VARIABILITY OF SOILS ALONG A CATENA

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by

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Abstract:

Several surface soil properties and topographical measures were studied at two hillslopes within the Crawford Lake Conservation Area. These measures were examined to establish any interrelationships to support the catena concept proposed by Milne (1935).

The results of the study show that no similar patterns as found by Anderson and Furley (1975) and which include a decrease in organic matter and increase in pH, carbonate content or finer particles downslope could be found. Other factors which could be found within a three-dimensional soil landscape and may influence the soil processes along a catena should also be adopted. This may then describe all relationships that could affect soil development across a hillslope.

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CHAPTER 1

INTRODUCTION

Soils on any hillslope are the product of vertical pedogenic processes such as clay illuviation, lateral geomorphic processes such as the transport of sediment by creep, and variations in soil moisture conditions with slope position (Conacher and Dalrymple, 1977). The resulting sequences of soils down a slope is called a catena, a concept first proposed by Milne (1935). Milne (1935 a,b) conceived the catena as a unified theoretical framework for the functional aspects of soil formation on hilly terrain.

Subsequently, Morison et al. (1948) proposed that a soil catena, in relation to an individual soil profile, contains eluvial, colluvial and illuvial sections which are linked to one another by sub-surface downslope movement of water or throughflow. The downslope concatenation of soils is produced by selective transport of soil materials by throughflow, in the same way that the soil profile is produced in part, by selective transport of soil materials in vertically percolating water.

Anderson and Furley (1975) who studied catenae in the Berkshire and Wiltshire chalk downs sought to establish interrelationships amongst selected surface soil properties and topographical measures (slope gradient and length). Analysis revealed that properties associated with organic matter diminish fairly evenly downslope, whereas properties associated with soluble constituents (pH, carbonates) increase downslope.

Secondly, particle-size analysis showed an abrupt increase in finer soil material immediately downslope of the maximum gradient in the transect.

This study aims to determine whether similar results can be found from two catenae which are found under similar climatic conditions and parent material, but vary in other properties (eg. aspect, gradient and vegetative cover).

CHAPTER 2

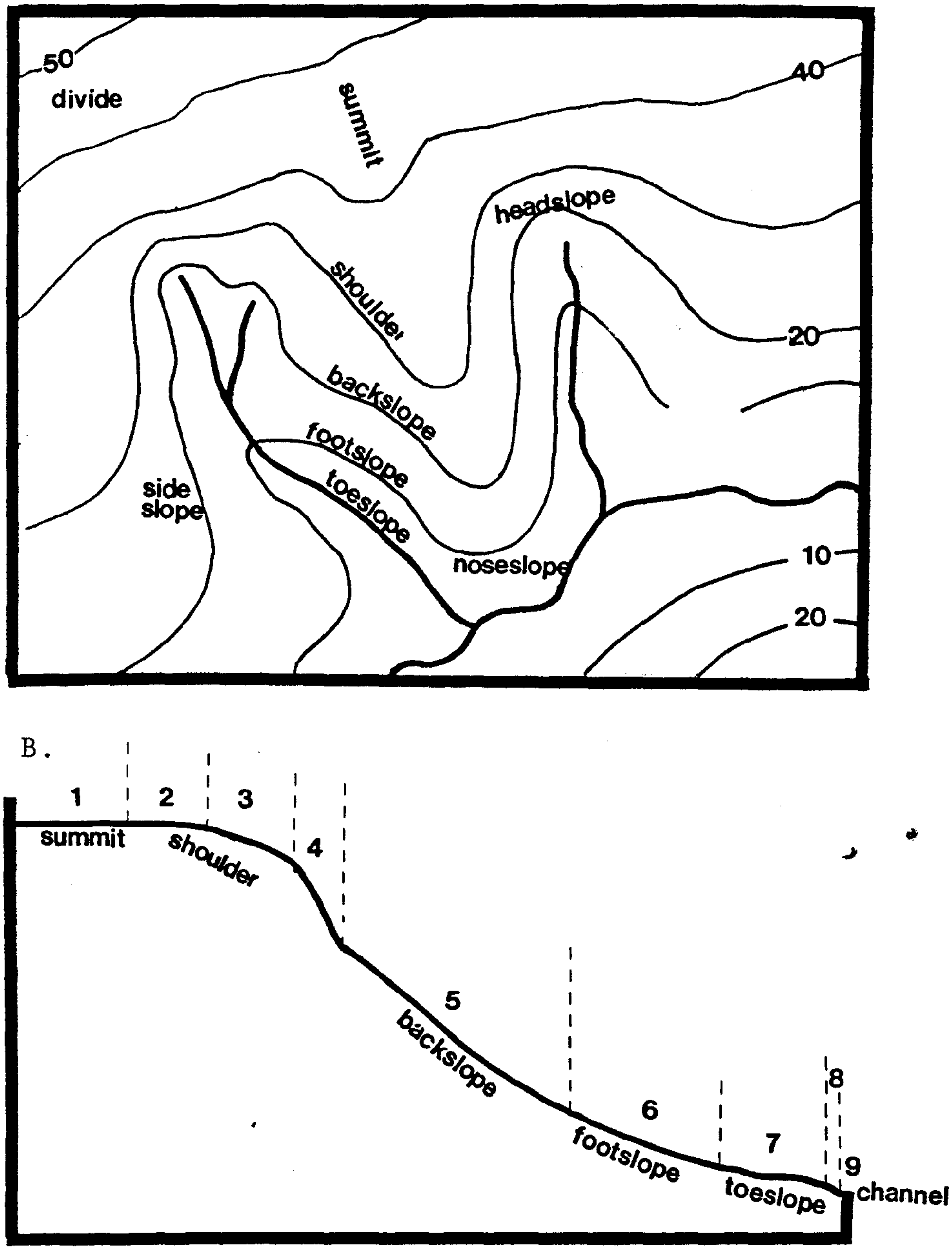
LITERATURE REVIEW

A soil catena has been described as a topo-drainage sequence (Bushnell, 1942). The catena is an often-used concept that has basis in the fact mainly in those areas of the world where the groundwater table is present within the soil profile of the soils formed in depressions. The terms "well-drained, moderately well-drained, imperfectly drained and poorly drained" have been used to describe soil individuals associated in toposequence where drainage related to the water table is involved (Soil Survey Staff, 1951).

The soils related in a catena are seen to have properties that can be related to their position on the landscape (Ruhe, 1969). The reasons for these relationships may not be easily seen. It may be because of microclimatic relationships, water table relationships, vegetative relationships, erosion-deposition or a combination of these. Relationships do occur and can be observed.

Many investigators have established relationships between topographical measures, usually slope angle, distance from watershed or slope curvature and soil properties. Early works concentrated on relations along a catena. A variety of soil properties, ranging from grain size characteristic to nitrogen content have been tested against a smaller variety of relief measures. One paper by Anderson and Furley (1975) sought to establish relationships between several soil properties and

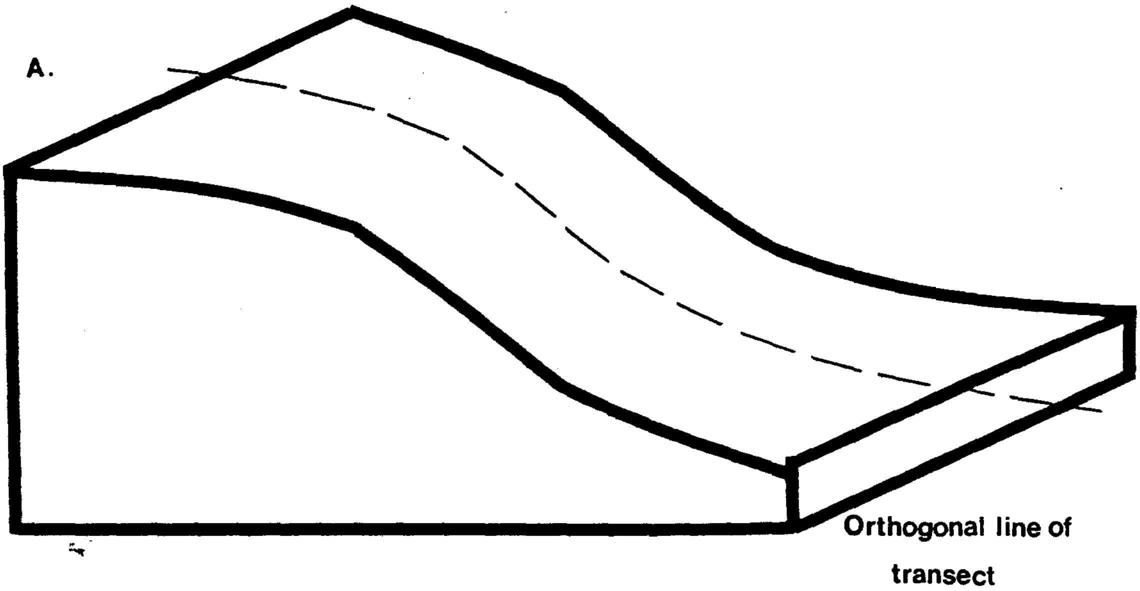
A. fig.2.0



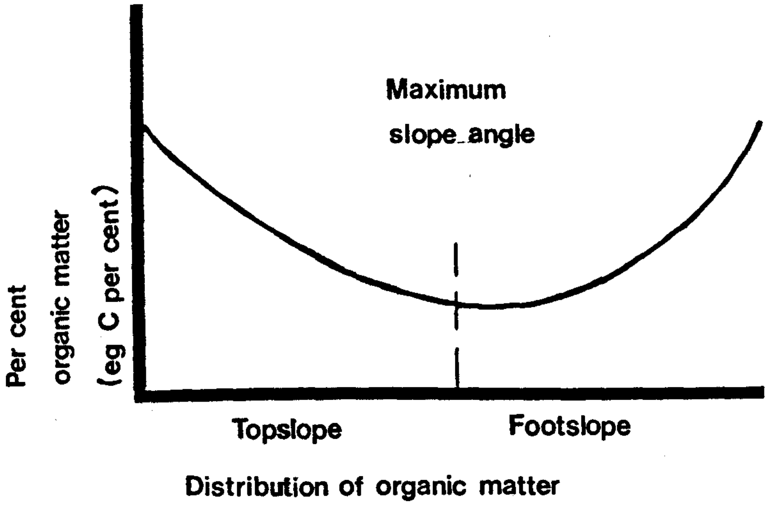
Geomorphological and slope profile components of a drainage basin. The terminology follows Ruhe and Walker(1968). Fig.2.0b follow the nine-unit landsurface model of Conacher and Dalrymple (1977).

fig.2.1

A.



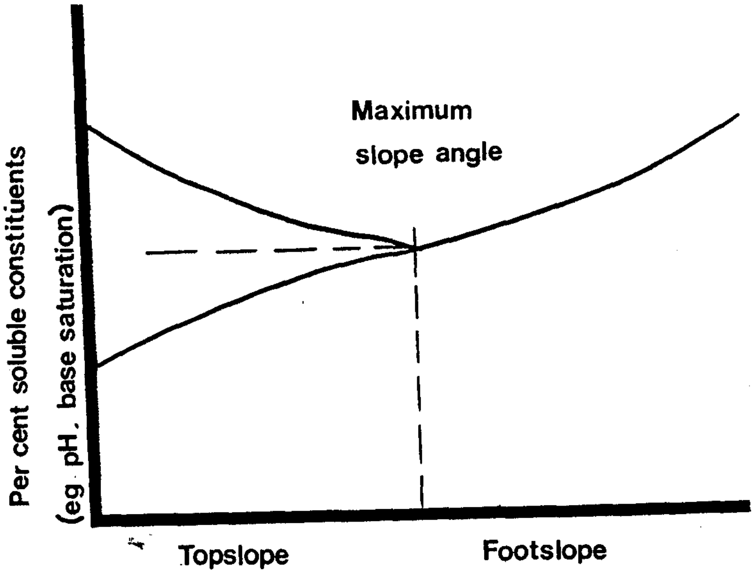
B.



(A.)Convex-concave slope form typical of chalk slopes in England. (B. to D.)models illustrating the distribution of individual soil properties over a slope od form (A.).(E.)discontinuous distribution patterns of soil properties (from Anderson and Furley, (1975)).

fig.2.2

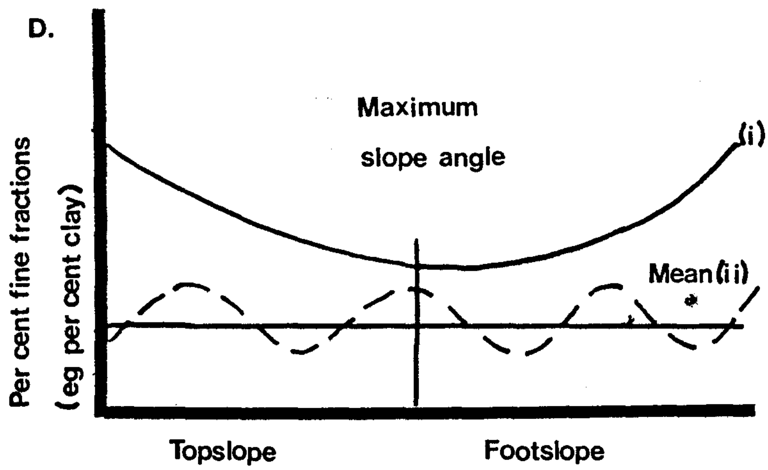
C.



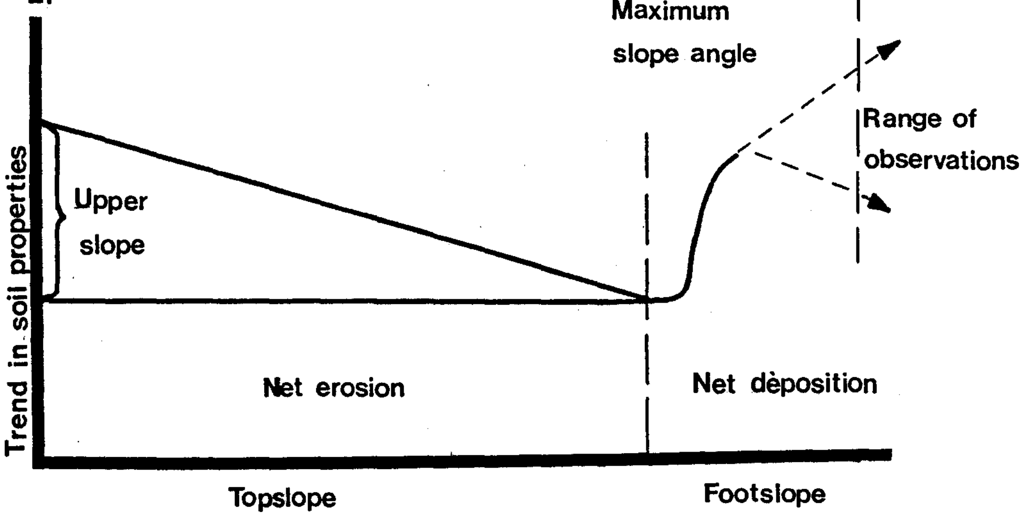
Distribution of soluble constituents

D.

(i) Calcareous soils
(ii)Compared to acidic sands in the area



E.



topographical measures (fig.2.1 A-E). In an earlier paper (Furley, 1968) had suggested that some slopes could be divided into two sections; an upper generally convex section where net erosion is greater than net deposition and a lower generally concave section where net deposition predominates; the zone of interaction between the two sections being known as the junction. Conacher and Dalrymple (1977) proposed a nine-unit, landsurface model as an appropriate framework for pedogeomorphic research (fig.2.0).

Walker and Ruhe (1968,1968a) developed hillslope models of landscape systems, both open systems in which drainage basins are part of a more extensive drainage network, and closed systems in which drainage is in a closed basin. Several geomorphic components and slope profile components could be distinguished (fig.2.0). These different components could affect the distribution and age of the resulting soil landscapes.

The simulated pattern of material redistribution along a catena, starting from a uniform distribution of material, showed, as would be expected, an overall downslope translocation of material. Such lateral translocation of material along caternary sequences is well documented. Ballantyne (1963) demonstrated that recent accumulation of salts in toeslope soils of south eastern Saskatchewan had been derived from summit positions by translocation during periods of abnormally high precipitation. Another example by Holowaychuk et al. (1969), found that strontium 90 burden levels in very poorly drained soils were much higher than in better drained soils in an area of Alaska. This difference was accounted for by the lateral redistribution of leachates from high-lying to low-lying landscape positions. One of the feq studies which quantifies the downslope movement of material is the one by Smeck and Runge (1971) in a catena in Cass County, Illinois. Smeck and Runge (1971) noticed that in some soils more phosphorus had accumulated in the B horizon than could be attributed to eluviation from the A horizons. In other soils more phophorus had been lost from the A horizons than had accumulated in the B horizon. To explain this, Smeck and Runge (1971) quantified net gains and losses of phosphorus in each profile. Adams and Raza (1978) quantified gains and losses of iron along two catenae in mid-Wales.

It has also been found that computer models also generate a down-slope movement of mobile soil material. This movement leads to an initial build up of material at the junction of convex and concave portions of the catena, a situation found by Furley (1971). This peak is not static, but progresses downslope. The notion of a transient concentration wave along a catena is not unreasonable since ions do progress through a vertical column of soil (Yaalon, 1965) and may well move down a soil catena in the same way (Yaalon et al., 1974).

Ever since Milne (1935) first proposed the concept of the catena, many other studies have come to similar conclusions of relationships across a hillslope. It is with this framework that the following study was developed to determine whether such relationships could be found.

CHAPTER 3

METHODOLOGY

Field Analysis

Sixteen samples were collected along two transects and at various depths corresponding to changes in horizons. Soil descriptive information is given for the surface soil samples correspondind to such soil properties as color, texture, and structure. Soil color is described using the Munsell soil chart and the soil texture by field test and followed up by laboratory analysis.

Laboratory Analysis

For each soil sample the moisture content was determined by drying a pre-weighed soil sample at 100 C and then reweighing to determine the loss of weight due to the evaporation of the soil moisture. From the oven dried weight and volume of container used to collect the sample, the bulk density and porosity can be found. The pH value was determined by suspending an electrode in a mixture of soil and CaCl to determine the hydrogen ion activity. The carbonate content was ascertained by applying HCl to soil and allowing the carbonates to effervese away. The difference in weight loss gave an estimate to the amount of carbonates that had been present. Organic matter was determined by the hydrogen peroxide method. The hydrogen peroxide reacted with the organic matter and the subsequent weight loss gave an estimate of the amount of organic matter. The particle size distribution was ascertained using mechanical sieving.

Using these methods with surface soil samples, analysis along each transect could be graphed.

CHAPTER 4

SITE DESCRIPTION

Location of Site

The sites to be studied were found within the Crawford Lake Conservation Area (fig. 4.0). Crawford Lake can be found at the intersection of Guelph Line and Steeles Avenue in Halton County.

Two sites were chosen which varied in location, aspect, elevation, gradient and vegetation cover. Site 1 is found in the south-west corner of the lake and Site 2 is found in the north-west corner.

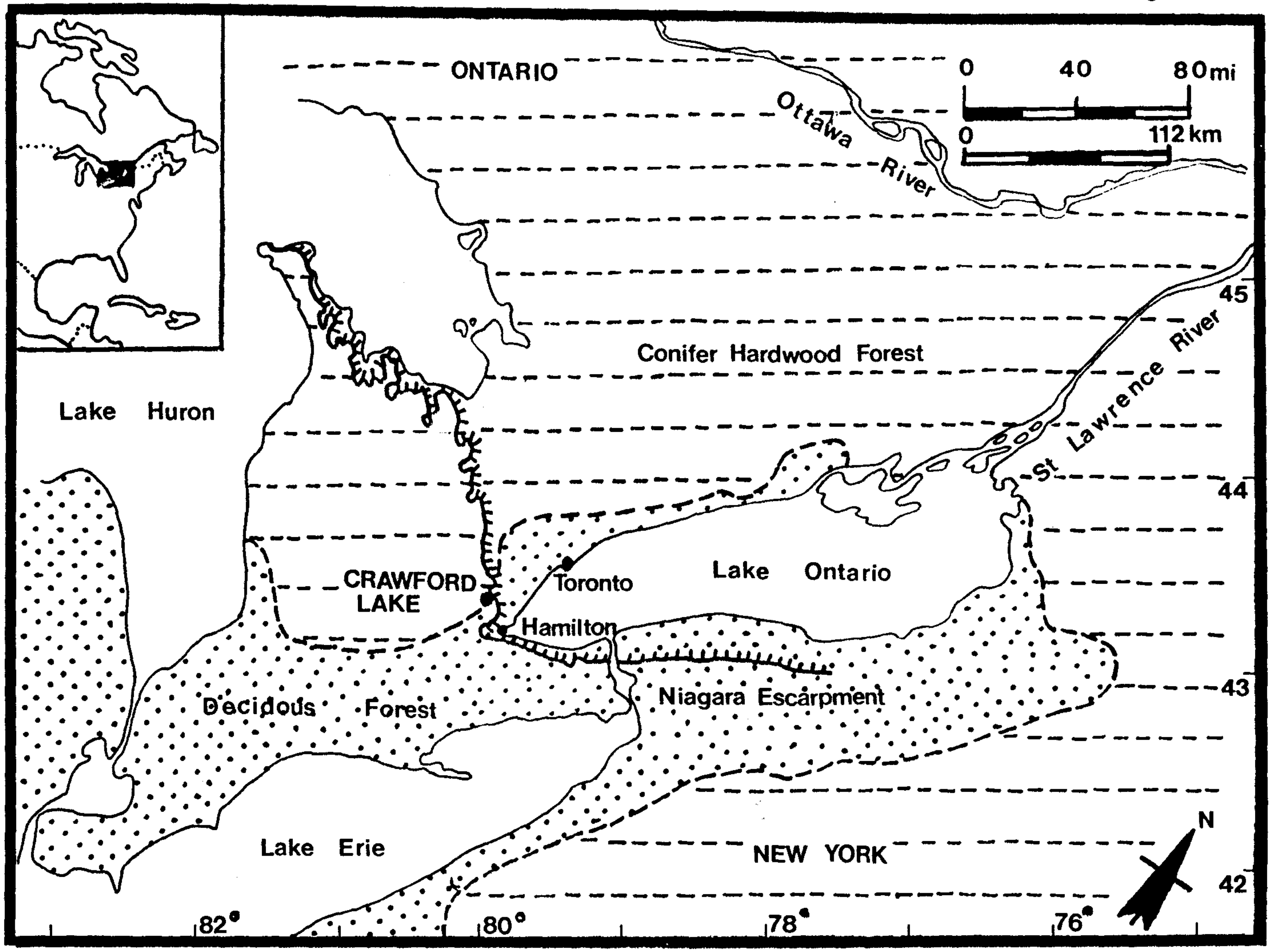
Soil samples were taken along a transect at each site at different positions on the slope (fig.4.1 and 4.2). Soil samples were also taken at various depths. The heights of the profiles and slopes were determined by levelling across the slope.

CLIMATE

Crawford Lake experiences a moist continental climate with short, warm summers and long, cold winters. There is a mean annual precipitation of 84 cm with an average of over 127 cm of snow. The mean annual temperature for the south slope climatic region is 6.6 C. Micro-climate attributed by the escarpment may have some effect on the plant species (Bell, 1976). This could have an affect of soil movement to areas directly adjacent to the escarpment.

CRAWFORD LAKE SITE

fig.4.0



(from Bell,1976)

Profile of Site 1

fig.4.1

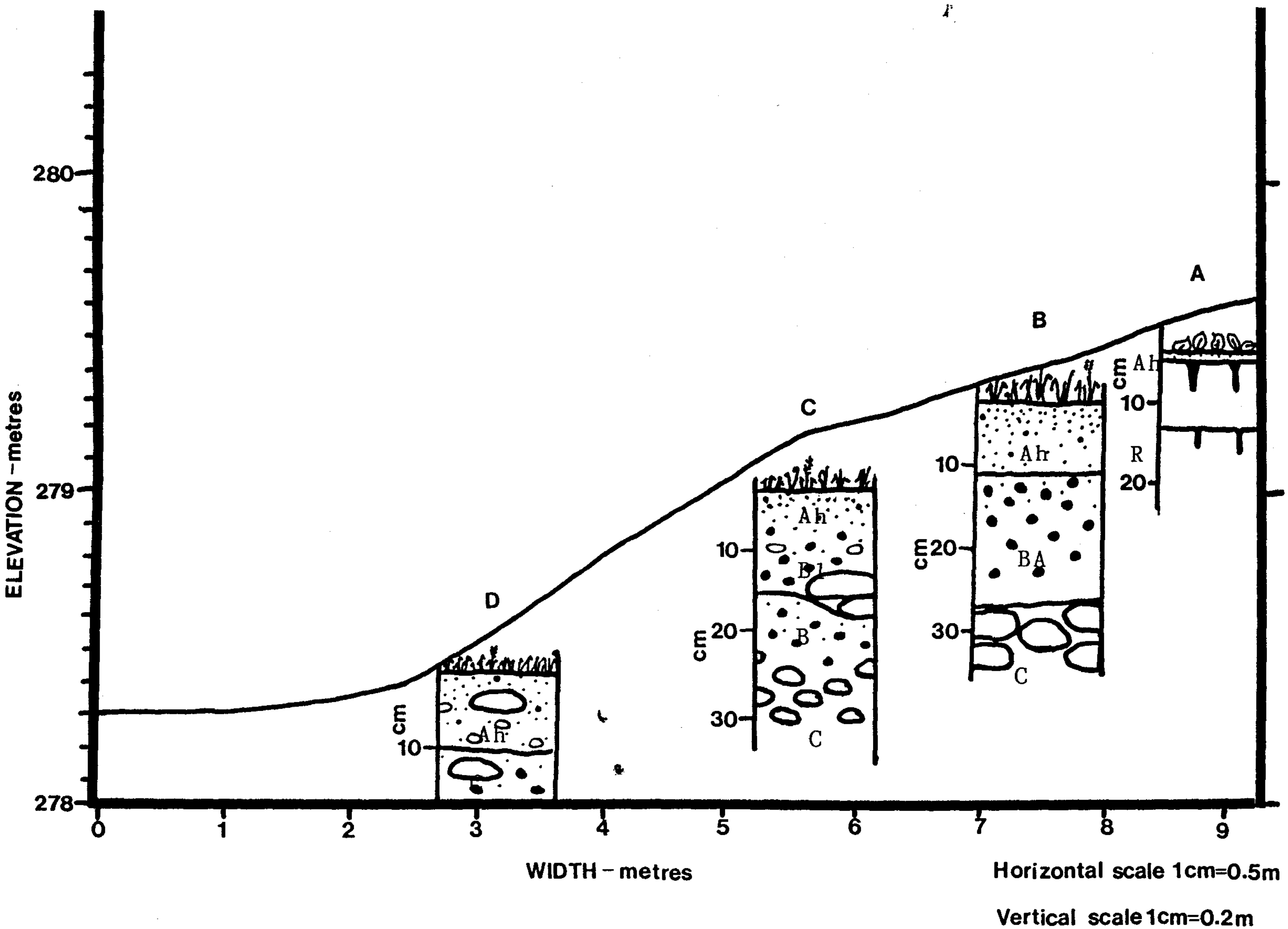
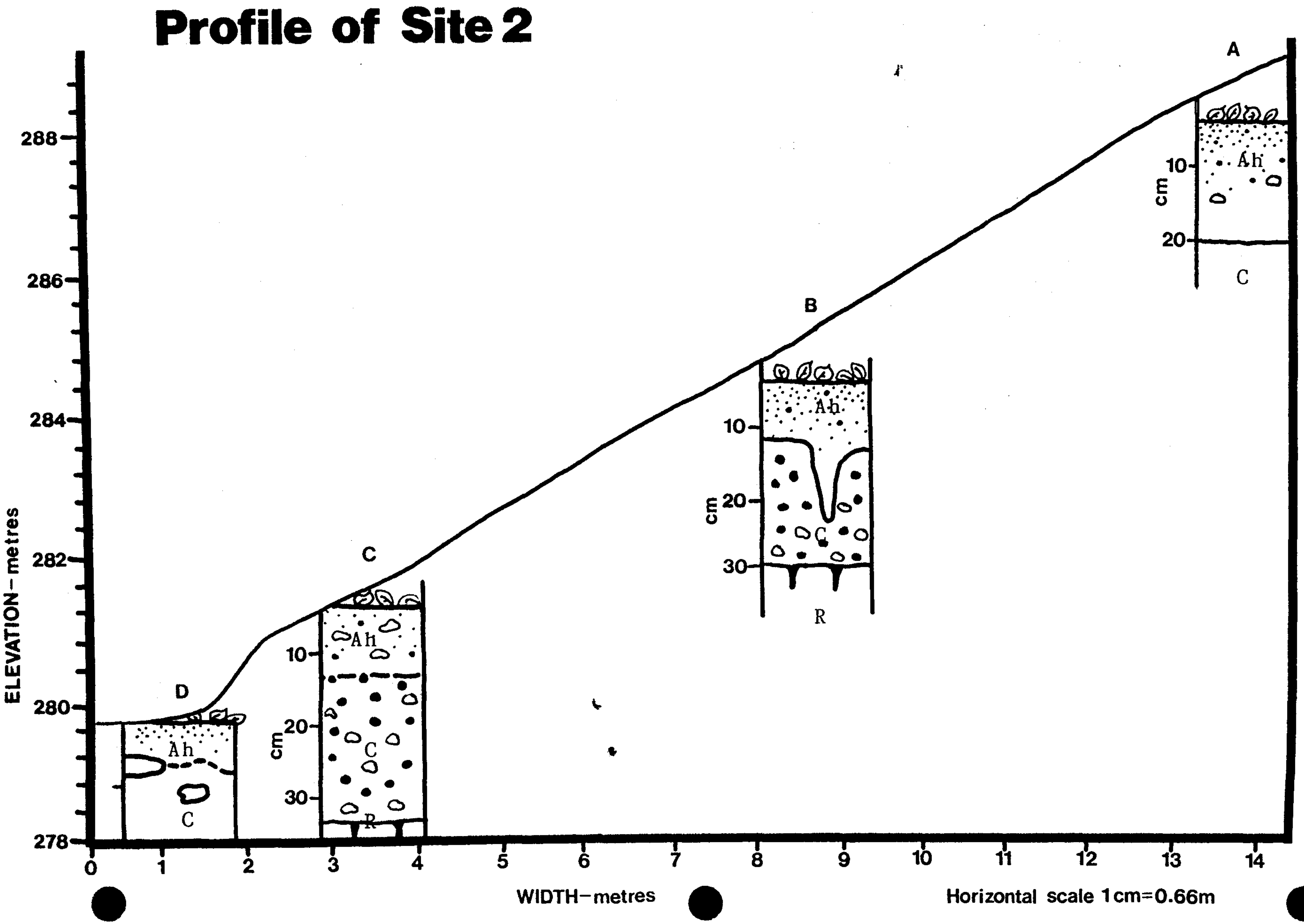


fig.4.2


Profile of Site 2
ELEVATION-metres
288
286
284
282
280
278
WIDTH-metres
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
A
B
C
D
Ah
C
R
cm
10
20
30
Horizontal scale 1cm=0.66m
Vertical scale 1cm=0.8m

15

TOPOGRAPHY

The topographic range within the conservation area is 60 m (fig. 4.3). The highest points are found in the north-west and north-east corner, at 305 m. The lowest point is found at the south-west corner and has an elevation of 276 m.

Site 1 has an elevation that ranges from 278.3 to 279.6 m over a distance of 9.3 m and has an easterly facing slope. Site 2 ranges from 279.8 to 289 m over a distance of 14.3 m with the slope facing south. The gradient for Site 2 is much steeper than for Site 1. This could have an affect on the variability of soil size distribution and eluviation.

HYDROLOGY

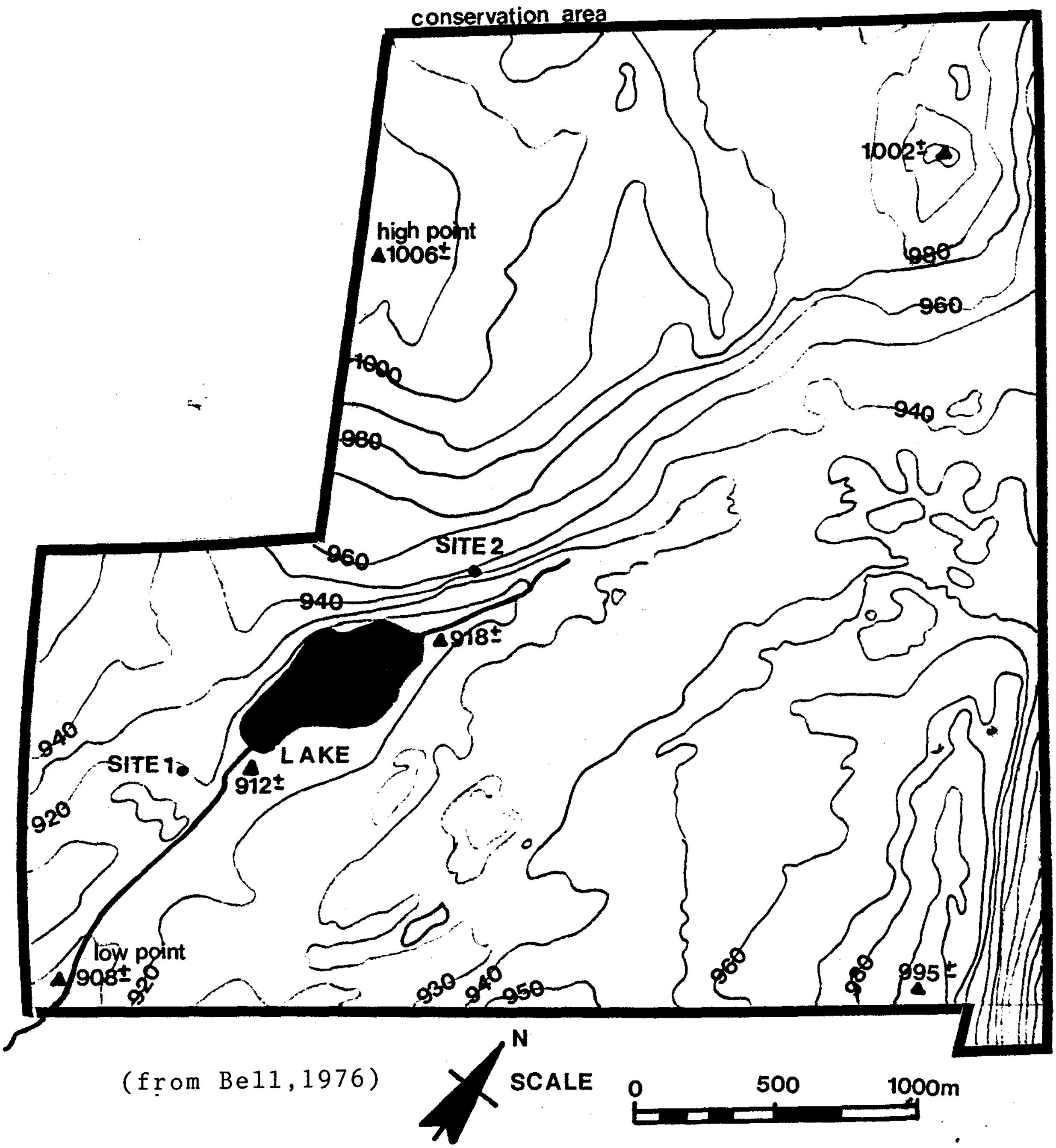
Most of the conservation area is well-drained (fig.4.4). Poor to variable drainage occurs at the southern end of the lake and may be associated with the Farmington soils. The surface drainage flows generally from the north-east to the south-west. The spring area is usually wet in the spring, but dries up during the drier months. Hydrological data obtained from planning maps show that groundwater is not far from the surface (Bell, 1976).

GEOLOGY

The rock formations which influence Halton County are of Lower and Middle Silurian Age. One of the most prominent geological features is the Niagara Escarpment. The escarpment

Topography of site area

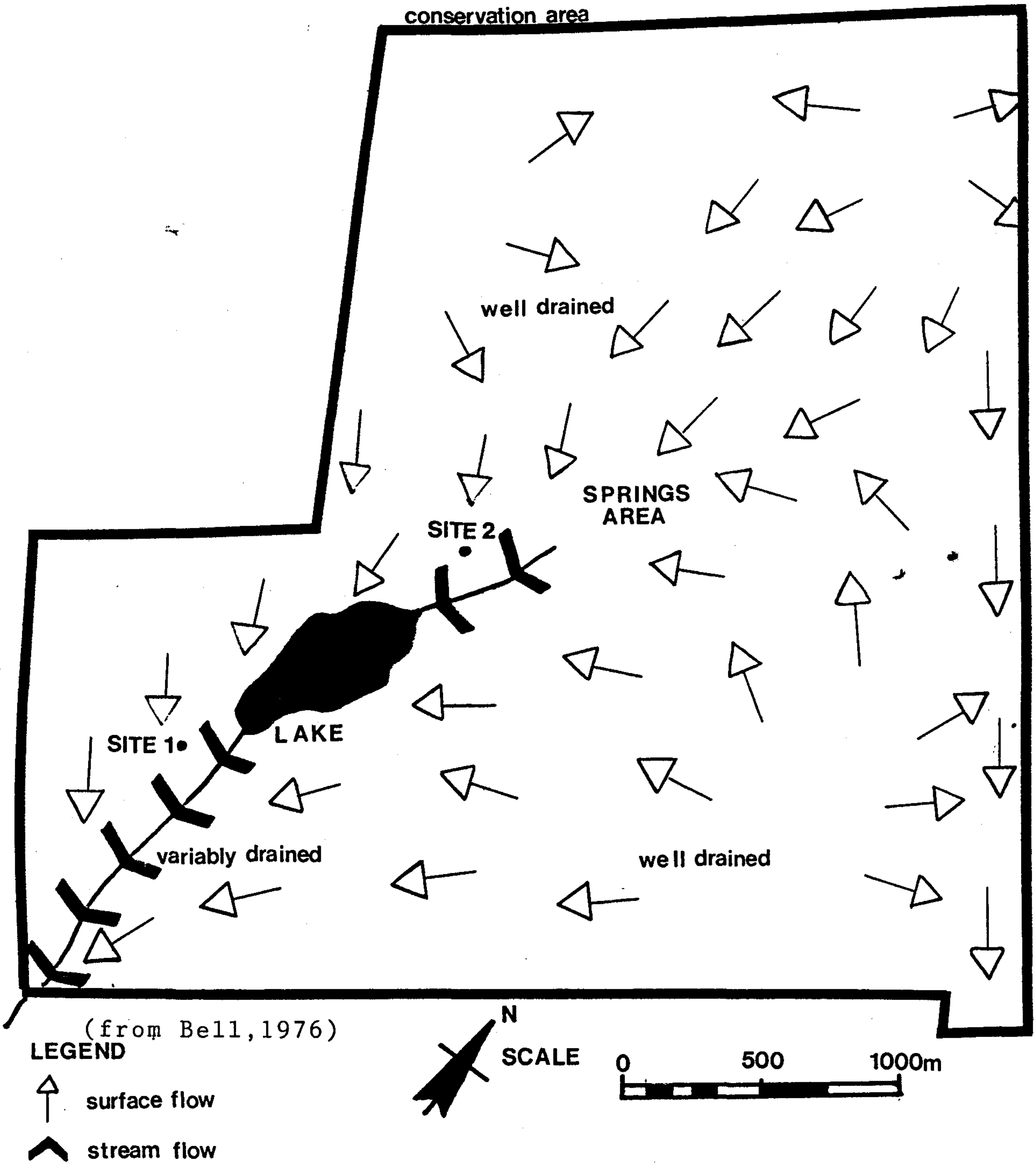
fig.4.3



(from Bell,1976)

fig.4.4

Hydrology of site area



(from Bell,1976)

features the various rock units that affect the conservation area and most of southern Ontario. Resistant Amabel-Lockport Formation forms the cap rock while the underlying formation consist of non-resistant soft shales, soft sandstones and soft thinly-bedded limestones. These less resistant formations form a slope, the steepness of which varies in accordance with the degree of resistance offered to erosion by the different rock layers. The conservation area is situated on this large limestone (dolomite) ridge or mountain belt. The soils within the site area were derived from the nearby rock formations.

Of the two glacial ice sheets, the Illinoian and Wisconsinan that touched southern Ontario at all, the Wisconsinan ice sheet was the most recent. It was at this time that Crawford Lake was formed. The last major spillway system came along the escarpment. Many channel segments were occupied at various times. When the ice retreated slightly, the Crawford Lake channel was abandoned. A small stream remains at the southern end of the lake. Establishment of peat at this end has reduced the lake outflow substantially.

The geology of the conservation area is largely affected by the solubility of the limestone to rainwater. Due to the relative ease to which limestone can be dissolved with water, much of the area is karst landscape.

SOILS

Soils in the Crawford Lake area are a result of glacial moraines and spillways (Bell, 1976). The Dumfries soil series occurs on most of the conservation area and can be found at both sites (fig. 4.5). These soils developed on the coarse textured till of the moraines and in association with gravelly kames, poorly drained mineral and organic soils. The profile consists of a dark gray-brown surface with a loam texture, although a water sorted thin overlay with sandy loam texture may be encountered. Surface soil reaction is neutral to alkaline. The underlying Ae horizon is gray-brown in color and may be absent in distrubed or eroded areas. The B horizon is dark brown, of variable thickness (7-15 cm) and finer textured than the A or C horizons. The underlying till is gray brown stoney and calcareous. The depth of solum (A and B horizons) varies from 22 to 45 cm. The steep slopes are susceptible to erosion and the gray calcareous parent materials are often exposed. The overall drift for the immediate area is 1 m and from the lake to the escarpment up to 7.6 m (Bell, 1976).

Table 4.0

DUMFRIES SERIES

Classification: Order - Luvisolic
Great Group - Gray Brown Luvisol
Subgroup - Brunisolic Gray - Brown Luvisol
Family - Dumfries

Horizon	Depth	Description
Ah	0 - 13 cm	very dark gray (10YR3/1)loam; fine

		crumb and granular structure; friable very stony; pH 7.0
Ae1	13 - 23	dark yellowish brown (10YR4/6)granular and small weak subangular blocky; friable; stony; pH 7.0
Ae2	23 - 41	brown (10YR5/3) loam; weak medium subangular blocky; friable; stony; pH 7.0
Bt	41 - 46	reddish brown (7.5YR5/5) loam; medium subangular blocky; friable; stony; pH 7.4
Ck	46+	yellowish brown (10YR5/4) stony loam till; calcareous; pH 7.8

Table 4.1
Analysis of Dumfries Profile
Particle Size Distribution Percent

Horizon	Depth	Sand%	Silt%	Clay%	Organic Matter%
Ah	0-8	42	45	13	6.7
Ae	8-15	47	42	11	2.1
Bt	15-20	43	37	20	1.6
Ck	20+	61	33	6	0.4

(Halton County Soil Survey)

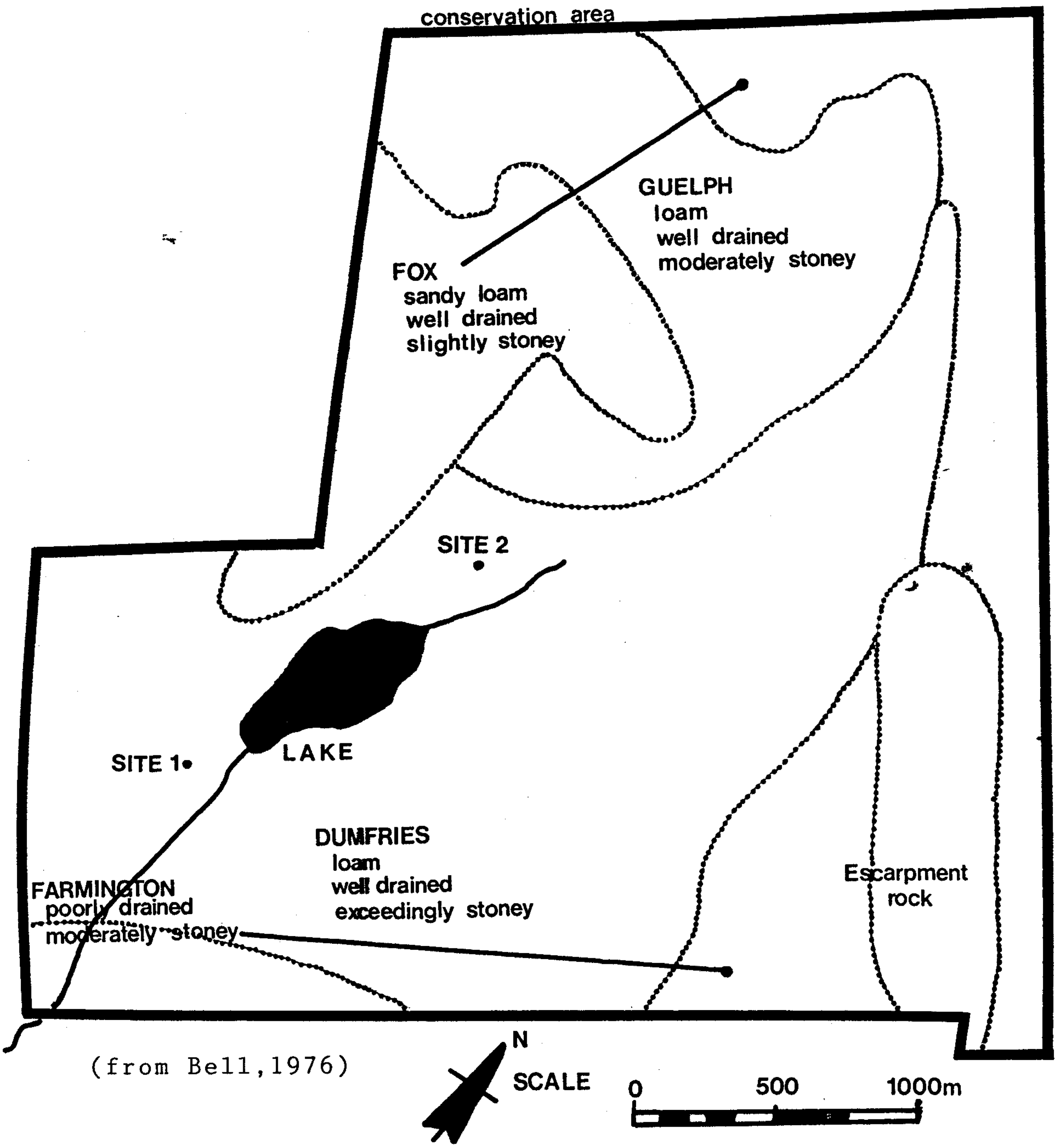
Several other soil series can also be found including the Fox, Guelph and Farmington soils.

VEGETATION

The Crawford Lake Conservation Area lies on the boundary between the deciduous Carolinian Forest and the Conifer-Hardwood region. This mean that the species from both forest types may be found. Generally, the hardwoods are the dominant trees but some conifers such as hemlock and white cedar may be domiant around the shores of the lake. White and red pine are found in areas of reforestation.

fig.4.5

Soils of site area



(from Bell,1976)

The majority of the forest is second growth hardwood forest, established after removal of the white pine in the late 1800's. Studies have shown that the forest around Crawford Lake was typical of the Conifer-Hardwood region, but logging has altered the species dominance. At present, it closely relates to the Carolinian Forest region.

Along the southern shore, much of the area is underlain by peat. The most common tree species are white cedar, white birch and trembling aspen. Peach leafed willow, red-osier dogwood and young white cedars form a dense undergrowth. Site 1 is found in this area. The vegetation along the slope is dominantly shrubs on the summit and grasses and wildflowers along the backslope. Site 2 is found at the northern end of the lake. The site is found beneath a dense canopy of white cedar and white elms along the back and toeslope. Introduced plantings of red and white pine are found at the shoulder and summit of the slope.

CHAPTER 5

RESULTS

Moisture Content

Variations of soil moisture content can be seen in figures 5.0 a,b. Site 1 experiences a high moisture content at the top and upper portion of the slope. Towards the lower portion, the moisture content drops and then increases. At Site 2, the base of the slope has the largest moisture content and this decreases towards the top of the slope. Both sites experience large differences in the moisture content, with Site 1 being much higher than Site 2.

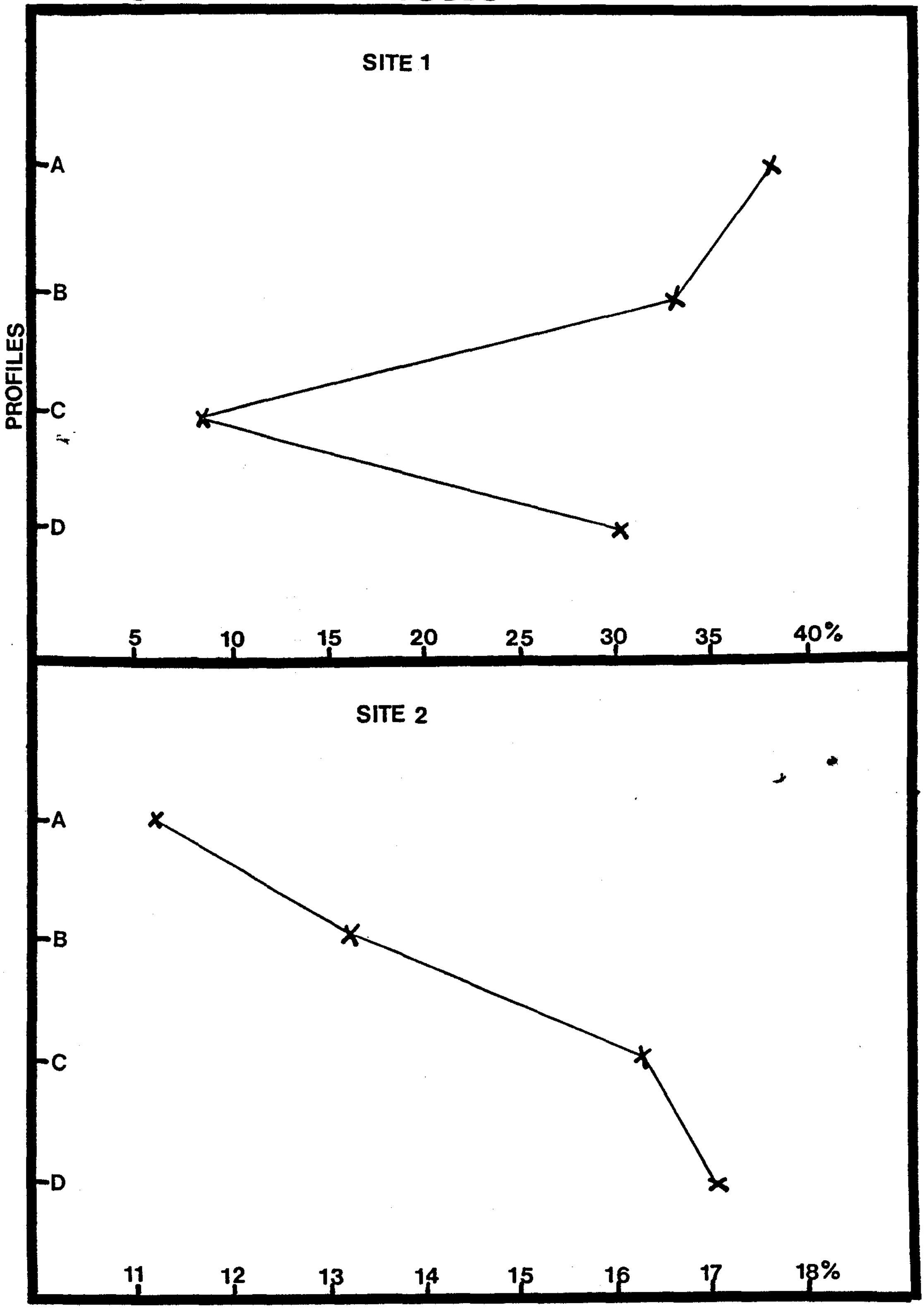
In most samples, the moisture content decreased with increasing depth in the soil profile. Since moisture content is affected by several other variables such as differences in microrelief, aspect and exposure could cause some variation in moisture regimes. This is also influenced by organic matter and salt contents. Since soil moisture is a function of several variables it should not be reliably evaluated from the soil catena.

Soil pH

Figures 5.1 a,b show that the distribution of pH vary along the slope at Site 2, but there is no change at Site 1. At Site 2, the pH ranges from a high of 6.6 at the top of the slope to a low of 5.3 towards the bottom of the slope. This may be due to

fig.5.0

Moisture content



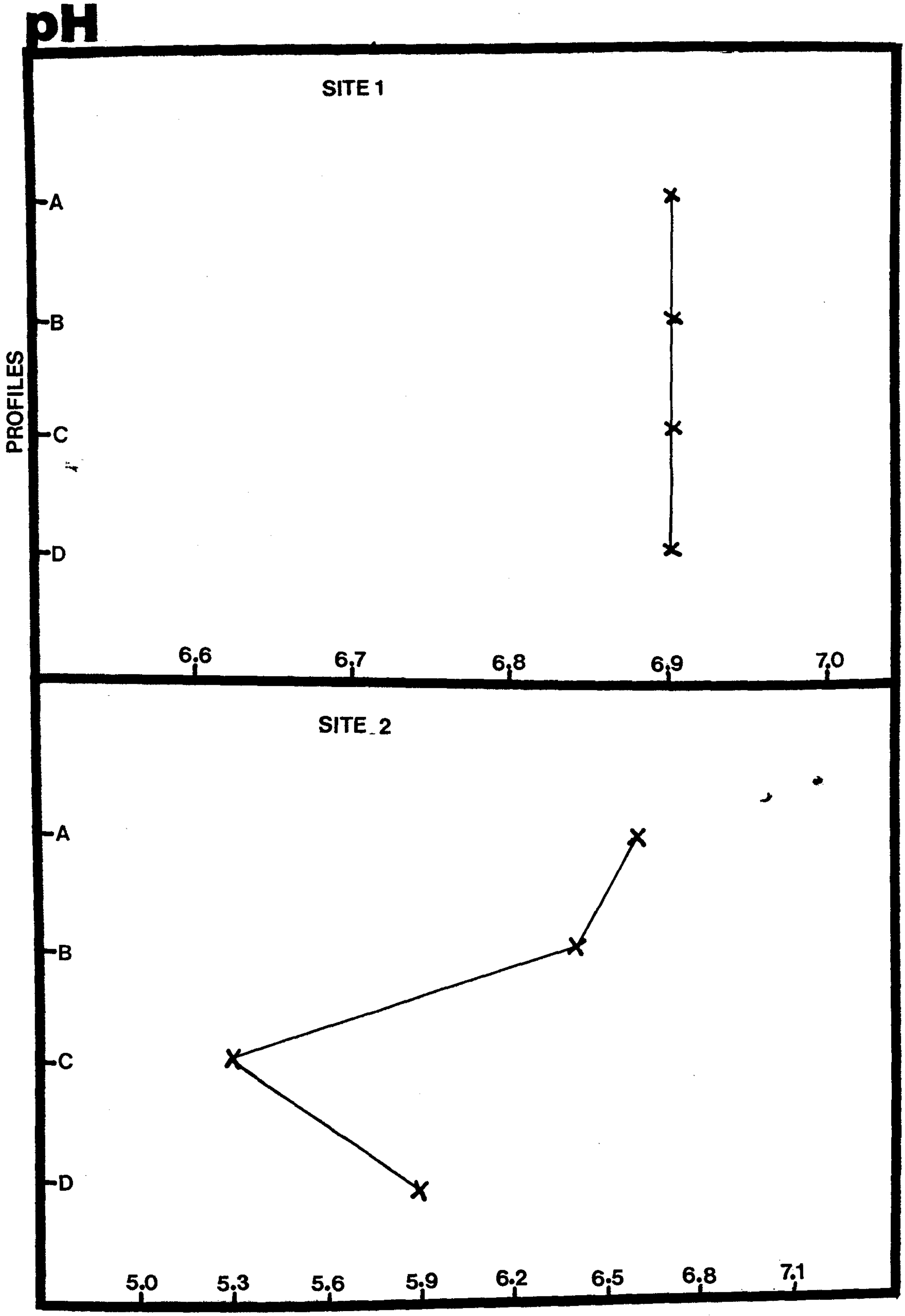

pH
SITE 1
PROFILES
A
B
C
D
6.6
6.7
6.8
6.9
7.0
SITE 2
A
B
C
D
5.0
5.3
5.6
5.9
6.2
6.5
6.8
7.1

Table 5.0

Soil Analysis of Crawford Lake

Site no.	Profile	Color	Structure	Moisture content	pH	Organic Matter content	Carbonates
1	A	2.5YR2/2	crumbly	35.8	6.9	56.03	21.34
	B	2.5YR2/2	crumbly	34.81	6.8	55.26	20.74
	C	2.5YR2/2	weak	9.24	6.9	48.30	13.32
	D	2.5YR2/2	crumbly	30.05	6.9	36.21	-
2	A	2.5YR2/2	crumbly	11.46	5.9	35.68	0.48
	B	2.5YR3/2	crumbly	13.13	6.4	39.83	3.36
	C	5YR3/2	crumbly	16.23	5.3	57.88	1.83
	D	2.5YR2/2	crumbly	17.02	5.9	48.30	5.77

the lower moisture content and low carbonate content. At Site 1, the pH values tend to be maintained at 6.9 throughout the profile. At Site 2, the pH value varies slightly with depth especially at the top and towards the base of the slope. Any differences in pH corresponds with an increase in organic matter content.

Carbonate Content

Figures 5.2 a,b show the variation in the carbonate content between sites 1 and 2. At Site 1, the carbonate content tends to decline with a lower elevation. At Site 2, the carbonate content increases, but then drops at profile C before increasing at the base of the slope. The greatest variation occurs between the two slopes since Site 1 has almost five times as much carbonate than Site 2. This difference could be due to the thin soil covering the dolomite. The decrease in carbonate at profile C corresponds with the decrease in pH. Site 1 shows a decline in carbonates throughout the profile. At Site 2, the carbonate content decreases with depth, but increases at the base of the slope.

Organic Matter Content

The variation in the organic matter content can be seen in figures 5.3 a,b. The organic matter shows little variation between both sites. At each site the organic matter content increases along the backslope, but then declines at profile D. Since both sites remain natural, cultural influences have no affect. Similary, although Site 1 is open and is vegetated by low brush and grasses and Site 2 by mixed forest, there is little difference in the organic matter content. At Site 1, there was an increase in organic matter with depth, but this is not consistant with Site 2. Generally, the organic matter content is unaffected by the slope or depth of soil.

Size Analysis

Figures 5.4 a,b show the difference in the size analysis and distribution along the slopes. At Site 1, the amount of sand decreased to profile C before increasing to profile D. Silt declined from profile A to B then rose at profile C before decreasing at profile D. The amount of clay increases to profile C before decreasing to profile D. Clay is found in the least amount while silt is found to be in the highest proportion. At Site 2, silt is also found to be in the largest proportion, while sand and clay are found in varying amounts along the slope. As the amount of sand increases, the proportion of clay declines.

Bulk Density and Porosity

Figure 5.5 shows the difference in bulk density between the sites, while figure 5.6 shows the variation in porosity. The bulk density at Site 1 increases to profile C before it decreases to 0.8 g/cm at profile D. However, at Site 2, the bulk density declines to profile C before rising at profile D. At Site 1, the variation of the bulk density correlates with the amount of silt and clay. As the amount of silt and clay increases, the bulk density increases. At Site 2, the bulk density increased with an increase in the percentage of clay, Similarly, as the clay content increase the porosity decreases. At Site 1 and 2, there tends to be an increase in bulk density and a decrease in porosity with depth.

fig.5.2

Carbonate content

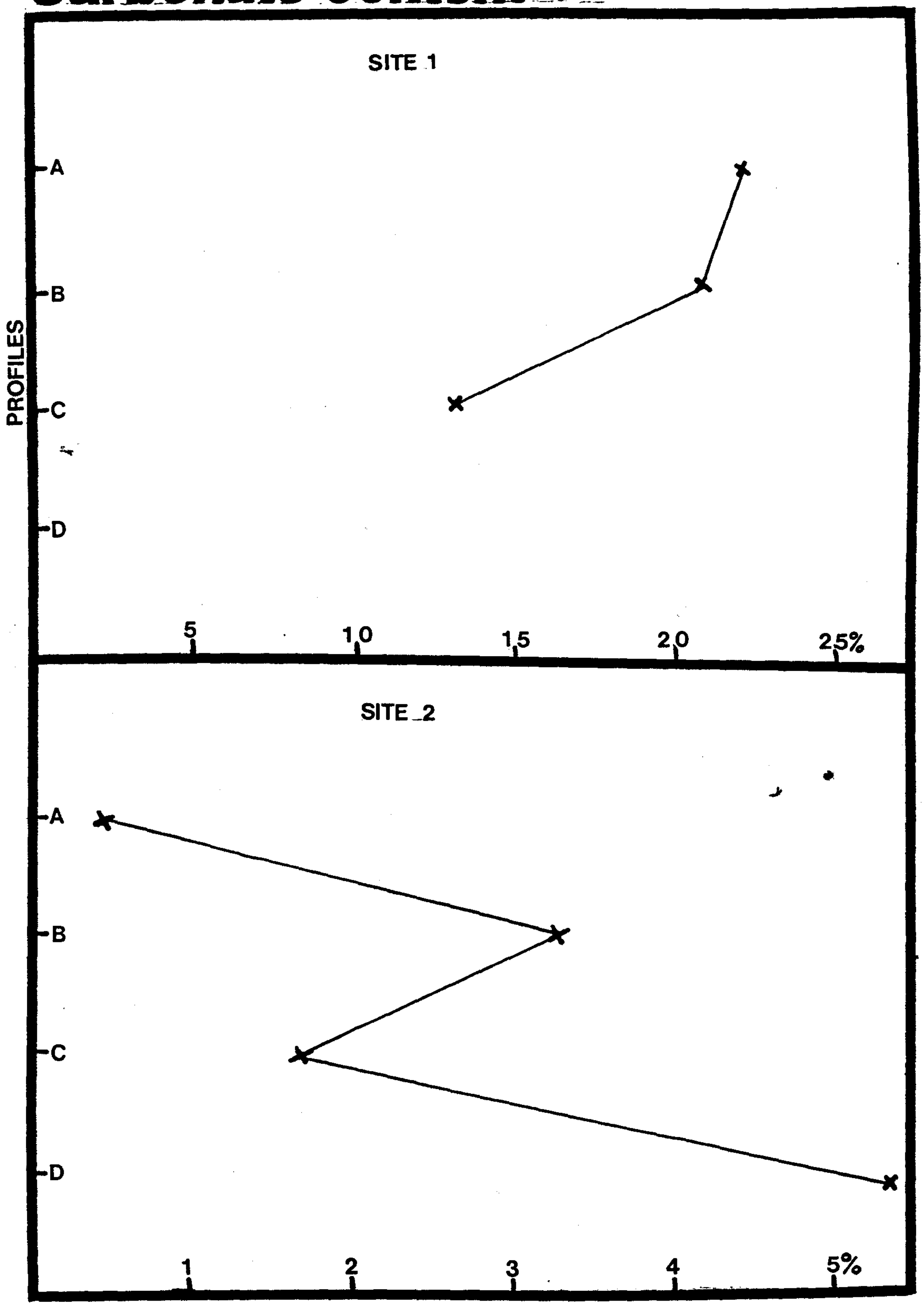


fig.5.3

Organic matter content

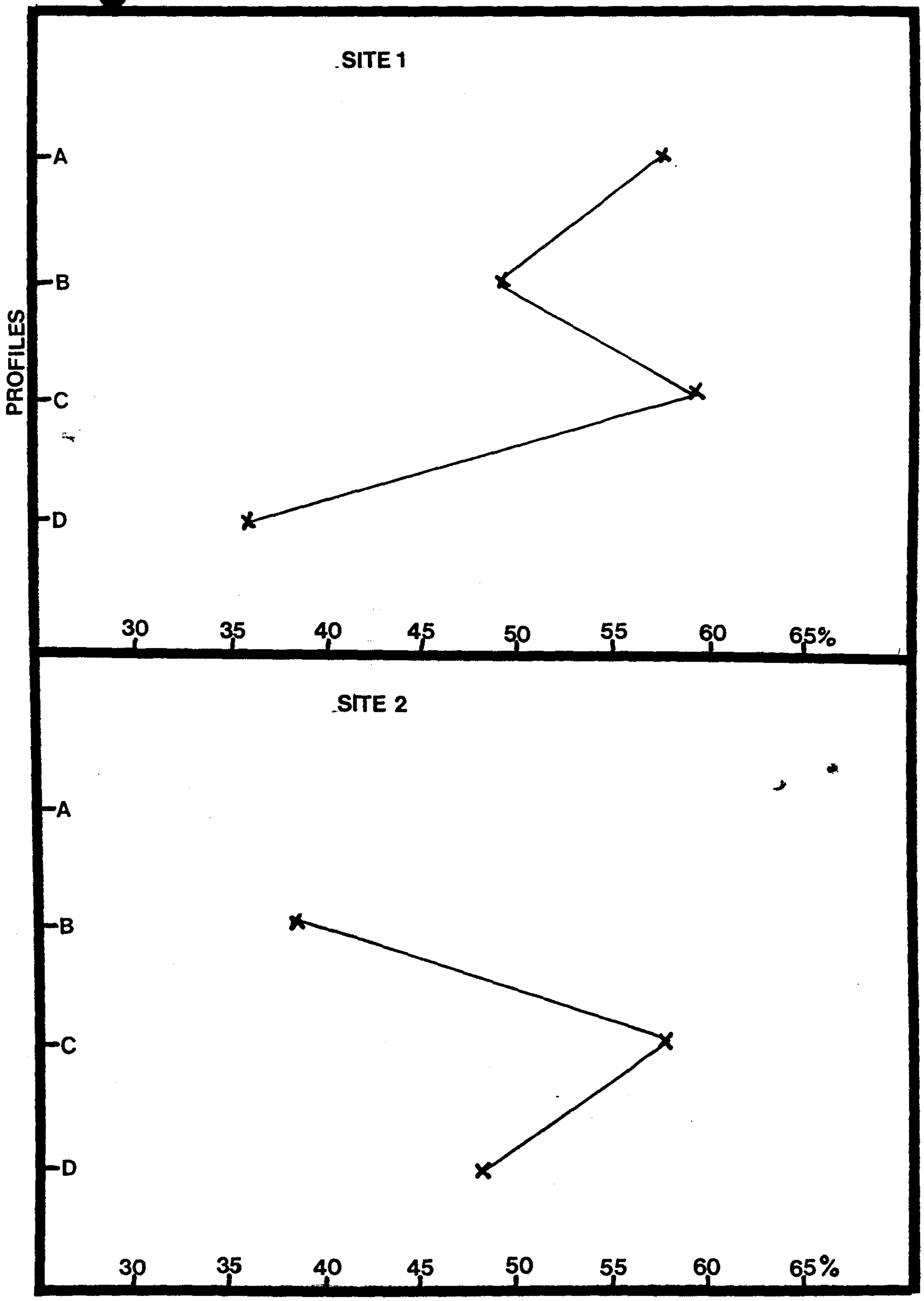
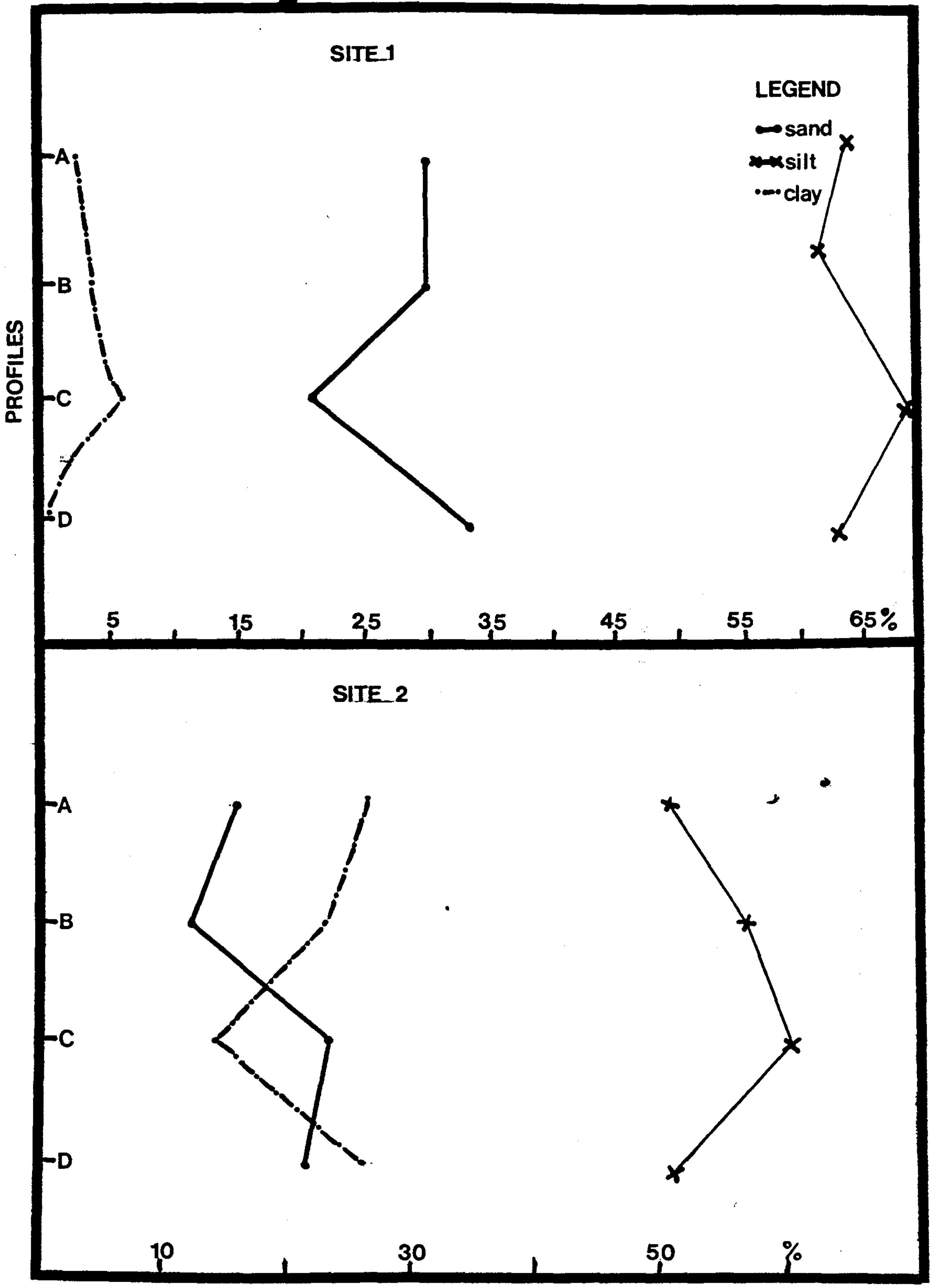
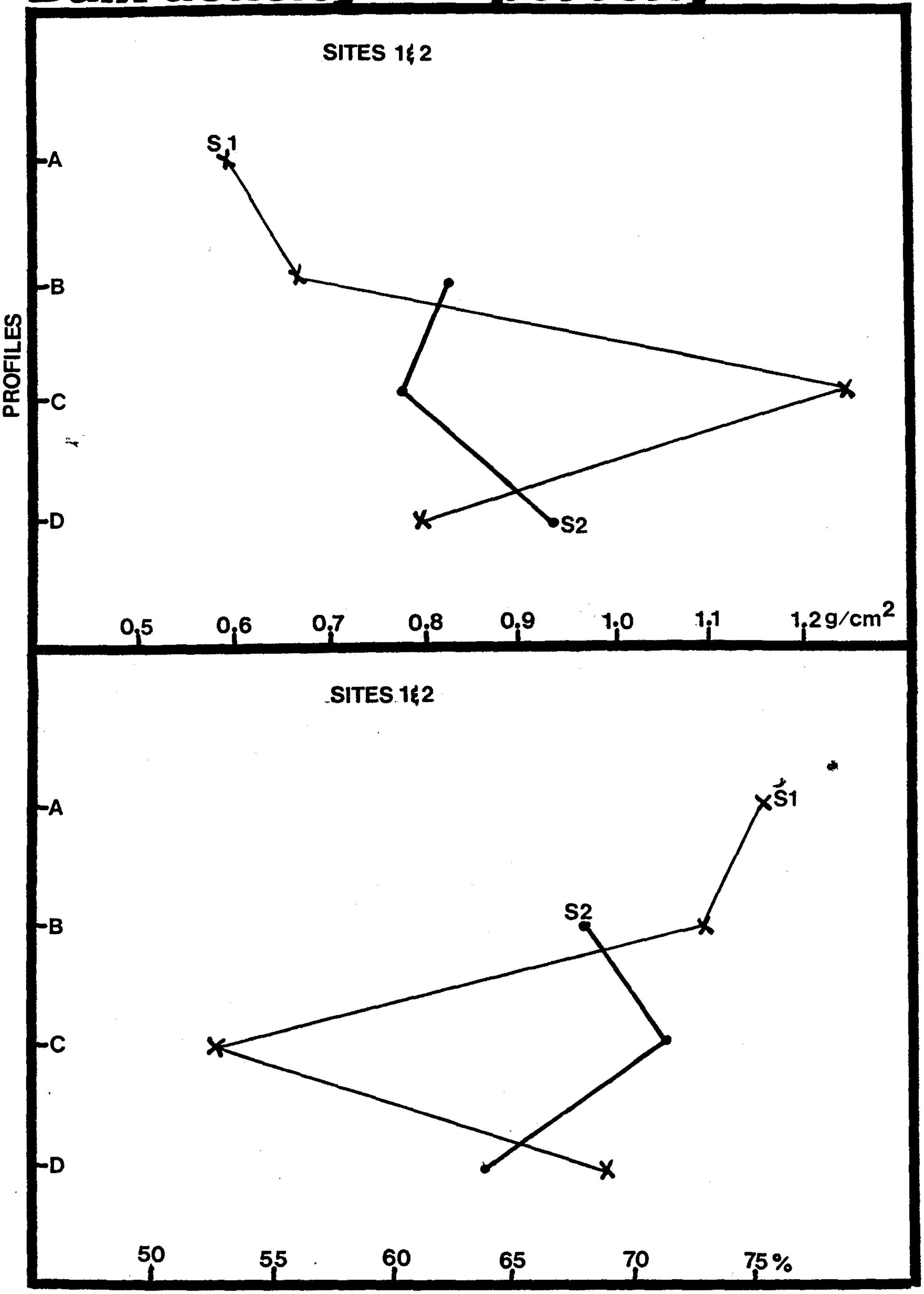


fig.5.4

Size analysis



Bulk density and porosity



CHAPTER 6

CONCLUSIONS

According to Anderson and Furley (1975) certain surface soil properties may be related to such topographical measures as slope gradient and slope length. Analysis on catenae in the Berkshire and Wiltshire chalk downs revealed a consistent pattern in the distribution of soil properties over five slope transects. These patterns showed that properties associated with organic matter (eg. moisture loss) decrease fairly evenly downslope, while soluble components (eg. pH, carbonate content) increase downslope. Studies also showed that there was an abrupt increase in finer soil material downslope of the maximum gradient of the transect.

The results put forward here indicate that similar generalizations cannot be made. Organic matter did not decrease evenly downslope at either Site 1 or 2. Losses of organic matter did occur, but increases in the organic matter at profile C did occur at both sites.

Moisture loss, a soil property related to the organic matter content was also supposed to decrease downslope. Site 2 followed a similar pattern, however Site 1 tended to lose moisture downslope.

Soluble constituents such as pH and carbonates were found by Anderson and Furley (1975) to increase downslope. At both Site 1 and 2 , the pH was either maintained or became more acidic.

Similarly, the carbonate content was found to decline at Site 1. Only at Site 2 did the amount of carbonate increase.

Examination of the particle size distribution at Sites 1 and 2 followed a similar pattern to that of Anderson and Furley (1975).

From these results, no pattern emerged which supported the generalizations put forth by Anderson and Furley (1975) and others (Daniel et al., 1971; Yaalon, 1975). Although the catena concept is useful, it fails to give full prominence to the three-dimensional character of soil processes. It is this fact which restricts this study from concluding that relationships occur between certain surface soil properties and topographical measurements.

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