depth of the soil in the tile field area had been disturbed when the office building was initially constructed and therefore exact classification was impossible. From visual observation of the soil profile made when the trenches were excavated, the soil consisted of 30.5 cm of gravelly heterogeneous material followed by a 15-20 cm layer of darker material containing tree roots underlain by 20 cm of cherty (40-50 %) clay. Bedrock in this area consists largely of cherty dolomite.

Soil pits were excavated to bedrock and located down slope from the second trench (Figures 1 and 2). Piezometers (Burk et al., 1987) made of plastic pipe were inserted laterally into the pit walls approximately 5 and 12 cm vertically from the bedrock. Piezometers were installed in the north and south walls and provided a check on lateral flow through the soil. The piezometers were used to determine the elevation of the saturated zone in the soil profile and to collect water samples for quality analyses.

Piezometers were also installed in both tile lines; two locations on each line. Installations at the north end of the upper line were destroyed when backfilling. At each location a piezometer was placed on the bottom of the trench and at the soil-bedrock interface. All piezometers were capped with a plastic end cap which had a small diameter hole drilled in it to maintain atmospheric pressure.

Water samples from the aeration unit, trenches and soil pits were collected monthly and analyzed for total solids (TS), volatile solids (VS), suspended solids (SS), COD (total and soluble), orthophosphate, ammonia, nitrate, chlorides, and fecal coliform. All chemical analyses were performed according to Standard Methods (American Public Health Assoc., 1981). Fecal

coliform were measured by the membrane filter technique, Standard Methods.

RESULTS

Figure 3 illustrates the saturated water levels in the lower trench and both soil pits. The saturated water level in the soil above the bedrock in the lower trench was consistently greater than 0.3 m above the bedrock. It would appear that the bedrock in this trench was relatively impermeable, filled with effluent and allowed the water to overflow along the bedrock-soil interface. In contrast, the piezometer in the upper trench remained dry the entire study indicating that no effluent was reaching the south end of the tubing. This could be the result of improper installation of the tubing or effluent was seeping out of the trench through a crevice in the limestone. The exact reason was not determined.

The soil surrounding Pit 1 was continuously saturated, with the water level approaching within 0.1 m of the soil surface on several occasions. Effluent spilled over the trench at the bedrock-soil interface and ran along the interface to keep the soil saturated. There were frequent seeps around Pit 1 and the soil surface was frequently soft and spongy. Water levels in Pit 2 were much lower, indicating little effluent movement from Pit 1. Either effluent is flowing in a different direction from Pit 1 or being intercepted by a fracture in the limestone. This point accentuates the difficulties of placing on-site systems in karst topography.

Table 1 represents average effluent characteristics (over the twelve month period) for the aeration unit. Its overall performance falls within ranges observed for similar devices (Hutzler et al., 1977). Based on COD it took the aeration unit 4 months to stabilize (Figure 4). After the stabilization period both total and soluble COD remained relatively consistent for a biological system. Soluble COD averaged 62 % of total over the study period. Suspended solids have never exceeded 35 mg/L.

Soluble COD in the lower trench has generally followed values coming from the aeration unit once the unit was stabilized. However, samples from the two soil pits have been quite variable with Pit 1 often above both trench and unit values. The large value from Pit 1 (2850 mg/L) in late June could result from initial flushing of natural materials. The large peak in October followed a period of heavy rains and would indicate a source outside the treatment system. The large jump in Pit 1 in May cannot be accounted for from the effluent. The samples from Pit 1 were very black and highly odorous which is indicative of septic conditions. It is also possible that a large organic load had passed through the aeration unit between sampling periods and had now moved into the pit.

Ammonia and nitrate values for the aeration unit, lower trench and Pit 1 and shown in Figure 5. Once stabilized, the

aeration unit produced a highly oxidized effluent, averaging 26 mg/L nitrate between October and March. The high nitrate levels from the aeration unit have not been observed in the trench or Pit 1. Levels in Pit 1 exceeded 1 mg/L only once (April) and levels in Pit 2 have consistently been below 0.4 mg/L. Denitrification could be occurring in the trench and Pit 1. Ammonia levels in Pit 1 have generally exceeded values in the unit effluent or trench. This may be indicative of anaerobic conditions in the trench and Pit.

For biological denitrification to occur, an organic energy source must be available and in septic tank tile fields, the energy source is the most difficult problem promoting the reaction. Laboratory researchers have often had to add methanol to promote denitrification (Sikora and Keeney, 1974). Stewart et al. (1979) added a sand-top soil mixture to laboratory columns dosed with aerated septic tank effluent. The organic carbon from the top soil served as an energy source for denitrification for 130-180 days but ran out, leading to higher nitrate values in the leachate.

The aeration unit in this study produces a highly nitrified effluent, an advantage if denitrification is desired. However, it also greatly reduces the organic carbon which is a disadvantage. If denitrification has been occurring in the trenches and Pit 1, then the carbon source most likely has been natural material from the surrounding soil. Higher nitrate levels measured in the lower trench over the last two sampling periods may indicate that the natural organic material is running out and one could expect higher nitrate values moving through the soil profile.

Orthophosphate levels in the unit effluent have been very consistent with an average of 6.3 mg/L. On-site septic systems with soil filter fields are usually effective in phosphorus removal and in most cases, phosphorus is not an environmental concern (Sawhney and Starr, 1977; Sawhney and Hill, 1975; Jones and Lee, 1979).

Fecal coliform data for the treatment unit (Table 2) was quite variable which is common for these systems (Hutzler et al., 1977). Coliforms generally do not move far in soils. Brown et al., (1977) found that coliforms were generally removed within 100 cm of the trench. Recovery of coliforms from deeper soils beneath the trench was found to be a result of effluent seeping through macropores (root channels and cracks). Canter and Knox (1985) reviewed the literature on this subject and concluded that bacteria are not likely to move far in loam or clay soils. However, in more permeable soils or porous materials (ie., karst bedrock), bacteria could move considerable distances and pollute shallow aquifers. The importance of insuring that septic effluent is treated by appropriate soil depth before being released into the environment was stressed.

The data does indicate that some coliforms were reaching both soil pits. Why Pit 2 indicates more movement than Pit 1 is difficult to assess. There may have been effluent movement through the limestone bedrock which bypassed Pit 1. In any case, coliform movement was considerably greater than in deeper soils as reported in the literature.

DISCUSSION

The aerator observed in this study does a good job of reducing organic, oxygen demanding material. COD and suspended solids are consistently low. It must be emphasized that this unit is well managed by personnel trained in waste treatment fundamentals. The average home owner may not give it as much attention. A second concern is the 4 month stabilization period. This unit was operated on a continuous basis year round. Homes which are used on a periodic basis (week end only) may not achieve as satisfactory results if the unit is not stabilized biologically. Operating the unit for short periods of time (weekends) may result in little treatment being achieved and could result in poorly treated effluent being discharged into the environment.

The effluent was highly oxidized, high in nitrates and orthophosphates. If this effluent were allowed to enter shallow wells or the lake without further treatment, significant degradation of water could occur. The tile field appears to be reducing both nutrients considerably, nitrate through denitrification and phosphorus through soil absorption. However, denitrification may not continue if natural organic energy from the soil runs out. This could result in higher nitrate concentrations flowing into the environment.

Because of the karst topography and the highly variable water levels, it is not certain that all of the effluent is being treated. The practice of excavating trenches into the limestone bedrock should be abandoned. Proper treatment of effluent occurs only when it can pass through a sufficient depth of soil. Excavating into the bedrock bypasses this basic treatment and can lead to environmental degradation. A mound or low pressure pipe system of effluent disposal would provide better treatment of the effluent and insure a greater degree of protection for the environment.

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Table 1. Aeration Unit Effluent Characteristics. Values are averaged over 12 month period.

TS mg/L	SS mg/L	Total COD mg/L	Soluble COD mg/L	PO ₄ mg/L	NH ₃ -N mg/L	NO ₃ -N mg/L	Chloride mg/L	Fecal Coliform #/100 ml
624	13.9	68	44	6.3	2.6	22.5	48	1935

Table 2. Fecal coliform data (colonies/ 100 ml.)

Month	Aeration Unit	Lower Trench	Pit 1	Pit 2
JUL	ND*	80	0	410
AUG	210	5	0	PD**
SEP	ND	35	0	30
OCT	1425	10	0	70
NOV	5900	110	40	10
DEC	1520	35	0	0
JAN	2240	10	0	0
FEB	1640	0	0	PD**
MAR	1440	0	0	PD**
APR	2340	30	15	PD**
MAY	700	0	7	PD**

*ND = No data.

**PD = Piezometer Dry, no sample taken.

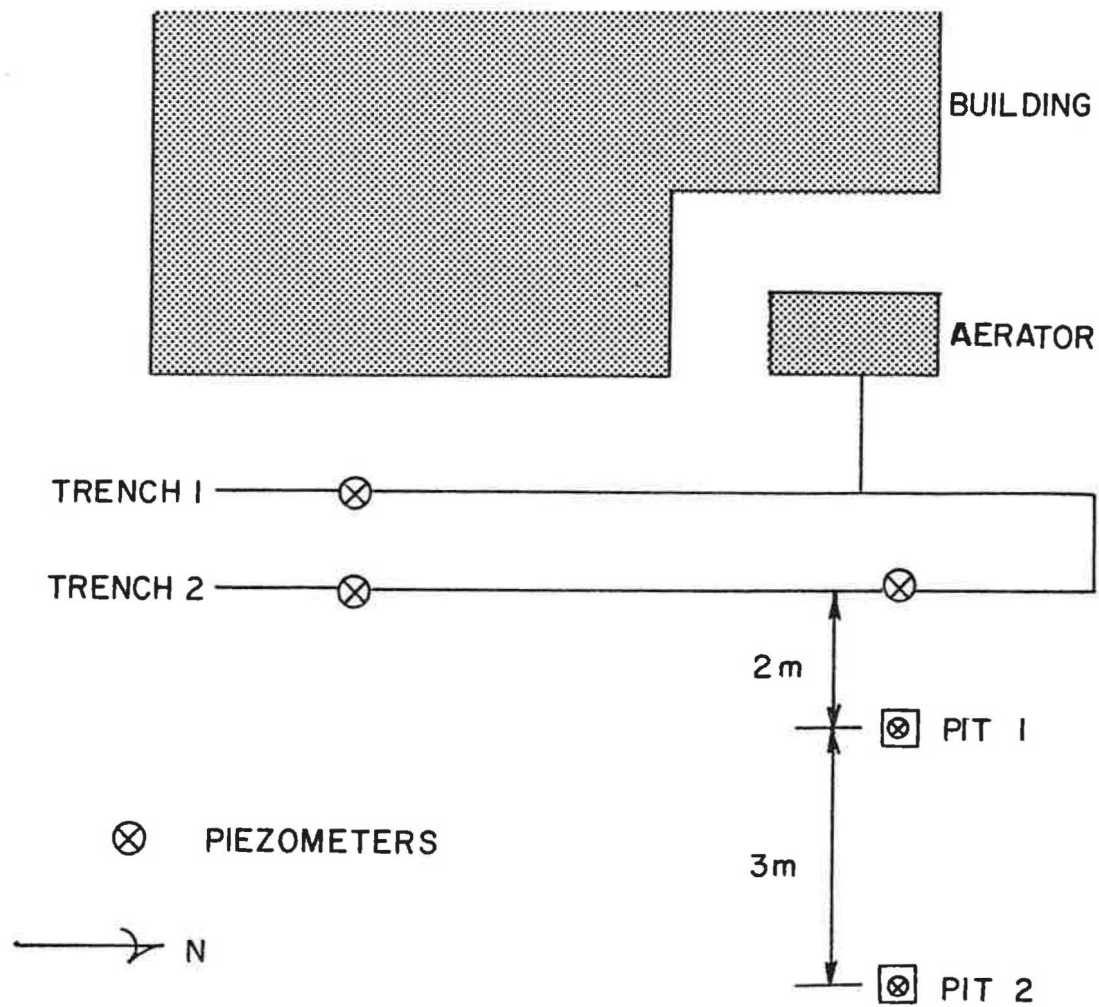


Figure 1. Plan view of aerator and tile field area.

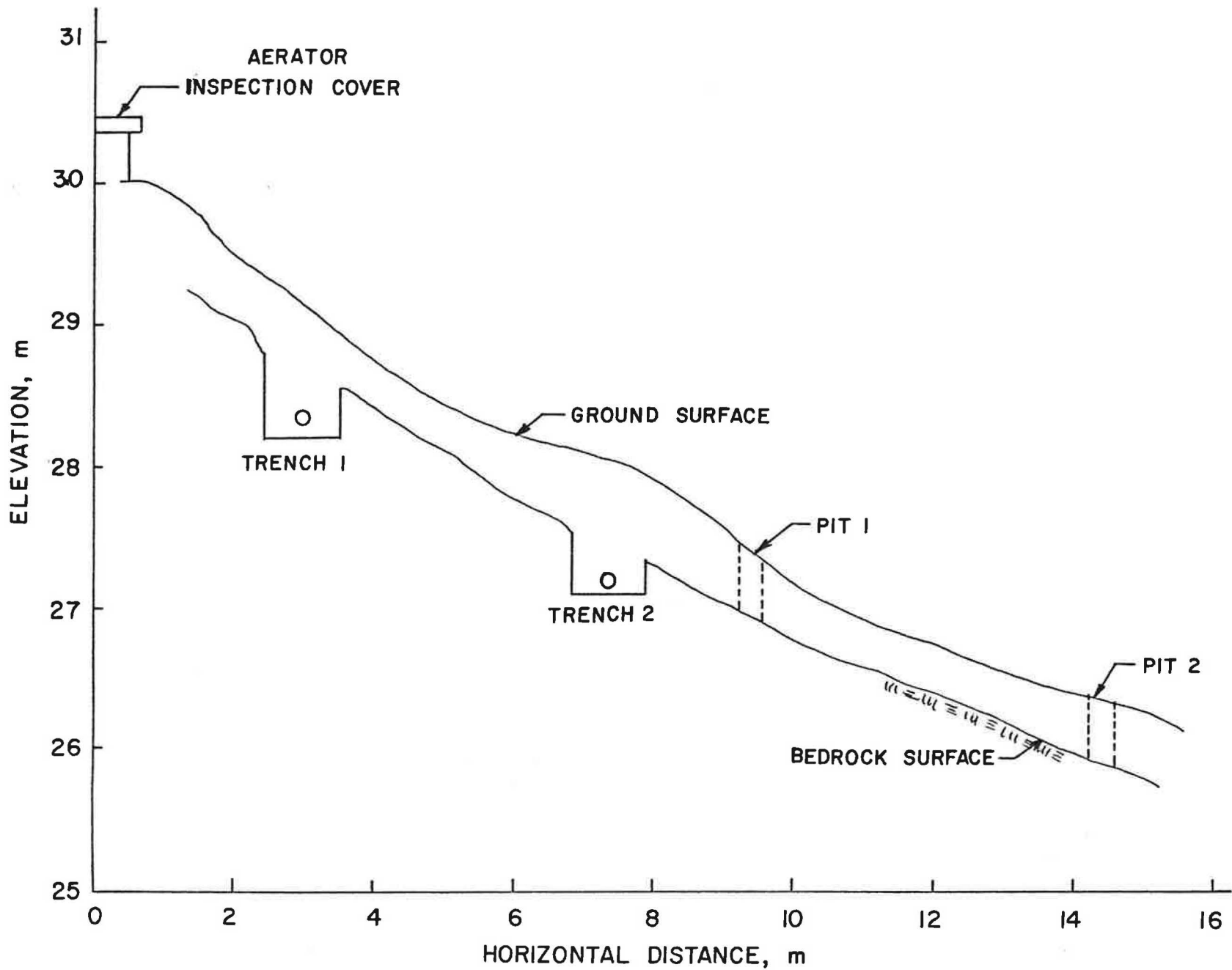


Figure 2. Elevation drawing of tile field and soil pits.

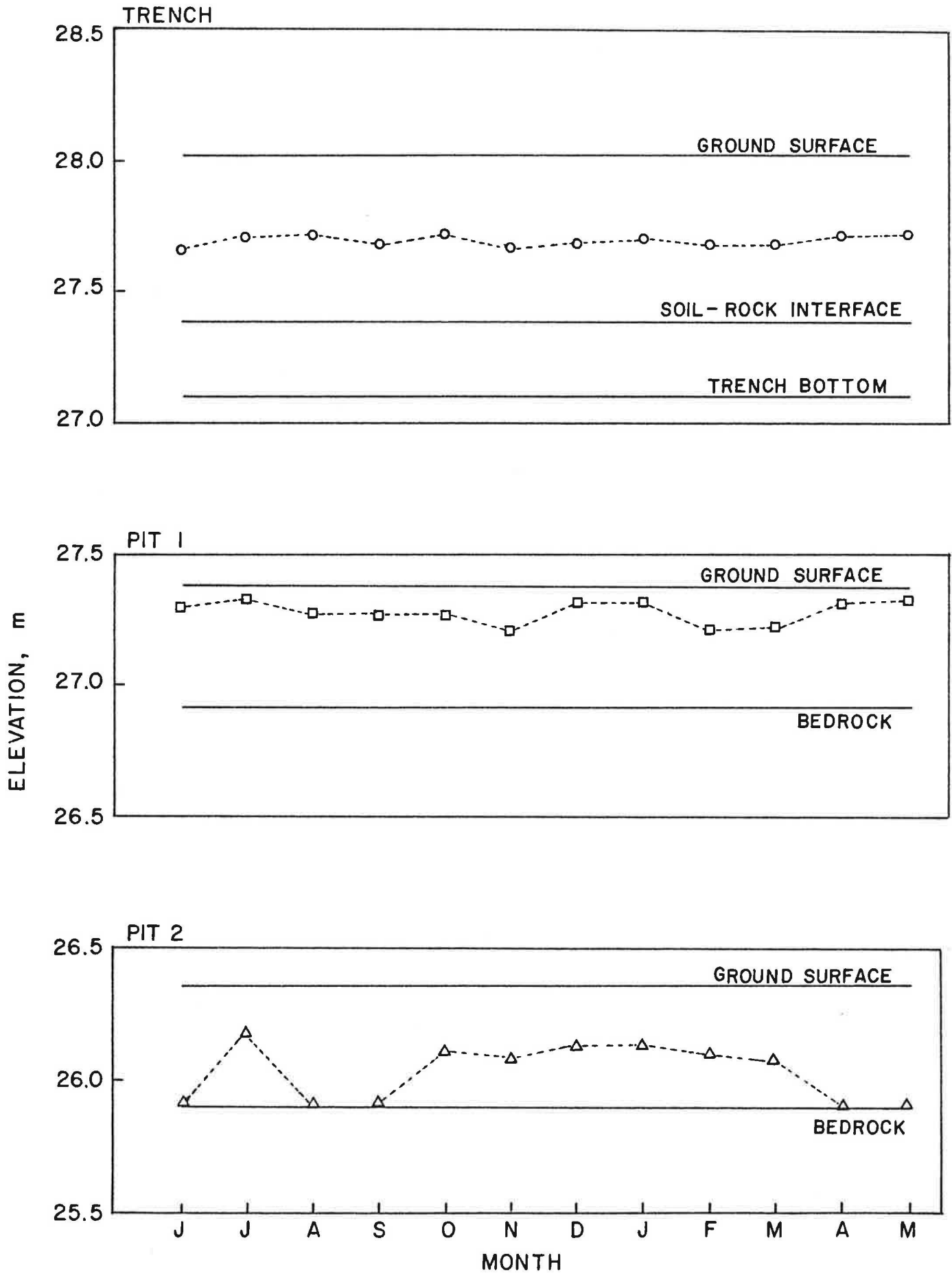


Figure 3. Saturated soil-water levels in tile trenches and soil pits.

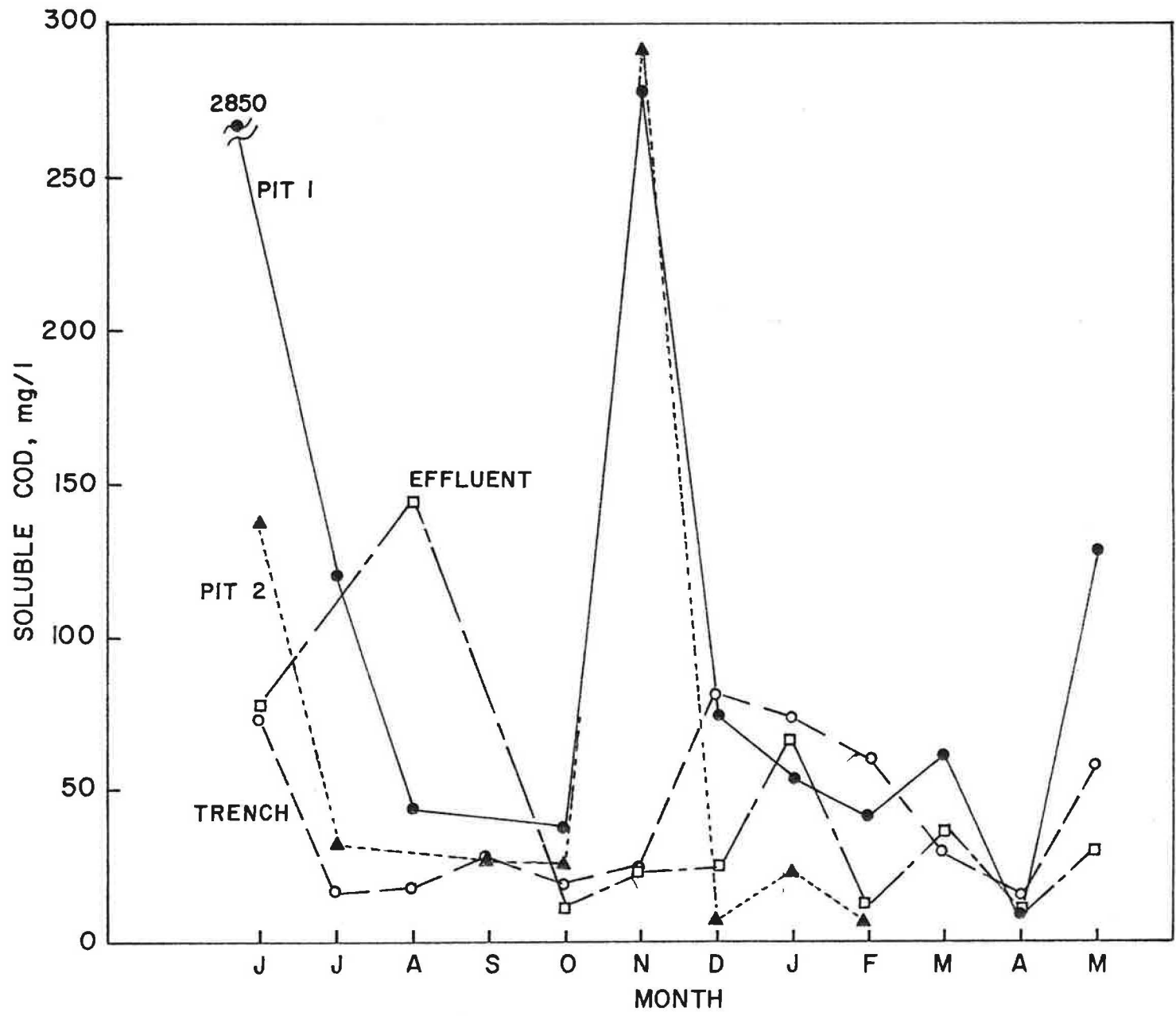


Figure 4. Soluble COD values over study period.

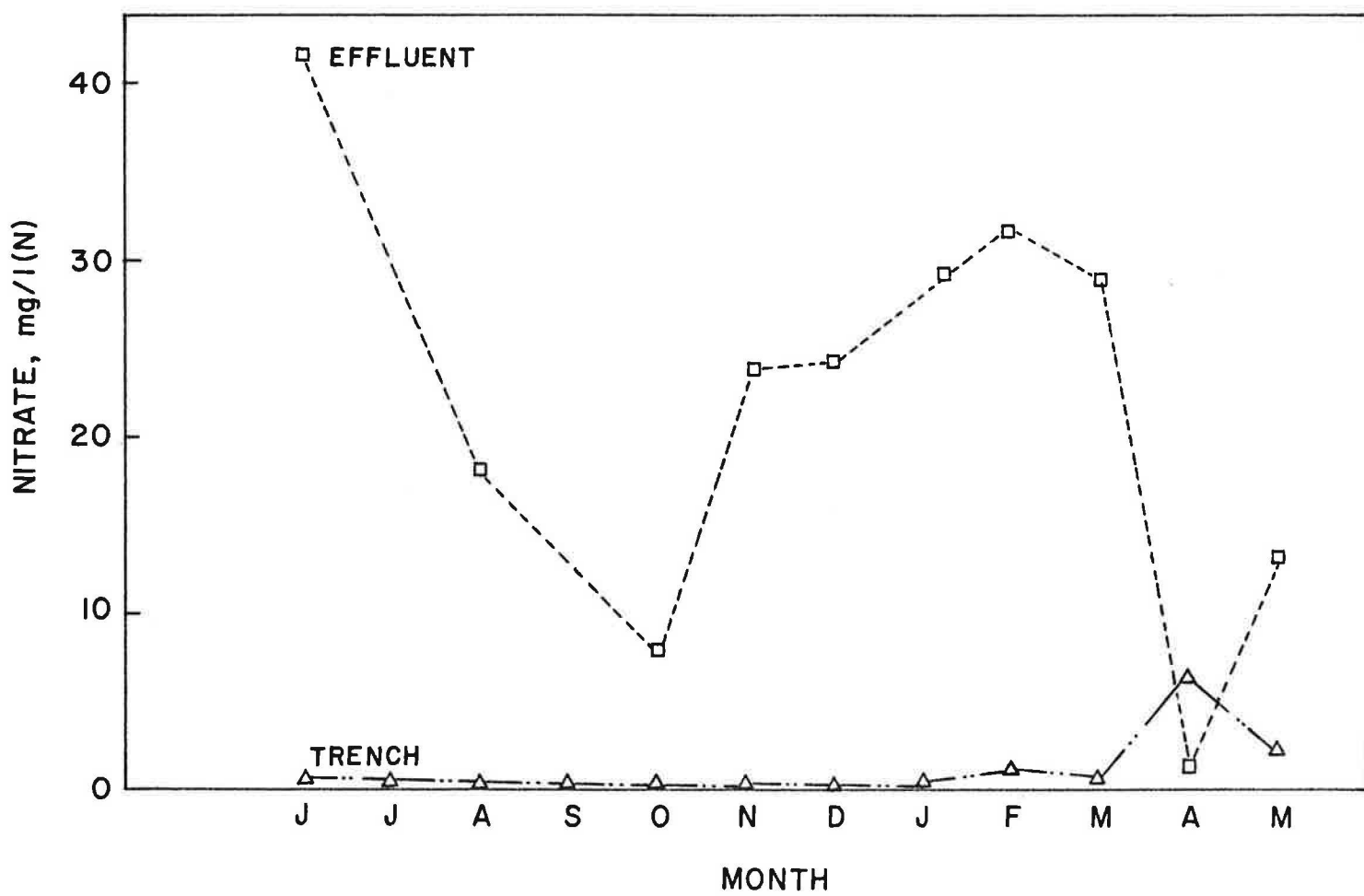
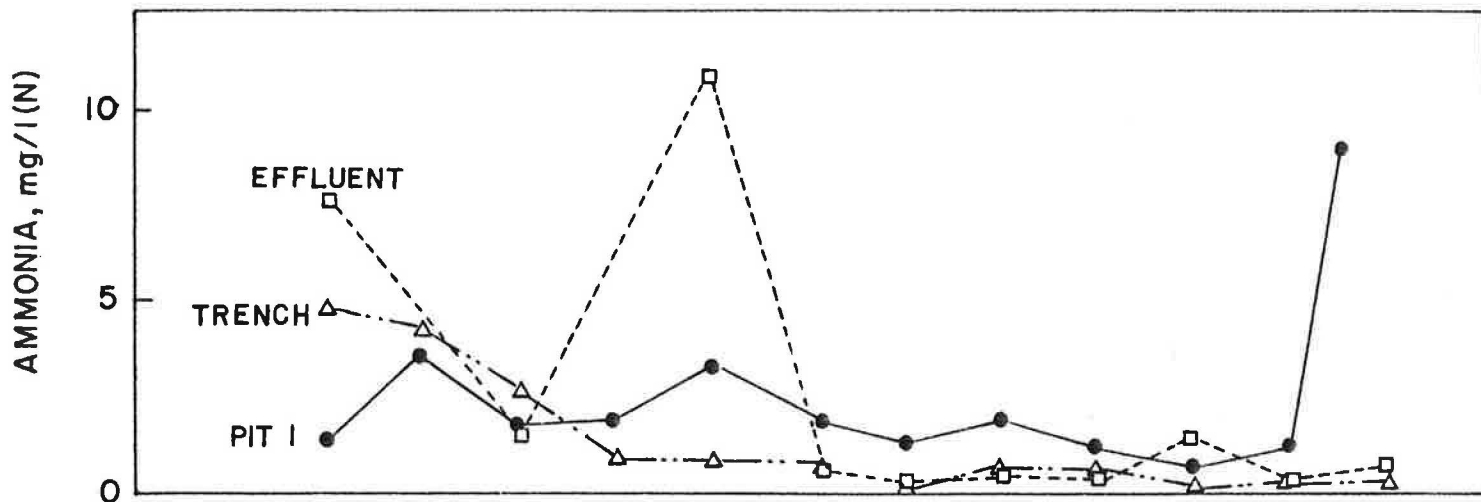


Figure 5. Ammonia and nitrate concentrations.

PHASE II

Zones of Water Saturation in Two
Ozark Soil Landscapes

INTRODUCTION

With the fast growth and development of the Lake of the Ozarks area as a major regional recreational area, the installation of effective on-site waste disposal systems is important. Many of the existing systems have either failed or are operating inefficiently such that the water quality of the lake is lowered and/or groundwater supplies are being polluted. Additionally, on-site waste failure can cause an unsightly, unaesthetic situation around many home sites. Much of this failure has been placed on a lack of adequate soil properties for on-site waste disposal. Many soil properties such as steepness of slope, shallowness to a restrictive zone (bedrock or fragipan), a relatively shallow impermeable horizon, and a relatively large amount of coarse fragments have been attributed to add to on-site waste disposal problems.

The objective of this project is to obtain baseline soil-land use information that will assist in designing effective on-site sewage disposal systems, including i) ascertaining if zones of water saturation existed during specific segments of the year within soil profiles which could cause on-site disposal problems and ii) if these zones occur, what is the major vector and speed of movement within these sloping landscapes.

MATERIALS AND METHODS

Two hillslopes representative of the deep soils (>150 cm to bedrock) which are commonly being utilized for development and on-site waste disposal around the Lake of the Ozarks were selected for analysis and monitoring. Both hillslopes were located in the Lake of the Ozarks State Park so to secure long-term monitoring of relatively undisturbed areas. Five monitoring sites were selected for each hillslope. Each site was selected based on landscape position (summit, shoulder, backslope, footslope) and probable degree of on-site waste disposal development.

Elevation and distance from each monitoring site were determined for each site in the hillslope (Fig. 1 and 2). Soil pits were dug for each site in a transect as outlined by Burk, et al. (198_). A detailed morphological description of each pedon was made according to the guidelines in Chapter 4 of the Soil Survey Manual (Soil Survey Staff 1981). Bulk sampling was done on a horizon-by-horizon basis. Sampling across the upper pit wall of each horizon was done to represent the array of variability in each horizon. Bulk density clods were also sampled, where possible, for bulk density and water retention difference. Bulk samples were air-dried and gently crushed with a wooden roller to avoid alteration of the particles. The crushed material was passed through a 2 mm equivalent spherical diameter (e.s.d.) sieve. Material >2 mm were estimated by vision on a volume basis.

Physical Analysis: Particle size analysis was done following the pipette method of Kilmer and Alexander (1949). Five sand size fractions (very coarse 2.0-1.0 mm, coarse 1.0-0.5 mm, medium 0.5-0.25 mm, fine 0.25-0.10 mm, and very fine 0.10-0.05 mm) two silt fractions (coarse 0.05-0.02 mm and fine 0.02-0.002 mm) and two clay size fractions (coarse 0.002-0.0002 and fine <0.0002 mm) were determined. Bulk density of natural clods was determined by the saran clod method (Franzmeier et al, 1965) and moisture content at -1/3 and -15 bar potential was determined using the clod or fine earth material from the clod on a pressure plate.

Chemical Analysis: Soil pH in water (1:1 ratio) and salt (0.01M CaCl₂) were measured on 10 g samples. Exchangeable bases were determined by leaching 1N NH₄OAc (pH 7.0) through a mechanical vacuum extractor (Soil Survey Staff, 1984). The leachates were analyzed utilizing an Instrumentation Laboratory AA/AE Spectrophotometer 551. Calcium and magnesium were determined by atomic absorption while potassium and sodium were determined by flame emission. Woodruff buffer was used to determine exchangeable acidity. Cation exchange capacity was consequently obtained by the summation method (Rhoades, 1982). Organic carbon was determined as

total carbon utilized a LECO CR-12 induction furnace.

Field Determination of Zones of Saturation. Lateral piezometers were installed in selected horizons of the monitoring sites as described by Burk, et al. (198_). In most cases the piezometers were duplicated by virtue of emplacing a piezometer within both side walls. Piezometers were monitored every two weeks, as well as rainfall from rain gauges placed on each site. A modified field method of determining saturated hydraulic conductivity by pumping water with a hand pump from piezometers with appreciable water was attempted once during the early spring of 1987. Slope factors using some of Goss and Youngs' (1980) baseline data were estimated to calculate the saturated hydraulic conductivities.

RESULTS AND DISCUSSIONS

The slope profiles of the two hillslopes and five soil pit monitoring sites are presented in figures 1 and 2. These two slopes and their associated soils are common for many areas of development around the Lake of the Ozarks. The Zion hillslope is representative of hillslopes which are short and possess lesser slope gradient than the Skinner hillslope which is representative of longer, steeper hillslopes.

Morphological descriptions of the soils for the two hillslopes are presented in tables 1 and 2. In the Zion hillslope pedons I-1 and I-2 are developed in loess overlying a cherty pedisegment of a local source underlain by a cherty clay material developed from dolomitic limestone while the three lower pedons are developed in a cherty local pedisegment over clayey residuum. In the Skinner hillslope loess over pedisegment over residuum is dominant in the upper four pedons while pedon II-5 does not exhibit a direct loess influence. Most of the soils possessed the classical A-E-Bt horizonation sequence found in Ozark landscapes. The two exceptions were pedons II-1 and II-2 where a dense, brittle fragipan (Bx)

horizon was present.

Of primary importance to possible zones of saturation and subsequent movement are the textural and structural sequences in the soil profiles. The morphological descriptions with support from particle size data (tables 3 -12) indicate a possible hydraulic gradient from a silt loam or cherty silt loam material (15-25% clay) in the A and E horizons developed in loess and/or pedisements with an abrupt change to a clay or cherty clay (50% plus clay) material developed from residuum. Additionally, many of the coarse fragments in the residuum derived portions are resistant, horizontally bedded, chert lenses which are relatively contiguous thus presenting a barrier to vertical water movement. These lenses are random thus are difficult to predict. Because of their dense, brittle nature the Bx horizons of pedons II-1 and II-2 present likely barriers to vertical water movement. In all these vertical barriers present a greater likelihood of lateral water movement.

The repeated occurrence of parting from platy structure (subangular blocky structure) in the E horizons above the more clayey Bt horizons is an indicator of local lateral water movement on a smaller scale. The occurrence of chromas of 2 or less on the ped coats on ped surfaces in the upper Bt horizons within the Zion hillslope may be an indicator of saturation during certain segments of the years (Soil Survey Staff, 1975).

Monitoring of the sites for possible zones of saturation from May 1986 to August 1987 showed some interesting patterns within each hillslope and components within each landscape (figures 3-12). In these figures, the occurrence of zones of saturation is depicted by the connection of points with a solid line where consistent water was found. We defined this consistent water as at least 1.5 cm of water in the bottom of the slip elbow attached to the lateral piezometer. Single points without connecting lines at a particular depth indicate that less than 1.5 cm of water was present. From observation in a simulated laboratory piezometer set-up

fields. Additionally, the influence of removing native vegetation, increasing runoff to certain areas from streets, driveways, and houses will have a unique localized influence and should be assessed before making clear on-site waste disposal guidelines and regulations. Also monitoring of water which moves vertically in the hillslope, particularly in the backslope position would be important in evaluating the influence of on-site waste disposal to the groundwater supply.

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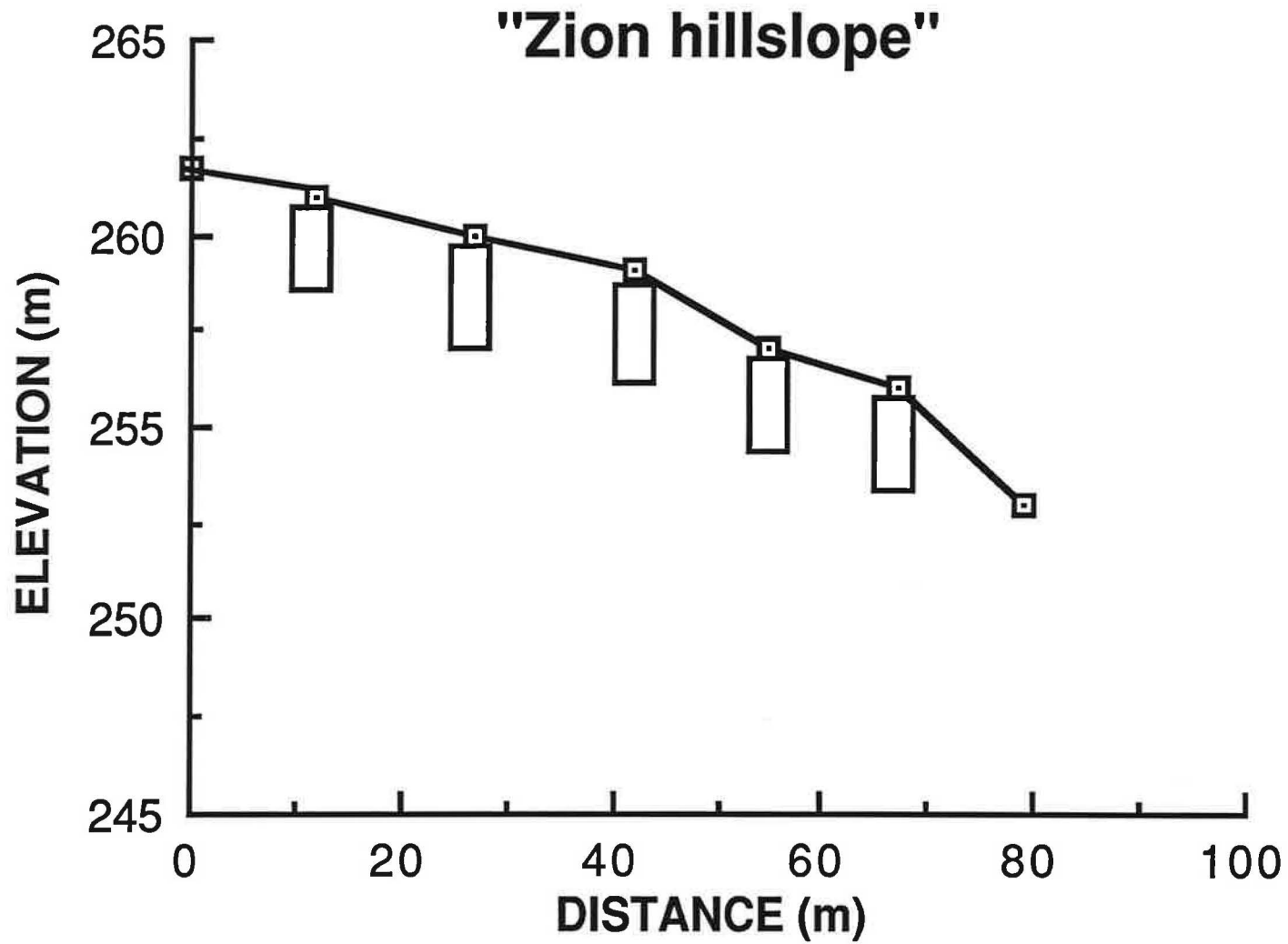


Figure 1

Table 1 (page 3)

continued, Zion hillslope.

Horizon	Depth cm	Matrix Color	Textural Class	Coarse Fragments ---%---	Structure	Clay Films	Color of Mottles	Ped Coat Colors**	Boundary
<u>PEDON I-5 Lower Backslope</u>									
A	0-8	10YR 3/2	v. cherty SiL	45	2msbk	---	---	---	cs
E1	8-30	10YR 5/3	v. cherty SiL	35	2msbk-1fpl	---	---	---	cs
E2	30-43	10YR 5/3	v. cherty SiL	40	1fsbk-1fpl	---	10YR 5/6	---	aw
2Bt1	43-64	5YR 4/6	CL	12	2f&msbk	2CVH	7.5YR 5/6	10YR 5/6	as
2Bt2	64-84	2.5YR 4/6	C	10	2msbk-2fsbk	2CVH	7.5YR 5/6	7.5YR 5/6 (H)	as
2Bt3	84-94	5YR 4/6	v. cherty SaC	35	2m&fsbk	2CH	7.5YR 5/6, 5/8	10YR 5/3	as
2Bt4	94-112	7.5YR 5/6	v. cherty C	50	2msbk (1fpl)	1CVH	5YR 4/6	7.5YR 5/6, 5/8	as
2Bt5	112-140	5YR 4/6	cherty C	15	2msbk	2CVH	---	10YR 7/2 (V)	---

* C - continuous, P - patchy, V - vertical, and H - horizontal.

** V - vertical, and H - horizontal.

we found 0.5 to 1.0 cm could be entrapped in the slip elbow without being able to move out into the soil when saturation levels decrease. Therefore some of these points may be relict.

First, the Skinner hillslope appears to be wetter (more zones of saturations, overall, and more occurrence of saturation in lower landscape positions) than the Zion hillslope. This situation can be best explained from the fragipan on the summit and upper shoulder areas of the Skinner hillslope holds up water from moving vertically. Thus there is an increased potential for water to drain from the large summit area into surficial horizons of the soils in the sideslopes.

Within each hillslope zones of saturation were more likely to occur during the late fall and winter months (November through April or May). Much of this occurrence coincides with the leaf off phase of the predominantly oak forest canopy. With greater rainfall in October 1986 and the lower evapotranspiration rate during the time of year was the main cause of the rapid occurrence of saturation in most of the sites. The rapid decrease of saturation in April and May correlates very well with leaf on condition.

Within the Zion hillslope saturation occurs primarily in the upper two sites (figures 3 and 4). The greater occurrence of saturation in the upper two profiles is primarily found in higher in the profile in the 2E and upper 3 Bt horizons. Ped coat colors for these two profiles were described as possessing chromas ≤ 2 (10YR 5/2, 6/2, 6/1) whereas the three profiles lower in the landscape were not. Low chromas such as these have been used as indicators of some degree of saturation during the biologically active part of the year (Soil Survey Staff, 1975). Low chromas (< 2) were described in the lowest horizons of many of the soils in the Zion hillslope of which some degree of saturation occurs during at least a small part of the year.

Zones of saturation within the Skinner hillslopes were more prevalent

throughout the hillslope than in the Zion hillslope. However the general pattern of less saturation with lower hillslope position as with the Zion hillslope was true for the Skinner hillslope. Additionally, the saturation in the lower landscape positions occurs lower within the profiles. Chromas of <2 in the upper parts of the profiles in the summit and shoulder positions are not likely present (table 2) even though zones of saturation exist (tables 8-10). However low chromas are present as mottles or ped coats in the same segments of the mid and lower Bt horizons of all five profiles where some degree of saturation exists. Many of these zones and low chroma areas coincide to areas immediately above a lens of horizontally bedded chert coarse fragments which are probably slowing the vertical movement of water in the soil.

The zones of saturation occur primarily in the upper portions of both hillslopes. This situation could be primarily a result of saturation and lateral movement off of the summit and shoulder areas of the landscape with a greater vertical vector in the mid-sections of the landscape (backslope) thus giving smaller volumes of water to move into the footslope positions. It is also possible that root interception and uptake of water by trees in the upper segments of the hillslope could influence the lack of saturation in the lower hillslope components during the growing season.

One startling observation for both hillslopes is the lack of saturation in the E horizons. This situation may be a result of the two week monitoring cycle which may not effectively assess the influx of water from frequent, moderate to intense rainfall events. Also, if and when it does occur in these horizons movement may be fairly rapid such that assessment at two week periods is not sufficient. A last reason for this lack of saturation may be a result of lesser overall rainfall than normal. Except for rainfall during October 1986 the overall distribution was less than normal.

The water movement patterns in both hillslopes may have an influence on the base saturation distribution in the hillslopes (tables 3-22). At critical subsoil depths base saturation is higher in the summit and should positions, lesser in the backslope areas, then increases slightly in the footslope areas. The unique occurrence of lower base saturation in the middle segments of the hillslope could be in part a result of the greater vertical water movement in these locations thus a greater leaching potential. These two patterns could assist in explaining the anomalous occurrence of Ultisols (older, low base status soils) on younger landscape components (backslopes) where Alfisols (mature, higher base status soil) are expected.

SUMMARY AND CONCLUSIONS

Zones of water saturation were documented in hillslope landscapes which are being developed for residential and recreational use. These zones more commonly occur in the summit and shoulder slope positions and are more prominent during fall and winter months. Movement appears to be lateral from the summit to the shoulder, especially in hillslopes which contain fragipans, with either plant uptake or vertical movement in the backslope positions allowing little saturation in lower footslope position.

Little saturation was found in the E horizons during the study. This lack of expected saturation in the E horizon may be a result of less than average rainfall or lack of sensitivity of the monitoring every two weeks between intense rainfall events.

From an application viewpoint, these zones of saturation could give problems to conventional on-site waste disposal systems in shoulder and summit positions with filter fields dug to depths approaching 75 cm. The use of interceptor lines or french drains may be appropriate to divert these zones away from septic filter

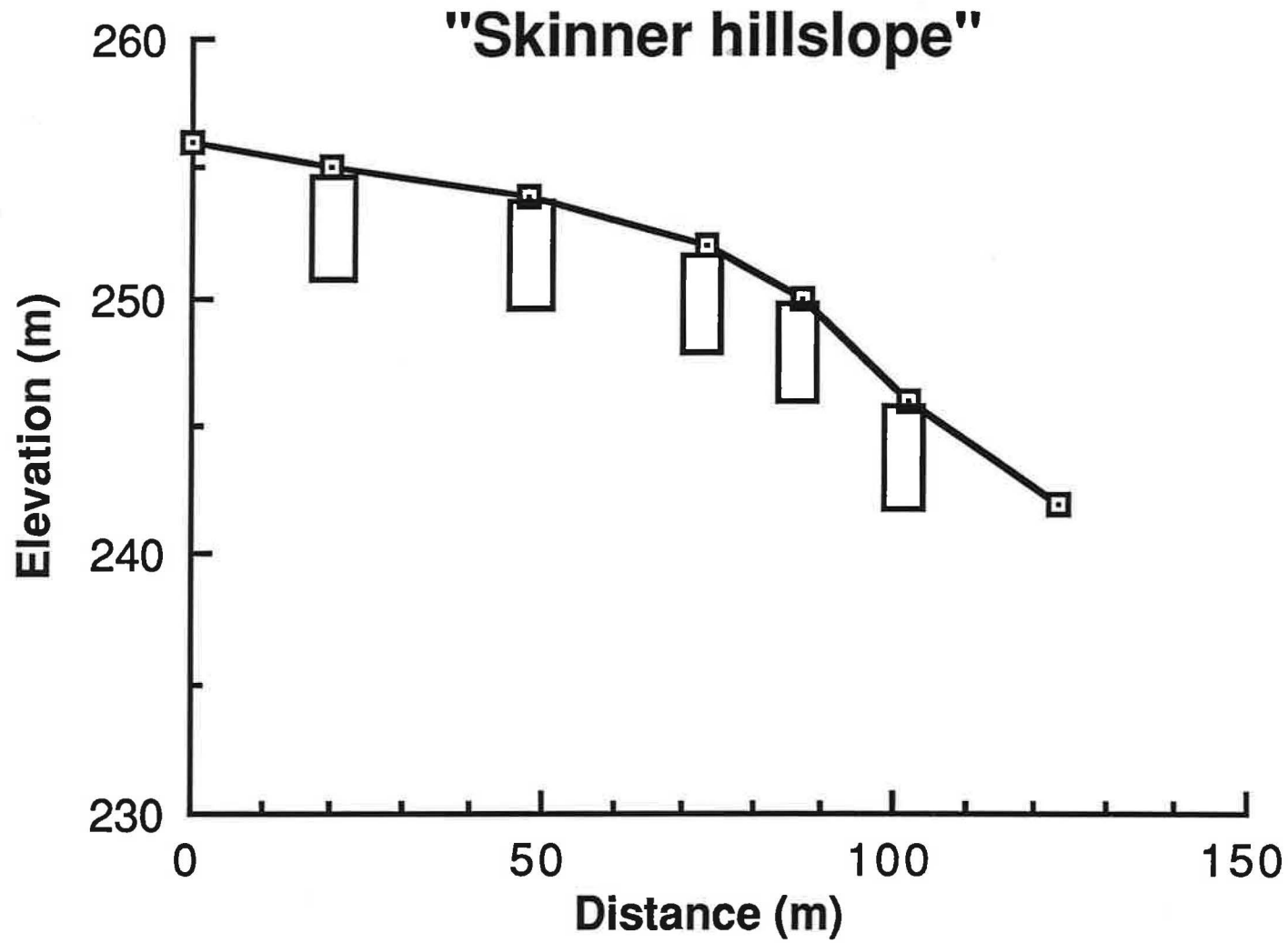


Figure 2

Table 1 (page 1)

Soil Morphological Descriptions from the respective pedons in the Zion hillslope.

Horizon	Depth cm	Matrix Color	Textural Class	Coarse Fragments ---%---	Structure	Clay Films [†]	Color of Mottles	Ped Coat Colors ^{††}	Boundary
<u>PEDON I-1 Summit</u>									
A	0-10	10YR 4/3	SiL	< 5	1msbk	---	---	---	cs
2E1	10-23	10YR 5/4	SiL	10	2msbk-1fpl	---	---	---	cs
2E2	23-33	10YR 5/3	cherty SiL	20	2fsbk-1fpl	---	---	---	as
3Bt1	33-58	10YR 3/6	cherty C	15	2msbk	2CVH	5YR 4/6	10YR 5/2 (V)	cs
3Bt2	58-76	2.5YR 4/6	C	10	2msbk-2fsbk	2CVH	5YR 5/6	10YR 6/2 (V)	cs
3Bt3	76-99	2.5YR 4/6	v. cherty C	35	2msbk-2fsbk	2CVH	5YR 5/6	10YR 6/1 (V)	as
3Bt4	99-122	5YR 4/6	cherty C	30	2msbk	2CVH	2.5YR 4/6	10YR 6/2 (V)	---
<u>PEDON I-2 Upper Shoulder</u>									
A	0-13	10YR 4/2	cherty SiL	15	2mgr	---	---	---	cs
E1	13-24	10YR 4/3	SiL	12	1msbk-1fpl	---	---	---	cs
2E2	24-43	10YR 5/3	v. cherty SiL	40	1msbk-1fpl	---	---	---	cs
2Bt1	43-64	7.5YR 4/4	cherty L	25	2fsbk	1PVH	7.5YR 5/6, 5/4	10YR 6/2	gs
2Bt2	64-76	7.5YR 5/6	cherty SiL	20	2msbk	1CVH	5YR 4/4	10YR 6/2	aw
3Bt1	76-107	2.5YR 3/6	C	10	2msbk	2CVH	2.5YR 4/6	10YR 6/2	cs
3Bt2	107-117	2.5YR 3/6	C	12	2m&fsbk	2CVH	7.5YR 5/6	10YR 6/2	---

Table 2 (page 3)

continued, Skinner hillslope.

Horizon	Depth cm	Matrix Color	Textural Class	Coarse Fragments ---%---	Structure	Clay Films	Color of Mottles	Ped Coat Colors	Boundary
<u>PEDON II- 5 Lower Backslope</u>									
A	0-9	10YR 3/2	cherty SiL	25	2f&mgr	---	---	---	cs
E1	9-20	10YR 4/3	v. cherty SiL	35	2f&msbk-1fpl	---	10YR 3/2	---	cs
E2	20-30	10YR 5/3	v. cherty SiL	35	2f&msbk-1fpl	---	---	---	cs
Bt1	30-51	10YR 5/3	ex. cherty SiL	60	2msbk	1PVH	---	10YR 5/4	cs
Bt2	51-81	10YR 5/3	ex. cherty SiL	70	1fsbk	1CV	10YR 5/3	10YR 5/4	cs
2Bt1	81-112	7.5YR 5/6	cherty C	20	2msbk-2fsbk	2CVH	10YR 6/2	2.5YR 3/6	cs
2Bt2	112-155	10YR 3/6	cherty C	20	2msbk-2fsbk	1CVH	10YR 6/2	2.5YR 3/4	---

† C - continuous, P - patchy, V - vertical, and H - horizontal.

** r - rhines.

*** V - vertical, and H - horizontal.

Table 1 (page 2)

continued, Zion hillslope.

Horizon	Depth cm	Matrix Color	Textural Class	Coarse Fragments ---%---	Structure	Clay Films	Color of Mottles	Ped Coat Colors	Boundary
<u>PEDON I-3 Lower Shoulder</u>									
A	0-18	10YR 4/3	cherty SiL	15	2mgr	---	---	---	cs
E1	18-36	10YR 5/3	cherty SiL	20	2mgr-1fpl	---	---	---	gs
E2	36-56	10YR 5/4	cherty SiL	30	1fsbk-1fpl	---	---	---	as
2Bt1	56-76	2.5YR 4/8	cherty CL	20	2msbk	2CVH	7.5YR 5/6	5YR 5/8	as
2Bt2	76-104	7.5YR 5/8	v. cherty C	55	1f&msbk (1fpl)	1CVH	5YR 5/6	5YR 4/6	as
2Bt3	104-130	2.5YR 4/6	cherty C	15	2msbk	2CVH	7.5YR 5/4	10YR 6/3, 7/2	as
2Bt4	130-152	2.5YR 4/6	C	10	2msbk	2CVH	7.5YR 5/6	10YR 5/2, 6/2	cs
2Bt5	152-183	2.5YR 4/8	C	10	2msbk	2CVH	5YR 4/6	7.5YR 6/2, 5/2	---
<u>PEDON I-4 Upper Backslope</u>									
A	0-15	10YR 4/3	cherty SiL	15	2fsbk	---	---	---	cs
E1	15-30	10YR 5/3	cherty SiL	30	1msbk-1fpl	---	---	---	cs
E2	30-56	10YR 5/4	v. cherty SiL	40	1m&fsbk-1fpl	---	---	---	as
2Bt1	56-79	5YR 4/6	C	10	2msbk (1fpl)	2CVH	7.5YR 5/6	2.5YR 4/8	as
2Bt2	79-99	2.5YR 4/6	C	< 10	2msbk	2CVH	7.5YR5/4	5YR 4/4	as
2Bt3	99-124	2.5YR 4/6	C	10	2msbk	2CVH	5YR 5/6	7.5YR 5/2	as
2Bt4	124-175	2.5YR 3/6	C	10	1mpr-2msbk	3CVH	7.5YR 5/6, 5/8	5YR 4/2, 4/3	---

Table 2 (page 1)

Soil Morphological Descriptions from the respective pedons in the Skinner hillslope.

Horizon	Depth cm	Matrix Color	Textural Class	Coarse Fragments ---%---	Structure	Clay Films [†]	Color of Mottles ^{††}	Ped Coat Colors ^{†††}	Boundary
<u>PEDON II-1 Summit</u>									
A	0-2.5	10YR 4/3	SiL	7	2m&fgr	---	---	---	cs
E	2.5-10	10YR 5/3	cherty SiL	25	2mgr-1fpl	---	7.5YR 4/4	---	aw
Bt1	10-27	10YR 4/4	cherty SiL	15	2msbk	1CVH	---	7.5YR 4/4	cs
Bt2	27-37	10YR 4/4	SiCL	< 5	2msbk	1CVH	10YR 5/6	10YR 3/4	cs
E'/2Btx	37-50	10YR 5/6	cherty SiL	30	1mbky	1PVH	---	10YR 6/2 (V)	cs
2Bx1	50-70	10YR 5/3	ex. cherty SiL	60	str1 mas	---	10YR 5/6 (r)	10YR 4/4 (H)	cs
2Bx2	70-94	10YR 4/4	ex. cherty SiL	75	str1 mas (1mpl)	---	10YR 5/3 (r)	---	cs
3Bt1	94-132	2.5YR 3/6	v. cherty C	35	2csbk-2msbk	1CVH	5YR 5/6	2.5YR 4/6	cs
3Bt2	132-152	2.5YR 4/6	cherty C	25	2msbk-2fsbk	1PVH	---	2.5YR 5/6	---
<u>PEDON II-2 Upper Shoulder</u>									
A	0-8	10YR 3/3	SiL	10	2f&mgr	---	---	---	cs
E	8-15	10YR 5/3	cherty SiL	15	2mgr-1fpl	---	---	---	cs
BE	15-28	10YR 4/4	cherty SiL	20	2msbk-1fpl	1PV	10YR 4/6	10YR 5/3	cs
Bt1	28-46	10YR 4/6	cherty SiL	25	2m&fsbk	1CVH	10YR 5/2, 6/2	10YR 4/4	cs
2Btx1	46-63	10YR 4/4	v. cherty SiL	50	1msbk	1CVH	10YR 6/4	10YR 5/3	cw
2Btx2	63-79	10YR 5/4	ex. cherty SiL	65	1msbk-str1 mas	1CVH	10YR 5/2, 5/6	10YR 5/4	cs
2Bt1	79-94	10YR 6/6	v. cherty SiL	50	1mpl-1msbk	1CV	10YR 5/6 (r)	10YR 6/2	cw
2Bt2	94-117	10YR 5/3	v. cherty L	45	2m&cpl	1CH	10YR 4/4	10YR 6/2	cs
3Bt1	117-140	2.5YR 4/6	cherty C	25	2msbk	1CVH	7.5YR 5/6	2.5YR 3/6	cs
3Bt2	140-165	2.5YR 3/6	cherty C	25	2csbk	1CV	7.5YR 5/4	10YR 3/6	---

Table 2 (page 2)

continued, Skinner hillslope.

Horizon	Depth cm	Matrix Color	Textural Class	Coarse Fragments ---%---	Structure	Clay Films ¹	Color of Mottles	Ped Coat Colors	Boundary
<u>PEDON II-3 Lower Shoulder</u>									
A	0-8	10YR 3/2	SiL	10	2mgr	---	---	---	cs
E1	8-18	10YR 5/3	SiL	10	2f&msbk-1fpl	---	---	---	cs
E2	18-25	10YR 5/3	SiL	10	2msbk-1fpl	---	---	---	cs
Bt1	25-36	10YR 4/4	SiL	10	2msbk	1CV	10YR 5/4	10YR 4/4	cs
Bt2	36-56	10YR 4/6	cherty SiL	15	2msbk	2CVH	---	10YR 4/4	cs
2Bt1	56-84	10YR 5/6	v. cherty SiL	35	2msbk	1PVH	10YR 6/4	10YR 4/4, 5/6	cs
2Bt2	84-109	2.5YR 3/6	cherty CL	30	2m&fsbk	1CVH	---	10YR 5/6	aw
3Bt1	109-132	2.5YR 3/6	v. cherty C	40	2msbk-2fsbk	3CVH	10YR 6/2	7.5YR 5/6	cs
3Bt2	132-157	2.5YR 3/6	cherty C	25	2msbk-2fsbk	2CVH	10YR 6/2	7.5YR 5/6	---
<u>PEDON II-4 Upper Backslope</u>									
A	0-8	10YR 3/2	cherty SiL	15	2f&mgr	---	---	---	cs
E1	8-20	10YR 4/2	SiL	10	2msbk-1fpl	---	10YR 3/2	---	cs
E2	20-28	10YR 5/4	cherty SiL	15	2msbk-1fpl	---	---	---	cs
Bt1	28-53	10YR 5/4	v. cherty SiL	35	2f&msbk	1P&CV	---	10YR 4/4	gs
2Bt	53-81	10YR 5/4	v. cherty SiL	55	2fsbk	1CVH	10YR 4/3	10YR 4/4	aw
3Bt1	81-112	2.5YR 4/6	v. cherty C	45	2msbk-2fsbk	1CVH	10YR 5/2, 6/2	7.5YR 5/6, 5/8	cs
3Bt2	112-147	2.5YR 3/6	cherty C	20	1f&mpl	2CVH	7.5YR 5/4	10YR 5/3	cs
3Bt3	147-168	7.5YR 5/6	cherty C	15	2msbk-2fsbk	3CVH	2.5YR 3/6	10YR 6/1, 6/2	cs
BC	168-190	7.5YR 5/8	cherty SaCL	25	2fsbk	2CVH	2.5YR 4/6	10YR 3/6	---

Table 3

Particle-size distribution in Summit position, Zion hillslope.

Horizon	Depth cm	Coarse Fragments - % Vol -	Particle-size distribution (mm)											
			Sand					Silt			Clay			
			Very Coarse (2.0- 1.0)	Coarse (1.0- 0.5)	Medium (0.50- 0.25)	Fine (0.25- 0.10)	Very Fine (0.10- 0.05)	Total Sand	Coarse (0.05- 0.02)	Fine (0.02- 0.002)	Total Silt	Coarse (0.002- 0.0002)	Fine (<0.0002)	Total Clay
A	0-10	< 5	2.5	3.6	4.3	4.0	2.9	17.3	27.2	46.4	73.6	6.4	2.7	9.1
2E1	10-23	10	3.3	3.1	4.5	4.3	2.8	18.0	25.2	43.1	68.3	6.5	7.3	13.8
2E2	23-33	20	1.9	2.9	4.1	4.3	3.0	16.2	22.4	44.7	67.0	10.2	6.5	16.7
3Bt1	33-58	15	2.4	1.5	1.6	1.7	2.0	9.2	0.0	7.5	7.5	18.0	65.3	83.3
3Bt2	58-76	10	1.9	2.1	2.1	1.9	2.8	10.8	0.0	3.3	3.3	20.2	65.7	85.9
3Bt3	76-99	35	0.7	2.1	4.4	7.2	5.8	20.3	0.0	0.6	0.6	31.1	48.0	79.1
3Bt4	99-122	30	2.9	3.9	7.2	11.8	5.6	31.4	0.0	5.5	5.5	33.6	29.5	63.1

Table 4

Particle-size distribution in Upper Shoulder position, Zion hillslope.

Horizon	Depth cm	Coarse Fragments - % Vol -	Particle-size distribution (mm)											
			Sand				Silt			Clay				
			Very Coarse (2.0- 1.0)	Coarse (1.0- 0.5)	Medium (0.50- 0.25)	Fine (0.25- 0.10)	Very Fine (0.10- 0.05)	Total Sand	Coarse (0.05- 0.02)	Fine (0.02- 0.002)	Total Silt	Coarse (0.002- 0.0002)	Fine (<0.0002)	Total Clay
A	0-13	15	2.3	2.5	2.9	2.5	2.6	12.8	20.6	52.9	73.6	6.4	7.2	13.6
E1	13-24	12	3.4	2.7	4.0	4.0	2.7	17.0	23.8	48.2	72.0	6.9	4.1	11.0
2E2	24-43	40	11.7	3.9	3.8	4.3	2.7	26.4	17.5	41.7	59.2	11.1	3.3	14.4
2Bt1	43-64	25	10.0	5.2	4.1	5.4	4.6	29.3	15.2	31.6	46.8	14.6	9.2	23.8
2Bt2	64-76	20	9.0	4.5	2.8	4.1	5.0	25.4	16.3	33.1	49.4	12.3	12.9	25.2
3Bt1	76-107	10	1.5	2.5	1.9	2.5	4.6	13.0	4.6	16.8	21.4	21.3	44.3	65.6
3Bt2	107-117	12	1.9	1.5	1.5	2.1	4.0	11.1	12.5	17.6	30.1	17.6	41.2	58.8

Table 5

Particle-size distribution in Lower Shoulder position, Zion hillslope.

Horizon	Depth cm	Coarse Fragments - % Vol -	Particle-size distribution (mm)											
			Sand					Silt				Clay		
			Very Coarse (2.0- 1.0)	Coarse (1.0- 0.5)	Coarse Medium (0.50- 0.25)	Fine (0.25- 0.10)	Fine (0.10- 0.05)	Very Fine (0.05- 0.02)	Fine (0.02- 0.002)	Total Silt (0.002- 0.0002)	Total Clay (0.002- <0.0002)			
			-----%-----											
A	0-18	15	2.2	2.8	2.9	2.7	2.5	13.1	23.3	50.7	74.0	5.7	7.2	12.9
E1	18-36	20	4.1	2.7	4.4	4.6	3.3	19.1	23.1	47.6	70.7	8.2	2.4	10.6
E2	36-56	30	5.9	2.8	4.0	4.6	3.5	20.8	11.8	56.8	68.6	7.4	3.2	10.6
2Bt1	56-76	20	6.8	6.2	6.4	6.4	5.3	31.0	12.9	26.7	39.6	14.6	14.8	29.4
2Bt2	76-104	55	1.5	1.4	1.8	2.1	3.4	10.2	3.7	15.1	18.8	30.9	40.1	71.0
2Bt3	104-129	15	2.0	5.3	6.1	3.5	2.6	19.5	2.3	15.5	17.8	21.3	41.5	62.8
2Bt4	129-152	10	0.1	0.7	1.1	2.1	2.7	6.6	7.2	15.7	22.8	26.7	43.8	70.5
2Bt5	152-183	< 10	3.6	3.1	3.1	2.7	2.8	15.3	6.0	10.8	16.8	31.2	36.7	67.9

Table 6

Particle-size distribution in Upper Backslope position, Zion hillslope.

Horizon	Depth cm	Coarse Fragments - % Vol -	Particle-size distribution (mm)											
			Sand					Silt			Clay			
			Very Coarse (2.0- 1.0)	Coarse (1.0- 0.5)	Coarse (0.50- 0.25)	Medium Fine (0.25- 0.10)	Fine (0.10- 0.05)	Very Fine (0.05- 0.02)	Total Sand	Fine (0.02- 0.002)	Total Silt	Coarse (0.002- <0.0002)	Fine (<0.0002)	Total Clay
A	0-15	15	2.6	3.5	4.3	4.3	3.0	17.6	15.2	47.0	62.2	14.0	6.1	20.1
E1	15-30	30	3.8	4.1	5.3	5.8	2.9	21.9	21.5	48.3	69.8	6.9	1.3	8.2
E2	30-56	40	10.7	6.1	5.4	6.5	3.9	32.5	21.1	37.3	58.5	7.1	1.9	9.0
2Bt1	56-79	10	0.6	2.6	5.0	9.8	3.2	21.2	10.7	19.9	30.6	24.1	24.1	48.2
2Bt2	79-99	< 10	1.1	4.9	8.0	11.7	3.3	29.0	8.5	14.8	23.3	24.9	22.8	47.7
2Bt3	99-124	10	0.2	1.6	3.7	11.4	5.2	22.0	4.7	8.8	13.5	31.1	33.4	64.5
2Bt4	124-175	10	0.5	0.9	1.1	1.4	1.0	4.8	4.7	14.6	19.3	41.2	34.7	75.9

Table 7

Particle-size distribution in Lower Backslope position, Zion hillslope.

Horizon	Depth cm	Coarse Fragments - % Vol -	Particle-size distribution (mm)											
			Sand				Silt			Clay				
			Very Coarse (2.0- 1.0)	Coarse (1.0- 0.5)	Medium (0.50- 0.25)	Fine (0.25- 0.10)	Very Fine (0.10- 0.05)	Total Sand	Coarse (0.05- 0.02)	Fine (0.02- 0.002)	Total Silt	Coarse (0.002- 0.0002)	Fine (<0.0002)	Total Clay
A	0-8	45	2.4	2.6	3.0	3.4	2.6	13.9	17.6	49.2	66.8	13.3	5.9	19.2
E1	8-30	35	3.6	4.6	6.2	8.0	3.3	25.8	23.9	44.4	68.3	4.3	1.7	6.0
E2	30-43	40	5.6	6.1	7.2	9.3	3.9	32.1	21.2	38.8	60.0	6.4	1.5	7.9
2Bt1	43-64	12	3.7	7.1	5.4	8.4	3.5	28.0	10.2	25.8	36.0	14.5	21.5	36.0
2Bt2	64-84	10	2.4	3.3	3.0	5.7	2.9	17.3	7.0	15.7	22.7	21.7	38.3	60.0
2Bt3	84-94	35	1.9	4.7	11.8	22.1	6.9	47.4	5.3	12.0	17.3	8.1	27.2	35.3
2Bt4	94-112	50	3.4	4.6	5.9	9.6	5.5	29.1	8.7	21.9	30.5	10.0	30.4	40.4
2Bt5	112-140	15	0.0	0.4	0.8	1.1	1.6	3.8	4.8	16.1	21.0	33.4	41.8	75.2

Table 8

Particle-size distribution in Summit position, Skinner hillslope.

Horizon	Depth cm	Particle-size distribution (mm)												
		Coarse Fragments	Sand					Silt					Clay	
			Very Coarse	Coarse	Medium	Fine	Very Fine	Total Sand	Coarse	Fine	Total Silt	Coarse	Fine	Total Clay
			(2.0- 1.0)	(1.0- 0.5)	(0.50- 0.25)	(0.25- 0.10)	(0.10- 0.05)	(0.05- 0.02)	(0.02- 0.002)	(0.002- 0.0002)	(<0.0002)			
- % Vol - (----- % -----)														
A	0-2	7	15.8	3.1	3.7	3.1	2.2	27.8	9.3	41.5	50.8	12.6	8.7	21.3
E	2-10	25	1.7	2.4	2.9	2.8	1.5	11.3	25.0	43.3	68.3	7.5	12.9	20.4
Bt1	10-27	15	1.6	1.2	1.4	1.2	0.8	6.2	46.5	23.6	70.1	9.6	14.1	23.7
Bt2	27-37	< 5	3.0	1.9	2.6	2.6	1.4	11.6	18.6	36.4	55.0	12.7	20.7	33.4
E/2Btx	37-50	30	5.7	2.7	3.8	3.7	2.0	17.8	22.2	39.4	61.6	9.9	10.6	20.5
2Bx1	50-71	60	6.3	3.2	4.1	3.9	2.3	19.9	23.7	40.9	64.6	2.9	12.6	15.5
2Bx2	71-94	75	9.2	5.8	6.1	5.5	2.6	29.2	21.8	29.6	51.4	3.4	16.0	19.4
3Bt1	94-132	35	4.4	5.0	4.4	3.5	2.0	19.4	7.8	7.5	15.3	24.1	41.2	65.3
3Bt2	132-152	25	2.0	5.3	8.9	7.0	2.4	25.2	6.2	7.0	13.1	21.6	39.8	61.4

Table 10

Particle-size distribution in Lower Shoulder position, Skinner hillslope.

Horizon	Depth cm	Particle-size distribution (mm)												
		Coarse Fragments	Sand					Silt			Clay			
			Very Coarse		Coarse	Medium		Total Sand	Very Fine		Total Silt	Coarse		Total Clay
			(2.0- 1.0)	(1.0- 0.5)		(0.50- 0.25)	(0.25- 0.10)		(0.10- 0.05)	(0.05- 0.02)		(0.02- 0.002)	(0.002- <0.0002)	
- % Vol - (----- %-----)														
A	0-8	10	3.7	3.4	4.8	4.8	2.6	19.3	20.5	42.7	63.2	10.2	7.3	17.5
E1	8-18	10	4.5	3.2	4.4	4.5	1.8	18.5	22.8	48.8	71.6	6.6	3.0	9.9
E2	18-25	10	3.0	2.7	5.0	5.1	1.9	17.8	24.1	45.6	69.7	6.4	6.1	12.5
Bt1	25-36	10	3.3	2.8	4.4	4.8	2.1	17.2	22.3	43.5	65.9	9.4	7.5	16.9
Bt2	36-56	15	1.5	2.3	4.9	5.9	2.5	17.1	23.6	34.0	57.6	13.6	11.6	25.2
2Bt1	56-84	35	5.7	2.9	4.9	6.2	2.8	22.5	23.9	29.7	53.6	10.8	13.1	23.9
2Bt2	84-109	30	7.2	3.9	5.4	6.7	2.9	26.2	18.4	26.6	45.0	9.7	19.1	28.8
3Bt1	109-132	40	1.7	2.3	5.6	9.6	2.8	22.0	6.7	11.0	17.8	21.3	38.9	60.2
3Bt2	132-157	25	0.8	1.5	3.7	5.3	2.5	13.8	9.7	11.8	21.6	28.4	36.2	64.6

Table 11

Particle-size distribution in Upper Backslope position, Skinner hillslope.

Horizon	Depth cm	Particle-size distribution (mm)													
		Coarse Fragments	Sand					Silt					Clay		
			Very Coarse	Coarse	Medium	Fine	Very Fine	Very Fine	Total Sand	Coarse	Fine	Total Silt	Coarse	Fine	Total Clay
			(2.0- 1.0)	(1.0- 0.5)	(0.50- 0.25)	(0.25- 0.10)	(0.10- 0.05)	(0.05- 0.02)	(0.02- 0.002)	(0.002- 0.0002)	(<0.0002)				
- % Vol -	- % -														
A	0-8	15	5.4	5.3	7.7	7.8	3.2	29.4	14.4	36.9	51.3	13.6	5.7	19.3	
E1	8-20	10	5.3	3.8	5.6	6.1	2.0	22.8	23.3	45.6	68.9	5.1	3.2	8.3	
E2	20-28	15	5.3	3.5	5.6	6.0	2.0	22.4	21.2	44.7	65.9	8.6	3.1	11.7	
Bt1	28-53	35	6.4	3.3	5.1	5.4	2.0	22.2	24.0	41.5	65.6	5.6	6.7	12.3	
2Bt	53-81	55	11.1	4.7	4.7	5.4	2.5	28.5	21.3	34.8	56.1	7.0	8.4	15.4	
3Bt1	81-112	45	0.8	1.8	4.6	5.9	2.5	15.6	8.4	11.0	19.3	22.2	42.9	65.1	
3Bt2	112-147	20	1.2	1.7	3.0	4.1	1.7	11.7	8.3	9.6	17.9	26.0	44.4	70.4	
3Bt3	147-168	15	0.9	3.1	7.9	11.2	2.0	25.0	5.6	9.1	14.9	23.5	36.8	60.3	
BC	168-190	25	0.4	10.4	26.5	34.9	3.2	75.4	1.3	2.0	3.3	10.2	11.1	21.3	

Table 12

Particle-size distribution in Lower Backslope position, Skinner hillslope.

Horizon	Depth cm	Particle-size distribution (mm)												
		Coarse Fragments	Sand					Silt				Clay		
			Very Coarse	Coarse	Medium	Fine	Very Fine	Total Sand	Coarse	Fine	Total Silt	Coarse	Fine	Total Clay
			(2.0- 1.0)	(1.0- 0.5)	(0.50- 0.25)	(0.25- 0.10)	(0.10- 0.05)	(0.05- 0.02)	(0.02- 0.002)	(0.002- 0.0002)	(0.002- 0.0002)	(0.002- 0.0002)	(0.002- 0.0002)	(0.002- 0.0002)
- % Vol - (----- % -----)														
A	0-9	25	3.3	4.3	6.0	6.1	2.8	22.4	18.3	41.4	59.6	12.7	5.3	18.0
E1	9-20	35	6.1	5.1	8.0	8.8	2.7	30.6	20.8	38.0	58.8	8.2	2.4	10.6
E2	20-30	35	4.8	4.6	8.5	9.8	2.8	30.4	20.1	40.5	60.6	6.8	2.1	8.9
Bt1	30-50	60	8.1	6.2	10.7	12.7	3.2	40.7	18.9	31.3	50.3	3.6	5.4	9.0
Bt2	50-81	70	2.0	3.2	11.8	11.9	3.7	32.7	16.8	25.6	42.3	15.7	9.3	25.0
2Bt1	81-112	20	1.4	6.7	14.3	9.2	1.7	33.3	5.1	3.8	8.9	30.4	27.4	57.8
2Bt2	112-155	20	0.5	2.4	5.9	5.1	2.3	16.1	5.9	12.9	18.9	33.1	31.9	65.0

ZION HILLSLOPE - PEDON 1

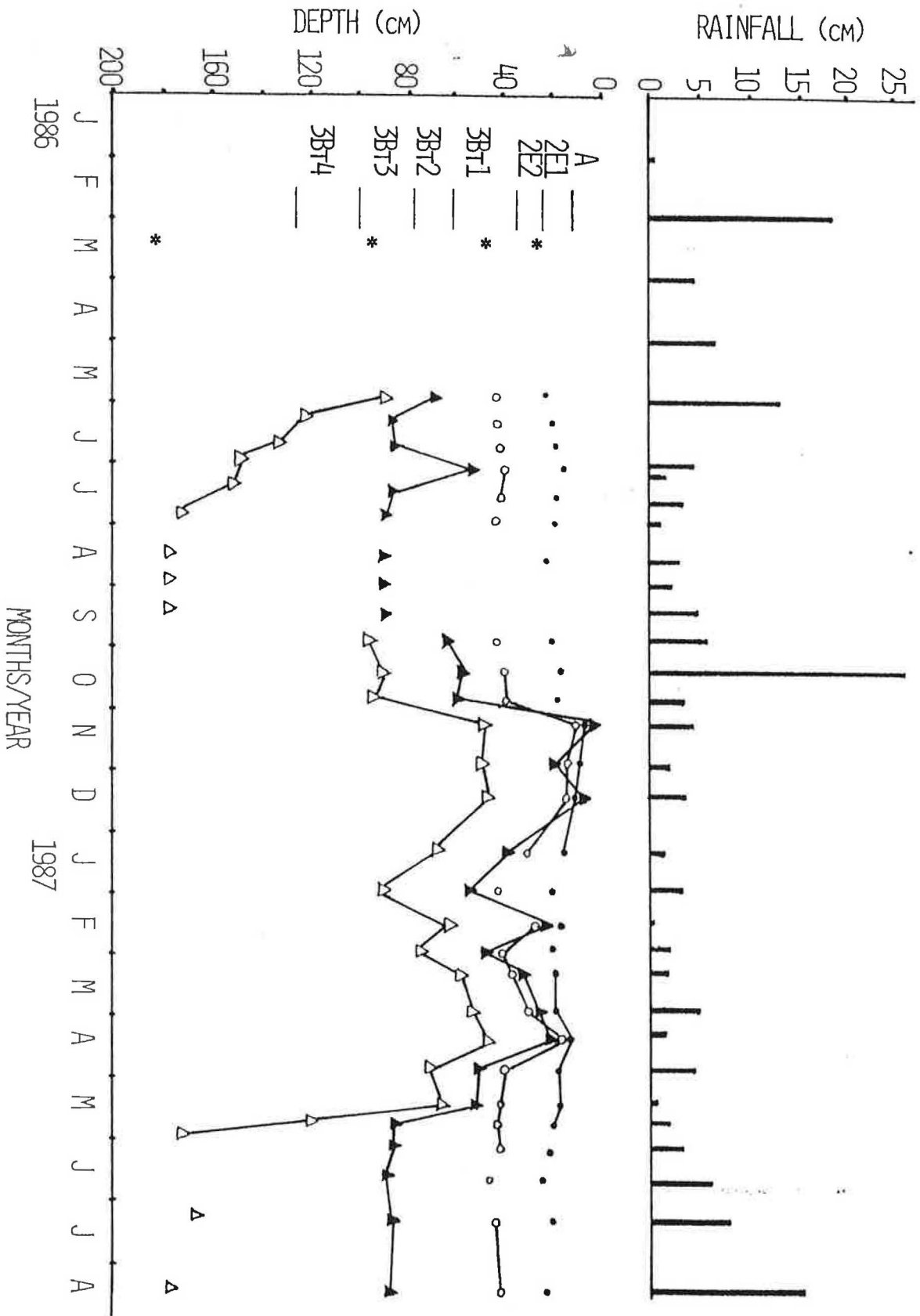


Figure 3

ZION HILLSLOPE - PEDON 2

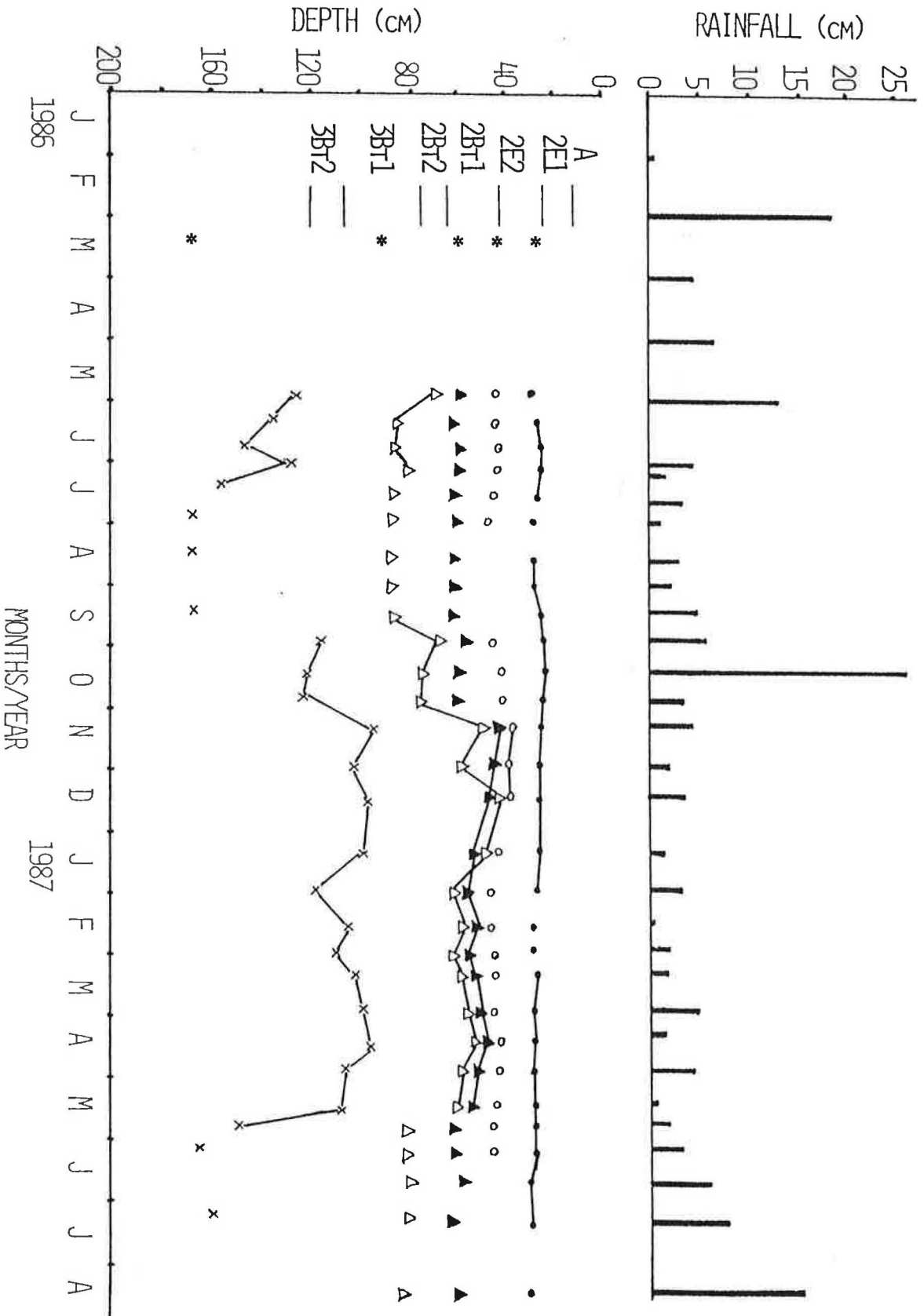


Figure 4

ZION HILL SLOPE - PEDON 3

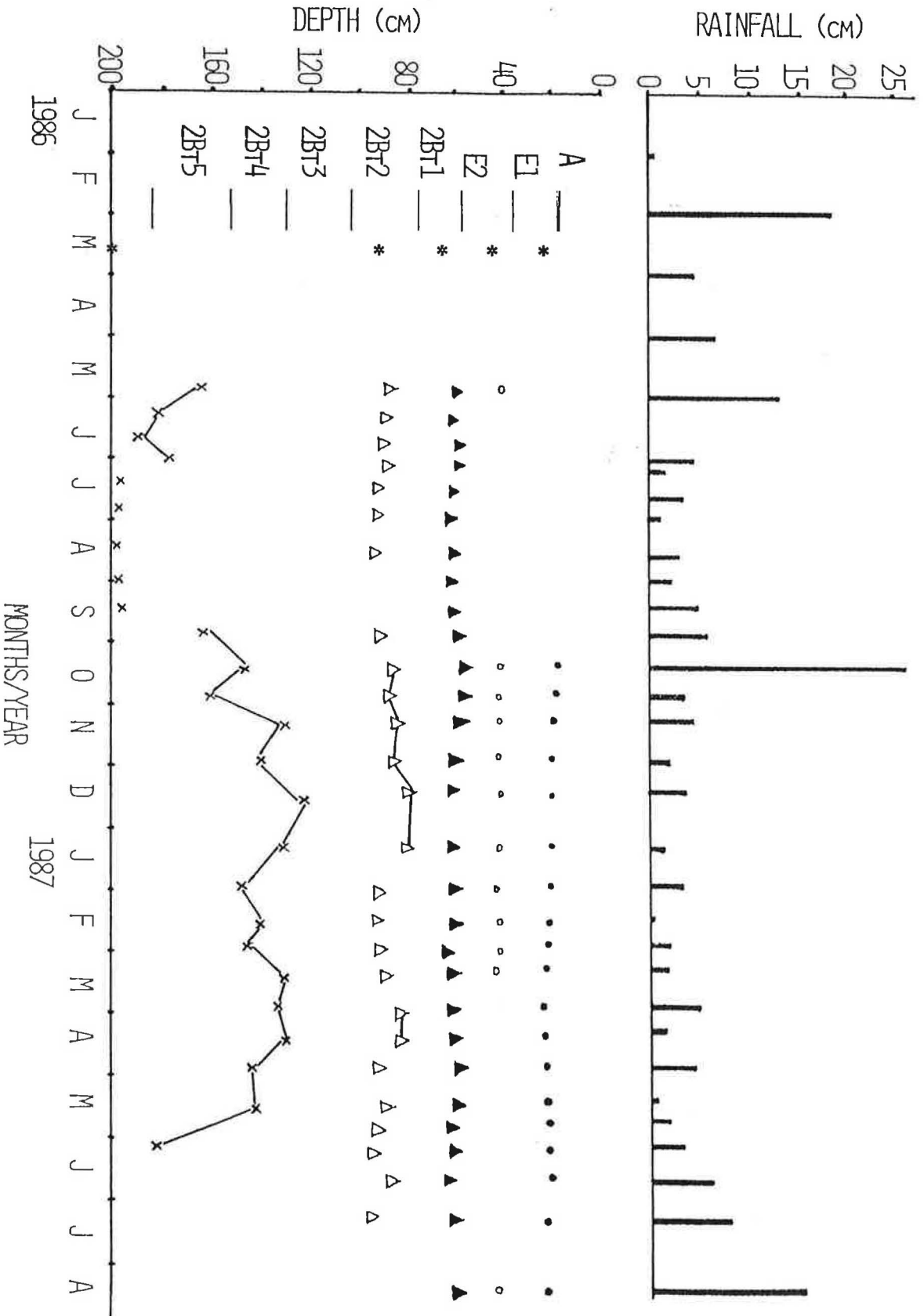


Figure 5

ZION HILLSLOPE - PEDON 4

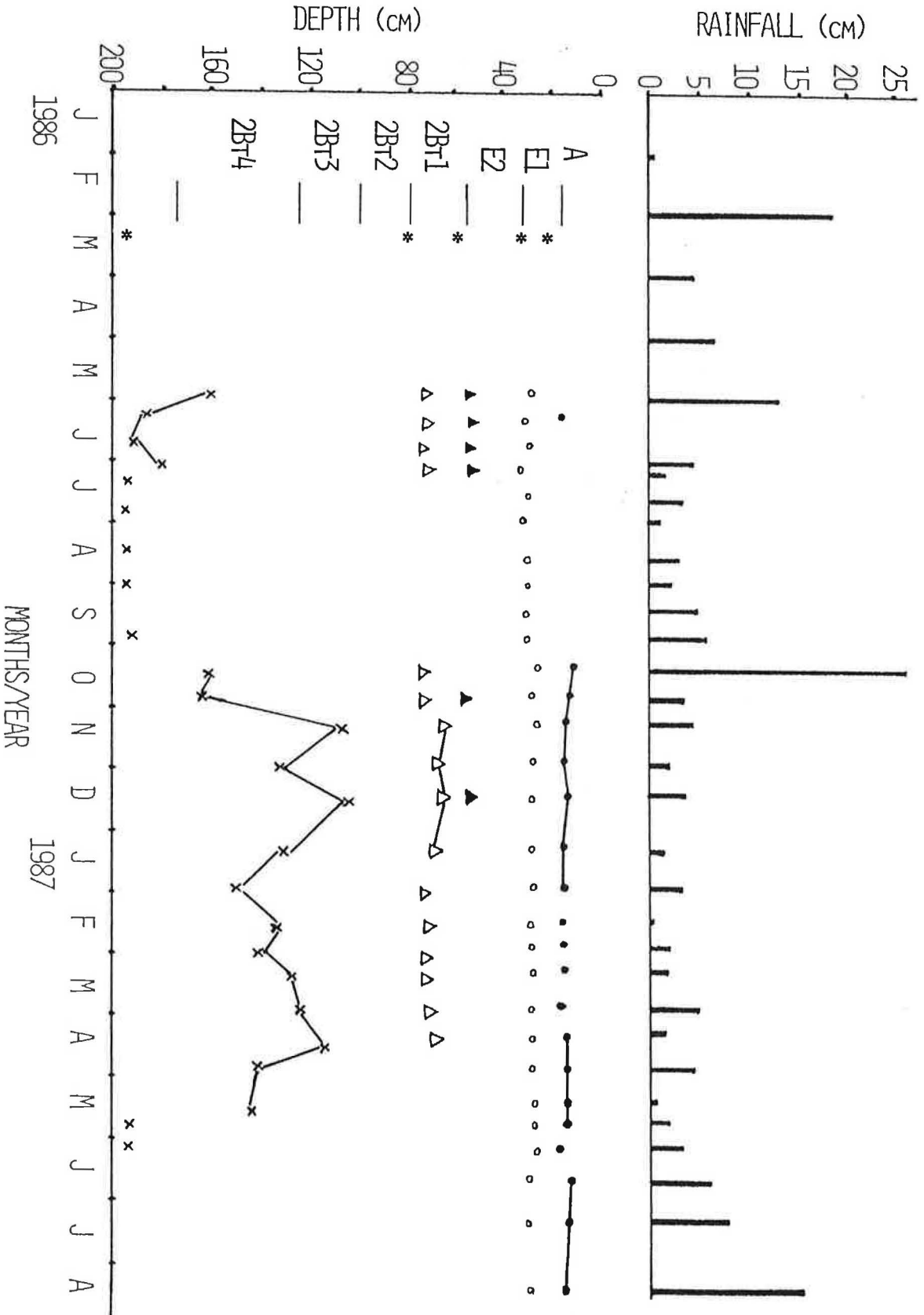


Figure 6

ZION HILLSLOPE - PEDON 5

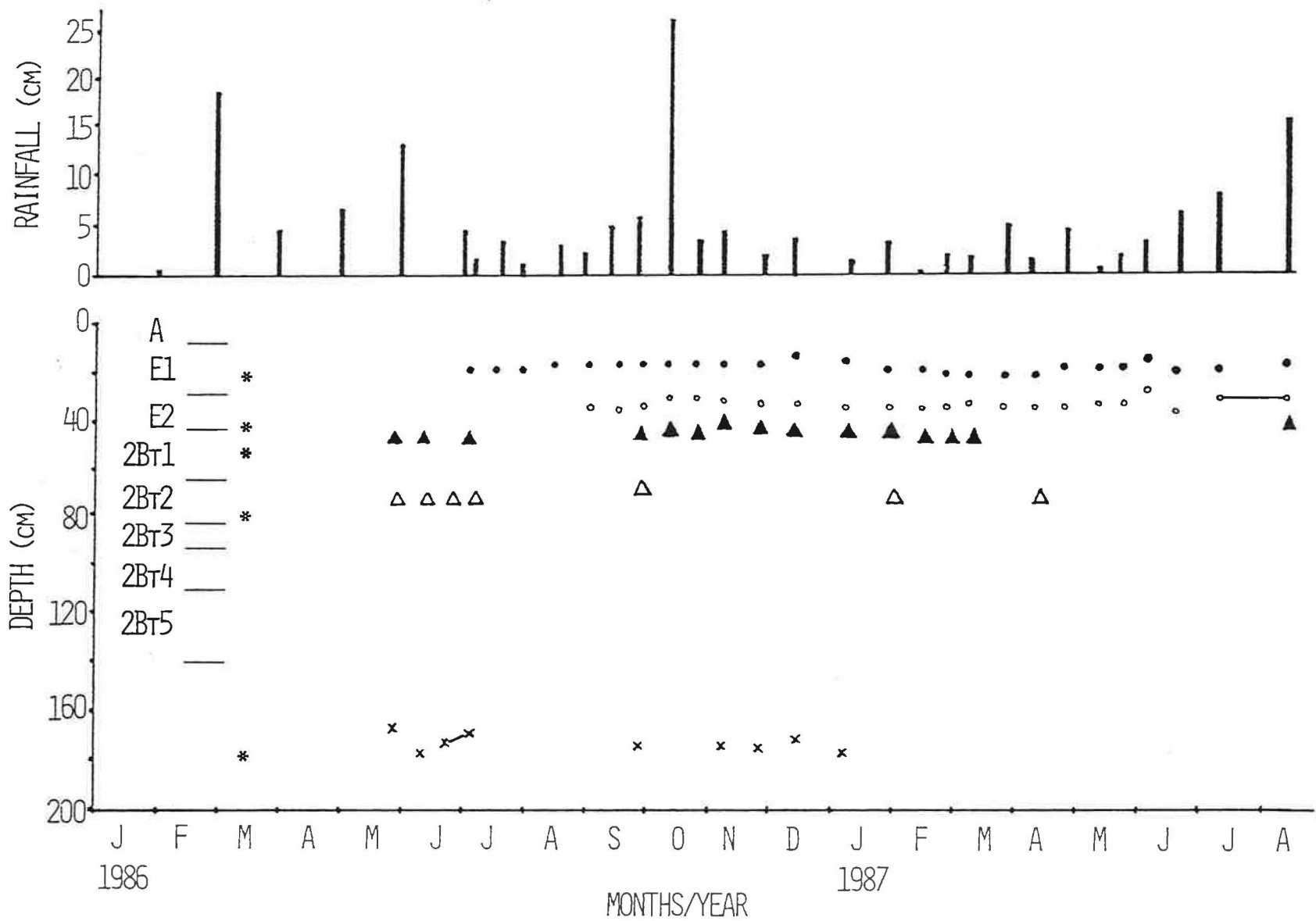


Figure 7

SKINNER HILLSLOPE - PEDON 1

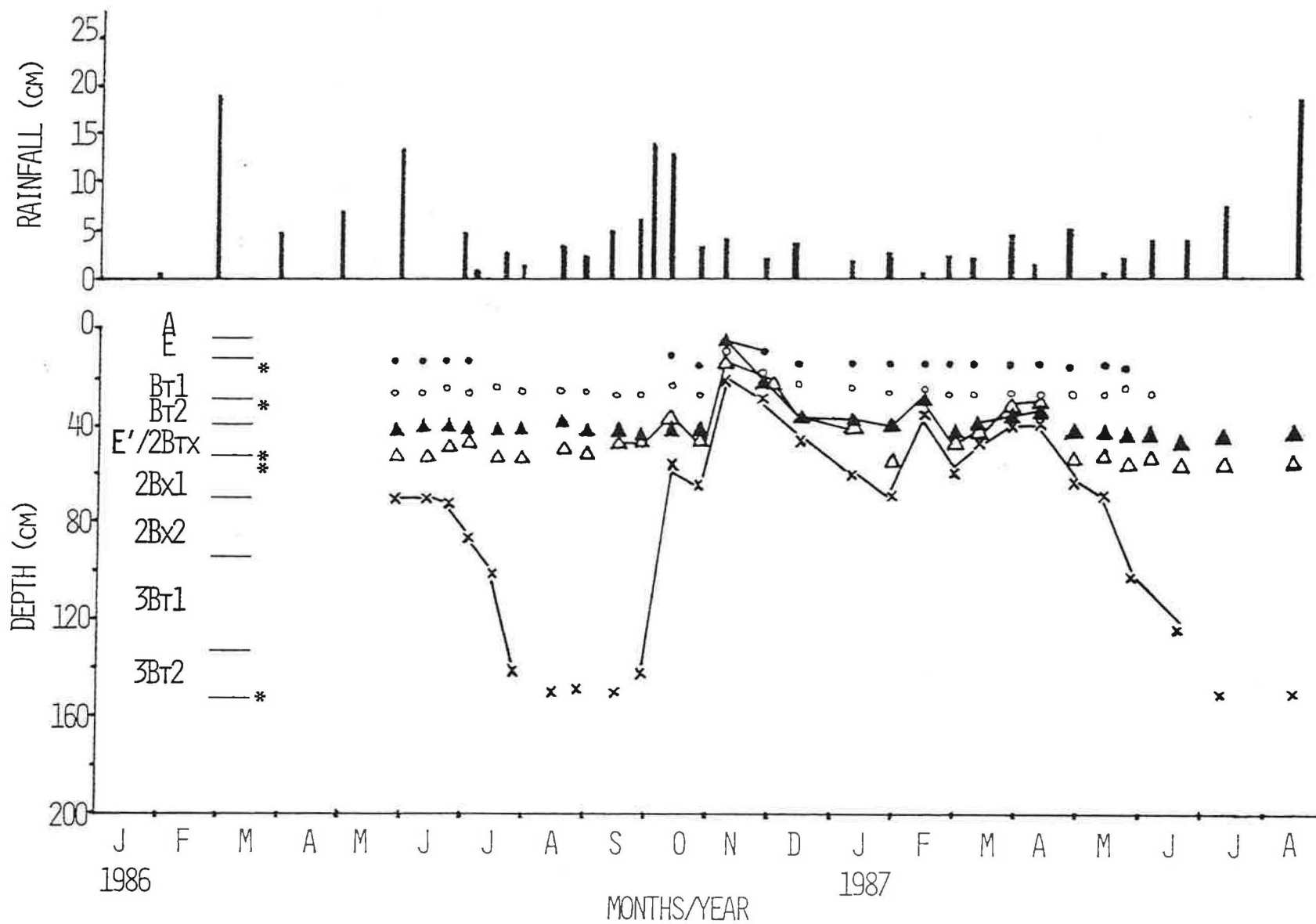


Figure 8

SKINNER HILLSLOPE - PEDON 2

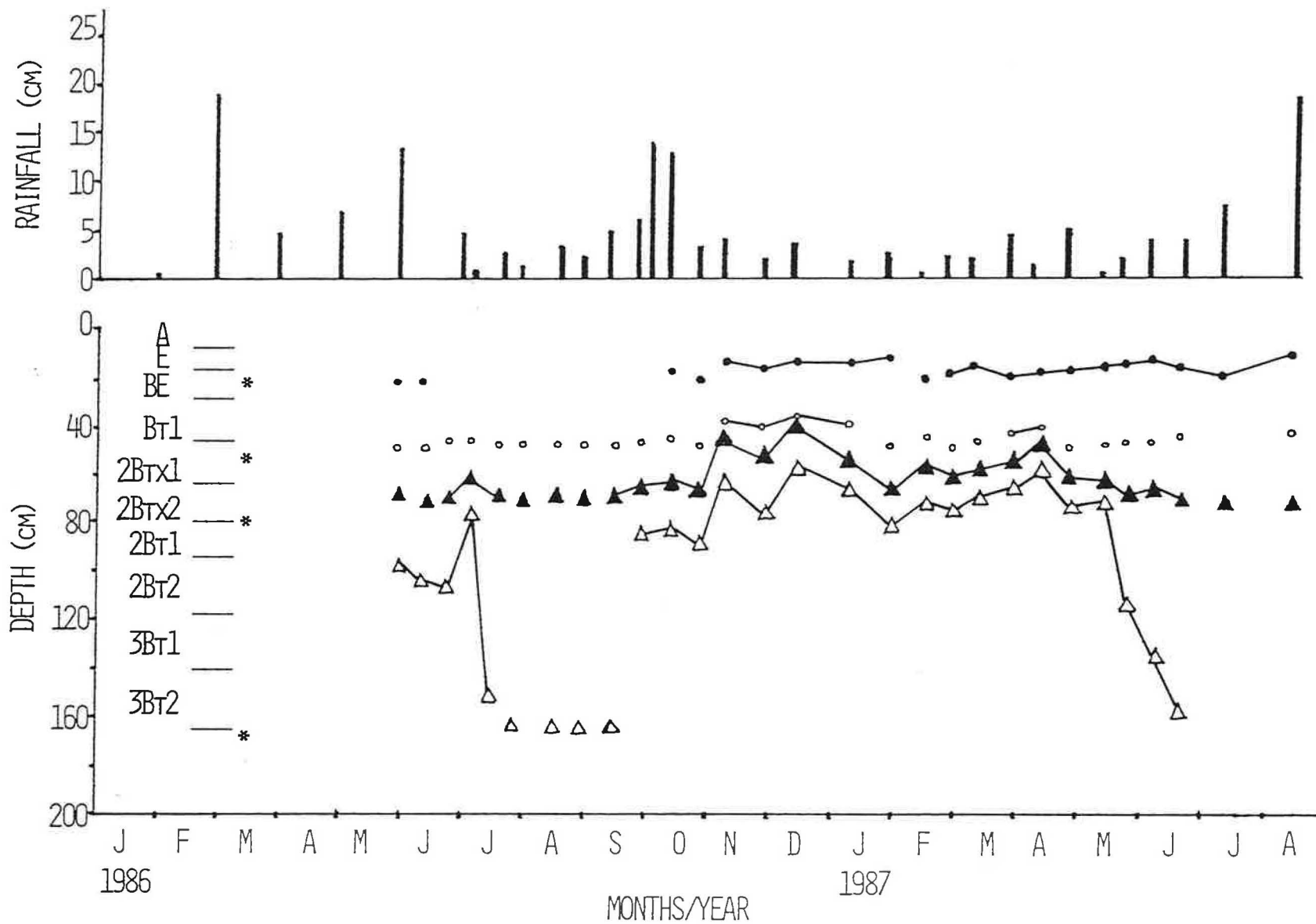


Figure 9

Table 9

Particle-size distribution in Upper Shoulder position, Skinner hillslope.

Horizon	Depth cm	Particle-size distribution (mm)												
		Coarse Fragments	Sand					Total Sand	Silt			Clay		Total Clay
			Very Coarse	Coarse	Medium	Fine	Very Fine		Very Coarse	Fine	Total	Coarse	Fine	
			(2.0- 1.0)	(1.0- 0.5)	(0.50- 0.25)	(0.25- 0.10)	(0.10- 0.05)		(0.05- 0.02)	(0.02- 0.002)	Silt	(0.002- 0.0002)	(<0.0002)	
- % Vol - (-----) -----) -----)														
A	0-8	10	3.5	3.8	4.9	4.5	2.7	19.4	20.1	42.7	62.8	7.0	10.8	17.8
E	8-15	15	4.6	3.7	4.6	4.5	2.0	19.4	23.7	48.5	72.1	2.0	6.4	8.4
BE	15-28	20	4.7	3.2	4.3	4.4	2.0	18.5	24.3	44.6	68.8	4.5	8.2	12.7
Bt1	28-46	25	4.9	2.9	4.2	4.1	1.8	18.0	25.0	43.1	68.1	6.5	7.5	14.0
2Btx1	46-63	50	6.5	6.1	6.1	5.5	3.0	27.2	20.4	32.0	52.4	8.3	12.1	20.4
2Btx2	63-79	65	7.6	7.1	6.8	6.9	3.0	31.4	21.8	31.6	53.4	8.3	6.8	15.1
2Bt1	79-94	50	3.4	5.7	6.8	7.4	3.6	26.9	24.2	31.8	56.0	9.8	7.3	17.1
2Bt2	94-117	45	14.9	7.9	4.7	5.4	2.7	35.5	16.7	22.5	39.2	16.0	9.3	25.3
3Bt1	117-140	25	1.5	2.6	3.7	5.2	1.6	14.5	4.3	3.0	7.3	23.4	54.8	78.2
3Bt2	140-165	25	1.2	1.0	1.9	3.7	1.2	13.8	2.9	9.0	11.9	27.6	46.7	74.3

SKINNER HILLSLOPE - PEDON 3

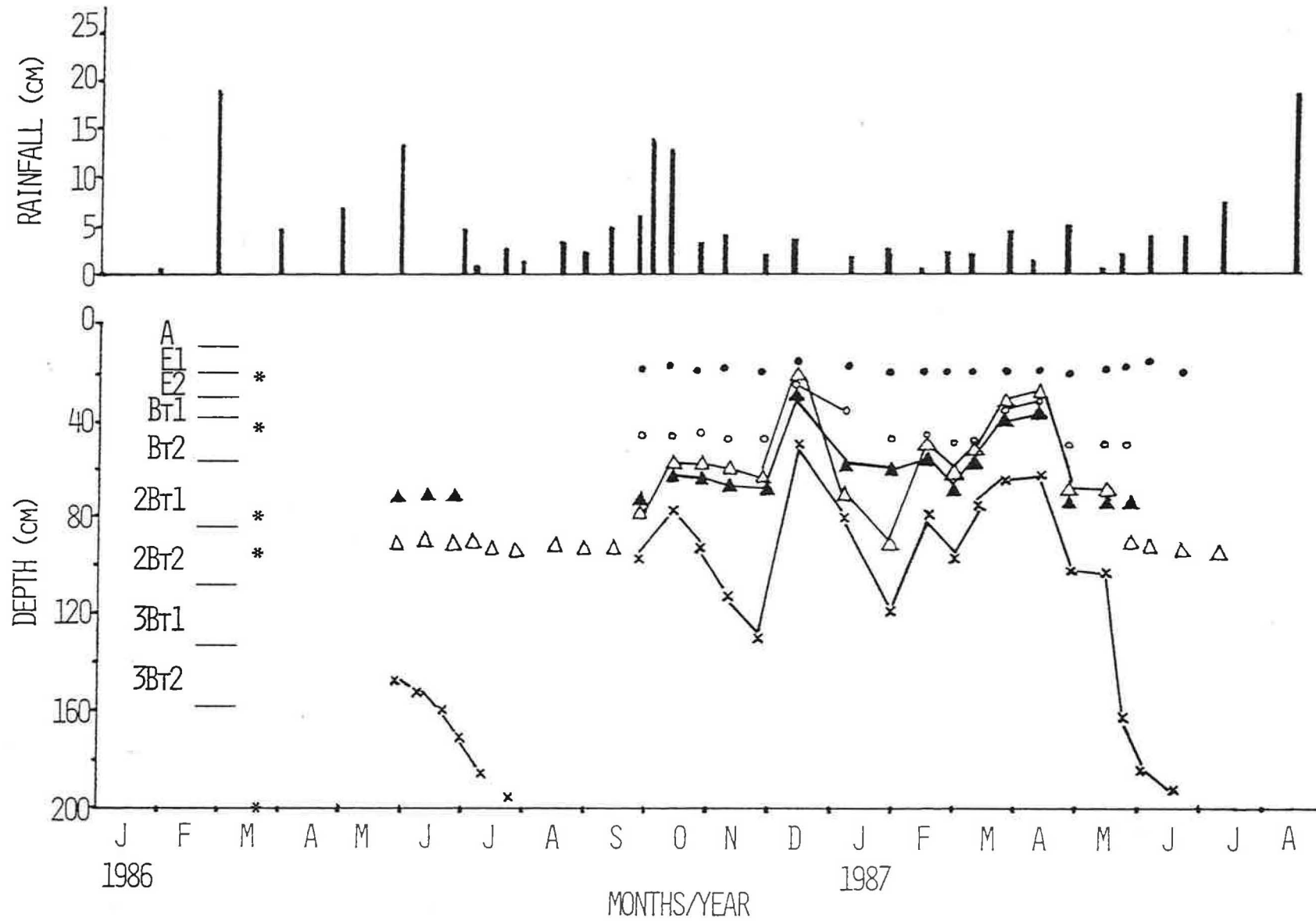


Figure 10

SKINNER HILLSLOPE - PEDON 4

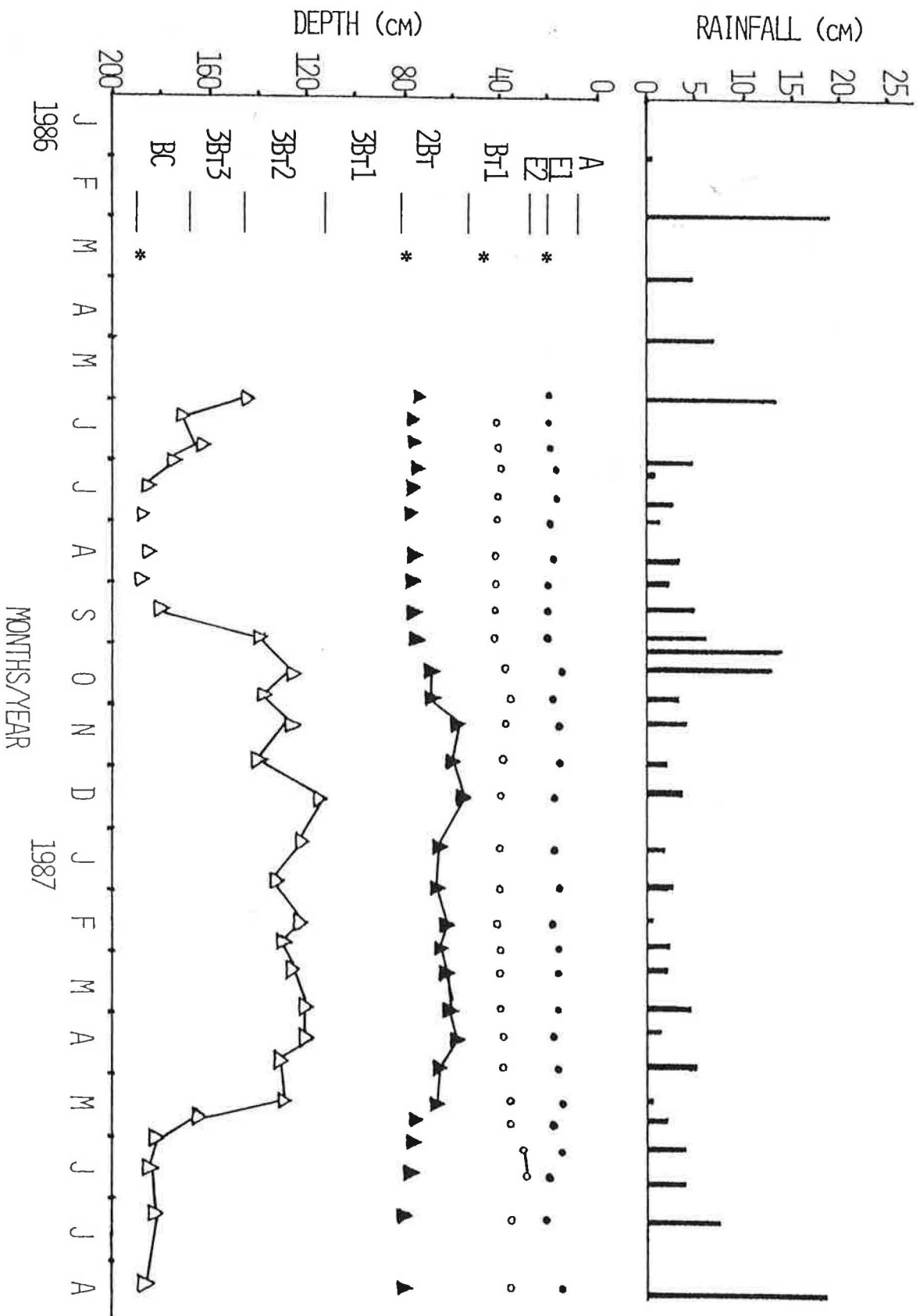


Figure 11

SKINNER HILL SLOPE - PEDON 5

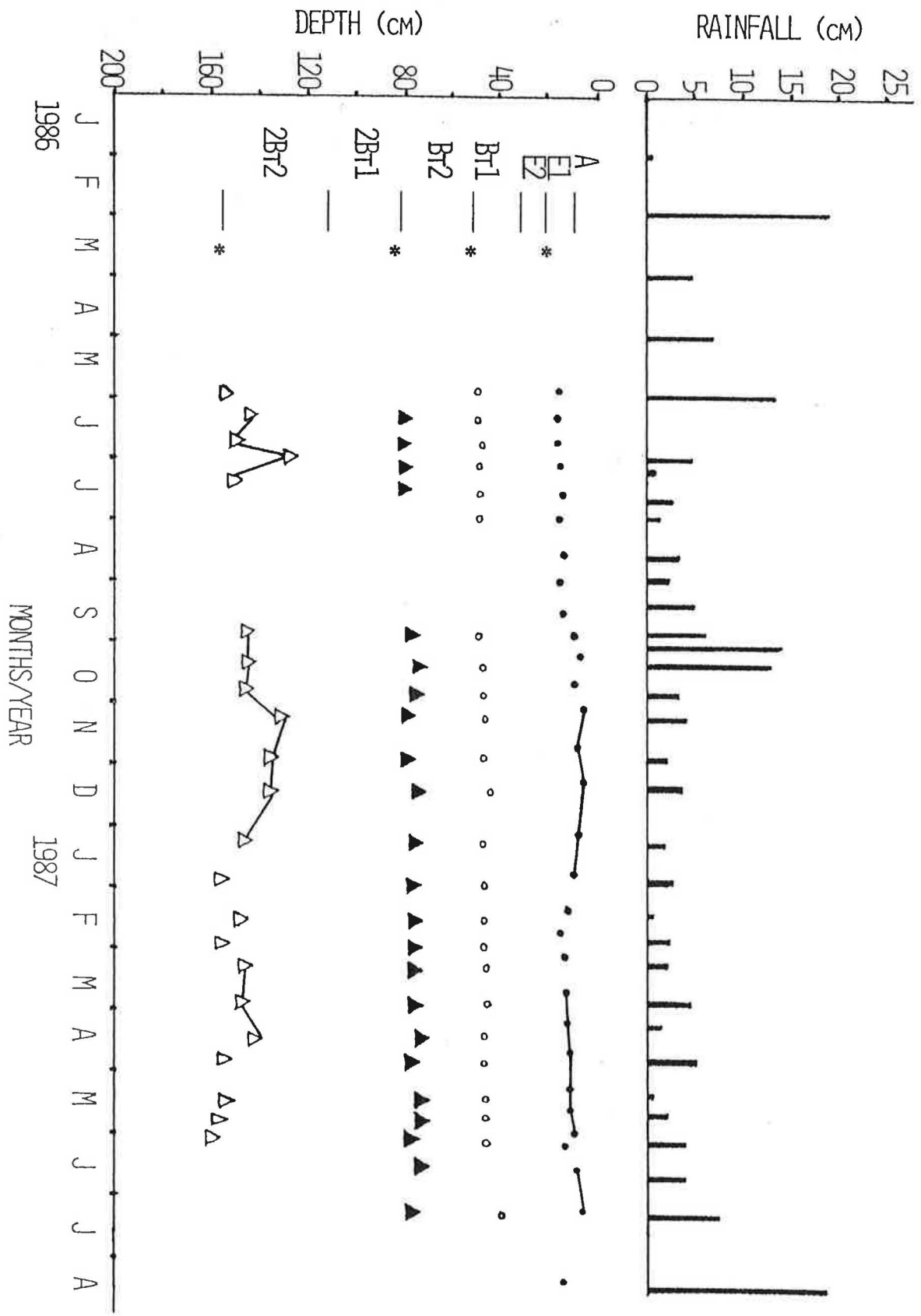


Figure 12

90-91

Influence of Acids on the Adsorption Capacity of Clay Minerals

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ABSTRACT:

The effects on CEC of four clay minerals (smectite, illite, poorly crystallized kaolinite, well crystallized kaolinite) treated with four different acids (citric, acetic, nitric, hydrochloric), each at 3 different concentrations have been evaluated. Concurrent pH monitoring and quantitative determination of aluminum ions released from the clay minerals into the acid media were also performed. Most significantly, .1M citric acid (a weak organic acid, pKa1 3.14) increased the CEC of smectite and illite 17% and 30% respectively. Generally, however, regular patterns of changes could not be discerned readily.

INTRODUCTION:

This study was designed to investigate the extent to which exposure to inorganic and organic acids alters the adsorption capacity of clay minerals. It was reasoned that the outcome could have a direct bearing on predicting the mobility of inorganic and organic pollutants through clays and soils.

The adsorption capacity of clay minerals is caused by the fact that these minerals possess a charge, caused either by substitution of metal cations of unequal valency within the crystal structure or by broken edges. Since clay minerals are essentially two dimensional crystals which are very small (generally less than 2 microns), some potential for chemical attack is expected. However, such potential is known to vary greatly amongst the different types of clay; whereas kaolinites offer the most resistance to chemical attack, smectites undergo degradation more readily. Illites' behavior is intermediary. Chemical degradation is predicted to change those properties of clay minerals which depend so much on the condition of the surfaces, particularly, the adsorption capacity.

Four different clays were selected from the Clay Minerals

Society's Source Clay Repository for this study: two kaolinites, one of poor crystallinity and one well crystallized, an illite from Cambrian shale, and a calcium-charged smectite. These clays were selected in order to encompass a wide range in cation exchange capacities and in resistance to acid attack.

A primary objective of this study was to test whether organic acids, due to their complexing abilities, were more effective than inorganic acids of similar concentration in changing mineral surface properties. Each of the four clays was subjected to each of four different acids. Citric acid was chosen specifically because of its known complexing ability. Acetic acid, also chosen, is an organic acid known to have a low to moderate complexing ability. Hydrochloric acid (non-oxidizing) and nitric acid (oxidizing) were chosen as the inorganic acids.

Three different concentrations (.1 M, .01 M, .001 M) of each acid were used for clay treatment. The clay minerals were treated with each of the four acids at each concentration for 1, 7, or 21 days. The pH of the media and the concentration of aluminum released in solution were monitored as a function of time. Changes in CEC and in the crystallinity (as determined by X-Ray diffraction) of the treated clays were monitored.

PROCEDURES:

Acid treatment:

About 2.5 grams (+/- .1 g) of clay was weighed (recorded to 4

significant figures) and place in a glass flask. A 150 mL aliquot of each of the acids (nitric, hydrochloric, acetic or citric) at the proper strength (.1, .01, .001 M) was then added, the flask stoppered and shaken briskly before being set aside. The samples were shaken daily with the exception of the one-day samples which were removed 24 hours after starting the acid treatment.

After a sample's proper treatment interval had elapsed the pH of the sample was recorded using a Fisher Accumet Selective Ion Analyzer, model 750, and a 20mL aliquot of the acid was removed and stored for analysis. The remaining acid in each sample was then neutralized to a pH between 7 and 8 by the dropwise addition of NH_4OH . The samples were then centrifuged. The clear supernatant liquids were decanted and the remaining clay samples were dried in a porcelain crucible under a heat lamp (60-70°C). The dried clay samples were stored for analysis.

Cation Exchange Capacity (CEC) Determination:

Because of the large number (at least 144) of CEC determinations to be performed, a simple yet precise method was needed. CEC determination by sodium saturation as outlined by Chapman (1965) was not chosen because of the difficulty in insuring efficient agitation and mixing with the plastic clays. Additionally, the method calls for repetitious steps. An alternative method (Chhabra, Pleyzier, and Cremers, 1975), based on the very high affinity of the silver-thiourea complex ion for the clay's exchange sites, was selected. It was shown by

Pleysier and Cremers (1973, 1975) that the reversible displacement of Ca^{2+} , Na^+ , and Al^{3+} by the monovalent Ag^+ -thiourea complex cation is accompanied by a free energy loss of about 5 kcal/equivalent. Consequently, the addition of a relatively dilute solution of the Ag^+ -thiourea ion is sufficient to saturate completely all exchange sites on the clay. The CEC then can be calculated by exposing a known weight of clay to a known (and excess relative to CEC) concentration of the Ag^+ -thiourea ion. Atomic Absorption (AA) spectroscopy is then used to determine the amount of silver remaining and the CEC is calculated as the difference.

In the present work, a .01 M Ag^+ -thiourea solution, adjusted to .1M in ammonium acetate and buffered to pH 7, was used. The solution was twenty fold excess (.2M) in thiourea to insure that the complex remained stable. The presence of .1M ammonium ion in the Ag^+ -thiourea solution does not interfere with the complete Ag^+ -thiourea saturation of the sample (Chhabra, Pleysier, and Cremers, 1975).

A total of .250 milliequivalent of Ag^+ -thiourea was made available for ion exchange. The weight of the clay sample was adjusted so as to adsorb no more than 10-30% of the available Ag^+ -thiourea. The amounts were approximately .07 g of smectite, .3 g of illite, and .7 g of each of the kaolinites for each determination.

A 25 mL aliquot of the .01M Ag^+ -thiourea solution was added to a known weight of each clay sample in a 100mL Nalgene

confidence interval about the average CEC value for each sample. Figure 1 shows the average CEC of each of the 21-day treated clay samples. The vertical bars bracket the 95% confidence interval about the average. The horizontal lines represent the CEC range of the untreated clays for comparison. In those cases, where the confidence interval of the treated clay overlaps the confidence interval of the untreated clay, we judged that there was no statistically significant change in CEC due to acid treatment.

All of the .1 M acids caused a statistically significant increase in the CEC of the smectite samples. Citric acid caused the greatest change followed by acetic, hydrochloric and nitric acids.

The only significant CEC change of the treated illites was for that sample treated with .1M citric acid.

Three of the treated poorly crystallized kaolinites showed a statistically significant drop in CEC. These were the kaolinites treated with the lowest strength citric acid, highest strength hydrochloric, and the intermediate strength nitric acid. The well crystallized kaolinites did not display any significant changes in CEC due to acid treatment.

pH Change:

The pH of the treatment solutions are shown in Figures 2-5. Both illite and smectite elevated the .001 M acids into the pH 7 to 9 range. Such a change was not noticed with either kaolinite. An exception appears to be the .001 M acetic acid which both kaolinites raised into the pH 6 range. The kaolinites, in some

cases, actually decreased the pH.

Aluminum Ion Release:

The concentrations of released aluminum ions at the end of each acid treatment are shown in Figures 6-9. In general, the concentrations can be ranked by the following trends: (1) citric > nitric > hydrochloric > acetic (2) 21 days > 7 days > 1 day (3) .1 M > .01M > .001 M. A few exceptions with the smectites and illites may be due to the limitations of the analytical method.

X-Ray Diffraction:

X-ray diffraction data for the citric acid treated samples were examined and compared with those of the untreated samples. No significant differences were apparent

CONCLUSIONS:

This study was motivated by the possibility that relatively weak organic acids, especially those of high complexing ability might significantly alter the CEC of clay minerals. Some significant changes were noted. For example, .1 M citric acid increases the CEC of smectite and illite 17 % and 30% respectively. Generally, however, regular patterns of changes are either absent or not strongly convincing. Additionally it was hoped that changes in CEC could be attributed to changes in crystallinity. X-ray diffraction of the clays treated with strong citric acid did not reveal any evidence of changes in crystallinity. Additionally, the extent of aluminum ion release could not be correlated with any specific CEC effects. Additional data are forthcoming; they will include the release of

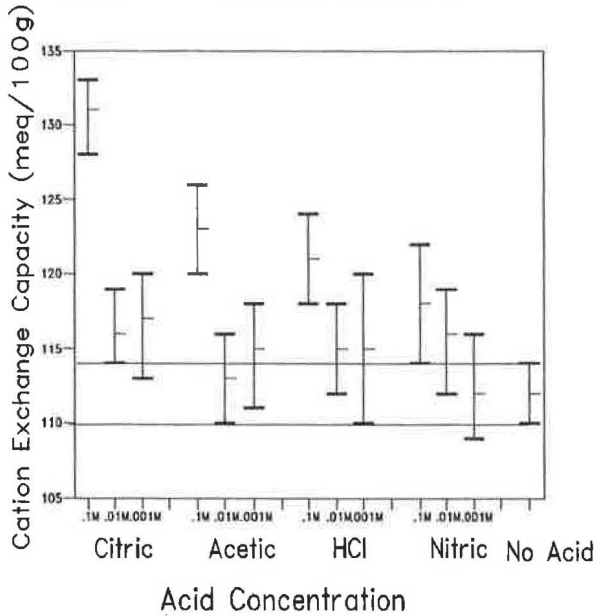
silicon into the treatment solution. It is anticipated that these data may clarify some of the observations.

Works Cited:

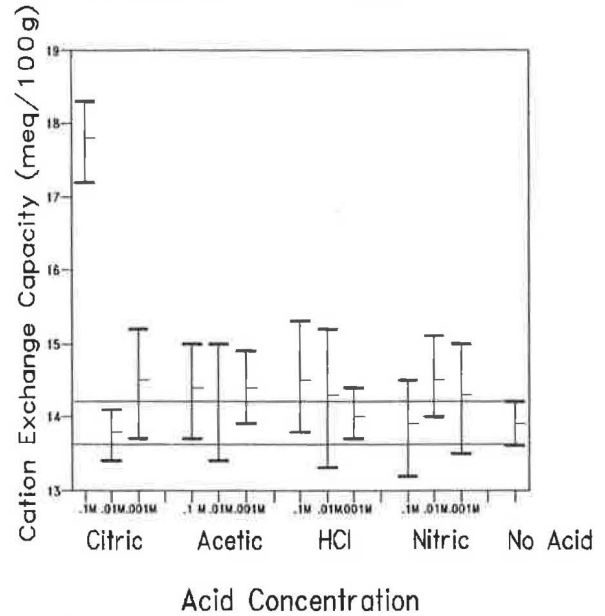
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Figure 1: Cation Exchange Capacities of Treated and Untreated Clays

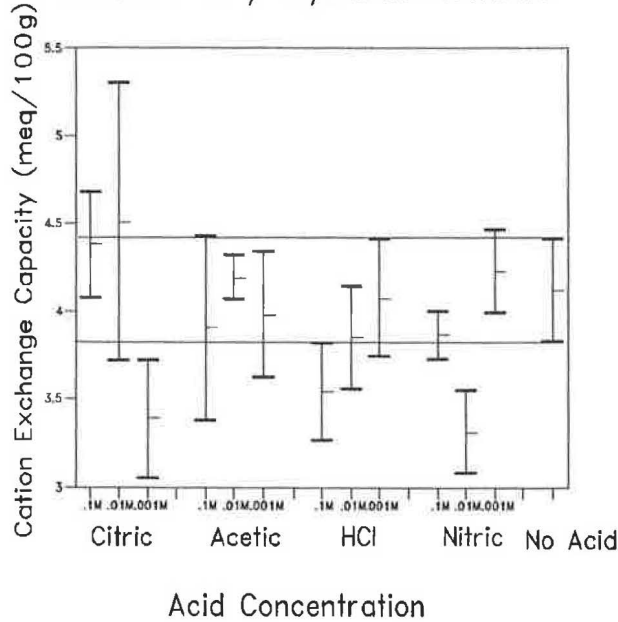
Average CEC Value and 95% Confidence Interval for Treated Smectites



Average CEC Value and 95% Confidence Interval for Treated Illite



Average CEC Value and 95% C.I. for Treated Poorly Crystallized Kaolinite



Average CEC Value and 95% C.I. for Treated Well Crystallized Kaolinite

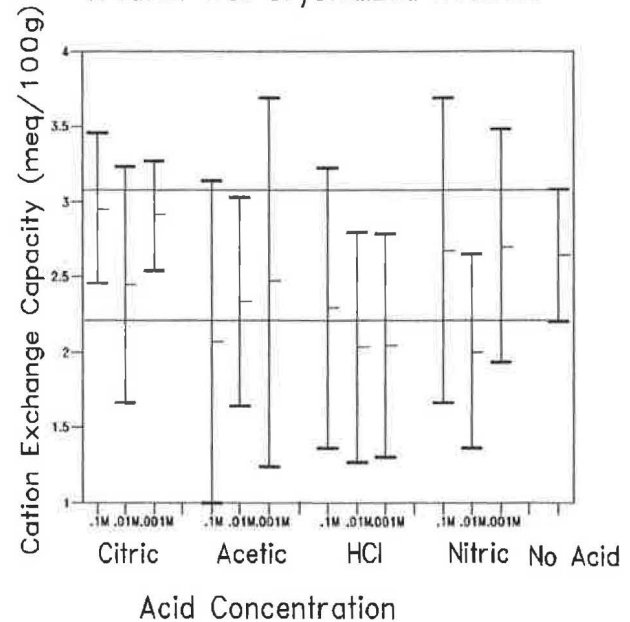


Figure 2: pH, Treatment Solution: Smectite

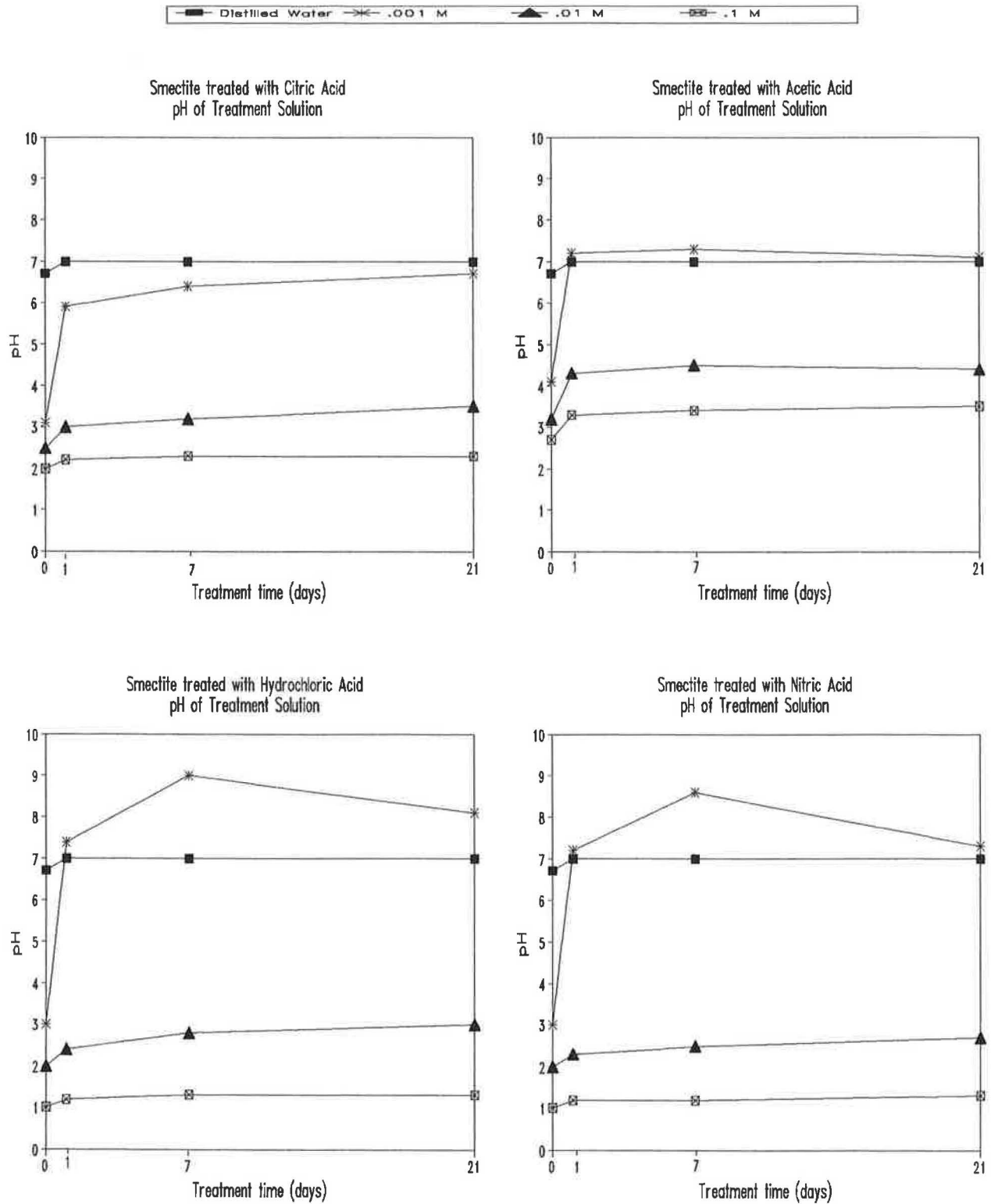


Figure 3: pH, Treatment Solution: Illite

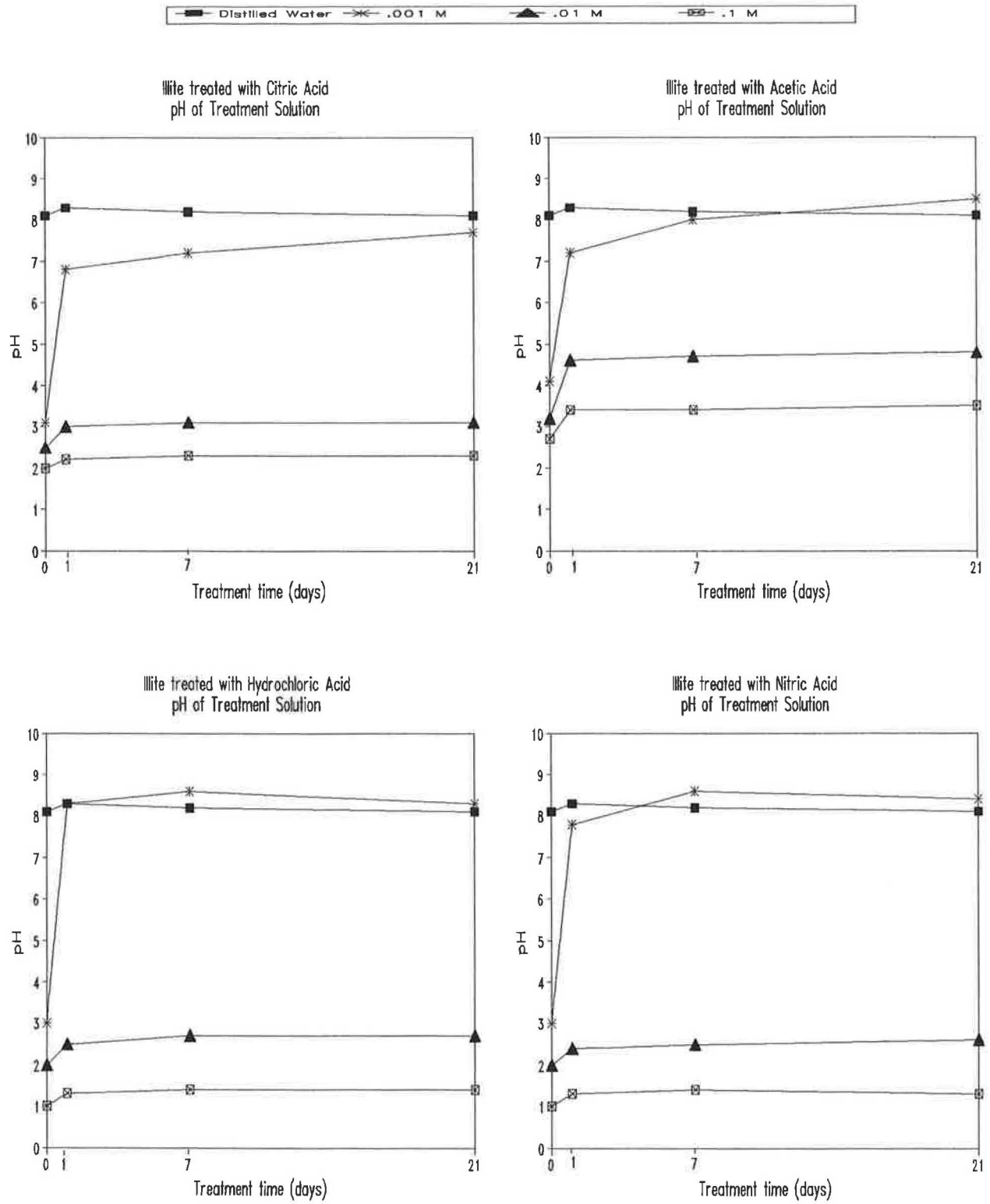


Figure 4: pH, Treatment Solution: Poorly Crystallized Kaolinite

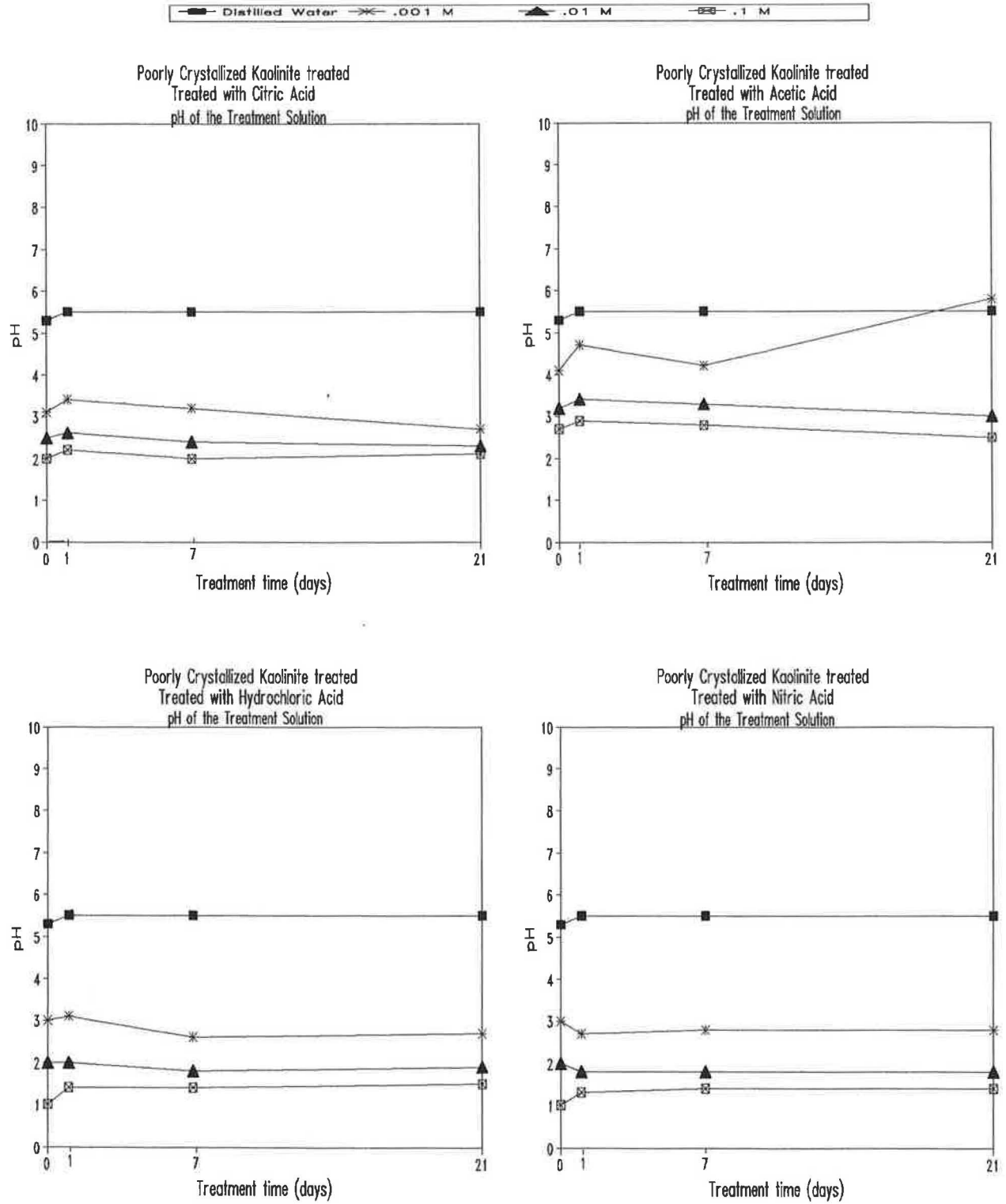


Figure 5: pH, Treatment Solution: Well Crystallized Kaolinites

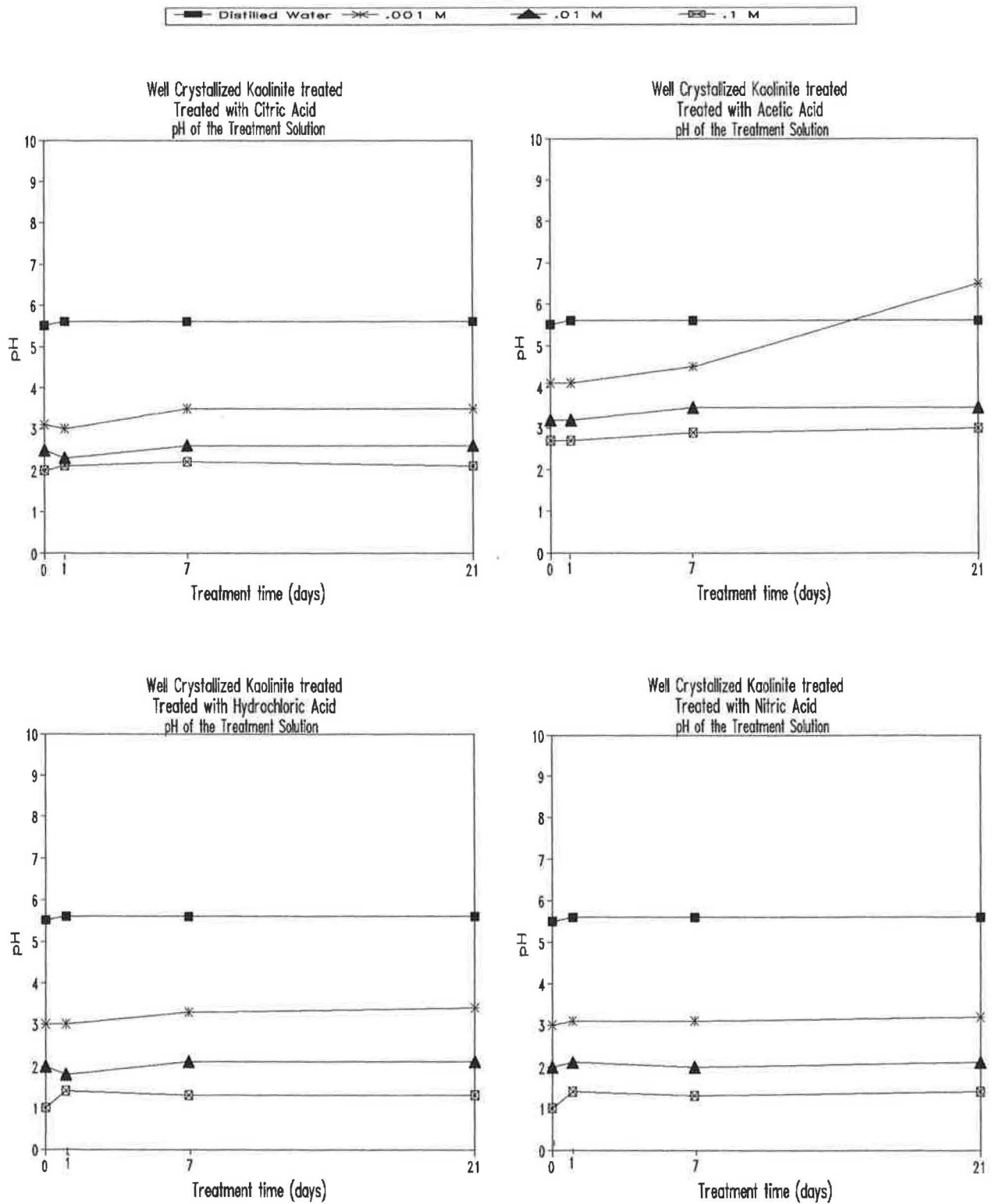


Figure 6: Aluminum Ion Concentration in Treatment Solution: Smectite

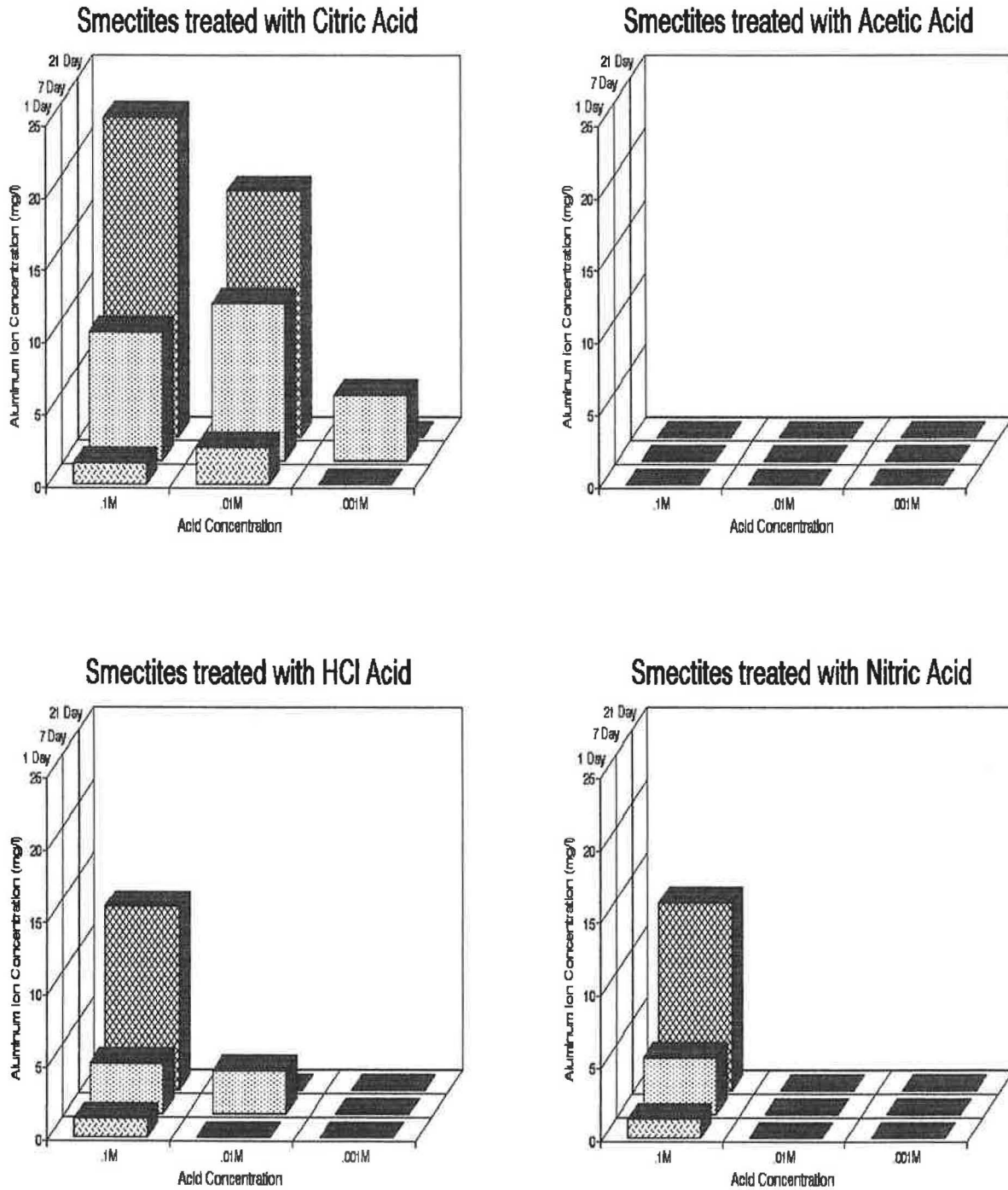


Figure 7: Aluminum Ion Concentration in Treatment Solution : Illite

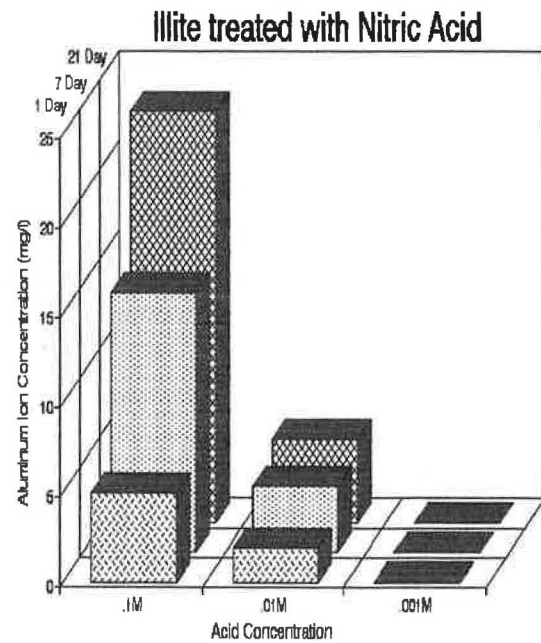
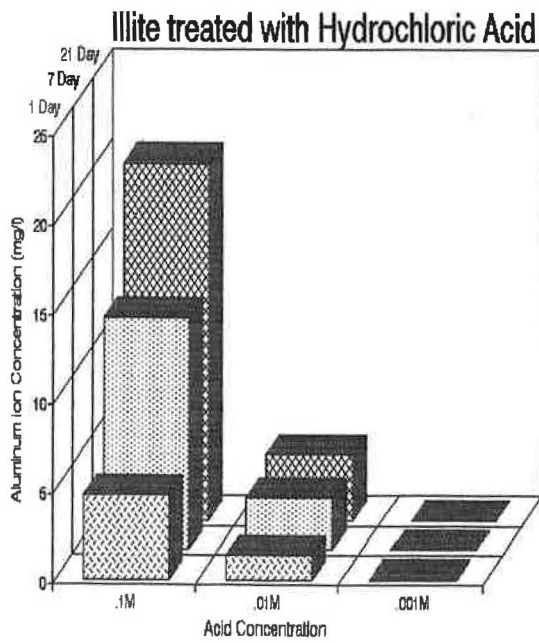
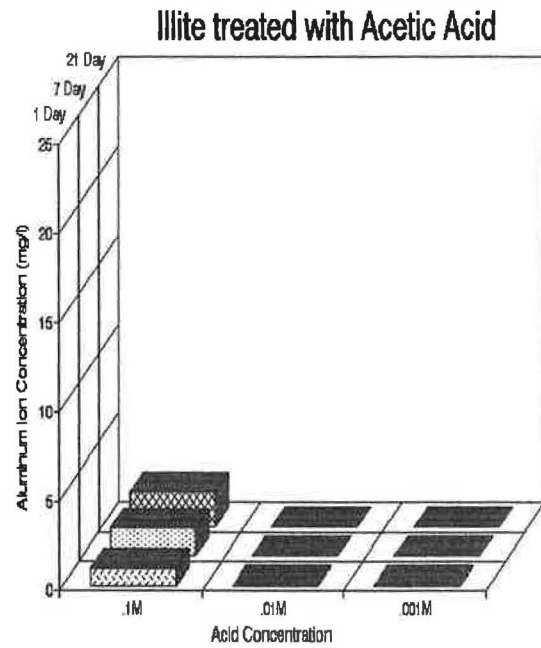
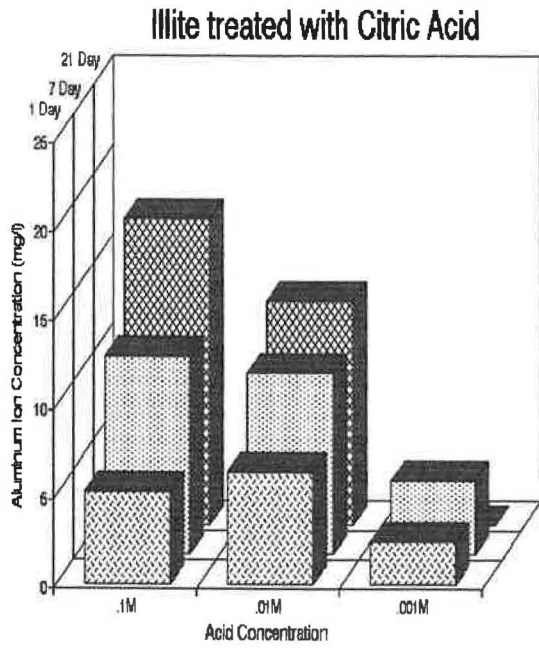


Figure 8: Aluminum Ion Concentration in Treatment Solution

Poorly Crystallized Kaolinite

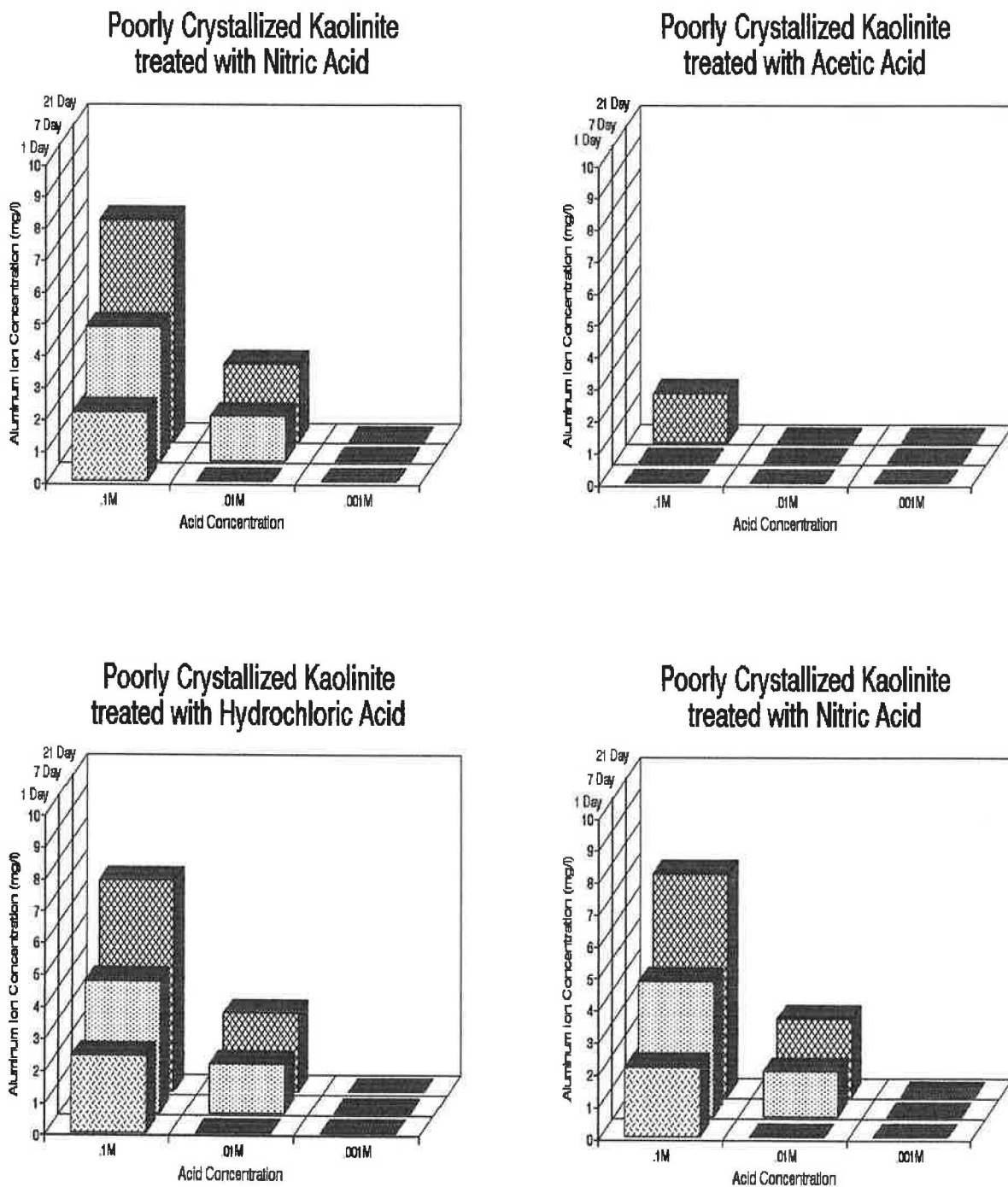
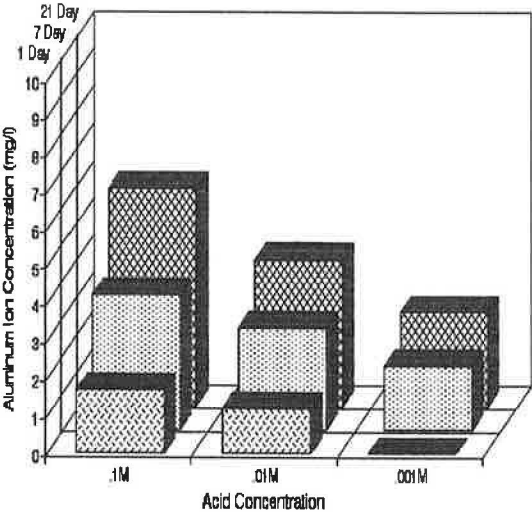


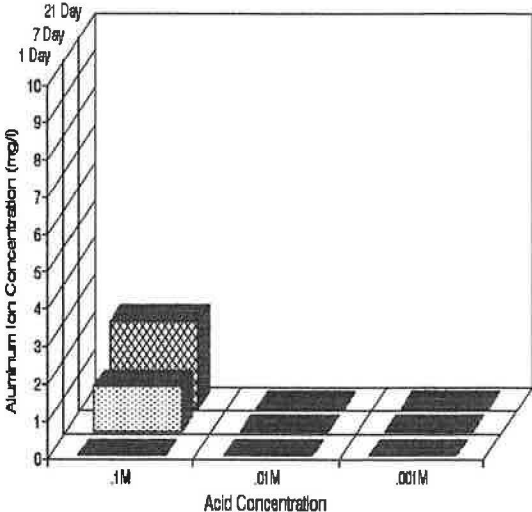
Figure 9: Aluminum Ion Concentration in Treatment Solution

Well Crystallized Kaolinite

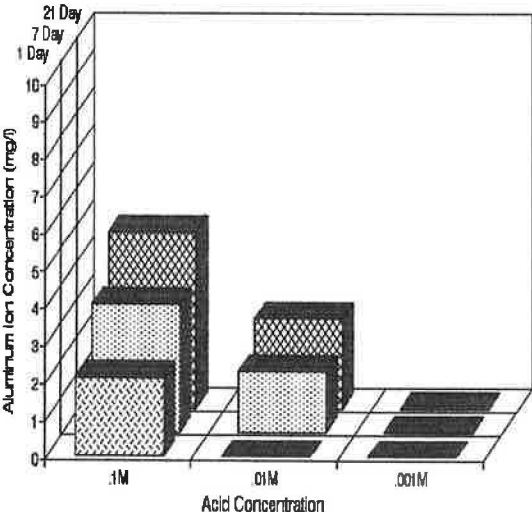
Well Crystallized Kaolinite treated with Citric Acid



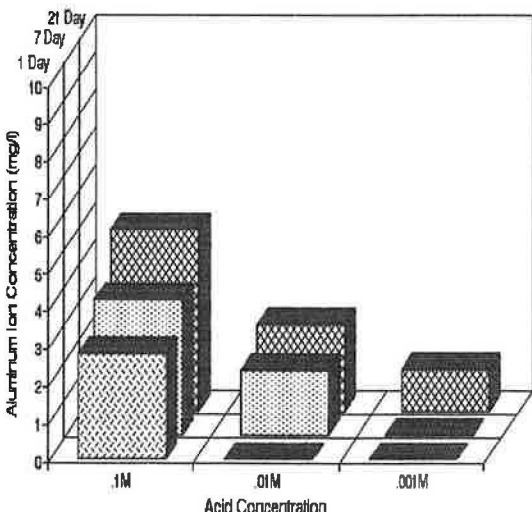
Well Crystallized Kaolinite treated with Acetic Acid



Well Crystallized Kaolinite treated with Hydrochloric Acid



Well Crystallized Kaolinite treated with Nitric Acid



APPENDIX 1: CATION EXCHANGE CAPACITY DATA

CEC Data and 95% Confidence Intervals for 21 day Treated Smectites

ACID:	Citric	Citric	Citric	Acetic	Acetic	Acetic	HCl	HCl	HCl	Nitric	Nitric	Nitric	Untreated
CONCENTRATION:	.1M	.01M	.001M	.1M	.01M	.001M	.1M	.01M	.001M	.1M	.01M	.001M	
	132	119	123	125	113	117	122	117	118	122	118	111	114
	123	115	123	125	115	123	124	121	123	125	118	115	115
	133	120	125	126	114	118	124	120	124	126	122	115	107
	132	121	116	123	116	122	122	120	123	121	123	115	110
	134	115	109	125	110	116	120	106	107	119	114	112	107
	139	127	122	134	125	117	131	116	124	122	125	125	117
	131	112	118	116	104	111	112	109	109	104	105	105	111
	127	112	111	117	109	108	116	111	100	115	112	100	110
	124	114	109	118	110	101	119	109	110	111	107	110	110
	132	117	120	125	118	119	123	118	119	119	118	116	111
	131	115	114	123	113	113	121	116	113	118	115	114	113
	129	113	114	122	112	113	121	115	114	116	114	110	117
	131	114	111	120	112	112	118	113	111	116	113	110	117
=====													
# of Samples:	13	13	13	13	13	13	13	13	13	13	13	13	13
Sample Average	131	116	117	123	113	115	121	115	115	118	116	112	112
Standard													
deviation:	4.19	4.29	5.68	4.71	5.00	5.94	4.51	4.77	7.56	5.90	5.86	5.93	3.56
Upper Limit													
95% C.I.:	133	119	120	126	116	118	124	118	120	122	119	116	114
Lower Limit													
95% C.I.:	128	114	113	120	110	111	118	112	110	114	112	109	110

CEC Data and 95% Confidence Intervals for 21 day Treated Illite

ACID:	Citric	Citric	Citric	Acetic	Acetic	Acetic	HCl	HCl	HCl	Nitric	Nitric	Nitric	Untreated
CONCENTRATION:	.1M	.01M	.001M	.1M	.01M	.001M	.1M	.01M	.001M	.1M	.01M	.001M	
	18.2	13.7	14	13.4	14.6	14.9	14.1	13.4	14	12.6	15.8	13.6	14.5
	18.5	13.8	14.5	15.5	15.9	14.4	15.7	15.9	14.7	15	14.3	12.6	14.3
	17.1	14	12.5	14.4	14.5	14.4	15.6	15.5	13.4	13.3	13.9	14.4	14.3
	16.8	14.2	15	14.2	13.4	14.6	13.3	13.4	13.7	13.9	14.3	15	13.8
	18.2	13.9	14.7	15	12.7	14.4	13.6	13.9	14.5	14.2	14.1	15	13.7
	17.3	12.9	15	13.5	13.9	12.9	14	12.8	14.4	13.4	14.1	15.1	13.5
	18.6	14.2	15.3	15.2	14.7	14.8	15	15.4	13.8	14.6	15.3	13.7	13.6
	17.4	13.4	14.9	13.6	14.2	14.7	14.9	13.9	13.8	14.1	14.4	14.8	13.7
=====													
# of Samples:	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Sample Average	17.8	13.8	14.5	14.4	14.2	14.4	14.5	14.3	14.0	13.9	14.5	14.3	13.9
Standard													
deviation:	0.69	0.44	0.89	0.82	0.95	0.63	0.90	1.16	0.45	0.77	0.66	0.90	0.38
Upper Limit													
95% C.I.:	18.3	14.1	15.2	15.0	15.0	14.9	15.3	15.2	14.4	14.5	15.1	15.0	14.2
Lower Limit													
95% C.I.:	17.2	13.4	13.7	13.7	13.4	13.9	13.8	13.3	13.7	13.2	14.0	13.5	13.6

Confidence Intervals were determined using the Student's t test

APPENDIX 1 CONT: CATION EXCHANGE CAPACITY DATA

CEC Data and 95% Confidence Intervals for 21 day Treated Poorly Crystallized Kaolinite

ACID:	Citric	Citric	Citric	Acetic	Acetic	Acetic	HCl	HCl	HCl	Nitric	Nitric	Nitric	Untreated
CONCENTRATION:	.1M	.01M	.001M	.1M	.01M	.001M	.1M	.01M	.001M	.1M	.01M	.001M	
	4.18	5.58	3.81	4.6	4.25	4.27	3.86	3.95	4.39	3.96	3.35	4.15	4.07
	4.51	5.29	3.99	4.93	4.01	4.34	3.95	4.1	4.5	4.12	3.5	4.12	3.76
	3.84	5.87	3.63	4.27	4.48	4.2	3.77	3.79	4.29	3.8	3.16	4.17	4.01
	4.5	3.87	3.14	3.49	4.16	3.81	3.35	3.79	3.88	3.81	3.3	4.19	4.13
	4.16	3.28	3.1	3.84	4.25	4	3.61	3.77	4.11	3.94	3.62	4.39	4.73
	4.16	4.03	2.98	3.47	4.25	4.11	3.02	3.1	3.99	3.94	2.78	4.58	4.54
	4.72	4.36	3.51	3.3	4.12	4.11	3.61	4.25	4.19	3.81	3.62	4.54	3.85
	4.95	3.82	2.94	3.34	4.03	3.02	3.18	4.03	3.22	3.57	3.18	3.68	3.85
=====													
# of Samples:	8	8	8	8	8	8	8	8	8	8	8	8	8
Sample Average:	4.38	4.51	3.39	3.91	4.19	3.98	3.54	3.85	4.07	3.87	3.31	4.23	4.12
Standard deviation:	0.36	0.95	0.40	0.62	0.15	0.42	0.33	0.35	0.40	0.16	0.28	0.29	0.35
Upper Limit 95% C.I.:	4.68	5.30	3.72	4.43	4.32	4.34	3.82	4.14	4.41	4.00	3.55	4.47	4.41
Lower Limit 95% C.I.:	4.08	3.72	3.05	3.38	4.07	3.63	3.27	3.56	3.74	3.73	3.08	3.99	3.83

Confidence Intervals were determined using the Student's t test

CEC Data and 95% Confidence Intervals for 21 day Treated Well Crystallized Kaolinite

ACID:	Citric	Citric	Citric	Acetic	Acetic	Acetic	HCl	HCl	HCl	Nitric	Nitric	Nitric	Untreated
CONCENTRATION:	.1M	.01M	.001M	.1M	.01M	.001M	.1M	.01M	.001M	.1M	.01M	.001M	
	2.49	1.74	2.5	1.21	1.79	1.36	1.6	1.33	1.38	1.91	1.36	2.03	2.06
	3.21	3.23	2.97	3.06	3.12	3.62	3.39	2.85	2.6	3.22	2.51	3.09	2.73
	3.21	3.27	3.28	3.34	2.14	3.66	3.62	2.74	2.81	3.26	2.92	3.38	2.73
	3	2.14	3.04	1.41	2.3	1.85	1.6	1.7	1.72	2.24	1.85	2.64	2.51
	2.31	1.4	2.38	0.93	1.56	0.99	1.42	1.04	1.13	1.61	1.24	1.59	2.4
	2.57	1.88	2.73	1.05	1.83	1.56	1.38	1.52	1.47	1.82	1.44	2.2	2.47
	3.86	3.45	3.44	3.46	3.58	4.24	3.02	3.04	3.15	4.66	2.72	3.99	3.59
=====													
# of Samples:	7	7	7	7	7	7	7	7	7	7	7	7	7
Sample Average:	2.95	2.44	2.91	2.07	2.33	2.47	2.29	2.03	2.04	2.67	2.01	2.70	2.64
Standard deviation:	0.54	0.85	0.39	1.16	0.75	1.32	1.00	0.82	0.80	1.10	0.70	0.84	0.48
Upper Limit 95% C.I.:	3.45	3.23	3.27	3.14	3.02	3.69	3.22	2.79	2.78	3.69	2.65	3.48	3.08
Lower Limit 95% C.I.:	2.45	1.66	2.54	1.00	1.64	1.24	1.36	1.27	1.30	1.66	1.36	1.93	2.20

Confidence Intervals were determined using the Student's t test

APPENDIX 2: pH DATA

SMECTITE:

pH of the treatment solution

ACID 0 DAY 1 DAY 7 DAY 21 DAY

CITRIC

.1 M	2.0	2.2	2.3	2.3
.01 M	2.5	3.0	3.2	3.5
.001 M	3.1	5.9	6.4	6.7

ACETIC

.1 M	2.7	3.3	3.4	3.5
.01 M	3.2	4.3	4.5	4.4
.001 M	4.1	7.2	7.3	7.1

HCl

.1 M	1.0	1.2	1.3	1.3
.01 M	2.0	2.4	2.8	3.0
.001 M	3.0	7.4	9.0	8.1

NITRIC

.1 M	1.0	1.2	1.2	1.3
.01 M	2.0	2.3	2.5	2.7
.001 M	3.0	7.2	8.6	7.3

DISTILLED WATER 6.7 7.0 7.0 7.0

POORLY CRYSTALLIZED KAOLINITE:

pH of treatment solution

ACID 0 DAY 1 DAY 7 DAY 21 DAY

CITRIC

.1 M	2.0	2.2	2.0	2.1
.01 M	2.5	2.6	2.4	2.3
.001 M	3.1	3.4	3.2	2.7

ACETIC

.1 M	2.7	2.9	2.8	2.5
.01 M	3.2	3.4	3.3	3.0
.001 M	4.1	4.7	4.2	5.8

HCl

.1 M	1.0	1.4	1.4	1.5
.01 M	2.0	2.0	1.8	1.9
.001 M	3.0	3.1	2.6	2.7

NITRIC

.1 M	1.0	1.3	1.4	1.4
.01 M	2.0	1.8	1.8	1.8
.001 M	3.0	2.7	2.8	2.8

DISTILLED WATER 5.3 5.5 5.5 5.5

ILLITE:

pH of the treatment solution

ACID 0 DAY 1 DAY 7 DAY 21 DAY

CITRIC

.1 M	2.0	2.2	2.3	2.3
.01 M	2.5	3.0	3.1	3.1
.001 M	3.1	6.8	7.2	7.7

ACETIC

.1 M	2.7	3.4	3.4	3.5
.01 M	3.2	4.6	4.7	4.8
.001 M	4.1	7.2	8.0	8.5

HCl

.1 M	1.0	1.3	1.4	1.4
.01 M	2.0	2.5	2.7	2.7
.001 M	3.0	8.3	8.6	8.3

NITRIC

.1 M	1.0	1.3	1.4	1.3
.01 M	2.0	2.4	2.5	2.6
.001 M	3.0	7.8	8.6	8.4

DISTILLED WATER 8.1 8.3 8.2 8.1

WELL CRYSTALLIZED KAOLINITE:

pH of the treatment solution

ACID 0 DAY 1 DAY 7 DAY 21 DAY

CITRIC

.1 M	2.0	2.1	2.2	2.1
.01 M	2.5	2.3	2.6	2.6
.001 M	3.1	3.0	3.5	3.5

ACETIC

.1 M	2.7	2.7	2.9	3.0
.01 M	3.2	3.2	3.5	3.5
.001 M	4.1	4.1	4.5	6.5

HCl

.1 M	1.0	1.4	1.3	1.3
.01 M	2.0	1.8	2.1	2.1
.001 M	3.0	3.0	3.3	3.4

NITRIC

.1 M	1.0	1.4	1.3	1.4
.01 M	2.0	2.1	2.0	2.1
.001 M	3.0	3.1	3.1	3.2

DISTILLED WATER 5.5 5.6 5.6 5.6

APPENDIX 3: ALUMINUM ION CONCENTRATION DATA

ALUMINUM ION ANALYSIS (mg/L)

TREATMENT	ACID	STRENGTH	SMECTITES	ILLITES	POORLY CRYST. KAOLINITES	WELL CRYST. KAOLINITES
21 days	CITRIC	.1M	22.09	17.19	8.9	5.77
21 days	CITRIC	.01M	17.04	12.57	5.14	3.89
21 days	CITRIC	.001M	**	**	2.44	2.49
21 days	ACETIC	.1M	**	2	1.52	2.3
21 days	ACETIC	.01M	**	**	**	**
21 days	ACETIC	.001M	**	**	**	**
21 days	HCl	.1M	12.57	19.97	6.62	4.71
21 days	HCl	.01M	**	3.71	2.44	2.37
21 days	HCl	.001M	**	**	**	**
21 days	NITRIC	.1M	12.85	22.97	6.94	4.88
21 days	NITRIC	.01M	**	4.67	2.45	2.32
21 days	NITRIC	.001M	**	**	**	1.05
7 days	CITRIC	.1M	8.84	11.14	4.57	3.64
7 days	CITRIC	.01M	10.77	10.2	2.93	2.7
7 days	CITRIC	.001M	4.51	4.24	1.67	1.72
7 days	ACETIC	.1M	**	1.55	**	1.23
7 days	ACETIC	.01M	**	**	**	**
7 days	ACETIC	.001M	**	**	**	**
7 days	HCl	.1M	3.43	13	4.13	3.42
7 days	HCl	.01M	2.89	2.87	1.55	1.61
7 days	HCl	.001M	**	**	**	**
7 days	NITRIC	.1M	3.79	14.49	4.21	3.63
7 days	NITRIC	.01M	**	3.73	1.42	1.69
7 days	NITRIC	.001M	**	**	**	**
1 day	CITRIC	.1M	1.43	5.18	1.48	1.7
1 day	CITRIC	.01M	2.52	6.33	**	1.18
1 day	CITRIC	.001M	**	2.39	**	**
1 day	ACETIC	.1M	**	1.04	**	**
1 day	ACETIC	.01M	**	**	**	**
1 day	ACETIC	.001M	**	**	**	**
1 day	HCl	.1M	1.27	4.75	2.37	2.15
1 day	HCl	.01M	**	1.4	**	**
1 day	HCl	.001M	**	**	**	**
1 day	NITRIC	.1M	1.25	5.03	2.16	2.79
1 day	NITRIC	.01M	**	1.91	**	**
1 day	NITRIC	.001M	**	**	**	**

** BELOW THE DETECTION LIMIT (1.00 mg/L)