GEOLOGICAL AND MINERALOGICAL INTERPRETATION OF SHALLOW SEDIMENTS FROM THE NORTHEASTERN GRAND BANKS OF NEWFOUNDLAND

by

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ABSTRACT

The clay-sized minerals from 13 sites (51 samples) on the northeastern Grand Banks of Newfoundland have been analysed using X-ray diffraction and scanning electron microscope techniques. This data has been incorporated with pebble lithological and borehole stratigraphic analysis to provide additional information regarding the physical and chemical processes in the region from approximately mid-Tertiary times to the present.

Two chemical environments are interpreted for the shallow geology of the northeastern Grand Banks of Newfoundland based on clay mineralogy, color and the presence/absence of shells. In addition, three major stratigraphic units have been further defined to depths of 130 m below the seabed using the preceding criteria. These are as follows: 1. the uppermost Late Pleistocene/Holocene sediments; 2. the uppermost weathered zone of Tertiary marine deposits; 3. the underlying thick sequence of Tertiary marine deposits.

1. The uppermost Late Pleistocene/Holocene sediments which consist of gravels and sands (< 4 m thick; locally as only a thin veneer) are predominantly clay poor. Although the sands and gravels probably consist of reworked material, the clays generally reflect a northern provenance, having high average concentrations of illite (28%), quartz (14%), and feldspar (19%) along with a chamosite component. These clays have predominantly been deposited as a result of ice transport mechanisms. Where the signature varies to include expandable minerals (0-24%) and kaolinite (0-15%), it is probable that clays found within the

uppermost zone of weathered Tertiary marine sediments (directly underlying the Late Pleistocene/Holocene sediments) have been incorporated into the Late Pleistocene/Holocene regime by scouring ice which has broken through the desiccated crust of the unconformity. They could also be remnants of the underlying Tertiary sediments that were not completely removed from the area during transgression approximately 10,000 years ago. An increase in sodic feldspar contents as well as a general increase in the angularity of clay-sized minerals is seen in deeper waters (125 m) to the east of the Hibernia P-15 wellsite. This could reflect the less energetic reworking of particles at these depths under the present oceanographic regime.

2. The uppermost zone of weathered Tertiary marine sediments exhibits relatively high contents of kaolinite (7-18%) and high concentrations of expandable minerals (avg. 29%), as well as a clinochlore component not seen in Late Pleistocene/Holocene clays. The sediments change from a pale yellow color in the Late Pleistocene/Holocene to a dull olive brown in the underlying Tertiary unit. It is expected that this relatively thin subsurface weathered zone is composed of sediments derived by reworking and chemical alteration of the directly underlying Tertiary marine sediments. The presence of kaolinite is attributed to the leaching environment which accompanied subaerial exposure of the study area approximately 15,000 to 10,000 years ago. For the formation of kaolinite from such minerals as montmorillonite, labradorite and illite, the acidity would have had to have increased to a pH of 4 and conditions of oxidation would have prevailed. The absence of shells from this

interval is a further indicator of an acidic environment. This weathered Tertiary unit has an increase in silt/clay constituents and is hard and dense. The latter factor is attributed to subaerial weathering processes.

3. The lowermost unit (sampled to 130 m below the seabed) is comprised of eastward thickening and dipping olive colored Tertiary marine sediments which were deposited during transgressive and regressive phases. These sediments show a general coarsening upward trend, although all contain a predominance of very fine sand/silt/clay components. Expandable minerals (avg. 45%) constitute the highest abundance of clay-sized materials, which vary from almost 100% montmorillonite to 100% swelling chlorite. No pebbles > 28 mm were found in any of the cores, with the highest percentage of pebbles existing in samples from the Ben Nevis I-45 borehole.

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1. INTRODUCTION AND SCOPE OF THE STUDY

The purpose of this study is to analyse the geological and clay mineralogical characteristics of shallow Hibernia sediments, and where possible, correlate similar intervals throughout the area. Clay mineralogy is considered to be a useful indicator of the chemical environment in which these minerals were formed. This is particularly true in areas affected by subaerial weathering such as the depth interval between 70-110 m on the northeastern Grand Banks of Newfoundland which was exposed during times of low sealevel stand, approximately 15,000 to 10,000 years ago (Fader and King, 1981; Lewis and Barrie, 1981; and Barrie et al., 1984). Information regarding this weathered zone can be correlated geophysically (Vol. 2), lithologically and mineralogically on a regional scale.

The data base for this study (Figs. 1, 1a) consists of samples provided by Mobil Oil of Canada Ltd. from three geotechnical borehole sites drilled in 1980: Hibernia B-08 and O-35, and Ben Nevis I-45 (Geocon, 1980a, b, c). In 1983, three more geotechnical boreholes were drilled at the C1A, E1A and W1/W1A sites. Dr. C.F.M. Lewis co-ordinated a vibrocoring program in 1983 from the **CSS HUDSON** (Lewis, 1984); six of these vibrocores (HU83-017-5, 6, 8, 10, 14 and 16) have been studied. In addition, Petro-Canada has provided samples from their K-18 geotechnical borehole site which was drilled in 1984.

The clay mineralogy from 13 sites (51 samples) has been analysed using X-ray diffractometry and the scanning electron microscope to delineate the mineralogical changes in the < 2 micron sediment size fraction for the northeastern Grand Banks of Newfoundland. It was anticipated that these changes would occur both laterally and vertically throughout the greater Hibernia region as a result of weathering (mechanical and chemical), current winnowing (transport), differential flocculation and coagulation within the marine environment, and possibly local in situ formation. As well, the clay minerals are considered to be significant indicators of source and environment for the parent rocks from which they are derived.

Pebble lithologies for the Tertiary sediments have been analysed with the use of a binocular microscope (Fig. 18, Table 3). Grain size analysis of sediments supplied by Mobil Oil of Canada Ltd. have been determined for the C1A, E1A and W1/W1A borehole sites by mechanical seiving and pipette techniques (Fig. 17). These data have been incorporated with the work of Barrie et al. (1985) to expand their Holocene reconstruction of the geology of the northeastern Newfoundland shelf to approximately mid-Tertiary times.

2. GEOLOGICAL SETTING

The study area (Figs. 1, 1a) encompasses approximately 1,700 km^2 of the continental shelf off the coast of Newfoundland in water depths ranging from 70-120 m. Both regional and site specific studies have been conducted by King and Fader (1980, 1985), Amos and Barrie (1980), Fader and King (1981), Lewis and Barrie (1981), Barrie et al. (1984, 1985) and Lewis (1984), particularly with respect to Late Pleistocene/Holocene sedimentation.

Barrie et al. (1984, 1985) identified five sediment facies for the uppermost Late Pleistocene/Holocene sands and gravels which are < 4 m thick (Fig. 1). From west to east these are: 1. Sand Ridge Facies, 2. Grand Banks Gravel Facies, 3. Boundary Sand Facies, 4. Log Gravel and Sand Ribbon Facies, and 5. Continuous Sand Facies. They determined that these facies (with the exception of the easternmost Continuous Sand Unit) were under the influence of north-south to northnortheast-southsouthwest currents, predominantly storm-induced.

It is expected that these sand and gravel facies were derived from previously existing Tertiary marine or glacially-derived sediments which were reworked during transgression approximately 10,000 years ago (King and Fader, 1980, 1985; Fader and King, 1981; Lewis and Barrie, 1981; Barrie et al., 1984, 1985). Glaciers and pack ice originating in Greenland and/or the Canadian Arctic islands contribute minimally to the sediment supply off the east coast of Newfoundland at present (Fader and King, 1981; Lewis and Barrie, 1981; Barrie et al., 1984, 1985; Snelgrove, 1984). Except for this input, the region is sedimentologically starved.

King and Fader (1980, 1985), Hunter (1981), Fader and King (1981), Lewis and Barrie (1981) and Barrie et al. (1984, 1985) noted an unconformity directly underlying the Late Pleistocene/Holocene sands and gravels which had a much greater sound velocity than the overlying sediments on seismic profiles.

This seismic reflector was termed the "Tertiary unconformity". Below this reflector they encountered gently eastward dipping reflectors which terminated against the unconformity and were interpreted as Tertiary marine sequences. Arthur et al. (1982) determined that the sequence of prograded Tertiary beds comprised of fine sands, silts and clays is approximately 1.5 km thick.

3. METHODOLOGY

Pebble lithologies (Fig. 18) from 9 samples (5 locations, Fig. 1a) were examined using a binocular microscope and classified as igneous, sedimentary (siliciclastic and carbonate) or metamorphic. Detailed descriptions of the pebbles are given in Table 3. Grain size analysis (Fig. 17) using mechanical seive (1/2 phi intervals) and pipette techniques were obtained for 12 samples (3 sites) of Tertiary marine sediments.

Techniques used in the preparation of samples for clay mineral analysis followed a combination of standard procedures (Table 2). Although contamination was minimal, none of the samples was received intact and all had undergone varying archival procedures. The Hibernia 0-35, B-08 and Ben Nevis I-45 samples were dry when received, however this did not appear to affect the clay mineral properties investigated. All of the samples were prepared for X-ray analysis by the author in the Departments of Engineering and Earth Sciences at Memorial University of Newfoundland.

Visual examination showed organic content to be very low in all samples, so the dissolution by treatment with H_2O_2 was not undertaken. The removal of silt from the < 2 micron size fraction was initiated by settling in the presence of sodium hexametaphosphate. Flocculation was induced by the addition of 4 mL of 1 N $MgCl_2$ solution. The Mg^{2+} treatment was necessary to develop uniform cation saturation since the nature of cations in interlayer spaces can affect the expansion of expandable clay minerals (Cody and Thompson, 1976). The samples were then centrifuged and treated with sodium citrate and sodium thiosulphate to remove amorphous free iron oxides (Mehra and Jackson, 1960). The sodium hexametaphosphate was removed by washing prior to mounting the samples for analysis.

Although some untreated slides were prepared for comparison, it was decided that an internal standard was necessary because of the numerous difficulties resulting from differences in mass absorption characteristics within samples and between samples and analytical standards (Cody and Thompson, 1976). Therefore, all samples were spiked with a 10% talc internal standard as proposed by Heath and Pisias (1979) for the determination of the relative abundances of clay minerals. In addition, selected samples (Table 2) were treated by heating with concentrated (12N) HCl for 15 minutes. These samples were then allowed to settle using a vacuum apparatus onto 0.45 micron porous filters and mounted on glass slides. Selected samples were also heated at 110° and 250°C to remove loosely bound water from mineral phases. In most instances it was possible to differentiate the 0.354 nm chlorite peak from the 0.358 nm kaolinite peak. It was therefore considered impractical (because of the filter mounts) and unnecessary to remove the chlorite component by heating to 550°C.

3.1 External Standards and Quantitative Aspects

Analytical clay standards obtained from Ward's Natural Science Ltd. were prepared with a talc internal standard in keeping with the above methodology and X-rayed to determine weighted peak-area percentages. It was found that weight ratios of clay minerals (i.e. chlorite, kaolinite, illite and montmorillonite) corresponded quite well to Biscaye's (1965) weighting factors. Thus, the following peaks and weighting factors were used: the area of the 1.7 nm glycolated peak area for montmorillonite; four times the 1.0 nm peak area (glycolated pattern) for illite; and twice the 0.7 nm chlorite/kaolinite peaks. The 0.7 nm chlorite/kaolinite peak was apportioned using Biscay's (1965) ratio $\frac{0.358 \text{ nm peak area}}{0.358 \text{ nm} + 0.354 \text{ nm peak areas}}$.

Because of the differences in crystal structure, the talc internal standard was considered inappropriate for abundance determinations of quartz (0.426 nm), feldspar (0.325-0.318 nm), amphibole (0.842 nm) and pyroxene (0.299 nm). These four clay-sized minerals were thought to comprise a significant proportion of some samples and could not be discounted. Weighted ratios of feldspar (Ca and K), amphibole (hornblende) and pyroxene gave approximate weighting factors of 2 when varying known quantitites were X-rayed with known quantitites of clay minerals. Of the seven samples tested in this manner, weighting factors ranged from 1.5-2.2, 1.8-2.0, 1.9-2.2 for the feldspars, amphiboles and pyroxenes, respectively. Because of the difficulties inherent in the science of X-ray diffractometry, it was thought that a factor of 2 was appropriate for these minerals. Semi-quantification of quartz proved laborious, time-consuming and generally unsatisfactory. However, the importance of quartz as a clay-sized constituent in the < 2 micron range required that it be considered. Purchased standards were found to be too finely powdered to give satisfactory diffractogram patterns, and various sizes of the mineral had to be manually prepared in the laboratory. A 2 micron sample was derived by trial-and-error which produced acceptable peak areas. When apportioned and ratioed with clay and clay-sized minerals, the weighting factor for quartz was found to range from 1.2 - 1.5. A weighting factor of 1.3 was decided on for quartz, in keeping with results obtained by Mann and Müller (1980) for clays from the western North Atlantic.

3.2 Precision of Relative Abundances

It must be stressed that the percentages calculated for these samples are semi-quantitative at best, and reflect only the relative abundances of the identified minerals. Sources of error include: 1) lack of electronic precision in the X-ray circuits; 2) human error in area measurements; 3) slight changes in humidity and/or temperature; 4) the small size (approximately 45 cc) of the original sample; 5) the lack of successive runs on most samples for testing of consistency of results; 6) the presence of mineral phases which cannot be accounted for. Uncertainty could be greatly reduced by X-raying each slide several times and averaging the results. Because of the number of samples, and time required to perform multiple scans, this task was not undertaken.

Percent error noted in Table 1 for the bulk mineralogy is based on the weighted peak areas. Where these values are very high, the error is attributed to poorer crystallinity and/or an abundance of amorphous phases. As such, the percent error is also only a relative and semi-qualitative value.

In general, all the clay-sized minerals are well-crystallized to very well-crystallized. The description of order or crystallinity used within this study is relative within these bounds. Therefore, a mineral described as poorly crystallized is only poorly crystallized with respect to the other minerals studied here.

3.3 XRD Identification of Clay-Sized Minerals

The clay mineral groups observed in this study were identified by their characteristic basal X-ray diffraction reflections (peaks). Where these peaks overlap or where the crystallinity of the minerals makes identification difficult, the method of interpretation is noted in the detailed sample analyses (Appendix B).

3.3.1 Chlorite

Characteristic chlorite reflections are observed at 1.4 nm (001), 0.7 nm (002), 0.472 nm (003) and 0.353 nm (004). Biscaye (1965) reported that a partly expandable vermiculite-type mineral present in some original wet samples could alter to chlorite upon drying. If this is the case, the Hibernia B-08, 0-35 and Ben Nevis I-45 samples could have been affected; however, this factor is not taken into account in this study.

Carroll (1970) proposed a number of discernible features which can be used to identify chlorites; six of these have been utilized.

1) Most Mg- and low Fe- chlorites give a clear sequence of the first four or five basal reflections measured from d (001) = 1.4 + nm.
2) Fe-rich chlorites (chamosites) give weak 1st and 3rd basal reflections but strong 2nd and 4th order basal reflections.
3) The d (001) at 1.4 + nm will not expand upon glycolation.
4) With warm HCl treatment, well-crystallized chlorites tend to dissolve slightly, the less ordered chlorites dissolve to a greater degree.
5) The (001) reflection of Fe-chlorites (chamosites) could increase in intensity upon heating; Mg-chlorites (clinochlores) increase more.
6) Fe-chlorites are destroyed by boiling in HCl, while Mg chlorites are not as easily destroyed.

Schoen (1962) and Griffin et al. (1968) among others have summarized methods for the semi-quantification of the increase in the heavy atom (Fe + Mn + Cr) population of the chlorite octahedral layers. The ratio of the $\frac{(002 + 004)}{003}$ peak intensities described by Griffin et al. (1968) has been used here.

3.3.2 Swelling Chlorite

Swelling chlorites are complex minerals which have d spacings in the vicinity of 2.8 nm which increase to approximately 3.2 nm with the absorption of ethylene glycol (Brindley, 1972). Like chlorites, the Fe-rich varieties dissolve in acid. Heating at temperatures < 300°C for 1 hour will collapse swelling chlorites. These criteria have been used to tentatively identify swelling chlorite in this study, although there is some uncertainty when distinguishing swelling chlorite from vermiculite.

3.3.3 Illite

The basal sequence 1.0, 0.5, 0.33, and 0.25 nm not affected by glycolation characterizes the illite group, with the 1.0 nm and 0.5 nm peaks being the most useful for semi-quantitative evaluation. Kelly (1983) has noted that a ratio of 1.0 nm/0.5 nm peak intensities from 4 to 10 implies the presence of trioctahedral mica (biotite).

Identification of mica polymorphs in most of the samples in this study is made difficult due to the weakening of diffraction peaks by dilution of other clay minerals. Where the asymmetric 1.0 nm peak decreases in size upon glycolation and a diffuse 0.55

nm to 0.52 nm peak appears, the difference is attributed to interstratification with expandable minerals. Expandable minerals are considered to contribute < 20% if there is no shift in the position of the 1.0 nm peak (Kelly, 1983).

3.3.4 Vermiculite

Brown's (1972) criteria is used to distinguish vermiculite which is identified at 1.4 nm (001) and will not expand much beyond this with glycolation. It is not altered by acid, but dehydrates in steps.

3.3.5 Kaolinite

Kaolinite d reflections are noted at 0.715 nm (001), 0.358 nm (002); 0.235 nm (003) and 0.179 nm (004) (Brown, 1972). Only the (001) and (002) reflections were sufficiently intense for recognition in these samples. A slow scan (1/4° 2θ per minute) over the 0.35 nm reflection region was necessary for determining the individual contributions of chlorite and kaolinite to the 0.7 nm peak.

3.3.6 Montmorillonite

The (001) reflection of montmorillonite increases from an irrational series of peaks at approximately 1.5 nm to rational spacings at about 1.7-1.8 nm with glycolation (Brown, 1972). Most montmorillonites are not affected by acid treatment (except Ca-varieties) and dehydrate only by heating at temperatures >

300°C. This characteristic was used to distinguish montmorillonites from swelling chlorites.

3.3.7 Feldspar

Brown (1972) has summarized the work of Goodyear and Duffin (1954) who listed the characteristics for distinguishing plagioclase from alkali feldspars. These are as follows:

1) two very strong reflections in the 0.317-0.322 nm region;
2) a medium reflection of spacing 0.64-0.65 nm;
3) three medium to strong reflections with spacings 0.403-0.405, 0.374-0.378, and 0.361-0.367 nm.

It is also found that calcic plagioclases dissolve to some extent upon treatment with HCl.

3.3.8 Quartz

Although the 0.334 nm (101) peak of quartz is significantly more intense than the (100) peak at 0.426 nm, it nearly coincides with the strong (003) reflection of illite at 0.334 nm. For this reason, the area under the 0.426 nm peak has been utilized for identification and semi-quantification of quartz. This procedure was used by Biscaye (1965).

3.3.9 Amphibole

The d-spacing at 0.84-0.85 nm was used to identify amphiboles (Jackson, 1956). This spacing corresponds to the perfect cleavage plane of most amphiboles (Biscaye, 1965).

3.3.10 Pyroxene

Pyroxenes were identified in the 0.294-0.302 nm range in keeping with procedures used by Mann and Müller (1980). Pyroxene did not form a significant component in any of the samples analysed and in many instances it is not present.

4. RESULTS

The data analysed in this study, particularly the clay mineralogy, can be classified according to stratigraphic unit. These units are as follows: 1. Late Pleistocene/Holocene clays, 2. clays from the uppermost Tertiary marine sediments, and 3. Tertiary clay-sized mineralogy.

4.1 Late Pleistocene/Holocene Clays

The majority of samples from Holocene sediments come from the HU83-017-5 (0.88 m, 1.42 m, and 1.89 m), HU83-017-6 (0.42 m, 0.94 m, 1.32 m), and HU83-017-8 (1.00 m) vibrocores (Figs. 1 and 2). Vibrocores HU83-017-6 and HU83-017-8 were taken from the northern portion of a sand ridge (Lewis, 1984; Barrie et al., 1984, 1985).

The clay mineralogy (Table 1, Fig. 2) for the uppermost portion of vibrocore HU83-017-6 (0.42 m) is dominated by well-crystallized illite and chlorite (approximately 40% of each); this assemblage is often equated with northern latitude provenances (Chamley, 1979). Expandable minerals form only a minor component of the clay mineralogy (8%). Feldspar varieties are either potassic or sodic in composition. Concentrations of feldspar range from 14% in vibrocore HU83-017-6 to 19% in vibrocore HU83-017-8. Figure 3 from vibrocore HU83-017-8 (1.00 m) shows a potassic feldspar grain and two authigenic calcite floccules. It is of interest to note relatively high kaolinite contents at depths of 0.94 m (15%) and 1.00 m (9%) in vibrocores HU83-017-6 and HU83-017-8, respectively.

Illite is the dominant clay-sized mineral (49%) in a suite of poorly-crystallized phases at 1.32 m depth in vibrocore HU83-017-6. Significant quantities of apatite (up to 10% of the clay-sized assemblage) are also in evidence (Fig. 4).

Vibrocore HU83-017-5 (Figs. 1 and 2) was collected from the southern portion of the same sand ridge as vibrocores HU83-017-6 and HU83-017-8 (Lewis, 1984; Barrie et al., 1984, 1985). Illite, chlorite, quartz and feldspar form the major components of the clay-sized minerals. The < 2 micron size range generally comprises less than 0.5% of the total sediment fraction. There also appears to be a high abundance of amorphous phases.

At 0.88 m, the clay-sized mineral suite consists predominantly of illite (47%) and quartz (32%). Figure 5 shows two larger calcite crystals and smaller quartz and illite grains.

At 1.42 m the clay mineral assemblage somewhat resembles that found in vibrocore HU83-017-6 at 0.94 m. Relative abundances of kaolinite, illite and feldspar are 13, 27 and 27%, respectively. Glauconite is also found in this interval (Fig. 6). Both SEM and XRD data indicate the feldspar (13%) is a highly weathered potassic variety. The EDX results suggest the feldspar has a Fe-oxide coating (Fig. 7). It is probable that these clays were derived from the underlying weathered zone of Tertiary sediments.

Vibrocore HU83-017-16 was collected from the Boundary Sand Unit (Barrie et al., 1984, 1985). This site occurs to the south and east of the Hibernia P-15 wellsite in water depths of 85 m (Fig. 1). At 1.98 m the clay-sized mineral suite is typical of other Holocene sediments with illite (29%), feldspar (27%) and chlorite (22%) forming the bulk of the assemblage as interpreted from X-ray diffractograms. Calcium phosphate dominates the SEM photograph depicted in Figure 8.

Further to the east in the Continuous Sand Unit (Barrie et al., 1984, 1985), angular well-crystallized sodic feldspar (67%) (Fig. 9) dominates vibrocore HU83-017-14 at 1.48 m (Fig. 1). From the small number of vibrocore samples studied, it appears that clay-sized feldspar contents increase to the east in deeper waters, as does the crystallinity of clay-sized minerals in general.

4.2 Clays from the Uppermost Tertiary Marine Sediments

As seen by the significant change in color, seismic reflectivity (Vol. 2) and mineralogical abundances (Fig. 2) in vibrocore HU83-017-5 between 1.89-2.04 m, it can be assumed that the Tertiary unconformable surface occurs in this interval. The change is denoted by a marked increase in expandable minerals, chlorite, and kaolinite and a notable decrease in illite, quartz and feldspar. Similar relative abundances of minerals are seen in the Hibernia W1A borehole to the north. Chlorites differ in this interval, being well-crystallized, with a probable significant clinochlore component for the uppermost Tertiary sample, while the overlying Late Pleistocene/Holocene and underlying Tertiary marine sediments consist predominantly of chamosites. Poorly crystalline Fe swelling chlorite (a chamosite-like mineral?) however, is assumed to form a major proportion of the expandable mineral phases based on XRD studies.

Below the pale yellow or light grey Late Pleistocene/Holocene sediments there is a change in color to olive brown. The sediments are more resistant to penetration. At 2.04 m in vibrocore HU83-017-5, there is a significant increase in the expandable minerals content (from 4% at 1.89 m to 34% at this interval). These expandable minerals are considered to be predominantly swelling chlorite based on the X-ray diffractograms, but it is possible that iron-rich smectites (montmorillonites) also exist (Fig. 10). The notable Fe staining of quartz grains from this interval and the olive brown color of the sediment sample in general indicates there was abundant iron present which could have been incorporated within the lattices of more loosely bound mineral phases. Figure 10 depicts what is interpreted to be a swelling chlorite or nontronite, a ferric, Fe-rich smectite. Acid treatment on samples from this interval and X-raying indicate a clinochlore component as well as a well-crystallized variety of chamosite. This differs from Holocene sediments, where the chlorite is predominantly Fe-rich. The feldspar is potassic or sodic in composition. Kaolinite contributes approximately 7% to the clay-sized suite.

At 2.67 m in vibrocore HU83-017-5, expandable minerals (29%), chlorite (25%) and illite (26%) closely approximate the relative abundances found at 2.04 m. Kaolinite increases significantly to 16%, indicating an acidic leaching environment at the time of formation. This is environmentally compatible with the interpreted sodic to intermediate composition for the feldspar. Relatively high kaolinite concentrations (15% at 0.94 m in vibrocore HU83-017-6 and 13% at 1.42 m in vibrocore HU83-017-5) above the unconformity are possibly a result of the mixing of the underlying Tertiary sediments with the Late Pleistocene/Holocene sands. This mixing could occur as a result of scouring by ice or dredging by fishing trawlers through the hard crust of the unconformity.

Although the author has not noted gibbsite within this unit, Barrie et al. (1985) have tentatively identified its presence. Gibbsite has been experimentally formed from aluminum-interlayers in montmorillonite under experimental conditions at a pH of < 4.3 (Barnhisel and Rich, 1963).

The Ben Nevis I-45 samples which are located in deeper water (101 m) to the southeast of the Hibernia P-15 wellsite show high kaolinite concentrations at 3.0-3.7 m (18%). Figure 11 shows the presence of plagioclase feldspar and glauconitic illite at this interval. The presence of biotite is noted (Fig. 12).

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4.3 Tertiary Clay-Sized Mineralogy

Significant trends appear to exist down section in the Tertiary sediments with respect to clay mineralogy. Figure 13 shows a composite of clay mineralogical relative abundances for Hibernia sites B-08, 0-35, C1A, E1A and W1/W1A, surrounding the P-15 wellsite. The clay mineralogy for the Petro-Canada K-18 wellsite at the southernmost point of the study area is depicted in Figure 14.

Kaolinite occurs only in minor quantities (approximately 2-6%) throughout the samples examined. In general it is well-ordered and its abundance seems independent of increases or decreases of other minerals. Illite concentrations are largely independent of those of other minerals, although they fluctuate in amount (8-52%). The illite in most samples is interpreted to be of a muscovite variety and is generally interstratified with < 20% of expandable minerals (probably vermiculite). Illite concentrations are erratic in the upper 50 m. Below this depth they are somewhat reduced and percentages do not vary as greatly as above.

The relative abundance of what is interpreted to be a chamosite variety of well-crystallized chlorite forms an interesting contrast with the quantities of expandable minerals throughout the 130 m section. The concentrations of these mineral phases appear inversely related (Fig. 13). Where the expandable minerals increase in content, chlorite decreases. Part of the reason for this negative correlation could be that samples with the highest expandable minerals content are largely composed of interstratified swelling chlorite with lesser amounts of montmorillonite and/or vermiculite.

The concentration of kaolinite remains relatively constant (between 4 and 9%) below 3.7 m at the Ben Nevis I-45 borehole site (Fig. 15). Illite abundances fluctuate, but in general decrease with depth. Below 16 m chlorite and expandable minerals exhibit the same inverse trends as those which occur in the vicinity of the Hibernia P-15 wellsite. The Ben Nevis I-45-12 interval could correlate with the Hibernia E1A-83 interval, while other similarities seem to exist for the I-45-13/E1A-85, I-45-14/E1A-90, I-45-17/C1A-87, and I-45-18/W1-70 samples.

5. DISCUSSION

The 13 sample sites throughout the northeastern Grand Banks of Newfoundland have been correlated from the seabed surface to maximum depths of 130 m where this information exists. Three major sedimentary units are in evidence on the northeastern Grand Banks. These are: 1. the uppermost Late Pleistocene/Holocene sediments; 2. the uppermost weathered zone of Tertiary marine sediments; 3. the underlying thick sequence of Tertiary marine deposits.

When analysing clay mineralogy for the purpose of detecting the source environment, the effect of sea water on clay minerals must be taken into consideration. Carroll and Starkey (1960) found that when treated for 10 days in sea water, the removal of SiO_2 and Al_2O_3 from clay minerals occurred in the order: montmorillonite>mixed-layer mineral>illite>kaolinite. In montmorillonite, the effect of sea water was to increase the amount of exchangable Mg^{2+} and reduce the amount of exchangable Na^+; exchangable $Mg2^+$ also increased in illite (Carroll and Starkey, 1960). This is because sea water contains a variety of dissolved solids and gases, and in systems containing more than one cation, the cation having the mean free bonding energy takes the positions on the clay mineral surface having the highest bonding energy (Carroll and Starkey, 1960). Therefore, Na^+ fills sites of weaker negative charge while Ca^{2+} and Mg^{2+} are bonded to the sites of strongest negative charge (Carroll and Starkey, 1960). Buckley (1972) and Carroll (1958) have also noted this process of halmyrolysis, or general process of interaction between minerals and their changing chemical environment.

Carroll (1958) has noted that in an unrestricted marine environment with little or no bacterial activity, the sediments (i.e. clays) deposited would be similar in color to those being transported to the sea. This is because the iron oxide films on the clay minerals would be stable on the clay particles and no removal would take place (Carroll, 1958).

5.1 The Uppermost Late Pleistocene/Holocene Sediments

This unit ranges from a maximum of 4 m thick to only a thin veneer within the study area. These sediments are considered to consist of reworked earlier deposited glacial material or older underlying marine deposits (Barrie et al., 1984, 1985; Fader and King, 1981; Lewis and Barrie, 1981). Iceberg rafted debris also contributes minimally to the total sediment supply of the area.

No large rivers drain into the eastern continental shelf off the coasts of Newfoundland and Labrador, so the present supply of sediments to this area is probably limited and consists of the ice-born supply or minute particle sizes which are carried as suspensates in the ocean waters. These particles or floccules are deposited onto the seafloor under particular conditions of salinity, concentration and the ability of these particles to flocculate. Barrie et al. (1985) note that the sands in this unit are pale yellow in color. Clay mineralogical analysis in this study has shown that the coloration is due to the presence of iron (Fe^{2+} and Fe^{3+}) present in such mineral phases as chlorite and illite.

Minor amounts of iron oxide coatings prevalent in the uppermost zone of weathered Tertiary marine sediments which directly underlie the Holocene sands, could be incorporated to some extent by events which disturb the upper 1-4 m of the seabed. It is therefore expected that the intensity of the color of the total sediment fraction would vary slightly throughout the area.

The minor quantities of Late Pleistocene/Holocene clay-sized minerals (0-2%) in the <2 micron size of the total sediment fraction indicate that much of these components have been winnowed out of the sands and gravels over the last 15,000 years or in fact, were never present. Of the Late Pleistocene/Holocene sediments studied, the clay-sized fraction averages 0.2% by weight of the total sediment sample. In general, Late Pleistocene/Holocene clays exhibit signatures of a northern latitude provenance, having high concentrations of illite accompanied by varying proportions of quartz, chlorite, feldspar and amphibole. Abundant possible sources such as the Precambrian sediments and volcanics of the Avalon Zone (King, 1982) exist for illite and chlorite. These sediments could have been transported eastward into the study area by glacial activity as postulated by King and Fader (1985). Weathering of shales in the Canadian Arctic Islands and the igneous rocks of coastal Labrador are other possible sources (Hiscott, 1984). Metasediments in the Makkovik sub-province could have contributed to the illite/chlorite suite seen here (Greene, 1974).

The dominance of calcium phosphate in the SEM photograph from vibrocore 16 (Fig. 8) indicates that the calcium phosphate could form as a cementing agent at this interval. The phosphate enrichment could be due to the upwelling of cold waters of the Labrador current which would produce an influx of phosphate to the area (D.E. Buckley, personal communication).

Watanabe and Tsunogai (1984) have studied phosphate enrichment in a coastal sea (Funka Bay, Japan) and discovered maxima for March-April and July-August. They attribute the large seasonal variation in interstitial phosphate to the adsorption and desorption of interstitial phosphate coincident with the depth of the active sulfate reduction layer. Phosphate is easily adsorbed onto surface sediments under oxic conditions and desorbed from them under anoxic ones. In the study area, phosphate could be adsorbed onto solid phases (i.e. clay minerals) during an influx of organic matter which consumes oxygen at the bottom interface, brought about by input from the Labrador current. Watanabe and Tsunogai (1984) have suggested that the adsorption of phosphate occurs even in a weakly reducing environment.

At the HU83-017-6 vibrocore site (0.42 m) the clays exhibit characteristics similar to those of the Tertiary weathered zone materials (a relatively high content of kaolinite and expandable phases) in addition to the dominant chlorite-illite assemblage common to Late Pleistocene/Holocene sediments. These sediments are interpreted to have been combined with those of the Late Pleistocene/Holocene unit from the underlying sequence by scouring of the seabed (possibly by icebergs). In time it is considered that these clays will either be removed from the area by resuspension during violent storm surges, or more probably masked by burial from the slow bedload transport of sand from the north or north west (Barrie et al., 1985). Conversely, it is also possible that these clays are the last remnants of material that was removed from the area during transgression. This could explain the weathered Tertiary signature (high percentages of expandable minerals and kaolinite) along with clay mineral assemblages indicative a northern latitude provenance (high quartz, illite and chlorite abundances).

While no previous studies of the clay mineralogy have been conducted on sediments from the northeastern Grand Banks of Newfoundland, some investigations have been carried out to the north, northeast, and south of the study area. Piper and Slatt (1977), Alam and Piper (1977, 1981) and Piper et al. (1978)

examined surficial and cored sediments from the eastern continental margin of Canada. They determined that the surficial Late Pleistocene/Holocene clay-sized sediments were dominated by illite (> 60%) and chlorite (< 25%) with lesser amounts of quartz (< 10%), feldspar (< 10%), kaolinite (0-10%), montmorillonite (0-10%) and amphibole (< 5%). In most of their samples from the northeastern Newfoundland shelf, montmorillonite was present, but kaolinite was absent, suggesting dominant Tertiary lithologies (Piper and Slatt, 1977). They attribute higher quantities of clay-sized feldspar and quartz and dominance of illite/chlorite assemblages to local source derivation, primarily from the Precambrian and lower Paleozoic igneous and sedimentary rocks found on the Island of Newfoundland and adjacent offshore areas. These data correspond to Unit A of Piper et al. (1978) in cores obtained from 50°N, north-east Newfoundland shelf, which contain approximately 70% illite, with subordinate chlorite and rare montmorillonite and kaolinite. Although illite was by far the most abundant clay-sized mineral found in the surficial continental shelf sediments studied here, higher quantities of feldspar and quartz also exist, probably locally derived from the west during the preceding glaciation. This is supported by the work of Alam and Piper (1977) who found that pre-Wisconsinan clays collected from cores from the tops of seamounts close to the continental shelf south of the Grand Banks contained grey muds (65% illite, 20% chlorite, 5% kaolinite, and 10% montmorillonite) which are similar to tills derived from Newfoundland, and reworked tills on the Grand Banks (Alam and

Piper, 1977). Cores from the Grand Banks slope were found to have illite, chlorite, montmorillonite, montmorillonite-mixed layer clays and kaolinite as the clay-sized constituents, in order of decreasing abundance (Alam and Piper, 1981).

5.2 The Uppermost Tertiary Marine Sediments

This weathered zone of marine sediments is olive brown in color, probably reflecting chemical weathering (acidification and leaching) of sediments which were originally similar in nature to those which presently directly underlie them. Thom and Roy (1985) have noted a similar weathered Pleistocene substrate of leached or cemented sand, and partly oxidized fine sediments on the embayed coast of New South Wales.

This unit is thickest where seabed elevations are highest, and thins with increasing water depths. Thus, for the samples studied, thicknesses are greatest near the Hibernia P-15 wellsite (approximately 1.5-2 m) and thin to a point where the unit is barely perceptible near the Ben Nevis I-45 wellsite in water depths of 101 m. The attitude of this weathered zone generally follows the seabed topography, dipping gently to the east with slopes of approximately 1:1,000. This unit is not seismically detectable farther to the east at the vibrocore HU83-017-14 site.

Physically, the weathered zone is very hard. This was first documented during the drilling of the Hibernia B-08 borehole (Geocon, 1980) when the core barrel was broken off, leading to the conclusion that the drill bit had encountered a lag gravel interface at this interval. Subsequent vibrocore (Lewis, 1984) and borehole samples obtained by the **MV PHOLAS** for Mobil Oil Canada Ltd. show that this unit is composed of silt with some sand and 0.5-2% clays. Expandable mineral phases comprise 30-50% of the < 2 micron size fraction in the weathered zone. Because of the capacity of these minerals to fill pore spaces, it is expected that the extreme upper sediments of the weathered zone would form a relatively impermeable crust which would have repelled the penetration of sea water over the past 10,000 years as long as the crust remained intact. When disturbed by icebergs or fishing trawler "doors" and exposed to water infiltration, the original structure and fabric of the soil would be destroyed. It is expected that this effect would result in the release of these sediments into the Late Pleistocene/Holocene sedimentary regime. This is possibly seen in samples from vibrocore HU83-017-6 (0.42 m) where the clay mineralogy exhibits both Tertiary and Late Pleistocene/Holocene characteristics.

Differences in the color of the sediments from this seismically reflective interval first demonstrated that the geological history for this area was unlike that attributed to the existence of Late Pleistocene/Holocene sands and gravels. Lewis (1984) and Barrie et al. (1985) have noted that the color changes from a pale yellow or light grey in the Late Pleistocene/Holocene sediments to a dull olive brown at this weathered zone. A further difference is that the silt and clay content of the weathered zone soils is higher than that for the Holocene sediments (Barrie et al., 1985).

Evidence for the predominance of an acidic leaching environment under conditions of good drainage at the time of subaerial exposure is seen in the relatively high kaolinite contents. Carroll (1970) has noted that where montmorillonite originally existed, the combination of chemical leaching, a moist climate and good drainage could convert montmorillonite to halloysite and then halloysite to kaolinite. Jackson et al. (1948) have also documented the conversion of labradorite and illite (of which there is an abundant supply on the continent to the north of the study area) to kaolinite. An increase in acidity to a pH of 4 and oxidation favours weathering leading to the formation of kaolinite (Jackson et al., 1948). The fact that some montmorillonite does coexist with the kaolinite suggests that this subaerial weathering was not continued for a prolonged period of time so that complete desilication of the montmorillonite did not occur. Englund and Jørgenson (1973) have shown that both K-feldspar and biotite will eventually alter to kaolinite in cation deficient environments, such as those which exist under leaching conditions. Another possible source for the formation of kaolinite is in the weathering sequence hornblende --> vermiculite --> kaolinite as discussed by Tomita et al. (1970) for the weathered hornblende-andesite of Kagoshima.

It is expected that the effects of chemical weathering would decrease with depth. This would be reflected mineralogically by a decrease in kaolinite contents and a slight increase in montmorillonite and possibly illite and feldspar concentrations.

5.3 Tertiary Marine Sediments

These sediments, which form a thick unit below the weathered zone, are predominantly olive green to grey in color. Several intervals exhibit the presence of amorphous iron oxides which were removed during laboratory testing by the techniques of Mehra and Jackson (1960). Where these oxides existed, the sediments were olive brown.

Figure 17 shows the gentle eastward dip of units, some of which can be correlated laterally. The presence of large areas of gravel, including boulders, channel fill of glaciomarine sediment and till indicates that glaciers did extend over the Grand Banks during the Wisconsinan (G.B. Fader, personal communication).

For the most part, the Tertiary sediments consist of silts and clays (Fig. 17). Some sedimentary layers contain H_2S and are highly fissured. Laminations and bioturbation are noted locally throughout the 130 m, which is the deepest recovered section studied. Unfortunately, few of the intervals recorded as "clays" were available for analysis, however sand and silt intervals contain 1.5-6% clay-sized constituents.

Below the weathered zone, sands with silt and clays extend for 56 m, 57 m, 60 m, 60 and 59 m in the Hibernia WI, 0-35, C1A, E1A and B-08 boreholes, respectively. As shown in Figure 17, although these units are similar in thickness, they occur at greater depths below the seabed due to the gentle eastward dip of the beds. Analysis of the clay mineralogy from Hibernia boreholes W1 and 0-35 (Fig. 16) show that this unit is dominated by expandable mineral phases which are probably predominantly swelling chlorites with lesser amounts of montmorillonite as indicated by acid and heat treatments. The presence of montmorillonite indicates environments which favour high cation concentrations (Englund and Jørgensen, 1973) and an alkaline system in which Na-feldspars can alter to montmorillonite. Rex and Martin (1979) have studied the authigenic formation of clays as a result of submarine weathering of granodiorite and found that kaolinite, K-mica, montmorillonite and halloysite were the products formed. Abundant sources for granodiorite exist along the coasts of Labrador, Greenland and the Flemish Cap (King et al., 1985). Umpleby et al. (1978) have studied sediments of the Labrador Shelf and discovered that a predominance of montmorillonite in the mid-Cretaceous to early Paleocene sediments implied the prevalence of semi-arid, savanna-like conditions on adjacent provenance areas. It is therefore probable that these Tertiary sediments were in part derived from Cretaceous units. A thin zone of clayey soil which is less than 1 m thick at 39 m depth in the Hibernia C1A borehole is seen to increase to a thickness of 9 m from 40 to 49 m depth at the E1A borehole site (Fig. 17). This zone then thins between the E1A and B-08 sites to 4 m in thickness, forming a clayey pod or wedge within a thicker sand unit.

A thin unit (4-6 m) of olive grey silty clay is found below the sand in boreholes W1, 0-35 and C1A. No samples from this section were analysed. Units above 66 m depth between the C1A and E1A boreholes are not directly correlatable (Fig. 16) although some similarities do exist. This silty clay pinches out between the C1A and E1A boreholes and is replaced by a 6 m thick wedge of gravel with shells, silt and clay at the E1A site. Below the silty clay is a sequence of sand containing silt and clay components which thickens to the east from 8 m at the W1 borehole location to 14 m at the E1A site. This is underlain by a dark grey silt with minor clay. One sample of the clay-sized material from the silt unit was examined mineralogically from the E1A borehole. This interval contains approximately 2% of <2 micron sediments which are tentatively classified as 40% montmorillonite and vermiculite, 25% swelling chlorite and vermiculite, 16% chlorite and 11% illite. Kaolinite, quartz, feldspar, apatite and amphibole were identified as lesser components. This same pattern of minerals is identified at 96 m for the E1A borehole and 75 m and 130 m in the W1 borehole which contain 3, 3 and 6% clay-sized constituents, respectively.

5.4 Stratigraphy and Textural Distribution

From figure 16, it appears that there are zones of locally restricted sediments, both laterally and vertically. In general, however, major units can be traced from borehole to borehole and these units do show correlatable qualitites such as color, grain size and in some instances, clay mineralogy.

Figure 17 depicts the stratigraphy and textural distribution for some of the Tertiary marine units (samples provided by Mobil Oil of Canada Ltd.). These units show a coarsening-upwards trend indicative of marine regression leading to subsequent subaerial exposure of the region. For the most part, the sediments are negatively skewed to the right, and in general show unimodal distributions in the fine sand/silt ranges except for areas below 80 m depth from the seabed where silts and clays become more evident. This is particularly noted for the lower two samples from the WI borehole and the deepest samples from the C1A and E1A boreholes. It is interesting to note that the Tertiary marine sequences show a general fining of sediment with increasing water depth; this has been noted on a more regional basis for the Holocene sediments by Barrie et al. (1985).

Clasts larger than 2 mm were not noted in core samples more than 36 m below the seabed (W1 borehole) (Fig. 18, Tables 3 and 4). At 36 m in the W1 borehole sample the sediments are found to be angular and composed of approximately 75% light brown chert/25% granite and rhyolite. Here and at the 0-35 borehole site (11 m depth) are the only locations where chert has been found, although it was present in lesser amounts in the 0-35 sample (25%). The I-45 borehole has provided the most pebbles in the 2-5.6 mm size range. Angular buff colored limestone was noted at 10.7 and 12.2 m depths, while angular fragments of oolitic dolomite and limestone occurred at 15.2 m. Most of the pebbles from this location are subangular to angular. Metamorphic rock fragments (quartzite and gneiss), which are not seen in samples to the west, and granites are evident here.

5.5 General Comments

The differences between Late Pleistocene/Holocene and Tertiary clay mineral assembleges suggest different provenances. Studies by Barrie et al. (1985) showed relatively similar pebble lithologies throughout the Holocene and Tertiary sections, leading to the conclusion that the Holocene sediments are derived from reworked, earlier deposited or glacially derived material. Salient points for consideration are:

1. The Tertiary unconformity is seen to be highly variable, locally, with channel-like and erosional features that have been interpreted from seismic data (Vol. 2). The hard, dense nature of the unconformity suggests these features were formed during subaerial exposure. Would small rivers, which could have existed on the peneplain-like surface of the study area during subaerial exposure, or an active westward-migrating surf zone encountered during marine transgression have had enough energy to create this dissected surface? If so, why is the dissection noted only locally? If marine erosion was responsible for the removal of part of the weathered zone, why was the remainder that exists today not eroded as well?
2. If it is assumed that reworking occurred during transgression, it would have affected the silt and clay constituents as well as the larger fractions. The significantly different assembleges encountered between the Late Pleistocene/Holocene and weathered Tertiary clays indicate that the sources for clays are unique. If

Wisconsinan glaciation for the study area is not considered, other mechanism(s) by which Tertiary clays were removed from the area and how clays with northern provenance signatures were deposited must be considered. During a transgressive event with an active wave base, it is probable that most of the fines (silts, clays and fine sands) would be removed from the area and deposited in deeper waters. This then, would mean that most of the clays which do exist on the Grand Banks at present were transported by ice and are hence allochthonous. If however, Wisconsinan glaciation is considered, sources for high illite, quartz, and chlorite clay-sized minerals, such as the Island of Newfoundland and adjacent offshore areas could be considered, along with input from present northerly originating ice.

Dr. Guy Lefebvre, who has experimentally studied the erosivity of clay deposits at Sherbrooke University, indicates that because of the highly fissured and small-scale rough nature of desiccated deposits, their susceptibility to erosion is very great (personal communication). His criteria for erosion could be applied to the uppermost weathered Tertiary marine sediments in the Hibernia area, in which it is very likely that the encroaching sea would be capable of removing much of the fine sands, silts and clays from the study area. Although fissures and similar structures were not noted by Barrie et al. (1985) in vibrocore 5 (2.03-2.7 m), it is probable that they do exist within this unit on the Grand Banks.

6. SUMMARY AND CONCLUSIONS

Three distinct geological units which can be identified on the basis of geophysical techniques, borehole and vibrocore samples, and clay mineralogy exist within the upper 130 m of sediments in the greater Hibernia area. These units are: 1. Late Pleistocene/Holocene sediments, 2. a weathered zone of Tertiary marine sediments, and 3. a thick sequence of Tertiary marine silts, clays and fine sands. Tertiary bedrock reflectors dip gently toward the east in deeper waters and units generally thicken in this direction.

Two chemical environments have been identified on the basis of clay mineralogical analyses: 1. an acidic leaching environment for the uppermost weathered Tertiary marine sediments; 2. an alkaline environment during the deposition of thick Tertiary marine sediments. Variations in the relative abundances of clay-sized minerals among correlatable units can be shown to be in part due to differential settling mechanisms and flocculation.

Geotechnical research from other areas on the erodibility of weathered deposits (G. Lefebvre, personal communication) supports the theory of Barrie et al. (1985) of a common source for some of the Holocene and Late Wisconsinan/Tertiary sediments. This then would indicate that the clay minerals found in Holocene sediments today are primarily allochthonous and reflect deposition by ice transport.

7. RECOMMENDATIONS FOR FUTURE STUDY

In analysing the clay mineralogy from Lower Cook Inlet and Kodiak Shelf, Alaska, Hein et al. (1979) found that current patterns could be inferred from the clay/mineral distribution pattern even if the clay-size fraction is a minor sediment component, and in areas where coarse-grained relict deposits occur. Although analyses of more surficial sediment samples is necessary to determine if their technique is applicable to the Grand Banks it is possible that these effects are evident in the eastward increase in clay-sized feldspar contents.

Hein et al. (1979) also discussed the role of clay minerals with respect to the adsorption of petroleum or other compounds by bottom sediments. They determined that this adsorption would not be great because most of the Kodiak shelf is covered by coarse-grained material (much like the Hibernia area); however, the total cation exchange capacity of suspended sediment was relatively high in Lower Cook Inlet, suggesting a larger percentage of clay minerals occurred in suspension giving greater particle surface areas and surface charges available for adsorption of hydrocarbons. In future field seasons it could be beneficial to sample the suspended sediment above the seabed, immediately following a storm period, or during periods when the Labrador current is at its strongest.

Results from this study, particularly those obtained from the "weathered zone" of Tertiary sediments are encouraging in further defining the geological history for the Hibernia area. This is relevant both to scientists and industry for hydrocarbon development of the region. The northeastern Grand Banks of Newfoundland are unique in that Tertiary beds are very close to, or exposed at the seabed surface. Future vibrocoring or possibly drilling expeditions would be beneficial for supplementing the relatively small data base now in existence. In particular it would be useful to obtain samples from units C and A (Barrie et al., 1984, 1985) to determine if the higher relative abundances of feldspar and the increase in angularity of minerals which are seen to the east are consistent among a number of samples.

Barrie et al. (1985) have defined preliminary values for the reworking of Holocene sediments. Studies are also underway to determine the rate of sediment transport within the area (J.V. Barrie, C.F.M. Lewis, personal communication). If this can be achieved it could be useful in determining an age for Holocene sediments which contain Tertiary clay signatures. If it is correct to assume the Tertiary sediments were incorporated into the Holocene regime by iceberg scouring, this method of relative dating could be valuable in determining iceberg flux over the past 10,000 years. Once incorporated into the Holocene sedimentary regime, it is unlikely that the clays would be removed by resuspension because of their cohesive nature, except possibly over long periods of time or unusually strong storm surges. The other possibility for the existence of clays from the Tertiary weathered zone co-existing with more recent clays indicative of a northern latitude provenance is that the Tertiary clays are remnants of the transgressive phase which flooded the region approximately 10,000 years ago. Subsequent sediment input from northerly-orginating ice would have provided the higher quartz, illite, chlorite and feldspar abundances found in the majority of Late Pleistocene/Holocene sediments studied. Again, too few samples exist from these intervals for conclusions to be drawn at this time.

In studying cores from the mid-Atlantic continental shelf off Deleware Demars et al. (1979) discovered a unique shallow fresh water aquifer which extends over a large portion of the shelf in Pleistocene sediments. Definition of a chemical environment for the uppermost Tertiary marine sediments as indicated in this study, reaffirms the importance of pH, Eh and salinometer determinations. These relatively simple measurements could be taken on board ship upon immediate recovery of samples.

The underlying Tertiary marine sediments are seen to onlap, the result being that the Tertiary strata which have been truncated by the unconformity are due to different transgressive pulses. It would be valuable to know if these different units which can be mapped, have resulted in differing physical and mineralogical properties during weathering. A vibrocore program incorporating geological and geotechnical techniques at specified sites across the study area would add to the confidence that could be placed on the physical properties of these weathered surfaces.

Another valuable geo-historical marker lies in the amount of disturbance the Tertiary unconformity has experienced. A wealth of geophysical records now exist (the unconformity is best determined on the Huntec DTS profiles) on which the degree of erosion/channelization can be noted. A map depicting this could be useful in further developing a late Wisconsinan history for the area.

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APPENDIX A

LITERATURE REVIEW: CLAY MINERALOGICAL PROPERITES

CLAY MINERAL PROPERTIES

The following discussion relates to the true "clay minerals", belonging to the phyllosilicate or layer silicate family of minerals, the structures of which are composed of well-defined silicate layers, as well as clay-sized particles (< 2 microns in diameter) of quartz, feldspar, pyroxene and amphibole. This material is transported from the continents to the oceans by glaciers, rivers and atmospheric winds (Griffin et al., 1968; Heath, 1969). It is also thought that weathering could influence the chemistry of fine-grained sediments (Englund and Jørgensen, 1973; Jackson et al., 1948).

Chlorites

Chlorites are 2:1 type silicates with interlayers of octahedral hydroxide sheets (Longstaffe, ed., 1981). Extensive substitution occurs within the octahedral sites, giving a general formula of $(Mg, Fe, Al)_3 (Si,Al)_4 O_{10}(OH)_2 \cdot (Mg,Al)_3(OH)_6$ (Brownlow, 1979). Most chlorites have a low ion exchange capacity and are non-swelling.

Jackson et al. (1948) assign chlorites to weathering stage IV which is expected to occur in significant amounts only in youthful soils or those represented by the early stages of weathering. They also indicate that chlorites commonly occur in sedimentary deposits protected from leaching. In studying ocean bottom sediments off Hawaii, Swindale and Fan (1967) have documented instances of chlorite replacing gibbsite, which is unstable in sea water.

Chamley (1979) suggests that chlorites, kaolinites and micas (as well as quartz and feldspars) are deposited closer to continental land masses than are the smaller, less floccuable minerals because of differential settling mechansisms. Gibbs (1983) later studied the coagulation rate of clay minerals taken from the Yukon River (45% chlorite, 29% illite, and 20% montmorillonite). He found that in a solution with a pH of 7, the material had a collision efficiency (collision between two particles produces a floc) of 0.198 sec^{-1} and a $T_{1/2}$ of 52 min (using the equation $dn = 4 \alpha \emptyset nG$; where α is the collision efficiency factor, $\emptyset$ is the volume of solid material per unit volume of solution, n is the number of concentration of particles, and G is the mean velocity gradient. The rate of coagulation measured in minutes is $T_{1/2}$ and is denoted as the time for particle number to reach one-half the original particle number). He found that the effect of size was most pronounced at lowest salinity; however chlorite samples seemed to be less affected by salinity than those samples containing higher concentrations of illite, kaolinite and montmorillonite. Chlorites are predominantly high latitude clay minerals, found in greater abundances in the polar regions of the world (Griffin et al., 1968) where chemical processes are subordinate to mechanical weathering processes.

Illite

Illite (hydromica) is the term generally used for all clay-grade micas which are non-swelling. The general formula can be written $K_{0-2}Al_4(Al,Si)_8O_{20}(OH)_4$ (Brownlow, 1979). Like chlorites, illites are found in greater abundances in northern ocean deposits, reflecting a continental input (Griffin et al., 1968). Coagulation rate experiments performed by Gibbs (1983) showed that the collision-efficiency factor (α) for illite increased rapidly at low salinity, then levelled off at various higher salinities. He found that the larger surface area for unit volume for the 1 to 2 micron fraction as compared with the 2- to 4 micron fraction caused a faster coagulation rate for the 1- to 2 micron fraction. He also showed that the coagulation rate for the illite increased rapidly with increasing salinity.

Montmorillonite

Montmorillonite, a dioctahedral smectite is made up of an octahedral sheet (gibbsite sheet) between two tetrahedral sheets with an ideal formula of $(Al, Mg, Fe^{3+}{}_4 - (Si,Al)_8 O_{20} (OH)_4 \cdot nH_2O$ (Brownlow, 1979). Montmorillonite has a high degree of ion exchange with adjacent solutions due to a deficiency of positive charge which allows for extensive adsorption of cations on the surface and edges of clay sheets (Brownlow, 1979). As noted by Brindley (1981), the presence of interlayer cations smaller in number than in micas, permits hydration and solvation of the interlayer cations and a reversible intracrystalline swelling. Englund and Jørgensen (1973) note that montmorillonite is formed as an intermediate stage in the weathered sediments with high contents of illite and chlorite.

Swelling Chlorite and Vermiculite

Brindley (1972) has defined swelling chlorites as long-spacing swelling minerals. He suggests that the swelling chlorites are imperfect structures with discontinuous brucite layers between the talc layers. The imperfect brucite layers would provide insufficient ionic attractions to prevent expansion.

Vermiculites are macroscopically crystalline, three-sheet, mica-like minerals (Brindley, 1981). Glycolization of vermiculites results in expansion from 1.435 nm to 1.45 nm, much less than that for montmorillonite (smectites).

Vermiculites are thought to form from mica, chlorite, serpentine, talc, hornblende and feldspar (Walker, 1972). Varieties can be trioctahedral and dioctahedral. Illite and chlorite are often associated with vermiculite, as is montmorillonite (Walker, 1972). Vermiculites have a high cation-exchange capacity due to the presence of cations associated with the water molecules in interlayer positions (Walker, 1972).

Kaolinite

Kaolinite is a non-swelling clay made up of repeated units of tetrahedral sheet and octahedral sheets of the gibbsite type, having an ideal formula of $Al_4Si_4O_{10}(OH)_8$ (Brownlow, 1979). Halloysite is similarly structured but in addition has a water layer (Brownlow, 1979). It is the only kaolinite group mineral which exhibits a natural hydrated form in which the normal separation of the kaolinite layers, 0.715 nm is increased to about 1.01 nm by a sheet of water molecules which is removed very easily at temperatures as low as 60°C (Brindley, 1981).

According to Englund and Jørgensen (1973), kaolinite forms directly from the weathering of potassium feldspar. It is usually formed in geological regimes undergoing intense weathering (Griffin et al., 1968; Jackson, 1948) and is therefore more abundant in low latitude sediments. Experiments conducted by Gibbs (1983) show that the collision-efficiency factor ( ) for kaolinite rises rapidly at low salinities and levels off as salinity increases. He discovered that the coagulation rate for kaolinite was greater than that for illite or montmorillonite under conditions of increasing salinity. These data concur with the prediction made by Chamley (1979) that kaolinite would be deposited closer to the continental source rather than farther out to sea due to differential settling mechanisms.

APPENDIX B

DETAILED X-RAY ANALYSIS

DETAILED X-RAY ANALYSIS

VIBROCORE SAMPLE HU83-017-5

DEPTH (m)	
0.88	The chlorite is not well crystallized or it is highly weathered. The feldspar is probably potassic in composition. The presence of vermiculite is indicated by a shift in the glycolated peak from 13.8 to 14 A. Montmorillonites are poorly cyrstallized, low in quantity and are probably interstratified with mixed layer minerals. Chlorite and kaolinite are very poorly crystallized or highly weathered. Broad (001) and (002) reflections indicate the disorder of kaolinite. Mixed layering of mica is shown by a series of reflections on the low angle side of the 10 A peak forming a shoulder. The illite is poorly crystallized with the peak expanding upon glycolation. There is a possibility of minor gibbsite in evidence at 4.85 A and 4.32 A; however, it is difficult to distinguish from paragonite (illite) in the same regions.
1.89	The montmorillonite is poorly crystalline and there is evidence for vermiculite with the 14 A expansion upon glycolation. Chlorite is low in crystallinity. At 7.11 A there is some evidence for the existence of chamosite (Fe-silicate) but this cannot be confirmed from the diffractogram.

Muscovite is the dominant mica, and the feldspars range from sodic to intermediate in composition. Upon acidification the (001) and (003) reflections almost disappear, while the (002) and (004) reflections are not significantly changed indicating the presence of some Mg chlorite. The chlorites are well-crystallized. Upon treatment with HCl, the (001) reflection is greatly diminished, signalling a large amount of Fe-rich swelling chlorite comprising the expandable mineral content. The feldspar is probably sodic to intermediate in composition since the peak is not altered by acid treatment. Upon glycolation there is a decrease in the 10 A peak size and the appearance of a diffuse 5.5 A to 5.2 A peak indicating some of the illite is interstratified with expandable minerals. The illite is probably predominantly muscovite.

2.67 Kaolinite is characterized by sharp (001) and (002) reflections, indicating it is probably well ordered and therefore possibly formed in situ. Chlorite (001) and (003) reflections almost disappear upon acidification while the (002) and (004) reflections are also greatly reduced. From this information we can assume the co-existence of Fe and Mg chlorites, with the Fe-rich chlorites also contributing considerably to the expandable mineral peak area. The illite peak becomes more intense on heating, but decreases only slightly with glycolation, therefore the illite is probably interstratified with minor amounts of expandables. Feldspars are probably sodic to intermediate in composition as they are not destroyed by HCl treatment.

VIBROCORE SAMPLE HU83-017-6

Depth (m)

0.42 Upon acidification the chlorite reflections broaden and decrease markedly in area, therefore the variety is probably Fe-rich and less well-ordered. Mixed layers of montmorillonite/vermicu-lite/chlorite are indicated by reflections on the high angle side of the 14 A peak. Of the expandable minerals, approximately 8%, 10% and 82% have been tentatively identified as Mg - montmorillonite, vermiculite and swelling chlorite, respectively. The feldspar is probably sodic to intermediate in composition. Minor amounts of apatite are also encountered.

0.94 This sample contains a high content of amorphous phases, possibly as a result of glacial flour; therefore, there is a high percentage of error in the calculations from this interval due to minerals not accounted for. The chlorites show very poor crystallinity and almost completely dissolve upon acid treatment indicating an Fe- variety. The feldspar also dissolves with acidification which is indicative of more calcic than sodic feldspars. However, a very finely-grained intermediate feldspar is more in equilibrium with the high kaolinite content and lower abundance of Fe-chlorite, much of which would have been removed in an acidic environment. The illite peak is characteristic of poorly crystalline 2 M muscovite, which is probably detrital in origin. Although not included in the computations, there is the possibility of a relatively high proportion (up to 10%) of apatite within the interval.

VIBROCORE SAMPLE HU83-017-8

Depth (m)

1.00 Except for feldspar, which is probably plagioclase, the minerals are very poorly crystallized and poorly ordered. The relative abundances of the minerals are similar. The poor crystallinity and high abundance of amorphous phases make the percent error very high for this interval.

8.4 VIBROCORE SAMPLE HU83-017-10

0.66 Similar to sample 83-017-8 (Depth = 1.00 m).

0.87 Chlorite and kaolinite from this interval are very poorly crystallized, as are most of the other minerals except for illite which is moderately well-crystallized and the plagioclase feldspar which is very well crystallized.

VIBROCORE SAMPLE HU83-017-16

1.48 This interval contains a high proportion of amorphous material. Chlorite is only moderately crystallized, while illite and plagioclase are well-crystallized.

1.98 Similar to sample 83-017-8 (Depth = 1.00 m).

PHOLAS BOREHOLE SAMPLE CIA

Depth (m)

1.0 - 1.03 The chlorites from this interval are well-crystallized. Acid dissolution does not affect the (002) reflection; however the (004) reflection does decrease in size. We can therefore assume the existence of a well-crystallized, predominantly Fe-chlorite with some Mg - component. These chlorites are probably metamorphic in origin. Expandable minerals are reduced upon acidification, indicating the predominance of Fe-rich swelling chlorite or, less probably, calcic montmorillonite. The asymmetric 10 A peak of illite decreases slightly upon glycolation but does not shift position. This is characterisiic of minor interstratifications of expandables (probably vermiculite) with the illite.

A moderate reduction in the feldspar peak area occurs with acid treatment; however the untreated feldspar reflections are weak to intermediate in intensity, indicating an intermediate composition which is in keeping with a moderately acidic environment as evidenced by the relatively high (9%) kaolinite content. Minor amounts of apatite are present.

1.08 - 1.11 This interval exhibits the same characteristics as the above sample.

2.15 - 2.18 The chlorite from this interval is poorly crystalline, and possibly some of it is diagenetic in origin. The (004) reflection broadens and shifts upon glycolation. Illite is highly interstratified with expandable minerals, however, there is no strong evidence for the existence of vermiculite. Feldspar components have weak reflections.

59.19-59.22 Chlorite is characterized by strong (002) and (004) reflections which diminish markedly upon acidification, indicating a well-ordered, Fe-rich variety. The feldspar component is not affected by acid treatment. The expandable minerals are greatly reduced by acidification.

99.42-99.49 The chlorite component is either Mg-rich or a very well-ordered Fe-variety which does not dissolve upon acidification. Expandable minerals both collapse with heating at 250°C and dissolve with acid treatment, indicating a predominance of swelling chlorite.

PHOLAS BOREHOLE E1A SAMPLES

Sample	Depth (m)	
51	8.0 - 8.05	This sample contains well-crystallized Fe-rich chlorites with very strong (002) and (004) reflections. No mixed layering is seen with the chlorite. Swelling chlorite comprises approximately 85-95% of the expandable minerals. Some vermiculite could be present, as well. Montmormillonite comprises only about 3% of the total sample. The feldspar is probably intermediate to sodic in nature.
57	12.52-12.58	The minerals identified in this interval are similar in nature to the above sample. The (001) chlorite peak gains slightly in intensity with heating. A series of reflections on the low angle side of the 10 A peak and its increase in intensity with heating indicates the illite is probably interstratified with 20% or more expandables. This is also seen in the 10 A peak shift with

		glycolation. The presence of vermiculite is indicated by a 14 A peak on untreated and glycolated samples. Minor quantities of apatite are also indicated.
83	80.08 - 80.12	The chlorites are very well-crystallized and probably Fe-rich as indicated by the strong (002) and (004) reflections. The 10 A illite peak expands slightly upon glycolation, but does not shift in position. Vermiculite is probably not a major component of the expandable minerals, which are tentatively broken into two components: 1) approximately 40% montmorillonite and vermiculite; 2) approximately 25% swelling chlorite and vermiculite. A moderate 3.2 A reflection indicates the feldspar is intermediate-sodic. Some apatite is indicated.
85	88.7	The chlorites in this interval are well-ordered and probably an Fe-variety. The kaolinite is also well-ordered. Illite shows minor interstratification with expandable minerals. Glycolation shows expansion to 19 A of some of the expandable minerals, indicating the presence of some Mg-montmorillonite.
90	96.0-96.12	The chlorites are well-crystallized and of an Fe-variety. Sharp (001) and (002) kaolinite

reflections also indicate a good ordering. The illite, which is probably a muscovite variety shows an increase in intensity of the 10A peak with heating in stages from 110 - 250° due to the dehydration of expandable minerals. Upon heating to 250°, the 17A swelling chlorite peak completely collapses. The expandable minerals are predominantly swelling chlorite and calcic-sodic montmorillonite with minor vermiculite. Feldspar is probably sodic to intermediate. Minor amounts of apatite are also indicated.

PHOLAS BOREHOLE WIA/WI SAMPLES

76	2.08- 2.20	Chlorites from this interval are only 2.20 moderately well-crystallized and of an Fe-variety. Feldspar occurs in very minor amounts.
13	36.10- 36.15	In this interval, the 10 A illite peak becomes more intense on heating as the expandable minerals are dehydrated. With glycolation a diffuse 5.5 - 5.2 A peak appears, although there is no shift in the 10 A illite peak. Vermiculite is interstratified with chlorite and montmorillonites which are calcic or sodic. Expansion at 11 A on the glycolated samples indicates halloysite could be present. The feldspar is intermediate to sodic.

27	51.28- 51.31	Poorly-crystalline Fe-chlorite and poorly crystallized kaolinite with diffuse (001) and (002) peaks characterize this interval. Expandables form only a minor component.
42	75.02- 75.15	Chlorite of an Fe-variety is well crystallized and interstratified with minor amounts of expandable minerals. The illite, which is probably muscovite, is not interstratified with other minerals. The expandable minerals are probably composed of some vermiculite and swelling chlorite with montmorillonite.
70	130.52- 130.56	The chlorite is well-crystallized and contains mostly iron with some magnesium. The peaks become more intense on heating. The 10 A illite peak becomes more intense on heating and broadens slighly with glycolation. Vermiculite probably comprises 10-20% of the expandable minerals, while 45-55% is made up of swelling chlorite and montmorillonite.

HIBERNIA B-08 BOREHOLE SAMPLES

4a	7.92- 8.19	The Fe-chlorite is well crystallized, as is the kaolinite. Illite shows minor interstratification with expandable minerals. Expandable minerals are probably comprised of calcic or sodic montmorillonites, swelling chlorite and vermiculite. Feldspar is not observed.

4b	8.18-	The (002) chlorite peak shifts slightly upon glycolation, suggesting the presence of some expandable minerals. The (002) peak decreases somewhat while the (004) reflection is markedly reduced with acid treatment. The 10 A illite peak becomes better defined with glycolation and acidification. Feldspar is sodic to intermediate in nature.
4c	8.31- 8.53	Similar to sample 4b.
5	9.14- 10.06	The chlorite from this interval is not as well-crystallized as it is in the above samples. It also contains some expandable mineral interstratification. Illite, which is probably muscovite in variety is also interlayered with expandable minerals. The feldspar 3.2 A reflection is very strong, indicating the presence of plagioclase.
5a	10.2- 10.7	Chlorite and kaolinite are both well-crystallized. Illite is interstratified with < 20% expandable minerals. Feldspar is of an intermediate variety.

HIBERNIA O-35 BOREHOLE SAMPLES

3	10.6- 11.23	The mineral phases identified from this interval are generally poorly crystallized and

		there is a high abundance of amorphous phases, giving a high percent of error in the calculations. The illite, which is probably mustcovite is well-interstratified with expandable minerals. Some of the montmorillonite is of an Mg-variety.
4	12.19- 12.5	With glycolation, the (002) and (004) reflections of well-crystallized, predominantly Fe-chlorites shift slightly and become more diffuse. The (001) reflection becomes more apparent with glycolation; while (002) and (004) decrease slightly with acidification. The illite exhibits some interstratification with expandable minerals. There is little evidence for the presence of vermiculite. The broad hump identifying expandable minerals is almost destroyed with acidification and is completely destroyed upon heating to 250°C, indicating the predominance of swelling chlorite and calcic (or sodic) montmorillonite. The feldspar is intermediate to sodic in nature.
8	19.81- 20.12	The chlorite (002) and (004) peaks increase and become more diffuse on glycolation and significantly reduced with acidification, therefore it is likely well crystallized and Fe-rich. The kaolinite is not as well ordered as the chlorite. The 10 A illite peak shifts slightly with glycolation and is destroyed by acidification,

indicating the presence of some trioctahedral mica or mixed poorly crystallized illite/calic montmorillonite/swelling chlorite. An expansion to 17.8 A with glycolation indicates an Mg-montmorillonitic component for the expandable minerals, while the collapse of the 12-15 A hump with acidification shows the predominance of swelling chlorite or calcic montmorillonite. The plagioclase content reduces with HCl treatment indicating an abundance of calcic grains.

9	21.6- 21.9	This interval shows similar mineral phases and characteristics to the above sample.
10	22.6- 22.9	Similar to samples 8 and 9.

BEN NEVIS I-45 BOREHOLE SAMPLES

2	3.0- 3.7	The Fe-chlorite is well-crystallized and interstratified with some expandable mineral phases. Kaolinite is also very well crystallized. The illite which is probably muscovite, is poorly crystallized and mixed with expandable minerals which form a very minor component of the total sample.
5	7.3- 7.62	Similar to sample 2 except for the well-crystallized sharp 3.2 A peak of plagioclase

		feldspar.
11	16.15- 17.37	The Fe-chlorite is well-crystallized, with the (002) and (004) reflections decreasing significantly upon acidification. The 10 A illite peak decreases slightly and broadens with glycolation. The expandable phases are probably composed of minor Mg-montmorillonite, calcic montmorillonite, and swelling chlorite; the latter two are destroyed with acid treatment. Feldspars are better defined with acidification, indicating their sodic to intermediate composition.
12	18.29- 18.59	Similar to sample 11.
13	21.34- 23.16	Similar to sample 11.
14	21.34- 23.16	The (002) chlorite reflection is slightly reduced, while the (004) peak is completely destroyed by acidification. There is a slight decrease in the 12-15 A expandable mineral hump with acidification and a decrease and shift to 9 A with heating to 250° indicating the presence of some calcic montmorillonite and swelling chlorite. Some of the expandable phases are removed from the 10 A illite peak due to acid treatment.

17	25.91- 26.52	The Fe-chlorite from this interval is well-crystallized and interlayered with minor expandable minerals. Illite contains a moderate amount (20% or greater) of interstratified expandables. The plagioclase is well crystallized. Expandable minerals are probably composed of Mg-montmorillonite/swelling chlorite/vermiculite. Some apatite could exist at this interval.
18	28.3- 28.7	All the minerals identified from this interval are well-crystallized. The chlorites are an Fe-variety, with the (002) and (004) reflections decreasing upon acidification. The 10 A illite peak shows less crystallinity with HCl treatment. Feldspar content is decreased with acid treatment. The expandable minerals are greatly reduced with acidification and heat treatment. There is some shift to the 9 A region upon heating to 250°C. Vermiculite is probably only a minor component.

K-18 BOREHOLE SAMPLES

6 16 31	5.0-5.25 17.4-17.62 40.0-40.42	Samples from these intervals display similar clay mineralogical characteristics and so are considered together. All contain high proportions of expandable minerals. Chlorite and illite are well-crystallized. Unlike samples from other sites, the illite is not interstratified with expandable phases (if present, they exist in very

		minor quantities). As well, chlorite exists in an unstratified state. Feldspar occurs only in minor amounts.
23 36	28.0-28.45 47.5-47.94	Expandable minerals are decreased (38%) at this interval, being less well ordered and probably containing a vermiculite as well as montmorillonitic component as indicated on the glycolated pattern. Illite shows some interstratification with expandable minerals (vermiculite?).
40	57.5-58.04	This sample is unique to the K-18 site, having a much more scattered diffractogram pattern, indicating less order or a higher abundance of amorphous phases than exist for the other samples studied.
47 50	78.5-79.08 10.0-100.36	Illite and chlorite are both interstratified moderately with expandable mineral phases. Montmorillonite and vermiculite probably both exist as expandable minerals. Quartz represents only a minor component of sample 47 and does not appear at all in sample 50.

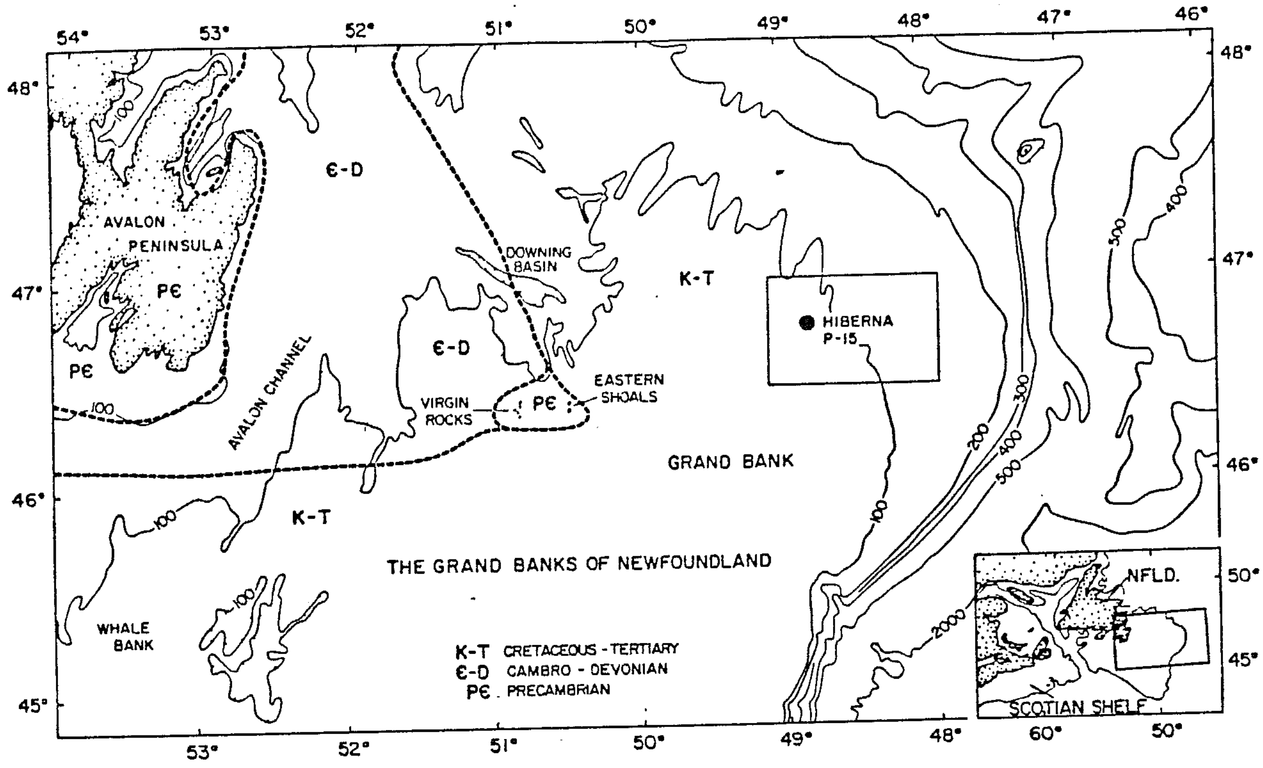


Figure 1a. Index map showing the location of the study area on the northeastern Newfoundland shelf and regional bedrock geology (after King et al., 1985).

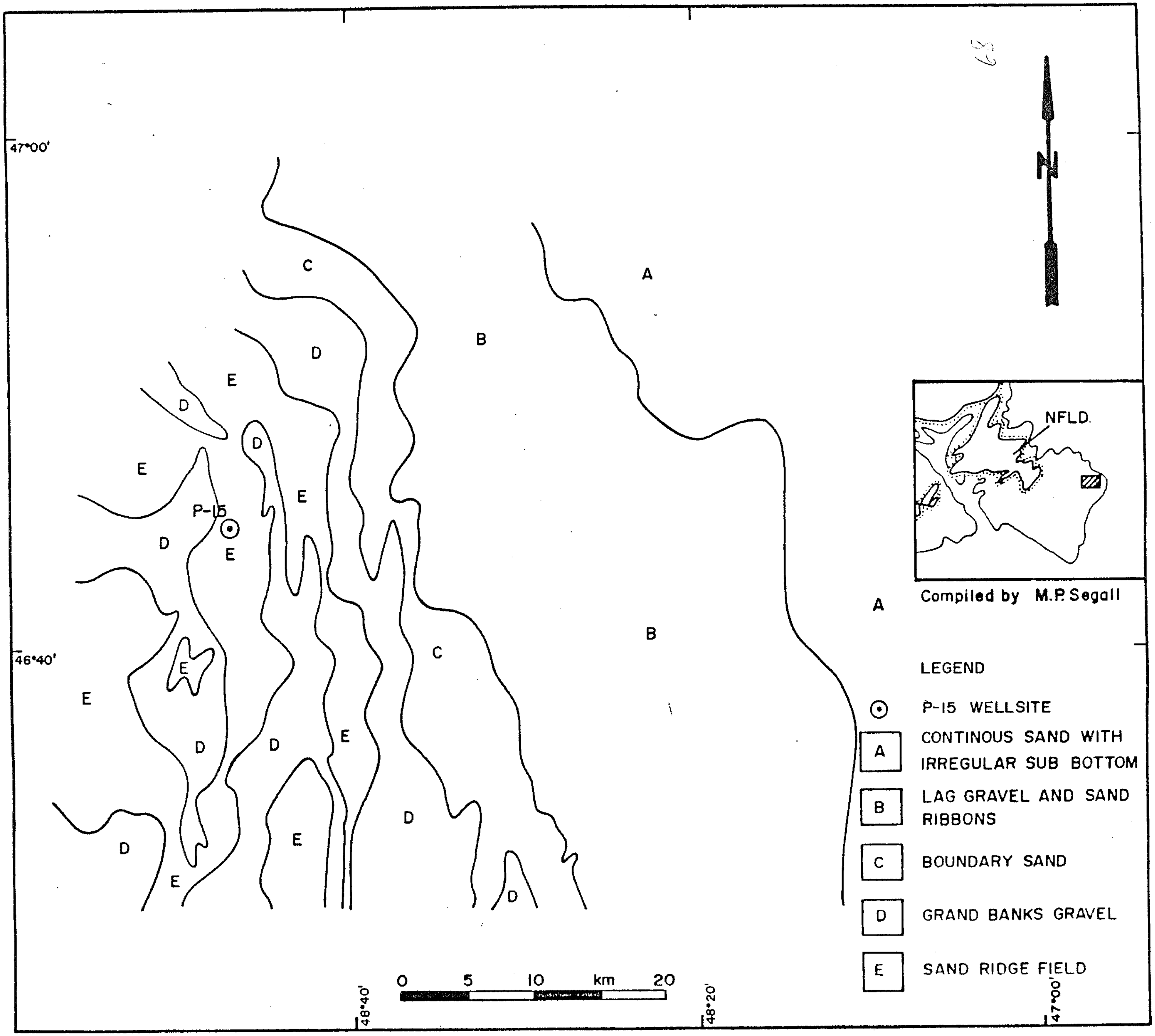


Figure lb. Study area showing surficial sediment facies distribution (after Barrie et al., 1985).

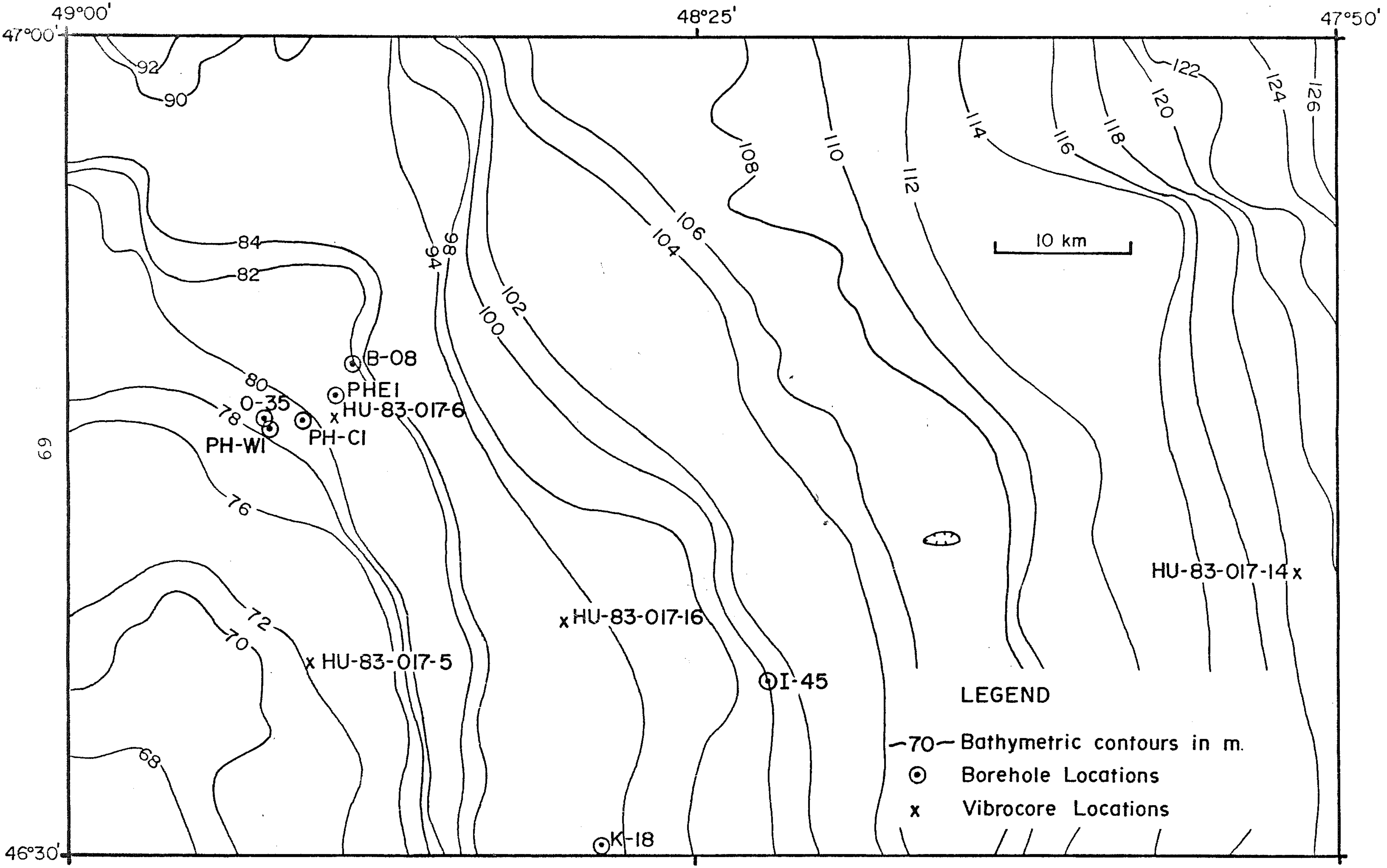


Figure Ic. Bathymetry shown in m of Northeastern Grand Banks of Newfoundland and Sample Locations.

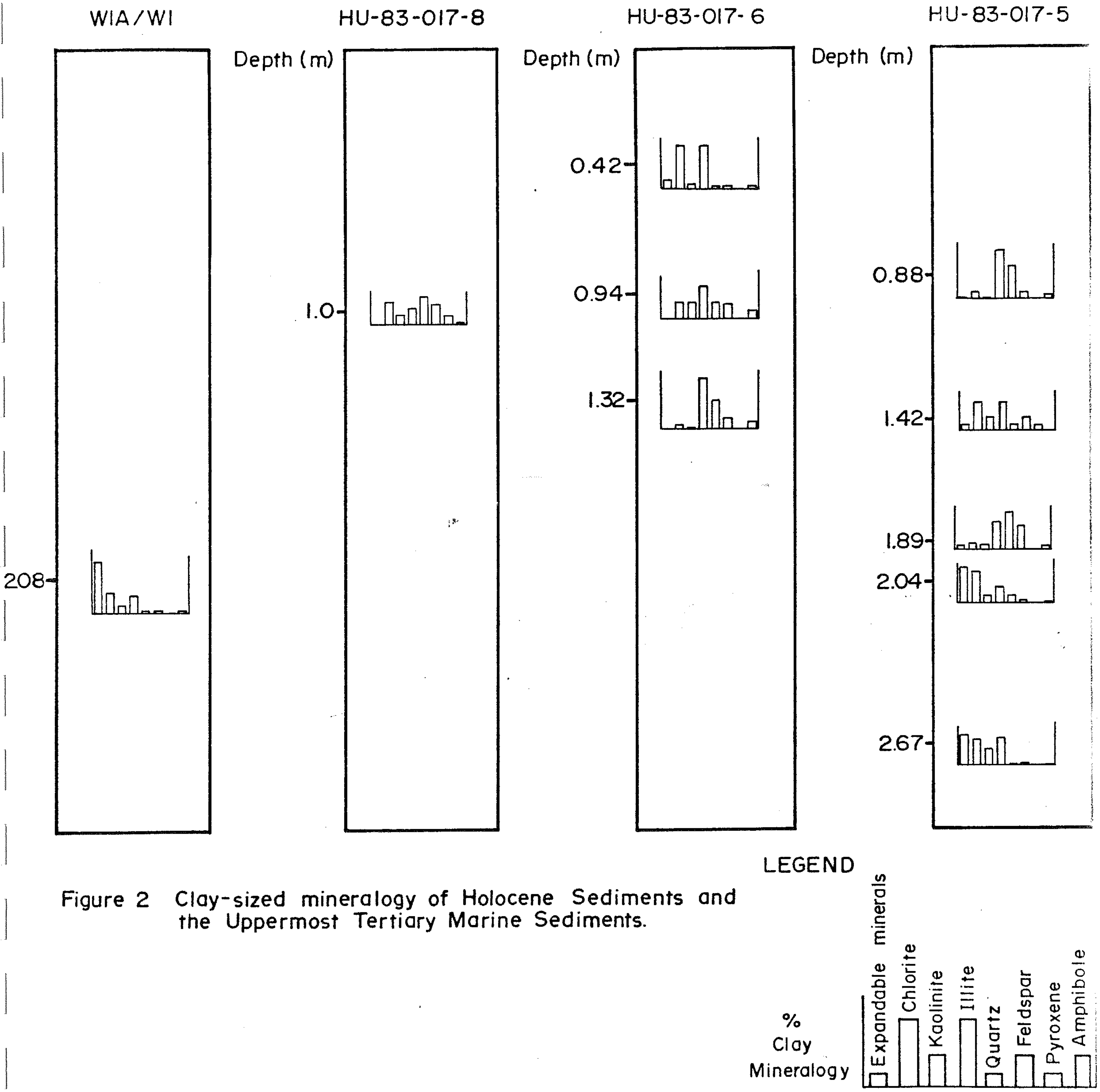


Figure 2 Clay-sized mineralogy of Holocene Sediments and the Uppermost Tertiary Marine Sediments.

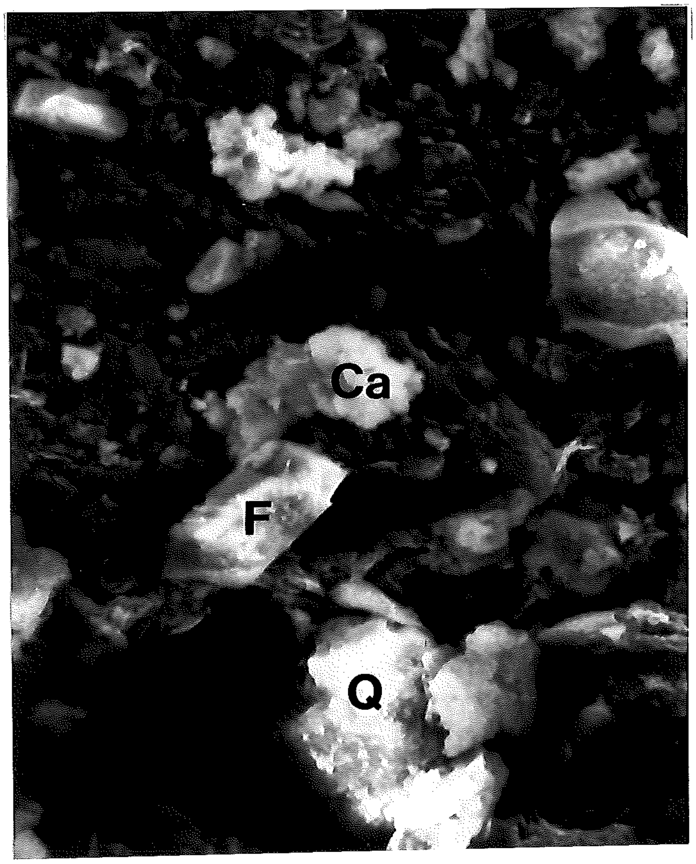


Figure 3.

SEM/EDX analysis of vibrocore sample HU83-017-8 (1.00 m) showing the presence of clay-sized authigenic calcite floccules (Ca), K-feldspar (F), and quartz (Q) (x 2,500).

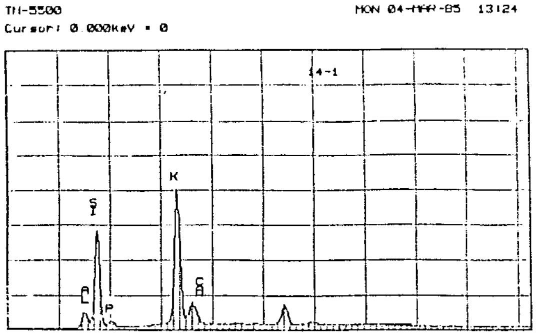
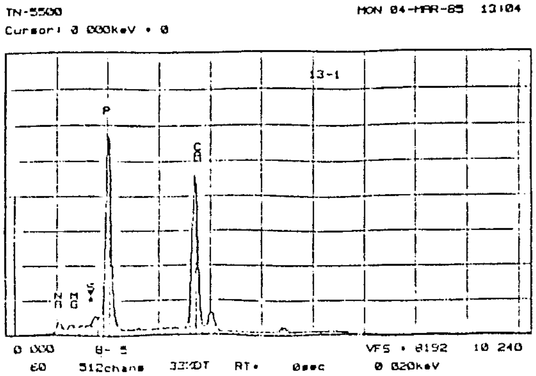


Figure 4.

SEM/EDX analysis of vibrocore sample HU83-017-6 (1.32 m) showing the presence of clay-sized apatite (A), feldspar (F) and quartz (Q) (x 800).



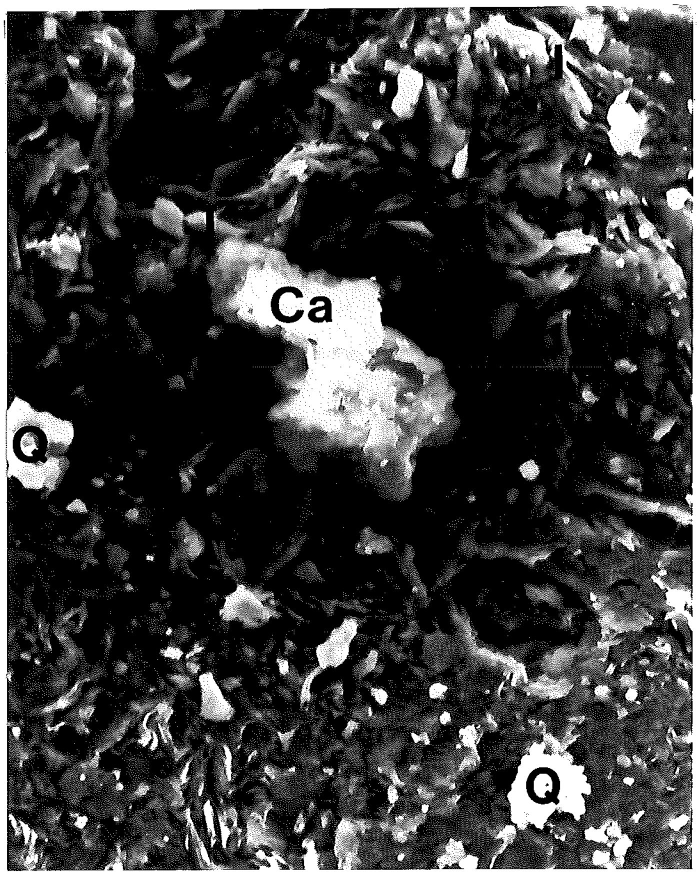


Figure 5.

SEM/EDX analysis of vibrocore sample HU83-017-5 (0.88 m) showing the presence of large clay-sized calcite crystals (Ca) and smaller quartz (Q) and illite grains (I) (x 800).

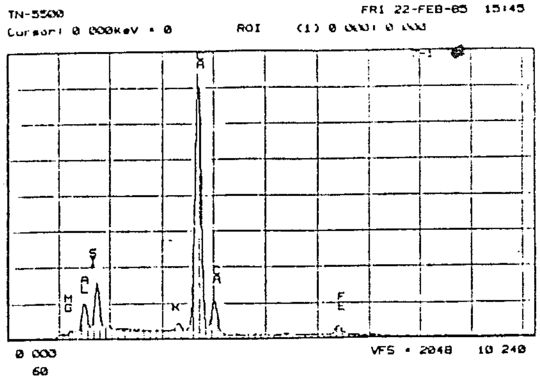
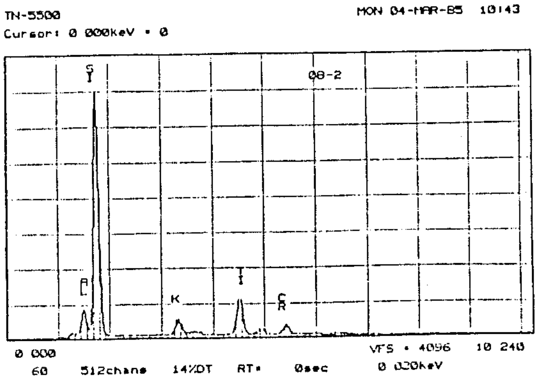


Figure 6.

SEM/EDX analysis of vibrocore sample HU83-017-5 (1.42 m) showing the presence of glauconite (x 400).



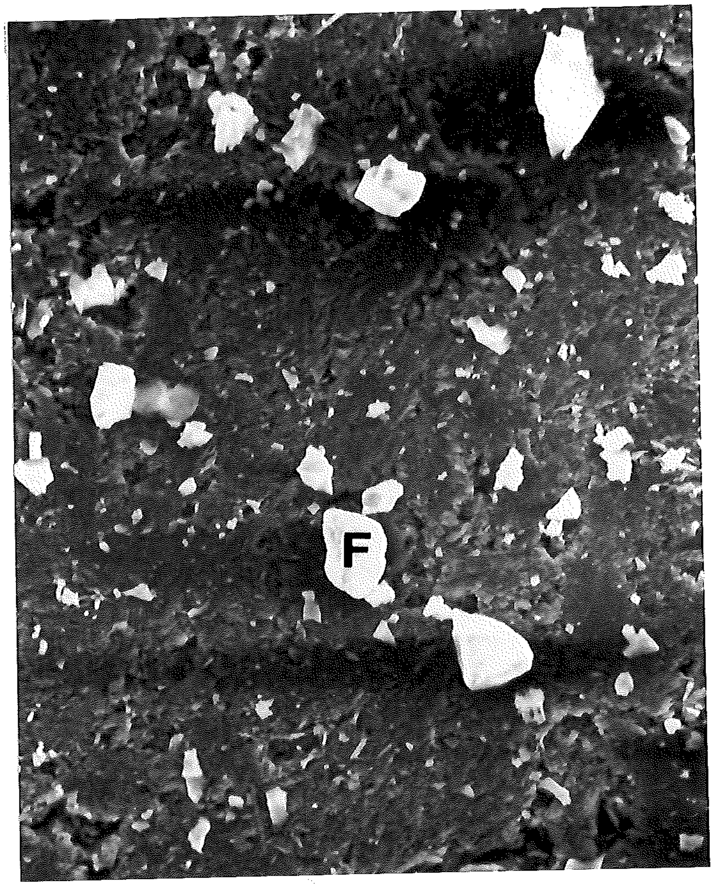
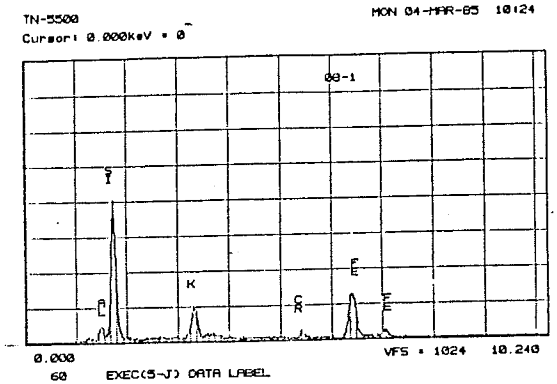


Figure 7.

SEM/EDX analysis of vibrocore sample HU83-017-5 (1.42 m) showing a highly weathered, clay-sized K-feldspar crystal with Fe-coating (x 250).



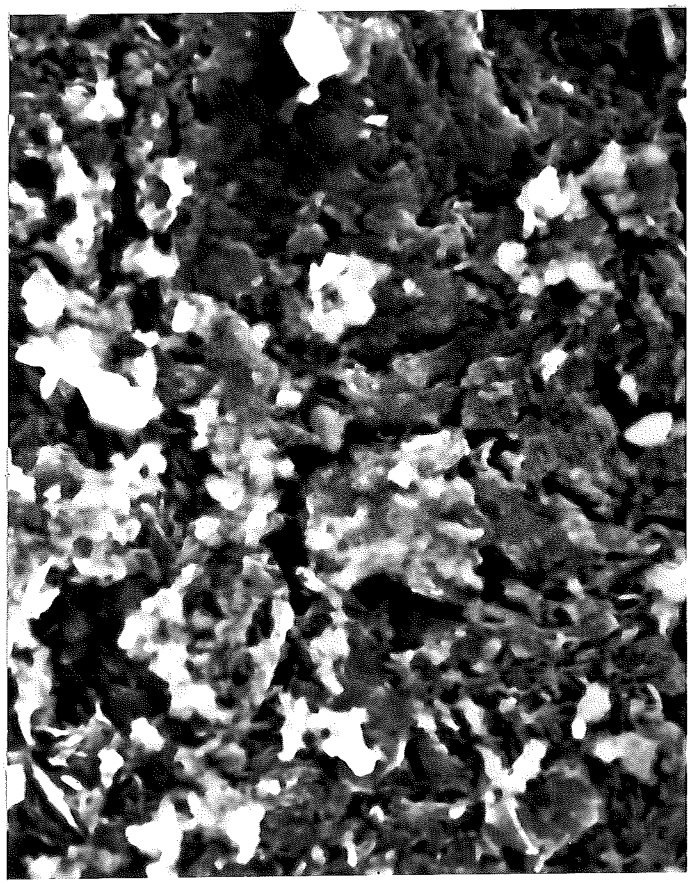
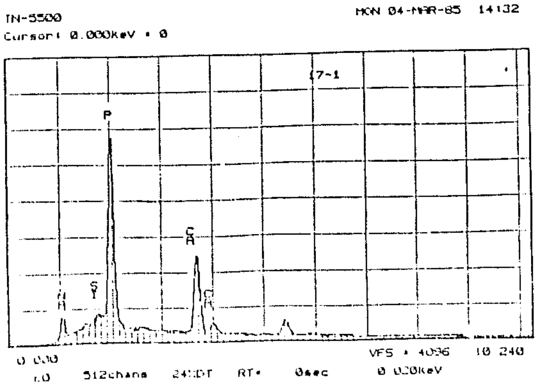


Figure 8.

SEM/EDX analysis of vibrocore sample HU83-017-16 (1.98 m) showing the dominance of calcium phosphate which could be acting as a cement at this interval (x 1,190).



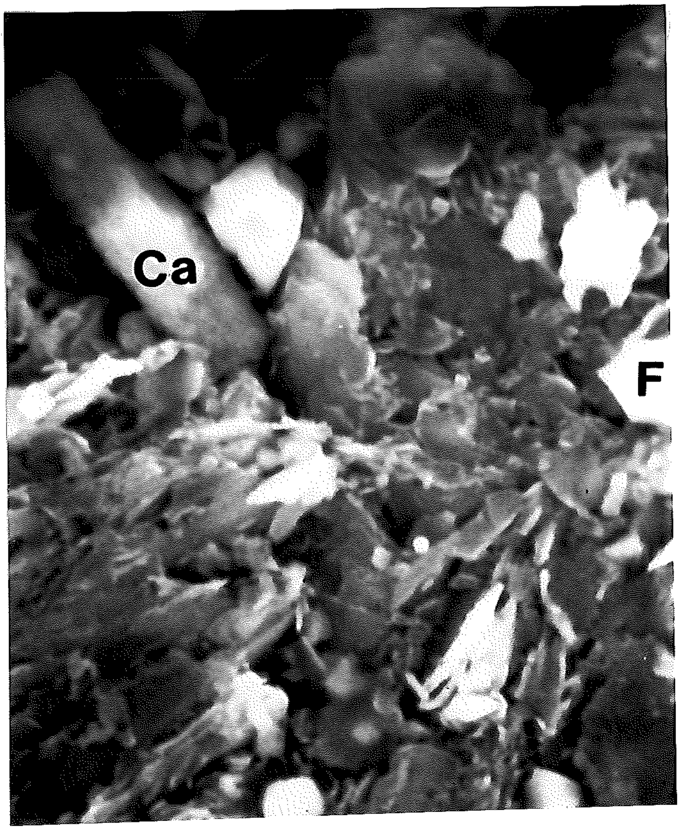
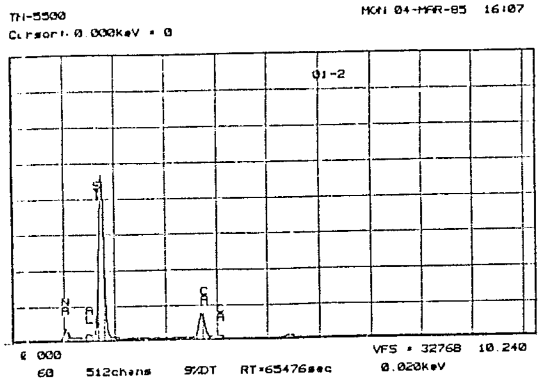


Figure 9.

SEM/EDX analysis of vibrocore sample HY83-017-14 (1.48 m) showing the presence of clay-sized calcite (Ca) and sodium feldspar (F) (x 2,200).



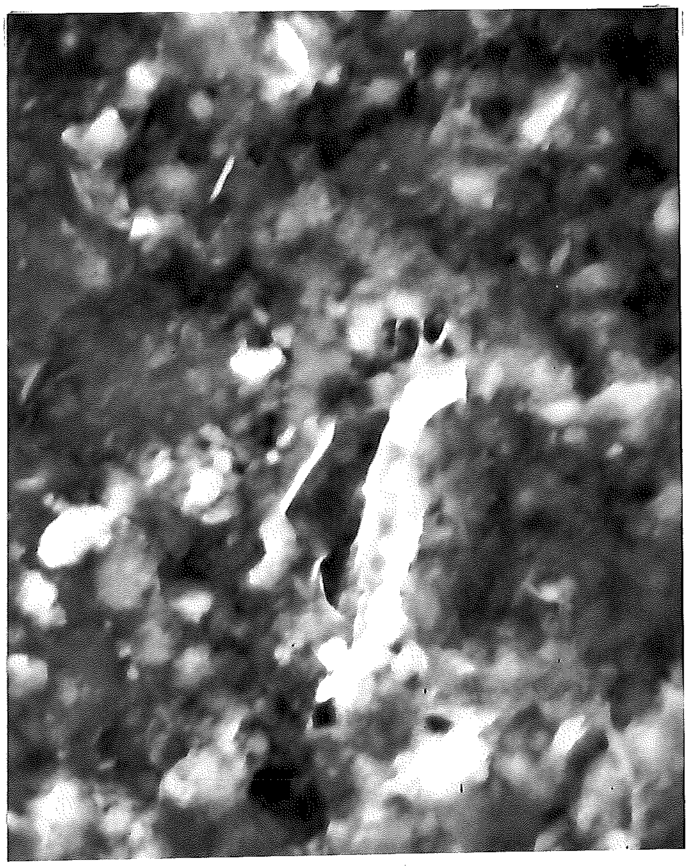


Figure 10.

SEM analysis of vibrocore HU83-017-5 (2.04 m) showing the presence of clay-sized swelling chlorite or nontronite (x 400).

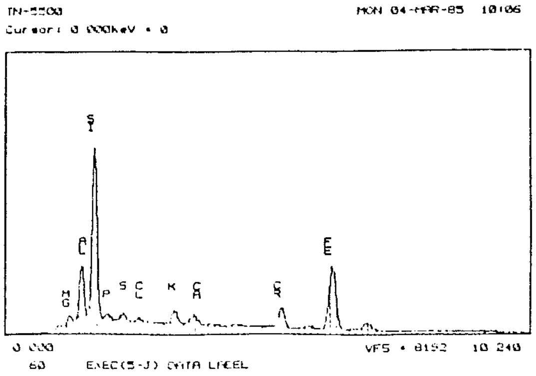
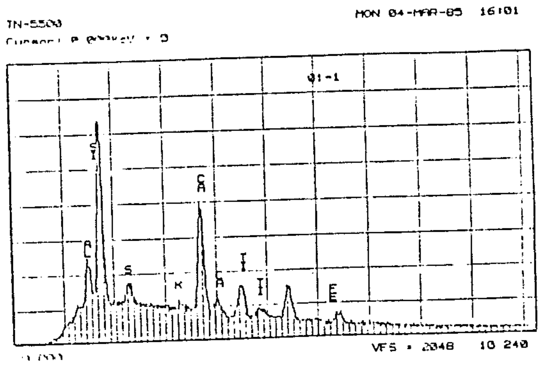


Figure 11.

SEM/EDX analysis of I-45 borehole sample 2 (3.0-3.7 m) showing the presence of plagioclase feldspar (F) and glauconitic illite (I) (x 250).



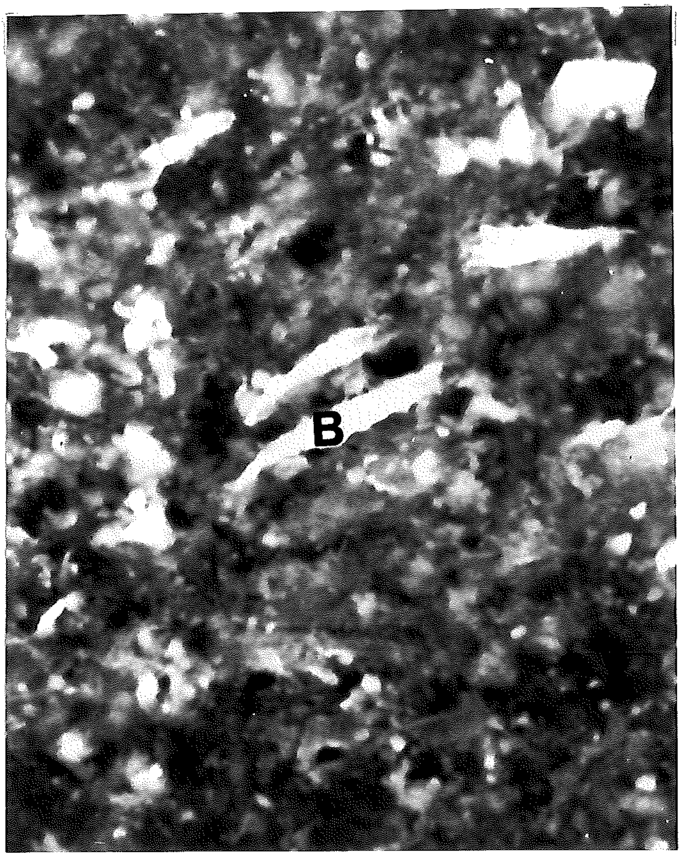
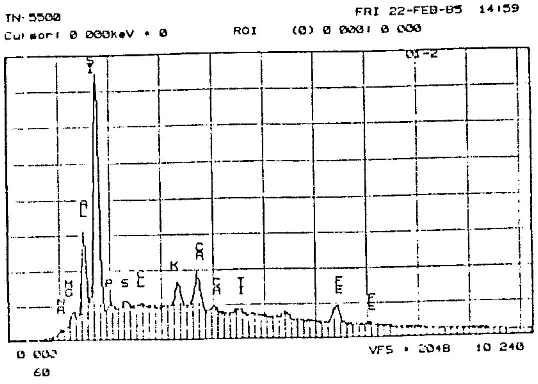


Figure 12.

SEM/EDX analysis of I-45 borehole sample 2 (3.0-3.7 m) showing the presence of clay-sized biotite (B) (x 400).



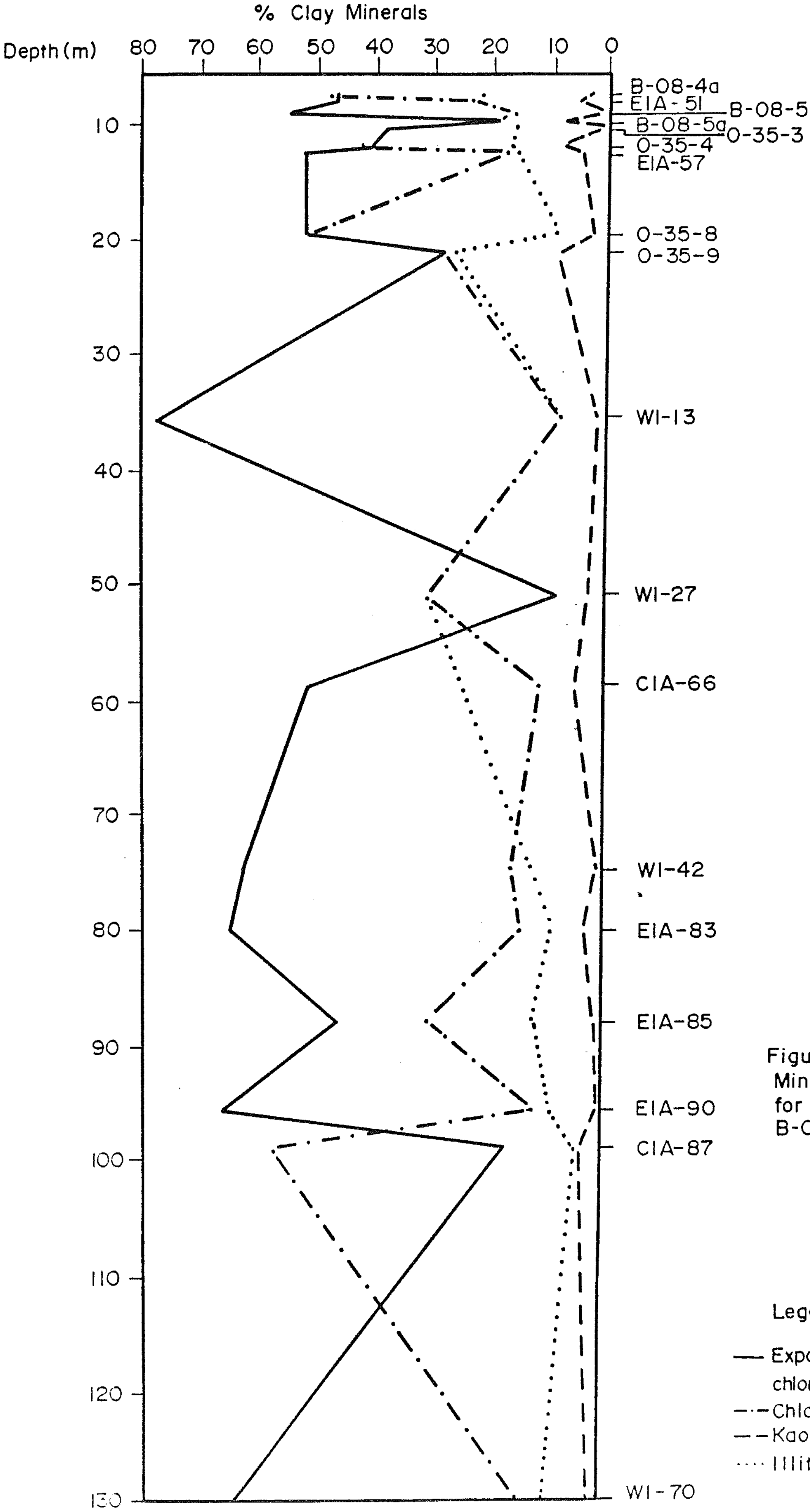


Figure 13 Compilation of clay Mineral Relative Abundances for the Upper Tertiary: Sites B-08, 0-35, CIA, EIA, WI/WIA

Legend

— Expandable Minerals (swelling chlorite, montmorillonite, vermiculite)
—·— Chlorite
— — Kaolinite
···· Illite

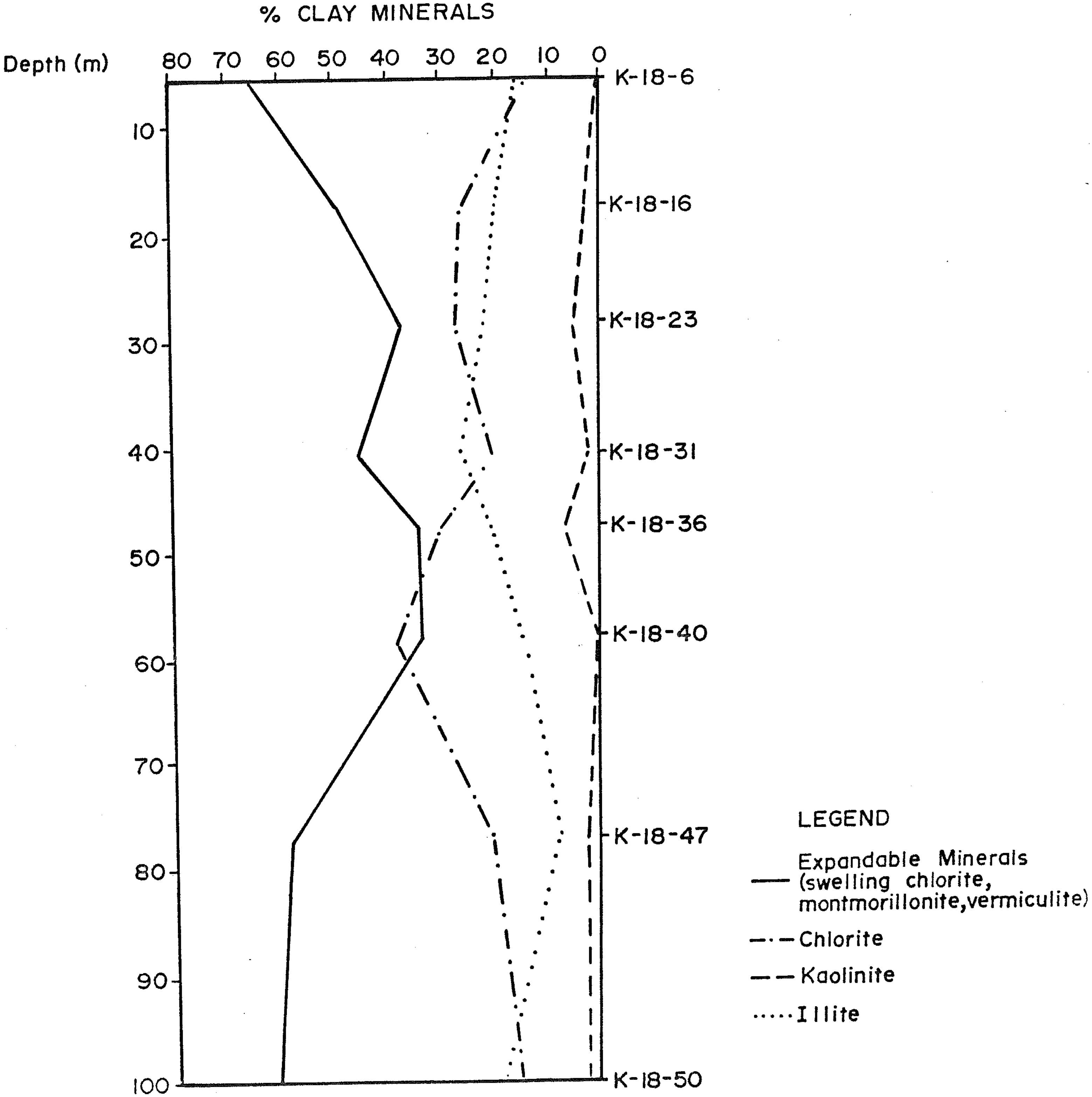


Figure 14 Clay mineralogy for the K-18 borehole samples.

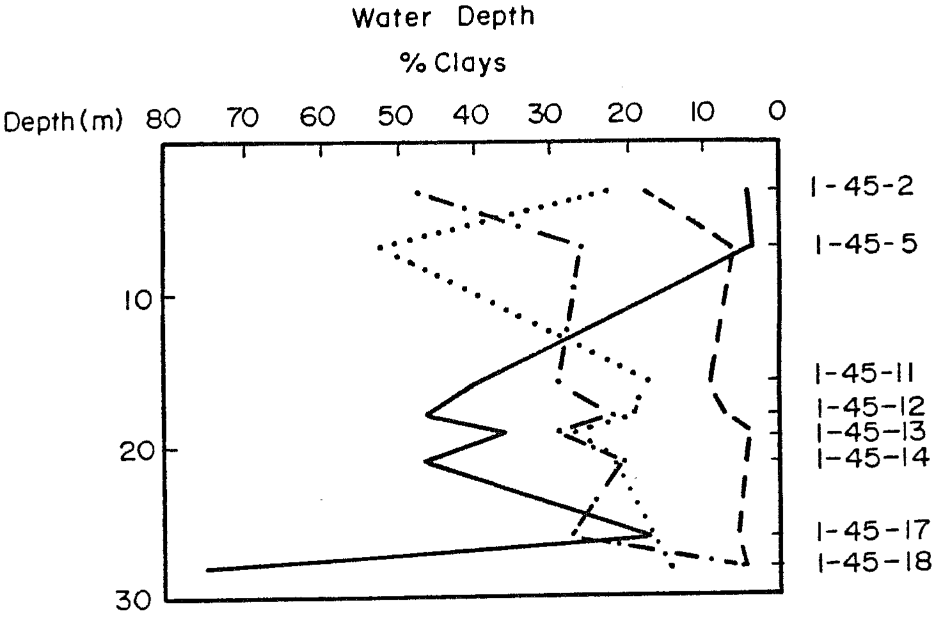


Figure 15 Clay mineralogy for the I-45 Borehole samples.

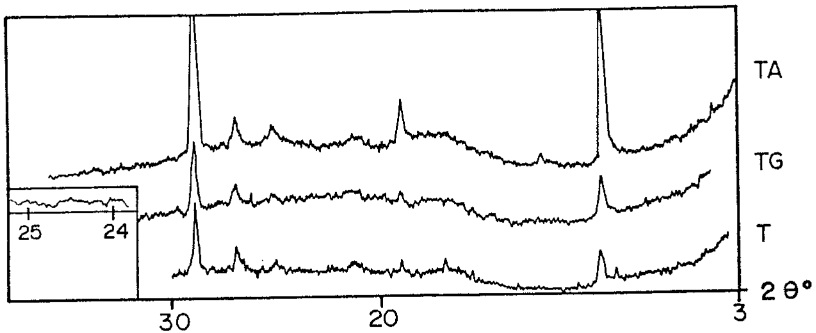
Legend

—— Expandable Minerals (swelling chlorite, montmorillonite, vermiculite)

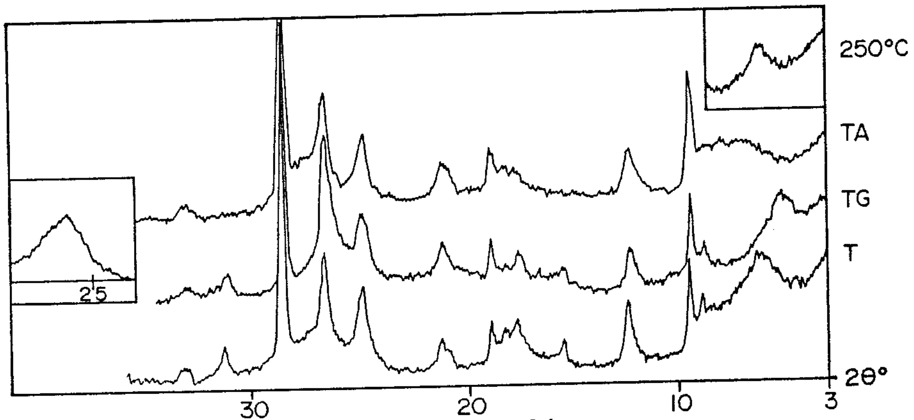
—·— Chlorite

– – Kaolinite

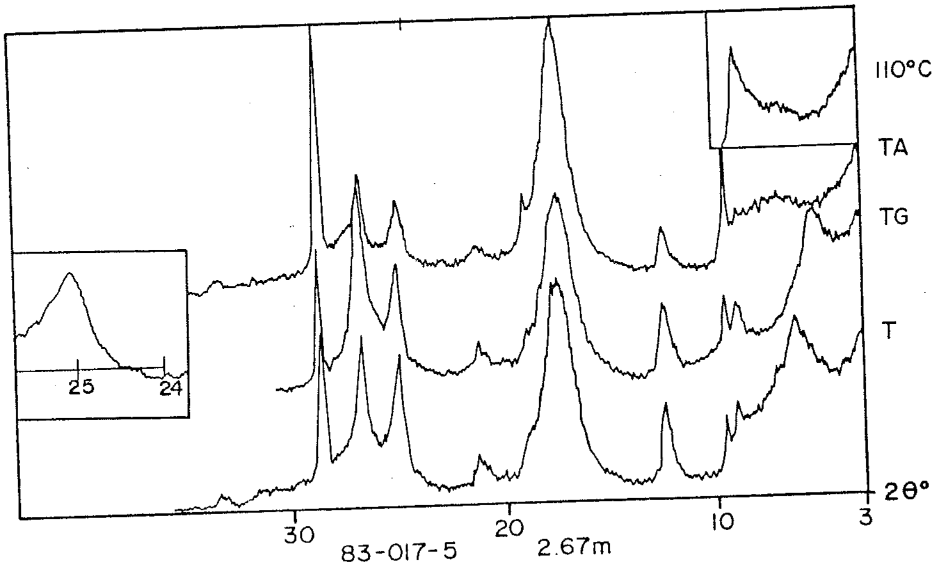
····· Illite



83-017-5 1.42m



83-017-5 2.04m



83-017-5 2.67m

Figure 19. X-ray Diffractograms for selected samples, HU83-017-5.

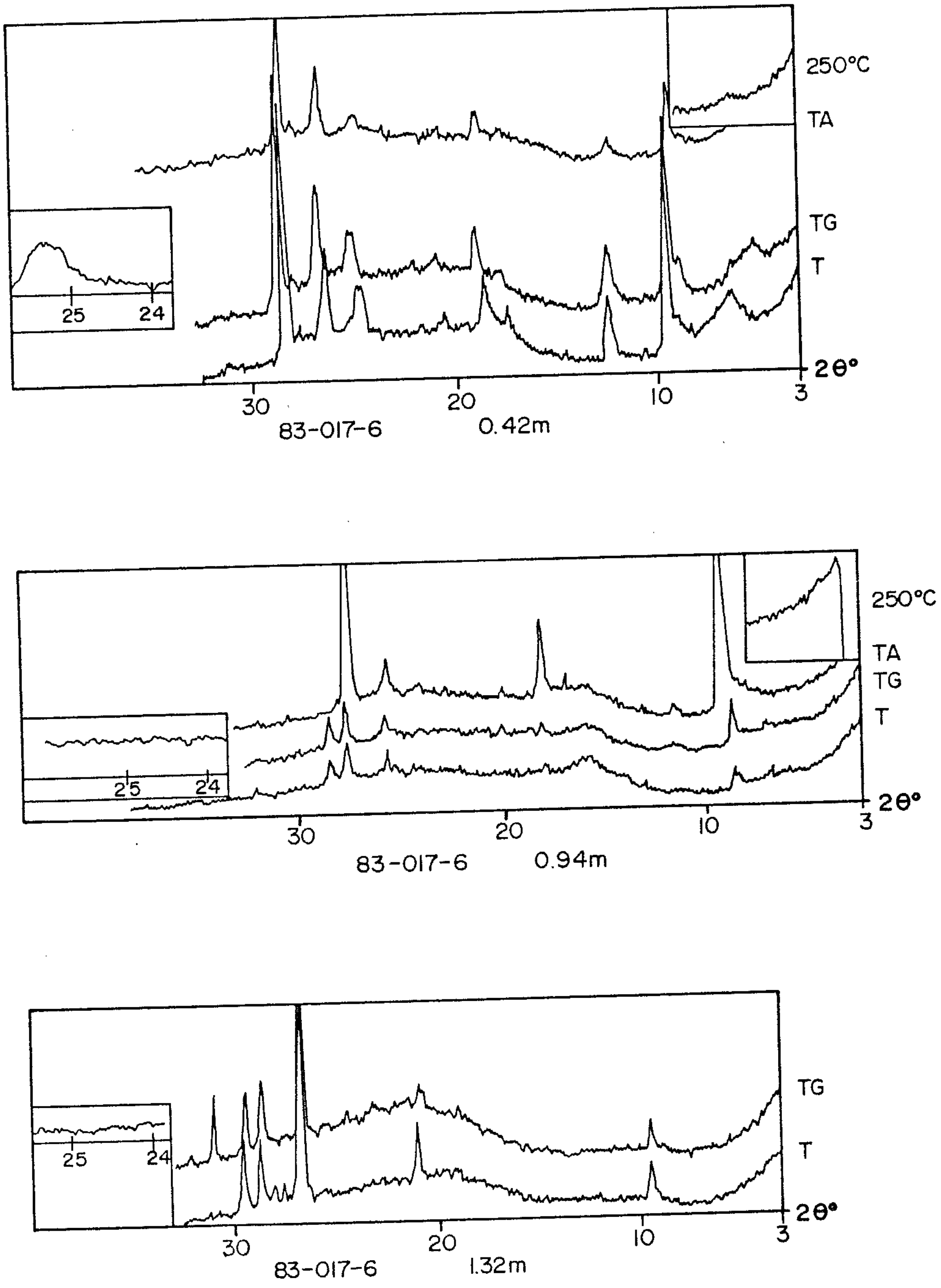


Figure 20. X-ray Diffractograms for selected samples, HU83-017-6.

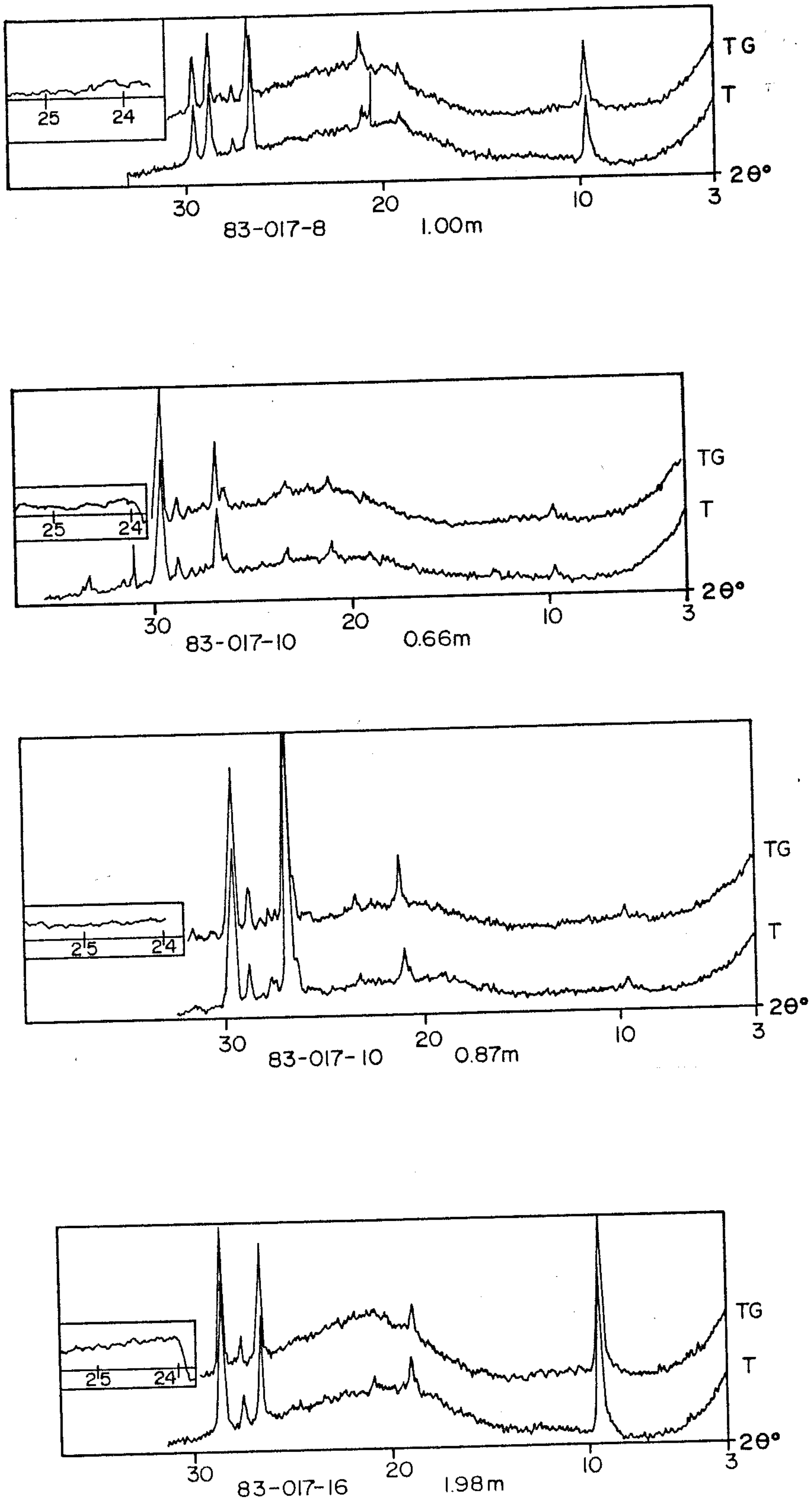
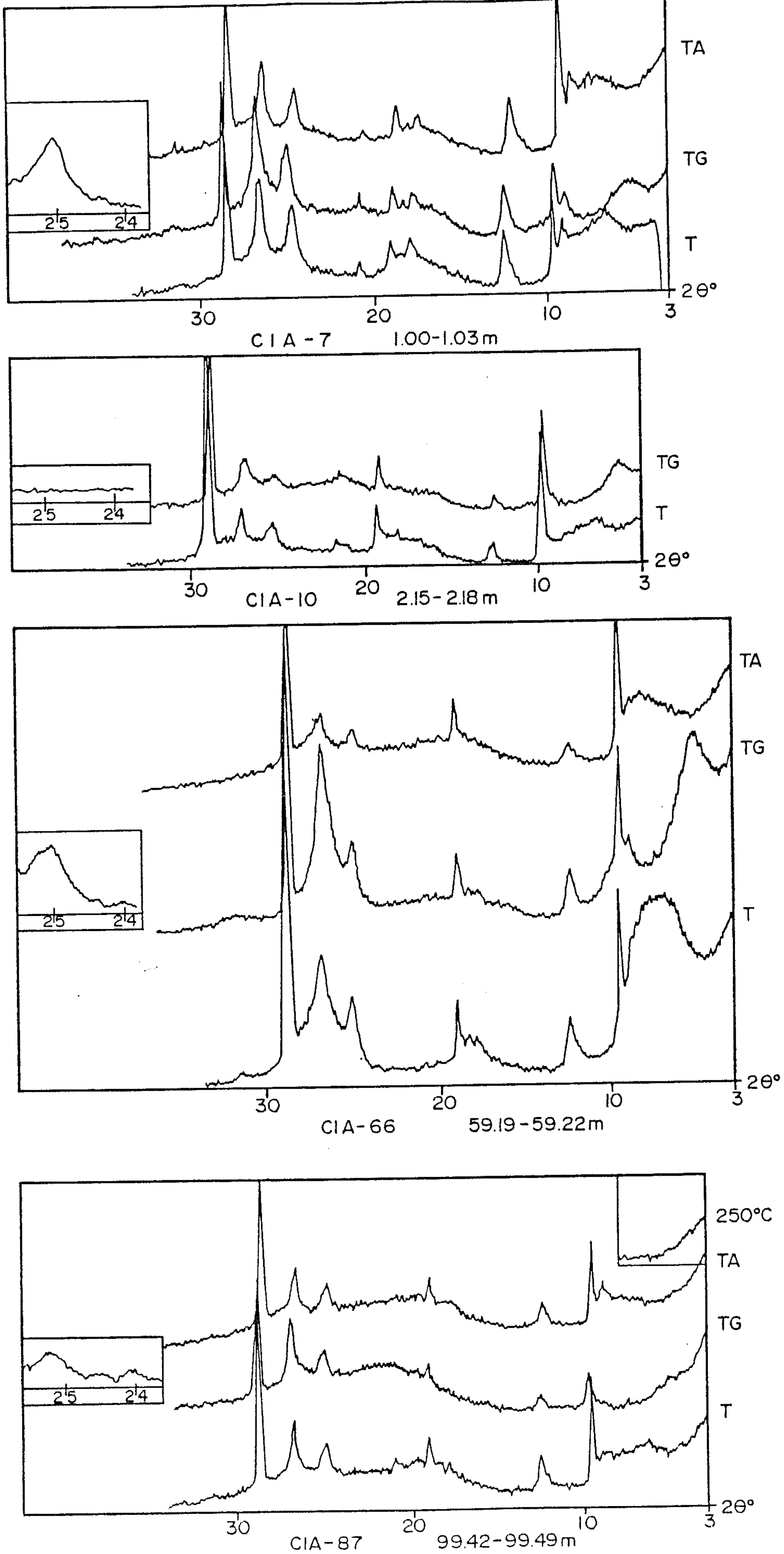


Figure 21. X-ray Diffractograms for selected samples, HU83-017-8, HU83-017-10, and HU83-017-16.



ClA-7 1.00-1.03m

ClA-10 2.15-2.18m

ClA-66 59.19-59.22m

ClA-87 99.42-99.49m

Figure 22. X-ray Diffractograms for selected samples, ClA.

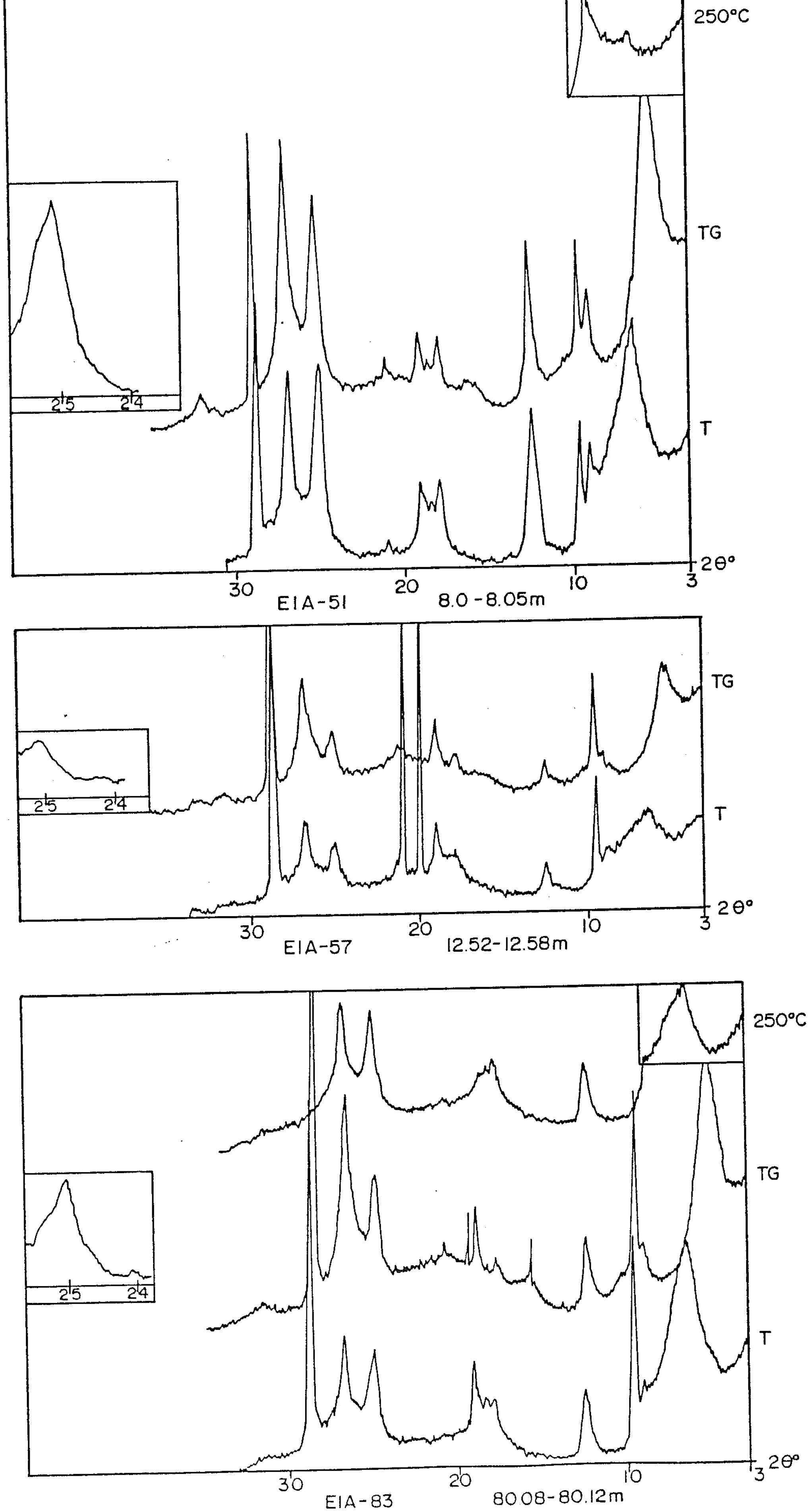
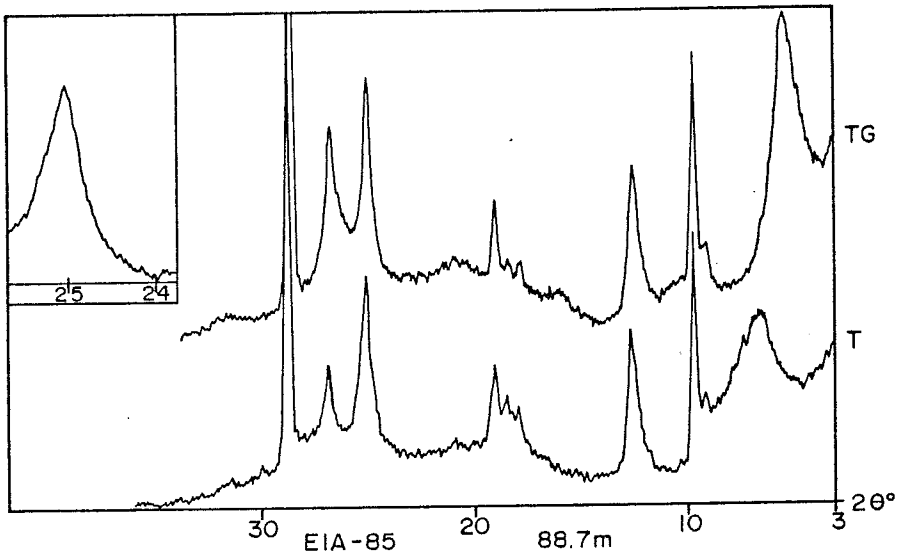
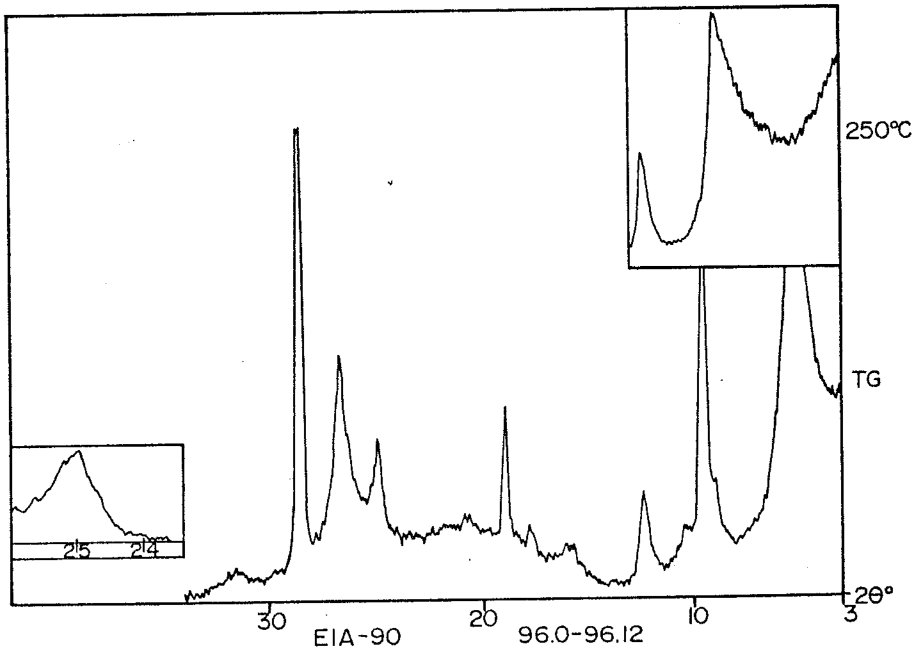


Figure 23. X-ray Diffractograms for selected samples, ElA.


25
24
TG
T
2θ°
30
EIA-85
20
88.7m
10
3


250°C
TG
25
24
2θ°
30
EIA-90
20
96.0-96.12
10
3

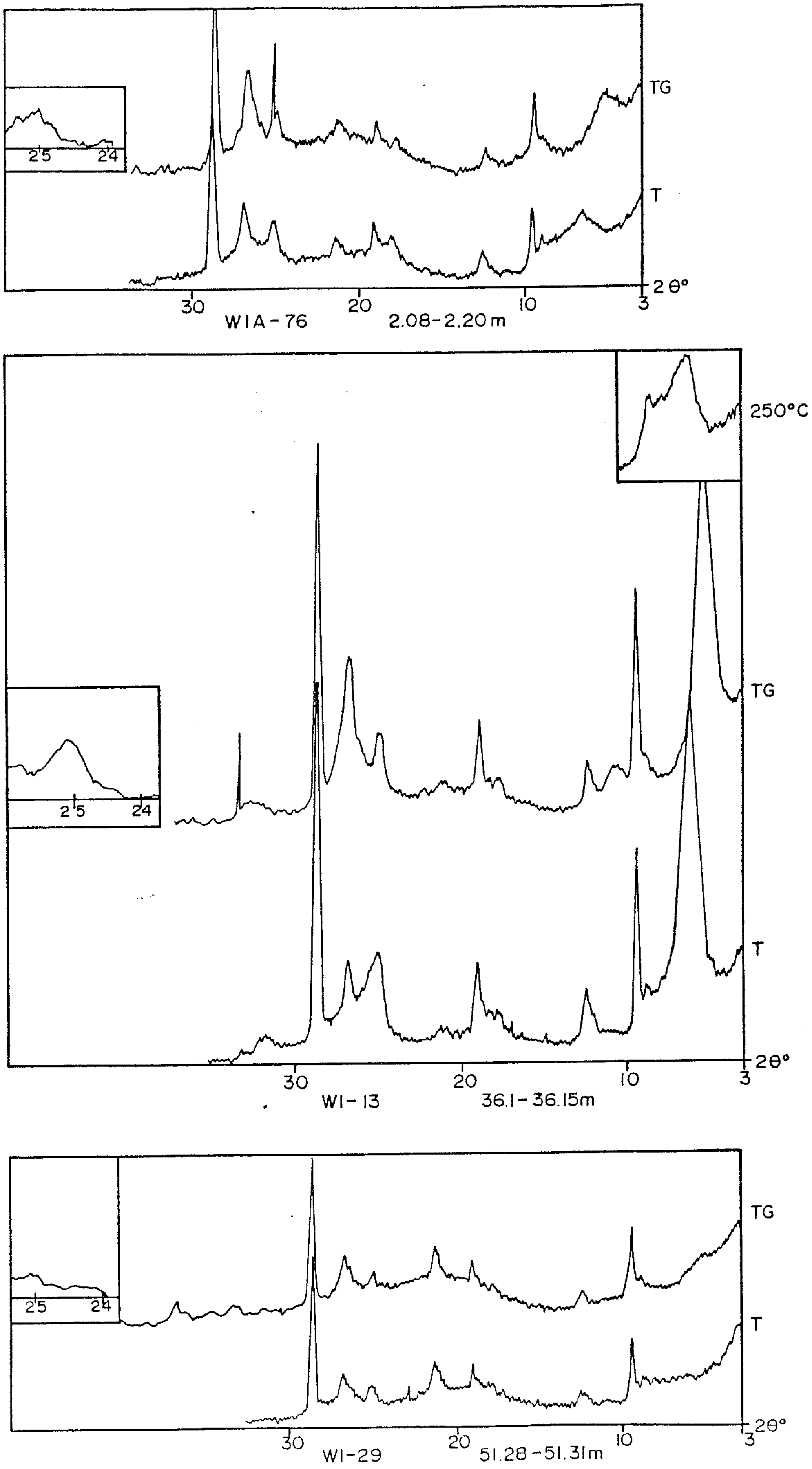
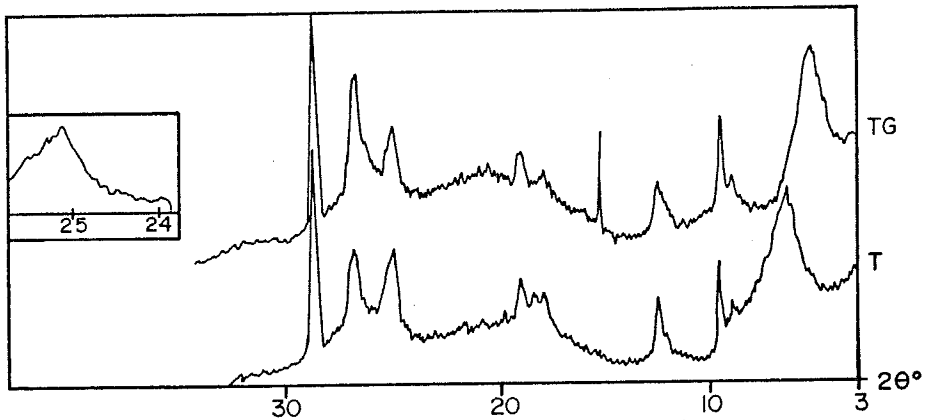
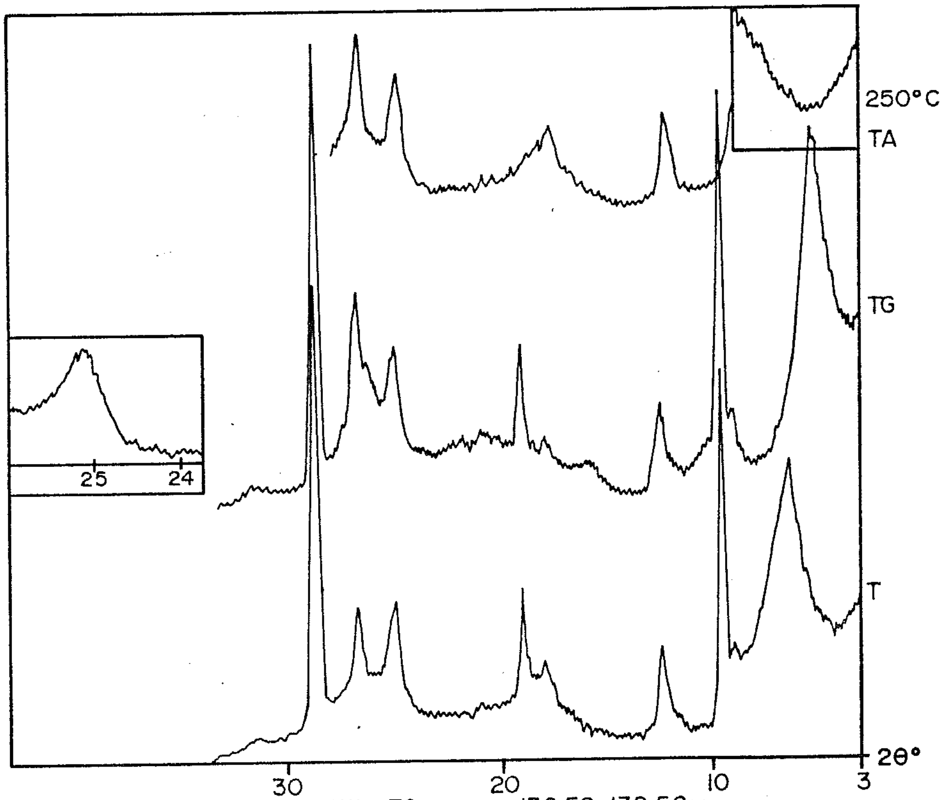


Figure 24. X-ray Diffractograms for selected samples, W1A/W1.



WI-42 75.05-75.15m



WI-70 130.52-130.56m

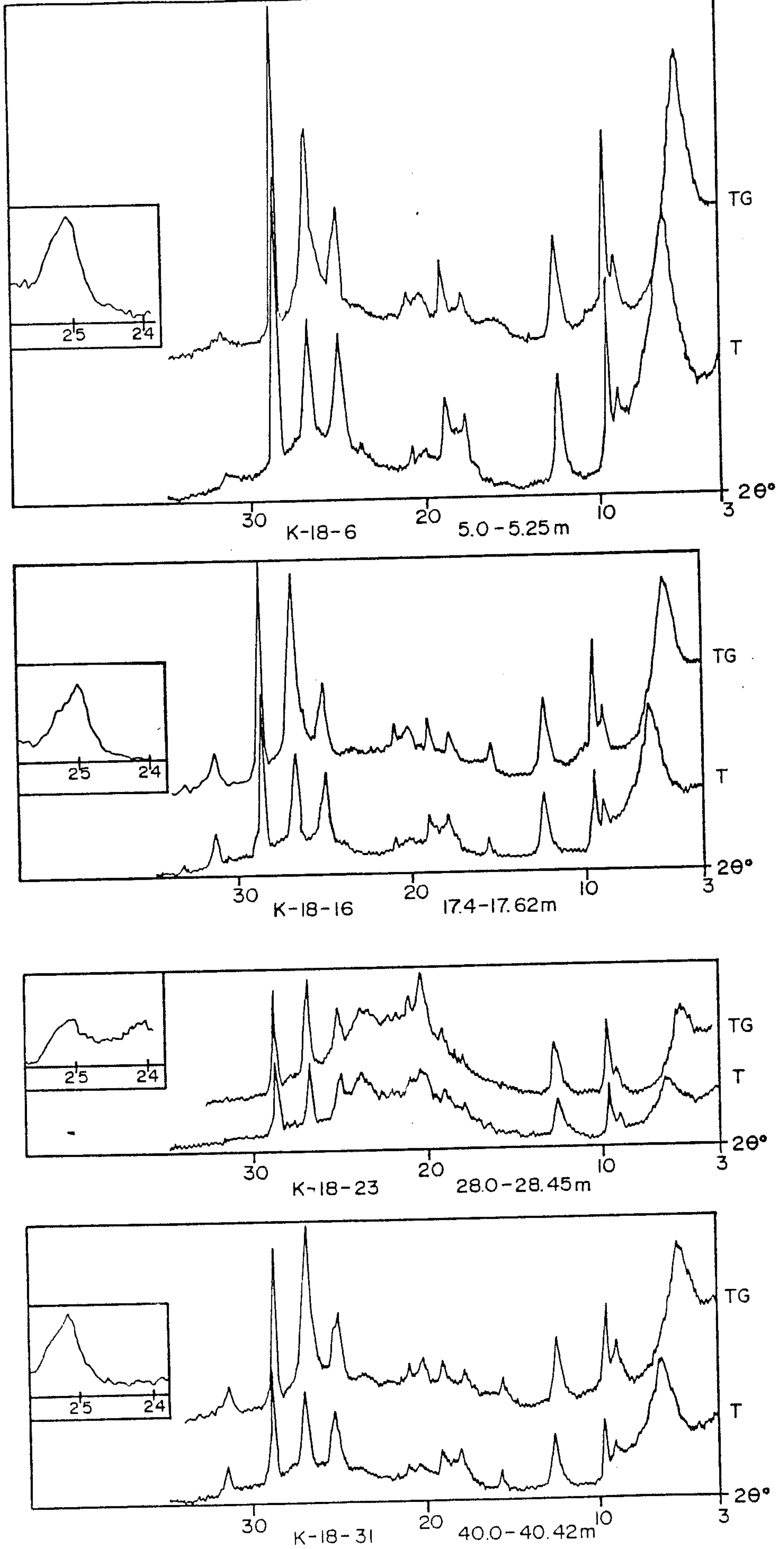
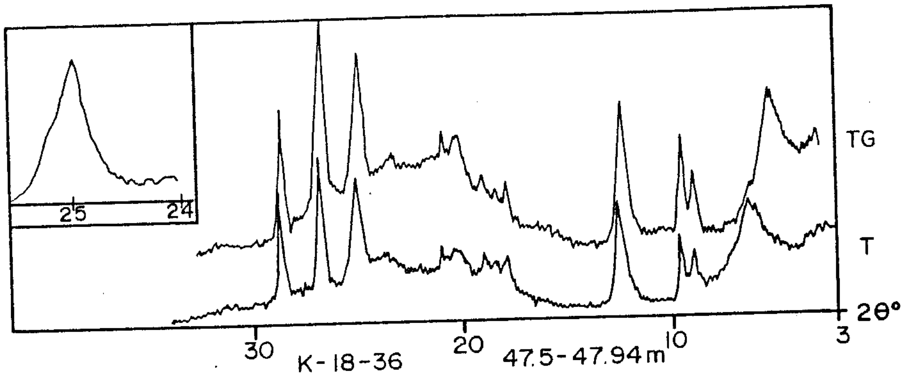
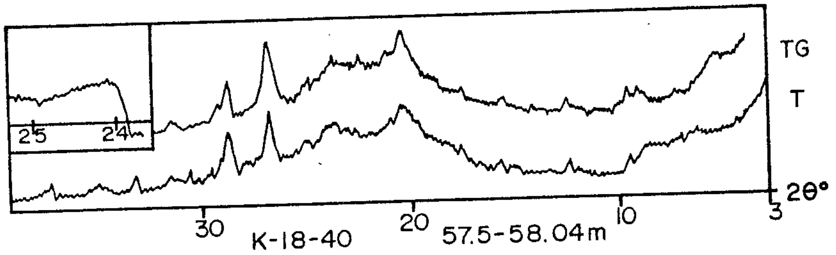
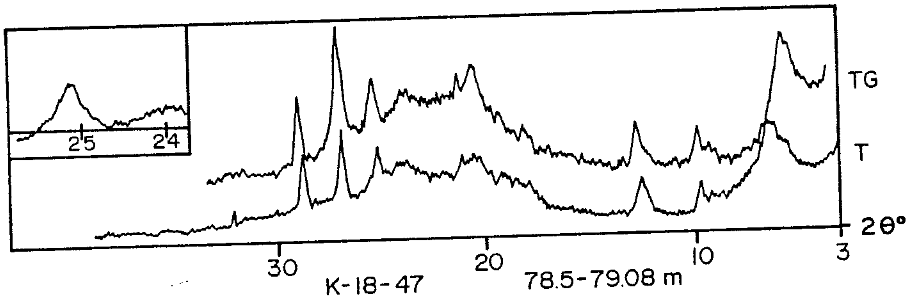
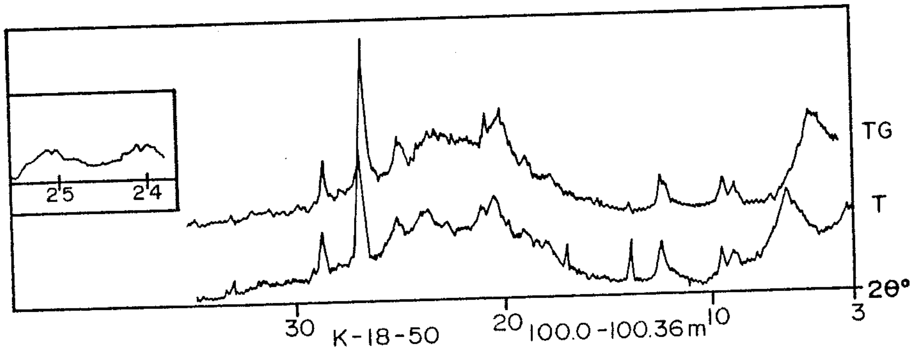


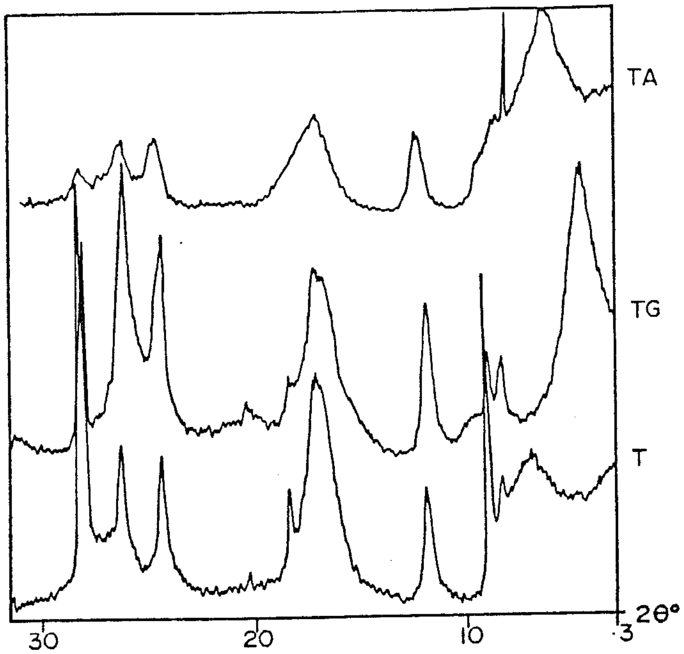
Figure 25. X-ray Diffractograms for selected samples, K-18.


25
24
TG
T
2θ°
30
20
10
3
K-18-36
47.5-47.94 m

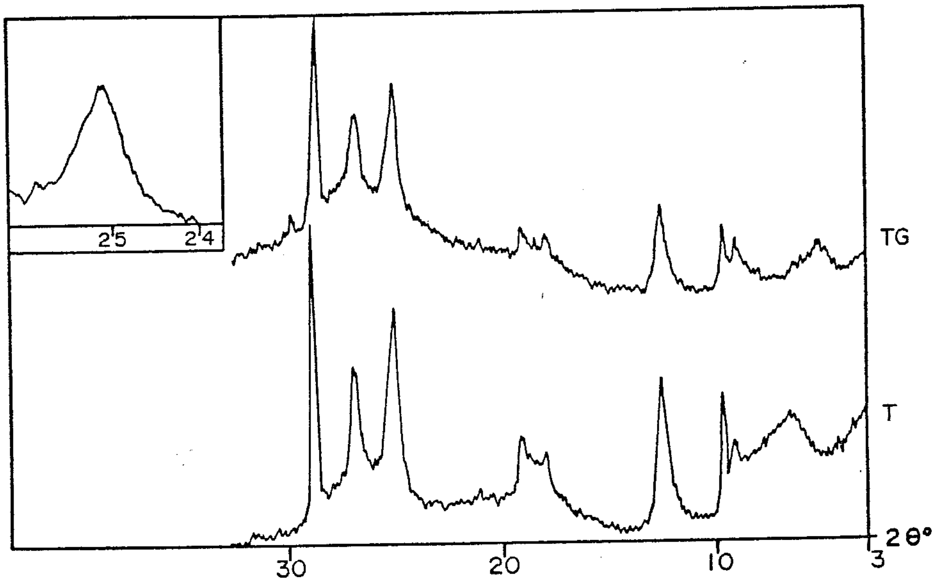

25
24
TG
T
2θ°
30
20
10
3
K-18-40
57.5-58.04 m


25
24
TG
T
2θ°
30
20
10
3
K-18-47
78.5-79.08 m

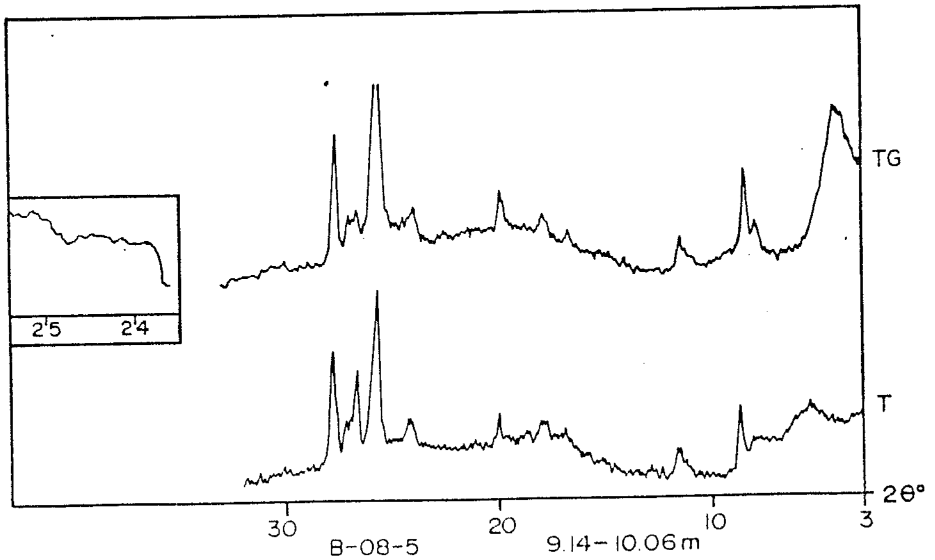

25
24
TG
T
2θ°
30
20
10
3
K-18-50
100.0-100.36 m



B-08-4b 8.18-8.31 m



B-08-5a



B-08-5 9.14-10.06 m

Figure 26. X-ray Diffractograms for selected samples, B-08.

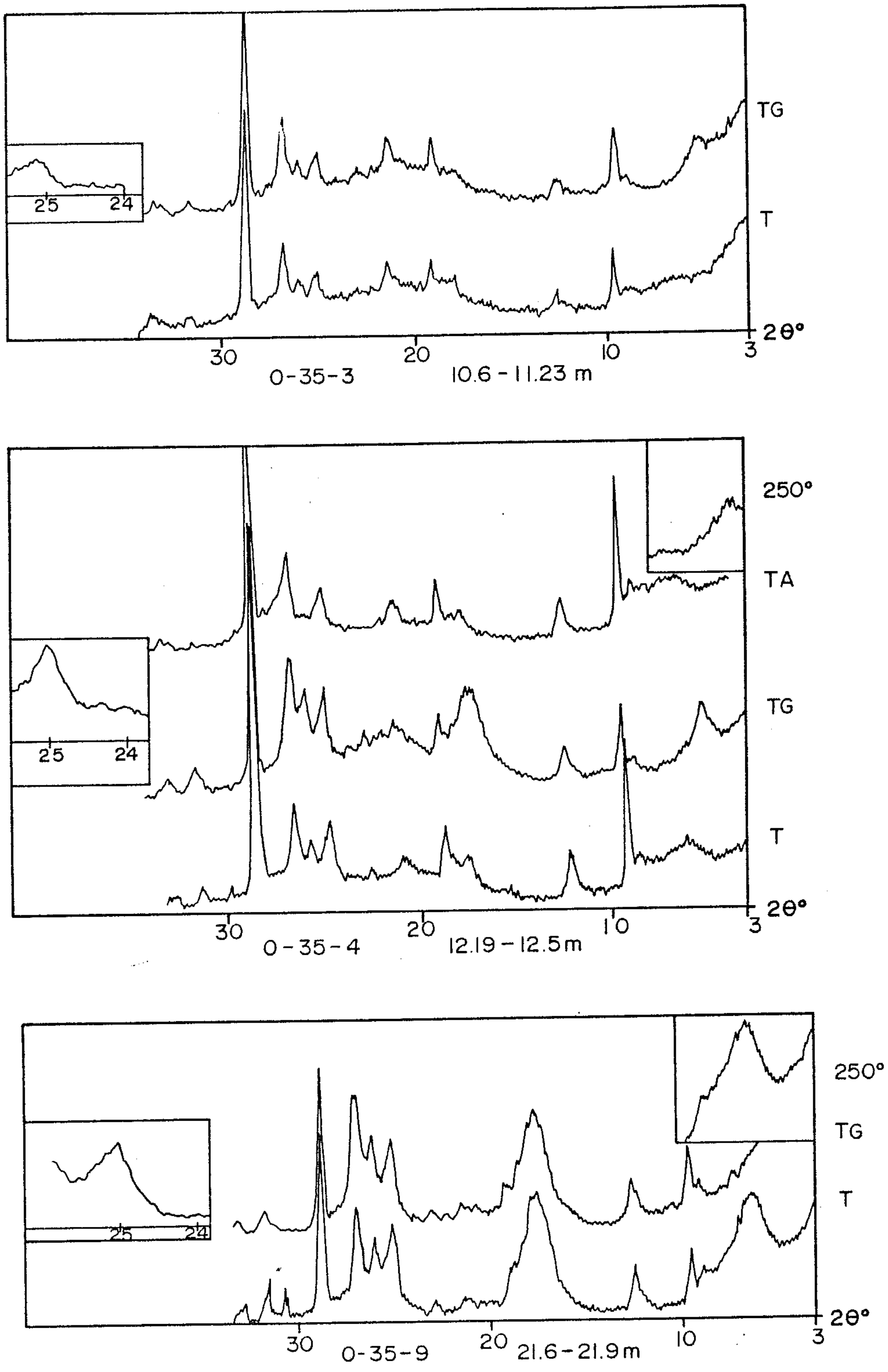
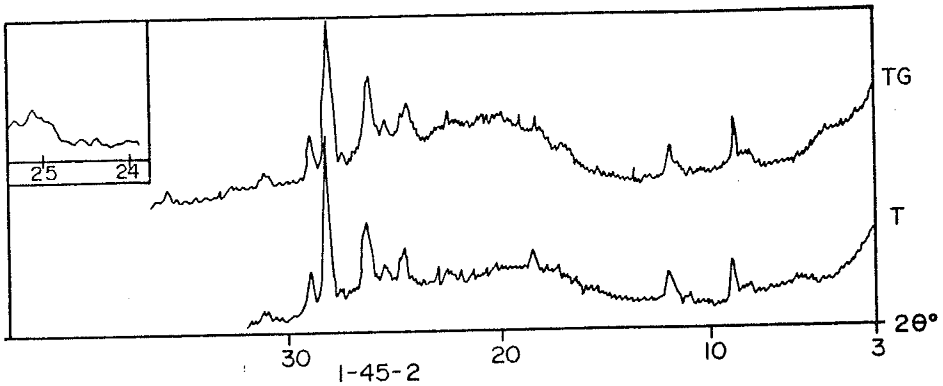
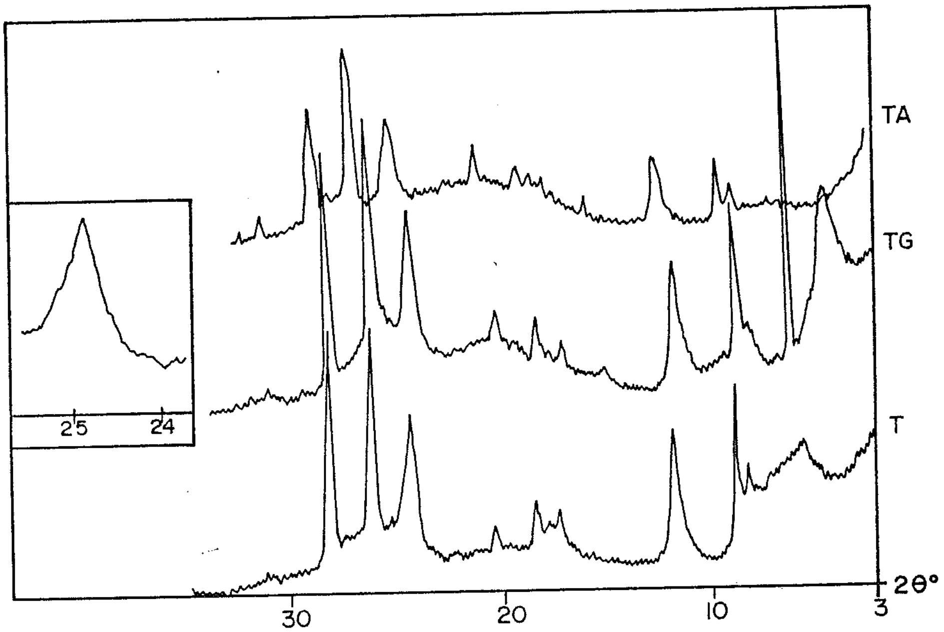


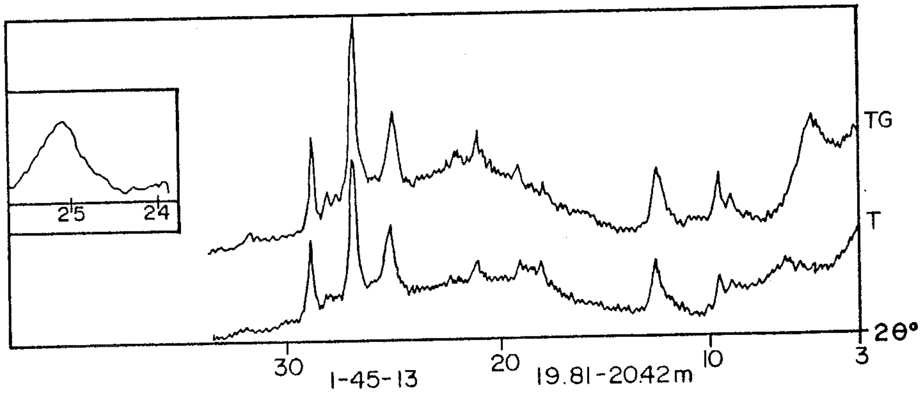
Figure 27. X-ray Diffractograms for selected samples, O-35.



1-45-2

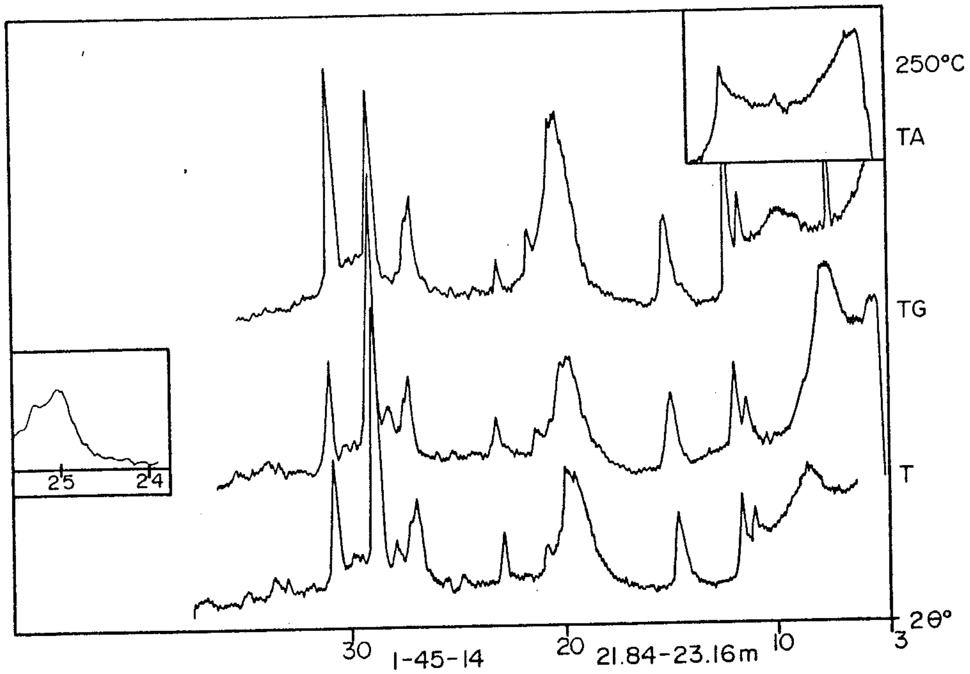


1-45-11 16.15-17.37m

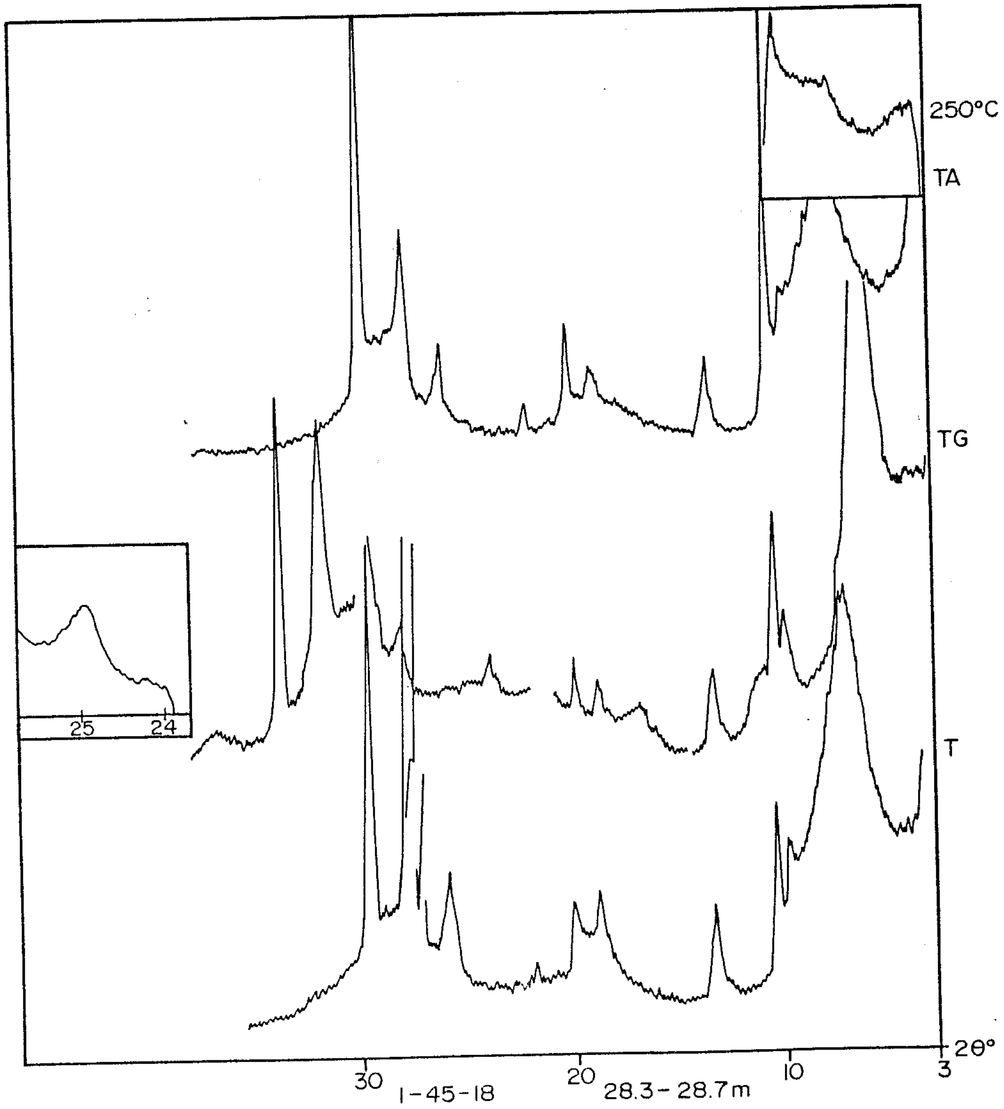


1-45-13 19.81-2042m

Figure 28. X-ray Diffractograms for selected samples, I-45.



1-45-14 21.84-23.16m



1-45-18 28.3-28.7m

HIBERNIA CLAY MINERALOGY

Table 1

Sample	Bulk Mineralogy = 100%									Clay Mineralogy = 100%			
	E	C	K	I	Q	F	P	A	Error	E	C	K	I
83-017-5-0.88	1	7	1	47	32	7	-	5	20	2	13	2	83
63-017-5-1.42	6	27	13	27	7	13	7	-	20	8	37	18	37
83-017-5-1.89	4	6	4	26	35	22	-	3	20	10	15	10	65
83-017-5-2.04	34	30	7	16	8	3	-	2	5	39	34	8	19
83-017-5-2.67	29	25	16	26	1	2	-	1	15	30	26	17	27
83-017-6-0.42	8	41	4	40	2	2	-	3	25	9	44	4	43
83-017-6-0.94	-	16	15	31	16	14	-	8	35	-	26	24	50
83-017-6-1.32	-	4	1	49	28	11	-	7	40	-	7	2	91
83-017-8-1.00	-	21	9	15	26	19	8	2	40	-	47	20	33
83-017-10-0.66	-	24	6	27	12	30	-	1	25	-	42	11	47
83-017-10-1.00	-	5	3	33	10	32	-	16	15	-	13	7	80
83-017-14-1.42	-	5	5	11	9	67	-	5	40	-	24	24	52
83-017-16-1.98	-	22	7	29	5	27	-	10	40	-	38	12	50
0-35-3	38	31	2	16	3	7	1	2	30	44	36	2	18
0-35-4	41	32	8	14	-	2	1	2	15	43	34	8	15
0-35-8	52	26	3	9	2	5	2	1	15	58	29	3	10
0-35-9	29	29	9	27	1	2	1	2	6	30	31	10	29
B-08-4a	48	26	3	22	1	-	-	-	30	48	26	3	23
B-08-4b	50	28	6	15	-	-	-	1	20	50	28	6	16
B-08-4c	42	19	4	16	1	11	-	7	20	52	23	5	20
B-08-5	55	18	2	16	1	6	-	6	2	60	20	2	18
B-08-5a	20	40	8	27	-	1	2	3	15	21	42	8	29
I-45-2	4	47	18	22	2	4	-	3	40	4	52	20	24
I-45-5	3	26	6	52	2	8	-	3	10	3	30	7	60
I-45-11	40	29	9	17	3	1	-	1	4	42	31	9	12
I-45-12	46	22	7	19	2	2	1	1	25	49	24	7	20
I-45-13	36	29	4	27	2	1	-	1	40	38	30	4	28
I-45-14	46	20	4	22	4	2	1	1	2	50	22	4	24
I-45-17	17	27	5	17	20	10	3	1	40	26	40	8	26
I-45-18	75	5	4	14	1	-	-	1	40	76	5	4	14
C1A-7	24	34	9	26	1	3	-	3	2	26	37	10	28
C1A-10	46	16	7	27	1	2	-	1	35	48	17	7	28
C1A-66	52	13	7	26	1	1	-	-	10	53	13	7	27
C1A-87	19	58	6	7	2	3	-	5	30	21	64	7	8
E1A-51	47	24	5	22	1	-	-	1	30	48	25	5	22
E1A-57	52	18	5	16	2	2	1	4	20	57	20	5	18
E1A-83	65	16	5	11	1	1	-	1	3	67	16	5	12
E1A-85	47	32	4	14	-	-	-	1	2	48	33	4	15
E1A-90	67	15	3	11	1	-	1	2	25	70	16	3	11
W1A-76	49	20	8	17	2	2	-	2	25	52	21	9	18
W1-13	78	9	2	8	1	-	-	2	5	80	10	2	8
W1-27	10	32	4	32	8	5	3	6	40	13	41	5	41
W1-42	63	18	3	14	1	1	-	-	20	64	19	3	14
W1-70	65	17	4	13	1	-	-	-	10	66	17	4	13
K-18- 6	65	15	1	16	1	1	-	-	5	67	15	1	17
K-18-16	49	26	3	20	1	-	-	1	10	50	27	3	20
K-18-23	38	28	5	22	2	3	1	1	5	41	30	5	24
K-18-31	47	22	2	27	1	-	-	1	25	48	22	2	28
K-18-36	35	33	9	22	-	-	-	1	30	36	33	9	22
K-18-40	35	38	-	17	-	6	-	4	20	39	42	-	19
K-18-47	60	23	2	10	2	-	1	2	40	63	24	2	11
K-18-50	58	16	3	19	2	2	-	-	40	60	17	3	20

E = Expandable Minerals
C = Chlorite
K = Kaolinite
I = Illite

Q = Quartz
F = Feldspar
P = Pyroxene
A = Amphibole

Table 2. Hibernia Clay Analysis - Samples, Depths and Treatments

SAMPLE	DEPTH (m)	TREATMENT					
		U	T	TG	TA	H (110°)	H (250°)
83-017-5	0.88		X	X			
83-017-5	1.42	X	X	X	X		
83-017-5	1.89		X	X			
83-017-5	2.04	X	X	X	X		X
83-017-5	2.67	X	X	X	X		X
83-017-6	0.42		X	X	X		X
83-017-6	0.94	X	X	X	X		X
83-017-6	1.32		X	X			
83-017-8	1.00		X	X			
83-017-10	0.66		X	X			
83-017-10	1.00		X	X			
83-017-14	1.48		X	X			
83-017-16	1.98		X	X			
CIA-7	1.0-1.3	X	X	X	X		
CIA-10	2.15-2.18	X	X	X			
CIA-66	59.19-59.22	X	X	X	X		
CIA-87	99.42-99.49	X	X	X	X	X	X
EIA-51	8.0-8.05		X	X			X
EIA-57	12.52-12.58		X	X			
EIA-83	80.08-80.12	X	X	X			X
EIA-85	88.7		X	X			
EIA-90	96.0-96.12		X	X		X	X
WIA-76	2.08-2.20		X	X			

SAMPLE	DEPTH (m)	TREATMENT					
		U	T	TG	TA	H (110°)	H (250°)
WI-13	36.10-36.15	X	X	X			X
WI-27	51.28-51.31		X	X			
WI-42	75.05-75.15	X	X	X			
WI-70	130.52-130.56		X	X			X
0-35-3	10.60-11.23		X	X			
0-35-4	12.19-12.50		X	X	X		X
0-35-8	19.81-20.12		X	X	X		
0-35-9	21.60-21.90		X	X	X	X	X
0-35-10	22.60-22.90	X	X	X	X		
B-08-4a	7.92-8.18		X	X			
B-08-4b	8.18-8.31		X	X	X		
B-08-4c	8.31-8.53		X	X			
B-08-5	9.14-10.06		X	X			
B-08-5a	10.20-10.70		X	X			
I-45-2	3.0-3.70		X	X			
I-45-5	7.30-7.62		X	X			
I-45-11	16.15-17.37		X	X	X		
I-45-12	18.29-18.59		X	X			
I-45-13	19.81-20.42		X	X			
I-45-14	21.34-23.16		X	X	X		
I-45-17	25.91-26.52		X	X			
I-45-18	28.30-28.70	X	X	X	X	X	X
K-18-6	5.0-5.25		X	X			
K-18-16	17.4-17.62		X	X			

SAMPLE	DEPTH (m)	TREATMENT					
		U	T	TG	TA	H (110°)	H (250°)
K-18-23	28.0-28.45		X	X			
K-18-31	40.0-40.42		X	X			
K-18-36	47.5-47.94		X	X			
K-18-40	57.5-58.04		X	X			
K-18-47	78.5-79.08		X	X			
K-18-50	100.0-100.36		X	X			

U = Untreated
T = Talc Treated
TG = Talc Treated and Glycolated
TA = Talc and Acid Treated
TH (110°C) = Heated at 110°C
TH (250°C) = Heated at 250°C

Table 3. Pebble Lithologies for the 0-35 and I-45 Boreholes.

HIBERNIA BOREHOLE SAMPLES

Borehole Number	Depth (m)	Size (mm)	Point Count %	Rock Classification	Rock Type	Roundness	Color
0-35 #3	10.7-	4- 5.6	100	Igneous (1)	rhyolite (1)	subangular	reddish brown
		2.8- 4	67 33	Sedimentary (1) Igneous (2)	chert (1) rhyolite (2)	angular angular	brown reddish brown
I-45 #1	1.5- 1.8	2.8- 5.6	11	Sedimentary (3)	fossiliferous limestone (1) limestone (1) conglomerate (1)	subangular angular subangular	light grey grey grey matrix
			64	Igneous (18)	granite (13) rhyolite (2) agglomerate (1) diorite (?)(1) unidentified (1)	subangular to angular angular angular subangular angular	reddish brown light grey matri-
			25	Metamorphic (7)	quartzite (6) gneiss (1)	angular angular	
I-45 #3	4.5- 4.9	2- 2.8	100	Igneous (2)	basalt (?) granite (1)	angular subangular	dark grey grey/white
I-45 #5	7.3- 7.6	2- 8	20	Sedimentary (1)	sandstone (1)	rounded	light grey
			20	Igneous (1)	basalt (?) (1)	subangular	dark grey
			60	Metamorphic (3)	gneiss (1) quartzite (2)	angular angular	black & white highly weathered
I-45 #6	7.6- 9.1	2- 2.8	100	Sedimentary (1)	shale (1)	subangular	black

Table 3 cont'd. Pebble Lithologies for the 0-35 and I-45 Boreholes.

HIBERNIA BOREHOLE SAMPLES (CON'D)

Borehole Number	Depth (m)	Size (mm)	Point Count %	Rock Classification	Rock Type	Roundness	Color
I-45 #6A	9.1-9.5	2-2.8	100	Igneous (2)	unidentified (1)	subangular	very dark grey
					granite (1)	angular	black and white
I-45 #7B	10.7-11.1	2-4	30	Sedimentary (3)	limestone (3)	angular to subangular	buff to light grey
			40	Igneous (4)	granite (4)	subrounded to subangular	grey/white
			30	Metamorphic (3)	quartzite (3)	subrounded to subangular	
I-45 #8	12.2-12.8	2-5.6	6	Sedimentary (1)	limestone (1)	angular	buff
			33	Igneous (6)	unidentified (3)	subangular to angular	black
					rhyolite (1)	subangular	reddish brown
					agglomerate (1)	subangular	light grey
					granite (1)	subangular	
			61	Metamorphic (11)	gneiss (3)	angular	black
					quartzite (8)	subangular to angular	buff to grey
I-45 #10	15.2-15.4	2-5.6	12	Sedimentary (7)	oolitic dolomite (1)	angular	
					limestone (4)	angular	light grey to buff
					shale (1)	angular	black
					silstone (1)	subrounded	grey
			75	Igneous (43)	granite (41)	subangular to angular	black and white
					balsalt (2)	angular	dark grey
			12	Metamorphic (7)	gneiss (2)	angular	black
					quartzite (5)	angular	dark grey

Table 4. Pebble Lithologies for the C1A, C1A and W1/W1A Boreholes.

PHOLAS BOREHOLE SAMPLES

Station Number	Depth (m)	Size (mm)	Point Count %	Rock Classification	Rock Type	Roundness	Color
C1A #7	1.00- 1.03	4	100	Sedimentary (1)	siltstone (1)	angular	grey
E1A #57	12.52- 12.58	2.8	80	Sedimentary (4)	conglomerate (1) quartz sandstone (3)	subrounded subangular	grey
			20	Igneous (1)	gabbro (?) (1)	subangular	
W1 #13	36.10- 36.15	≥4	100	Sedimentary (2)	chert (2)	subangular	light brown
W1 #13	36.10- 36.15	2.8	57	Sedimentary (4)	chert (4)	rounded to subangular	light brown
			43	Igneous (3)	granite (1) rhyolite (2)	subangular angular	
W1A #73	1.10- 1.15	2.8	19	Sedimentary (4)	limestone (1) siltstone (3)	angular angular	buff black
			38	Igneous (8)	granite (3) pyroxenite (?)(5)	subangular to subrounded angular	
			43	Metamorphic (9)	quartzite (7) schist (2)	very angular angular	greyish-white dark

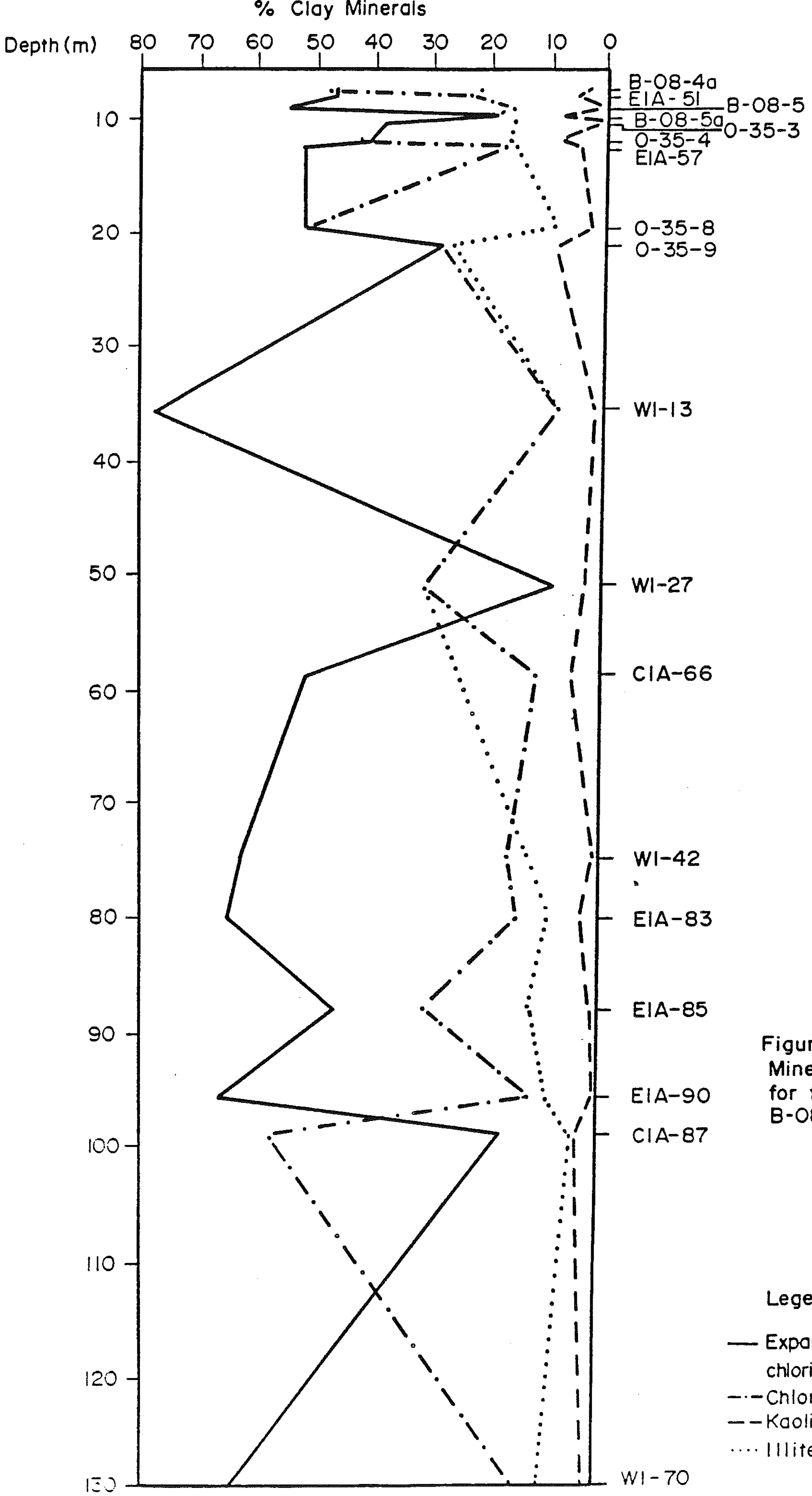


Figure 13 Compilation of clay Mineral Relative Abundances for the Upper Tertiary: Sites B-08, 0-35, CIA, EIA, WI/WIA

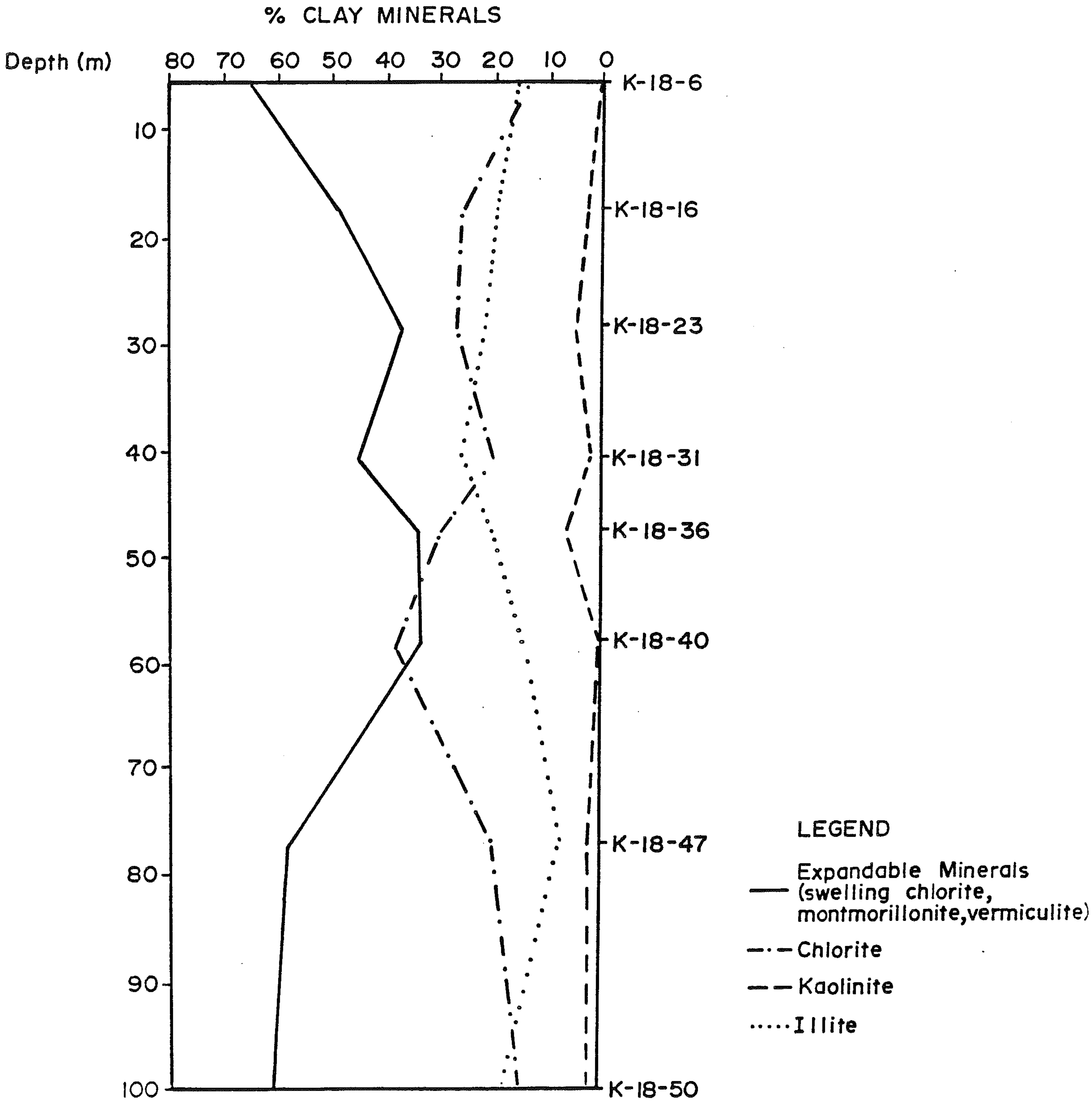


Figure 14 Clay mineralogy for the K-18 borehole samples.

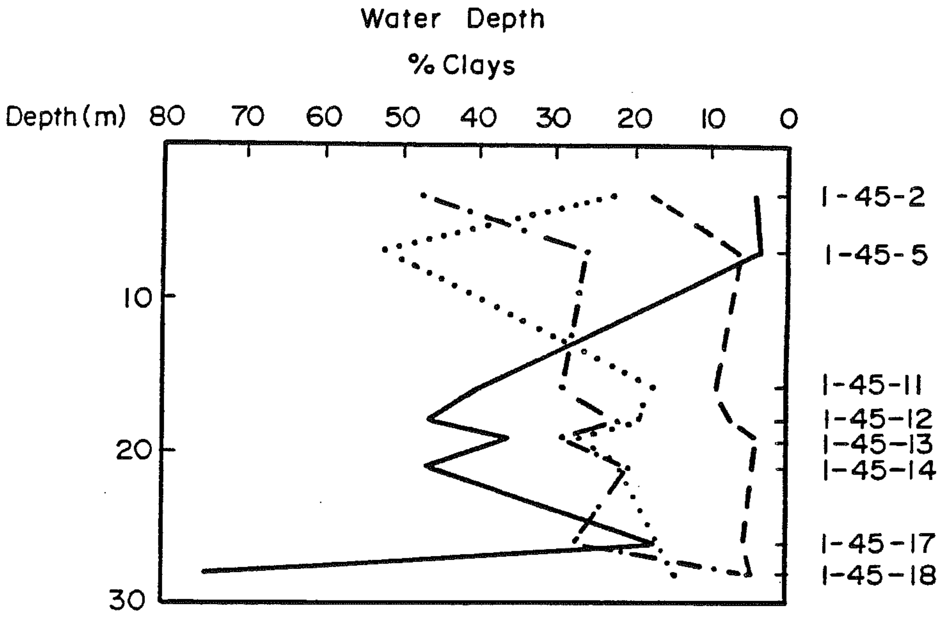


Figure 15 Clay mineralogy for the I-45 Borehole samples.

Legend

—— Expandable Minerals (swelling chlorite,
montmorillonite, vermiculite)

—·— Chlorite

— — Kaolinite

····· Illite

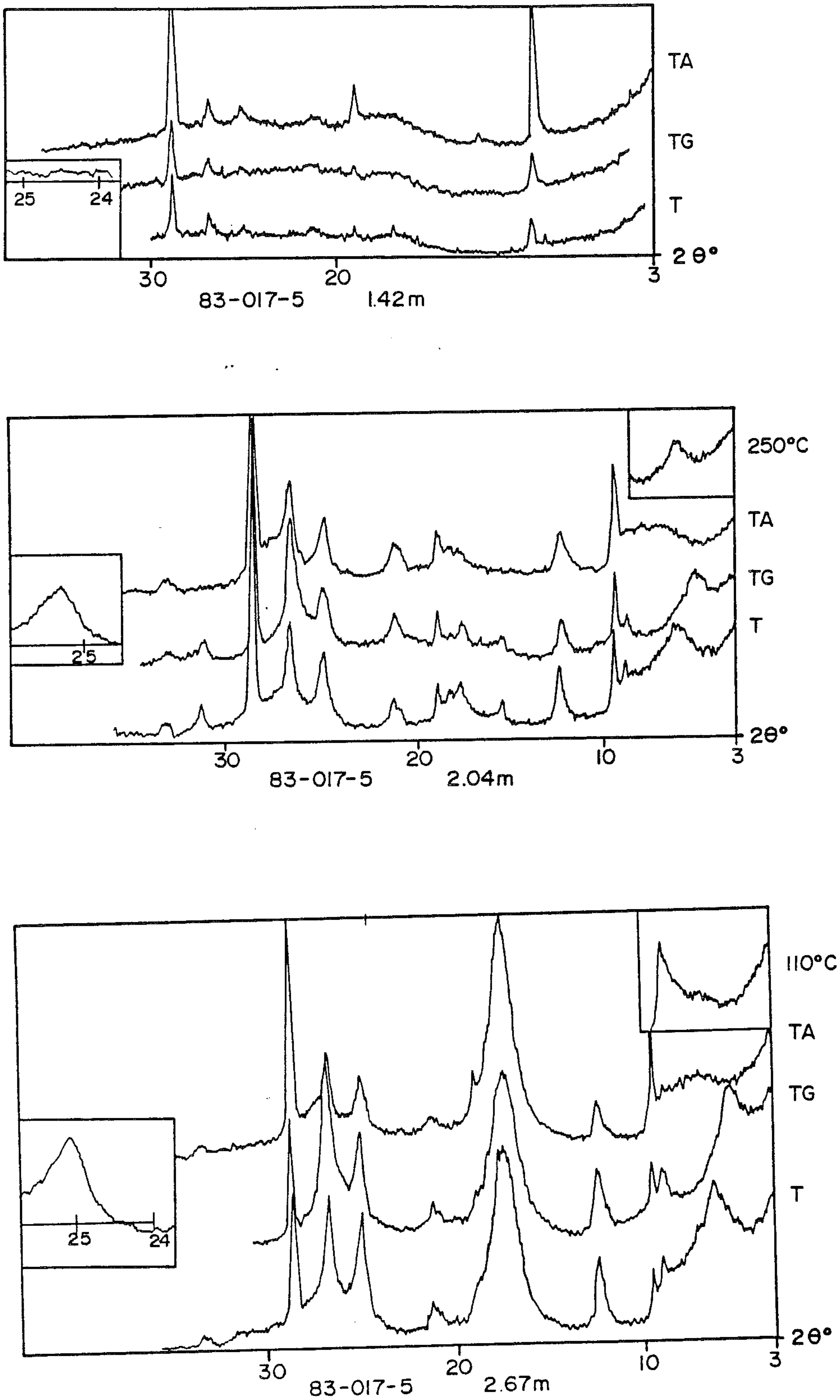
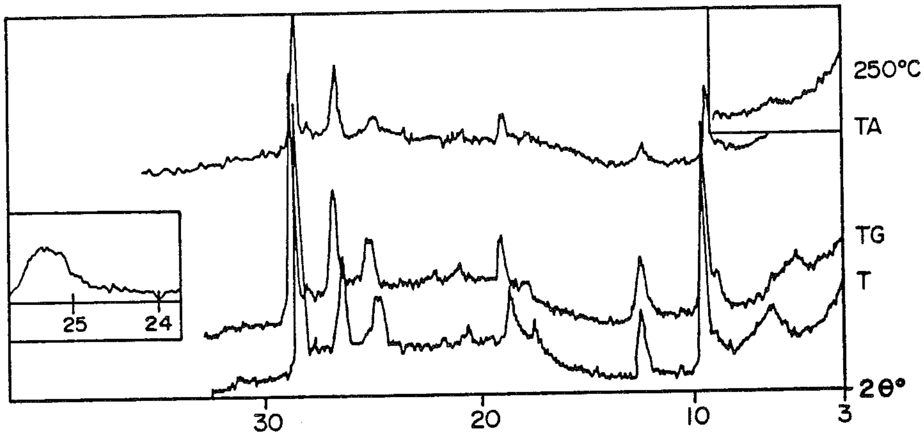
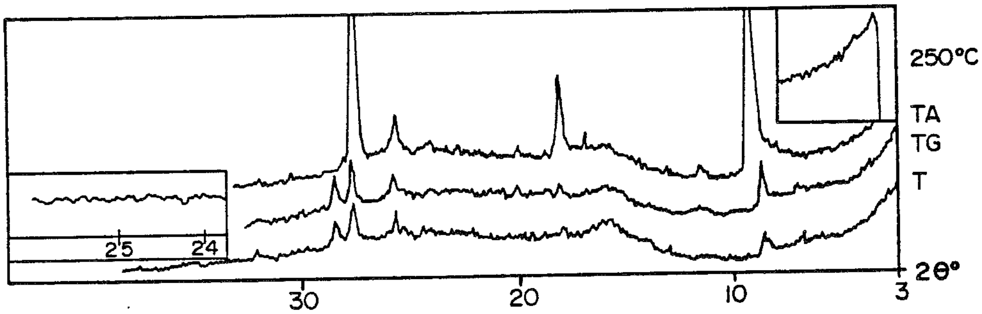


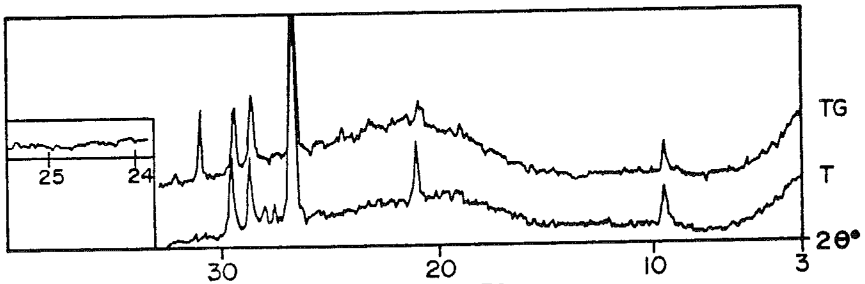
Figure 19. X-ray Diffractograms for selected samples, HU83-017-5.



83-017-6 0.42m



83-017-6 0.94m



83-017-6 1.32m

Figure 20. X-ray Diffractograms for selected samples, HU83-017-6.

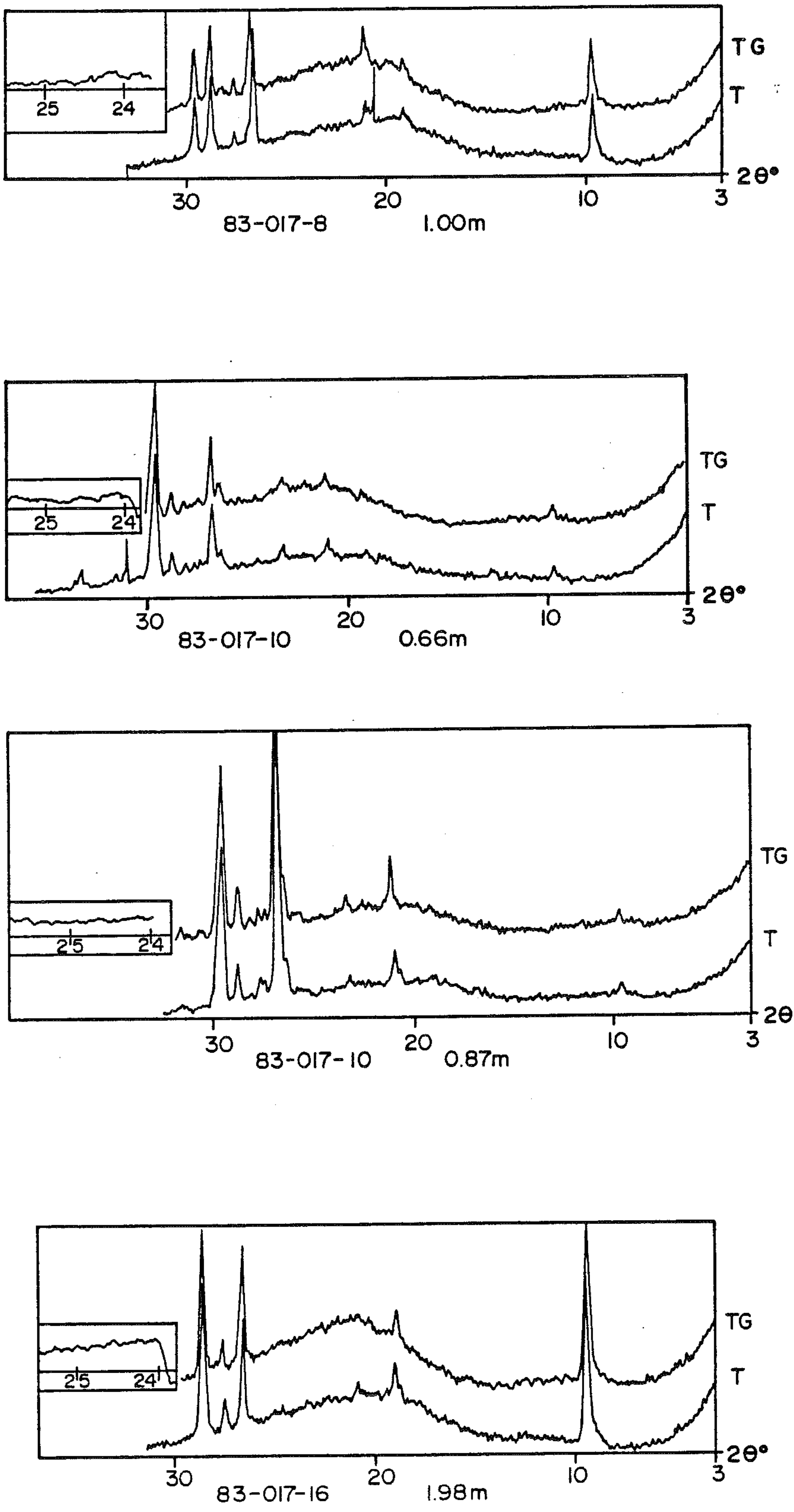


Figure 21. X-ray Diffractograms for selected samples, HU83-017-8, HU83-017-10, and HU83-017-16.

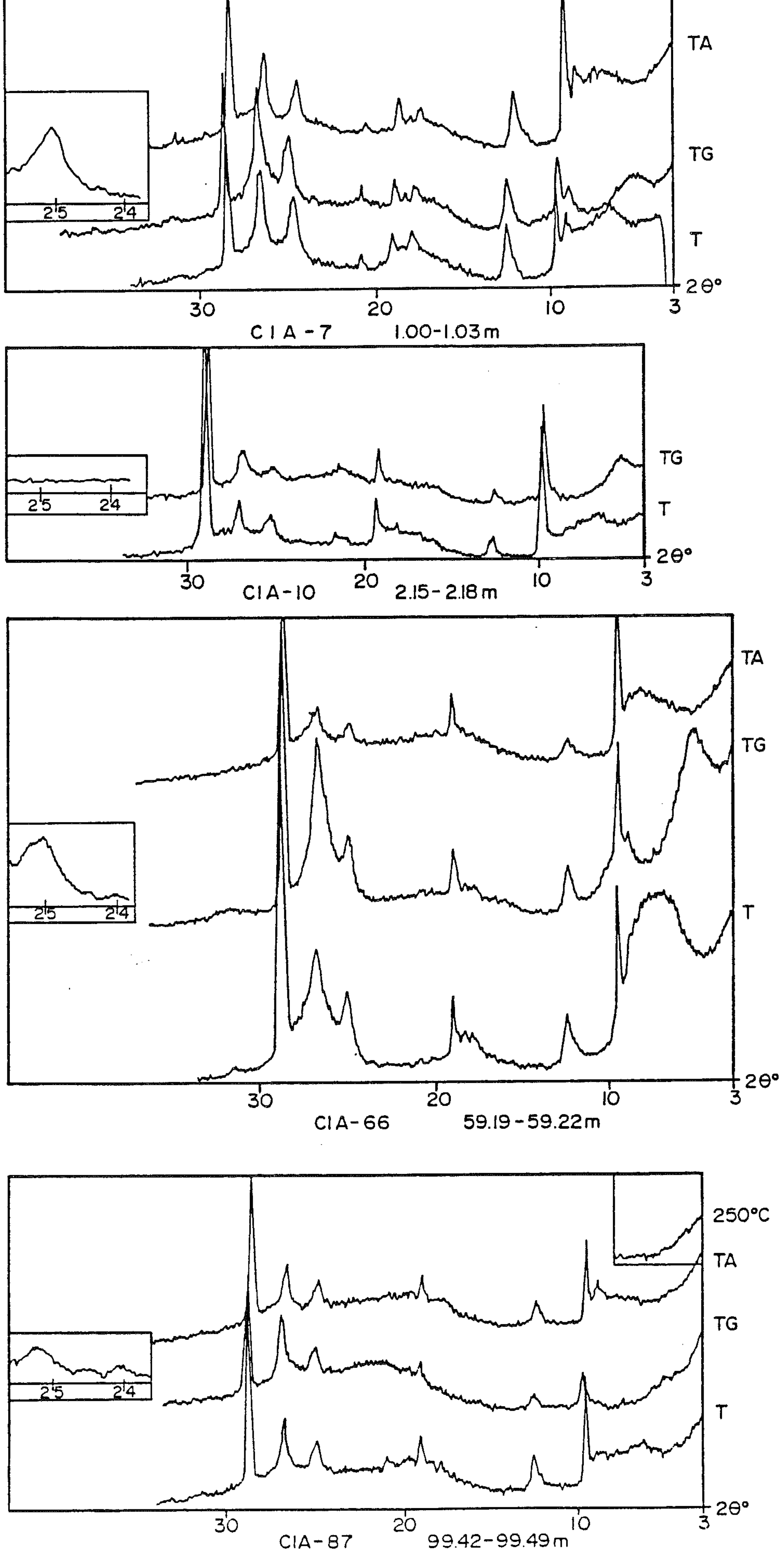


Figure 22. X-ray Diffractograms for selected samples, ClA.

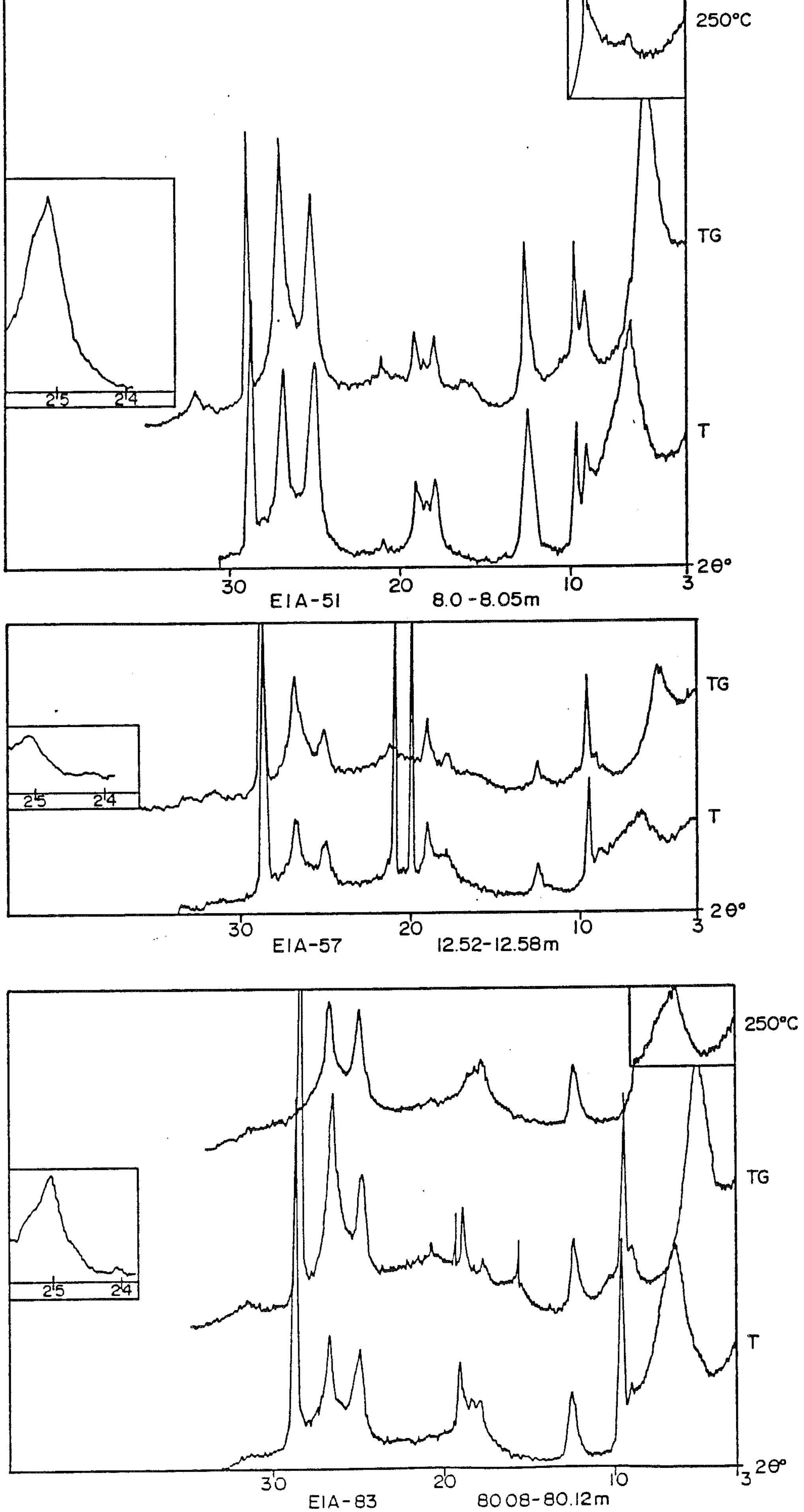
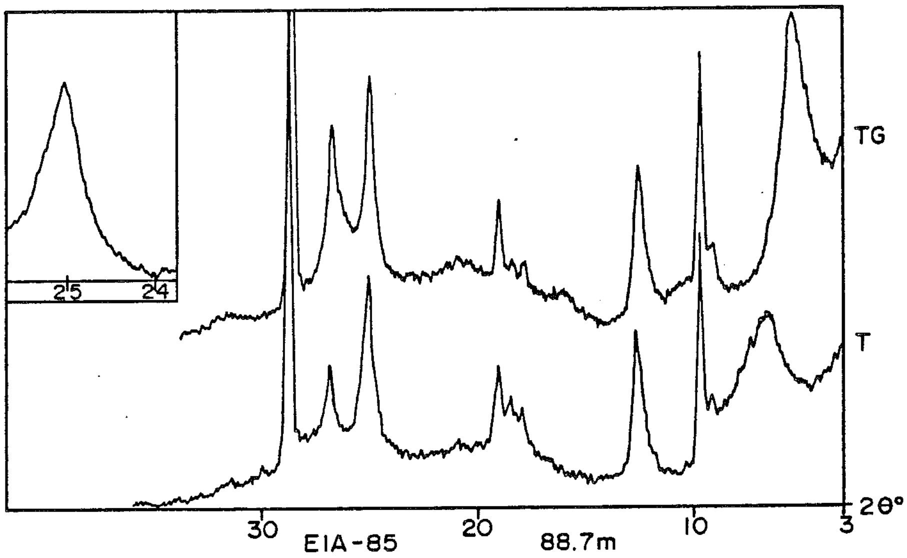
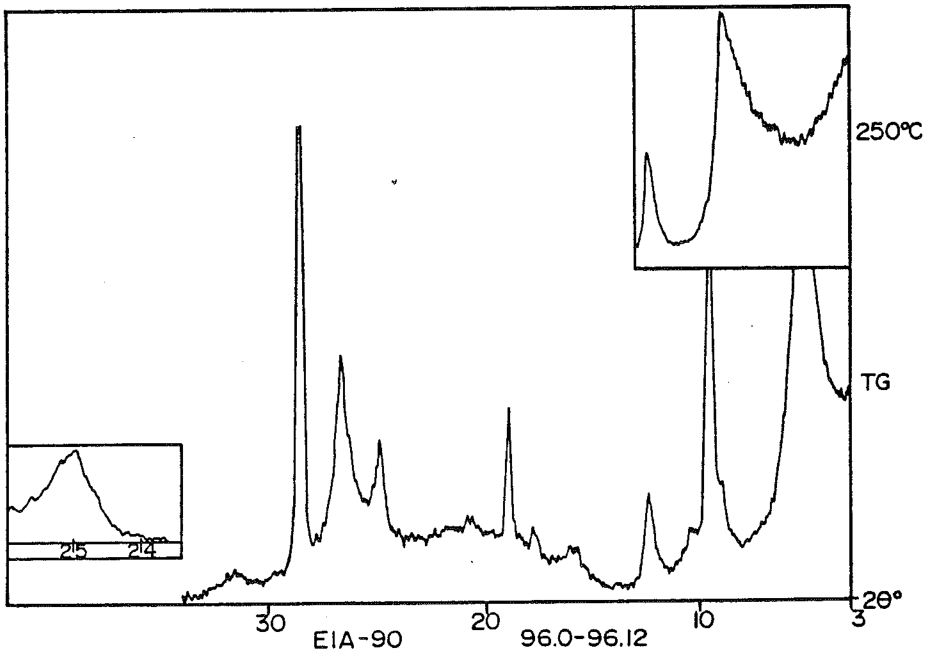


Figure 23. X-ray Diffractograms for selected samples, E1A.


25
24
TG
T
2θ°
30
20
10
3
EIA-85
88.7m


250°C
TG
25
24
2θ°
30
20
10
3
EIA-90
96.0-96.12

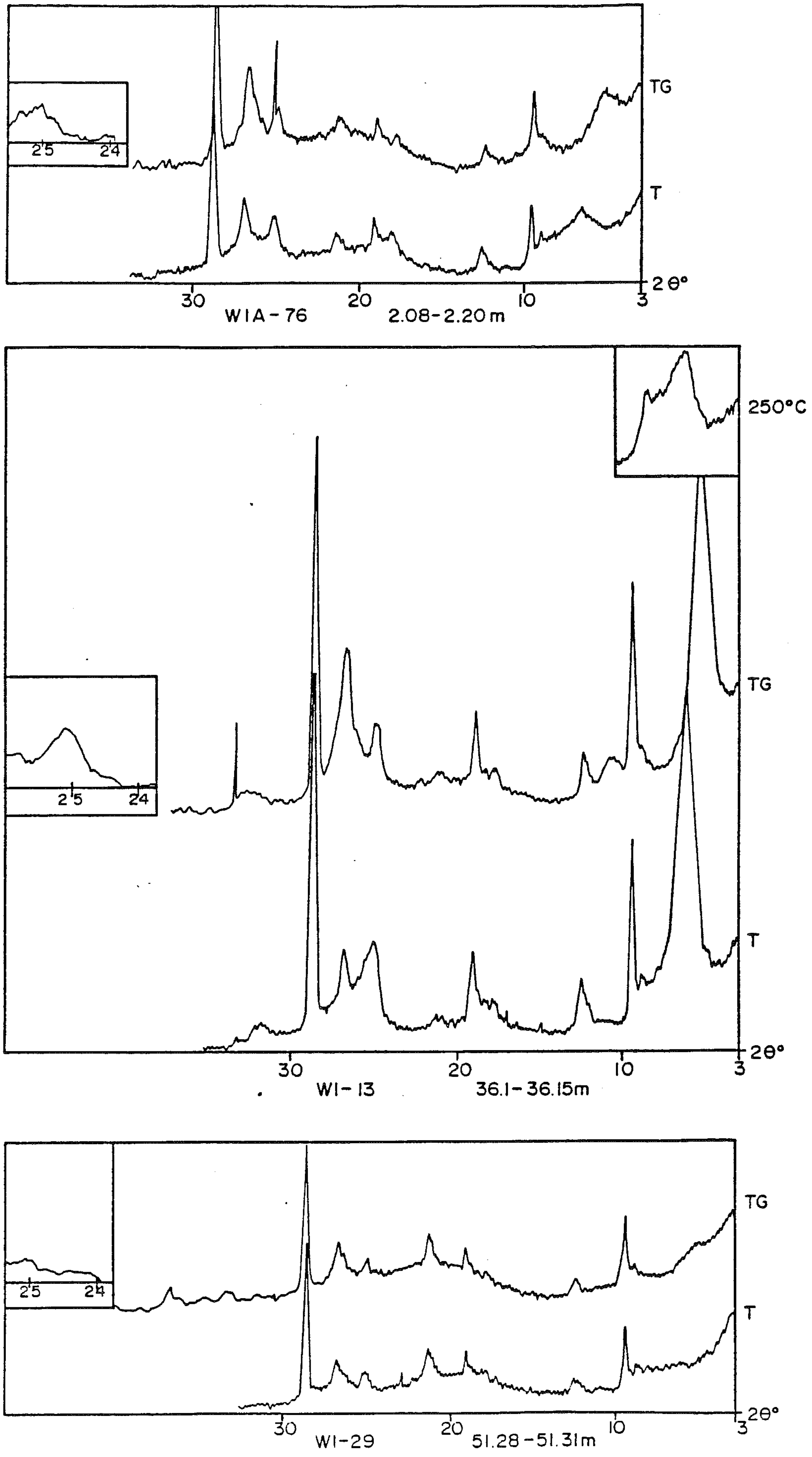
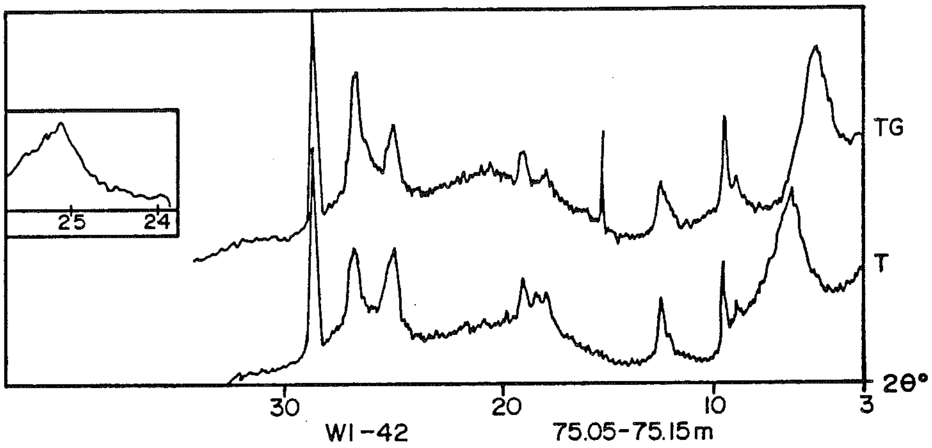
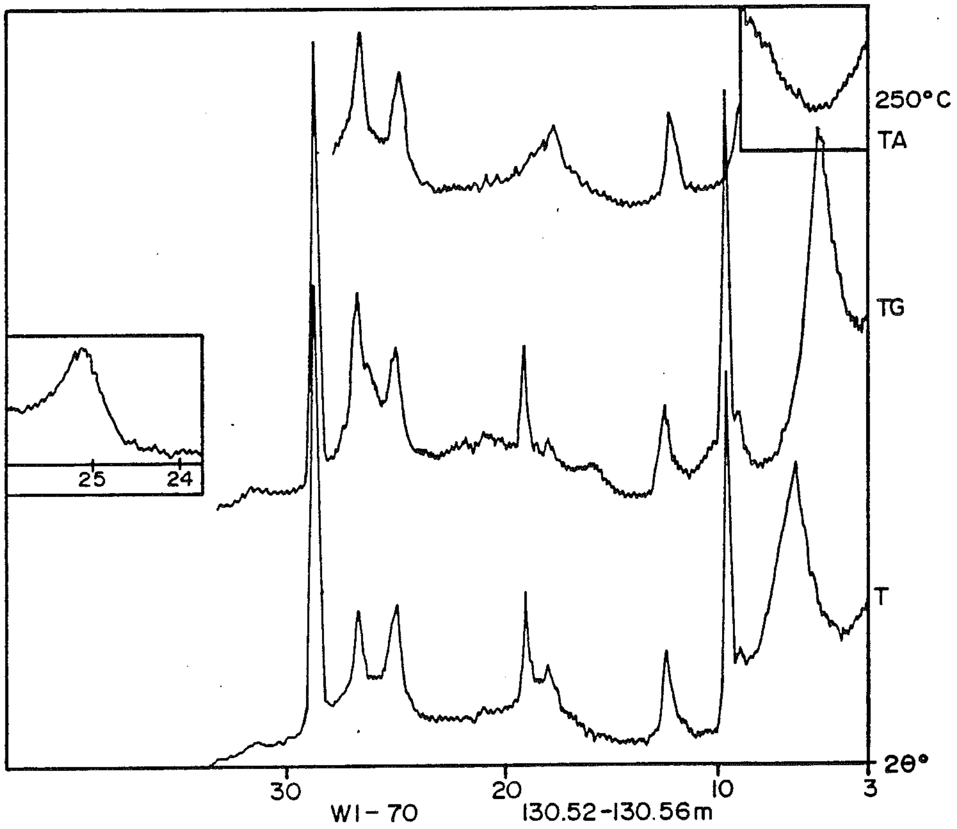


Figure 24. X-ray Diffractograms for selected samples, W1A/W1.


TG
T
2θ°
25
24
30
20
10
3
WI-42
75.05-75.15 m


250°C
TA
TG
T
2θ°
25
24
30
20
10
3
WI-70
130.52-130.56 m

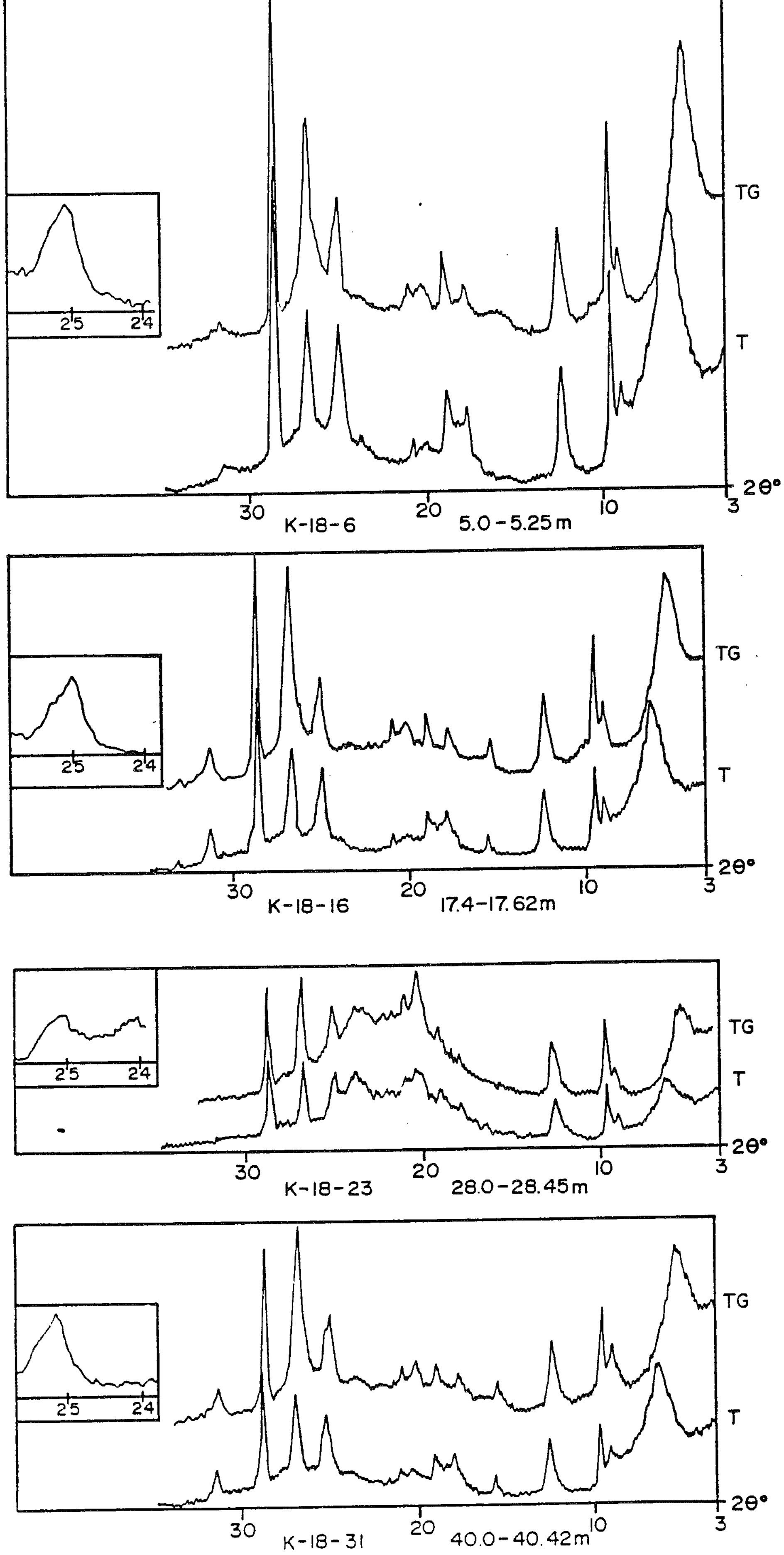
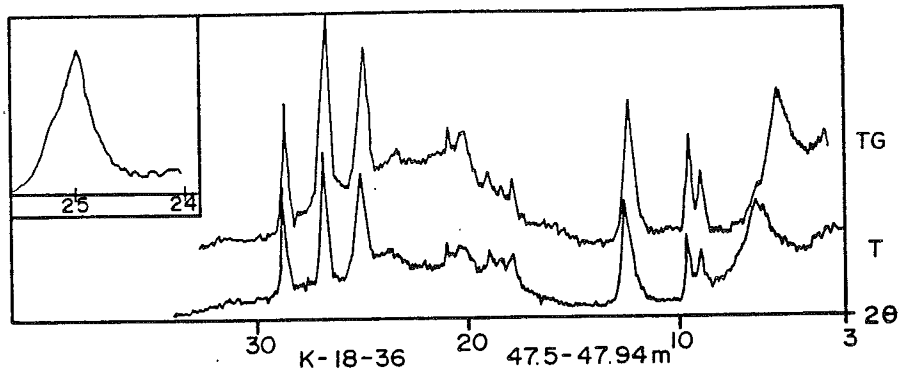
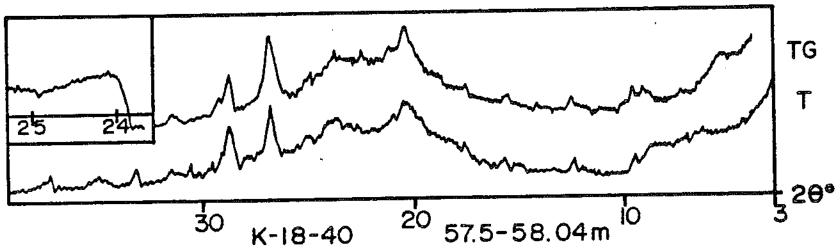


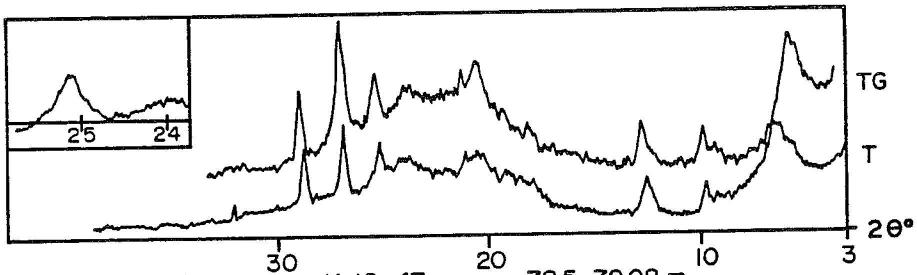
Figure 25. X-ray Diffractograms for selected samples, K-18.



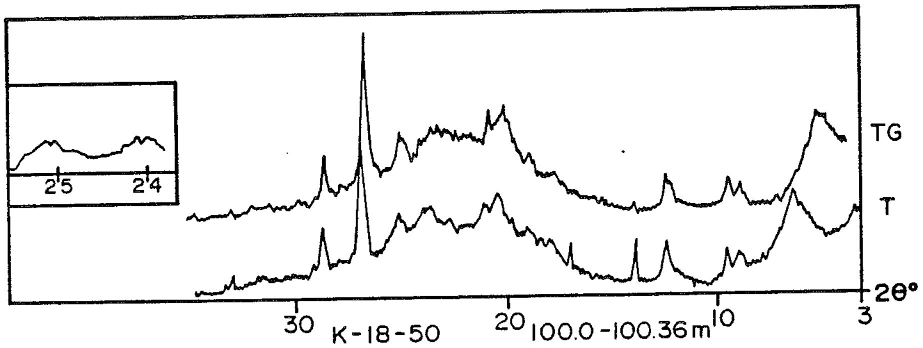
K-18-36 47.5-47.94 m



K-18-40 57.5-58.04 m



K-18-47 78.5-79.08 m



K-18-50 100.0-100.36 m

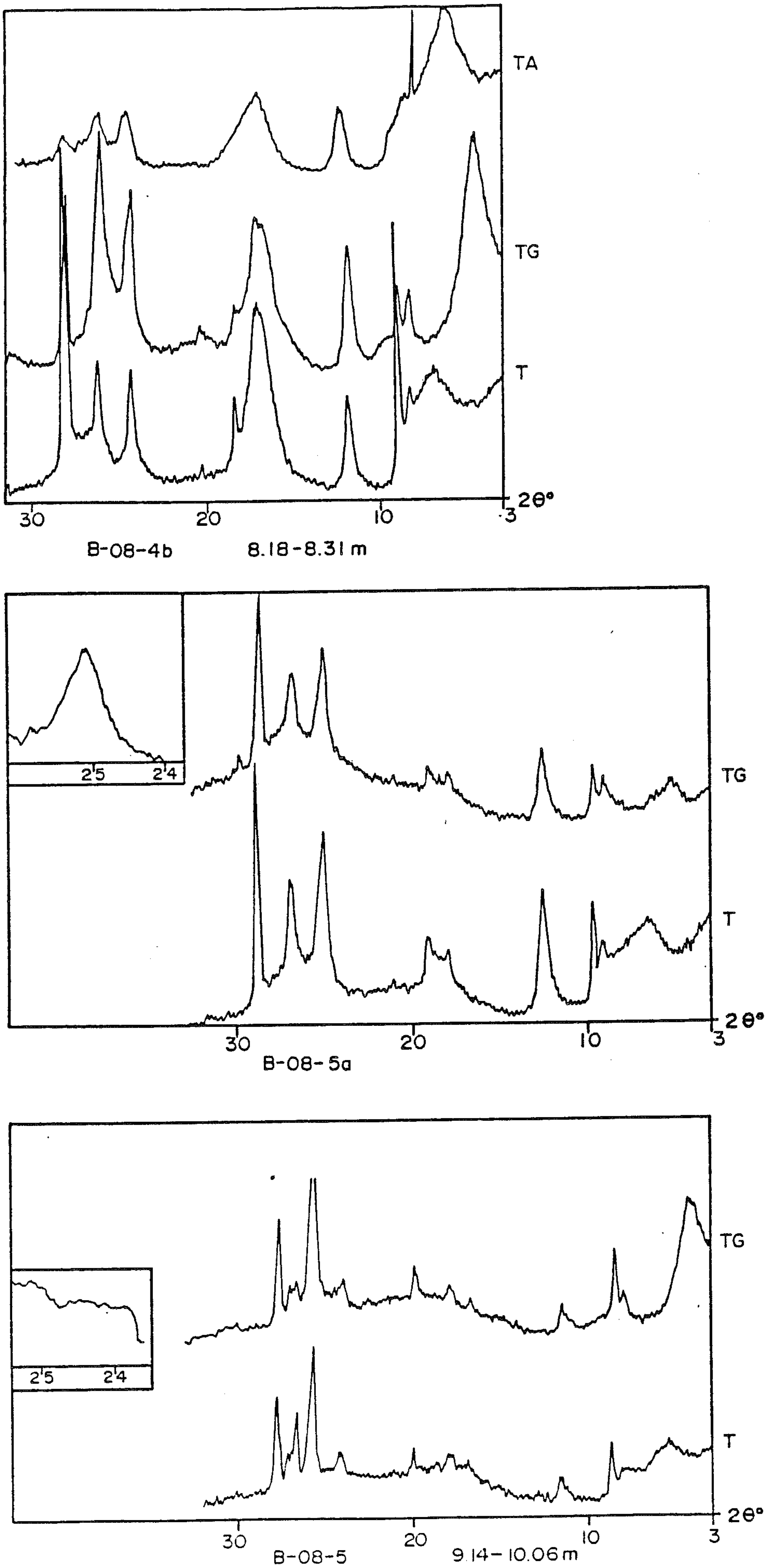


Figure 26. X-ray Diffractograms for selected samples, B-08.

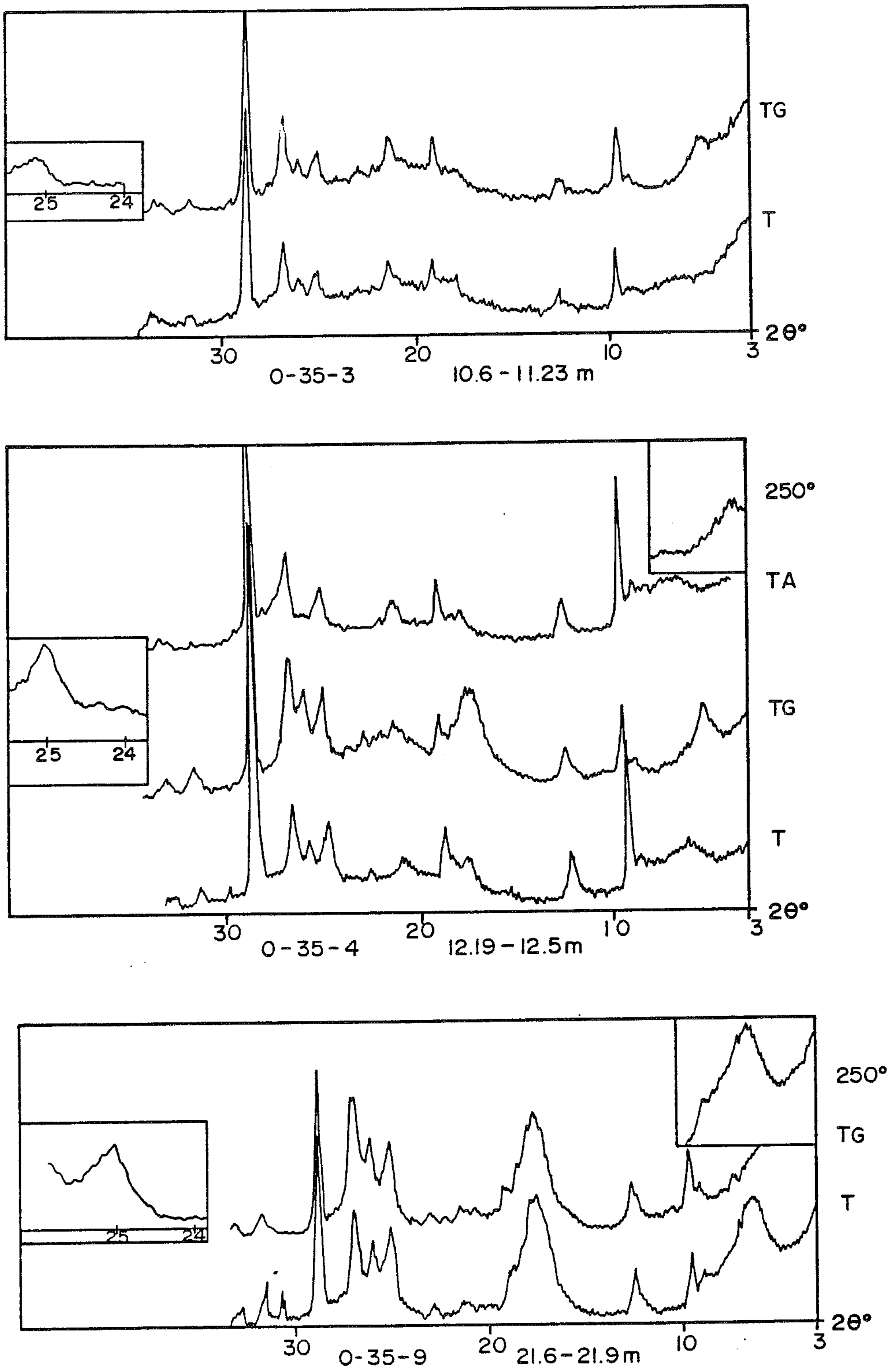


Figure 27. X-ray Diffractograms for selected samples, 0-35.

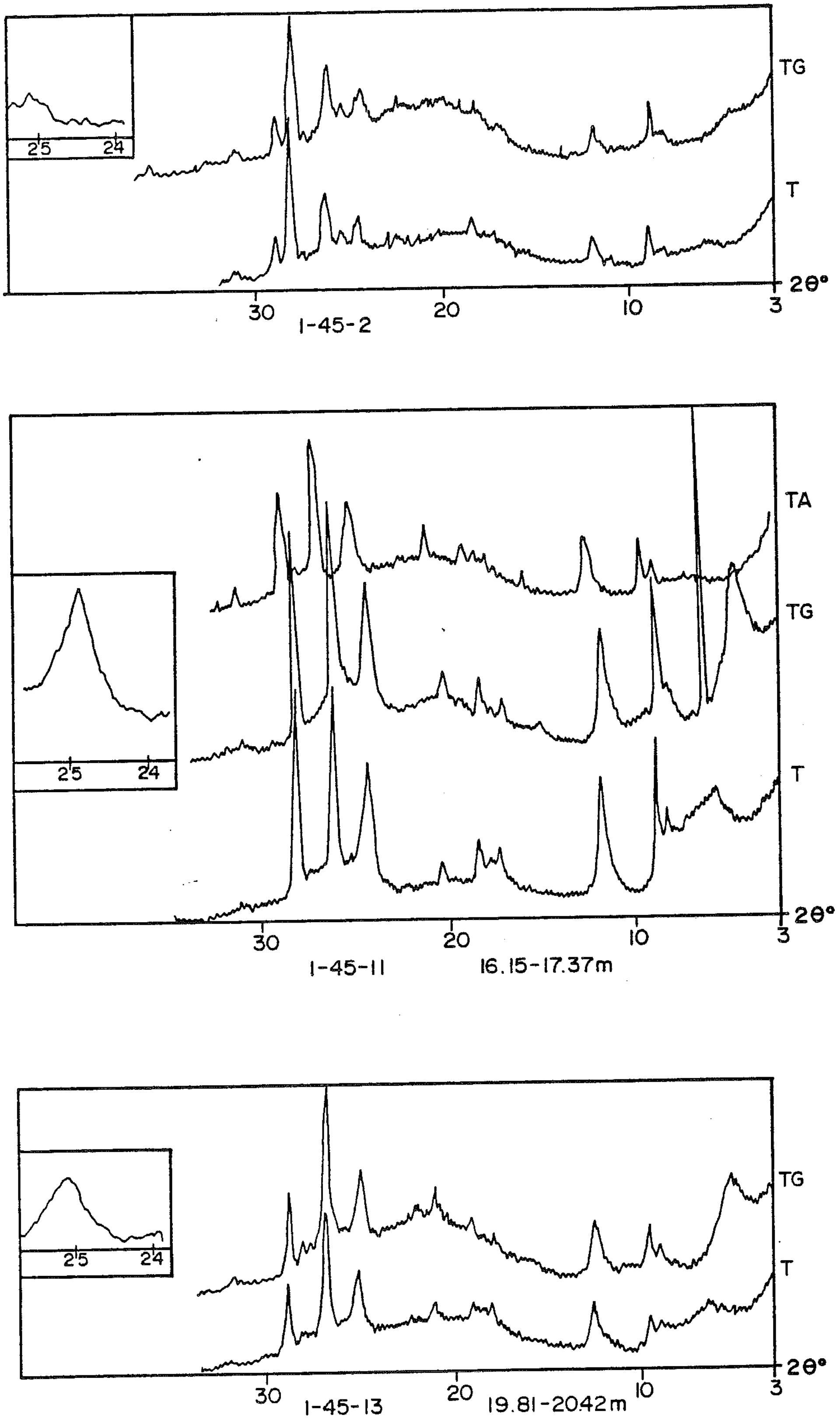
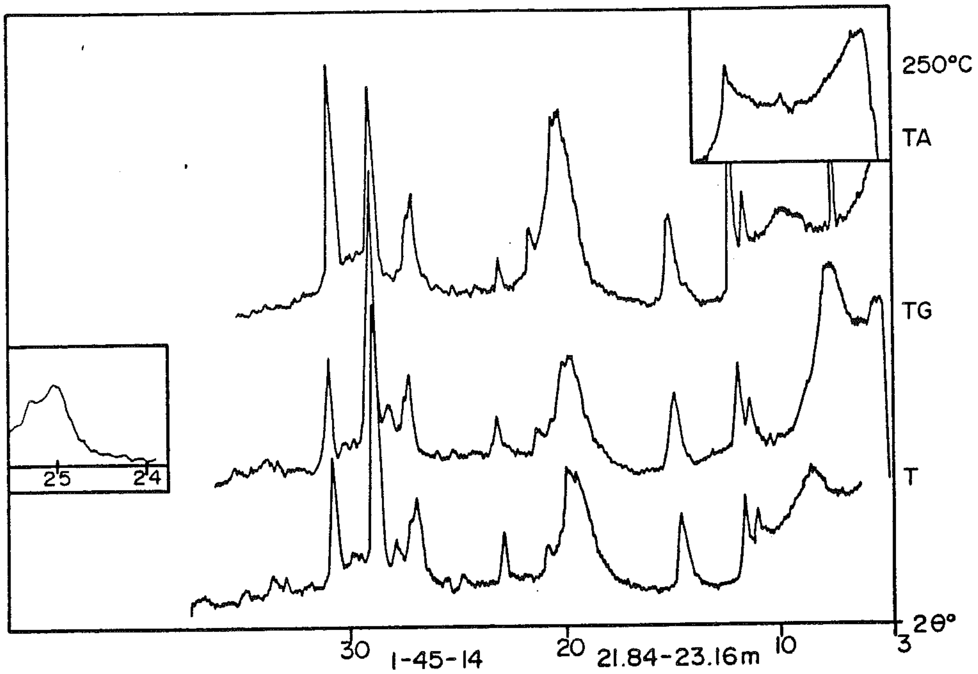
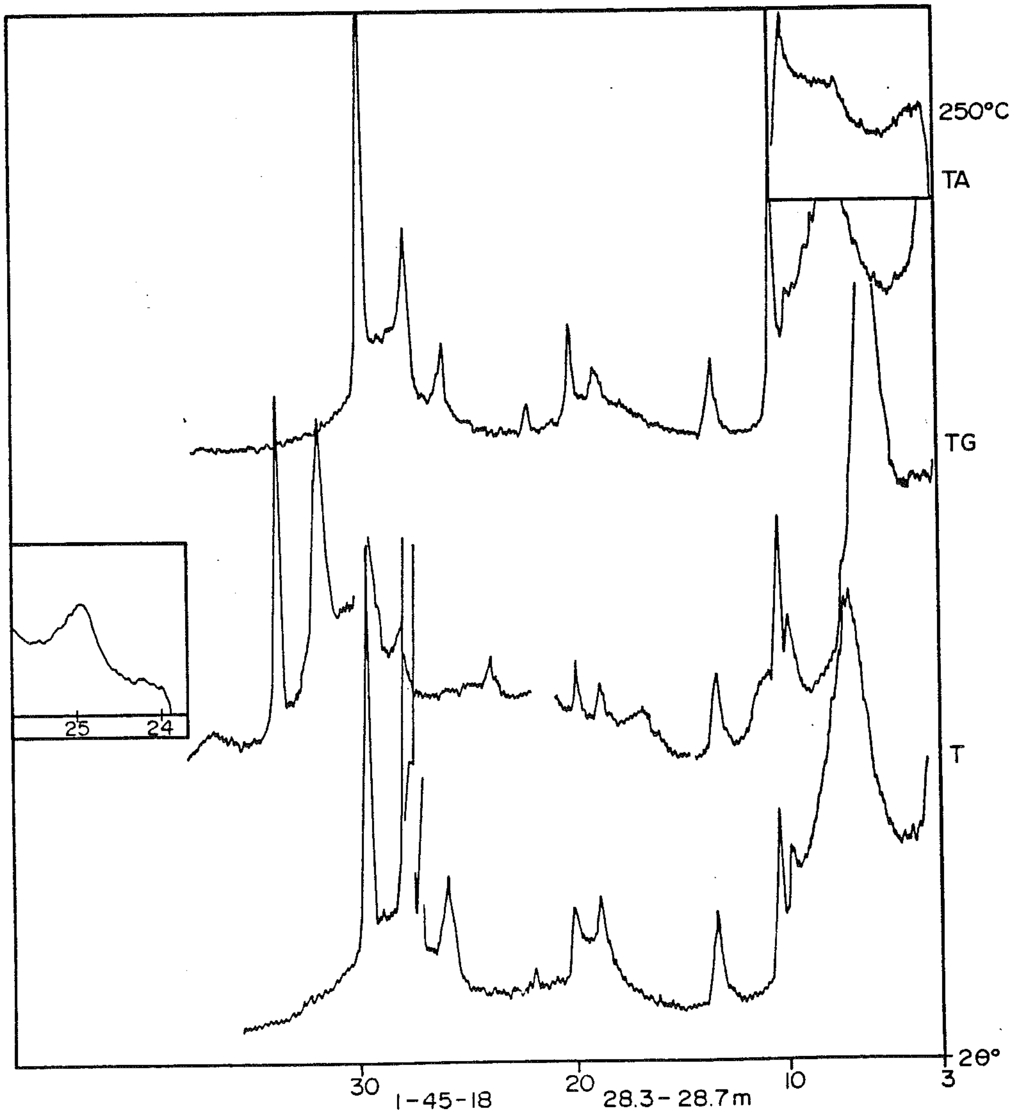


Figure 28. X-ray Diffractograms for selected samples, I-45.



1-45-14 21.84-23.16m



1-45-18 28.3-28.7m

HIBERNIA CLAY MINERALOGY

Table 1

Sample	Bulk Mineralogy = 100%									Clay Mineralogy = 100%			
	E	C	K	I	Q	F	P	A	Error	E	C	K	I
83-017-5-0.88	1	7	1	47	32	7	-	5	20	2	13	2	83
83-017-5-1.42	6	27	13	27	7	13	7	-	20	8	37	18	37
83-017-5-1.89	4	6	4	26	35	22	-	3	20	10	15	10	65
83-017-5-2.04	34	30	7	16	8	3	-	2	5	39	34	8	19
83-017-5-2.67	29	25	16	26	1	2	-	1	15	30	26	17	27
83-017-6-0.42	8	41	4	40	2	2	-	3	25	9	44	4	43
83-017-6-0.94	-	16	15	31	16	14	-	8	35	-	26	24	50
83-017-6-1.32	-	4	1	49	28	11	-	7	10	-	7	2	91
83-017-8-1.00	-	21	9	15	26	19	8	2	40	-	47	20	33
83-017-10-0.66	-	24	6	27	12	30	-	1	25	-	42	11	47
83-017-10-1.00	-	5	3	33	10	32	-	16	15	-	13	7	80
83-017-14-1.42	-	5	5	11	9	67	-	5	40	-	24	24	52
83-017-16-1.98	-	22	7	29	5	27	-	10	40	-	38	12	50
0-35-3	38	31	2	16	3	7	1	2	30	44	36	2	18
0-35-4	41	32	8	14	-	2	1	2	15	43	34	8	15
0-35-8	52	26	3	9	2	5	2	1	15	58	29	3	10
0-35-9	29	29	9	27	1	2	1	2	6	30	31	10	29
B-08-4a	48	26	3	22	1	-	-	-	30	48	26	3	23
B-08-4b	50	28	6	15	-	-	-	1	20	50	28	6	16
B-08-4c	42	19	4	16	1	11	-	7	20	52	23	5	20
B-06-5	55	18	2	16	1	6	-	6	2	60	20	2	18
B-06-5a	20	40	8	27	-	1	2	3	15	21	42	8	29
I-45-2	4	47	18	22	2	4	-	3	40	4	52	20	24
I-45-5	3	26	6	52	2	8	-	3	10	3	30	7	60
I-45-11	40	29	9	17	3	1	-	1	4	42	31	9	12
I-45-12	46	22	7	19	2	2	1	1	25	49	24	7	20
I-45-13	36	29	4	27	2	1	-	1	40	38	30	4	28
I-45-14	46	20	4	22	4	2	1	1	2	50	22	4	24
I-45-17	17	27	5	17	20	10	3	1	40	26	40	8	26
I-45-18	75	5	4	14	1	-	-	1	40	76	5	4	14
C1A-7	24	34	9	26	1	3	-	3	2	26	37	10	28
C1A-10	46	16	7	27	1	2	-	1	35	48	17	7	28
C1A-66	52	13	7	26	1	1	-	-	10	53	13	7	27
C1A-67	19	58	6	7	2	3	-	5	30	21	64	7	8
E1A-51	47	24	5	22	1	-	-	1	30	48	25	5	22
E1A-57	52	18	5	16	2	2	1	4	20	57	20	5	18
E1A-83	65	16	5	11	1	1	-	1	3	67	16	5	12
E1A-85	47	32	4	14	-	-	-	1	2	48	33	4	15
E1A-90	67	15	3	11	1	-	1	2	25	70	16	3	11
W1A-76	49	20	8	17	2	2	-	2	25	52	21	9	18
W1-13	78	9	2	8	1	-	-	2	5	80	10	2	8
W1-27	10	32	4	32	8	5	3	6	40	13	41	5	41
W1-42	63	18	3	14	1	1	-	-	20	64	19	3	14
W1-70	65	17	4	13	1	-	-	-	10	66	17	4	13
K-18- 6	65	15	1	16	1	1	-	-	5	67	15	1	17
K-18-16	49	26	3	20	1	-	-	1	10	50	27	3	20
K-18-23	38	28	5	22	2	3	1	1	5	41	30	5	24
K-18-31	47	22	2	27	1	-	-	1	25	48	22	2	28
K-18-36	35	33	9	22	-	-	-	1	30	36	33	9	22
K-18-40	35	38	-	17	-	6	-	4	20	39	42	-	19
K-18-47	60	23	2	10	2	-	1	2	40	63	24	2	11
K-18-50	58	16	3	19	2	2	-	-	40	60	17	3	20

E = Expandable Minerals
C = Chlorite
K = Kaolinite
I = Illite

Q = Quartz
F = Feldspar
P = Pyroxene
A = Amphibole

Table 2. Hibernia Clay Analysis - Samples, Depths and Treatments

SAMPLE	DEPTH (m)	TREATMENT					
		U	T	TG	TA	H (110°)	H (250°)
83-017-5	0.88		X	X			
83-017-5	1.42	X	X	X	X		
83-017-5	1.89		X	X			
83-017-5	2.04	X	X	X	X		X
83-017-5	2.67	X	X	X	X		X
83-017-6	0.42		X	X	X		X
83-017-6	0.94	X	X	X	X		X
83-017-6	1.32		X	X			
83-017-8	1.00		X	X			
83-017-10	0.66		X	X			
83-017-10	1.00		X	X			
83-017-14	1.48		X	X			
83-017-16	1.98		X	X			
CIA-7	1.0-1.3	X	X	X	X		
CIA-10	2.15-2.18	X	X	X			
CIA-66	59.19-59.22	X	X	X	X		
CIA-87	99.42-99.49	X	X	X	X	X	X
EIA-51	8.0-8.05		X	X			X
EIA-57	12.52-12.58		X	X			
EIA-83	80.08-80.12	X	X	X			X
EIA-85	88.7		X	X			
EIA-90	96.0-96.12		X	X		X	X
WIA-76	2.08-2.20		X	X			

SAMPLE	DEPTH (m)	TREATMENT					
		U	T	TG	TA	H (110°)	H (250°)
WI-13	36.10-36.15	X	X	X			X
WI-27	51.28-51.31		X	X			
WI-42	75.05-75.15	X	X	X			
WI-70	130.52-130.56		X	X			X
0-35-3	10.60-11.23		X	X			
0-35-4	12.19-12.50		X	X	X		X
0-35-8	19.81-20.12		X	X	X		
0-35-9	21.60-21.90		X	X	X	X	X
0-35-10	22.60-22.90	X	X	X	X		
B-08-4a	7.92-8.18		X	X			
B-08-4b	8.18-8.31		X	X	X		
B-08-4c	8.31-8.53		X	X			
B-08-5	9.14-10.06		X	X			
B-08-5a	10.20-10.70		X	X			
I-45-2	3.0-3.70		X	X			
I-45-5	7.30-7.62		X	X			
I-45-11	16.15-17.37		X	X	X		
I-45-12	18.29-18.59		X	X			
I-45-13	19.81-20.42		X	X			
I-45-14	21.34-23.16		X	X	X		
I-45-17	25.91-26.52		X	X			
I-45-18	28.30-28.70	X	X	X	X	X	X
K-18-6	5.0-5.25		X	X			
K-18-16	17.4-17.62		X	X			

SAMPLE	DEPTH (m)	TREATMENT					
		U	T	TG	TA	H (110°)	H (250°)
K-18-23	28.0-28.45		X	X			
K-18-31	40.0-40.42		X	X			
K-18-36	47.5-47.94		X	X			
K-18-40	57.5-58.04		X	X			
K-18-47	78.5-79.08		X	X			
K-18-50	100.0-100.36		X	X			

U = Untreated
T = Talc Treated
TG = Talc Treated and Glycolated
TA = Talc and Acid Treated
TH (110°C) = Heated at 110°C
TH (250°C) = Heated at 250°C

Table 3. Pebble Lithologies for the 0-35 and I-45 Boreholes.

HIBERNIA BOREHOLE SAMPLES

Borehole Number	Depth (m)	Size (mm)	Point Count %	Rock Classification	Rock Type	Roundness	Color
0-35 #3	10.7-	4- 5.6	100	Igneous (1)	rhyolite (1)	subangular	reddish brown
		2.8- 4	67 33	Sedimentary (1) Igneous (2)	chert (1) rhyolite (2)	angular angular	brown reddish brown
1-45 #1	1.5- 1.8	2.8- 5.6	11	Sedimentary (3)	fossiliferous limestone (1) limestone (1) conglomerate (1)	subangular angular subangular	light grey grey grey matrix
			64	Igneous (18)	granite (13) rhyolite (2) agglomerate (1) diorite (?)(1) unidentified (1)	subangular to angular angular angular subangular angular	reddish brown light grey matri-
			25	Metamorphic (7)	quartzite (6) gneiss (1)	angular angular	
I-45 #3	4.5- 4.9	2- 2.8	100	Igneous (2)	basalt (?) granite (1)	angular subangular	dark grey grey/white
I-45 #5	7.3- 7.6	2- 8	20	Sedimentary (1)	sandstone (1)	rounded	light grey
			20	Igneous (1)	basalt (?) (1)	subangular	dark grey
			60	Metamorphic (3)	gneiss (1) quartzite (2)	angular angular	black & white highly weathered
I-45 #6	7.6- 9.1	2- 2.8	100	Sedimentary (1)	shale (1)	subangular	black

Table 3 cont'd. Pebble Lithologies for the 0-35 and I-45 Boreholes.

HIBERNIA BOREHOLE SAMPLES (CON'D)

Borehole Number	Depth (m)	Size (mm)	Point Count %	Rock Classification	Rock Type	Roundness	Color
I-45 #6A	9.1-9.5	2-2.8	100	Igneous (2)	unidentified (1)	subangular	very dark grey
					granite (1)	angular	black and white
I-45 #7B	10.7-11.1	2-4	30	Sedimentary (3)	limestone (3)	angular to subangular	buff to light grey
			40	Igneous (4)	granite (4)	subrounded to subangular	grey/white
			30	Metamorphic (3)	quartzite (3)	subrounded to subangular	
I-45 #8	12.2-12.8	2-5.6	6	Sedimentary (1)	limestone (1)	angular	buff
			33	Igneous (6)	unidentified (3)	subangular to angular	black
					rhyolite (1)	subangular	reddish brown
					agglomerate (1)	subangular	light grey
					granite (1)	subangular	
			61	Metamorphic (11)	gneiss (3)	angular	black
					quartzite (8)	subangular to angular	buff to grey
I-45 #10	15.2-15.4	2-5.6	12	Sedimentary (7)	oolitic dolomite (1)	angular	
					limestone (4)	angular	light grey to buff
					shale (1)	angular	black
					silstone (1)	subrounded	grey
			75	Igneous (43)	granite (41)	subangular to angular	black and white
					balsalt (2)	angular	dark grey
			12	Metamorphic (7)	gneiss (2)	angular	black
					quartzite (5)	angular	dark grey

Table 4. Pebble Lithologies for the C1A, C1A and W1/W1A Boreholes.

PHOLAS BOREHOLE SAMPLES

Station Number	Depth (m)	Size (mm)	Point Count %	Rock Classification	Rock Type	Roundness	Color
C1A #7	1.00- 1.03	4	100	Sedimentary (1)	siltstone (1)	angular	grey
E1A #57	12.52- 12.58	2.8	80	Sedimentary (4)	conglomerate (1) quartz sandstone (3)	subrounded subangular	grey
			20	Igneous (1)	gabbro (?) (1)	subangular	
W1 #13	36.10- 36.15	≥4	100	Sedimentary (2)	chert (2)	subangular	light brown
W1 #13	36.10- 36.15	2.8	57	Sedimentary (4)	chert (4)	rounded to subangular	light brown
			43	Igneous (3)	granite (1) rhyolite (2)	subangular angular	
W1A #73	1.10- 1.15	2.8	19	Sedimentary (4)	limestone (1) siltstone (3)	angular angular	buff black
			38	Igneous (8)	granite (3) pyroxenite (?)(5)	subangular to subrounded angular	
			43	Metamorphic (9)	quartzite (7) schist (2)	very angular angular	greyish-white dark