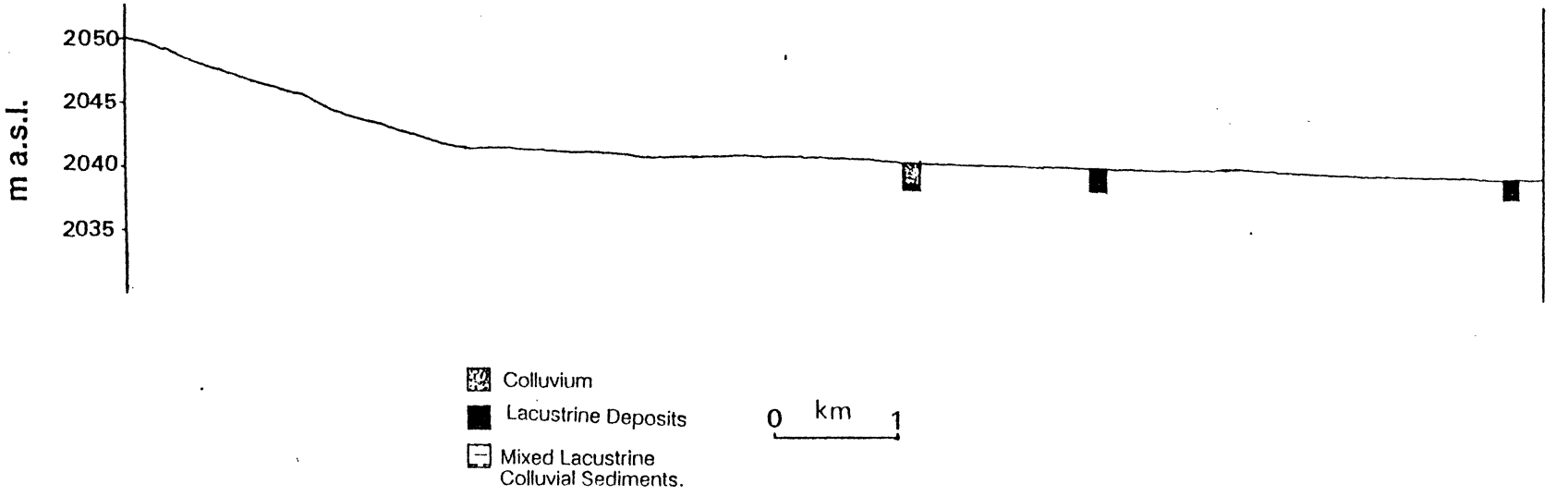

Figure 7.5 The slope profile of the Ajuno valley showing positions and simplified stratigraphy of the main sites investigated.

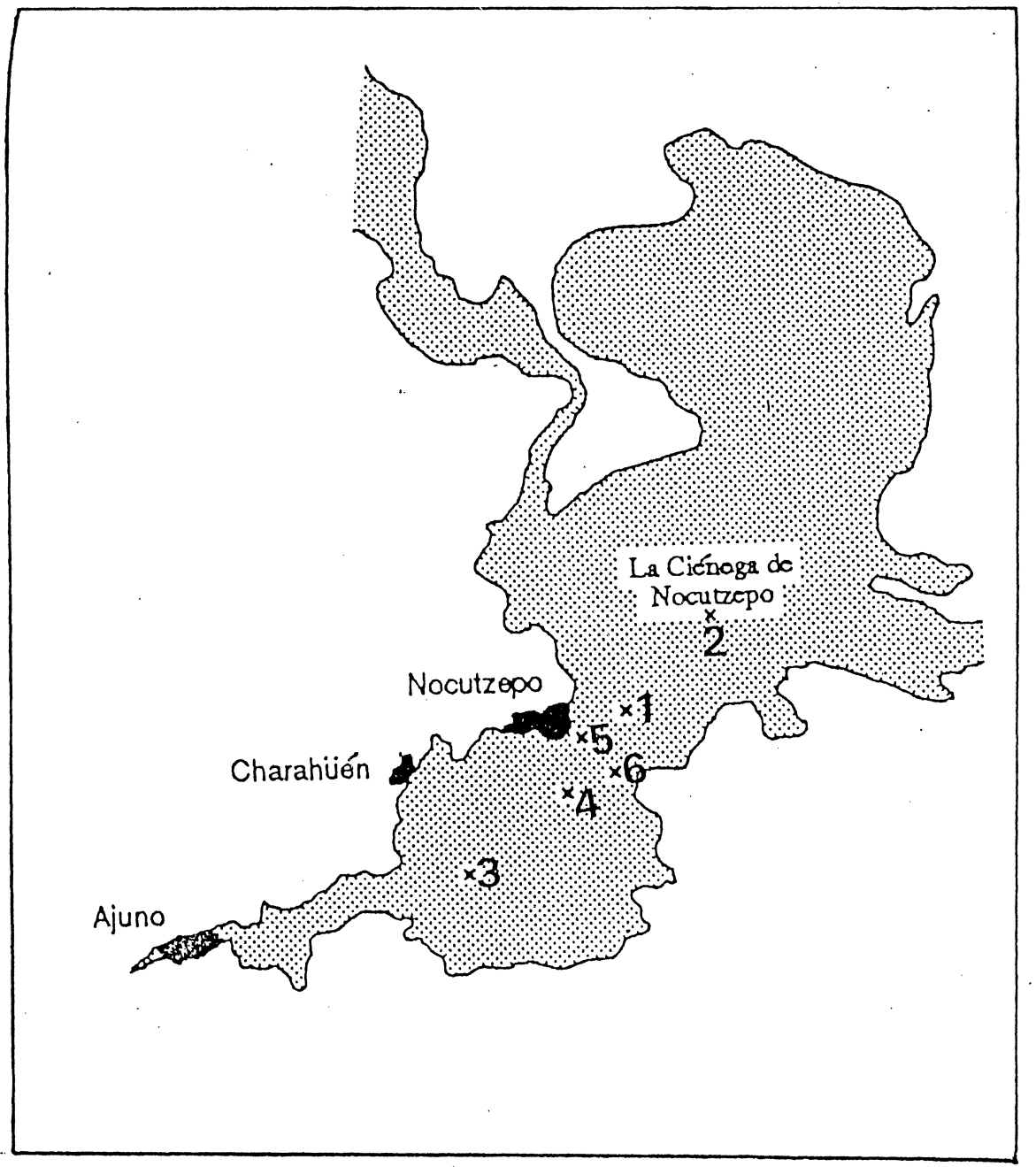

Figure 7.6 Location of the sites investigated in the Ajuno valley.

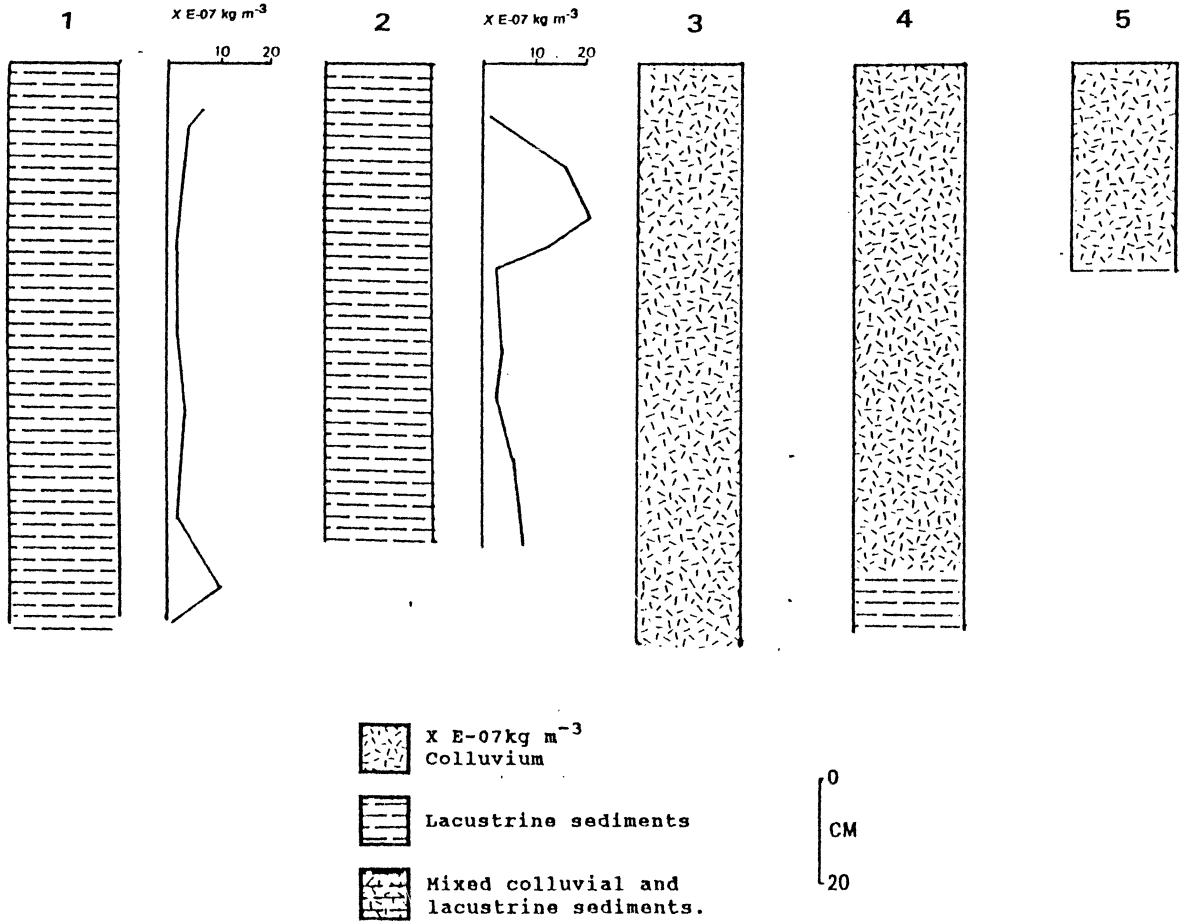

Figure 7.7 The stratigraphy of the sections investigated in the Ajuno valley with *X* where available.

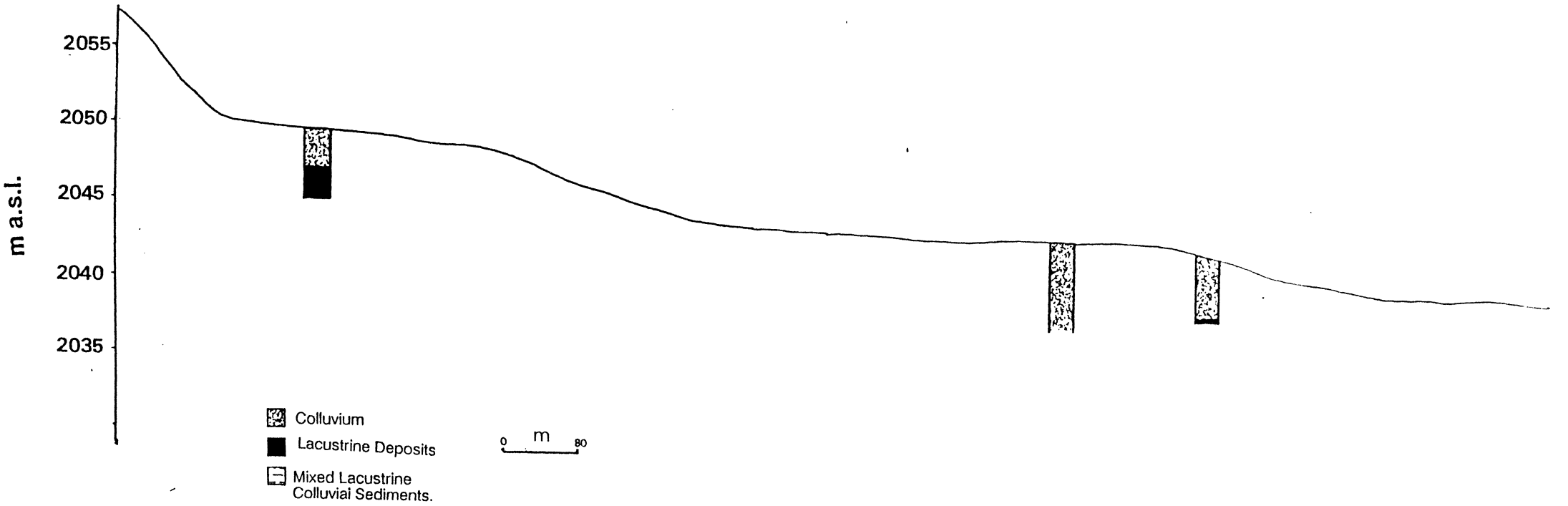

Figure 7.8 The slope profile of the Tzentzencuaro embayment showing the position and simplified stratigraphy of selected sites.

that the stratigraphy in the upper part of the valley is predominantly colluvium, while in the lower section the stratigraphy is dominated by lacustrine deposits. It is possible to distinguish two main units, however.

Unit I, consists of <1.9 m of very dark greyish brown (10YR 3/2) to dark yellowish brown (10YR 3/4), clay rich, lacustrine sediments. These sediments are characterised by low X of approximately 4 to 6 E-06 kg m^{-3}. At Ajuno 1 and 2 a coarse, black, sandy deposit was noted between 2.05 and 2.15 m, and 0.76 and 1.08 m respectively (Fig. 7.7). This deposit is very distinctive compared with other sediments exposed in this area having the appearance of a volcanic ash. The relatively low X values associated with this layer suggest, that despite its appearance, this layer is not volcanic in origin; ash deposits usually displaying very high X levels (Thompson and Oldfield, 1986), however, there is a slight increase in X above this layer at both Ajuno 1 and 2. It is possible that these sediment are organic-rich but contain a small quantity of material that has been washed down from the slopes.

Unit II, consists of <2.25 m of blocky, dark yellowish brown (10YR 4/6-10YR 3/4) silty clay colluvium. These sediments show varying degrees of iron staining and are rich in very fine charcoal fragments.

It is evident from the presence of lacustrine deposits at Ajuno 5 that in the past Lake Pátzcuaro stood at a level of at least 2,053 m a.s.l. The timing of this event cannot be determined, however, as the level of the lake has not been higher than 2046 m a.s.l. in the last 600-700 years (see chapter 6) these sediments must have been deposited over 700 years ago. It should be noted that, while there is ample evidence to indicate that the lake has stood at least 9 m higher than at present in the past 600 to 700 years (see chapter 6), inundating all the sites excavated, there is no evidence to indicate this in the sediment record. The reason for this could be two fold. Firstly, the lake level fluctuations over this period appear to have been rapid, which may have prevented great thickness of lacustrine material to accumulate. Secondly, the large quantities of material deposited from the slopes into the embayment may have overwhelmed the lacustrine

system with the sediment being primarily colluvial in origin. Thus, it is possible that some of the material termed "colluvium" may have been deposited under lacustrine conditions.

7.2.3 Tzentzéncuaro (Tzz)

The town of Tzentzéncuaro is situated on a small bedrock knoll surrounded by relatively flat terrain. To the south of this area is the large volcano locally known as '*El Estribo*'. This is bounded on the north side by a distinct scarp fault forming a steep slope that borders this part of the lake. '*El Estribo*' acts as a barrier to sediments that are transported off the *Sierras* behind it and consequently forms the main sediment source areas of the region around Tzentzéncuaro.

The slope profile from the scarp to the lake is relatively gentle particularly in the lower part of the slope (Fig. 7.8). Two distinct breaks in slope can be observed. Although these can not be easily picked out in the field or from aerial photographs, they are quite distinct on the topographic maps. The upper slope break is at an elevation of approximately 2,044.5 m a.s.l., and the lower at about 2,040 m a.s.l. (Fig. 7.8).

Throughout this part of the basin, road-cuts have exposed large areas of lacustrine sediment (Plate 7.2). In general these deposits consist of a white (10YR 8/1), fibrous material, with between 3 and 5% organic matter and 1-2% $CaCO_3$ content. Soils that have developed on them are generally infertile and probably account for the low agricultural productivity on the farmlands surrounding the towns of Tzentzéncuaro and Huecorio. It has been suggested by West (1948) that these sediments are volcanic in origin, and certainly white ashes are found at a number of locations in the basin, most noticeably at Ihuatzio and in the vicinity of Jarácuaro and Tocuaro (Fig.7.1). However, apart from having a similar colour the sediments exposed on the southern shore of the lake are very different from these ash deposits, being smooth, soft and most importantly, rich in diatoms.

Those areas were lacustrine sediments are at or close to the surface are readily

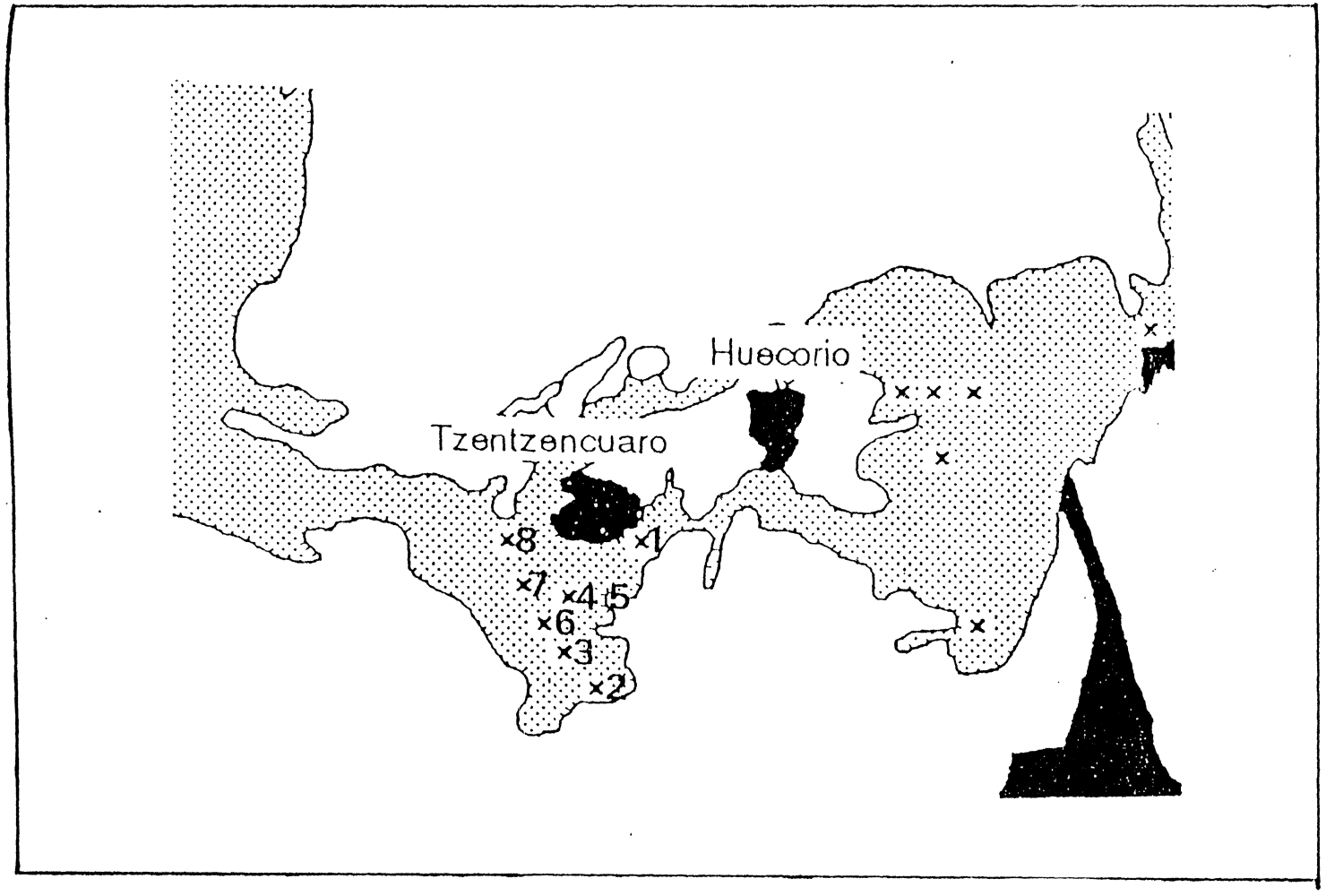

Figure 7.9 Location of the sites investigated in the Tzentzencuaro embayment.

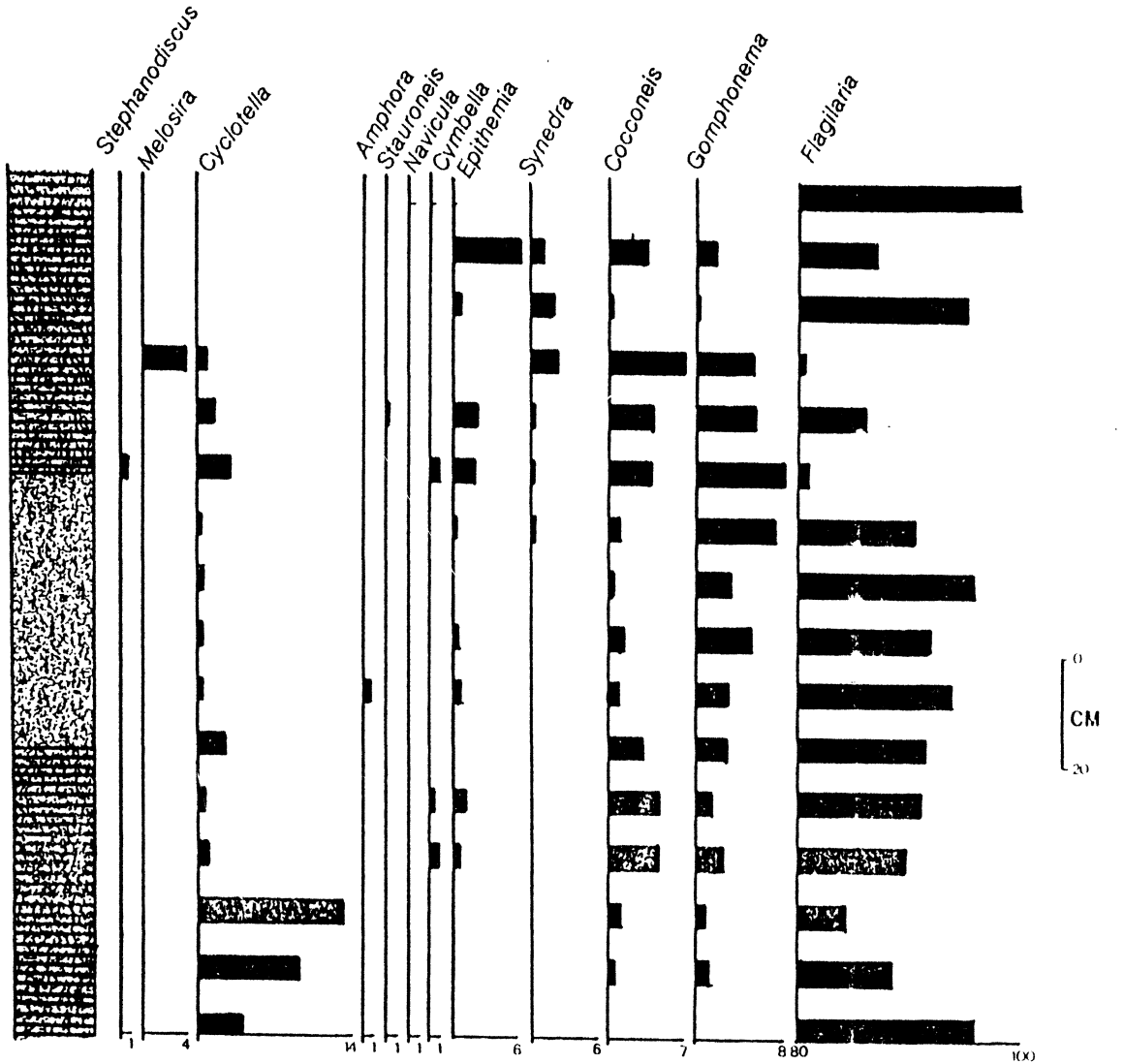

Figure 7.10 The main features of the diatom record from TZZ1.

identifiable as the soils that developed on them differ from those that have developed on colluvium. Soils that have developed on lacustrine sediments are generally light grey, friable, and light to feel while those that have developed on colluvium are reddy-brown in colour, moisture retentive and dense (see plate 6.3).

Eight profiles, between 0.37 and 3 m, were logged in this part of the basin, TZZ2 to TZZ8 roughly forming a transect from the base of the scarp slope down to the lake (Fig. 7.1 and 7.9), while TZZ1 is located at a road cutting along the main Pátzcuaro-Uruapan road (Fig. 7.1 and 7.9).

A 1.52 m section was exposed at TZZ1 (Fig. 7.10) consisting of almost pure white (10YR 8/1), well laminated, friable material. The laminations are much more clearly defined in the lower 70 cm of the section where occasional bands of more organic rich material, 3-5 mm thick, are interceded with the lacustrine sediment. Apart from a small amount of carbonate found in the more organic rich sediments there is no carbonate in these deposits. Similarly little organic material is present. This together with the low level of X (2-3 E-07 kg m^{-3}) suggested that this material was diatomaceous in nature. Samples collected from this site by Dr.Sarah Metcalfe have been analysed down to species level (Fig. 7.10), and the interpretation of these results has been provided by her.

The diatom assemblage at TZZ1 displays a classic lake margin flora, with the dominant species indicative of deposition in shallow waters less than 2 m in depth. The bottom part of the section (120-152 cm) has increasing levels of *Cyclotella* indicative of alkaline conditions. Between 30 and 120 cm the diatom assemblage is dominated by *Flagilaria* with a reasonable abundance of epiphytic species such as *Cocconeis* and *Gomphonema* which indicate deposition in shallow water with macrophytes. An increase in the level of epiphytic diatoms indicates gradually shallowing water and an increase in aquatic vegetation.

At 30 cm *Flagilaria* dominates the diatom assemblage once again and suggests more open water condition and reduced aquatic vegetation. Shallow, more alkaline

conditions are indicated by the return of ephyphytic species at 20 cm. In the upper 10 cm of the core *Flagilaria* accounts for over 90% of the diatom assemblage indicating deposition in shallow, but open water free of aquatic vegetation.

When compared with the results of the diatom analysis of the Mastercore (Bradbury, unpubl. data) it is apparent that the diatom assemblage of the sediments at TZZ1 do contain similar species. However, neither *Flagilaria* nor *Melosira* are found in the upper part of the Bradbury core (covering approximately the last 1000 years). This suggests that the diatomite exposed at TZZ1 is older than 1000 years. In addition, the levels of *Flagilaria* present in the Mastercore during the last 10,000 years reported by Bradbury (unpubl. data; Fig. 4.x) are quite low compared to that of TZZ1. A similar diatom assemblage to that of TZZ1 has been reported in the Basin of Zacapu (Metcalfe, 1985) on deposits >35,000 years old, and it is possible that the diatomite deposits found in the southern part of the Basin of Pátzcuaro date to the late Pleistocene.

The main stratigraphic units exposed at TZZ2-TZZ8 are shown in Figure 7.11. **Unit I**, consists of <85 cm of lacustrine sediments. At those sites furthest away from the lake these deposits consist of a light grey to white, crumbly material. Nearer the lake, where the sediments have a slightly higher moisture content, sediments are dark grey (10YR 4/1) in colour. Once exposed to the atmosphere these sediments rapidly dry out and become almost pure white in colour, and are similar both in colour and texture to those deposits exposed at TZZ1. These sediments are characterised by low X levels between 2 and 3 E-06 kg m^{-3}.

Unit II, is present at TZZ2 to TZZ7. It comprises 85 to 235 cm of dark yellowish brown (10YR 3/4) to reddish brown (5YR/ 4/4), blocky, silty clay, charcoal rich colluvium with occasional small stones. It is characterised by very high X values between 500 and 700 E-06 kg m^{-3}. Frequent distinct vesicular layers are noted which are indicative of deposition under sheet wash conditions.

Unit III, is found at only two sites, TZZ7 and TZZ8, forming a layer 70 and 125 cm thick respectively. This unit exhibits certain characteristics similar to the colluvial

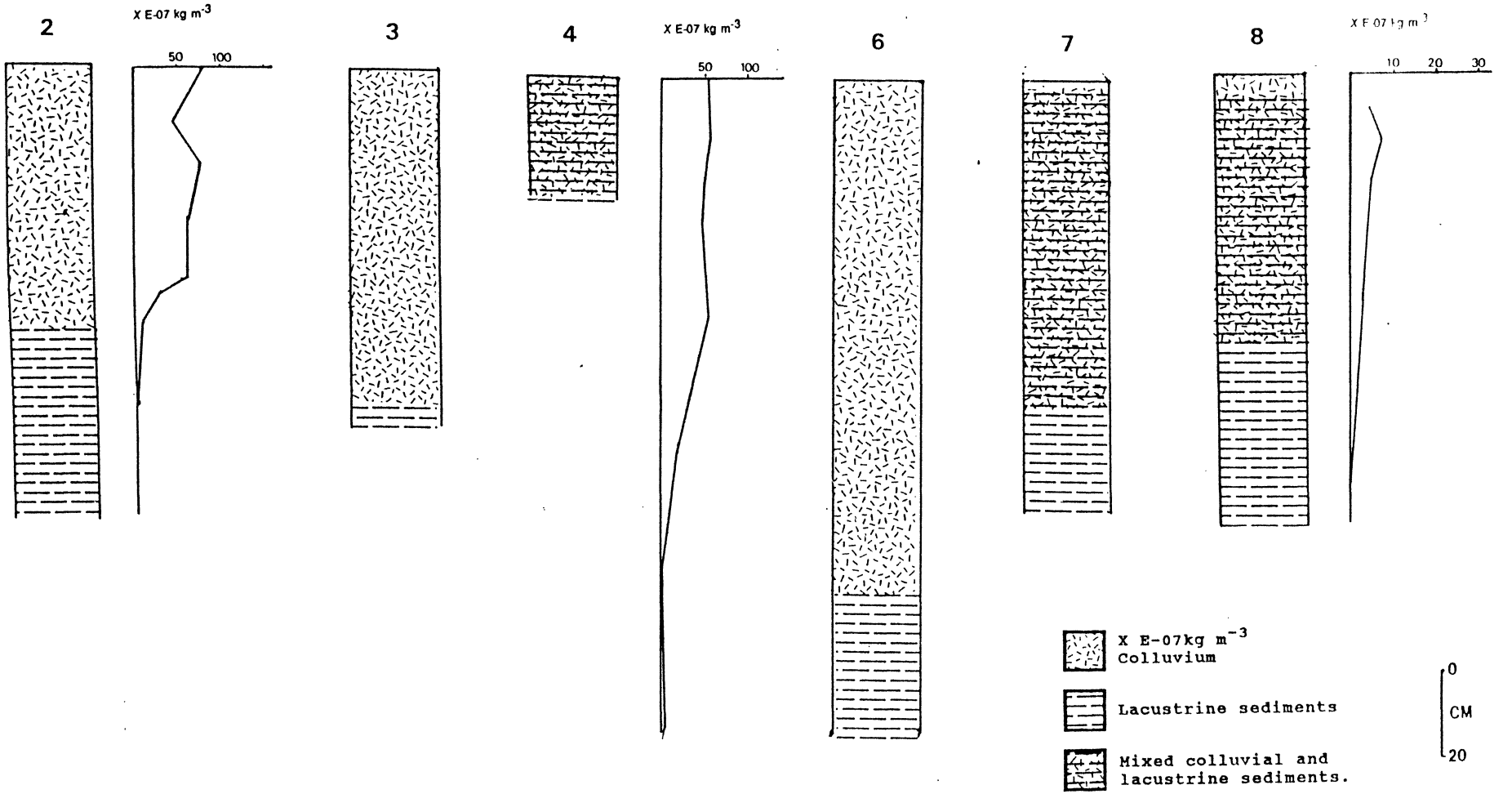

Figure 7.11 The stratigraphies of the sites investigated in the Tzentzencuaro embayment.

material observed up slope, being formed of a blocky, silty clay material with frequent vesicular and charcoal rich layers. Their light grey colour, however, is more in keeping with the lacustrine sediment exposed in this part of the basin, which would suggest that there is a mix of the two sediment types. χ levels also suggest little sediment input from the slope being approximately 5-7 E-07 kg m^{-3}, only slightly higher than those recorded on lacustrine sediments.

In Figure 7.8 five sections are shown in their relative heights and positions in the Tzentzéncuaro embayment. TZZ2, TZZ5 and TZZ6, that consists of lacustrine deposits overlain by colluvium, are all located above the 2,044.5 m break of slope. Those sites located below 2,044.5 m are dominated by lacustrine material.

χ was measured at 4 sites in this area TZZ1, TZZ2, TZZ6 and TZZ8 (Fig. 7.11). At TZZ2 and TZZ6 very low χ levels were recorded in the lacustrine sediments, although χ increases quite sharply in the base of **Unit II** (Fig. 7.x). The χ curve from TZZ8 is low throughout the section, although this increasesslightly in the upper part of the section indicating that there is a small quantity of colluvial material mixed in with the lacustrine sediments at this site. There is a slight change in the stratigraphy associated with this increase in χ, with a similar change was also noted at TZZ7 (Fig. 7.11). It is likely that this unit corresponds to the colluvial material observed upslope and that there is a transitional zone between predominantly colluvial and predominantly lacustrine material.

The information obtained from this site allows a number of conclusions to be drawn. Firstly, the two breaks of slope are interpreted as being representative of former shorelines. Attempting to assign dates to these features is hazardous, however, in view of the erosion currently experienced in this basin one would expect very old features to have been obliterated. During historical times, however, there is evidence to suggest that the lake has stood at much higher levels that at present. Certainly at the time of the Conquest the lake is believed to have stood between 2,043 and 2,045 m a.s.l. (see Chapter Six), and in recent years there is ample evidence to suggest that the lake level has been as high as 2,040 m a.s.l. Therefore, it is possible that these features relate to

quite recent high stands, but without a firmer dating control it is not possible to make anything more than inferences as to when these features were formed.

The stratigraphical evidence also indicates that Lake Pátzcuaro has stood at a higher level in the past. Lacustrine deposits exposed at TZZ2 are found at an elevation of 2,047.5 m a.s.l. some 10 m above the present level of the lake. Consequently the lake was not only higher but considerably more extensive than at present, extending to the foot of the '*El Estribo*' scarp, approximately 1.2 km further south than the present shore of the lake. However, the lack of dating control makes it impossible to determine when this high lake stand occurred and if it corresponds to the relict shorelines described above. The similarity of these lacustrine sediments to those exposed at TZZ1 has been noted and it is possible that they represent a contiguous depositional unit. As discussed earlier the diatom assemblage of these sediments is similar to that recorded on late Pleistocene deposits in the Basin of Zacapu (Metcalfe, pers. comm. 1991) and it is possible that the diatomite exposed in the upper part of the valley are relatively old.

As discussed above there is only a limited sediment source area in this part of the basin and this may account for the relatively thin colluvial deposits found at the sites around Tzentzéncuaro. As the lake is the final depository of this sediment one would expect a similar record to be seen in the lacustrine record.

7.2.4 Pátzcuaro

To the east of Tzentzéncuaro a further large former embayment is found (Fig. 7.1). As this is overlooked by the town of Pátzcuaro it will be referred to as the Pátzcuaro embayment. Five sites were investigated in this part of the basin (Figs. 7.12 and 7.13), three of which formed a transect from the upper to the lower part of the embayment. Two marked breaks of slope are apparent in this part of the Pátzcuaro Basin (Fig. 7.14). The upper lies at an elevation of 2,049 m a.s.l., while the lower is situated at approximately 2,044.5 m a.s.l., the same elevation as the upper slope break at Tzentzéncuaro (Fig. 7.8).

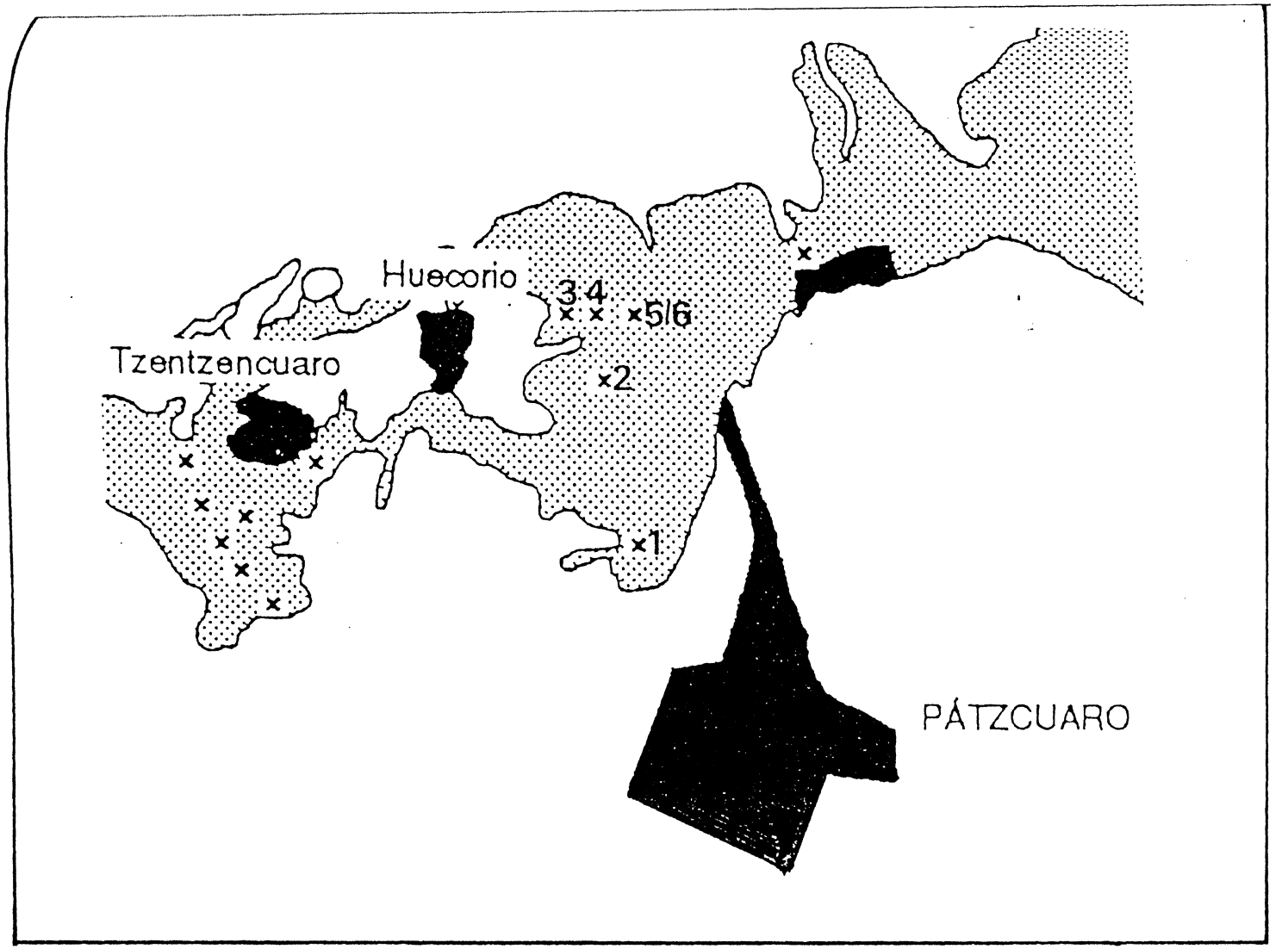

Figure 7.12 Locations of the sites investigated in the Pátzcuaro embayment.

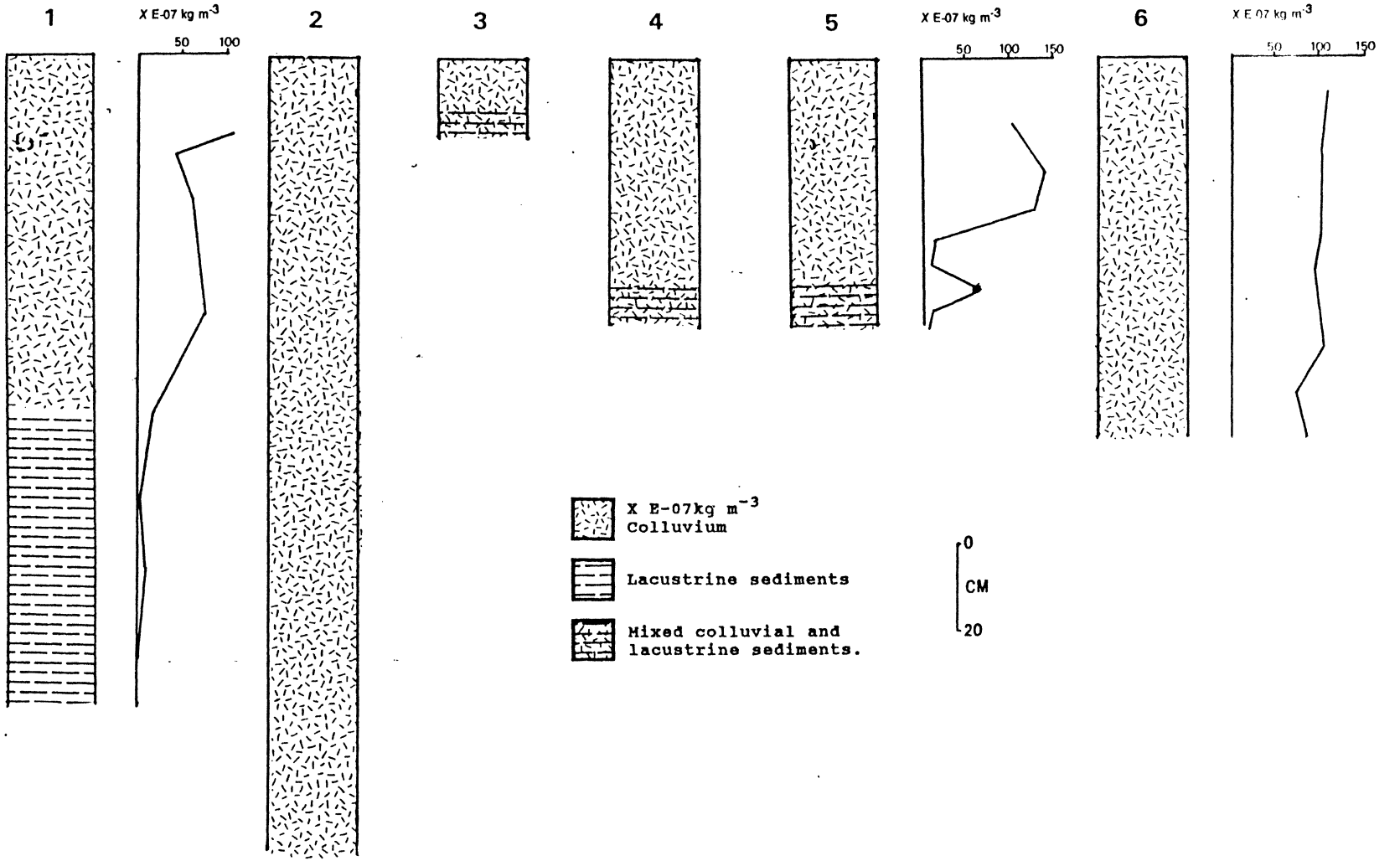

Figure 7.13 The stratigraphies of the sites investigated in the Pátzcuaro embayment.

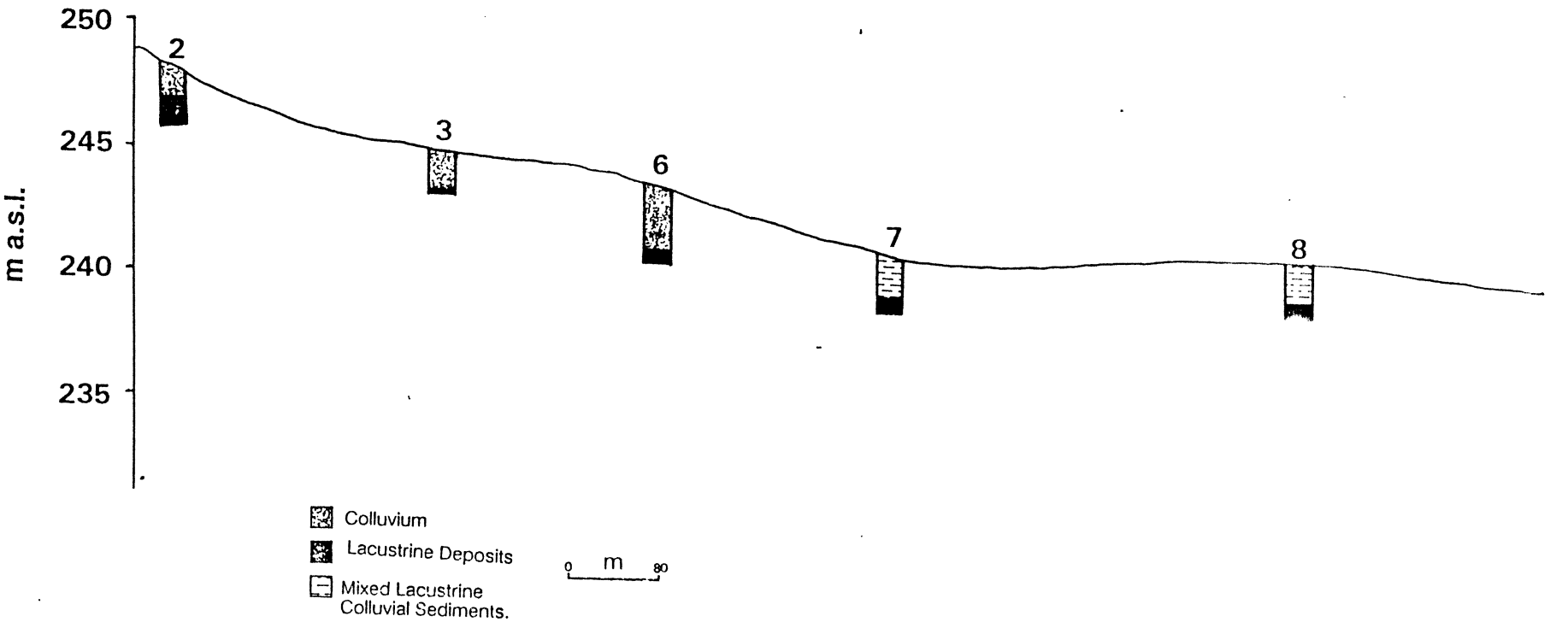

Figure 7.14 The slope profile of the Pátzcuaro embayment showing the positions and simplified stratigraphies of selected sites.

Two main stratigraphical units can be identified from the deposits in the Pátzcuaro embayment. **Unit I**, consists of <135 cm of friable, light brownish grey (10YR 6/2) to white (10YR 8/1), smooth, powdery material. A small amount of organic material is observed and iron-staining is present throughout this unit. These sediments are characterised by low *X* levels (2-4 E-07 kg m^{-3}), and both in appearance and colour are similar to those sediments exposed at TZZ1.

Unit II, comprises of <3.6 m of yellowish-red (5YR 4/6) to strong brown (7.5YR 4/6), silty clay, highly vesicular colluvium. Distinct layers of very fine charcoal are dispersed throughout these sediments which are also characterised by extensive iron-staining. This colluvium displays very high *X* levels in the order of 130 E-07 kg m^{-3}.

A considerable variation in the thickness of **Unit II**, is found in this embayment. At Pátzcuaro 1, for example, **Unit II** is 1.6 m thick, while at Pátzcuaro 2, 3.6 m of colluvium was logged before augering was abandoned. The difference in the thickness of this deposit probably reflects the proximity of different sites to the bedrock walls. Those sites located close to the centre of the embayment have a much greater thickness of colluvium than those situated near the side walls.

The stratigraphy of the Pátzcuaro embayment is similar to the seen at Tzentzéncuaro with lacustrine sediments overlain by colluvium. The change in sediment type is very abrupt and can be clearly seen by both the change in sediment type and the sharp increase in *X* at the base of **Unit II** (Fig. 7.13). This indicates that sediments at this site changed from lacustrine deposits with little sediment input into the lake to a situation where considerable quantities of material were being eroded from the slopes.

The Pátzcuaro embayment slope profile clearly indicated that there are three distinct breaks of slope. The two lower slope breaks at 2,044 m a.s.l. and 2,040 m a.s.l. correspond to those seen at Tzentzéncuaro and provide additional support for the idea that these are relict shoreline features. In addition, the presence of lacustrine sediments at Pátzcuaro 1 provides conclusive evidence that the lake has been at a level of at least 2,047 m a.s.l. in the past, and confirms the findings from Tzentzéncuaro.

7.2.5 Tzurumutaro

Only a single site was excavated at Tzurumútaro, situated on the southern shore of the southern limb of the lake (Figs. 7.1 and 7.15). This site, which stands at an elevation of 2,046.5 m a.s.l., is located at the foot of the *'Sierra de Colorado'*, one of the major volcanic peaks in the Pátzcuaro Basin. The upper 2 m of this section was exposed by a brick pit (Plate 7.3) and extended to 4 m by augering. **Unit I.** consists of 10 cm of black, clayey lacustrine deposits. This unit is overlain by 3.9 m of colluvium, **Unit II.** These colluvial sediments show a marked coarsening up the sequence with the upper 50 cm of the unit comprising of fine gravel 1-2 mm in diameter. The coarse nature of this sediment is probably a reflection of the close proximity of this site to *'Sierra de Colorado'*, the sediment source area.

Samples from the upper 2.2 m of this section were analysed for L.O.I., calcimetry and X. These sediments exhibit high values of X in the order of 800 and 1,350 E-06 kg m^{-3}. The amount of organic matter as determined by L.O.I. is between 10 and 12% while calcium carbonate content is low, with an occasional small peak as high as 4% observed.

7.2.6 La Ciénaga De Tzurumutaro

In the south eastern part of the basin there is a large area of almost completely drained marshland locally referred to as 'La Ciénaga de Tzurumútaro' (Fig. 7.1). This forms a large embayment, which in the past has been connected to the main lake forming an extended southern arm to the lake (see Chapter Six). The marsh was drained between 1962 and 1966 (CESE, 1988). The floor of the basin is almost flat with a slight depression in the central part. This depression tends to get waterlogged during the rainy season. To the north and south the embayment is bordered by steep slopes, while to the east it is bordered by relatively gentle slopes with no major peaks.

Three cross-sections were constructed from the detailed topographic maps (Fig.

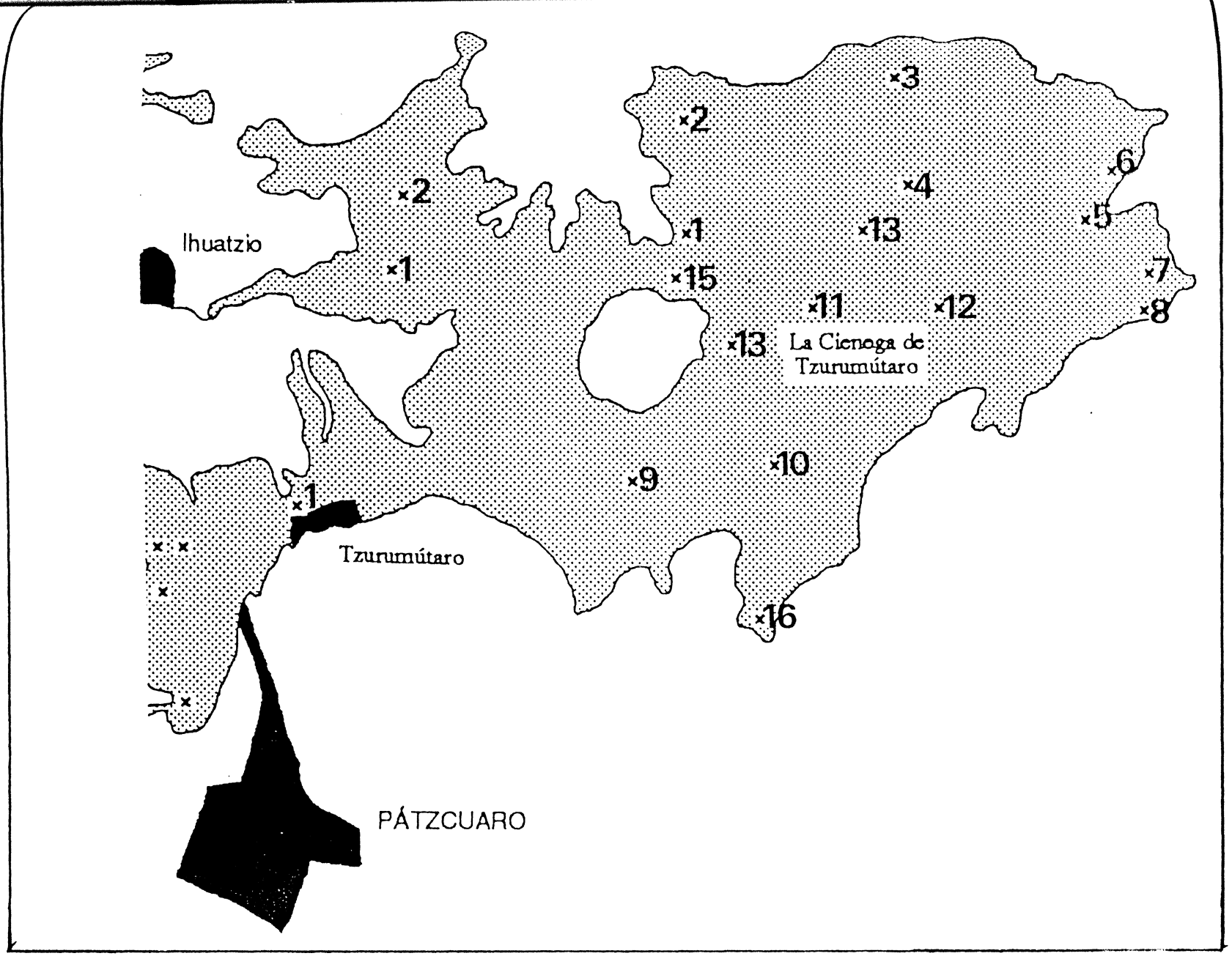

Figure 7.15 Locations of the sites investigated at Tzurumutaro, *La Cienaga* embayment and Ihuatizio.

7.16). Transect 1 which cuts the western end of the basin indicates that the southern slope in this part of the basin is very steep. Two breaks of slope are apparent the upper at 2,045 m and the lower at 2,042 m a.s.l. The northern slope has a much gentler profile, although a distinct break in slope is also noted at 2,045 m a.s.l. which may correspond to that on the southern slope and represent a former shoreline.

A second transect from the eastern slope extending westwards into the central part of the basin. Apart from a slight break of slope at 2,055 m a.s.l. there are no other features that represent an obvious change in the slope profile. Transect 3, which is located on the southern slope of the basin exhibits a relatively steep profile. Breaks in slope are recognised at 2,052 m and 2,048 m a.s.l. and do not correspond to any other features found in this region.

Sixteen sections between 0.5 and 6.9 m in depth were investigated in this part of the basin (Figs. 7.15 and 7.17), and two main sedimentary types were identified. **Unit I**, comprising of lacustrine sediments and **Unit II**, which consists of colluvium.

The lacustrine sediments, which form **Unit I**, were found at thirteen of the sites investigated in 'La Ciénaga' embayment. The greatest thickness logged was at LC12 (Fig. 7.17) where 2.73 m of lacustrine sediments were augered. These sediments are smooth, clay rich and unstructured. Although similar in texture and structure, a considerable variation in colour was noted between different sites with white, grey, blue and black deposits observed. These variations in colour appear to be related, in part, to changes in moisture content and where waterlogging occurs in the embayment sediments are gleyed. These sediments are characterised by very low X levels that are between 1 and 3 E-07 kg m^{-3}.

Unit II consists of colluvial deposits similar to those described for other areas of the Lake Pátzcuaro Basin. These sediments are predominantly silty clay, although at those sites located closer to the sediment source area deposits are generally coarser with occasional gravels and pebbles included. The colluvium ranges in colour from very dark brown (10YR 2/2) to dark yellowish brown (10YR 3/4), and is characterised by iron

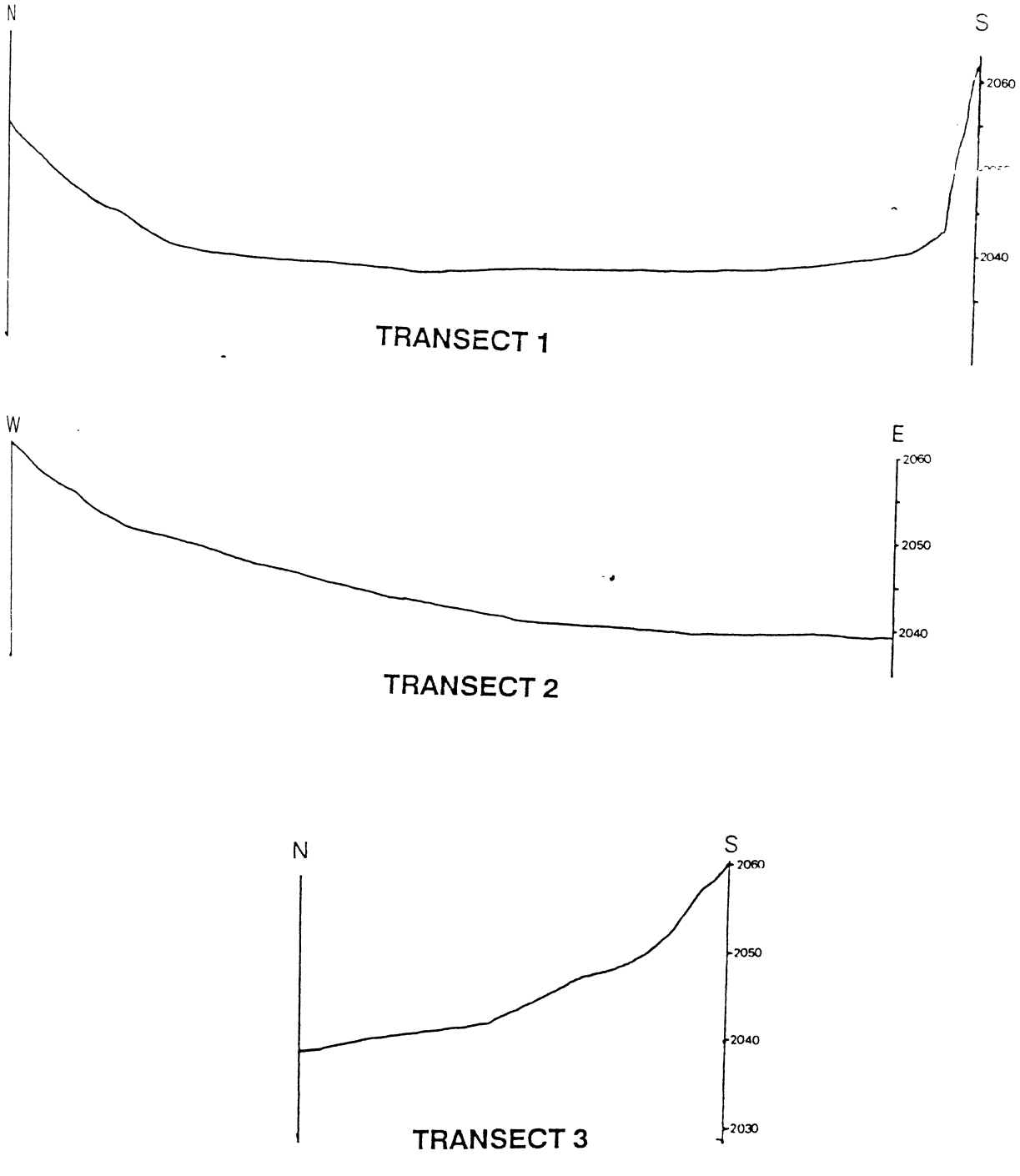

Figure 7.16 Slope profiles from La cienaga embayment.

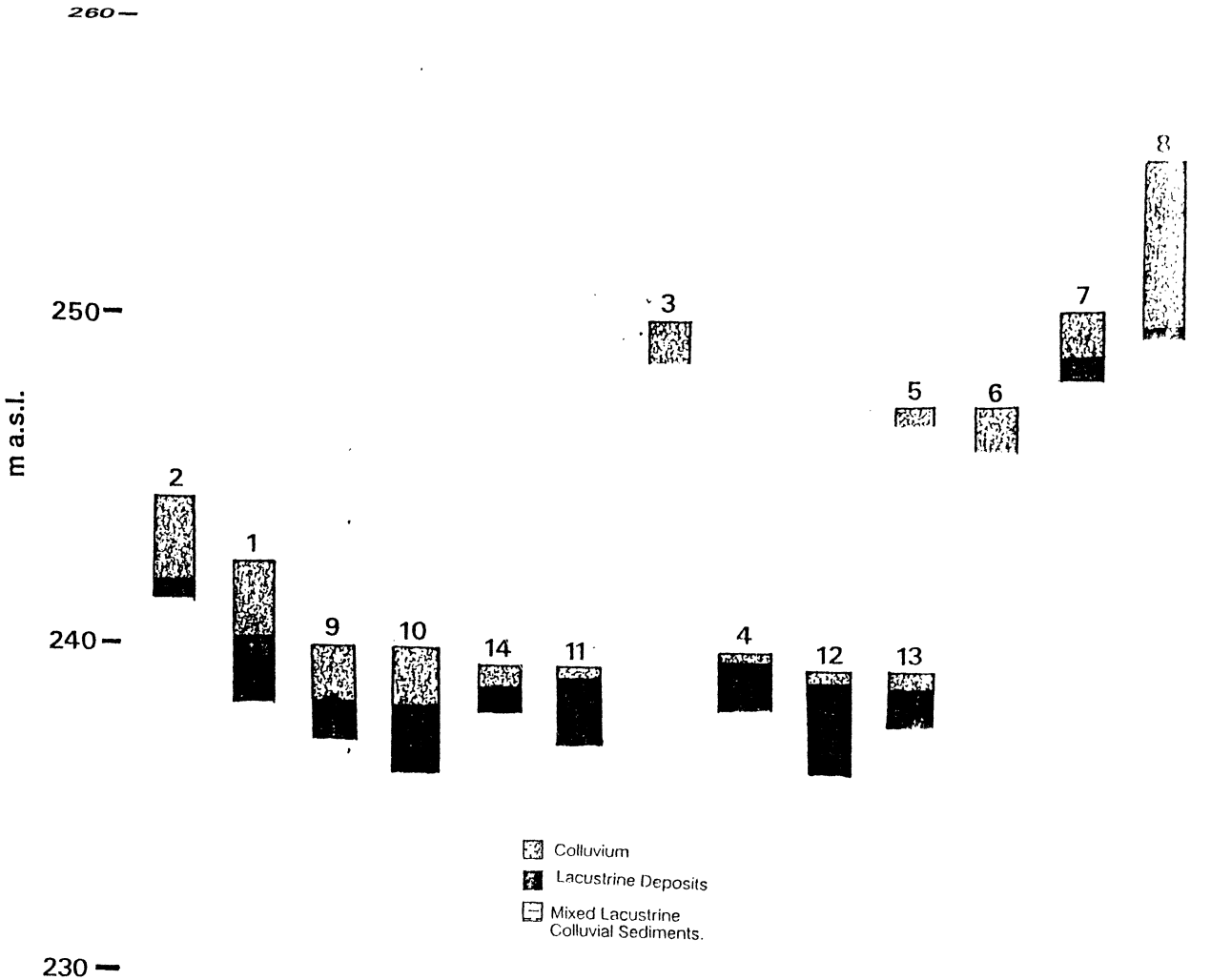

Figure 7.17 Simplified stratigraphies of the sections in La Cienaga Embayment in their relative heights and positions.

staining and abundant fine charcoal fragments. At many sites distinct vesicular layering is observed. At LC1, LC2 and LC15 shells were found in the upper 80 cm of colluvial sediment. Shells of this type were also noted in the marshy areas around the lake and suggests that some of **Unit II** was deposited into a marshy or shallow lake environment.

The thickness of **Unit II** varies from site to site and is greatest at those located near the sides of the embayment. Relatively little colluvial sediment has accumulated at LC4, LC11, LC12, LC13 and LC14 which are situated in the central part of the embayment.

LC16 is located on the southern slope of 'La Ciénaga' at an elevation of 2,053 m a.s.l., here a large arroyo emanating from the slopes to the south has exposed a thick sequences of colluvium. A 5.6 m section profile was logged and sampled. These sediments consist of coarse colluvium with large boulders found at the base of the section.

X was measured at 4 sites in this part of the basin LC1, LC2, LC10, and LC14 (Fig. 7.18). The results from this analysis clearly show that the lacustrine sediments have much lower *X* levels (3-4 E-06 kg m^{-3}) than the overlying colluvial material (50-90 E-06 kg m^{-3}). As discussed earlier, however, it is possible that those sediments which have been termed colluvium could have been deposited into the lake, but the large quantities of sediment that have been removed from the slope into the basin may have diluted the lacustrine sediments sufficiently to make their recognition difficult.

By placing all the sections in their relative heights above sea-level (Fig. 7.17) it is possible to determine how the main stratigraphic units relate to one another. With the exception of LC3, LC5, LC6, LC7, and LC8 all these site are situated between 2,039.5 m and 2,044.5 m a.s.l. and consist of varying thicknesses of lacustrine material overlain by colluvial sediments (Fig. 7.x). Five sites LC3, LC5, LC6, LC7, and LC8 are situated between 2,047.5 m and 2,055 m a.s.l. The stratigraphy at LC3 consists entirely of colluvium while at LC5 and LC6 the sediments are entirely lacustrine. The sites of LC7

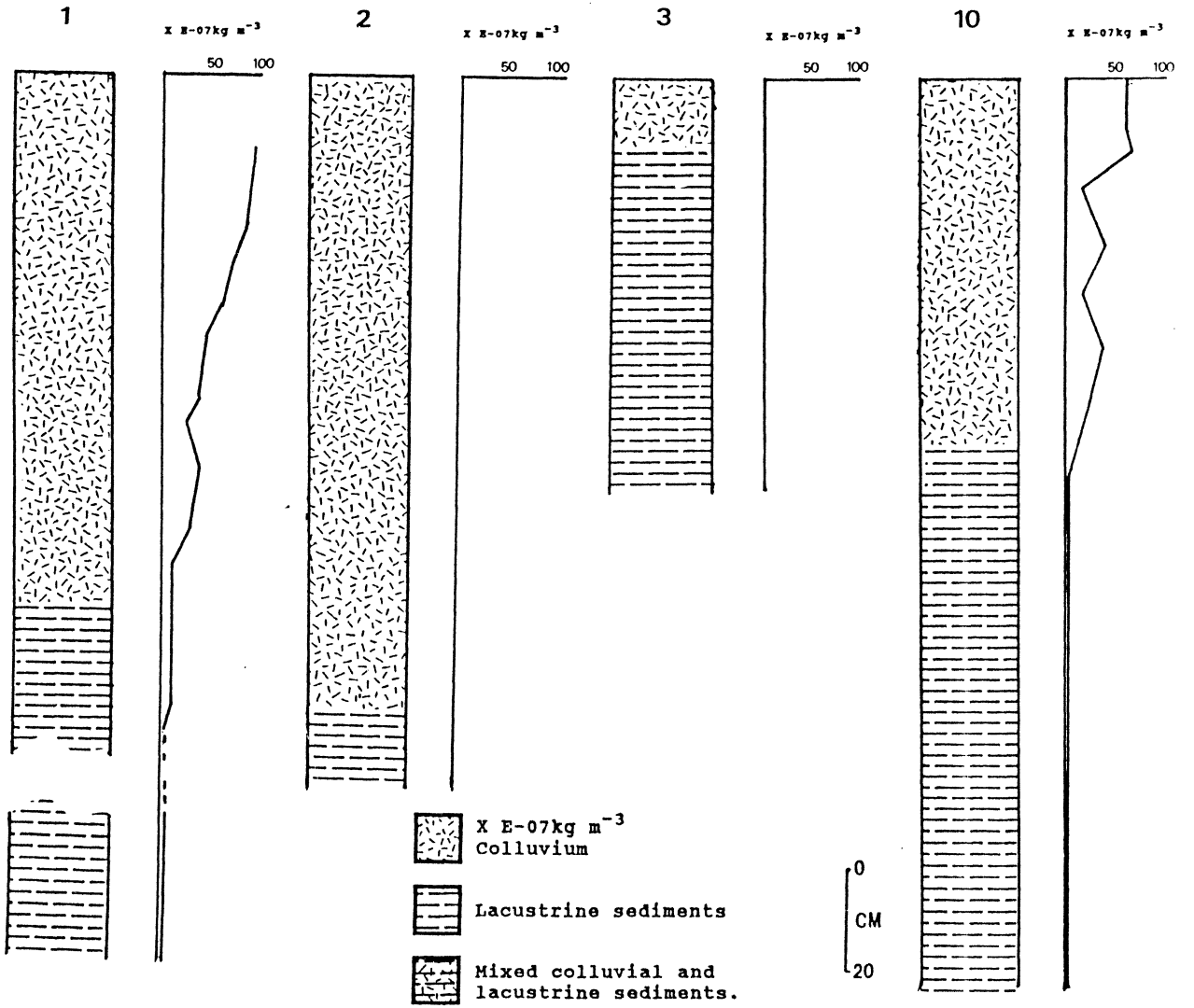

Figure 7.18 Selected stratigraphies from La Cienaga Embayment showing *X* where available.

and LC8 are located at the eastern extreme of 'La Ciénaga', and consist of lacustrine deposits overlain by colluvial material (Plate 7.4). The presence of lacustrine deposits at LC8 clearly indicates that the lake has been at a level of at least 2,050 m a.s.l., at least 13.5 m higher than present, in the past. However, as there are no dates associated with these deposits, it is impossible to determine when this high stand was. It is possible that these deposits accumulated at the same time as the lacustrine material found at high levels in the areas of Tzentzéncuaro and Pátzcuaro, but without further analyses of the sediment such statements can only be speculative.

It is evident from those sites situated close to the basin walls that considerable quantities of material have been transported from the slopes into the basin. For the most, these form high angled fan deposits which are draped over the lower slopes of the mountains. Many of the arroyos which incise these deposits expose quite considerable thicknesses of colluvium (in excess of 10 m in some places). Deposition of these sediments may have resulted in considerable changes in the shoreline by forcing the lake away from the walls of the basin. Sediment thickness diminishes with distance from the side walls of the basin and only a limited amount of slope material has accumulated in the main part of the basin, especially in the central area. This is possibly a reflection of the sediment transport system operating in this basin, the almost flat profile of the basin floor limiting transport of material towards the central area.

7.2.7 Ihuatzio

Ihuatzio is situated on the northern side of the southern limb of the lake (Fig. 7.1). To the east of this town is a small N-S orientated valley surrounded by steep hills on three sides. In the upper reaches of the basin a small area of badlands has developed (Plate 7.5) and the basin itself is incised by a major arroyo which exposes a thick sequence of colluvial material. The floor of this valley is quite steep although no features which might indicate former shore lines are apparent.

Two sites were excavated in this small area (Fig 7.15). In both cases only

colluvial material was found. At Ihuatzio 1, a 4.2 m section was excavated in the upper part of the valley at an elevation of 2,048 m a.s.l. The sediments exposed were similar throughout, consisting of vesicular, fine silty clay material with a small quantity of fine charcoal dispersed throughout. Additional analysis of the upper 2.2 m confirms the consistency of these deposits. X and X_{fd} are both high, but show little variation while the organic matter content varies between 9 and 10% except in the upper 10 cm where it increases to 17%. Like other colluvial deposits analysed from around the Pátzcuaro Basin, carbonate content is minimal being no greater than 2%.

7.2.8.Summary of the Southern Basin

A number of distinct breaks of slope can be identified in the Southern Basin (see Table 7.2 for elevations). Slope breaks between 2,048 and 2,049 m a.s.l. and 2,044-2,045 m a.s.l. occur in more than one of the embayments and are interpreted as representing former shorelines.

Seven embayments in the Southern Basin were investigated. With the exception of SFU, the stratigraphy at all the embayments generally consists of lacustrine sediments overlain by colluvium. The distribution of lacustrine material clearly indicates that the lake was formerly much more extensive than at present with lacustrine sediments being found as high as 13 m above than the present lake.

The colluvial sediments that cap these lacustrine sediments display remarkable similarity throughout this part of the basin. It is evident that this material has been transported from the surrounding slopes into the basin floor, and in many instances form large alluvial/colluvial fans, and colluvial deposits are generally thickest near the sediment source area. The thickness of the deposits does depend on the size of the sediment source area, In the area around Tzentzéncuaro, for example there is only a thin layer of colluvium because the sediment source area is limited.

Tzentzencuaro	2,044.5
	2,040.0
Pátzcuaro	2,049.0
	2,044.0
La Ciénaga de	2,055.0
Tzurumutaro	2,052.0
	2,048.0
	2,048.0
	2,045.0
	2,042.0
Quiroga	2,055.0
	2,049.0
San Jeronimo	2,043.0
Purenchécuaro	2,040.5

Table 7.2

Elevations of the major breaks of slope
in the Basin of Pátzcuaro

7.3 THE CENTRAL BASIN

In the central part of the basin, Lake Pátzcuaro is surrounded by steep slopes and consequently, there are few sites suitable for investigation. Much of the sediment eroded from the slopes has formed high angled fans made of colluvial material which in the past may have prograded into the lake. Attempts were made to expose sections in a number of areas of colluvial fill; however, in most cases the coarse nature of the sediment made it impossible for the auger to enter into the sediment. Apart form a single site at Napizaro (Fig. 7.1) only San Pedro Cucuchuchu was studied in any detail.

7.3.1 San Pedro Cucuchuchu (SPC)

Situated on the eastern shore of the lake, San Pedro Cucuchuchu (SPC) is overlooked by the Yacatas of Ihuatzio. This archaeological site was of some importance for a short time during the 14th century, but by the time of the Conquest was primarily an armed fortress (Warren, 1981). This town, together with Ihuatzio, sent 40 banners to war in the immediate pre-conquest period. Based on this information, the population of the two towns is estimated to have been between 4,000 and 5,000 (Warren, 1971), considerably higher than the present population of approximately 3,000.

Ten sections were investigated in this small basin (Fig. 7.19). The most varied stratigraphy was observed at a well, located at SPC8, which exposed an 8.2 m section. Although it was not possible to sample the sediments, based on colour it was possible to distinguish three main stratigraphical units. **Unit I**, consists of 1.4 m of white sediment. Without samples, however, it is not possible to conclude whether this sediment is white volcanic ash or diatomite. This is overlain by 0.9 m of black clay: **Unit II. Unit III**, consists of 5.75 m of reddish brown colluvium.

All other sites investigated in the SPC embayment consisted of colluvial sediments. The colluvium show similar characteristics, being vesicular and rich in fine charcoal fragments. The texture of these sediments is variable, however, being coarser

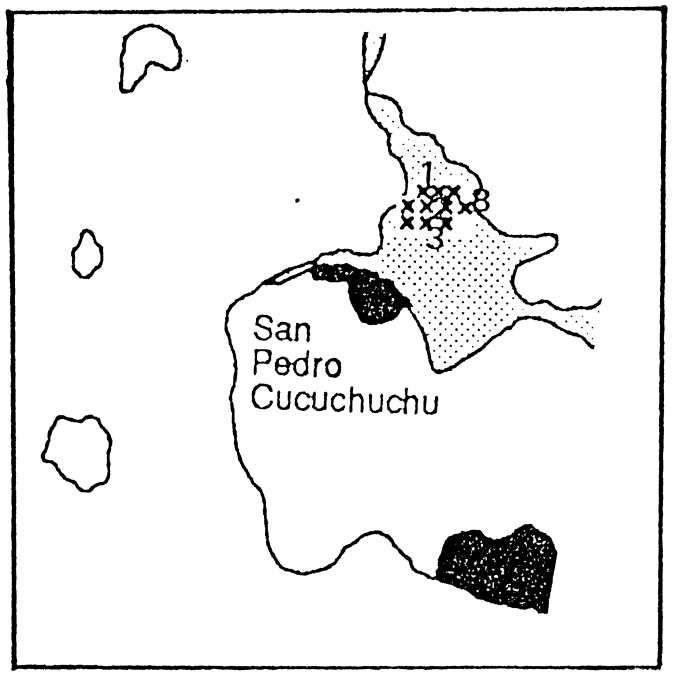

Figure 7.19 Location of the sites investigated in the SPC embayment.

at those sites located nearer to the sediment source area.

A 350 m long road cut, the top of which is 7.5 m above the 1989 lake level, was logged and sampled at three locations (Fig. 7.20; Plate 7.6). The road cut exposed a maximum of 1.65 m of sediment, and further samples were collected by using an auger allowing a total of 4.75 m of sediment to be investigated at SPC1 (Fig. 7.20). Based on these sections it is possible to divide **Unit III** into three sub-units.

Unit III(a) consists of a 3.45 m unit of yellowish-brown colluvium which coarsens up profile. This unit is characterised by high *X* of between 600 and 900 E-06 kg m^{-3}. At SPC2 and SPC3, the colluvium is overlain by similar sediment rich in gastropod shells. A date of 740±100 years B.P (OaX-2825) was obtained on shells taken from this layer. These shells are similar to those currently found in the lake where tule reeds grow and where the depth of water is less than 0.5 m. As these shells were taken from approximately 1.55 m from the top of the road cut this indicates that at about 770 years ago the lake stood at a level of between 2,042 and 2,043 m a.s.l. Overlying this shell rich unit are well-laminated silty clays, **Unit IIIb**. These are similar in colour to the underlying colluvium but are considerably finer and show a slight fining up the sequence suggesting deposition under increasing water depths. *X* remains high throughout this unit (700 to 900 E-06 kg m^{-3}) indicating that these sediments contain a considerable amount of sediment eroded from the slopes.

The upper colluvial unit, **Unit IIIc**, is similar to the lower one, being low in organic matter and carbonate content. It has a very blocky structure and is deeply fissured. Small charcoal fragments were found throughout.

7.3.2 Napizaro

Napizaro is situated on the western shore of Lake Pátzcuaro. A single borehole was augered approximately 300 m from the lake shore. Two stratigraphical units were observed. **Unit I**, consists of <1.12 m of organic rich, black, lacustrine muds interceded with fine gravels. This is overlain by 0.74 m of coarse, vesicular, charcoal-rich colluvium.

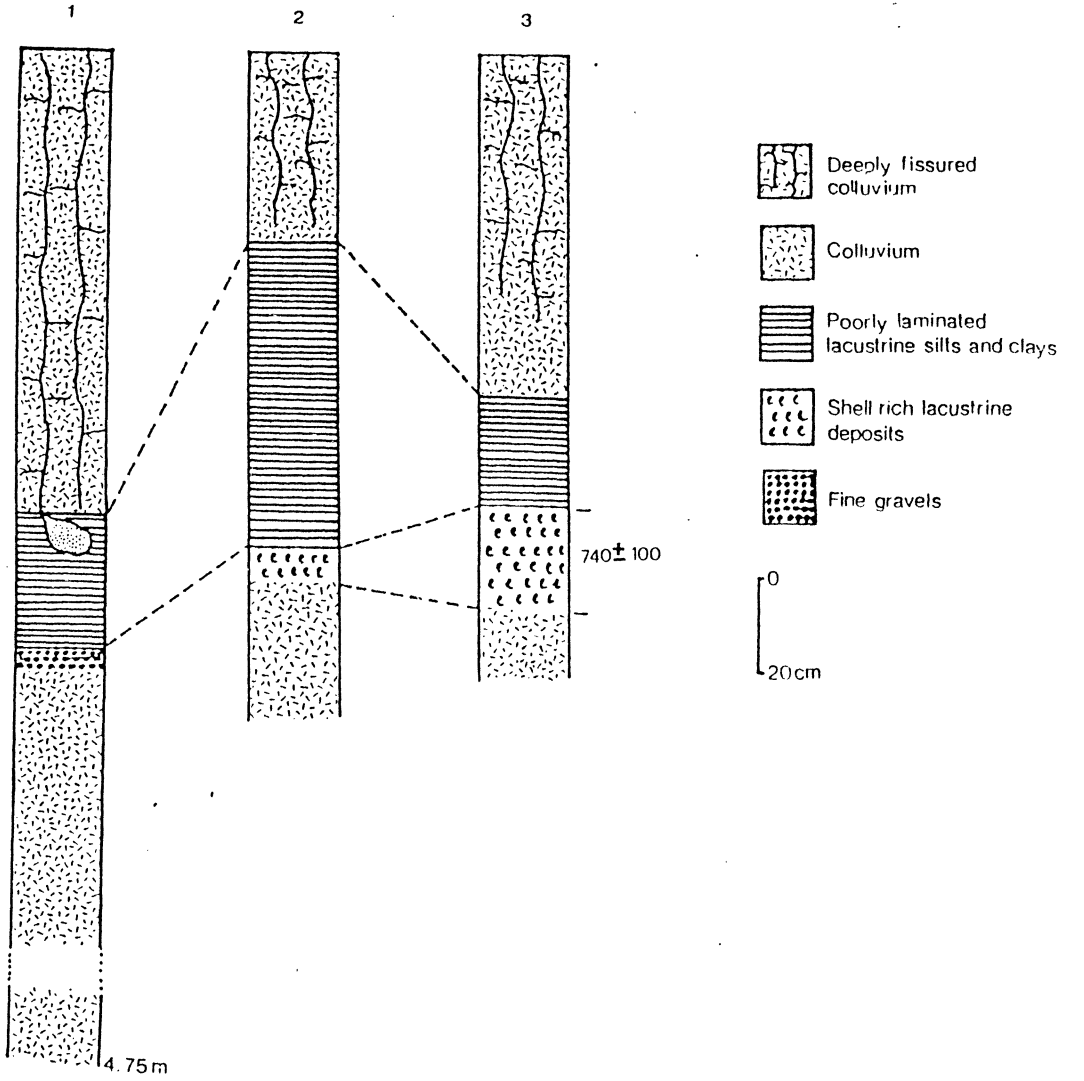

Figure 7.20 Selected stratigraphical sections from the SPC embayment.

When viewed from a distance it is apparent that this forms the distal end of a large alluvial/colluvial fan emanating from the sierras to the west and has prograded into the lake.

7.3.3 Summary of the Central Basin

The slopes that border the central basin of Lake Pátzcuaro are draped by relatively high angled alluvial/colluvial fans. It is not possible to determine the thickness of these deposits, although in the upper part of the SPC embayment over 15 m of sediment has been exposed by gullying. The date of 740±100 years B.P. indicated that there has been 1.55 m of sediment accumulation at this site since this period. Assuming a constant rate of deposition colluvium began to accumulate, in this embayment, approximately 2,500-2,800 years ago. The *X* readings on the colluvia are high and indicate that they are derived from slope material.

The sediments exposed in the SPC embayment indicate that Lake Pátzcuaro has been considerably more extensive and higher in the past. During the more recent high stand approximately 740 years ago the lake was about 6.5 m higher than at present

7.4 THE NORTHERN BASIN

The northern part of Lake Pátzcuaro is surrounded by steep, deeply gullied mountains. Based on aerial photographs and topographic maps it is possible to distinguish a dense network of gullies (Fig. 2.4). Although it is not possible to determine their age some of the larger ones are mentioned in a number of early Hispanic documents (Brand, 1951) and shown on maps from this period (Gorenstein and Pollard, 1983). It is evident that this part of the basin, in particular the north-eastern sector, has suffered the most severe erosion. The soil cover has been removed from vast tracts of land exposing large areas of bedrock and rendering much of the land in this region unsuitable for farming of any kind.

A number of very deep gullies that originate in the mountains behind Quiroga

have exposed great thickness of colluvial material of up to 25 m. Unfortunately, it was not possible to log these sections in any detail. The great thickness of sediment that flanks the mountains in this part of the basin made it difficult to find sites that exposed anything other than colluvium, which provides only a limited amount of information on this part of the basin. A total of five sites were investigated and these will be described in an anti-clockwise manner from Tzintzuntzan to San Jerónimo Purenchécuaro.

7.4.1 Tzintzuntzan

Tzintzuntzan is located on the southern shore of the northern limb of the lake situated between the mountains of *Tariaqueri* and *Yahuarato* (Fig. 7.1). Little remains of the former Prehispanic City which at the time of the Conquest numbered some 35,000 inhabitants, and today it is little more than a village with a population of less than 3,000. Based on aerial photographs and field observations, it is apparent that there is an intricate system of terraces cut into the hills surrounding the town. Most of these have been abandoned and subsequent erosion has made their form difficult to distinguish (Plates 7.7 and 7.8). It has been suggested that these terraces were probably constructed in prehispanic times (Donkin, 1979) and were probably under intense cultivation when the Spanish arrived. A painting of one of the first Spanish monks to arrive in this area, clearly depicts the terraces of Mount *Tariaqueri* in the background. It also shows the use of dams in the gullies to store water which can was then diverted on to the terraces in a simple form of irrigation (Nuñez, pers. comm. 1989).

Sediments were investigated at two sites situated immediately adjacent to one another. An 8.4 m section had been exposed by the excavation of a well situated in the centre of town (Fig. 7.1 and 7.21). At the base of the section 45 cm of greyish lacustrine clays were found. This is overlain by 7.95 m of colluvium. This section is located at an elevation of 2,047 m a.s.l. and approximately 500 m from the lake. The presence of lacustrine sediments at this site indicates that in the past the lake stood at a much higher

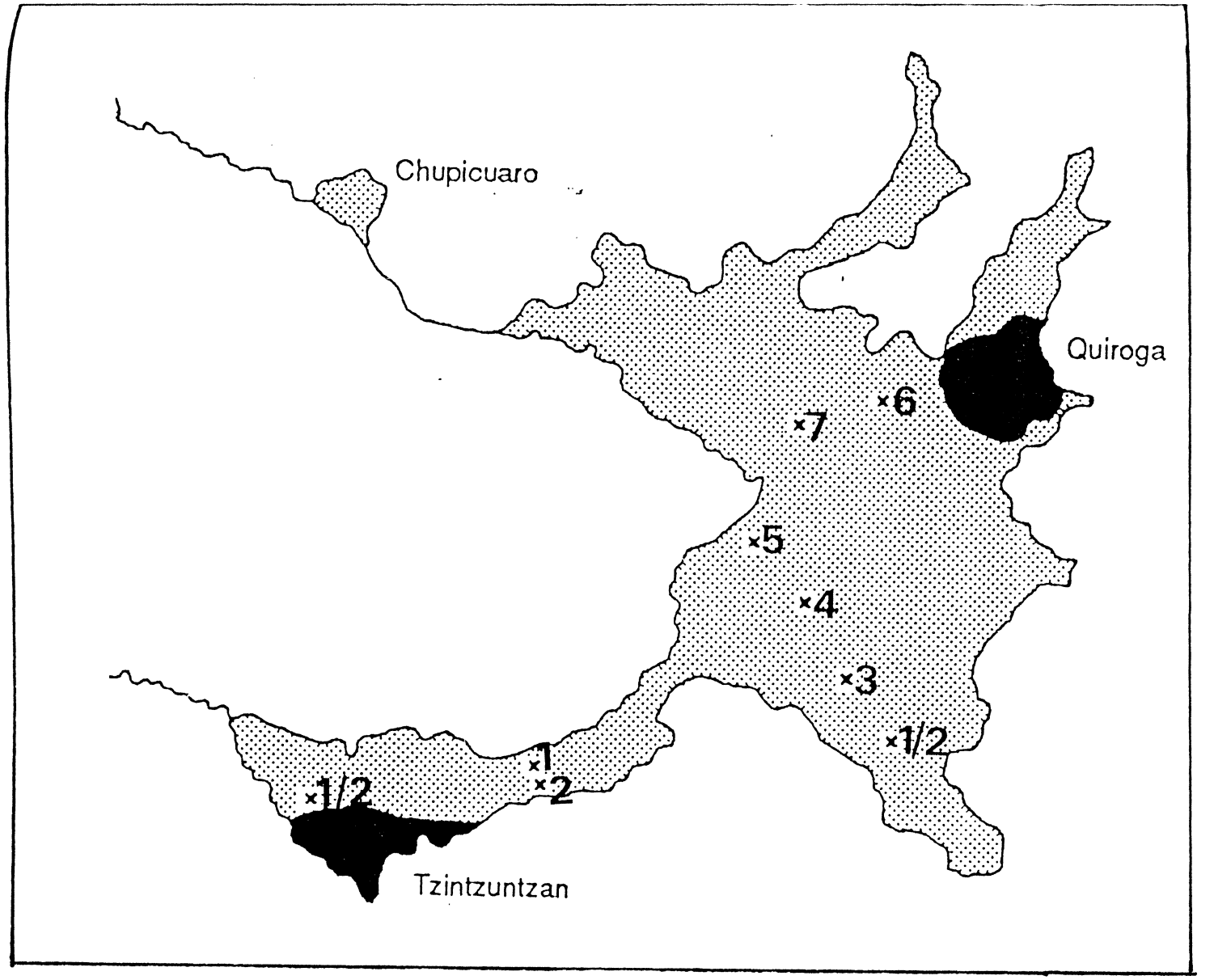

Figure 7.21 Location of the sites investigated at Tzintzuntzan, Tzocorio and Quiroga.

elevation and more extensive than at present.

A second site 100 m to the east exposed 3.36 m of colluvial sediment. This is made up of gritty-silt which is highly vesicular in character and has a large amount of fine charcoal fragments dispersed throughout. A large amount of ceramic material was removed from this section at 1.04 m. The ceramic type was identical to that presently used in this area and suggests that it is at least Post-Hispanic in age and more probably much younger. In view of this, it would appear that there has been quite a considerable amount of sediment accumulation at this site in recent years.

7.4.2 Tzocurio

The small settlement of Tzocurio is situated approximately 1 km to the east of Tzintzuntzan. This site stands at the foot of the mountain of *Yahuarato* and much of the vegetation from the lower slopes has been removed. Draping the lower slopes of the mountain are alluvial/colluvial fans which have prograded into the lake. Two sites were excavated in this part of the basin, one close to the lake shore, and a second approximately 300 m up slope (Fig. 7.21). In both cases only a single unit of colluvium was sampled; the two sections being 2.15 m and 1.98 m deep respectively. The colluvium is similar to that exposed in other parts of the basin being a structureless, dark reddy brown, silty-clay, rich in charcoal fragments. It is evident that much of this sediment was deposited into the lake in the past. The site nearest the lake shore has only recently been exposed although the stratigraphy does not indicate that these sediments are lacustrine in nature.

7.4.3 Quiroga (Q)

Bordering the eastern part of the northern basin is a large area of gently sloping colluvial, alluvial and lacustrine deposits which are currently under intense cultivation. This colluvial plain is surrounded by steep deeply gullied mountains. A number of these gullies incise the upper part of the colluvial sediments although do not remain deeply

entrenched for much distance into the almost flat deposits. It is quite noticeable that many of these features terminate at a similar position and may well have discharged into the lake when the level of the lake was higher. There is evidence that these features have not formed recently and a number of documents make reference to these forms in the early Hispanic period (Brand, 1951; Gorenstein and Pollard, 1983).

The slope profile of the Quiroga embayment displays two possible breaks of slope at 2.055 and 2.049 m a.s.l. (Fig. 7.22). Six sites were logged and sampled in this part of the basin, four forming a SE-NW transect from the upper part of the basin down to the shore of the lake (Fig. 7.21) while two further sites were excavated in the sediments to the SW of the town of Quiroga. As in other parts of the basin, the stratigraphy of this region can be broadly divided into colluvial and lacustrine sediments. The logged sections from sites Q1 to Q4 are shown in their relative heights and positions in Figure 7.22. Although colluvial sediments are seen at all the sites only at Q1 and Q4 are lacustrine deposits found. In the case of Q1 a 5.4 m section was exposed by a gully and extended to 6.3 m by augering (Fig. 7.23). This site is situated 1.4 km from the lake at an elevation of approximately 2,055 m a.s.l. At the base of the section is 0.35 m of lacustrine sediments with occasional fine gravels. This is overlain by 5.95 m of colluvium. The presence of lacustrine sediments at this site clearly indicates that the lake has been both more extensive and has stood at a higher elevation in the past. At Q4, situated close to the present lake shore, 42 cm of lacustrine sediments are overlain by 26 cm of colluvium with an abrupt boundary between the two sediment types. The stratigraphy at the remaining sites in the basin comprises reddish-brown colluvium, rich in charcoal fragments and with occasional vesicular layers. At all other sites investigated in the Quiroga embayment the stratigraphy consists of charcoal rich colluvium.

7.4.4 San Jerónimo Purenchécuaro

San Jerónimo Purenchécuaro situated on the northern shore of Lake Pátzcuaro was an important Prehispanic settlement in the basin. The mountains bordering the lake

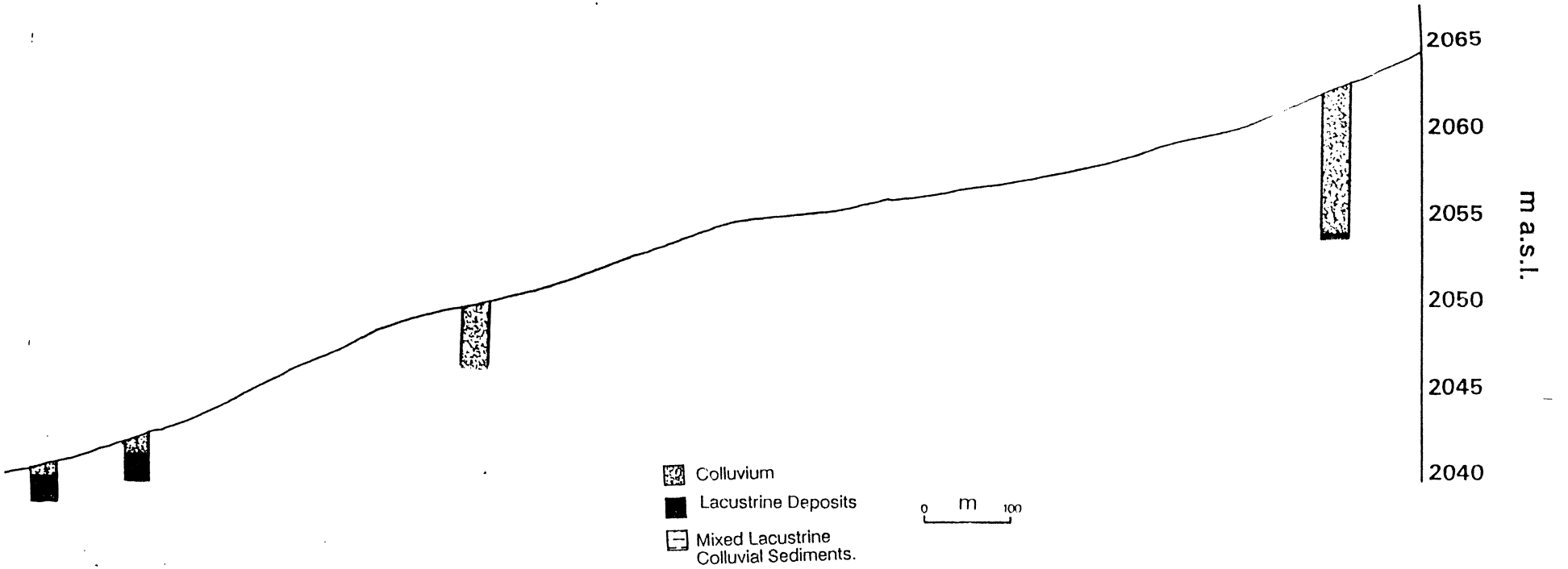

Figure 7.22 The slope profile from the Quiroga embayment showing simplified stratigraphies for selected sites.

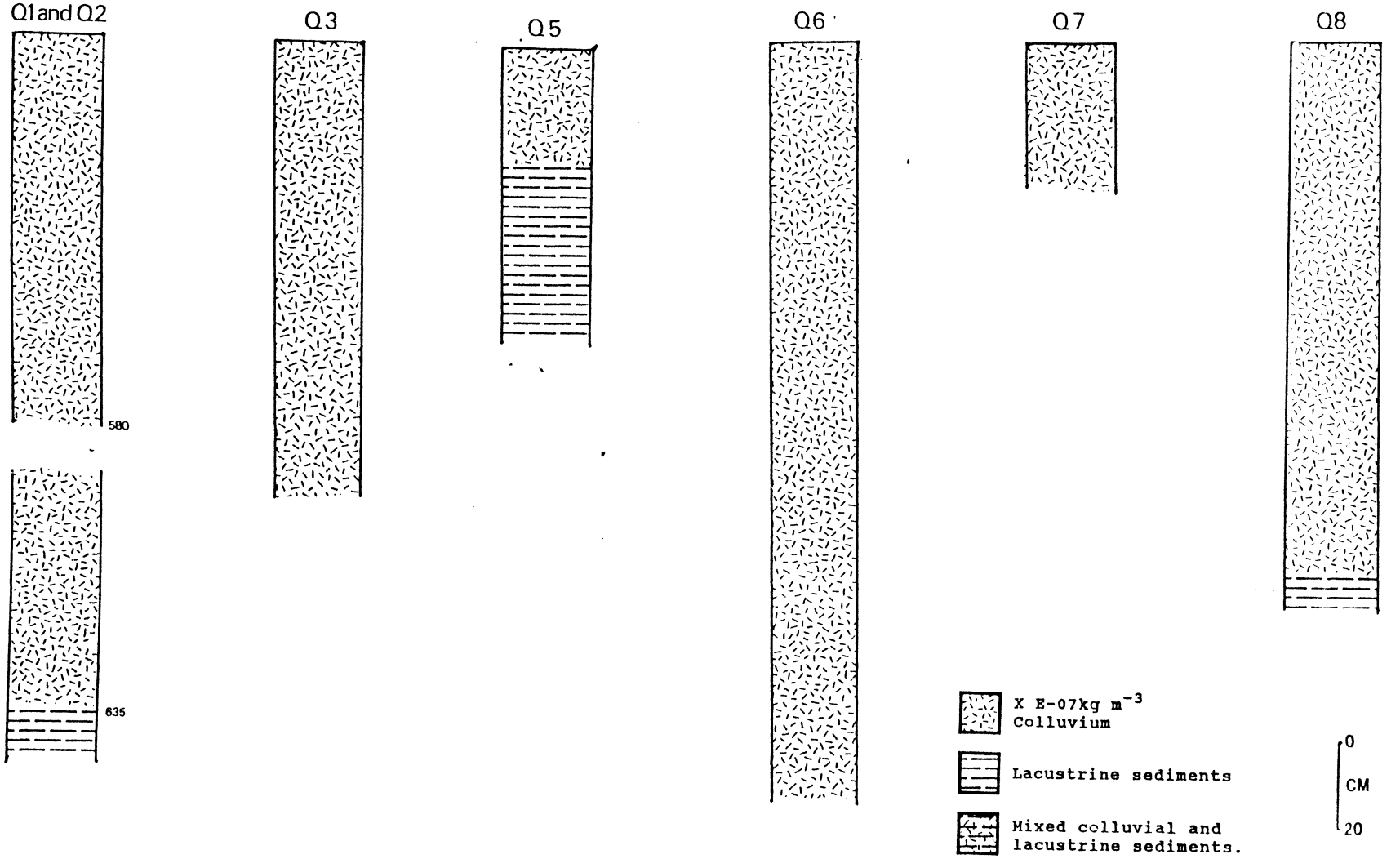

Figure 7.23 Stratigraphies of sites investigated in the Quiroga embayment.

rise steeply behind the town. Because of the steepness of the slopes, local farmers have created a series of broad terraces. A number of deep arroyos incise these slopes exposing thick colluvial deposits. Four profiles were logged and sampled in one of the main arroyos that emanates from the sierras and discharges into the lake (Fig. 7.24). All of these profiles were situated between 2,040 and 2,045 m a.s.l. This site is situated approximately 0.5 km from the site investigated by Street-Perrott et al. (1989).

The slope profile constructed from the topographic maps for this part of the basin confirms the high angle of the deposits in this part of the basin. Two distinct breaks of slope can be distinguished-the upper at an elevation of 2,048.5 m and the lower at 2,043 m (Fig. 7.25).

Two distinct stratigraphical units were identified at the four sites exposed. The oldest unit, **Unit I**, consists of dark organic rich lacustrine sediments <33 cm thick. This is overlain by a thick unit of colluvium, **Unit II**. At SJP4 4.10 m of colluvium were exposed. These sediments consist of brownish silty clay. Fine charcoal is dispersed throughout this unit and the sediments also exhibit a degree of iron staining. Occasional bands of fine gravels are interceded within the colluvium (Fig. 7.26).

7.4.5 Summary of the Northern Basin.

As with the central and southern part of the catchment the stratigraphy of the northern embayments can be divided into lacustrine and colluvial sediments. The evidence from the four main sites clearly indicates that Lake Pátzcuaro was once considerably more extensive than at present and stood at an elevation of at least 2,050 m a.s.l. A huge thikness of sediment has infilled these embayments which in the areas around Quiroga is in excess of 25 m thick and clearly reflects the extent of degradation in this part of the basin. While this may reflect the greater disturbance it should be noted that there is a much greater sediment source area and that the slopes in this part of the basin are very steep. This may result in this part of the basin being more susceptible to erosion.

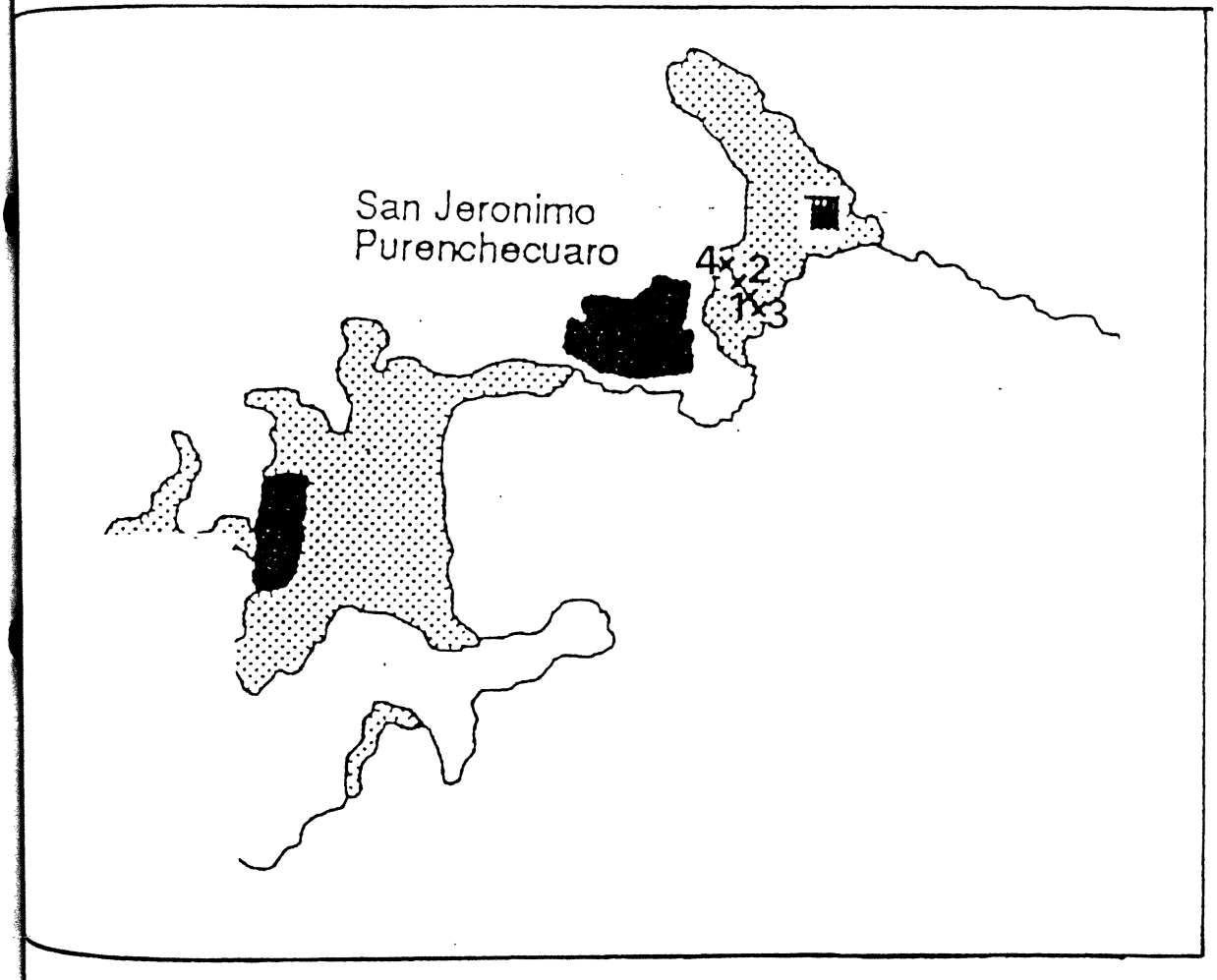

Figure 7.24 Location of the sites investigated in the SPJ embayment.

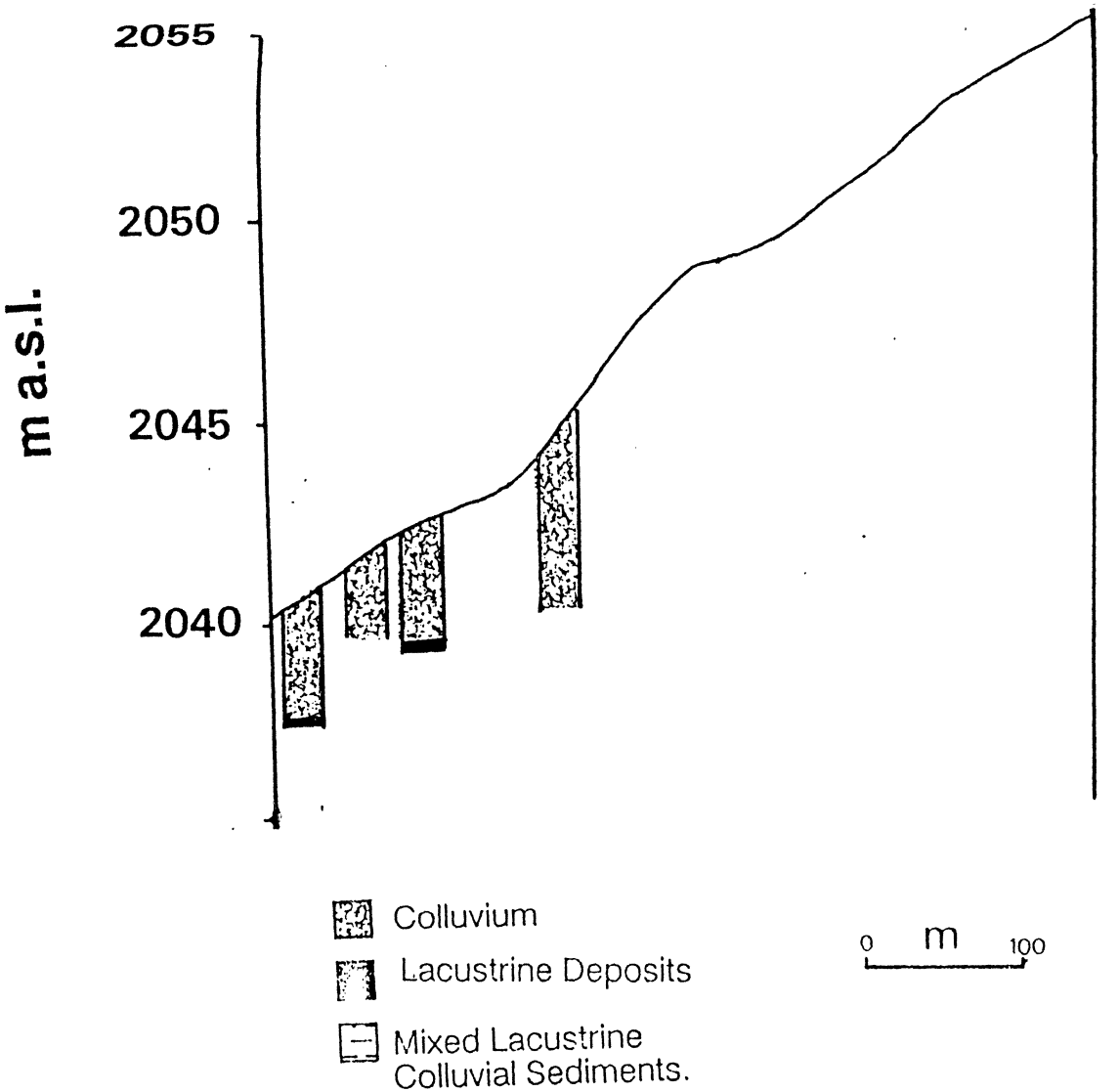

Figure 7.25 Slope profile from the SPJ embayment showing simplified stratigraphies.

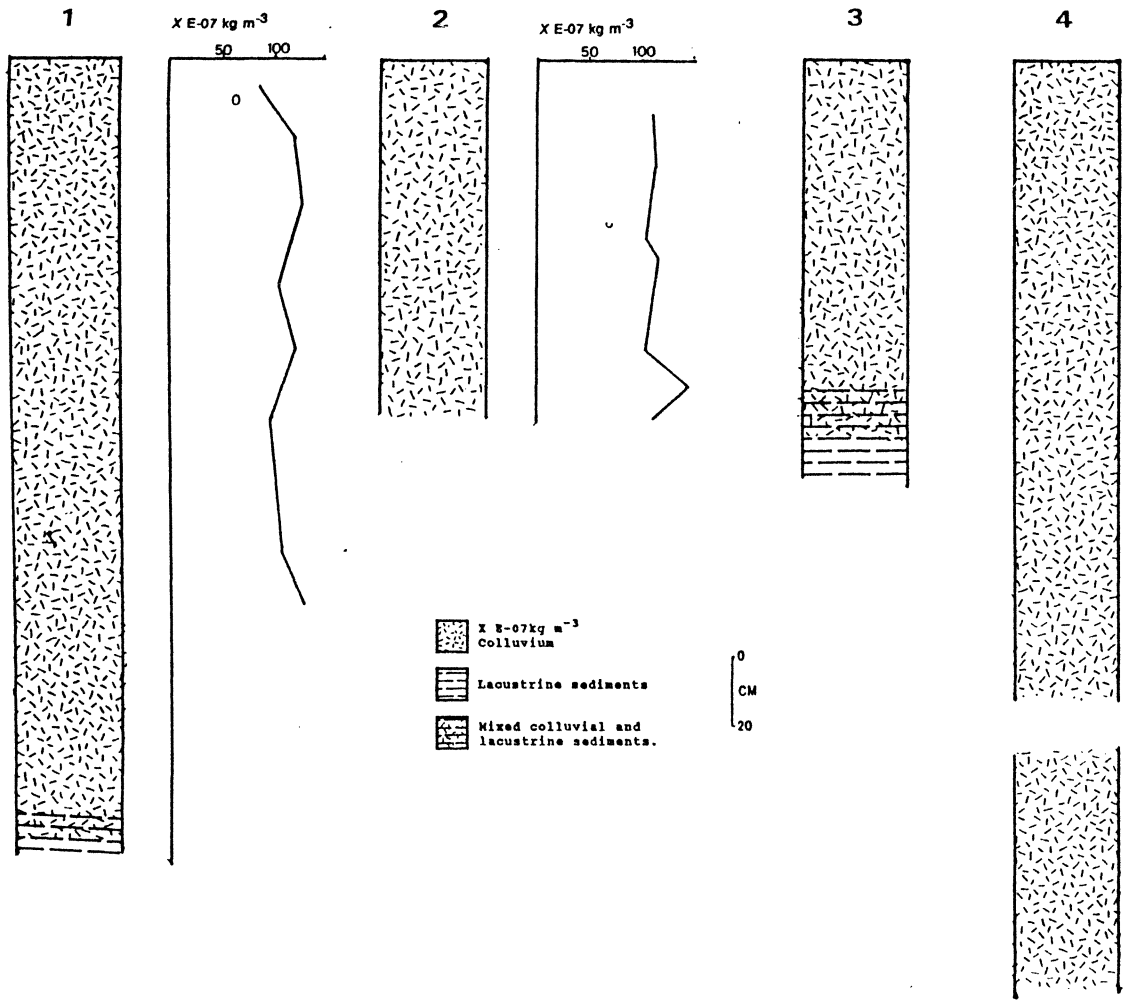

Figure 7.26 Stratigraphies of the SPJ embayment showing *X* measurements where available.

Evidence of former shorelines are found at both SPC and Quiroga. At both sites a distinct break is noted at 2,049 m a.s.l. and may relate to the same shoreline feature.

7.5 SUMMARY OF THE TERRESTRIAL RECORD

Unlike Street-Perrott et al.(1989) it has not been possible to identify different erosional episodes based on the terrestrial record, the main reasons for this being the lack of suitable stratigraphic sections within the catchment where different sedimentological units could be identified. This has been further hindered by the relatively few ^{14}C dates which have been obtained on these sediments. Despite these drawbacks it is possible to draw a number of conclusions from the available data.

Firstly, it would appear that the thickness of colluvium that has accumulated around the lake is greater in the northern part of the catchment than the south. This is especially true in the areas around Quiroga where in excess of 25 m of sediment are exposed in some places. While this implies that there has been a greater degree of degradation in the northern part of the catchment it is possible that differences in the thickness of colluvial sediments reflects the steepness of the slope, and the size of the sediment source areas, both of which are greater in the northern part of the catchment.

These colluvial deposits investigated are similar around the entire basin although they tend to be much coarser closer to the sediment source area. These sediments are frequently vesicular and indicate sheet wash was active during their deposition. Fine charcoal fragments are dispersed through much of the colluvium which suggests that burning was widespread throughout the basin during the build up of these sediments. As this area is not susceptible to natural fires it is likely that burning was deliberate and was probably associated with slash and burn farming techniques. This suggests that much of this colluvium has accumulated during the period of settlement within the Lake Pátzcuaro Basin.

^{14}C dates from this investigation and that of Street-Perrott et al. (1989) indicate that there has been a considerble build up of colluvium in the last few centuries.

Unfortunately as 14C dates within this time span often have large errors it is not possible to conclude whether this sediment is Pre or Posthispanic in age.

There is a considerable amount of evidence to indicate that the lake has been more extensive and much higher in the past, inundating many of the areas now filled with sediment. Lacustrine deposits were found considerable distances from the lake and as high as 13 m above the present lake level. The relationship between the lacustrine and overlying colluvial deposits indicates that there was quite an abrupt change in stratigraphy and it is possible that the onset of erosion was quite sudden and catastrophic. Unfortunately, there are no dates for the boundary of these two units to determine when sediment began accumulating in these embayments. A date of 2,300 B.P. at the base of Street-Perrott's section does, however, provide a minimum date for the onset of deposition of colluvial material within the catchment.

Evidence of former shore lines is scant. A number of breaks of slope can be identified around the basin (see table 7.2) of which three are found in more than one part of the basin. The highest of these is found at 2,055 m a.s.l., more than 18 m above the present lake level and were noted in both the north and south part of the basin. At four different places in the catchment, Pátzcuaro, La Ciénaga, Quiroga and SJP, breaks of slope between 2,048 and 2,048 m a.s.l. are noted. A further series of slope breaks between 2,044 and 2,045 m a.s.l. were observed at Tzentzéncuaro, Pátzcuaro and La Ciénaga. The presence of these features in different parts of the basin suggests that these features are relict shorelines. The date of these high stands can not be determined, however, the two highest features are older than 660 years as at no time during this period has the lake been above about 2,045 m a.s.l. Only the lowest of these shorelines could have formed in this time. Neither is it possible to determine whether these highstands relected wetter climates or have formed as a result of tectonism within the catchment.

CHAPTER EIGHT: PHYSICAL PROPERTIES OF THE LAKE SEDIMENT RECORD.

8.1 INTRODUCTION

A total of twenty-one (lake-sediment) cores from Lake Pátzcuaro was investigated (Fig. 8.1). The stratigraphy, L.O.I., calcimetry, magnetic susceptibility (χ), bulk density and moisture content were analysed on all but one of these cores. In addition χ_{fd}, grain size and sediment chemistry were determined on selected cores. Analyses can be divided into those techniques to determine physical properties and those to determine chemical properties of the cores. Due to the large quantity of data collected the results and discussion of the lacustrine record will be given in two chapters. The physical properties as well as the results of the $CaCO_3$ analysis will be presented in this chapter. Chapter Nine will cover the results of the sediment chemistry analysis.

Based on the initial analyses of the cores, it was apparent that the lake can be divided into three main areas; the Southern, Central and Northern Basins. The salient features of the stratigraphy in each basin will be discussed below. Only selected cores will be described in detail in this chapter, Detailed written descriptions are available in Appendix B.

8.2 THE SOUTHERN BASIN

Six cores were collected from the southern part of the basin: LP1, LP2, LP3, LP4, LP11 and LP12 (Figs. 8.1 and 8.2). The preliminary analyses of these cores indicated that LP11 provided the longest record of sediment accumulation in this part of the lake, and in addition contained abundant material suitable for dating. Accordingly, LP11 is taken to be the representative core for the southern part of the lake.

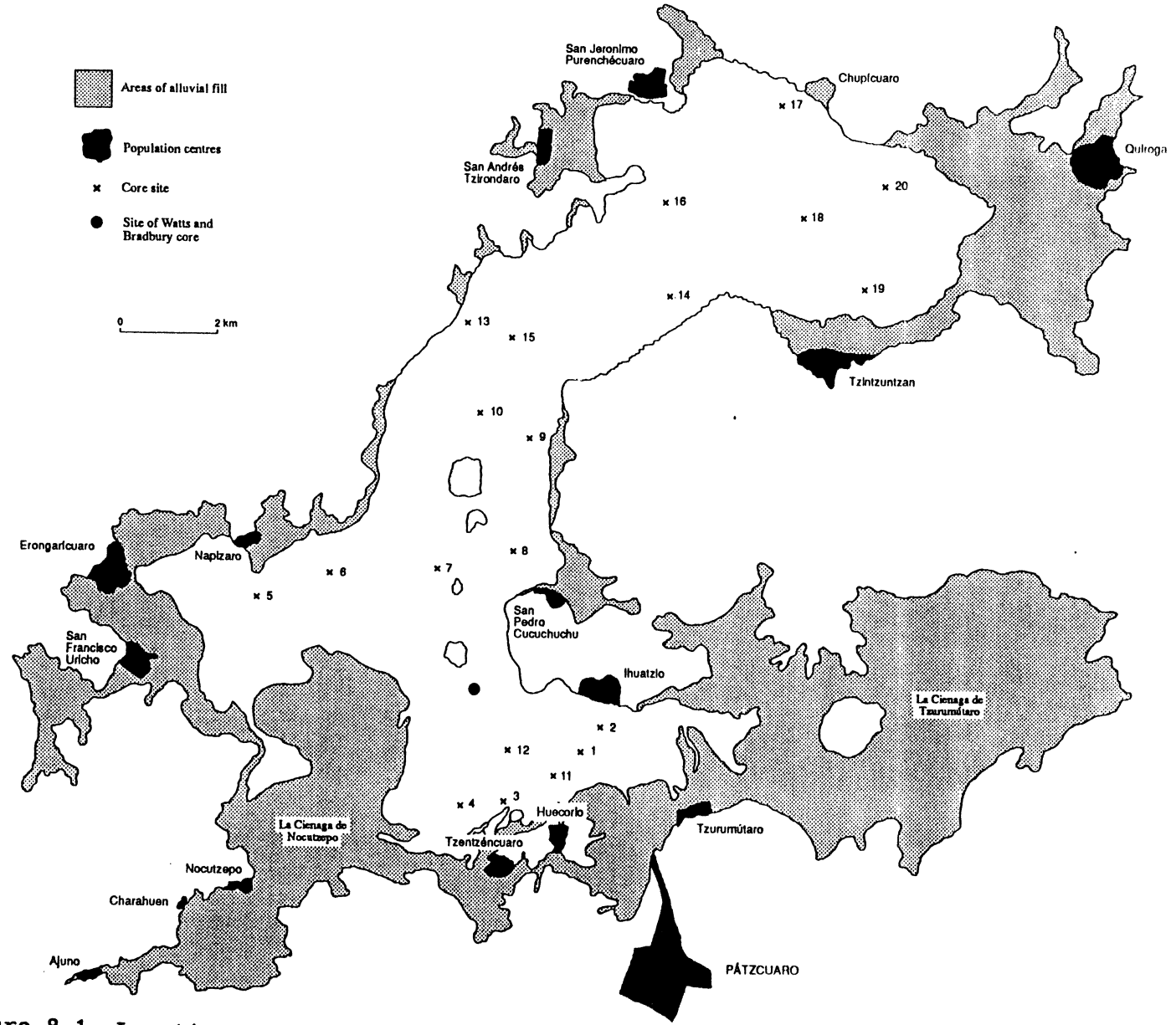

Figure 8.1. Location of the cores used in this investigation.

8.2.1 Stratigraphy

LP11 was collected approximately 700 m from the lake shore, directly north of the town of Huecorio (Fig. 8.1). A 1.89 cm core was recovered (at this site) from a water depth of 2.76 m. The oldest unit comprises 24 cm (189-165 cm) of crumbly, very dark-greyish brown (10YR 3/2), silty sediment. A thin band of small white non-calcareous nodules was observed between 183 and 181 cm. In the upper part of the unit, ostracodes are present. A 24 cm thick clay deposit overlies this unit. Between 142 and 124 cm a silty, dark grey-brown (2.5Y 4/2) layer rich in ostracodes and root and vegetation remains is found. This is capped by 4 cm of coarse sandy sediments. A 43 cm thick layer of smooth, very dark greyish-brown (10YR 3/2) clay is found between 120 and 78 cm, overlain by 10 cm of ostracode-rich silty clay. The upper 68 cm comprises structureless clay similar in colour and texture to that found between 120 and 78 cm.

The stratigraphy of LP11 is similar to that found at other sites in the southern section of Lake Pátzcuaro (Fig. 8.2). The sediment found at the base of all the cores is an organic-rich gyttja, which varies in thickness being greatest at LP1, LP2 and LP12 (Fig. 8.2). The most obvious difference is that the lowest of the three clay units observed at LP11 (165-142 cm) is not represented at all sites in the Southern Basin (Fig. 8.2). As LP11 is the longest core collected from this part of the lake, it is possible that this unit was not sampled in every case. Another explanation could be that there have been spatial variations in the rate of sediment input, resulting in a greater thickness of sediment at LP11.

Two distinct clay units are noted at LP1, LP2 and LP4 (Fig. 8.1 and 8.2); the lower of these is believed to correspond to the middle clay unit at LP11. This unit is not found at the other sites in the Southern Basin. The uppermost clay layer found at LP11 is present at all other sites forming a unit 50-70 cm thick. A number of ostracode-rich sediment layers are seen in all the cores. However, with the exception of the uppermost unit, it is not possible to determine whether all of these form contiguous layers.

8.2.2. Radiocarbon Dates And Sediment Accumulation Rates

Ostracodes from three different ostracode-rich layers (174-175 cm, 130-131 cm and 79-80 cm) were extracted from LP11 and submitted for ^{14}C dating (Table 7.1). These yielded dates of 3,640 70 years B.P. (OaX-2819), 2,650 60 years B.P. (OaX-2818) and 1,190 70 years B.P. (OaX-2817), respectively (Fig. 8.x). A fourth date of 480 60 years B.P. (OxA-2822) was obtained on a shell taken from LP12/30 cm.

Using these dates, it is possible to draw some inferences about the sediment accumulation rates at the two sites. Between 3,640 and 2,650 years ago sediment accumulation at LP11 was approximately 4.4 cm/100 years. This rate decreased slightly to 3.4 cm/100 years between 2,650 and 1,190 years ago. In the last 1,190 years sediment accumulation at LP11 has almost doubled to 6.6 cm/100 years. This is similar to the accumulation rate of 6.0 cm/100 years recorded on the upper 30 cm of LP12.

8.2.3. Moisture Content And Bulk Density

The variations in the moisture content and bulk density of the cores from the Southern Basin are shown in Table 8.1. At LP11 the basal sediments contain approximately 85% moisture. The moisture content decreases at 170 cm to 75-79% and remains at this level until 130 cm where it increase to 82%. Moisture contents of 70-78% characterise the clay unit found between 80 and 120 cm. At 80 cm, the sediment contains a slightly greater amount of water. In the upper 70 cm of the core the clays contain relatively large quantities of water which, in general, exceed 80%.

It is interesting to note that the deposits at the base of LP11 have a higher moisture content than the sediments in the upper part of the core. In general, the organic and ostracode-rich sediments do contain a larger quantity of water than the clays. This difference in moisture content may reflect a number of factors although grain size variation is probably the most important, clay sediments being more easily compacted than silty material.

The bulk density of these sediments reflects the moisture content. In general those sediments that contain a greater amount of moisture have a lower bulk density than those sediments which contain less moisture.

The amount of moisture within the sediment at individual sites does vary (Table 8.1). In general, however, the sediments contain a large quantity of water (65-80%). At all the sites investigated the overall relationship between stratigraphy and moisture content remains the same, with the organic-rich deposits having a greater moisture content and lower bulk density than the clay units (Table 8.1).

8.2.4. Carbonate content ($CaCO_3$)

Variations in the carbonate content of LP11 (and other cores from the Southern Basin) are shown in Figure 8.2. At the base of the core the sediments contain approximately 5% $CaCO_3$, dropping to zero at that part of the core where the white nodules are present. The $CaCO_3$ content rises sharply at 170 cm where it accounts for 28% of the dry weight of the sediment. Above 170 cm, $CaCO_3$ content decreases to about 9-11%. A second, very large peak in $CaCO_3$ is seen at 133 cm, and accounts for nearly 60% of the dry weight of the sediment at this level. Above 133 cm, $CaCO_3$ content decreases to approximately 10% and remains at this level except for a slight increase in the upper 10 cm of the core. Peaks in $CaCO_3$ correspond to the deposits that are rich in ostracodes, while both the organic-rich gyttja and clay units display relatively low $CaCO_3$ contents.

Variations in $CaCO_3$ content at other sites in the southern part of Lake Pátzcuaro are shown in Figure 8.2. In all the cores a number of $CaCO_3$ peaks are seen. However, considerable differencesin the magnitude of the peaks are noted from site to site, although it is apparent that peaks in $CaCO_3$ correspond to layers in which ostracodes are present at all the sites investigated.

Core LP 5

Depth (cm)	% Moist. Content	Bulk Density
0	81.5	0.22
9	80.9	0.29
19	76.5	0.23
29	78.1	0.25
40	74.9	0.26
50	77.0	0.24
60	77.1	0.25
70	76.3	0.25
80	73.2	0.30
90	-	-
99	71.5	0.31
110	-	-
120	69.8	0.34
130	71.6	0.32
140	75.3	0.29
150	72.8	0.32
160	69.3	0.37

Core LP 10

Depth (cm)	% Moist. Content	Bulk Density
0	64.1	0.25
9	77.1	0.25
19	79.2	0.22
30	79.8	0.21
40	77.6	0.23
49	74.9	0.29
60	78.4	0.23
70	89.8	0.20
90	74.8	0.27
110	68.1	0.37
134	71.6	0.31
150	71.3	0.34
166	76.8	0.25
175	80.3	0.21
189	-	-

Core LP 11

Depth (cm)	% Moist. Content	Bulk Density
1	80.0	0.26
10	87.8	0.20
21	72.9	0.19
30	79.9	0.20
40	80.5	0.22
50	82.5	0.19
60	79.5	0.12
71	82.6	0.19
81	77.8	0.23
90	74.4	0.29
101	69.9	0.34
110	71.6	0.33
130	82.2	0.19
140	74.3	0.24
150	75.4	0.26
161	78.0	0.25
175	85.0	0.16
182	80.0	0.23

Core LP 19

Depth (cm)	% Moist. Content	Bulk Density
10	63.7	0.37
30	62.7	0.46
40	59.6	0.55
50	62.2	0.42
60	65.2	0.46
70	67.7	0.46
80	65.0	0.42
90	64.6	0.39
100	70.4	0.33
110	72.0	0.34
120	74.3	0.28
130	67.0	0.35
140	77.8	0.21
150	75.5	0.25
160	66.4	0.38
170	68.2	0.38
180	68.2	0.36
190	64.0	0.43
200	67.4	0.38
210	67.8	0.38
220	64.9	0.38
230	76.9	0.24

Table 8.1: Results of moisture content and bulk density analyses for selected cores from Lake Pátzcuaro

8.2.5 Loss-on-ignition

There is an overall upwards decrease in L.O.I. in core LP11 (Fig. 8.2). In the lowest 19 cm organic matter accounts for over 40% dry weight. L.O.I. decreases to 20-25% at approximately 170 cm; remaining at this level until 120 cm. Between 120 and 130 cm there is a slight increase to 30%, but above 120 cm it decreases again to approximately 20%. In the upper 120 cm of the core, the sediments contain approximately 20% organic matter, although slightly higher values are recorded between 70 and 80 cm and in the upper 10 cm.

Similar trends in organic-matter content are observed at all other cores in the southern part of the lake. Generally, L.O.I. is high in the bottom part of the cores, although the amount of organic matter measured at other cores is not as high as that at LP11. High L.O.I. values are associated with organic gyttja. Many of the small peaks in L.O.I that are observed in the upper part of the cores correspond to layers that are rich in ostracodes. The percentage of organic matter within the clay units is relatively low compared with the gyttja and ostracode-rich layers: usually less than 20% and in most cases between 10 and 12%.

8.2.6 Magnetic susceptibility (*X*)

The *X* curve for LP11 is shown in Figure 8.2. At the base of the core, *X* is relatively low, varying between 10 and 15 E-06 kg m^{-3}. A distinct, but small, peak in *X* is recorded between 146 and 166 cm with values of over 200 E-06 kg m^{-3}. Between 122 and 146 cm, *X* decreases to 15-49 E-06 kg m^{-3}, but increases markedly at 123 cm forming a peak between 80 and 123 cm with *X* values of 350-400 E-06 kg m^{-3}. Low *X* values are recorded for the sediments between 70 and 80 cm, but *X* increases sharply at 70 cm with values as high as 630 E-06 kg m^{-3} which are maintained in the upper 70 cm of the core. It is evident that these peaks in *X* coincide with the clay units described in section 8.2.1. *X* is much lower in the organic gyttja and ostracode layers. *X*

curves from the other 5 cores in the Southern Basin show remarkable consistency between sites (Fig. 8.2), although the size and magnitude of individual peaks does vary. The most noticeable difference is found between LP3, LP4 and LP11 collected close to the southern shore of the lake and LP1, LP2 and LP12 which were collected further to the north, adjacent to Ihuatzio (Fig. 8.1). The *X* curves from the former three sites displaying a greater number of *X* peaks compared to the latter three sites.

8.2.7. Grain Size

The mean grain size of the sediments from LP11 are shown in Figure 8.2. Considerable variations in mean grain size are apparent; in general, the deposits from the base of the core are much more coarse than those in the upper part. Between 170 and 189 cm the sediments have a mean grain size between 13 and 15 μm. This decreases slightly at 170 cm before exhibiting a marked increase at about 150 cm where the sediments have a mean grain size of approximately 25 μm. This increase coincides with ostracode rich sediments. Between 80 and 130 cm, the mean grain size is 7-10 μm. In the upper 80 cm of the core the mean grain size generally varies between 5 and 6 μm.

It is evident that changes in grain size are coincident with changes in the stratigraphy, clay units having a much smaller mean grain size than other sediment types. The coarsest deposits appear to be the sediments rich in ostracodes.

8.2.8 Summary and interpretation of the Physical properties of the Southern Basin

The stratigraphic record from LP11 covers the last 5,000 to 6,000 years. Over this period, there has been a considerable change in the type of sediment accumulating at this site. At the base of the core, organic sediments with a high $CaCO_3$ content are seen. A change in the stratigraphy is noted at 170 cm with a decrease in $CaCO_3$, organic content and grain size. This coincides with a small peak in *X*. This evidence implies that there was an increase in the input of sediment from the lake catchment into the lake at this time, suggesting disturbance within the drainage basin. A date of

3,640±70 years B.P. on ostracodes taken from immediately below this unit provides a maximum age for the onset of disturbance at this site.

Assuming a constant rate of sediment accumulation, between ^{14}C dates, this period of disturbance within the southern part of the basin continued for approximately 200-400 years, after which greater stability within the basin is inferred by the build up of carbonate-rich sediments with low *X* values. This evidence suggests that there was little sediment entering the lake from the catchment during this time period.

A dramatic change in the stratigraphy is seen at 120 cm. $CaCO_3$ levels drop dramatically, as do L.O.I. and grain size. These changes are coincident with a sharp increase in *X*, and indicate a shift in the sediment source from sediments being endogenic in origin to one where they are derived from the catchment. This second episode of disturbance is bracketed by the dates of 2,650±60 years B.P. on ostracodes taken 10 cm below, and 1,190±70 years B.P. on ostracodes from immediately above, this unit.

A layer of ostracode-rich sediments, which are characterised by low *X* values, is found between and 80 cm in LP11. During the accumulation of these sediments there was little input of material into the lake from the catchment. A date of 1,190±70 years B.P. on ostracodes extracted from the base of this unit provides a minimum date for the onset of deposition. This unit is characterised by a large quantity of root and vegetation remains; a feature that was observed at all the sites in the southern basin. At LP3, large pieces of tule reed were extracted from this layer; at the present time the depth of water at LP3 (2.5 m) is too deep for reeds to survive. It is believed that the large quantity of organic remains in the sediment may reflect a lower lake level during the deposition of this ostracode-rich layer.

The stratigraphy and *X* record from the uppermost 70 cm provide a clear indication that from approximately 900 years ago sediment accumulation at LP11 and in the Southern Basin in general, has been dominated by the input of material from the catchment into the lake and indicates a period of extensive disturbance within the basin.

Other sites can readily be correlated with LP11. The main difference is that the amount of sediment accumulating at individual sites, and the number and magnitude of χ peaks in the records. What is most apparent, however, is that in the two earliest phases of disturbance sediment appears to have effected the more southerly part of the lake, implying that sediment entering the lake during these periods of disturbance was from the southern shore of the lake. It is only in the most recent phase of disturbance that all parts of Southern Basin have been affected.

8.3 THE CENTRAL BASIN

Eight cores were collected from the central part of the lake and are located in two main regions (Fig. 8.1). LP5, LP6, LP7 and LP8 were taken along an east-west transect between Erongarícuaro and San Pedro Cucuchuchu, while LP9, LP10, LP13 and LP15 were all collected north of the Island of La Pacanda (Fig. 8.1). In addition, samples were taken at 10 cm intervals from the core collected by Bradbury and Saporito: called here the Master core (MC). The MC was collected south-east of the Island of Janitzio at the boundary of the Southern and Central Basins. However, as the stratigraphy at this site is similar to that seen at LP7 and LP8 the MC will be discussed in this section.

Four cores from this part of the lake have been studied in greater detail than the others. Analyses on the MC have included pollen (Watts and Bradbury, 1982), diatoms (Bradbury, unpubl. data), and geochemistry (Saporito, 1975). Additional analyses, made on the MC, as part of this investigation included χ, χ_{fd} and sediment chemistry. Grain size has been determined on three cores; LP5, LP7 and LP10. Chemical analyses has been made on the last of these cores. These results are shown graphically in Figure 8.3.

8.3.1 Stratigraphy

This description of the MC is based on that outlined by Saporito (1975). The MC was collected from 6.23 m of water, south east of the Island of Janitzio (Fig. 8.1). A 14.2 m core was collected although only the results from the upper 3.36 m will be given here, as this more than covers the time period under consideration in this thesis.

The upper 3.36 m of the core comprises of 70 cm (258-336 cm) of gyttja. This is overlain by a silty material with distinct ostracode rich layers in it. A layer of very fine clay sediment is seen between 223 and 168 cm which is capped by 30 cm of sediment rich in ostracodes. An abrupt change in sediment to a clayey deposit occurs at 73 cm. This unit extends to the top of this core.

LP5 was collected approximately 2 km east of the town of Erongarícuaro. At the time of coring, the depth of water in this part of the lake was 2.5 m. The considerable amount of aquatic vegetation found in this area made it impossible to core any nearer to the shore. A 1.69 m core was retrieved at this location.

The lowest 8 cm of the core (161-169 cm) consist of crumbly, black (5YR 2.5/1) clayey sediment overlain by 13 cm (148-161 cm) of dark reddish-brown (5YR 3/2), silty clay. Between 132 and 148 cm, a layer of ostracode-rich silty sediment with abundant root and plant remains is seen. At 132 cm there is an abrupt change to a smooth, very dark greyish-brown (10YR 3/2) structureless clay. Ostracodes and root remains are absent from the base of this unit, but become abundant between 115 and 100 cm. The ostracodes are associated with a silty, dark-reddish brown (5YR 5/2) sediment. The upper 100 cm of the core consists of a very dark greyish-brown (10YR 3/2) to dark grey brown (2.5YR 3/2) smooth clay. Root material is present throughout this unit although is more abundant in the upper 30 cm of the core.

At LP10 a 1.91 m long core was taken 1.3 km from the lake shore. The water depth at the time of coring was 7.55 m. The basal part of the core (188-191 cm) is

formed of black (5YR2.5/1), organic gyttja. This is overlain by a silty unit rich in root and plant remains; ostracodes are present in the upper part of this layer. A thick unit of (10YR 3/2) smooth, structureless clay is present between 90 and 163 cm. This is overlain by 18 cm (72-90 cm) of silty sediment, rich in root remains and ostracodes. The upper 72 cm comprises smooth structureless clay similar to that found below 90 cm.

8.3.2 Radiocarbon Dates And Sediment Accumulation Rates

Two cores from the Central Basin have been dated using ^{14}C. The chronology of the MC is based on seven ^{14}C dates of which three fall in the Holocene epoch and two within the time frame of this investigation. An age of 9,210 years B.P was recorded on sediments from 4.22 m. A second date of 3,640 years B.P. on sediments at 2.57 m and the youngest date available on the core from 1.97 m is 2,890 years. Based on these dates average accumulation rates can be estimated. Between about 9,000 and 3,500 years ago sediment accumulation at this site was at approximately 2.9 cm/100 years. Sediment accumulation increased markedly between 3,500 and 2,900 years to 8 cm/100 years. In the last 2,900 years, it has decreased slightly to 6.8 cm/100 years.

Three samples from LP5 were submitted to the Oxford University Radiocarbon Accelerator Laboratory (Table 7.1). Samples which included ostracodes, a shell and fishbone were taken from 153 cm, 100 cm and 76 cm respectively. The first two yielded dates of 2,920±80 years (OaX-1821) and 1580±60 years (OaX-2821), respectively. The fishbone collected from 76 cm failed to yield a date. Using these dates, it is possible to estimate the rate of sediment accumulation at LP5. Between 2,920 years and 1,580 years B.P. the rate of sedimentation was approximately 3.9 cm/100 years. The rate of accumulation increased to 6.3 cm/100 years over the last 1,580 years. These sediment accumulation rates are similar to those recorded in the southern part of Lake Pátzcuaro.