

4.5 HOLOCENE ENVIRONMENTAL CHANGE IN THE BASIN OF PATZCUARO

Deevey (1943, 1944) collected cores from a number of lakes in México. He considered those taken from Lake Pátzcuaro to provide the most interesting record of vegetation change. On the basis of changes in the pollen sequence he identified three zones; a lower zone representing pine-oak forest, a middle zone corresponding to a period of aridity and a top zone which reflected human occupancy of the region. As these cores lacked dating control, his conclusions can only be considered tentative at best.

Additional geochemical and diatom analysis was undertaken on two of Deevey's cores by Hutchinson and Patrick (Hutchinson et al., 1956). Based on their results and correlation with Sears' (ibid) results from the basin of México they concluded that four climatic zones could be identified from the cores. Before 3,500 years B.P. the climate was arid. A period of relatively wet conditions occurred between 3,500 and 2,500 years B.P. The period 2,500 to 1,100 B.P. was characterised by fluctuating conditions with at least one very dry phase, with wetter conditions prevailing between 1,100 and 600 years B.P.

Hutchinson et al (1956) concluded that the most striking feature of the geochemical record is a large peak in CaCO_3 found in the middle of both the cores which they concluded implied lower lake levels. These data are supported by the results of the diatom analyses of these layers which indicated low lake levels as well. Like Deevey's earlier study, this work was hindered by the lack of dating control and all their conclusions are based on correlation with pollen sequences in the Basin of Mexico which at the time were also poorly dated.

In 1973 J. P. Bradbury and M.S. Saporito recovered a 15.2 m core from the southern part of Lake Pátzcuaro. Seven ^{14}C dates are available for this core which has a basal age of 44,000 years (Watts and Bradbury, 1982). This core which has been analysed for geochemistry (Saporito, 1975), pollen (Watts and Bradbury, 1982) and

diatoms (Bradbury, unpubl. data). The results of these different studies, relating to the Holocene period, are shown in Figure 4.7).

The study of the sediment chemistry by Saporito (1975) is not a complete analysis and is based on a partial digestion technique. This limits the value of his results. However, like Hutchinson *et al* (1956) he identified a number of peaks in Ca. In addition Fe, and K increase in the upper 2 m of the core implying increased input of detrital sediment into the lake over the last 3,000 years (Fig. 4.7).

The pollen record from this core has been analysed in greater detail. The lower portion of the core, which covers the period 44,000-9,500 years B.P., is dominated by pine, with lesser percentages of alder and oak, and low but consistent amounts of grass, juniper, fir and ragweed. While the last three taxa are only present in small amounts their disappearance from the pollen record at 9,500 B.P. is of considerable significance and has been interpreted as signifying the Pleistocene/Holocene boundary (Watts and Bradbury, 1982).

Between 11,000 and 5,000 years B.P., pine continues to dominate the record with lesser percentages of grass, alder and oak. A decline in the percentage of alder and an accompanying increase in chemo-ams occurs after 5,000 years B.P. and has been interpreted by Watts and Bradbury (1982) as signifying either the removal of riparian alder by early agriculturalists, or a slight shift towards a more arid climate. A

decrease in the level of *Alnus* at approximately 5000-6000 years ago has also been noted in the pollen record from the Zacapu Basin (pers. comm, 1991). The diatom assemblage associated with this level indicates lower lake levels and has been interpreted as inferring more arid conditions (Metcalf, pers. comm, 1991)

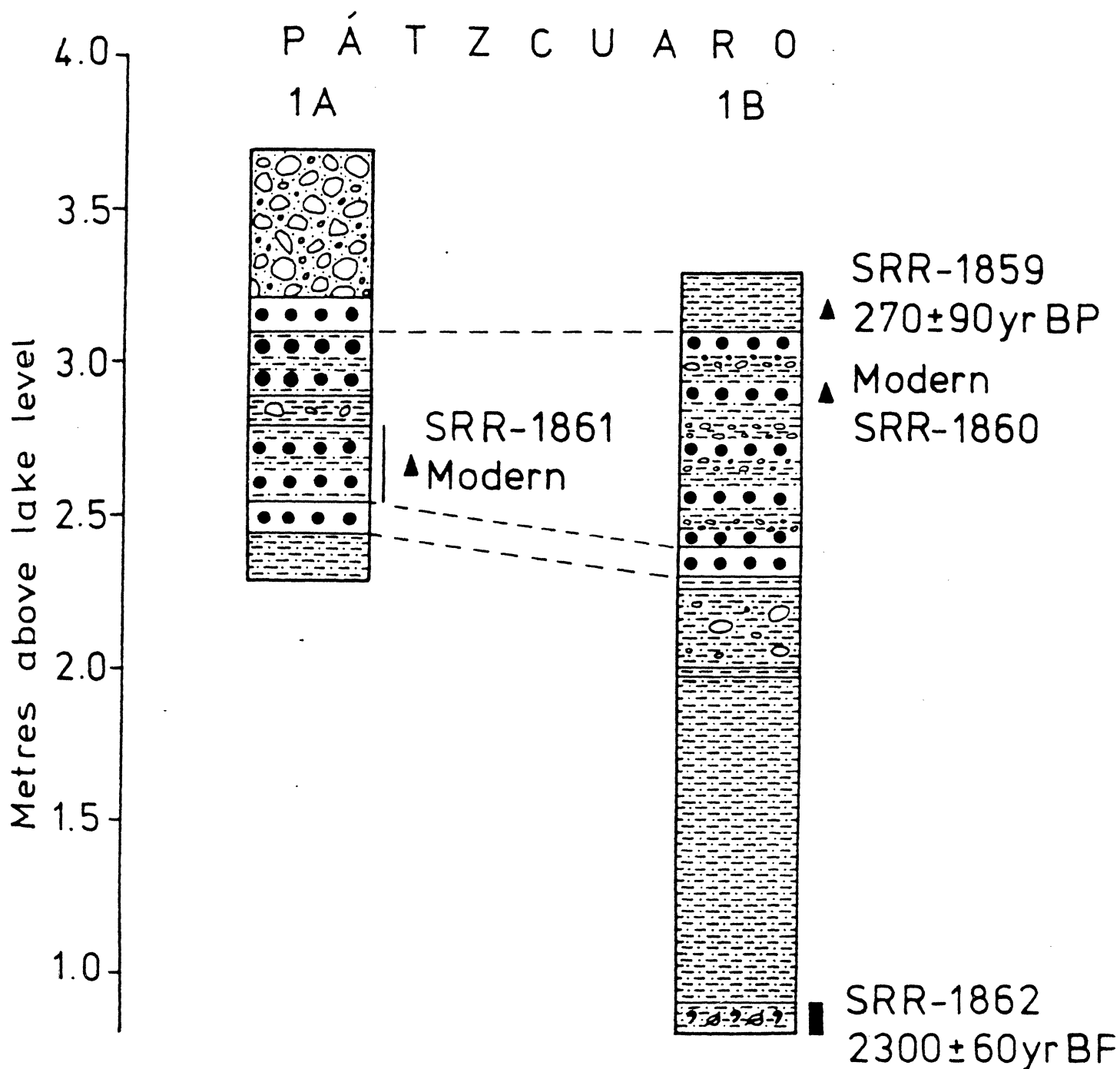
The appearance of maize in the pollen record approximately 3,600 years ago provides the first evidence of human occupation in the Basin of Pátzcuaro. There is some evidence that the lake shore vegetation may have become denser and more productive in the last 3,500 years with sedge pollen in greater abundance and other pond weeds frequently observed. It is suggested that infilling of the lake may have

changed the lake's character.

Diatom analysis on the mastercore has been carried out by Bradbury, but as yet his findings have not been published. This section will detail his results from the upper 4.43 cm of the core which covers the Holocene period (Bradbury pers. comm. 1988). Between 253 and 336 cm the diatom record is dominated by *F. pinnata* and *M. distans* with a lesser amount of *M. ambigua*. There is a marked increase in the *M. ambigua* at 253 cm with a concomitant decrease in *F. pinnata* and *M. distans*. This may suggest a slight change in the nutrient status of the lake from low nutrients in which *F. pinnata* and *M. distans* can survive to higher nutrient status which allows other species to increase thus competing with them. An abrupt change in diatom species occurs at 173 cm, with the almost total disappearance of *F. pinnata* and *M. distans*, and a marked decrease in *M. ambigua*. This coincides with the appearance of *M. granulata* which accounts for almost 80 % of the diatoms at this level. This shift in species composition may reflect a change towards more turbid conditions in the lake, *M. granulata* being a large planktonic diatom that requires particles within the water to keep it afloat and is generally indicative of an increase in the input of catchment material in the lake (Bradbury, 1975).

M. granulata displays a significant decline between 80 and 120 cm with a corresponding increase in *M. ambigua* and *F. pinnata* suggesting a return to less turbid, relatively nutrient rich conditions. The upper 73 cm of the core is dominated by *M. granulata* and *Stephanodiscus* species; *M. ambigua*, *M. distans* and *F. pinnata* virtually disappearing from the diatom record. The high level of the former two species indicates both turbid conditions and increased levels of eutrophication. The very top of the core exhibits a large increase in *Stephanodiscus* spp. (Bradbury, Unpubl. data) which is indicative of cultural eutrophication.

Evidence of long term disturbance within the Basin of Pátzcuaro has been reported by Street-Perrott et al. (1989) who investigated a 2.49 m high section situated close to the northern shore of the lake. They identified two colluvial units (Fig. 4.8), the lowest was dated at 2,300 years B.P. at the base of the exposure, while the upper one



● ● ● Gritty silt loam in form of sand-sized pellets

▨ Gritty silt or silt loam

▨ Well bedded silt

○ ○ Gravel

☐ ☐ Leaf impressions

◡ ◡ Shells

Dating samples :-

▲ Charcoal

■ Other

Figure 4.8 Colluvial stratigraphy of section described by Street-Perrot et al. (1989)

yielded three ^{14}C dates ranging from 270 years B.P. to 'modern'. They concluded that the first phase of erosion was probably triggered by the introduction of maize agriculture in the basin, while the second more intense phase, may have begun in the late Postclassic but intensified after the Conquest as a result of the introduction of European farming techniques and widespread deforestation.

4.6 ENVIRONMENTAL DEGRADATION IN MEXICO: A SUMMARY

Widespread environmental degradation has been inferred from a number of palaeolimnological investigations in Central México. These records indicate that there has been an increase in the accumulation of clastic material and hence erosion ^{that} dates back to at least 3,000 years B.P. and clearly predates the arrival of the Spanish. Generally, erosional events have been identified by increased sediment accumulation rates. More recent investigations (eg. Metcalfe et al, 1989) have adopted a multidisciplinary approach which has allowed better interpretation of the palaeoenvironmental record to be made and it has been possible to associate disturbance phases with different Mesoamerican cultures. Attempts to assess the extent of environmental degradation, however, have been hindered as most of these studies have been based on a single core. Thus, while it is possible to determine periods of disturbance these data have limited use in determining the extent of anthropogenic accelerated erosion.

CHAPTER FIVE: RESEARCH METHODOLOGY

5.1 INTRODUCTION

There are a variety of techniques which help in the reconstruction of past environments: geomorphological, palaeoecological, archaeological and palaeolimnological to name but a few. It is evident, however, that while each individual line of evidence provides useful information the most successful palaeoenvironmental investigations have adopted a multidisciplinary approach (Metcalf *et al.*, 1991). With this in mind, this project has followed several lines of investigation, which together with existing data should provide the basis for reconstructing environmental change during the late Holocene in the Basin of Pátzcuaro.

This study can be divided into three main areas which were designed to help establish palaeoenvironmental conditions based on, 1) the historical record, 2) the terrestrial record, and 3) the lacustrine record. The methods of data collection and analysis are outlined below.

5.2 ARCHIVAL AND HISTORICAL RESEARCH

There is little information on the archaeology of the Basin of Pátzcuaro prior to the arrival of the Purépecha approximately 1,000 years ago. Even then details remain scant. Investigations have focused on the two main sites of Tzintzuntzan and Ihuatzio (Fig. 2.2) and although these have provided interesting information on the form of settlement and cultural development, they have added little information that is of use to this investigation.

In view of this, it has been necessary to follow other lines of research and a particularly important source of information has been documentary evidence. Although no pre-Hispanic documents pertaining to this area have survived, conditions during this time and the immediate post-Conquest period are outlined in the *Relación de*

Michoacán. Historical information can be 'gleaned' from documents housed in the various archives in Mexico City (Archivo General de la Nacion, AGN), Morelia (capital of the State of Michoacán, Archivo General del Estado de Michoacan, AGEM) and Pátzcuaro. Over 120 manuscripts were studied in all. Chronicles, travellers' descriptions and monographs that mentioned the Basin of Pátzcuaro were a further source of information. In addition, a search was made for any paintings, maps and photographs that would help in the reconstruction^{of} the environmental history of the area since the Conquest.

Originally it was intended to use this information to gain a greater insight into changes in agriculture, livestock numbers and forest conditions since the arrival of the Spanish in this region. In the process, however, it was discovered that many documents made reference to the lake itself and in some cases provided sufficiently detailed descriptions that it was possible to make some estimates of the position of the lake-shore. Once established, former shore lines were plotted on maps of the drainage basin at a scale of 1:5,000 with a contour interval of 1 m (SARH, Unpubl. data) allowing quite reliable estimates of the level of the lake to be made. Based on such information it was possible to make some estimates of fluctuations in the level of Lake Pátzcuaro over the last 600 years.

This study was complimented by interviews carried out in a number of villages which border the lake. Attempts were made to locate some of the older inhabitants who were asked to recount their memories of changes in lake level and conditions within the basin through their life time. In those instances where Purépecha was the first language of the interviewee, the interview was conducted through a translator.

5.3 THE LACUSTRINE RECORD AND TERRESTRIAL RECORD

Investigations that have been undertaken in the Basin of Pátzcuaro (eg. Deevey, 1944, 1957; Hutchinson et al., 1956; Watts and Bradbury, 1982; Street-Perrott et al., 1989) indicate that the terrestrial and lacustrine record should provide an excellent basis

for reconstructing late Holocene palaeoenvironments within the basin. Thus, the research methodology was designed to build on and complement this existing information. Although the methods of data collection differed, many of the analytical techniques were the same.

5.3. FIELD WORK

Data were collected during three periods of fieldwork. The first, between May and July 1987, was of a reconnaissance nature. A major programme of fieldwork was undertaken between March and July 1988 with additional information obtained at various times during a year of study at the Universidad Nacional Autonoma de Mexico (UNAM) during the 1988/1989 academic year.

5.3.1 TERRESTRIAL RECORD

Terrestrial sections were investigated in a series of transects beginning near the lake-shore and gradually moving upslope. Sites were located on aerial-photographs and later pinpointed on 1:50,000 topographic maps (DETENAL, 1978). Sections were either exposed by gullies or, as in most cases, excavated using a bucket auger. A total of 64 sections were logged and in most cases sampled.

The stratigraphic sections were logged in the field making note of colour, texture, structure, hardness of the material, presence of organic matter, pH, and moisture content. Any material that could be dated was removed from the section and stored in plastic bottles covered in tin foil and placed in a cool, dark place.

5.3.2 LACUSTRINE RECORD

To allow spatial and temporal variations in sediment accumulation and input into the lake it is necessary to collect a series of cores. Attempts were made to take them along a number of transects, situated several kilometres apart, so that all parts of the lake would be covered. This proved to be difficult, however, as in some parts of the lake

it was impossible to take bearings on sufficient monuments to obtain an exact location. In addition, it was not possible to core in many of the shallower parts of the lake because lake weeds became entangled with the boat's motor.

Twenty cores were considered to be the minimum required to make reasonable estimates of sediment accumulation. These varied in length from 1.42 to 2.85 m, with the longest cores taken from the northern part of the lake. In addition, samples were taken at 10 cm intervals from the 15.2 m core collected from Lake Pátzcuaro by Bradbury and Saporito in 1973.

Cores were collected using a simple coring instrument that was designed and constructed in the field. As a large number were to be collected a simple and rapid device was required that could be managed by a single person. The core barrel consisted of 5 cm diameter PVC tube 3.5 m in length. Two bolts, in the form of a cross were inserted 10 cm from the upper part of the tube (Fig. 5.1) so that a rope could be attached to the coring barrel and permit easy retrieval. A heavy metal sleeve was placed over the tubing and used to guide the coring barrel into the lake sediment. In the shallower parts of the lake additional tubes were added to the sleeve so that the barrel could be pushed in to the lake sediment. Where the depth of water was greater than 5 m a rope was attached to the sleeve which was then lifted and dropped so that the sleeve acted like a hammer (Fig. 5.1).

The corer was lowered to the sediment/water interface and generally entered the surface sediments without force. If the corer entered at an angle it was retrieved, washed out and lowered again. When the core barrel was filled or would not enter any further into the sediment it was pulled up using a tripod and winch system. Any water retained in the upper part of the coring barrel was carefully syphoned off. Unfortunately, the extremely high moisture content of the upper section of the sediment column resulted in some loss of sediment in most cores. Having drained off the excess water the ends of the core barrel were sealed using egg-shaped polystyrene bungs. These were then covered in plastic and taped with durable box tape to prevent further moisture loss. The

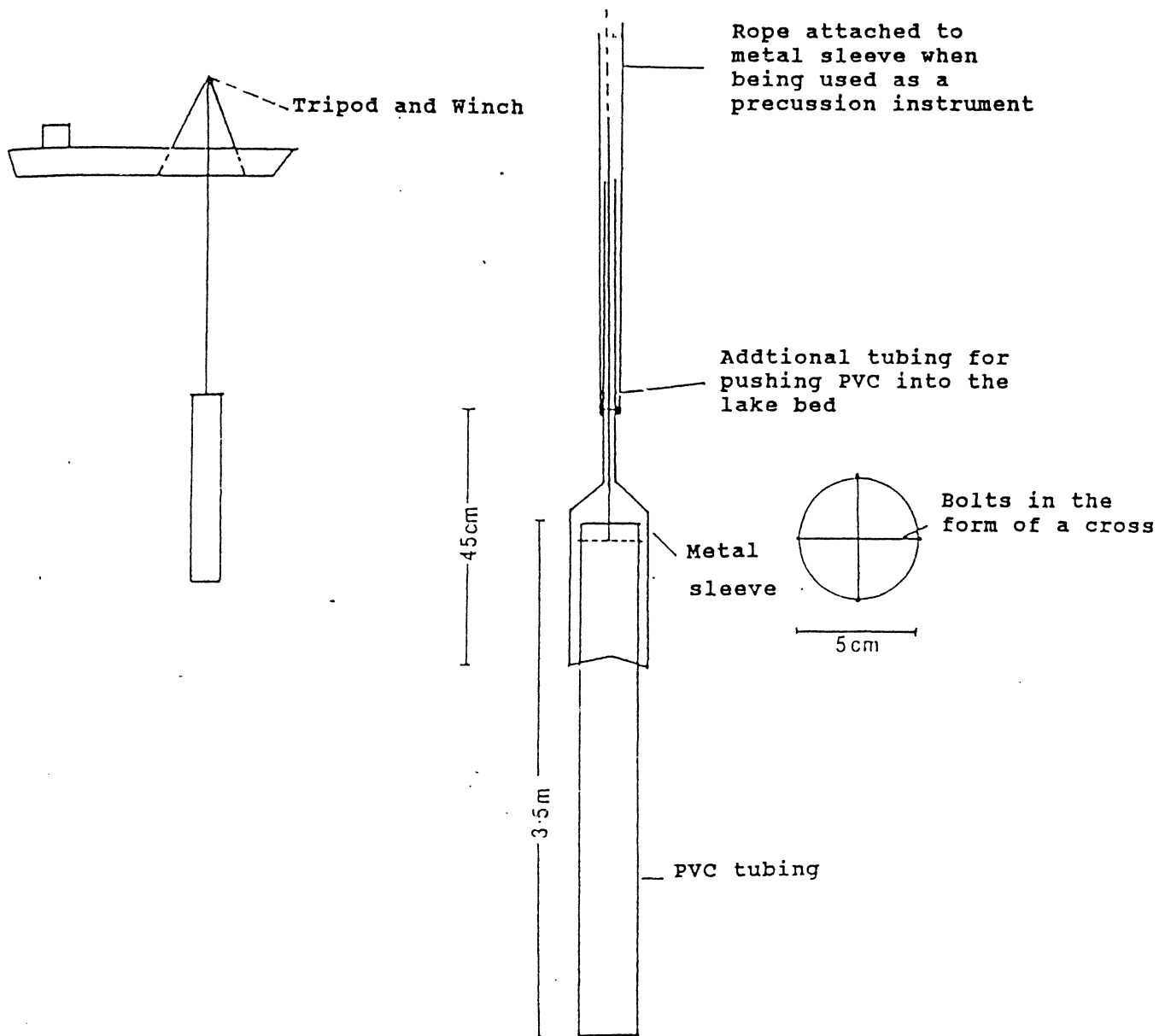


Figure 5.1 The coring device constructed for this project.

cores were stored horizontally in the laboratories of PESCA until opened.

A small flat bottomed boat which could be easily anchored was used as a coring platform. Coring was only possible in the morning when the lake was sufficiently calm to allow the boat to be properly anchored.

5.4 LABORATORY ANALYSES

The majority of the laboratory analyses has been on the lake cores, and thus the following discussion is with reference to this part of the investigation. Those times where terrestrial samples were analysed will be highlighted.

As discussed above a total of 20 short cores were collected with additional samples from the Bradbury core also analysed. Due to the large number of cores collected it was impossible to carry out full analyses of each core. The different analyses carried out at each site are shown in Table 5.1.

5.4.1 Stratigraphy

Initial analysis of the cores was carried out in the laboratories of PESCA in Pátzcuaro. The barrels were cut into short sections between 10 and 20 cm in length, and the sediment extruded using a metal rod which had a diameter slightly smaller than the inside of the PVC tubing. Each section was measured immediately after extrusion so any compaction could be accounted for. The cores were cut in half and one was immediately wrapped in cling film and aluminium foil for shipping to England.

Stratigraphic variations often provide a preliminary insight into changes in drainage basin dynamics. Thus, prior to any sampling, the cores were logged noting variations in colour, texture, structure, grain-size, vegetation and macro fossils content. Any material that could be potentially radiocarbon dated was extracted, washed with distilled water, dried at 40°C and stored in a plastic phial.

Core No	Bulk Dens	X	X _{td}	L.O.I.	Calci- metry	Sediment Chemistry	Grain Size
1	x	x		x	x		
2	x	x		x	x		
3	x	x		x	x		
4	x	x		x	x		
5	x	x		x	x	x	x
6	x	x		x	x		
7	x	x		x	x	x	
8	x	x		x	x		
9	x	x		x	x		
10	x	x	x	x	x	x	
11	x	x	x	x	x	x	x
12	x	x		x	x		
13	x	x		x	x		
14	x	x		x	x		
15	x	x		x	x		
16	x	x		x	x		
17	x	x		x	x		
18	x	x		x	x		
19	x	x	x	x	x	x	x
20	x	x		x	x		
Master Core		x	x				x

Table 5.1: Completed analyses by lake core.

5.4.2 Bulk Density

Immediately after the cores were logged samples, of known volume were taken at 10 to 15 cm intervals. These were to enable the moisture content and bulk density of the sediments to be calculated. 10 cm³ PVC pots were weighed, filled with sediment, reweighed and then dried for one week at 40°C before being weighed again. This information is required to allow more accurate estimate of sediment influx to be made. In addition, changes in the bulk density may reflect changes in the sediment type.

5.4.3 Organic matter

Various investigations have shown that during periods of disturbance within a drainage basin there may be an increase in the amount of inorganic material deposited into a lake (eg. Mackareth, 1966; Engstrom and Wright, 1984). To determine variations in the inorganic content, samples ca. 1.5 to 3.0 grams were taken at 5 cm intervals from all the cores. These were dried for one week at 40°C, crushed and then dried overnight at 105°C to remove all moisture. Organic content was determined by loss-on-ignition at 550°C for one hour in a Carbolite type ESE 12/10 muffle furnace.

5.4.4 Magnetic mineral analyses

Analyses of the magnetic properties of a sediment provides a powerful tool for the reconstruction of palaeoenvironments. Various techniques have been developed over the past decade although the most useful in this case is that which determines magnetic susceptibility (X). X is the degree to which a given substance can be magnetised (Thompson and Oldfield, 1986). This varies depending on mineralogy, although in general, metallic minerals exhibit higher X than non-metallic ones. Material that accumulates at the lake bed which is a product of the lake itself ie. endogenic or authigenic in origin generally has a low X . Input of material from the lake catchment will generally increase the X especially if it contains ferrimagnetic minerals. In an area such

as the Basin of Pátzcuaro, which is surrounded by volcanic deposits rich in ferrimagnetic minerals, high X readings would be expected to reflect periods of sediment input into the lake and hence erosion. In addition, in studies such as this where multiple cores are taken, it is possible to use X as a rapid means of core correlation (Bloemendal, 1981; Dearing *et al.*, 1981; Thompson and Oldfield, 1986) and it therefore provides a useful method for the quantification and characterization of sediment influx (Oldfield, 1977). Samples were taken at 5 cm intervals and dried for a week at 40°C . These were then crushed using a mortar and pestle and the powdered sediment poured into 1 cl plastic tubes. Samples from the master core were taken at 10-15 cm intervals. X was measured using a Bartington's MS1 Susceptibility Meter. For every fifth sample three repeat measurements were made to ensure that the readings could be replicated.

From measurements of X at different frequencies an additional parameter, frequency dependent susceptibility (X_{fd}), can be determined. The low frequency X reading is made by placing the sample in a small alternating magnetic field. All magnetic grains show a "relaxation" time to this change in field, although large grains respond more quickly to this change than smaller ones. At low frequencies all grains will have time to reach "full susceptibility". Under high frequency alternating magnetic fields smaller grains are unable to respond to the change in magnetic field and therefore never achieve full susceptibility giving a lower X reading than at low frequency (Walden, *pers. comm.*, 1990). X readings at high and low frequency are made and the differences between the two are shown as a percentage of the low frequency reading. The greater the difference between the two, the smaller the magnetic grains are. This provides useful information on the type and degree of weathering of the material being considered. Volcanic ashes for example exhibit high X readings, however, as they are generally formed of large magnetic grains they have low X_{fd} readings. Weathered soils on the other hand have small magnetic grains and record higher X_{fd} readings.

5.4.5. Grain size analysis

Variations in sediment grain size can provide important information on changes in drainage basin dynamics. Binford (1987), for example, noted that the mean grain size of sediments from Lake Quéxil in the Petén Lake District of Guatemala decreased markedly during periods of disturbance within the lake catchment. Grain size variations may provide information on sediment transport within the lake such as the effects of sediment focusing. Thus a number of questions can be answered using this information.

The predominant surface currents of Lake Pátzcuaro are from south to north which may result in transportation of sediment to the northern part of the lake; analysis of suspended solid concentrations indicate that this is the case (Chacón Torres, 1989). In addition, as the lake is deepest in the north it is possible that sediment focusing towards this part of the lake may occur. Consequently, sediment accumulation in the lake may be in part affected by transport mechanisms which operate in the lake. Finer silt and clay sediments are the most likely to be transported and thus, if there is sediment transfer, a greater percentage of fine silt and clay sediments would be expected for the cores in the northern part of the basin as compared to the south.

In order to determine whether this is the case, the grain size of five cores taken along an north-south transect was analysed. Samples were taken at 10-15 cm intervals dried at 40°C weighed and left overnight in 6% H₂O₂. These were then heated until all the organics were removed and reactions ceased. Carbonate material such as ostracodes were removed by adding a small amount of HCl to the sample. The material was then washed through a 180µm sieve. Material greater than 180µm was placed in a petri dish, dried and weighed to determine the percentage of sediment that fell into the sand-sized category. The remaining fines were collected in plastic containers and analysed for silt/clay fraction using a Cilas laser granulometer.

5.4.6 Sediment Chemistry

Lacustrine sediments play an important role in helping determine the many processes operating within a lake ecosystem (Jones and Bowser, 1978). These sediments can be broadly divided into the organic and inorganic fraction which are derived from a variety of sources. Material transported into the lake from both within and outside the catchment are termed the allogenic fraction. Those that originate from processes operating within the lake are called the authigenic fraction (Engstrom and Wright, 1984). Using a variety of techniques it is possible to establish changes in the 'make-up' of lacustrine sediments and use this to infer changes within the basin. By analysing the down-profile changes of lake sediment cores it is possible to determine changes within the lake system through time and use this to infer environmental change.

Changes in the chemistry of lake sediments can provide a wealth of information which can be used in palaeoenvironmental reconstruction. In a closed lake basin such as Pátzcuaro the amount and type of salts that accumulate in the sediment profile are a function of lake level fluctuations and concentration of associated variations in the dissolved salts (Hardie *et al.*, 1978). Thus if endogenic processes are the main agent of transfer of calcium (Ca), magnesium (Mg) and strontium (Sr) to the sediment column, these can be used to determine the evaporative concentration in a lake basin. These data can then be used to help infer climatic conditions prevailing in the region at the time that the sediment was deposited. With a decrease in the level of the lake there will be a concomitant increase in the level of salts accumulating in the lake sediment and this provides some indication of relative lake levels which in turn may be used to infer climatic conditions.

Iron (Fe), aluminium (Al), manganese (Mn), silica (Si) and potassium (K) are not easily leached from soils. The influx of these elements may then be associated with the inputs of detrital material due to soil erosion in the catchment (Engstrom and Wright, 1984). Total phosphorus (P) concentrations in the sediment will be calculated in order to

estimate the amount of nutrients entering the lake from the catchment.

5.4.7 Sample Preparation

Samples were prepared using a wet-chemical extraction technique outlined by Engstrom and Wright (1984). This technique was developed to separate out the acid soluble authigenic fraction ('a' fraction), the biogenic fraction ('b' fraction) and the clastic mineral fraction ('c' fraction). They concluded that separating out these fractions provided a better method of determining the geochemical history as each fraction contains different environmental information.

The authigenic fractions include: biochemically precipitated carbonate minerals, amorphous and cryptocrystalline Fe and Mn oxyhydroxides, phosphates and biogenic silica (opal). Organic material, however, may be allochthonous or autochthonous in origin and can present a major problem in interpreting this data. Although it only contains a small amount of inorganic cations, organic matter can complex or sorb large amounts of metallic ions from solution within the lake. Allochthonous organic matter also chelates cations from soil solutions and may enter the lake in both dissolved and particulate form. While metals bound to the particles are strictly allogenic it is difficult to determine their origin. This organic matter is usually removed in chemical fractionation so that chemically bound metals may be analysed.

The reagents used in this digestion technique are amongst the most vigorous extractants and can lead to the inadvertent breakdown of clastic material. This is especially true in the first stage of the digestion process when sediments are treated in 30% H_2O_2 . Engstrom and Wright (1984) suggested that one way of determining if any degradation has occurred during sample preparation is to compare the fractionation results for one of the conservative elements such as K which occurs in the lattice of silicate minerals. If silicate degradation is minimal, then the concentration of K in the 'c' fraction should be almost the same as the total content in the sediment.

In his work in Labrador Engstrom (1983) found that this was the case. The results

in this study do not conform to this and the quantities of K in the 'a' fraction are similar to those found in the 'c' fraction. This suggests that the digestion procedure has been too vigorous for these sediments and that there has been a considerable amount of clastic degradation during the preparation of the samples. It should be noted, however, that the soils that surround Lake Pátzcuaro are extremely weathered. As these soils contain a large quantity of organic material and due to the degree of weathering experience a greater degree of chelation as compared to the soils in Labrador, it is likely that a large quantity of allogenic material is extracted in the acid soluble 'a' fraction. Thus in this study it is believed that the 'a' fraction consists of authigenic minerals together with the more weathered allogenic fraction, while the 'c' fraction consists of the more unweathered clastic material.

5.4.8 Element Analysis

Samples were analysed for the following cations Fe, Al, Ti, Mg, Mn, K, Si, Sr, Ca, Zn, Cu, by atomic absorption spectroscopy using a computerized Perkin Elmer 3030 spectrophotometer. Chemical interference and unwanted ionization in the A.A.S. flame were suppressed by the addition of lanthanum or potassium (>0.2% w/v) as chloride. A deuterium arc background corrector was used for measurements at wavelengths <390nm. Buffers were added to most samples and standards. Pb was measured only on the Master Core. Because of the low levels of Pb in the sediment it was necessary to measure this using a Perkin Elmer Graphite Furnace 1100B which is able to measure smaller concentrations than flame spectrophotometry.

P_2O_5 -P and SiO_4 were determined using a CHEMLAB system 4 auto analyser using the same digestants used for A.A.S. analysis. To minimize matrix effects, standards were made up with the same acid concentrations as in the final solutions.

The carbonate content of the sediment was measured nonometrically. Samples taken every 5 to 10 cm were taken from all the cores. Five percent HCL was used to liberate CO_2 from carbonate on 0.2 gm of ground sample. The displaced gas was

measured by the displacement of liquid in a Bernard calcimeter, calibrated with pure CaCO_3 . Although calcite is very soluble in HCL it must be noted that there is a possibility that this technique may measure other carbonate salts, however, it is not possible to measure the potential error involved.

5.4.9 Radiocarbon dating

Thirteen samples were submitted to the Oxford University Accelerator Radiocarbon Dating Laboratory. Nine samples from the lake cores with a further 4 samples from terrestrial sites. Seven of ^{the} samples from the cores consisted of small quantities of ostracodes. Approximately 1 cm^3 of sediment was taken from the section to be dated and left for 2-3 hours in 30% H_2O_2 before being slightly heated. These were then passed through a $180 \mu\text{m}$ sieve and washed thoroughly with distilled de-ionized water. This removed most of the organics and left the ostracodes relatively free of sediment. The samples were then placed in petri dish and dried at 40°C . The ostracodes were then picked from the residue and placed into small glass phials and submitted to the laboratory. The other two samples, which consisted of a shell and fish bone, were washed in distilled de-ionized water and dried at 40°C , prior to submission.

The four terrestrial samples consisted of three charcoal samples and one shell specimen. Once collected these samples were wrapped in cling-film and aluminium foil and stored in a cool, dark place. Prior to submission to the laboratory the shell sample was washed and dried. The charcoal samples were submitted without any pre-treatment.

5.5 STATISTICAL ANALYSES

5.5.1 Correlation

To estimate the degree of inter-relation between the different variable groups, a correlation matrix was obtained for each data set. This was done in MINITAB using Pearson's correlation coefficients and provided an initial insight to how individual

variables were related to one another and allowed general groupings to be distinguished.

5.5.2 Simultaneous R- and Q-Mode Factor Analysis

In this thesis, the data sets produced by the geochemical technique are multivariate. Thus, to determine how each data set relates to one another a multivariate approach should be adopted. Factor analysis provides a useful tool for finding order in large data sets (Johnson, 1980), and its uses and abuses are described in a variety of geological (Davis, 1986) and geographical (Johnson, 1980) literature. Two modes of factor analysis can be conducted: R-Mode which is similar to principal component analysis and attempts to uncover the interrelations between variables and Q-mode which attempts to find patterns or groupings of the samples within their arrangement in 'multivariate space' (Walden, 1990).

To perform factor analysis it is first necessary to standardize the raw data matrix to remove the effects of different variables being measured on different scales. When R- and Q-mode analysis are conducted separately, the simplest scaling procedures used in each technique are different and thus the factor extracted and various factor loadings differ. In the past a number of palaeolimnological investigations which have been based on geochemical data have utilized factor analysis. In general, a Q-mode factor analysis has been applied as this has been more successful at describing geochemical data (Steininger, 1988).

If a common standardization procedure is applied, an R- and Q-mode factor analysis can be run simultaneously with common factors been extracted (Davis, 1986). These common factors can be plotted on a single 2-D diagram and provides a powerful tool for analysing multivariate data. The resultant diagrams of simultaneous R- and Q-mode factor analysis offer considerable potential for the detection and explanation of multivariate pattern in a data set. Firstly, the R-mode factor analysis will show how the

original variables relate to one another, indicating which variables are behaving in a similar or dissimilar way. Secondly, the Q-mode analysis, allows sample groups to be distinguished and thirdly as the samples and variables appear in the same diagram in the same 2-D space it will allow the relationship between the two to be made.

Factor analysis was carried out using MINITAB PC (release 7.2) on a basic IBM compatible computer. The method used is the same as that outlined by Walden (1990), and a fully worked example is shown in Appendix A. The raw data have to meet a number of requirements if R- and Q-mode factor analysis is to be valid. Each variable should be variably distributed and the number of samples should be somewhat larger than the number of variables (Davis, 1986). A drawback to this technique is that the MINITAB version will not run if any data points are missing. Where data were not available an average of the data points above and below within the core were used.

5.6 DETERMINATION OF SEDIMENT ACCUMULATION

To determine the spatial and temporal variations in sediment input into Lake Pátzcuaro, it was necessary to calculate the volume of material that had accumulated in different parts of the lake. Because of the irregular shape of the lake and the distribution of core sites the most suitable method for determining sediment accumulation was by Theissen's Polygons (Theissen, 1911). This method was designed for rainfall gauges over an irregular area and basically a single site represents a given area. The lake was divided into 21 polygons following the technique outlined by Theissen (1911). This is done by placing lines that are equidistant between two adjacent core sites. Each polygon is associated with a core site and the features of that core are assumed to be the same for the entire polygon.

Once constructed the area of each of the polygons was calculated using a simple digitizing package written by Peter Bragg, Department of Geography, University of Sheffield. Once the area of a given polygon was established it was multiplied by the thickness of the layer in the core representing that polygon. To determine the actual

volume it was necessary to subtract the water content. This gives the volume of sediment that had accumulated within a specific polygon, and includes all material from both within the lake and from the catchment. As it is not possible to determine what percentage of organic material or CaCO_3 is derived from the lake and catchment respectively, for the purpose of this investigation it was assumed that they were authigenic in origin.

CHAPTER SIX: VARIATIONS IN THE LEVEL OF LAKE PATZCUARO DURING HISTORICAL TIMES

6.1 INTRODUCTION

Lake basin hydrology, and hence the behaviour of lakes, is influenced by many factors. Halley (1715) recognised that lake levels fluctuate in response to changes in the climate, while Jackson (1833) recognised that lakes fluctuated due to variations in precipitation, runoff and groundwater. Closed lake basins which lack surface outlets are most sensitive in this respect (Street-Perrott and Harrison, 1985). While climatic conditions can play an important role in determining lake level status (Street, 1980; Street-Perrott et al. 1989) it is known that other factors can significantly influence lake behaviour. Human activities, for example, can change many aspects of basin hydrology, which can have a considerable, often detrimental, impact on a lake system.

In another context, lakes situated in tectonically active regions can experience rapid and often considerable fluctuations. Tamayo (1964), for example, cited the case of Lake Chapala situated approximately 120 km north-west of Lake Pátzcuaro, which reached an '*...extraordinary level...*' after the earthquake of 1567. Whether the lake responded by an increase or decrease in its level is not stated, however!

Attempting to reconstruct lake-level curves based on proxy data can be problematic and many lines of evidence need to be investigated to allow even a very general record to be determined. A major drawback to many studies has been the lack of dating control; without a detailed chronology it is difficult to draw anything more than broad conclusions about the lake's behaviour and the causal mechanisms underlying such changes. Even in those instances in which a detailed chronology is available, the time interval between dates is often such that small scale or abrupt fluctuations are frequently overlooked.

Studies have used historical sources to document lake level fluctuations over the recent period and to determine how these have been influenced by climatic and other

factors. However, there is a paucity of data of this type and in addition records rarely exceed 100 to 150 years (Hastenrath, 1967; Burgis and Morris, 1987).

6.2 THE CASE OF LAKE PATZCUARO

The level of Lake Pátzcuaro has been monitored on an intermittent basis since the early 1920s (Chacon Torres, 1989). The record clearly indicates that the lake has fluctuated considerably over this period. In addition, a number of studies in the basin have indicated that the lake has fluctuated on both long (Hutchinson *et al.*, 1956; Deevey, 1957; Watts and Bradbury, 1982; Gorenstein and Pollard, 1983) and short time scales (De Buen and Zoyoza, 1942; Chacon Torres, 1989). Most of these authors agree that at the time of the Conquest (A.D. 1521) Lake Pátzcuaro stood at a higher elevation than present. Saporito (1975) suggested that the lake was some 100 m higher when the Spanish arrived in the basin and that since this time the level of the lake has been dropping at an average rate of 20 cm yr^{-1} . A more recent study by Gorenstein and Pollard (1983), however, concluded that the lake was between 10 and 20 m (2045-2055 m a.s.l.) higher at the time of the Conquest, their conclusions being based on cartographic and aerial photographic interpretation.

A number of factors could result in changes in the level of Lake Pátzcuaro. Firstly, it lies in an area which is considered to be climatically sensitive and has been subject to considerable climatic variation on both the long and short-term (Watts and Bradbury, 1982; Metcalfe, 1985, 1987; Chacon Torres, 1989; Metcalfe and Hales, *in press*). As this is a closed lake basin one would expect the lake to respond to these climatic variations. Secondly, sedentary agriculture has been practiced in this basin for at least the last 3,500 years, and this together with high population densities (both in the past and at present) may have resulted in changes in the hydrological cycle of the basin. A third factor is that the lake lies in a known tectonically active area and although there is no historical evidence of volcanic activity within the basin, the eruptions of Jorullo (AD. 1759; fig. 2.1) and Paracutin (AD. 1943; Fig.2.1) affected the region. Today, there is still

considerable earthquake activity in this region, usually on a small scale. However, documentary evidence clearly indicates that this region has suffered severe earthquake damage on several occasions in the past most notably in AD 1702 (AGEM, 1702), 1857, and 1858 (Salas, 1956). As this region has been influenced by so many factors, it is important to follow as many lines of evidence as possible in order to determine the different factors that have affected the lake basin.

6.3 METHODOLOGY

In order to determine variations in the level of Lake Pátzcuaro, several lines of investigation have been used in this study. As records of lake level are not available until the 1920s, documents have been the main source of information. A small amount of information can be obtained from the *Relación de Michoacán*, which provides sufficient detail to allow some estimates of pre-Hispanic lake levels to be made. The most important source of information for the postconquest period comes from documents relating to land disputes. These frequently give detailed descriptions of the location and areas of the land involved and its distance from the town or lake shore. Of particular importance are those land disputes that involved the ephemeral islands of Apupuato and Copujo (Fig. 6.1); mention of these islands allows the level of the lake to be determined quite accurately. Additional information was also gained from a number of documents which delimited the lands belonging to individual towns. In order to prevent the haciendas from stealing land it was decreed that villages were to have all the land 600 varas from the church in all directions. If there was any natural barrier in one direction, the land would be added to another side of the boundary. Despite this decree there were continual fights with the hacienda owners and the villages over land rights. Several disputes in the Basin of Pátzcuaro gave the distance from the church to the edge of the lake is given. The data obtained from all these sources were then plotted onto maps at 1:5,000 scale, with a contour interval of 1 m (SARH, unpubl. data), which allowed estimates of the level of the lake to be made.

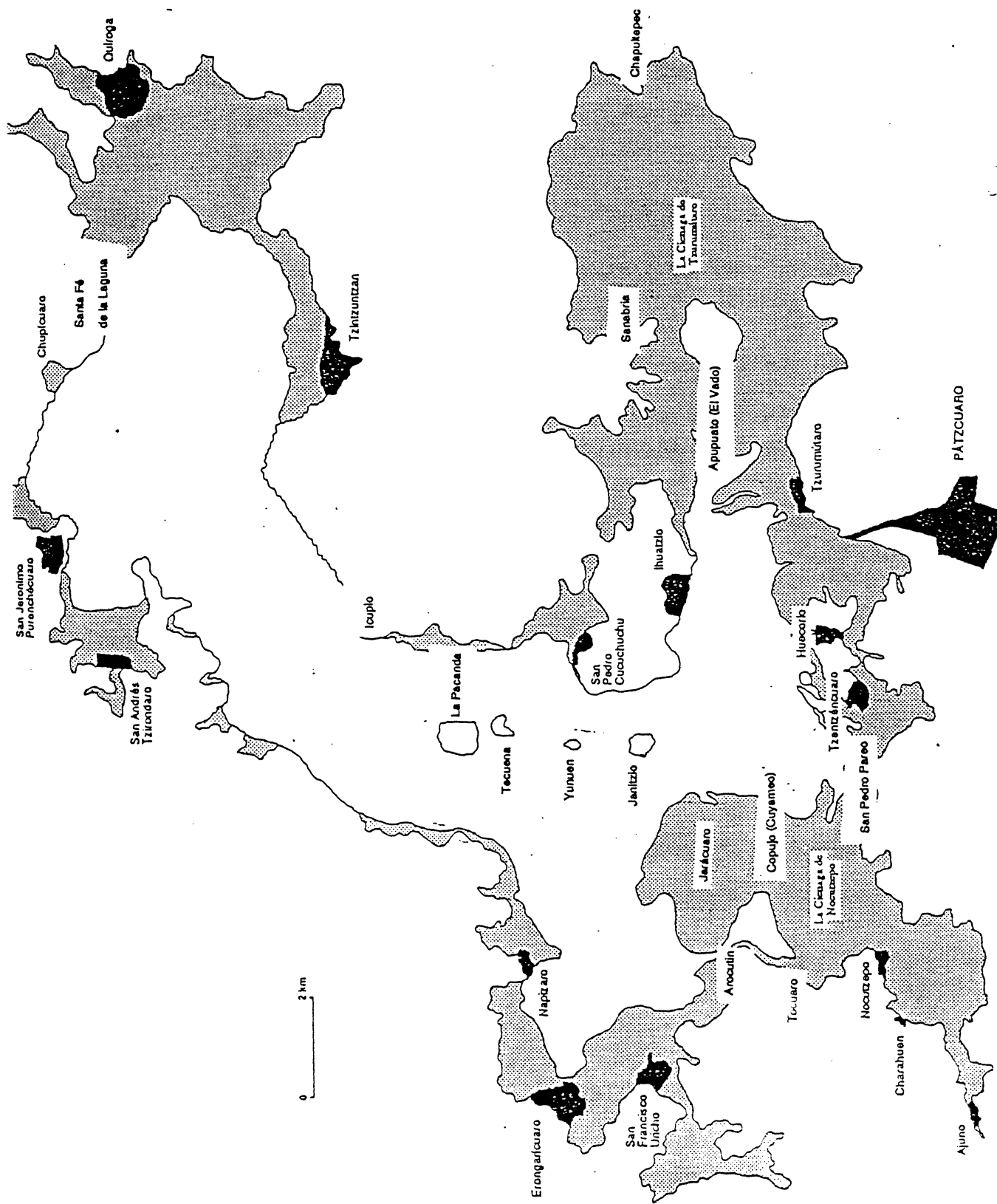


Figure 6.1 Location of the sites used to determine variations in the level of Lake Pátzcuaro.

The second major source of data was the intermittent records held by SARH which document lake level changes since the 1920s. These data were supplemented by interviews conducted in a number of towns around the lake: Tzuramutaro, Santa Fé de la Laguna, Tzentzécuaro, Ihuatzio, and the Islands of Jarácuaro and La Pacanda. The latter provide a detailed record of lake changes during the twentieth century.

6.4 THE PREHISPANIC RECORD

No pre-Hispanic documents pertaining to the Lake Pátzcuaro Basin remain; however, the *Relación de Michoacán* is considered to be a reliable source of information on the immediate pre- and post-Conquest period of this region (Warren, 1971). In the early part of the *Relacion* which describes the times of *Tariacuri* one of the most important Purépechan rulers, there are several references to a place called *Cuyameo* which is described as an island visible from Haramutaro and accessible from Uricho.

'... y venieron de largo los de una isla llamada Cuyameo, los viejos y viejas, monchacas, y otra muchos gentes, y venieron todas donde estaba Tariacuri...'

'... at length there came those from the Island called Cuyameo, old men and women, the young people and many others, and they came to where Tariacurie was...'
Relación de Michoacán, (1956) page 119.

This island has been located by Gorenstein and Pollard (1983) as present day Copujo, an area of relatively flat land which now extends from the south west shore of the lake immediately south of the Island of Jarácuaro (Fig. 6.1). The highest point on this former island is 2,041.4 m a.s.l. (SARH, unpubl. data) and thus at the time of *Tariacuri* the lake must have stood below this level. At the present time, Copujo (*Cuyameo*) ceases to be an island when the level of the lake drops below 2,039 m a.s.l. As will be discussed in Chapter Seven, sediment accumulation has occurred in this region since the arrival of the Purépecha in the Basin of Pátzcuaro. In the southern part of the lake there has been less than 1 m of sedimentation over this time. Thus, it can be safely concluded that the lake stood at a height of 2,039 ± 1 m a.s.l. at the time of *Tariacuri*.

Apart from this early reference, no other information that can be used to determine the level of the lake is available until the *Relación de Michoacán* describes the way of life in the basin immediately prior to the Conquest. Apupuato is described as an island where the Calzonzin (the Ruler of the Purépecha) stored gold, silver and ornamental feathers. This island now rises as a hill (called El Vado) to the east of the Ihuatzio basin, approximately 1.5 km inland from the AD.1988 shore of the lake. Utoyo is also identified as an island where treasures were stored and it is suggested by Gorenstein and Pollard (1983) that this refers to the present-day island of Uranden Morolos which is situated near the southern shore of the lake in front of the town of Tzentzécuaro (Fig. 6.1). A third island, Urandeni, used for the storage of gold, has been located as present day Urenden Morales (Gorenstein and Pollard, 1983). For all these sites to have been islands, the level of the lake must have been higher than 2,041.5 m a.s.l.

This description from the *Relación de Michoacán* is confirmed by the early *pinturas* of the Basin of Pátzcuaro which were drawn shortly after the Conquest. Several copies of these *pinturas* remain, the most important of which are the Beaumont map (1932; Plate 6.1) and the Seler map (1908; Plate 6.2). These maps are believed to have been drawn some years after the Conquest, possibly at the same time that the *Relación de Michoacán* was written. Although these *pinturas* differ, they show basically the same scene. The Beaumont map clearly depicts six islands: La Pacanda, Tecuena, Yunuen, Janitzio, Jarácuaro and Apupuato. A seventh island is shown on the Seler Map. In the case of the Seler Map, however, the islands are incorrectly labelled and it is not possible to determine on this basis alone which islands are depicted. It is likely, however, that six of the islands are the same as those shown in the Beaumont Map while the seventh is one of the two Uranden Islands. It seems unlikely that Cupujo (Cuyameo) is among the islands depicted as suggested by Gorenstein and Pollard (1983) since the minimum lake level required for Apupuato to become an island, 2,041.5 m, would result in Copujo being completely inundated.

The *Pinturas* can also provide us with evidence to estimate the maximum possible level of the lake at the time of the Conquest. Both the Beaumont and the Seler Maps clearly mark the town of Tzentséncuaro on the southern shore of the lake (Plates 6.1 and 6.2). This town is situated on a bedrock knoll surrounded by gently sloping terrain (Plate 6.3). If the level of the lake rose to 2,046 m this knoll would form an island. As the town is shown to be some distance from the lake shore and is never referred to as an island in any of the documents or descriptions studied, we can infer that it has never been completely surrounded by water in historical times. Based on the terrestrial record, however, it is clear that much of the sediment surrounding this knoll is lacustrine in origin and indicates that at some time in the past Tzentséncuaro has in fact been an island (see Chapter Seven). Thus, based on this information it is possible to conclude that in the immediate pre- and post-Conquest period Lake Pátzcuaro stood at a level between 2,041.5 and 2,045.5 m. As an elevation at the lower limit of this the lower range would result in Apupuato being connected to the mainland and the upper limit cause Tzentséncuaro to become an island it is concluded that a lake level of approximately 2,044.1 m is a reasonable estimate for this period. Thus not only was the lake higher than at present but the lake itself was considerably more extensive covering an area of approximately 15,048 ha compared to about 10,109 ha at present (unpubl. data. SARH). This represents an increase in the area of the lake of 67 %.

The estimated level of the lake of 2,044.1 m is not greatly different from the lower limit suggested by Gorenstein and Pollard (1983); however, it should be noted that their upper limit of 2,055 m a.s.l. would have resulted in many of the Purépechan settlements they have located in the basin being inundated by the lake.

6.5 THE EARLY COLONIAL PERIOD

During the time referred to as the Colonial Period, more detailed information can be obtained from documents and maps. Apupuato, which provides a useful marker for determining lake levels, appears to have remained an island throughout the sixteenth

century as it is clearly marked as such on two maps of México dating from AD. 1579 (Plate 6.4) and 1580. Furthermore sections of the Island of Apupuato were purchased from Dona Beatriz de Castilleja on three occasions; AD. 1597, 1598 and 1600 (AGEM, 1715). The final reference to Apupuato as an island is found in 1674 (AGN, 1674, 1730). This document details a long-running land dispute between the Haciendas of San Nicolas de Sanabria owned by the Augustines and La Tareta which belonged to the Jesuits. Part of this document, referring to the early stages of the dispute, clearly indicates that there was a bridge connecting the village of Tzuramutaro with the island and that this bridge was the scene of a number of fights between the workers of the two different Haciendas. In the review of the case, dated 1730, it is said that at the time of the original dispute that:

'...el cerro de Apupuato por los anos que expressan los titulos certificados estaba circundado de agua y a todas lados aislados...'

'...the hill of Apupuato for the years that are expressed in the certified titles was surrounded by water and isolated on all sides ...'

(AGN. Tierras 445)

It appears that the Apupuato ceased to be an island in the late 1600s. A document regarding the Hacienda of San Nicolas de Sanabria refers to this hill as '*El Vado de Apupuato...*' indicating that there was a ford at this site during this period (and it was possible to cross at this point). Certainly there is a ridge at this point which would form a causeway if the lake level dropped below 2041.5 m a.s.l. and would allow people to walk across from Sanabria to Tzuramutaro without having to go around the lake via Chapultepec.

It is important to note that although the lake appears to have remained above 2,041.5 m a.s.l. from the time of the Conquest until the late 1600s, there is some evidence to suggest that the lake was fluctuating or declining during this period. In the '*Proceso contra Don Pedro, Gobernador de Cirosoto, 1560-1564*' (The case against Don Pedro, Governor of Cirosoto, 1560-1564) it is stated that:

'...y que las dichas tierras eran laguna, y en secandose la laguna iba haciendo romper tierras de ella...'

'...and that the said lands were lake, and that when it dried he ploughed the land...'

(Lydia Espinoza, pers. comm. 1989)

A second document describing the dispute between the indigenous people of the Island of La Pacanda and the heirs of Juan Paruata and Beatriz de Castilleja (1609-1612) indicates that the level of the lake had dropped after the the death of Antonio Huitzimengari in 1562. The defendant asked the islanders if they knew

'...que distancia de tierra es la que quedo despues que la laguna fue menguando...'

'...what amount of land had remained after the lake level had dropped...'

The islanders replied

'...no saben ques cantidad de tierra es la que quedo desecada despues que la laguan fue secando y menguando...'

'... they did not know how much land was left dry after the lake had diminished...'

(cited in Alvarez y Gasca, 1952).

Thus both sides of the dispute agreed that the lake had become lower during this time. However, as Apupuato is clearly depicted as an island in AD.1579 (Plate 6.4) and 1580 and still referred to as such in 1600, it would suggest that if the level of the lake had fallen below 2,041.5 m a.s.l. during this period, it was not for a prolonged period of time.

Falling lake levels in the early part of the 18th century are confirmed by a number of documents dating to 1714 (AGEM, 1714) that make reference to the Island of Cupujo. As discussed above, Apupuato and Copujo cannot co-exist as islands and therefore the presence of Cupujo indicates that the level of the lake was below 2,041.4 m and that Apupuato was joined to the mainland. The documents discussing the Island of Cupujo all refer to a land dispute concerning the towns of Tocuaro, Arocutin and

Jarácuaro (Fig. 6.1) who all claimed that the land belonged to their community. The area of the island is given as 1.5 cabellerias, approximately 64 ha. Using the SARH maps (unpubl.), it is possible to calculate that (for the island to have been of this size) the level of the lake would have been approximately 2,039 m a.s.l.

6.6 THE EIGHTEENTH CENTURY

Apupuato ceased to be an island by AD 1715, although, there is evidence to suggest that the area to the east (of the hill) still referred to as '*La Ciénaga*' (the swamp/marsh) formed a large areas of marshland at this time and is clearly stated in a number of documents (eg. AGN, 1715). Although the lake must have fluctuated during this period there is no evidence of major changes over much of the 18th century. A map of the diocese of Michoacan from 1748 (Plate 6.5) clearly depicts Lake Pátzcuaro showing much of the southern arm to be vegetated and possibly depicts large areas of aquatic vegetation. This would suggest that this part of the lake was quite shallow at this time. Today there is a considerable amount of aquatic vegetation in this part of the lake where the depth of water rarely exceeds 1.5-2 m. It is possible that this indicates that the level of the lake in 1748 was not much different from today.

Documents from 1763, relating to the town of Tocuaro mention that in addition to the lands surrounding the town, the townspeople had access to a third part of the Island of Copujo, equivalent to one half of a cabelleria. This is the same amount designated to this town in 1714 which would suggest that there had been no significant change in the level of the lake over this period.

Two documents outlining land claims from the towns of Puacuaro (AD.1779) and Tzentzécuaro (AD. 1783) (Lydia Espinoza, pers. comm. 1989) provide us with some means of estimating the lake level at this time. In both cases the distance from the church to the shore of the lake is provided. In the case of Puacuaro it is said that from the church eastwards it was 228 varas (191.5 m) and to the south 375 varas (305 m). For Tzentzécuaro to the north it was 500 (420 m) while to the west it was 420 varas

(353 m). By plotting these on the SARH maps it is possible to determine that the level of the lake at this time was just over 2,040 m a.s.l.

Towards the end of the 17th century there is evidence to suggest that the lake level was dropping. In a document that outlines a land dispute between the towns of San Pedro Pareo on the southern shore of the lake and the Island of Jarácuaro concerning:

'... un pedazo de tierra, que ha descubiertola laguna llamadao Pazcuaro, a causa de las escasas aguas del estes ultimos anos...'

'...a piece of land that has been uncovered from the lake called Pazcuaro as a result of the scarcity of rains in the last few years...'

(AGEM, Tierras and Aguas, 1793)

Unfortunately the document only describes these lands and does not name them. However, a large flat expanse of land called Pasteuras appears between San Pedro Pareo and Jarácuaro when the level of the lake drops below 2,038.5 m. If the level of the lake drops to about 2,035.5 m a.s.l. it is possible to walk from San Pedro Pareo to Jarácuaro. It seems likely that the piece of land in dispute was this area of land.

6.7 THE NINETEENTH CENTURY

Little information was found concerning the early part of the 19th century. This may be due to the fact that for the first part of this century there was considerable upheaval in México. The War of Independence which resulted in México becoming a Republic in 1821 was followed by a long period of domestic strife and civil unrest. Michoacan was very much at the forefront of this trouble and it is possible that documents were not kept or that civil procedures that had taken place under Spanish law were not the same under Mexican law. Certain bound documents pertaining to land disputes and sale of land are available to the end of the Colonial period but after this are difficult to find until the late part of the 19th century when Porfirio Diaz came to power.

Other lines of evidence, however, suggest that the level of the lake dropped during the first half of the 19th century. According to local history the Island of La Pacanda was fortified during the middle part of the 19th century by General Epitacio Huerta (Salas, 1956; Toledo et al., 1982). It is possible to see the upper part of this wall today although it is still partially submerged (Plate 6.6). This suggests that the level of the lake during construction of the wall must have been slightly lower than the 1989 level of 2,036.8 m a.s.l.. Toissant (1942), however, noted that there is nothing to document the construction of a fortress on the Island and goes on to say that it appears unlikely that the General would build a fort on an island that could be easily blockaded.

A similar fortification was constructed around the Island of Janitzio during the War of Independence although it has now been totally dismantled for building material. It is possible that La Pacanda was fortified at the same time. Although it is not possible to conclude the exact timing of the construction of this wall it was certainly built prior to the 1940s as it was during this period when the lake dropped to ^avery low level and the wall was rediscovered (Sr. Ramirez, pers. comm. 1989).

During 1841, Pátzcuaro was visited by the English woman La Senora Calderon de la Barca who wrote a diary of her travels through México (Calderon de la Barca, 1843). Her book describes in great detail the landscape and terrain through which she was passing. She arrived in the Basin of Pátzcuaro from Morelia via '*La Puerta de Chapultepec*' (Fig. 6.1). From there she travelled to Tzintzuntzan and it is not until she arrives there that she mentions the lake. It is possible that the lake was so low at this time the first time she could have seen the lake would have been when she arrived at Tzintzuntzan. Had it been high she would have first seen the lake when she arrived at Sanabria.

Interviewees from the towns of Ihuatzio and Tzurumutaro all recalled that when much of the southern arm of the lake dried out in the 1940s and 1950s the remains of many tree trunks were uncovered. These formed distinct rows as if deliberately planted to delimit fields. It is unlikely that this was done prior to the Conquest and it is possible

that these were planted during the 18th century when the lake is believed to have stood at a very low level.

One of the most interesting documents concerning the lake relates to the Island of Janitzio. The document dated 1882, provides clear evidence that the level of the lake rose substantially in the latter part of the 19th century. It states that;

'...por cause del ascenso progresivo que se nota en las aguas del lago desde el temblor del 19 julio de 1858, llegando hoy a una nueva altura de ocho varas sobre el nivel que tenia su superficie antes de ese ano, habian caido sucesivamente ciento veinte casas invadidas por el agua...'

'... due to the progressive rise that has been seen in the lake waters since the earthquake of 19th July 1858 the lake has today reached a new level 8 varas (6.7 m) above the level of its surface prior to that year and 120 houses have collapsed as a result of inundation by the waters...'

(cited in Bogrand, 1965)

Assuming that the lake stood at approximately 2,036 m a.s.l. in the mid-1800s it must have risen to approximately 2,043 m a.s.l. by 1882. There is a considerable amount of evidence confirming that the level of the lake stood at a higher level at this time. Villarello (1909), for example, stated that:

'El nivel de las aguas en el lago de Pátzcuaro ha ido descendiendo con gran lentitud en el transcurso de los anos; y ahora se encuentran en la Hacienda de Charahuen, al Poniente de Pátzcuaro tierras cultivados que antes estuvieron cubiertos por las aguas del lago. Este descenso del nivel de las aguas ha permitido bajar y acortar el camino que va de Pátzcuaro para Huricho y Erongarícuaro.'

'The level of the waters of Lake Pátzcuaro have been slowly descending over the years and now at the Hacienda de Charahuen to the west of Pátzcuaro there are cultivated lands that before were covered by lake waters. This decrease in the level of the lake has allowed the road from Pátzcuaro to Uricho and Erongarícuaro to be lowered and shortened.'

(Villarello, 1909)

In addition, a small jetty used by the Hacienda of Charaguén during the latter part of the 19th century is now situated over 3 km from the lake shore at an elevation of approximately 2,043 m a.s.l. This clearly indicates that the lake stood at a higher elevation and covered a much greater extent than today.

6.8 THE TWENTIETH CENTURY

Evidence of changes in the level of Lake Pátzcuaro during the 20th century comes from two main sources; a series of interviews that were carried out in several of the villages that border the lake and actual gaugeboard readings of the height of the lake which began in the 1920s.

Interviews were carried out with the older members of a number of lake side communities with the aim to establish whether or not they could recall if the lake had been higher or lower than present during their lifetime. As discussed above in the early part of the 20th century Villarello (1909) noted that the level of the lake had dropped in recent years. Two women from the town of Santa Fé de La Laguna aged approximately 85 and 90 years both recalled the lake being considerably higher than present when they had been children. Both remembered that the lakeshore during the 1910s and 1920s covered the line of the present road from Morelia to Guadalajara which would suggest that the lake stood above 2 040 m a.s.l. Serafino Telavera Alejandre an 86 year old miller from Ihuatzio, also noted that the lake had been much higher when he had been a child recalling times when the level of the water in *La Ciénaga* was so high that the road had been periodically inundated. This observation was also confirmed by Sr Anastacio Martinez Gonzalez an 87 year old man from the town of Tzuramutaro. A map constructed in 1906 (Plate 6.7) shows that *La Ciénaga* covered a large area at this time although it was not connected to the lake. A number of the older residents from the town of Tzentzencuaro remembered that during the early part of this century the lake shore had skirted the north and western part of the lake. All the people interviewed who could recall the early part of this century commented that Lake Pátzcuaro had stood at a level much higher than present in the early years of this century. Certainly photographs believed to have been taken in the 1920s and 1930s clearly indicate that the lakeshore bordered Apupuató at this time (Plate 6.8), whereas today it stands over 1.3 km from the

lakeshore.

Numerous interviewees recalled that the level of Lake Pátzcuaro dropped significantly during the 1940s and 1950s. Between 1939 and 1941 the lake was monitored on a daily basis by De Buen and Zayoza (1942). They concluded that during the year its level fluctuated by approximately 0.8 m but over the period 1939-1941 they recorded an actual drop in mean level of 0.8 m. It should be noted that there appears to be quite a discrepancy between the gauge board used by De Buen and that currently being used. The level of the lake as recorded by De Buen and Zayoza (1942) on the 1st August 1939 was 2035.41 m a.s.l. while on April 19th 1989, SARH recorded a lake level of 2,036.76 m a.s.l. This would suggest that the level of the lake in the late 1930s^{and} early 1940s was lower than at present. In view of the fact that the jetty on the Island of Jarácuaro in 1938 is now situated approximately 2.7 m (Plate 6.9) above the lake, indicating a drop in the level of the lake over this period, it is believed that one or both of the scales gaugeboards is at the wrong elevation. As present figures are based on a geodetic point they are probably more accurate.

The level of the lake began dropping in the 1940s and 1950s before reaching a recorded low in 1955 (SARH, unpubl. data). The level of the lake at this time is believed to have been 2033.7 m a.s.l. There are numerous accounts of the desiccated nature of the lake at this time. San Pedrito which had formerly been a small island became connected to the land and has been this way ever since. Residents on the Island of Jarácuaro recalled that it was possible for the bus to go directly from San Pedro Pareo to the Island where there is now lake. Similarly the people of Ihuatzio were able to walk directly from Ihuatzio to Tzuramútaru across the dried out lake bed.

In 1953 the problem of water transport in this region was so severe that the local communities began to excavate a channel through the marsh so that canoes could be used to cross the lake. The severity of this period of lake desiccation becomes more obvious when it is realized that only 35 years before it had been possible to bring a small steam boat into this region which had become a marsh in the 1950s (Plate 6.10).

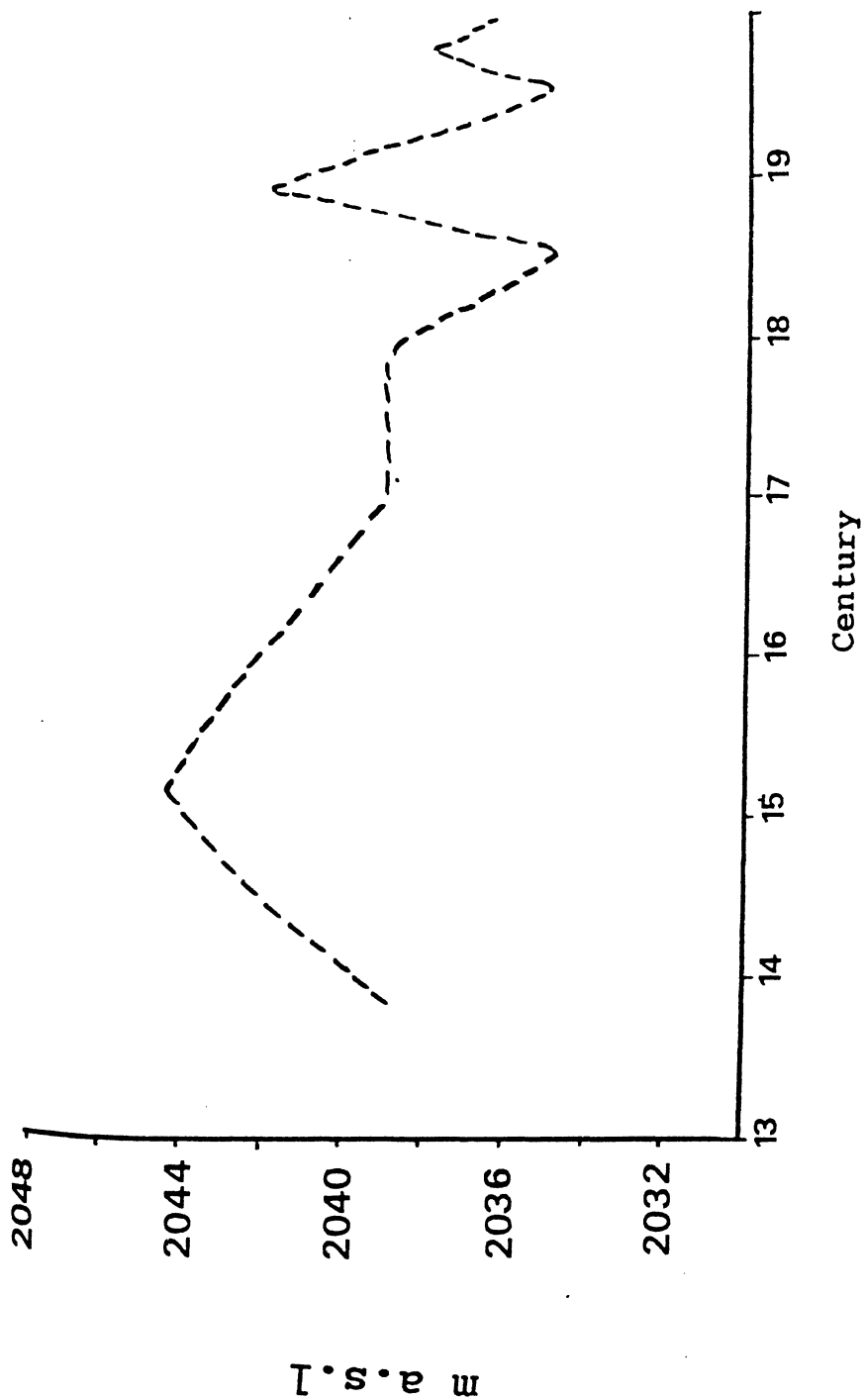


Figure 6.2 Fluctuations in the level of Lake Pátzcuaro over the last 600 years.

They also suggested that the lake had dried out to the same extent in past periods as there are numerous accounts that when the lake level dropped in this period numerous drowned walls and tree trunks that had been planted in a linear fashion were exposed. This would suggest that the lake had stood a low level for a considerable period in the past.

In 1967 the lake level began rising again. This was in part a result of the complete draining of the region known as *La Ciénaga de Chapultepec* to the east of the lake and to the west of the lake *La Ciénaga de Nocupetzo*. During the 1980s the level of the lake began to decline once again to the point where there is considerable concern as to the future of the lake (Plate 6.11).

6.9 DISCUSSION

The level of Lake Pátzcuaro has fluctuated considerably over the long and short term. Figure 6.2 shows the general trend in the level of the lake since the late 1300s. It is suggested that at the time of *Tariacuri* ca. 1380 the water surface stood at a level of approximately 2,039 m a.s.l., but rose sometime during the 15th century to a new height of approximately 2,044 m a.s.l. by the time the Spanish arrived in this area in AD. 1522. It is possible that this rise in the level of the lake was in response to a slight change in the climate. Metcalfe (1987) suggested that the Aztec period approximately 600-460 years B.P. (ca. 1325-1521 A.D.) was characterized by conditions wetter than present, and that during this time the level of the lakes in the Basin of México rose considerably. The rise in the lake levels in the Basin of México was not constant, however, (Torquemada, 1615, cited in Metcalfe, 1987) and while there were considerable problems with flooding in the early part of the 15th century, the lake dropped substantially in the late part of the 15th century to the point where it was difficult for canoes to bring food to the Island of Tenochtitlán. By the time of the arrival of the Spanish the lake had risen once again and it was necessary for Cortés to use ships on his assault of the island. Unfortunately the information available for Lake Pátzcuaro is not

sufficient to draw more than the general conclusion that the lake rose between 660 and 460 years B.P (AD. 1390 and 1522).

While the level of Lake Pátzcuaro fluctuated throughout the 16th century there is no evidence to suggest that it dropped below the level of 2,041 m a.s.l. during the period AD. 1522-1680, although it undoubtedly experienced frequent and possibly quite large fluctuations. The overall trend during this period, however, is one of falling lake levels. By 1715 the lake had dropped from the level of approximately 2,044 m a.s.l., recorded at the time of the Conquest, to about 2,039 m a.s.l. There is evidence that Pátzcuaro suffered considerable earthquake damage in 1702 (AGEM, 1702); however, there is insufficient information to determine whether this influenced the level of the lake. It is more likely that the decrease in the level of Lake Pátzcuaro was in response to drier climatic conditions and certainly there is evidence to suggest that Central México experienced somewhat drier conditions during this period (Metcalf, 1987).

The latter part of the 18th and early 19th centuries were characterized by periods of intense drought conditions (Metcalf, 1987). Florescano (1980) attempted to trace the history of drought in México using information from crop yields. These data, together with evidence of hydraulic works in the Basin of México, have been used by Metcalf (1987) to establish a sequence of droughts for this period. Droughts in the 18th century were coupled with frost suggesting a more meridional atmospheric circulation (Metcalf, 1987). The droughts of the early part of the 19th century which affected the whole country helped trigger the Revolution of Hidalgo (1810) which led to the eventual independence of México. It is suggested that these droughts resulted in the gradual lowering of the lake during this period. Certainly there is evidence that the level of the lake dropped in the latter part of the 18th century due to a lack of rain (AGEM, 1793).

The rise in the level of the lake between 1858 and 1882 is attributed by the Islanders of Janitzio to the massive earthquake of 1858. As the rise was over a period of years it is unlikely that it was due to movement of the basin floor. It is also unlikely that the lake-level increase was due to climatic factors, as the Central plateau (including the

Neo-Volcanic Axis) experienced severe drought conditions in the latter part of the 19th century which intensified to extreme drought conditions in the early decades of the 20th century (Metcalf, 1987).

Lake Pátzcuaro is fed in part by groundwater springs and it is possible that a greater amount of water reached the lake after the 1858 earthquake as a result of the opening up of springs into the lake. Locals reported that a number of springs appeared in the areas around Ihuatzio after the earthquake of 1985 which does suggest that basin hydrology can be affected by such events.

The drop in the level of the lake at the turn of this century reported by Villarello (1909) was probably a response to the extremely arid conditions experienced throughout this area at this time. Prolonged periods of drought at this time resulted in a numerous crop failures, and was probably one of the main factors that triggered civil unrest and eventually led to the Mexican Revolution.

For the twentieth century, there are more specific data available on fluctuations in the level of the lake. Chacon Torres (1989) has published a water-level curve from the 1920s until the present day from which it is evident that even over this short period the lake has experienced quite considerable variations. In general, these changes appear to be closely related to changes in the climate and it appears that the lake will respond quite rapidly to even the slightest changes in the input/output ratio. As discussed in Chapter 2, his simulation of observed and expected lake levels based on precipitation and evaporation data shows that there is a strong positive correlation between the two. He did note that the correlation between the two in the latter part of 1942 was less positive and suggested that earthquake activity in association with the eruption of Paracutin may have affected the hydrological cycle. While this may be the case it is more likely that the drop in the level of Lake Pátzcuaro during the 1940s and 1950s was a result of considerably less than average rainfall throughout this period.

A rise in the level of Lake Pátzcuaro during the mid-1950s was probably a response to wetter climatic conditions, although it has been suggested that the draining

of the *Ciénaga of Tzurumutaro* and the *Ciénaga de Nocupetzo* introduced a substantial volume of water to the lake and may have augmented this rise (CESE, 1986).

Since 1977 the level of Lake Pátzcuaro has shown a gradual decline. This has been concomitant with a reduction in precipitation over this period (Chacon Torres, 1989). However, the problem is being exacerbated by the increasing quantity of water that is being utilised by local people for irrigation and domestic purposes. The area of *La Ciénaga de Tzuramutaro* is intensively irrigated and much of the water that formerly entered the lake from this part of the basin no longer does so. In addition, large quantities of water are removed from the lake to irrigate agricultural land around Erongarícuaro and Quiroga. This problem is highlighted by the fact that in the period 1988-1990 when the area received above average rainfall the lake continued to register a sharp fall while other lakes in the region, for example Lake Chapala, have begun to rise.

6.10 CONCLUSIONS

The level of Lake Pátzcuaro has fluctuated quite considerably over the last 660 years. Many of these changes are quite significant and will have resulted in quite considerable changes in the volume of the lake. It is evident that the lake does respond very rapidly to changes in the prevailing climatic conditions and thus, is sensitive to climatic change. Although climatic factors have been the main cause of lake level variations over the last 600 years it is evident that tectonism could be a significant factor in causing lakes to rise and fall in this region. The ever increasing quantities of water that are being extracted or prevented from reaching the lake are beginning to have effect on the level of the lake and in recent years the lake has continued to fall despite above normal rainfalls.

CHAPTER SEVEN: THE TERRESTRIAL RECORD

7.1 INTRODUCTION

Bordering Lake Pátzcuaro are alluvial, colluvial and lacustrine deposits (Fig. 7.1). In many parts of the basin, in particular the southern section, these form relatively low-angled surfaces. In recent years the area of these deposits has increased significantly as a result of a rapid lowering in the level of the lake.

A preliminary investigation of these deposits has been made by Street-Perrott *et al.* (1989) who concluded that the Lake Pátzcuaro basin has suffered at least two periods of disturbance over the last 2,300 years. In view of these findings, it was decided that the terrestrial stratigraphic record would provide an important source of information on the erosional history of the Pátzcuaro Basin, and might at the same time shed further light on past lake levels. In addition, information gained from studying the stratigraphic sequence of sediments surrounding Lake Pátzcuaro could complement the investigation of the lacustrine record.

As mentioned above the sediments that have accumulated around the lake are made-up of alluvial, colluvial and lacustrine sediments. At most of the sites examined it was not possible to distinguish between alluvial and colluvial deposits, however, most of these deposits appeared to be colluvial in nature displaying features that suggested material transported by wash and mass movement processes. Thus, in this thesis all material that has been washed from the slopes will be referred to as colluvial regardless of the form of transport.

In this study, sixty-four sections were logged in the sedimentary deposits which surround the lake (Fig. 7.1). Due to the large number of sites studied, samples were only collected from every other section, unless more detailed analyses were required. In general, samples were taken every 15-20 cm except where major stratigraphic changes were observed, where a smaller sampling interval was used. Most of the main embayments around the lake were investigated. Each of these areas will be described

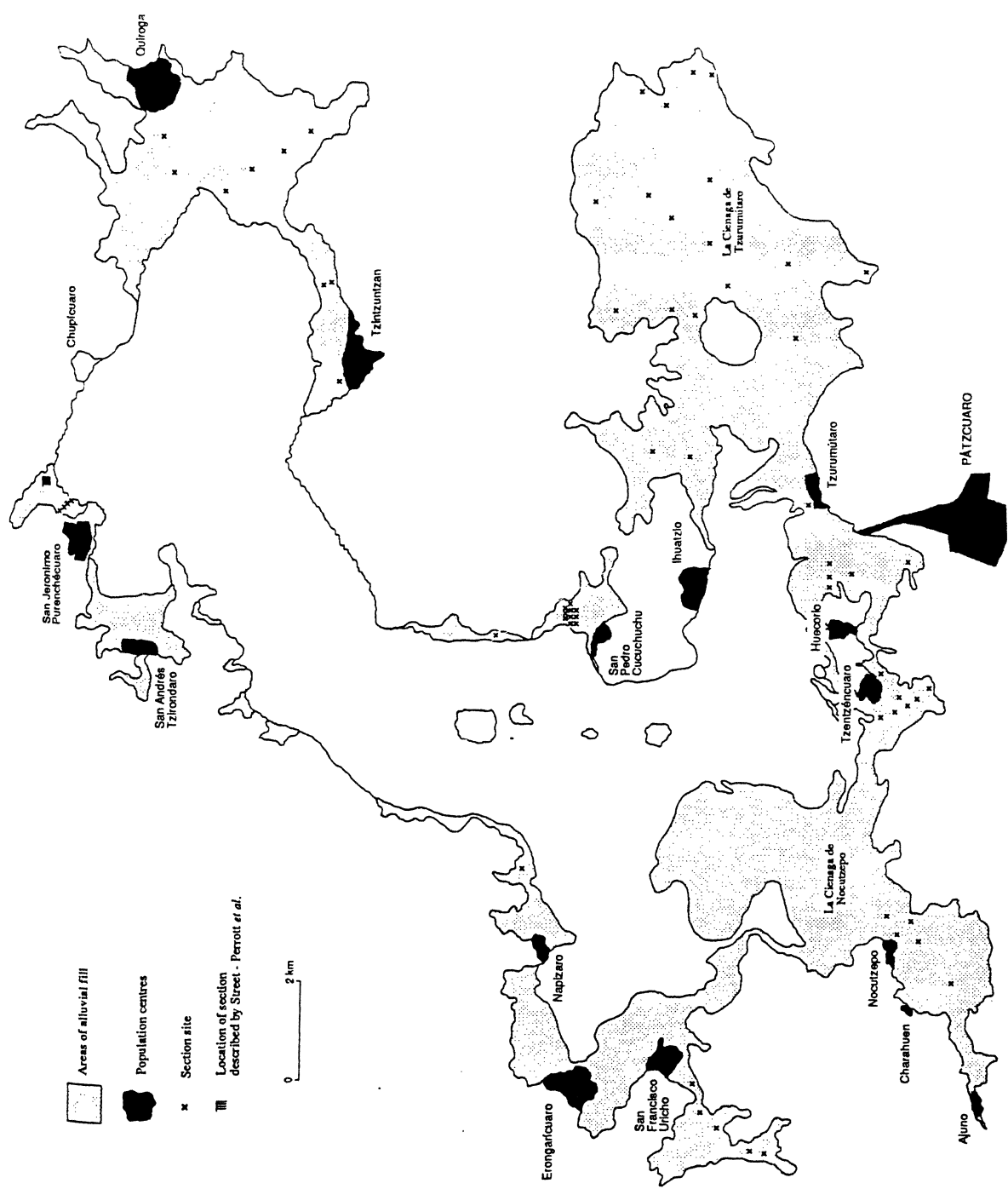


Figure 7.1 Location of the terrestrial sites investigated in the Basin of Pátzcuaro.

Lake #	Stratigraphic Association	Date	Material	1911		2012	
				AD	c.	AD	c.
OxA-2817	LP. 11/80, cm	1190 ± 70	ostracods	AD	c. 720-945	AD	c. 680-975
OxA-2818	LP. 11/130, cm	2650 ± 60	ostracods		c. 900-800 BC		c. 990-600 BC
OxA-2819	LP. 11/174, cm	3640 ± 70	ostracods		c. 2135-1925 BC		c. 2285-1780 BC
OxA-2820	LP. 5/100, cm	1580 ± 60	shell	AD	c. 415-550	AD	c. 340-600
OxA-2821	LP. 5/153, cm	2920 ± 80	ostracods		c. 1260-1015 BC		c. 1385-920 BC
OxA-2822	LP. 12/30, cm	480 ± 60	shell	AD	c. 1405-1450	AD	c. 1315-1490
OxA-2823	LP. 19/150, cm	880 ± 60	ostracods	AD	c. 1030-1245	AD	c. 1020-1260
OxA-2824	LP. 19/223, cm	2530 ± 60	ostracods		c. 800-540 BC		c. 810-410 BC
OxA-2825	SPC. 3/155, cm	740 ± 100	shell	AD	c. 1215-1295	AD	c. 1040-1410
OxA-2851	SFU. 1b/210, cm	270 ± 60	charcoal	AD	c. 1515-1950	AD	c. 1460-1950
OxA-2852	SFU. 2/160, cm	90 ± 60	charcoal	AD	c. 1680-1950	AD	c. 1660-1950
OxA-2853	SFU. 3/41, cm	180 ± 60	charcoal	AD	c. 1650-1950	AD	c. 1640-1950

Table 7.1 Radiocarbon dates from the lake sediment and terrestrial sections.

separately and the results outlined under the sub-headings of the Southern, Central and Northern Basins. A series of slope profiles were also constructed using the detailed topographic maps provided by SARH (unpubl. data). These are at a scale of 1:20,000 with a 1 m contour interval. The locations of these slope profiles are shown in Figure 7.2.

Unfortunately, a long delay occurred during the shipment of these samples to England. For a period of nine months they were kept in storage on the docks at Veracruz, during which time mice entered the crate and took up residence. These 'squatters' like to utilise plastic in the building of their nests (Viles, pers. comm. 1990) and proceeded to destroy many of the plastic bags in which samples had been placed. When the crate eventually arrived in England over one half of the samples had been rendered useless. Consequently, results from this part of the study have been severely affected and rely mainly on field descriptions rather than laboratory analyses. More detailed analyses have been carried out on a limited number of sites that were logged and sampled in 1987. The results from these sites will be given in detail where available.

7.2 THE SOUTH BASIN

The majority of sites investigated were situated in the southern part of the basin where the deposits are best exposed. A total of 7 areas were examined in detail (Fig. 7.1); the results from each different area will be described separately in an anti-clockwise direction from San Francisco Uricho in the southwest to Ihuatzio in the south-eastern part of the study area (Fig. 7.1).

7.2.1 San Francisco Uricho (SFU)

San Francisco Uricho is a small town located on the south-western shore of the lake (Fig. 7.1). During Prehispanic times it was here that canoes for the fishermen of Lake Pátzcuaro were made. Both behind and in front of the town there are gently sloping colluvial deposits which are currently under intense cultivation. A deep gully originating in the sierras behind the town incises these deposits, exposing thick

sequences of sediment (Plate 7.1). Five profiles were logged and sampled in this gully (see Figure 7.3 for locations) and are shown in Figure 7.4.

Based on the stratigraphy exposed down the gully it is possible to distinguish three stratigraphical units. Unit 1 consists of <62 cm of structureless, yellowish-brown (10YR 4/6) colluvium, rich in charcoal. This unit is only exposed at SFU1. These sediments contain approximately 10% organic content and are low in carbonate. Although very variable, X is very high being between 900 and 1,400 E-06 kg m⁻³. X_{fd} is between 6 and 7%. A large quantity of charcoal was found at the boundary between Units I and II (Plate 7.4). Fragments of this charcoal have been dated to 270+/-60 years B.P. (OxA-2851). This date provides a minimum age for the deposition of Unit I.

Unit II, consists of <30 cm of well-rounded gravels. This unit was exposed at SFU1, and at the base of the profiles SFU2 and SFU3 (Fig. 7.4). The gravels are clast held and are well drained. At SFU3 they exhibit a distinct fining up sequence with clasts as large as 30-40 cm at the base, to 2-3 cm in the upper part of the unit.

A second colluvial deposit, Unit III, exhibits similar characteristics to Unit I. This deposit is recognised at all five profiles investigated. A slight coarsening upwards of the sediment is noted in this unit and becomes more marked downstream. Unit III contains between 8 and 11% organic material, while carbonate content is low, generally <2%. This unit is characterised by high levels of X (900-3,400 E-06 kg m⁻³), with occasional large peaks seen. However, there is little consistency between profiles probably as a result of continual reworking of the sediment down valley, so that it is not possible to make any correlations on the basis of X . Perhaps more interesting at this site are the results of X_{fd} which like the other two units is high being between 6 and 9 % indicating that this sediment is of highly weathered nature most likely material weathered and transported from the upper slope region. At SFU5, at the mouth of the valley, distinct bedding was observed, suggesting deposition under fluvial conditions. The coarsening down valley probably reflects the fact that these sites are closer to the sediment-source area.

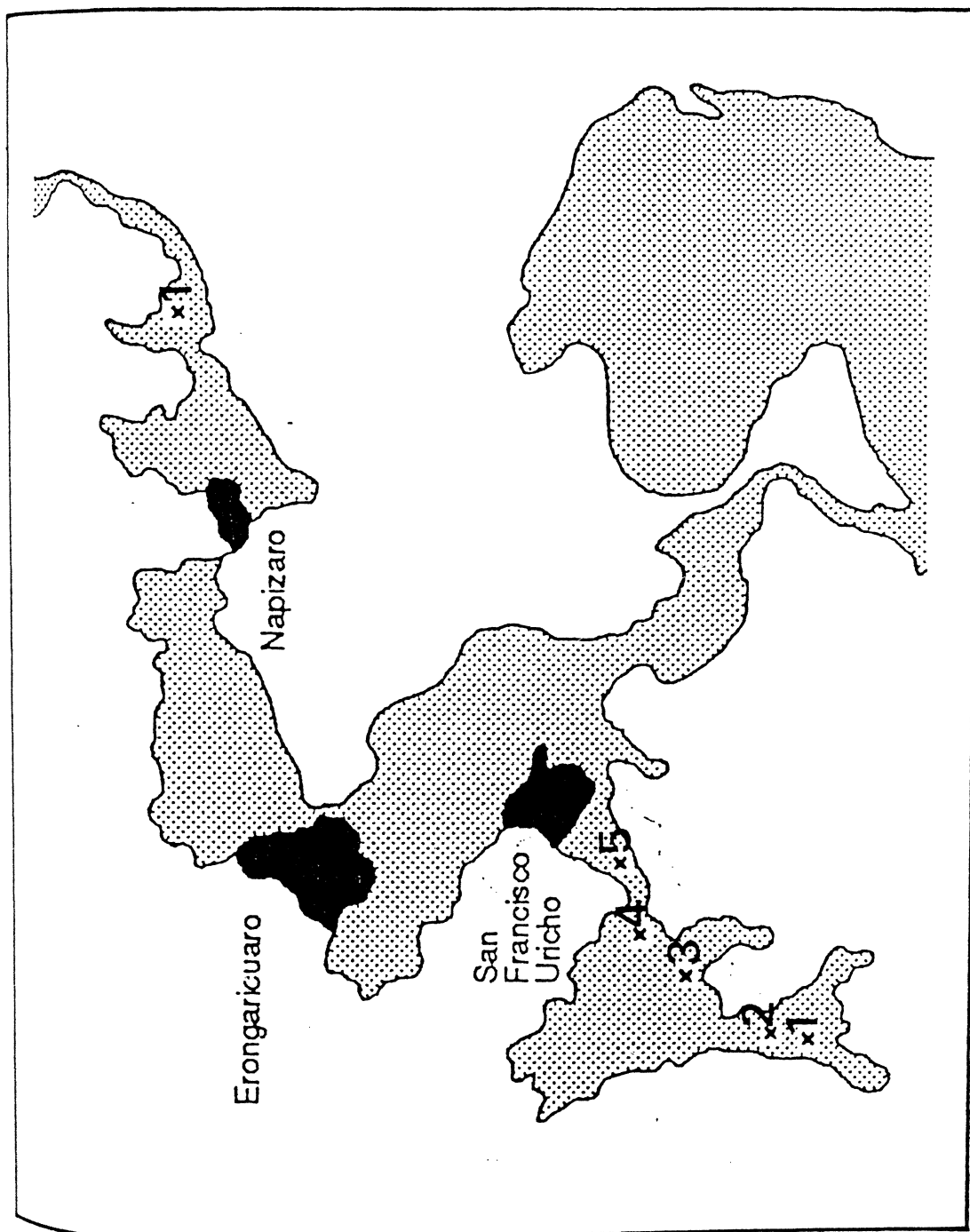


Figure 7.3 Location of the profiles investigated at SFU.

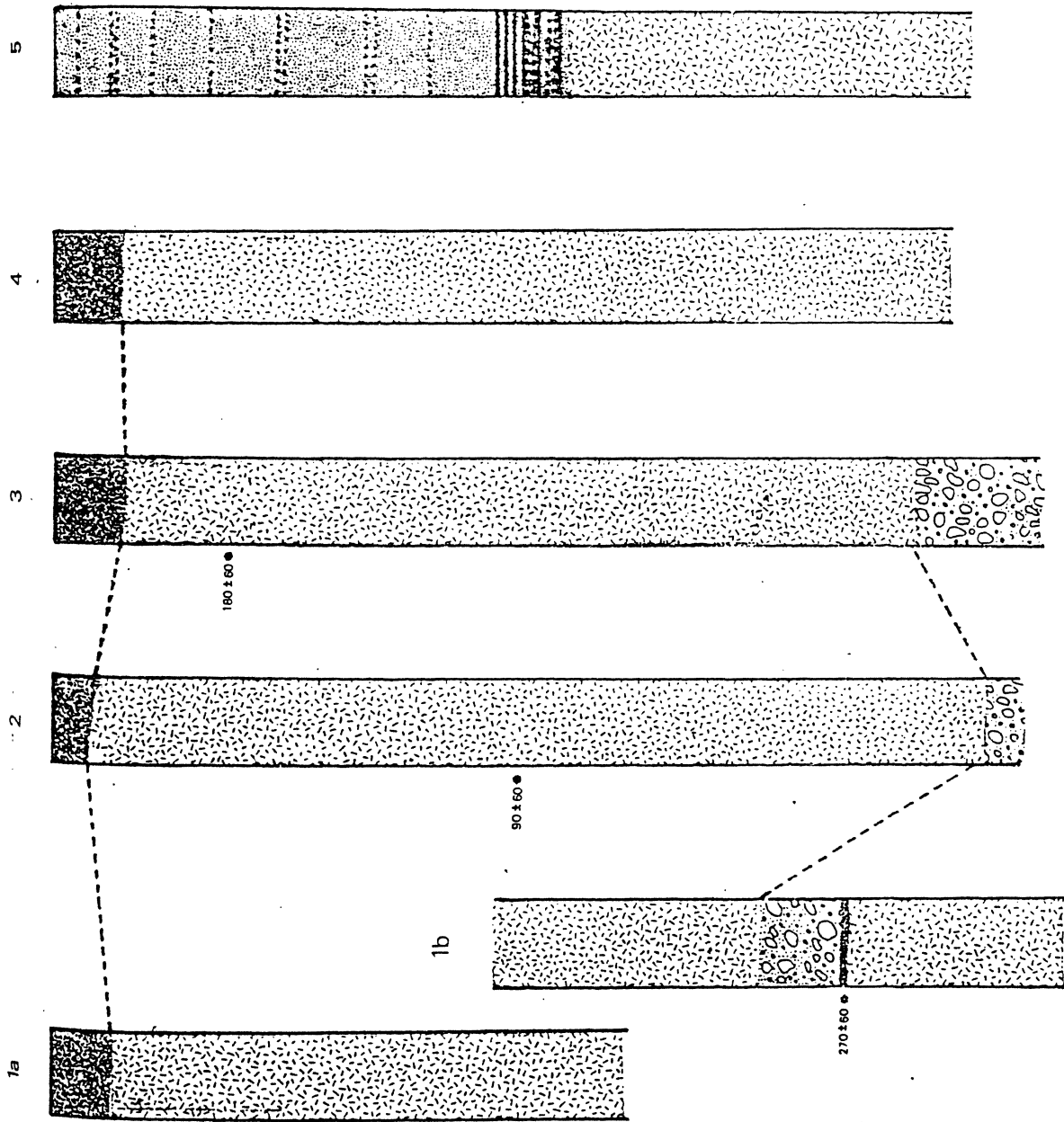


Figure 7.4 The stratigraphy of the the SFU profiles.

Charcoal fragments are found throughout this deposit and two ^{14}C dates were obtained on samples collected from Unit III. These dates are 90 ± 60 years B.P. (OxA-2852) at SFU2 (162 cm; Fig. 7.3), and 180 ± 60 years B.P. (OxA-2853) at SFU3 (41 cm; Fig. 7.3). These dates suggest that most of this colluvium is fairly recent, and are not unlike those obtained by Street-Perrott *et al* (1989) on their site in the northern part of the basin (Fig. 7.1). Initially it was believed that the two colluvial units recognised corresponded to those described by Street-Perrott *et al* (1989),^{and} the dates obtained on these sediments suggest that Units II and III have accumulated relatively recently, it is not possible, however, to determine when Unit I was deposited. Unfortunately, there are problems with ^{14}C dates in this time span (Stuiver and Pearson, 1986) and even though these dates suggest that this sediment was deposited in the Posthispanic period it is possible that deposition began during the late Postclassic.

7.2.2 Ajuno

The Ajuno valley is located on the south-west margin of the lake. It forms an elongate, steep sided valley which is believed to have formed part of the ancient fluvial system that flowed through the area prior to the closure of the basin (Barrera, 1986). Until recently this area formed a swamp known as 'La Ciénaga de Nocutzepo', which was artificially drained between 1962 and 1967 (CESE, 1988). Apart from the upper part of the valley near the town of Ajuno, the gradient of the valley floor is very low and at approximately 2 km from the lake lies less than 6 m above the 1988 lake level (Fig. 7.5). A distinct break in slope is observed at 2.042m a.s.l. in the vicinity of Charagüén, corresponding to a narrowing of the valley (Fig. 7.1 and 7.5).

Five sites were logged and sampled in the valley of Ajuno (Fig. 7.1 and 7.6). These lie along a general SW-NE line running from the central part of the valley south of the village of Tocuaro, towards the lake shore. The stratigraphy exposed at the five sites in the Ajuno Valley consists of lacustrine and colluvial sediments (Fig. 7.7). When these sites are seen in their relative heights and positions in the valley (Fig. 7.5) it is evident