DEPOSITIONAL ENVIRONMENT OF THE LOWER PALEOZOIC SEDIMENTS ON THE GRAND BANKS OF NEWFOUNDLAND

by

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ABSTRACT

Lower Paleozoic platformal sediments on the Avalon Peninsula continue offshore in the area between the Avalon Peninsula and the Virgin Rocks. Dating of ten drilled cores from the offshore area and continuous seismic profiles show that conformable deposition occurred from Cambrian to post-Silurian (?Devonian) time accumulating a stratigraphic thickness of some 8,000 m of fine grained sediments. This study undertakes to examine the sedimentological and ichnological aspects of the ten bedrock cores of 80 cm average length with an aim to establishing their depositional environment.

The cores are thought to represent three general environments; Ordovician black shales representing restricted shallow marine conditions appear to have predominated over a vast area; Late Ordovician and Silurian siltstones have evidence of deposition in more dynamic and well oxygenated conditions and probably represent a predominace of a normal shallow marine environment.

There is some evidence to suggest a cycling between normal marine and more restricted conditions in Silurian

times. Red siltstones and sandstones of probable Devonian age indicate a shallowing of the basin and deposition probably under terrestrial conditions.

INTRODUCTION

Field investigations on the Grand Banks of Newfoundland by King, Fader, and Jenkins (in preparation) indicate that the Lower Paleozoic platformal succession on the Avalon Peninsula continues offshore in the area between the Avalon Peninsula and the Virgin Rocks (Fig. 1). Their study included both an interpretation of seismic reflection profiles and lithologic and biostratigraphie examination of ten bedrock cores from the seabed. These cores constitute a composite sampling of this stratigraphic succession.

In the offshore the outcrop area of this Lower Paleozoic platform between Avalon Peninsula and Virgin Rocks is approximately 15,000 square kilometres (Fig. 1). The sediments are gently folded with dips rarely exceeding three degrees. The section is approximately 8,000 metres thick.

Jenkins (King, Fader & Jenkins, in preparation) dated these rocks as Ordovician to Silurian by acritarch palyno-

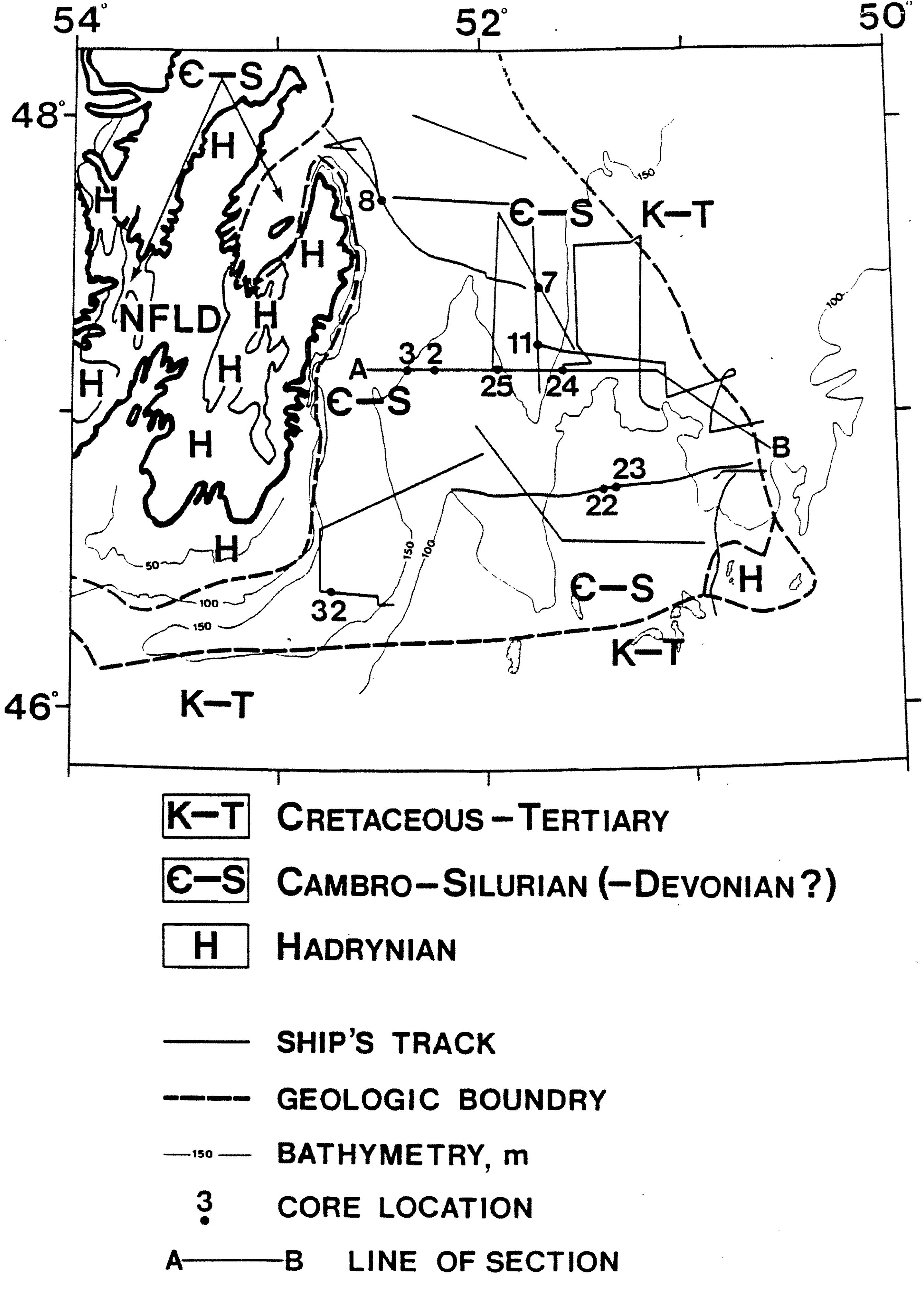


Figure 1 - Geology of the Avalon Peninsula and western Grand Banks of Newfoundand, showing high resolution seismic control and core locations. Line A-B illustrates the position of the seismic profile depicted in fig. 20. (after King *et al*, in preparation)

logy. Thick, undated sediments higher in the sequence may be Devonian. Several highly diagnostic ages were obtained and are noted by the asterisks in Table 1. The specific types of acritarchs found in these rocks is the subject of a separate paper by Jenkins (in preparation).

This study involves an examination of ten cores from the Lower Paleozoic succession taken across much of the area of outcrop (Fig. 1). King _et al_ (in preparation) have divided the area into a northern, southern, and central study area where seismic and sampling control are concentrated.

The ten cores under study are 2.5 cm diameter ranging from 8 cm to 480 cm in length with an 83 cm average.

The purpose of this study is to establish the depositional environments represented in this succession through an examination of the bedrock cores.

Table 1

DRILL STATION DATA

Sample No.	Location North	Location West	Water Depth (m)	Drill Penetration Into Seabed (cm)	Core Recovery (cm)	Age
77-011-3	47°09'48"	52°22' 6"	145	575	87	? Devonian
77-011-2	47°09'48"	52°12'48"	148	265	63	? Devonian
75-009-25	47°09'46"	51°57'28"	146	572	480	Late Silurian (Ludlovian)
77-011-22	46°46'12"	51°23'30"	86	288	36	Late Silurian * (Wenlockian to Ludlovian)
77-011-23-B	46°46'24"	51°20'30"	86	360	50	Silurian
77-011-7	47°25'18"	51°43'18"	180	135	10	Mid Silurian (Llandoverian to Wenlockian)
77-011-11	47°14'30"	51°45'12"	163	138	47	Mid Silurian * (Wenlockian)
77-009-24-A	47°09'32"	51°35'53"	130	150	110	Late Ordovician * (Caradocian to Ashgillian)
77-011-8	47°42'48"	52°30'48"	180	89	24	? Late Ordovician
77-011-32	46°21'06"	52°44'36"	170	86	16	Early Ordovician * (Late Arenigian to Early Llanvirnian)

*Diagnostic Age

(from King et al, in preparation)

GENERAL

These cores were collected by King and Fader onboard C.S.S. HUDSON in 1975 and 1977 using the Bedford Institute of Oceanography electric drill. The ten cores of concern in this study are listed in Table 1.

METHODS

GENERAL

These cores were collected by King and Fader ~~from~~ onboard C.S.S. Hudson in 1975 and 1977 using the Bedford Institute of Oceanography ~~B.I.O.~~ electric drill. The ten cores of concern in this study are listed in Table 1.

Cores were cut longitudually with a diamond saw and ground to a flat finish. The slabs were wetted and observations made under a binocular microscope. Core sketches were prepared at a vertical reduction of five times. Noted features were sedimentary structures, trace and body fossils and bioturbation. Brief descriptions of textures and lithologies were noted at the side and supplemented with thin section observations of texture and mineralogy. Grain size estimates were done from inspection of thin-section with reference made according to the Dunham classification. The thin-section analyses supplied control for less vigorous textural examinations under low power magnification using a binocular microscope. Generally the cores are uniform in texture and mineralogy, eliminating the need for a large number of thin-sections. On average, one thin-section per 20 cm of core was deemed sufficient. Rock colour was noted with reference to the Munsell Rock Colour Chart.

X-ray diffraction data were obtained on samples from most of the cores using a whole rock analysis technique. This provided semiquantitative mineralogical data to confirm optical identifications. Particulars of the X-ray analysis technique including the spectral plots are noted in appendix 1 and results are noted in the text.

BIOTURBATION STUDIES

Bioturbation structures are a prominent feature of many of the cores. An understanding of such structures can add significantly to knowledge and inferences made of the environment of deposition. Such features are a form of sedimentary structure that result from biogenic activity. They can occur in two aspects: figurative and deformative (Schafer, 1972). Figurative structures include forms such as tracks, trails, and burrows (trace fossils or lebensspuren). Deformative bioturbation structures are much less well defined and occur as irregular mottling, blebs and streaks. Description, nomenclature, and classification of figurative bioturbation structures is called ichnology. Their recognition in cores is limited because of the difficulty of observing their lateral extents. On the other hand, deformative structures are better exhibited in split cores (Young and Rahmani, 1974).

The classification of trace fossils (ichnology) has undergone evolution for almost two decades and has become quite complicated. The reader may consult Appendix II for a survey of ichnology and a better understanding of some of the terms used in this paper.

Bioturbation Study Method

As suggested earlier, the study of split core allows only a restricted view of features such as tracks and trails which may have a considerable lateral extent. Such trace fossils were rarely identified in the cores.

The degree of bioturbation along the length of the core is expressed graphically. An estimate of the relative amounts of figurative and deformative bioturbation is also similarly shown. Figurative bioturbation visible in the split cores is considered to be of the burrow type only.

Seilacher (1967) recognized distinct groups of burrow type trace fossils, each of which occur within a specific range on a bathymetric profile. Therefore, he could distinguish ichnofacies which he named after their respective index fossils. This relationship is illustrated in figure 4. Furthermore, Young et. al., (1974) noted a very general relationship between the attitudes of burrows and the depth of water in which they occur. In general vertical burrows are typical of nonmarine, littoral, or nearshore facies, whereas obliquely oriented burrows occur in shallow to in-

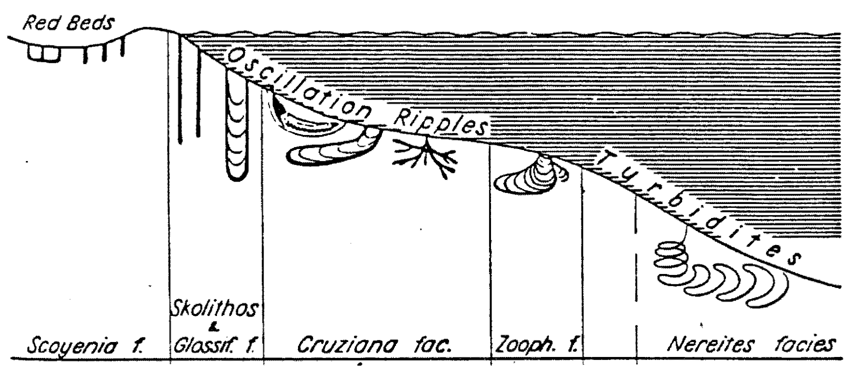


Figure 4

Generalized bathemetric distribution of the major trace fossil communities. (from Seilacher, 1967) termediate shelf depths, and horizontal burrows are usually associated with the deepest water environments. In this study the attitudes of the burrows is expressed continuously along the core in a graphic form.

CORE DESCRIPTION AND INTERPRETATION

INTRODUCTION:

Serious limitations are inherent in this study imparted by the fact that core samples contain no information pertaining to large-scale sedimentary structures, local geometry of deposits, patterns of stratigraphic succession and fossil assemblages. Furthermore these aspects are difficult to determine from cores spaced at distances in the order of several kilometers.

Despite these limitations, core samples allow a detailed study of localities in terms of lithology, fossils, and ichnological aspects of the rocks. Although direct links between lithology and paleoenvironment are rare, petrologic studies can yield significant information pertaining to the physical and chemical conditions of sedimentation. As these conditions are established, further environmental interpretation can be proposed by integrating data regarding the biologic aspects of the rock. This course is followed in the discussion of each core and the discussions are arranged in chronological order.

An idea of the physical framework of the area can be gained through figure 1 and the seismic profile (Fig. 20) though there is not sufficient seismic control to give a more complete representation of the area.

CORE 77-011-32-B AND C

Description

Core 77-011-32-B was drilled in the southern study area at 46°21'36"N 52°44'36"W approximately 15 km southeast of Cape Race. Because of the difficulties with core recovery, three attempts were made to obtain a sample of substantial length. However, core 77-011-32-B is only eight cm in length and core 77-011-32-C is 10 cm long (Fig. 5).

Some question arises as to the reliability of these short cores. The possibility that they are erratics rather than true bedrock exists but repeated sampling at the same location (within several hundred metres) yielded cores of similar material and bedding structure orientation. (Bedrock dip is approximately 2°to 3°.) Therefore, these cores are believed to represent the local bedrock.

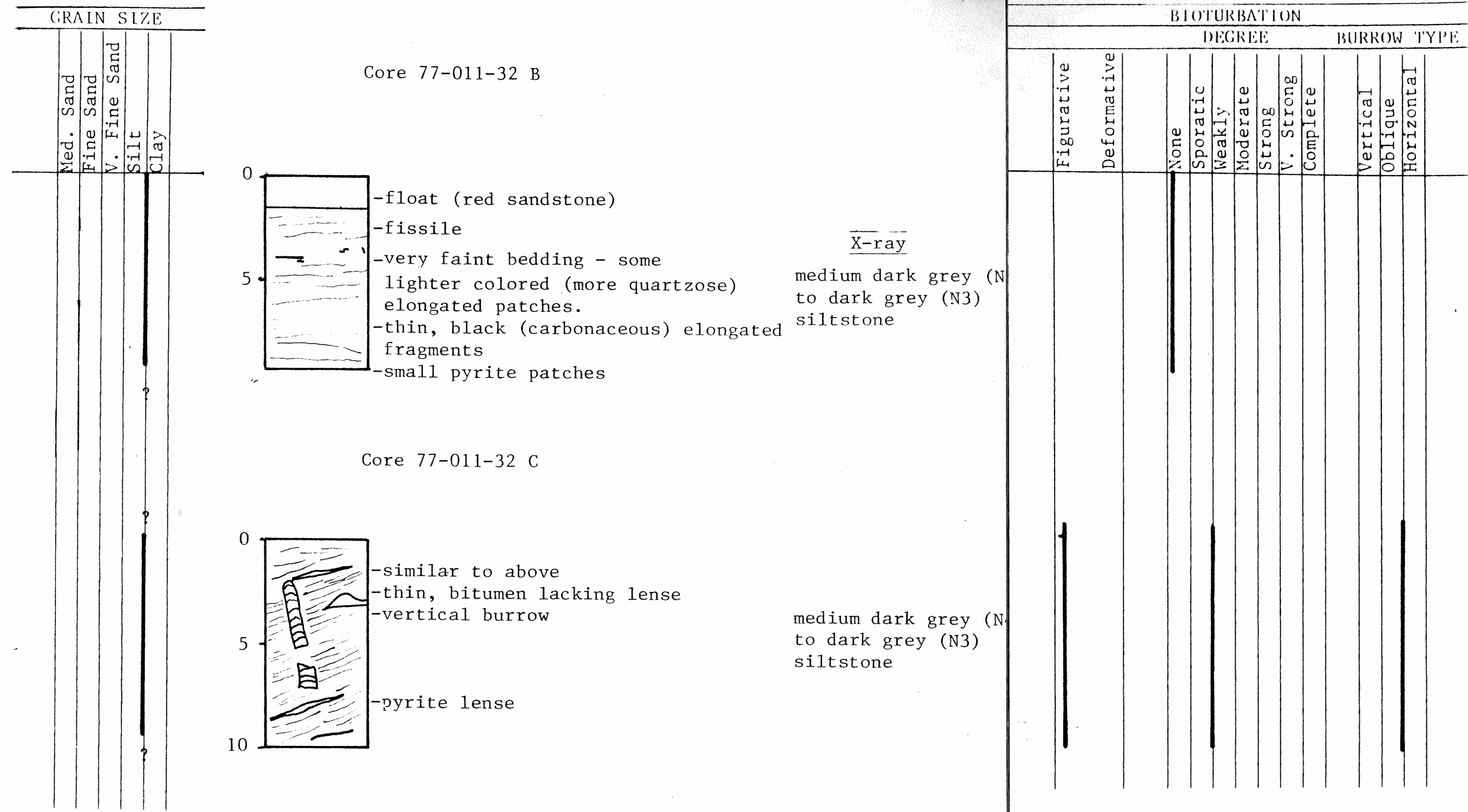


Figure 5.

Grain size, sedimentary structures, descriptions, sample locations, and bioturbation type.

Well preserved diagnostic acritarchs date the rock as Early Ordovician (late Arenigian to early Llanvirnian). It is the oldest sediment sampled in the succession.

Due to the high degree of fissility in this core, thin section preparation was not done. Therefore, an accurate measure of grain size was difficult. Inspection at low magnification confirmed a high content of fine silt. The texture, fissility and dark grey (N4) colour are properties which classify both cores as typical black shales.

The cores have very faint, low angle laminations of lighter colour (dark grey N3) silt with a lower carbonaceous content. Often the laminations are lenticular. Boundaries are slightly gradational, lending a "fuzzy" appearance to the structures. The presence of graptolities in Cambro-Ordovician black shales on land prompted a search for similar fossils in the cores. Carbonaceous material is present along the bedding plane as thin (0.5 mm) elongated black fragments, however, they appear to have no distinct lateral morphological continuity and are probably not graptolitic remains. Small lenses of pyrite crystals occur in the same mode as the carbonaceous material and are probably a replacement of it.

Generally signs of bioturbation due to infaunal deposit feeders are rare in black shales (Morris, 1977). In core

77-011-32-C a nearly vertical burrow about two mm in diameter and five cm long does occur. The burrow is inclined and has very faint meniscate laminae that indicate stuffing or infilling due to a downward movement of the producing organism.

Interpretation

The fine grained nature of this rock, the faint laminations, the small scale lenticular stratification, and the fissile properties of the rock all point to quite specific conditions of sedimentation. The parallel horizontal laminations represent deposition either as a result of differential settling of particles from suspension under tranquil conditions or within a tractional flow regime where bottom currents were not strong enough to sculpture the substrate. The lenticular structures represent slightly higher current velocities causing very similar but more discontinous stratification in a tractional flow regime. The lenses may represent sporadic tractional flow of flocculated silt particles and the initiation of bedforms at slightly higher current velocities. Gradational structural boundaries probably indicate differential settling rates of the constituents.

As in most black shales, the dark colouring in core 77-011-32 is due to carbonaceous material preserved under reducing conditions (Jenkins, per. comm.). Further evidence of these conditions is indicated by the presence of pyrite which occurs as lenses identical to the carbonaceous lenses and is therefore thought to be a diagenetic replacement. This black shale is similar to most marine black shales in that it has a very limited infauna because of the inhospitable Eh and "soft" substrate conditions (Morris, 1977). The identity of the one burrowing organism is unknown, however, the burrow is unlined suggesting that it represents a feeding trace (Fodinichnia) or grazing trace (Pascichnia) rather than a dwelling trace. The presence of the burrower suggests that although redox potentials within the sediment were low, oxidation conditions at the sediment-water interface were probably sufficient to suport this burrower. This condition may also help explain the small, lighter coloured lenses of low carbon content observed in the core. These lenses, which are thought to be the initial formation of small bedforms would have formed under slightly less restricted circulation conditions (greater currents and higher Eh) and consequently they would have a lower preserved carbon content. The carbon rich layers may represent the other extreme where circulation is a very restricted (low Eh) and the sedimentation rate very low, allowing a build up of (?pelagic) carbonaceous materal. In the mud facies of the Jurassic epeiric basin covering a large portion of northwest Europe Morris (1977) recognized vertical sequences of "normal", "restricted", and "bituminous" shale facies which are arranged in symmetrical cycles on both large (10's of m) and small (10's of cm) scales.

This core may reflect cyclic conditions of a similar nature but to a much lesser degree and on a very small scale. In light of the regional setting, (discussed later), this rock probably formed as part of the bituminous or very restricted shale facies of a shallow marine sea in a tranquil basin with a restricted oxygen budget due to restricted circulation.

CORE 77-011-8

Description

Sample 77-011-8, drilled at 47°42'48"N 52° 30'48"W contains only three gravel-sized rock fragments because of drilling difficulties. Although the sample is small, the drilling operation was repeated several times to ensure that the sample was representative. The rock fragments are massive medium dark grey (N4) siltstones (Fig. 6). They are barren of acritarchs so an age determination was not possible. However, seismic profiles indicate that the sample was taken approximately 1,050 m stratigraphically below core 75-009-24-A so the rock is Late Ordovician or older in age.

A microscopic analysis of one fragment revealed the presence of less than one per cent sand sized quartz and highly altered feldspar grains of silt size. The most prevalent alteration product is a brown platy chlorite-like

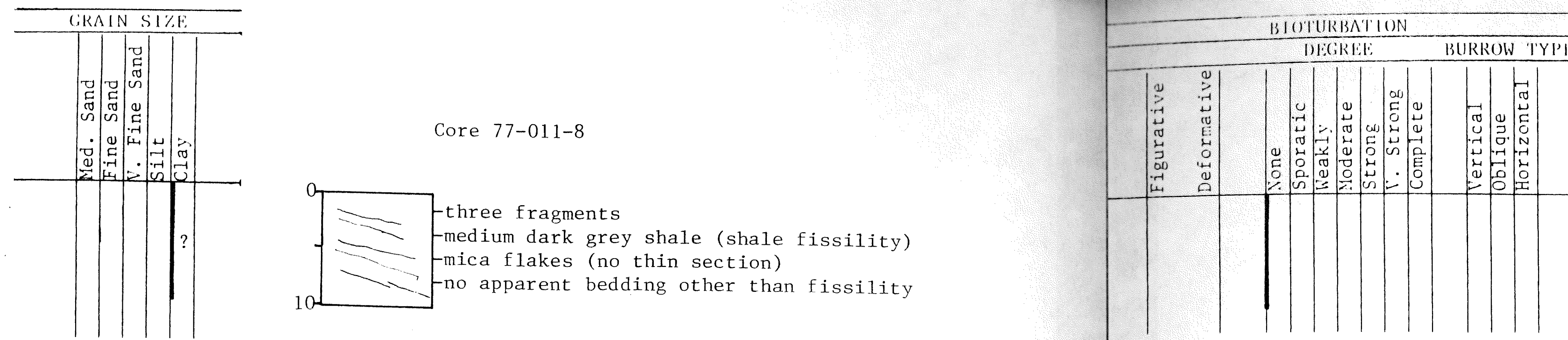


Figure 6.

Grain size, sedimentary structures, descriptions, sample locations, and bioturation type.

mineral, and constitutes a high percentage of the sediment. Some of the brown colouring is due to amorphous organic content. No fossils, sedimentary structures or bioturbation features are apparent in the rock.

Interpretation

Very little information is available for interpretation in core 77-001-8. The fine grained nature can be attributed to deposition in low energy conditions. The only texture observed is the fissility but because of the sample size it is unknown if this is a primary or diagenetic attribute. Given the unmetamorphosed slate of the succession, the fissility is probably primary. The otherwise structureless aspect of the rock may be due to very uniform sedimentation or complete deformative bioturbation. The latter would be unlikely under conditions of black shale deposition.

The dark colour caused by high organic content indicates anoxic substrate conditions at the time of deposition. Such conditions usually occur in basins with poor circulation and oxygen starvation.

CORE 75-009-24-A

Description

This core was drilled in the northern study area at 47°09'32"N 51°35'53"W. A core of 60 cm length was recovered. The presence of diagnostic acritarchs indicates an age of Late Ordovician (Caradocian to Ashgillian) for this core.

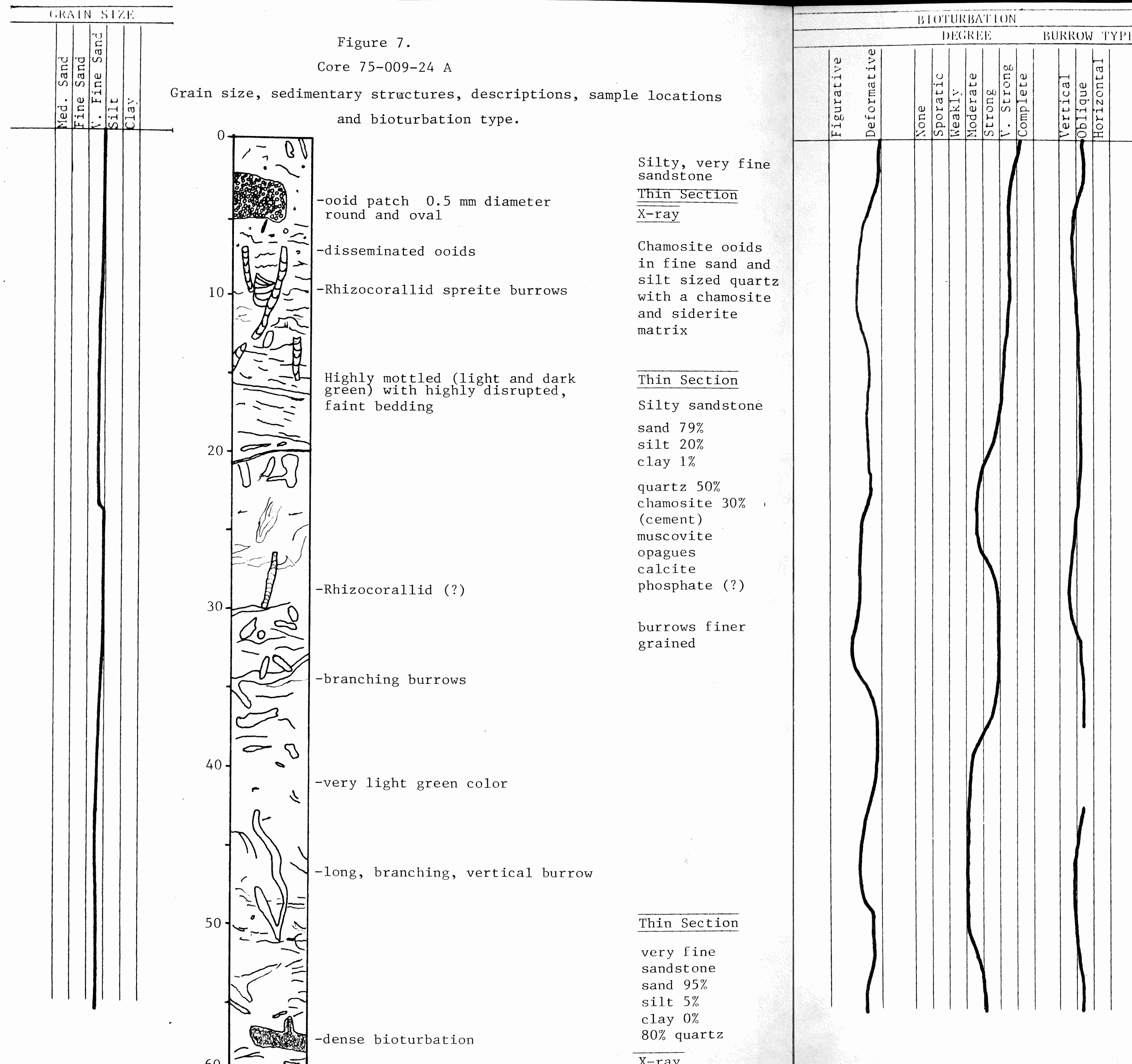
The sediment texture changes progressively from a very fine sandstone at the base of the core to a very fine silty sandstone at the top (Fig. 7). The rock is well indurated and lacks any fissility. Microscopic examination of three sites on the core show that silt content progresses from 5 per cent at the bottom to 30 per cent at the top. Clay sized particles are negligable except for secondary hematite on some quartz grains. An irregular intermixing of greyish olive green (5GY 3/2) and greenish-grey (5G 6/1) material gives the rock a mottled appearance.

Variations in quartz content and grain size along the length of the core are responsible for colour changes similar to those in the mottled areas. Detrital fragments of angular quartz are present and at the base of the core, occur as angular, interlocking, slightly recrystalized grains. Here the quartz abundance reaches 80 per cent but throughout the rest of the core quartz varies between 40 per

Figure 7.

Core 75-009-24 A

Grain size, sedimentary structures, descriptions, sample locations and bioturbation type.



cent and 60 per cent in a fine matrix. Iron oxide, muscovite and calcite clasts are present in roughly equal amounts and constitute approximately ten per cent of the rock. Phosphorite grains occur in trace amounts.

An oolite patch of ooids with median partical size of 0.4 cm is present near the top of the core. Within the patch, the ooids comprise approximately 80 per cent of the volume, the remainder consisting of very fine sand size quartz fragments, chlorite, minor accessories and secondary siderite and chlorite. Both siderite and chlorite identifications were confirmed using X-ray diffraction. Generally the nucleus is composed of highly altered feldspar but quartz is also present. The green chloritic mineral with the characteristic ooid onion-like layering has a low birefringence, and an index of refraction higher than that of quartz. The same mineral also occurs in the matrix, usually in a tabular or platy habit and is often present in contact with the ooids. It displays slight pleochroism, a small negative optical angle and a length-slow orientation. The chlorite mineral is also often associated with iron oxide. For these reasons it is believed to be the iron rich chlorite, chamosite. Kerr (1977) states that chamosite, unlike the other chlorites, usually occurs in oolitic form with pseudospherulitic structure, exactly as it is found in this core. X-ray diffraction spectra show well defined peaks in the chamosite range, however, most chlorites have similar spectra though usually with a broader range.

Chamosite has a very irregular atomic structure so positive identification is difficult without highly specialized preparation and technique.

The origin of ooids composed of chamosite is the topic of much discussion by several authors (Kimberly, 1979). Whether chamosite is of primary origin or a diagenetic replacement of iron oxide or carbonate has not been satisfactorily concluded. Mineralogic relationships in these rocks show little supportive evidence one way or the other.

The ooids contain several thin, concentric layers of fine, amorphous brown material, probably organic in composition.

Bioturbation of both the figurative and deformative types is very prevalent throughout the core. The degree of disturbance varies from strong to moderate except in the top 15 cm where the ooid bed has suffered very strong bioturbation, dispersing many of the ooids.

The figurative bioturbation is mainly in the burrow form. Most are relatively large, branch forms (three mm in diameter and five cm in length) and generally have a vertical attitude. They usually exibit meniscate laminae and are unlined. Microscopic inspection shows a higher mica content in the burrows which reflects some type of a biogenic mineralogic sorting.

Interpretation

The significantly higher sand content in core 75-001-24-A as compared to the other cores may be indicative of a near-shore influence and introduction of coarser grains or an increased residual sand content through the processes of reworking and winnowing. The high degree of bioturbation has disrupted primary sedimentary structures and only faint traces of bedding remain providing little information of conditions of sedimentation.

The presence of sand-sized ooids in an otherwise fine grain sediment may provide the most significant information regarding the depositional environment. Ooids generally form in high energy environments in water depths of about two m (Bathurst, 1976). Exceptions to this include cave pearls, calcrete (formed under subaerial conditions), and lagoonal (low energy) ooids. The two former types are not relevent to marine conditions and the lagoonal ooids are not compatable with the presence of chamosite (discussed later) and interpretation of textural observations.

The fact that the ooids occur in locally high concentration suggests that they have undergone little transport from the environment of their formation. Otherwise they would probably be disseminated throughout the sediment. However, some degree of transport is suggested by the fact that the ooids from a high energy environment occur with fine sands and silt representing lower energy conditions. It seems reasonable to suggest that the ooids were developed in a high energy environment such as an outer shelf bank where it was isolated from a coarse material influx. Ooids formed near the flanks of such a bank could conceivably be transported short distances down slope to a lower energy environment compatable with the fine sand and silt.

The presence of chamosite in the ooids and matrix provides further evidence for a shallow water environment (10 m to 60 m) and is generally accepted as an indicator of temperatures in the range of 25 to 27°C (Porrenga, 1967). Recent occurrences of chamosite are restricted to tropical areas where their formation is probably related to the warm bottom currents (Porrenga, 1967). If similar oceanic physio-chemical conditions existed in Ordovician times, this may well be an indicator of climatic conditions.

Vertical burrows, such as those in the core, are considered by many authors to indicate shallow water conditions (Seilacher, 1967, Young, 1974). However, exceptions have been noted (Pickerill _et al_ 1981.) and generalizations are difficult. The inhabitants of these burrows obtain their food by filter-feeding through an opening to the surface or from the surface of the substrate. Their burrows represent permanent or semi-permanent dwelling places (Domichnia) in an environment where currents supply ample nutrients yet may also cause rapid erosion or deposition (Seilacher, 1967). In the case of erosion, the reaction of the burrower is a downward (retreating) movement which produces convex upward (retrusive) spreiten. In the case of rapid sedimentation, an upward movement of the organism produces concave upward (portrusive) spreiten. This is illustrated in Figure 8. The figure also illustrates that if the cylindrial worm tubes are not visible in the rock, as is the case in this core, then one cannot determine the orientation of the producing organism (vertical or horizontal). Therefore, it is difficult to ascribe the spreiten to the *Rhizocorallium* or *Diplocraterion* ichnogenus. The former belongs to the *Cruzania* ichnofacies, (mainly horizontal burrowers), and is associated with a sublittoral environment (Fig. 9). *Diplocraterion*, however, is a member of the *Skolithos* ichnofacies associated with a littoral environment. The sublittoral environment is closer to that proposed on textural and compositional grounds.

CORE 77-011-11

Description

Core 77-011-11 was drilled at 47°14'30N 51°45'12"W to a depth of 138 cm below the seabed and a core of 42 cm was recovered. A Mid-Silurian (Wenlockian) age was determined for this rock using acritarchs.

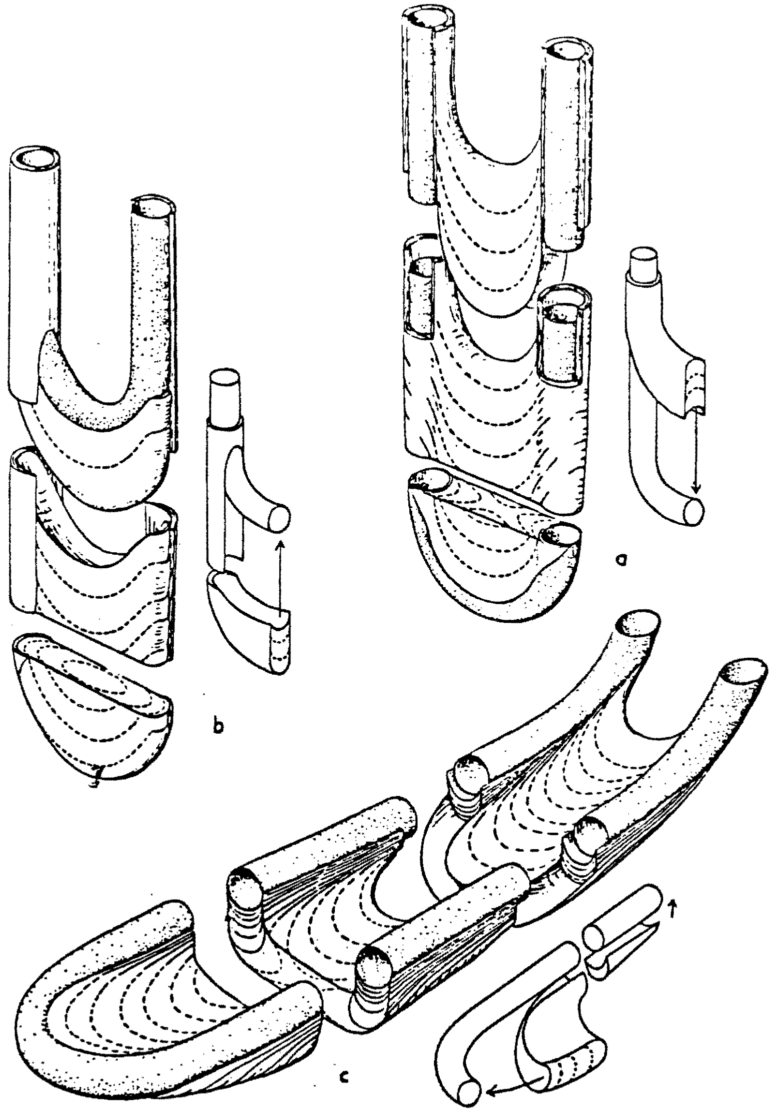


Figure 8

Structural types of rhizocorallid spreite burrows. a) Protrusive in vertical direction b) Retrusive in vertical direction c) Protrusive in horizontal, plus retrusive in vertical direction. This illustration also demonstrated that the presence of the sprieten alone is not sufficient to distinguish between vertical or horizontal burrowers.

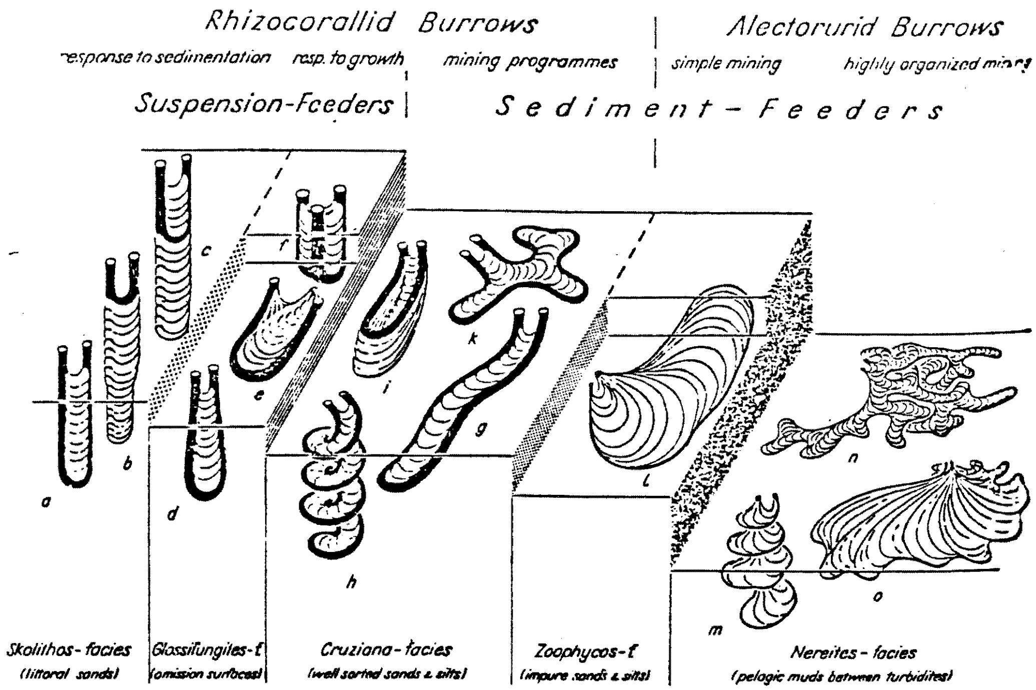


Figure 9

Bathymetric zonation of fossil spreite burrows. (from Seilacher, 1967) Rhizocorallid burrows occur in both the <u>Skolithos</u> and <u>Cruzania</u> facies so distinction on this basis requires positive identification of the burrow type; a difficulty in core study.

The sample is a highly fissile, medium grey (N5) micaceous siltstone (Fig. 10). Planar, laminated beds of a slightly lighter colour occur within one cm bands in the lower half of the core. Between these beds moderate bioturbation of the figurative type has altered the sediment structure and mineralogy. Very small diameter (0.5 mm), elongated, comparatively lighter coloured blebs occur in oblique and nearly horizontal orientations. These are probably the branch feeding burrows of *Chondrities*. Similar trace fossils occur in a bed near the top of the core which also contains a brachiopod valve and bryozoan fragment.

These rocks have an unusually high mica content. In thin sections, micas (or a clay mineral) oriented parallel to bedding constitute 40 to 50 per cent of the sediment. Their identity is difficult to ascertain in microscopic study but X-ray diffraction study indicates that they are probably a mixture of micas and illite.

Interpretation

Due to the high degree of fissility, structures were difficult to discern. The occurrence of brachiopod and bryozoan remains in a zone near the top of the core probably represent a poorly developed lag deposit, indicative of some degree of winnowing by bottom currents. The thin, unbioturbated, horizontal laminations indicate episodic deposition

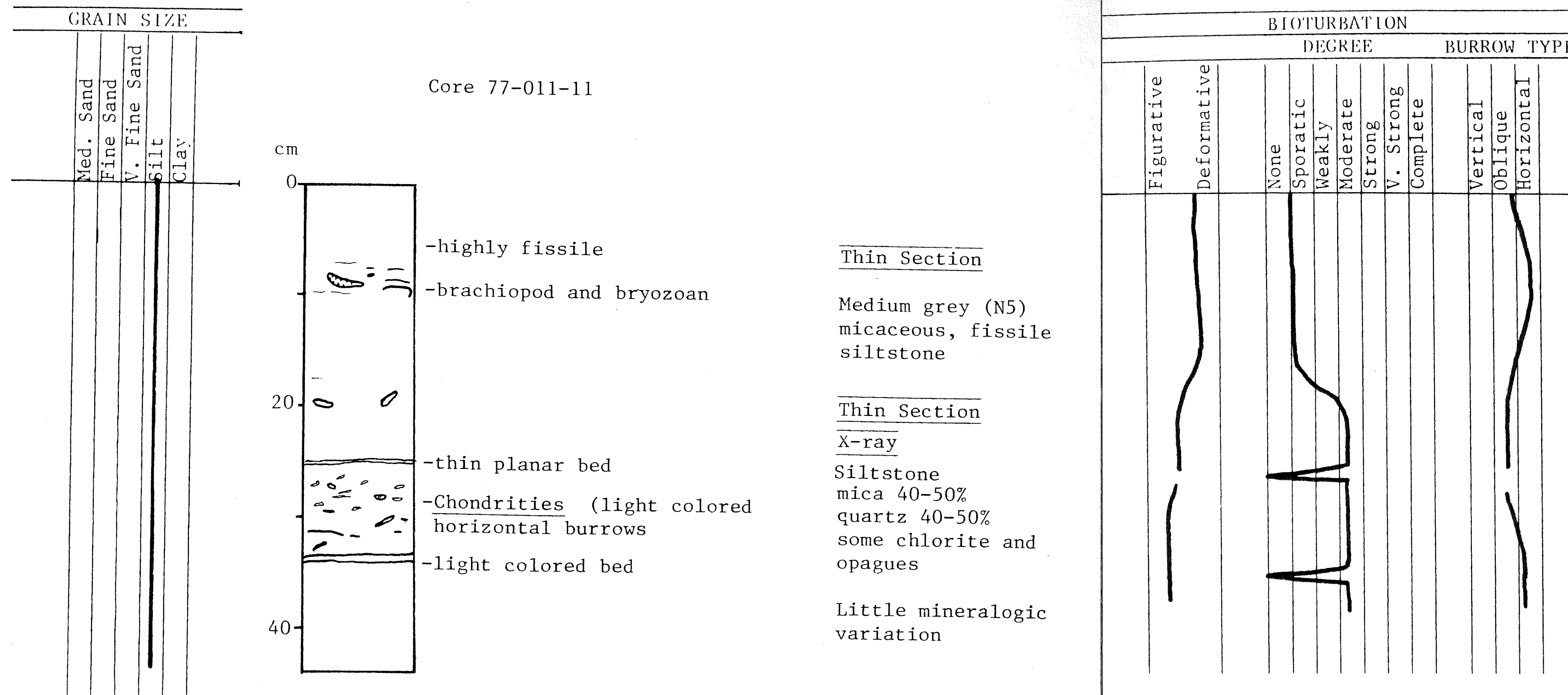


Figure 10.

Grain size, sedimentary structures, descriptions, sample locations, and bioturbation type.

under slightly different conditions than the thicker, completely bioturbated, intermediate beds. A number of the thicker beds contain small horizontal and inclined burrows of what is interpreted as the Chondirites ichnogenus. These strata were probably deposited at lower sedimentation rates giving time for the deposit feeder to thoroughly "mine" the sediment. The absence of evidence for scour and the absence of thick lag deposits suggest episodic, mildly turbid conditions.

CORE 77-011-7

Description

Cores 77-011-7 and 77-011-7B were drilled at 47°25'18"N 51°43'18"W, each with a recovery of only 15 cm of rock. The samples are of Mid-Silurian (Llandoverian to Wenlockian) age and have very similar lithologies (Fig. 11). Both cores have a medium dark grey (N4) colour which is indicative of high organic content. The samples exhibit a high degree of fissility because of their platy chlorite and micaceous minerals. Core 77-011-7 is very finely laminated unlike core 77-001-7B which suggests that the fissility is due primarily to diagenetic processes. The latter contains a well preserved calcareous Chonetid shell. Thin sections could not be prepared because of the high degree of fissility.

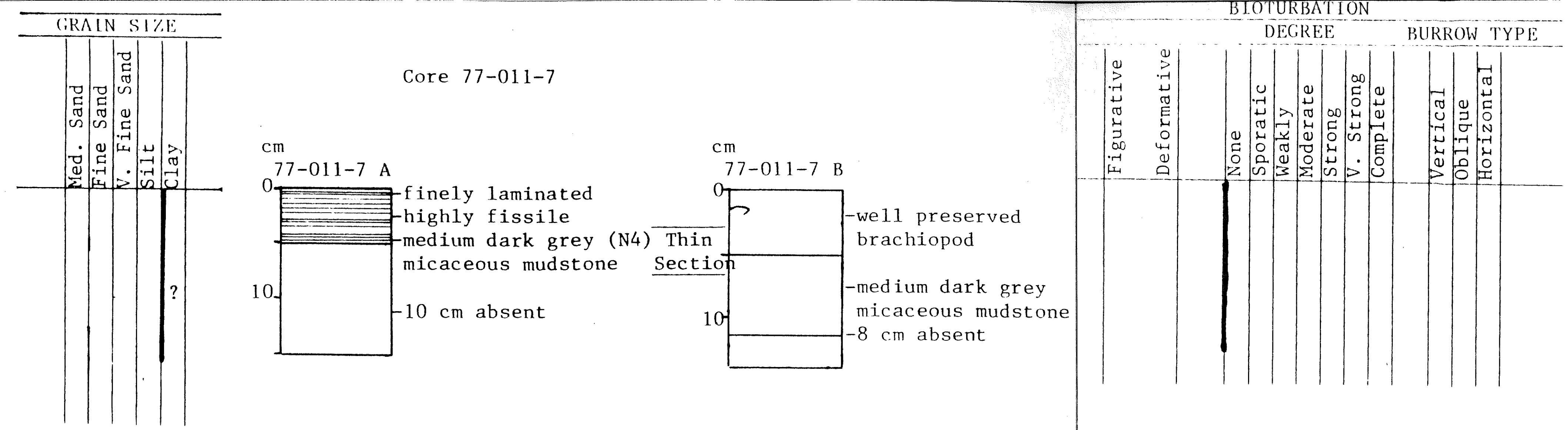


Figure 11.

Grain size, sedimentary structures, descriptions, sample locations, and bioturbation type.

No forms of bioturbation were observed in either core.

Interpretation

The environment of deposition of cores 77-011-7 and 77-011-7B is probably very similar to that of core 77-001-32. The presence of the brachiopod in core 77-011-7B (provided it lived and died in this location) suggests that the redox conditions were not too extreme; on the other hand, the shell may have been transported from a more hospitable environment. The fine laminations in core 77-011-7 probably formed as a result of grains falling directly out of suspension.

CORE 77-011-23-B

Description

Core 77-011-23-B was drilled in the southern study area at 46°46' 24"N 51°20' 30"W approximately 50 km NNW of the Virgin rocks. The core is only 41 cm in length but its structures are diverse and informative (Fig. 12). This sediment is barren of acritarchs but a Silurian age is infered by seismostratigraphic correlation.

Core 77-011-23-B has a light bluish grey (5B G/1)

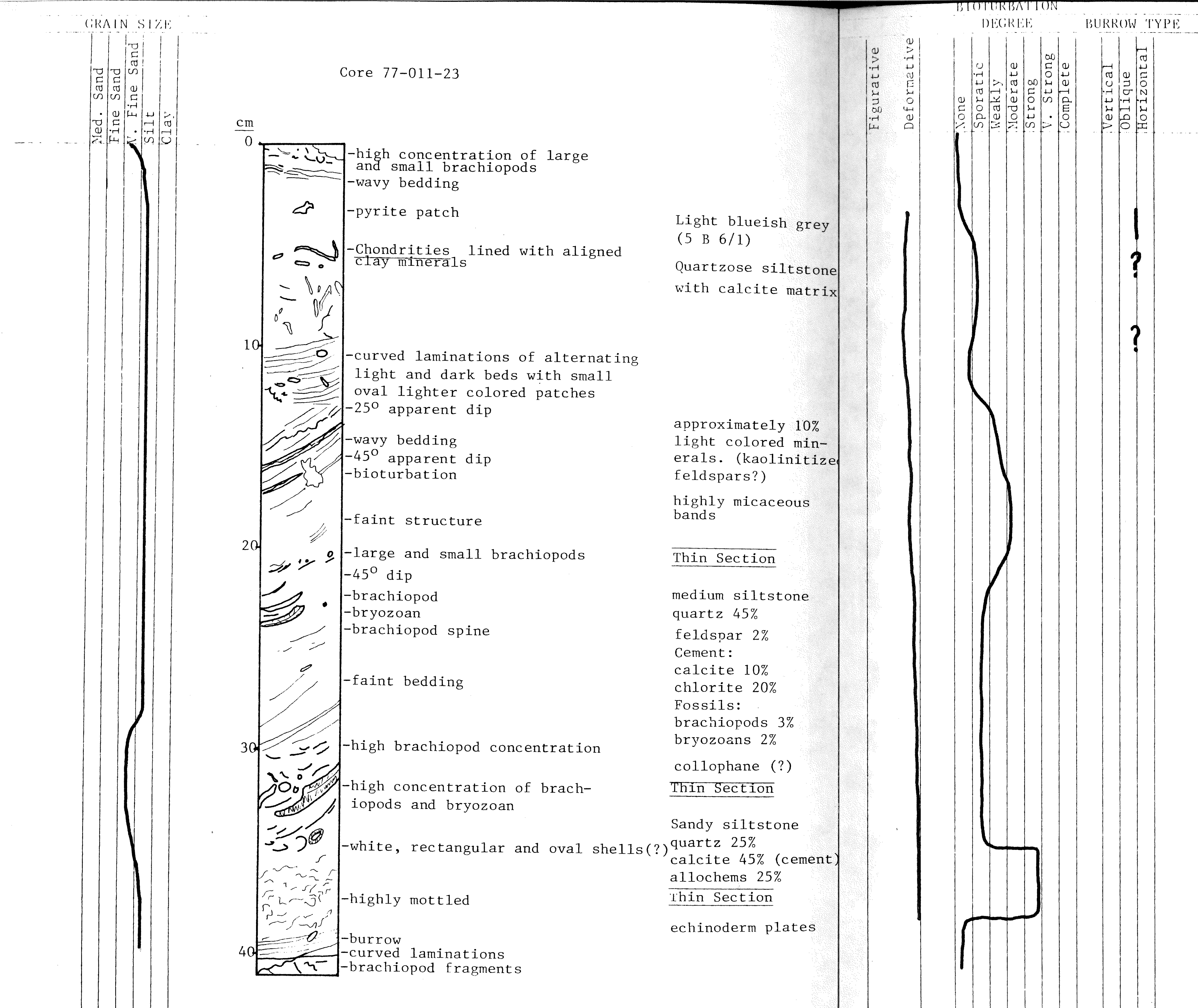


Figure 12.

Grain size, sedimentary structures, descriptions, sample locations, and bioturbation type.

colour. It is a fossiliferous, nonfissile siltstone with a calcite and chlorite matrix. Macroscopic inspection of the core shows variations in texture, sedimentary structures, body fossils and trace fossils throughout the core that occur in a somewhat cyclical pattern. At the base of the core a concentration of calcareous brachiopod fragments abruptly changes to very low angle, slightly curved, planar laminations which grade upward into a highly mottled material which has undergone strong deformative bioturbation. This is followed another thin (five cm) bed of abundant calcareous fossils including brachiopid tests and spines, bryozoan fragments, and rare echinoderm plates. This grades into high angle (30 to 40°), slightly curved, faintly laminated material, again disrupted by deformative bioturbation. Further up the core at 24 cm a similar sequence of fossil fragments, high angle (45°)planar laminations of alternating light and dark layers, and bioturbated sediment occurs. This is topped by another fossil rich bed. Thus there are roughly three complete units of fossil beds followed by planar or curved stratification topped by bioturbated material.

Two thin sections were used for textural and mineralogical studies to supplement low magnfication examination. The fossiliferous beds consist of about 25 per cent bryozoan and brachiopods with a very fine sandy silt matrix. In contrast, the laminated and bioturbated material above the fossiliferous beds of each unit are medium grained siltstones with only a minor amount of fine sand.

Subangular quartz grains vary in abundance between 25 and 60 per cent throughout the core. This variability is controlled by the variations in fossil abundance. Feldspars are rare (two per cent) and their state of alteration (sericitization) is variable but the plagioclase grains are surprisingly fresh. They may be of diagenetic origin. Accessory clasts account for less than 10 per cent of the sediment, consisting mainly of opague minerals, muscovite, and a phosphatic mineral (?collophane).

Cement type is also variable. Within and immediately below the fossiliferous beds a sparry calcite cement constitutes 45 per cent of the rock. Its mode of occurrence indicates a diagenetic origin. Between fossil beds, calcite abundance decreases to 10 per cent and platy chlorite minerals constitute 20 per cent of the cement.

A small (0.5 cm diameter) patch of microcrystaline pyrite occurs near the top of the core as does black, carbonaceous material.

Interpretation

One of the most informative features of core 77-001-23-B is the cyclic nature of the deposit as described above. Fragmented bryozoan and brachiopod shells in horizontal orientations at the base of each cycle attribute to the fact that a degree of tractional flow and associated hydraulic sorting (winnowing) occurred to produce a residual lag. The comparitively coarser grained (very fine sandy silt) detrital fraction associated with the fossiliferous beds is further evidence of a relatively higher energy flow regime as compared with the laminated beds which are thought to have been deposited under less dynamic conditions. A further inference concerning sediment supply to the region of deposition may also be made with respect to these beds. The hydraulic regime responsible for sorting, concentrating, and transporting these fossil fragments could simultaneously transport, at least in tractional flow, a much coarser and more highly concentrated sand fraction had the sand been present. The absence of sand in the core suggests that it is improbable that the local environment of deposition was supplied with any significant sand fraction.

The gradational boundaries from the fossiliferous to the laminated beds indicate a waning of current velocities and differential deposition of particles primarily from suspension. Where the laminated beds have a curved or wavy aspect, low or intermediate flow regime is believed to have produced small (several centimetres relief) infilling or laterally accreating scours (Potter et al, 1980). This also accounts for the change from steep to shallow dipping curved laminations depending on the position on the flanks of the scours. The gradation of the laminated beds into figuratively bioturbated material indicates that the primary laminated structures were initially more extensive and subsequently destroyed by bioturbation.

The cyclicity in the core can best be explained by the following succession of events: (1) the development of a fossiliferous lag by a dominantly erosional event, (2) lower energy small scale scour and fill and deposition from suspension, followed by (3) low rates of sedimentation, biotic influx, and (4) subsequent bioturbation. The preserved laminated beds may have been the lowermost sections of originally thicker beds which were deposited rapidly to a thickness greater than the depth to which the organisms could burrow. Such a succession is indicative of periods of relative quiescence (when bioturbation occurred) and the repeative nature of these events is indicative of storm related events.

Brenner and Davies (1973, 1974) have described similar but larger scale deposits in Upper Jurassic mudstones of the Western Interior, U.S.A. They describe lag deposits of unbroken shells associated with low energy muddy sediments. The deposits are thought to be the result of storm reworking of large shelf areas by storm waves and currents representing the weaker impact of storms in outer shelf areas.

CORE 77-011-22

Description

Core 77-011-22 was drilled at 46°46'12"N 51°23'30"W in the southern study area. Bedrock core recovery was 22 cm. The core was taken approximately 400 m stratigraphically above core 77-011-23 and was dated using acritarchs as Middle to Late Silurian age (Wenlock to Ludlow).

It is a medium grey (N5) finely laminated medium siltstone (Fig. 13). No calcareous body fossils are present in the rock, however, a limited number of vertical burrows occur.

Thin-section analysis of one segment at the top of the core revealed a 98 per cent silt fraction and very little fine sand. Texture is similar throughout the core. Angular quartz grains constitute 50 per cent of the rock and many of the grains have slightly sutured contacts. In addition to the quartz, very minor amounts of unaltered plagioclase are present. Micas and iron oxides make up a further 10 per cent.

Sedimentary structures are relatively well preserved in this core. Generally the faint planar bedding has a 20° dip. Rare crossed laminations are indicative of the pre-

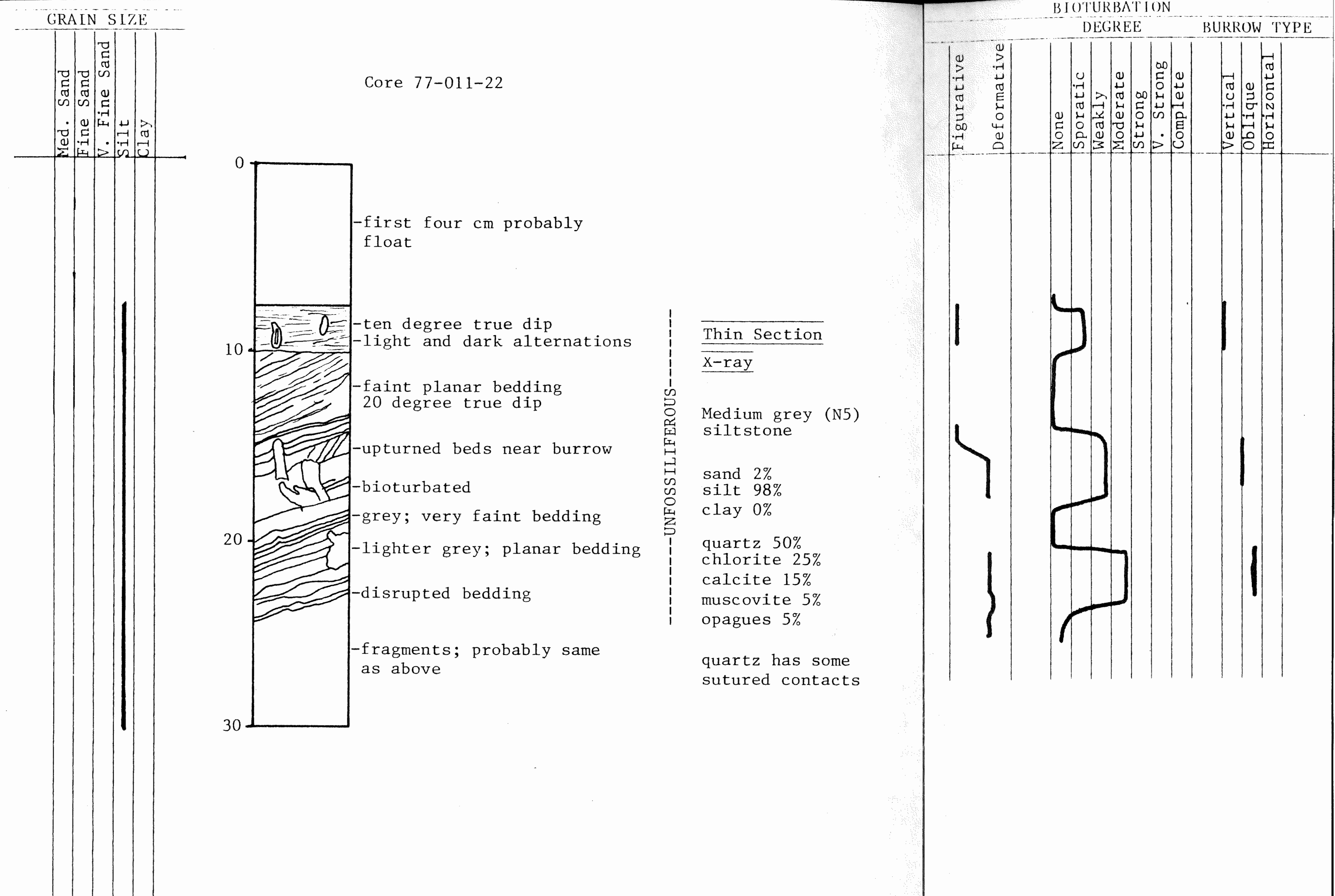


Figure 13.

Grain size, sedimentary structures, descriptions, sample locations, and bioturbation type.

uence of small bedforms and some degree of tractional flow. Near the base of the core the planer laminations are slightly disrupted, upturned and undulatory in nature.

Small areas of the core have undergone deformative bioturbation and still other areas exhibit burrow forms. One burrow-like structure extends two cm from a bioturbated bed upward into a laminated bed in which the laminations surrounding the burrow are slightly upturned. Vertical burrows of similar diameter (three mm) occur at the top of the core. No burrow sytems such as *Chondrities* are seen in these sediments.

Interpretation

The planar laminations which characterize most of core 77-011-22 could have formed either as the result of differential settling of constituents directly from suspension or sorting as the result of tractional flow. The high angle crossed laminations are indicative of some type of bedform genesis under tractional flow and therefore this is the most probable mode of deposition.

The disturbed laminations at the base of the core may be the result of some tractional flow (Potter *et al*, 1980) but may also be an early diagenetic feature caused by water escape. Dips between 10 and 20° also illustrate the dynamic conditions of sedimentation.

Most of the core appears to have been deposited under rapid sedimentation conditions. This is inferred from several features: Upturned laminae in thin beds could be the result of dewatering as rapidly deposited and therefore loosely packed grains rearrange into closer packing however the possibility that this feature is an escape burrow cannot be dismissed. The limited extent of bioturbation in the core illustrates that the system was too dynamic or rapidly deposited to allow time for extensive biogenic activity. Such a dynamic environment may also explain the absence of brachiopods or other body fossils.

CORE 75-009-25

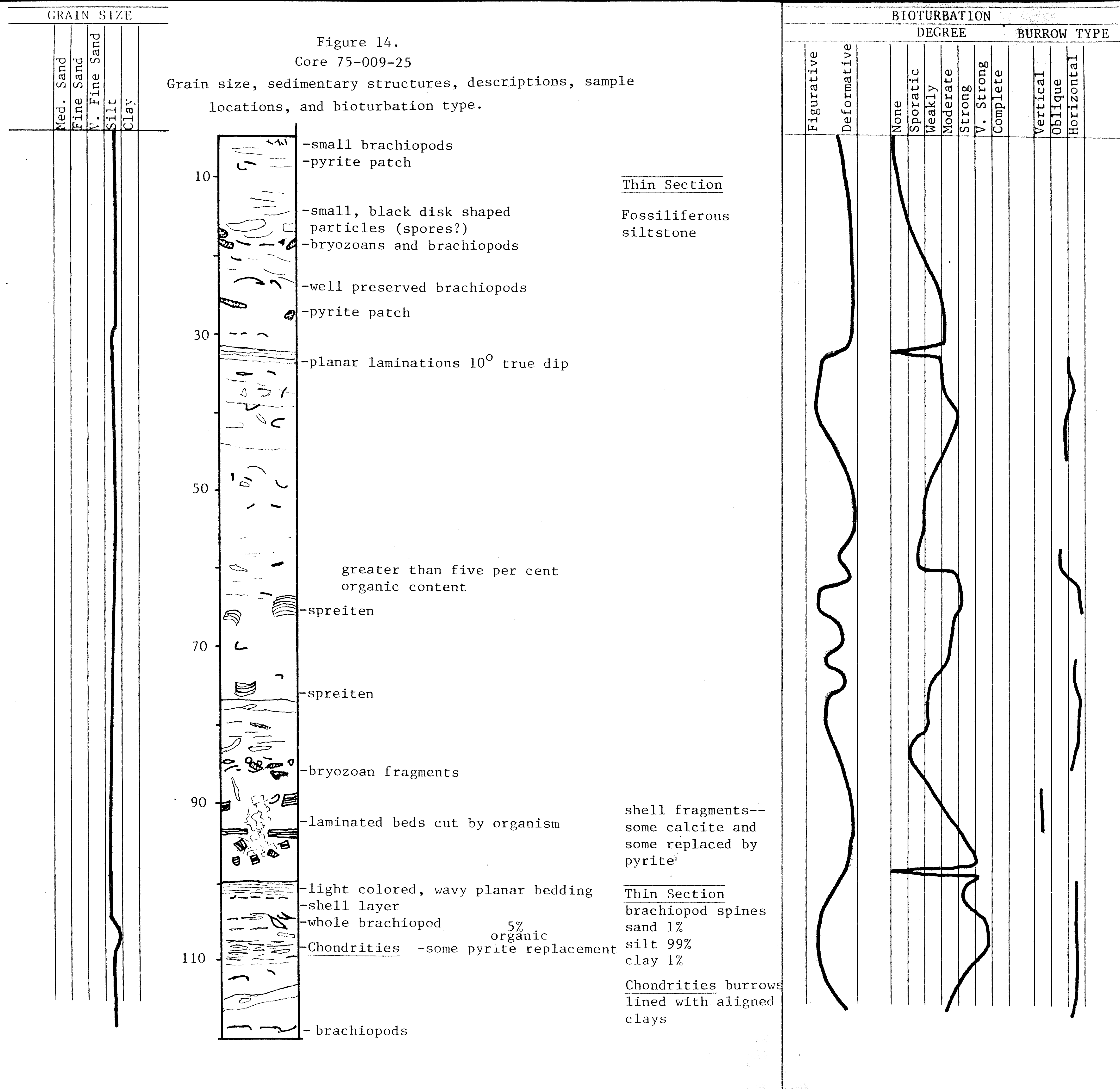
Description

Core 75-009-25 was drilled in the central study area 47°09'46"N 51°57'28"W and 450 cm of core was recovered.

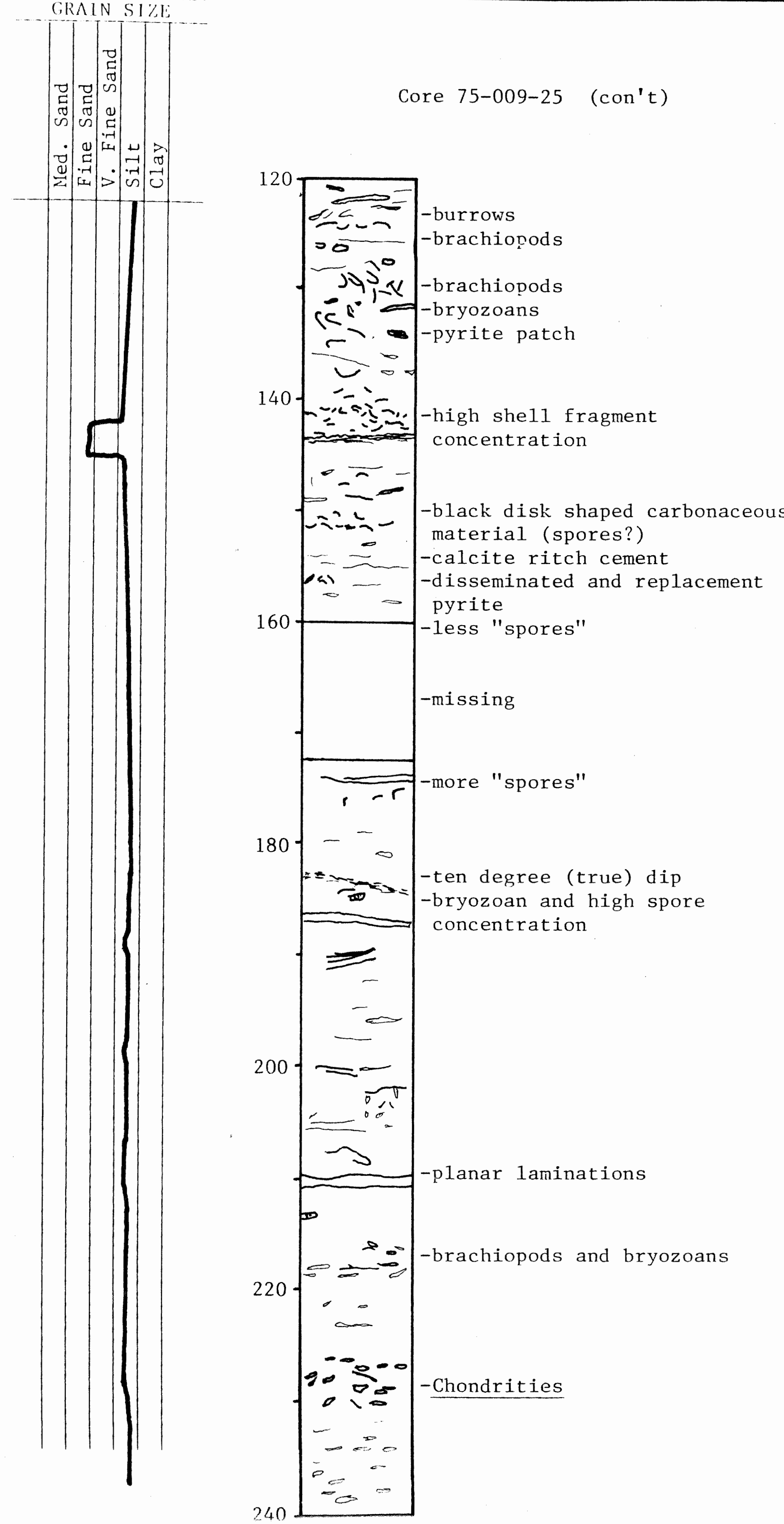
The sediment is primarily a medium dark grey (N4) colour but has slightly lighter grey (N5) and greener (5G 6/1) variations along the length of the core (Fig. 14).

The degree of fissility is highly variable in these sediments ranging from very fissile to nearly massive. Diagnostic acritarch specimens indicated a Late Silurian

Figure 14.
Core 75-009-25
Grain size, sedimentary structures, descriptions, sample locations, and bioturbation type.



Core 75-009-25 (con't)



Fossiliferous siltstone

Thin Section

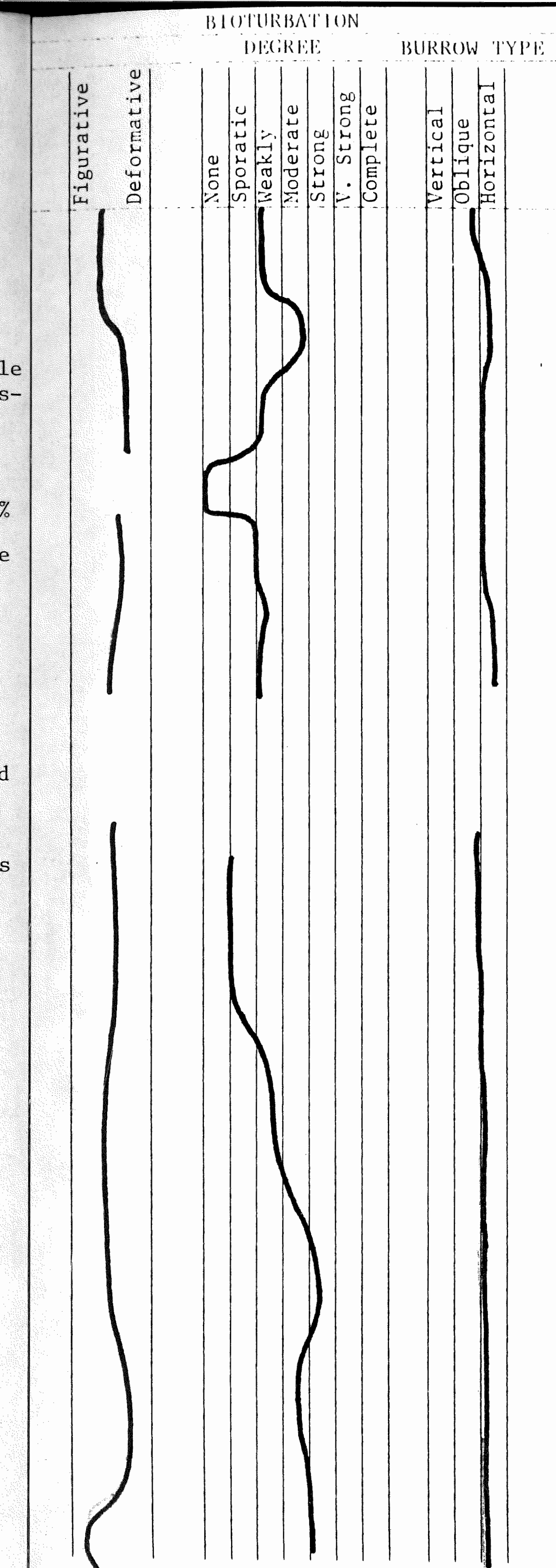
grainsize variable depending on presence of burrows

sand 1%
silt 99%
clay less than 1%

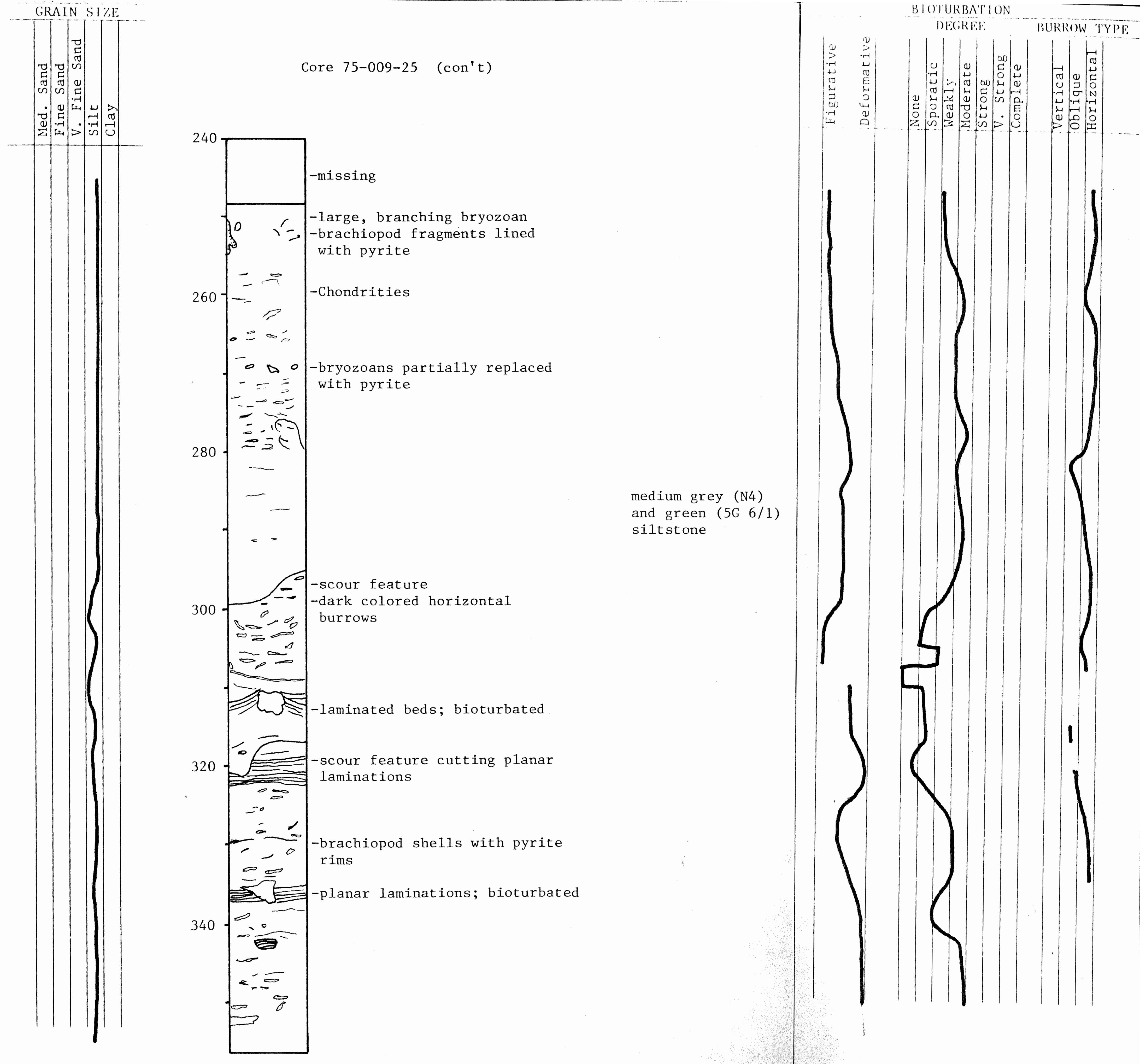
texturally mature

quartz 25%
muscovite 40%
opagues 5%
Cement:
calcite 15-60% (variable)
siderite (trace lining brachiopod shell)

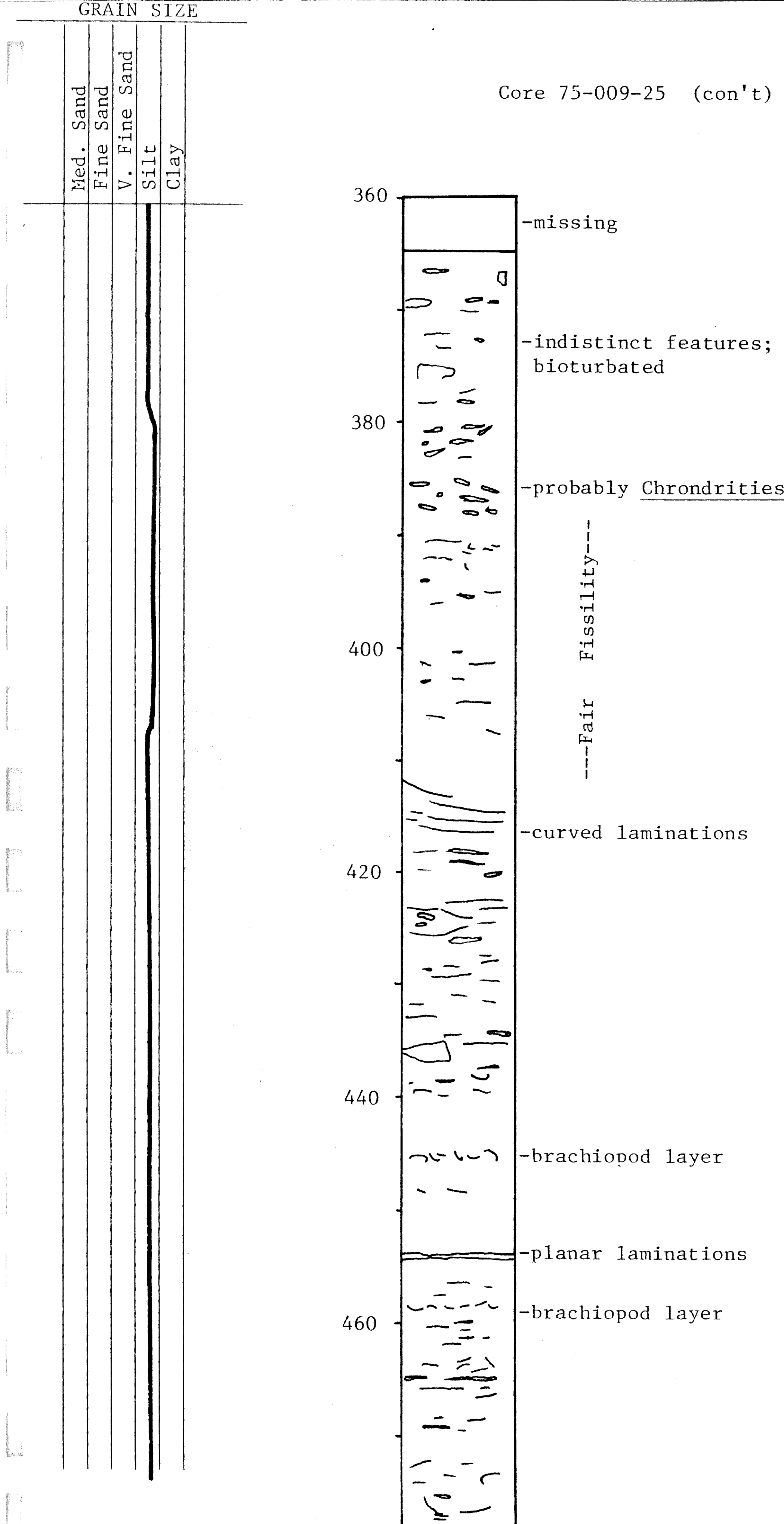
Brachiopods 10%
brachiopod spines



Core 75-009-25 (con't)



Core 75-009-25 (con't)

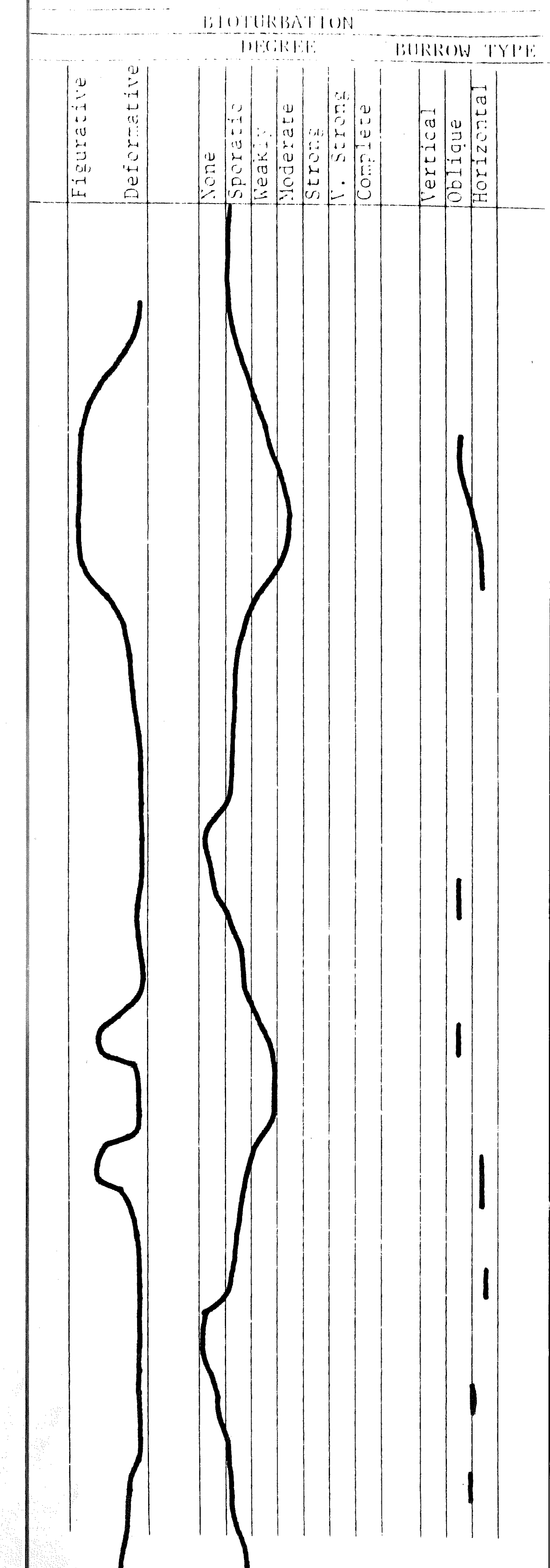


grey and green
siltstone

Thin section

sand 1%
silt 97%
clay 3%
but up to
sand 0%
silt 70%
clay 30%

quartz 40%
mica 40%
calcite 20%



(Ludlow) age.

Estimates of grain size indicate that the sediments are mudstones and siltstones . Four thin section analyses along the length of the core show that the sand fraction does not exceed one per cent. Estimates of silt abundance are all greater than 97 per cent except for small patches (on a microscopic scale) where clay sized particles compose 30 per cent of the sediment. Most of the clay-sized particles have diameters greater than two or three microns (very close to the silt-clay boundary) and their composition appears to be little different from the silt grains (i.e. few clay minerals).

This is the most fossiliferous core recovered from the study area and contains numerous Chonetid brachiopods identified by E. W. Bamber (pers. comm. to King & Fader, 1976). In its life habitat, the Chonetids' shells probably rested on the seabed with the brachial valve uppermost. Many of them had spines which may have served as balancers or for flotation on a soft substrate. Chonetids may not have been specific to any particular environment except that they are usually associated with fairly fine grained sediments. Although there were no faunal assemblages recognized in the core, in a study of Silurian brachiopod assemblages of the Welsh borderlands, Zeigler (1968) distinquished several communities with specific environmental affinities. His _Costistricklandia_ Community contained a very small percentage of Chonetid shells which were not represented in any other assemblage. This community occurs in fairly quiet off-shore conditions. It is not highly likely that an assemblage the same as the Costistricklandia community existed in this locality however the relationship does illustrate the compatability of the presence of Chonetids and quiet, offshore conditions.

In the core, the brachiopods occur only rarely as whole or unseparated remains and even these do not appear in their life positions but are concentrated along very thin (0.5 cm) beds. Sometimes they are disseminated throughout the sediment but show no specific orientation.

At two intervals (143-140 cm and 130-134 cm) in the core, calcite fossils occur in great abundance. The brachiopod shells are small (0.5 cm long) and many are fragmented. Thin-section inspection also revealed ooid-like structures with characteristic tangential and radial patterns of calcite. Their size (0.2 mm diameter), elliptical shape, and composition suggests that they are sections of brachiopod spines.

In addition to the brachiopods, bryozoan fragments are present. They occur as branched, unabraided forms and in one location as a thin horizontal bed of fragments.

Small disk-shaped particles of black carbonaceous maturial are present in variable abundances. Typically, they have a diameter of one mm and are 0.3 mm thick. Their origin is unknown.

Microscopic study at three locations on the core show considerable variation in detrital quartz content. Fossiliferous areas have little (25 per cent) to no quartz, but commonly, the subangular to subrounded quartz grains reach concentrations of 40 per cent. The rocks comprise between 40 and 60 per cent muscovite. Where aligned, they contribute to the high degree of fissility. Hematite and other opaque minerals make up another five per cent. Fine grained muscovite, clay minerals, and chlorite form a matrix in the relatively unfossiliferous parts of the core. A calcite cement accounts for the remaining five to ten per cent of the rock. The more fossiliferous areas have a much greater cement fraction. The intervals from 130 to 134 cm and 140 to 143 cm comprise a coquina of brachiopod and bryozoan fragments. A sparry calcite cement of diagenetic origin constitutes 60 per cent of the rock in this interval. Siderite is present in very minor amounts as a replacement after calcite. Siliclastic grains are surprisingly absent and the interval can be classified as a biosparite.

Thin, horizontal beds of fossils occur throughout the core. In addition, thin (one to two cm) horizontal beds of finely laminated silt occur at intervals along the core.

These beds are commonly deformed partially by bioturbation. In one case, blocky fragments of the finely laminated beds are randomly dispersed in the sediment immediately underlying such a bed (See Fig. 14; 90 cm to 95 cm interval). This suggests a relatively hard or cohesive substrate at the time of bioturbation.

Several areas of the core exhibit low angle planar and slightly concave laminations. Still, other areas show a truncation of beds by undulating surfaces with relief in the order of two cm to three cm. Much of the primary sedimentary stratification has been destroyed by figurative bioturbation.

Although several segments of the core show deformative types of bioturbation, biogenic action has produced many figurative structures. Most common are the fine horizontal and oblique burrows which, where present, permeate 60 to 70 per cent of the sediment. They have diameters of approximately 0.2 mm and are infilled with sediment comprised of almost 80 per cent clay minerals. The platy minerals are usually aligned parallel to the longitudinal axis of the core. These burrows are similar to those in many of the cores and probably are *Chondrities*. Also present are well developed concave upward and downward spreiten.

In summary, core 75-009-25 is a fissile, micaceous grey laminated siltstone of Ludlowanian age with bryozoans, brachiopods, various trace fossils, and evidence of deformative bioturbation.

Interpretation

The fine grained texture of the sediments throughout the core suggest a low energy environment of deposition. Although many of the primary sedimentry structures have been bioturbated, some were preserved and provide evidence for sedimentation conditions. The thin lag deposits of brachiopod shells and bryozoan fragments represent occasional reworking and winnowing of the bottom by weak currents. The thicker (4 cm) fossil concentrations are probably the result of much more substantial current activity and winnowing effective enough to remove essentially all the siliclastic component of the rock.

The truncated beds with undulating erosional surfaces are further evidence of local scouring by bottom currents. In addition, the curved, laminated beds result from small scale channeling.

These rocks lend some evidence of the geotechnical properties of the substrate at the time of deposition. The blocky, book-like fragments of bioturbated laminated beds at the 90 to 100 cm interval demonstrate that these beds were more cohesive than the underlying sediment at the time of bioturbation. Deposition of these laminated sediments directly from suspension would not be expected to produce such a hard substrate because under these conditions, irregularly shaped grains would be randomly oriented and, therefore, not well packed. However, under the influence of a weak current alignment of the grains would result in better packing and, therefore a harder substrate. Slight compaction and dewatering resulting from a thin sediment cover could also have a strengthening effect on the laminated beds.

The brachiopod spines found in this core demonstrate an adaptation of brachiopods to a very soft or soupy substrate. The increased surface of radiating spines allows greater bouancy and stability in an otherwise inhospitable environment. Presumably, the fossil bearing sediment between the firm, laminated beds was less consolidated.

In review, texture and sedimentary structures indicate a low energy environment in which deposition directly from suspension occured at a fairly low rate while supporting a fairly abundant epifauna and infauna. Intermittant substrate disturbances (probably storm related) produced fossil lag deposits, relatively hard laminated beds and various erosional surfaces.

Fossil concentrations in the presumably undisturbed sections of the core are considerably lower than in the fossil lag deposits, which occur at intervals throughout the core. If the shell lag deposits developed through winnowing of the overlying sediment (as opposed to being transported into the area) then relative shell concentrations in the two units give an indication of the amount of fine grained material which must have been removed to produce the lag. Sediment thicknesses anywhere from 10 to 50 cm or more would have to be reworked and winnowed to produce the residual fossiliferous beds.

Trace fossils may give further evidence of intermittant erosion and deposition. Convex spreiten, oriented both upward and downward, indicate upward and downward motion of the producing organism. This movement is generally thought to be a reaction by the organism to periods of deposition or erosion as it attempts to remain a certain depth below the sea floor. They are an indicator of energy levels dynamic enough to cause local, intermittant erosion and deposition.

Chondrities is abundant throughout most of the non-laminated sediments in the core. As part of the Cruzania ichnofacies (Seilacher, 1964), *Chondrities* indicates a normal, open shelf environment in depths below daily wave base yet still within storm wave base. More recent workers have found that *Chondrities* has a depth range considerably greater than this and that in some cases it may have formed in water depths considerably deeper than shelf depth. However, interpretation based on texture, sedimentary structures, chamosite, siderite, and ooid presence suggest shallow water deposition is most likely.

CORE 77-011-2

Description

Core 77-011-2, 60 cm in length, was drilled at 47°09' 48"N 52°12'48"W. It consists primarily of red sandstone (Fig. 15). It is barren of fossils so an age could not be determined by paleontological methods. However, if the general proportionality of time and stratigraphic thickness (see Fig. 20), which is evident throughout the sequence, can be extrapolated upward into the redbeds, then the age of these sediments probably extends well into Devonian time.

The sandstone varies in colour between a pale purple (5P 6/2) in the quartzose areas to a greyish purple (5P 4/2) where the silt content is higher.

The coarser beds consist almost solely of sand sized detrital grains with a fine to medium sand median. The sediments contain angular grains which are moderately sorted.

The rock is comprised of approximately 35 per cent quartz, 10 per cent chert and 35 per cent feldspar, 85 per

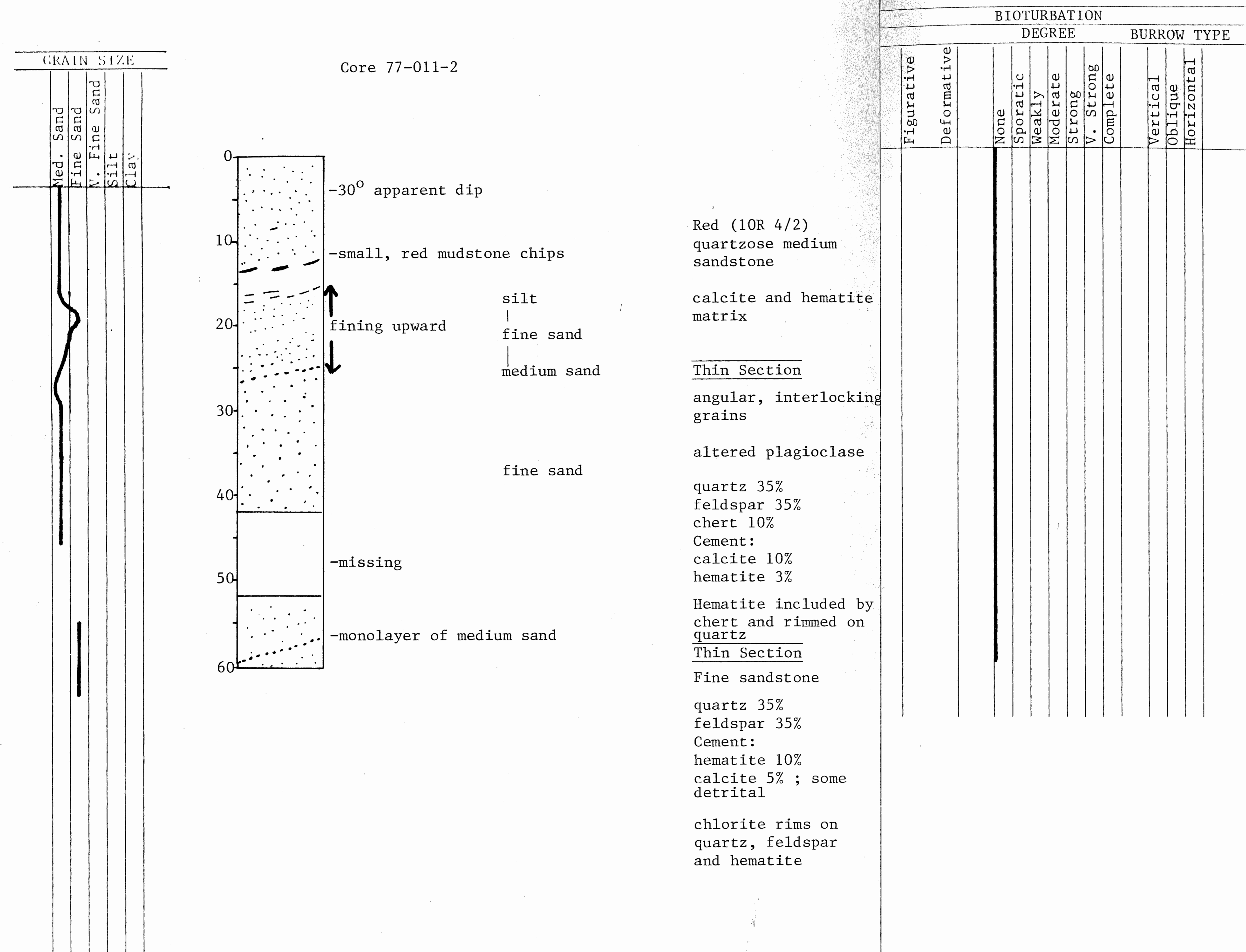


Figure 14.

Grain size, sedimentary structures, descriptions, sample locations, and bioturbation type.

cent of which is orthoclase, 15 per cent plagioclase and microcline and perthites in very minor amounts. Hornblende, mica, and calcite are also present. Hematite is present in the matrix and as a rim amount on quartz and feldspar grains. The hematite is, in turn, often rimmed by chlorite. The bulk of the cement, however, is calcite.

The only structures visible in this core are faint planar beds with a persistant 30° dip throughout. The seismic profiles in this area show dips of only 2° to 3°. Attitude sensors on the drill indicated a tilt considerably less than 30° so it is probable that the primary stratification was dipping about 20° to 30°. Both compositional and grain size variations are responsible for the laminations. Small, red mud chips are present at the top and bottom of the core. A graded bed which occurs in this 15 to 25 cm interval fines upward from medium sand to silt.

In summary, core 77-011-2 is a pale purple arkose of medium sand with minor structures and probably of Devonian age.

Interpretation

The distinguishing features of core 77-011-2 are the red colour and the relatively coarse texture. Most of the red colour probably originates from the thin coating of hematite on most of the grains. This coating may be primary or secondary. However, the environmental conditions at the time of deposition must have been relatively oxidizing to maintain the colour.

The relatively coarse grains required a fairly high energy regime for their concentration. The fining upward sequence in the core is indicative of waning current velocities. Probably the most significant elements in this rock are the small mudstone chips. Under a relatively high flow regime, it would be expected that these platy chips would soon be reduced to sand size grains. Their relatively large size suggests that they have undergone very little hydraulic working and were derived locally. They were probably desicated mud chips on a river bank or floodplain which were eroded during a high water stand.

Of further environmental significance is the high feldspar content in this rock. Because feldspars are highly subject to physical and chemical weathering (especially in a warm, moist climate as probably existed in Devonian time in this area), their presence in abundance indicates that the source rocks are more proximal than were those from which most of the other rocks of this sequence were derived. In addition, the arkose of core 77-001-2 quite likely had a source of "granitic" composition.

The fact that these rocks are barren of fossils in addition to these factors all suggest a terrestrial origin for these rocks. To be more specific about the environment of deposition is difficult without a knowledge of the geometry and aerial extent of the deposit.

CORE 77-011-3

Description

Core 77-011-3 was taken at 47°09'48"N 52°22'6"W 50 kilometres SE of St. Johns (Fig. 16). Almost one m of redbeds were recovered. These redbeds are about 500 m stratigraphically up section from core 77-011-2. They are barren of fossils so an age could not be determined. However, they are stratigraphically well above core 77-011-2 and probably of Devonian age.

The sediment is a planar laminated sandy silt of greyish red (1 OR 4/2 to 10 R 5/2) colour (Fig. 16). Rare small mottles of grey color occur where hematite is not present. Four microscopic textural analyses show silt content that varies from 75 to 85 per cent while sand size grains range in abundance between 5 and 15 per cent. The rock is a sandy coarse siltstone.

Quartz grains are abundant (70 per cent) and like other

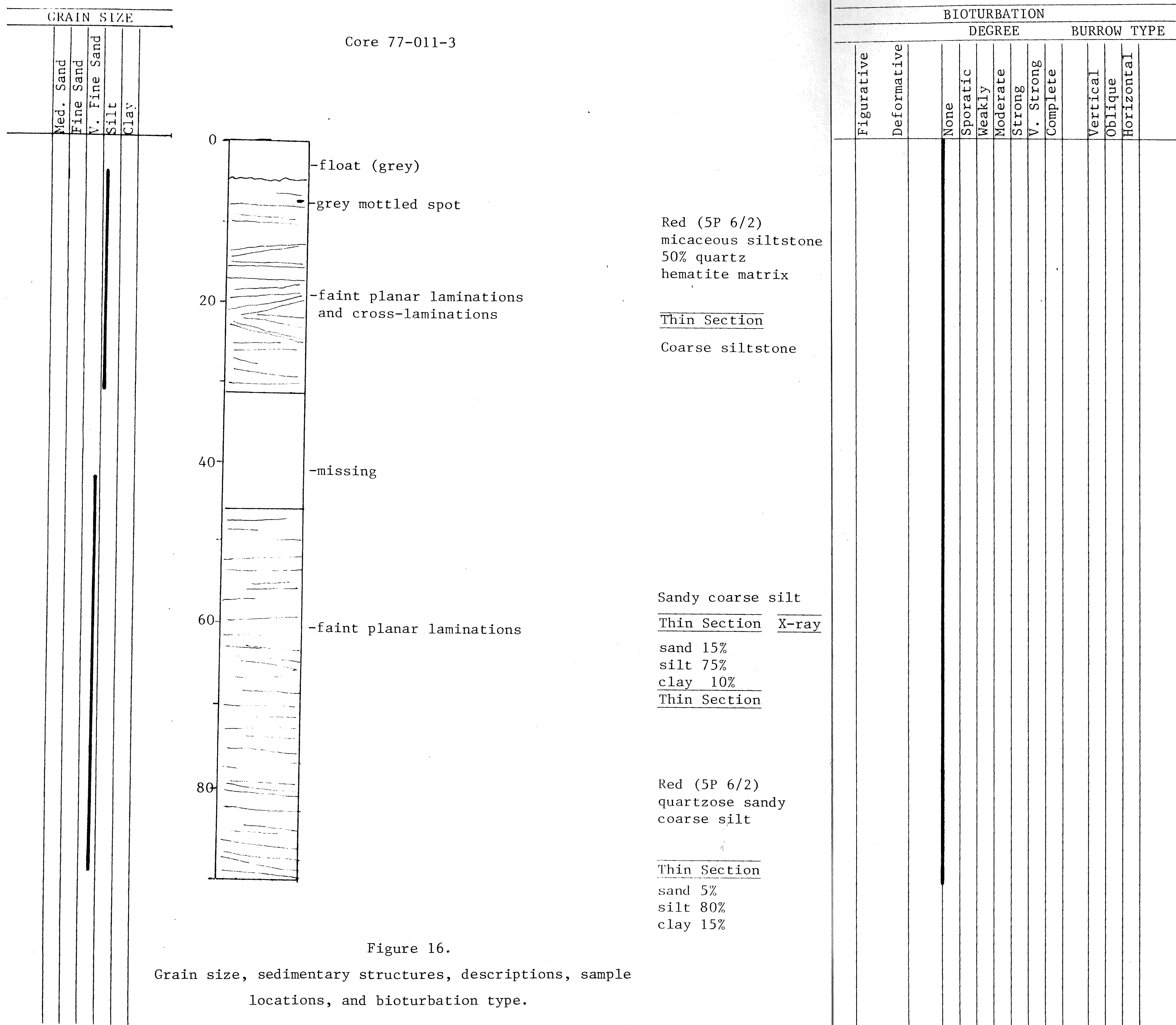


Figure 16.

Grain size, sedimentary structures, descriptions, sample locations, and bioturbation type.

siltstones in the sequence, feldspar content is very low. Oriented muscovite grains give rise to some fissility. Chlorite and calcite clasts are also present in minor amounts. The matrix is dominantly hematite which occurs as clay sized grains.

Faint horizontal planar laminations in the lower half of the core grade to planar laminations with truncated tops with dips exceeding 20 degrees.

Interpretation

The most obvious environmentally indicative aspect of this rock is the red colour. The colour presumably stems from the fine grained hematite matrix. Much debate in the literature surrounds the problem of primary or secondary origin of this colour. However, the environment of deposition (or at least the diagenetic environment) is under oxidizing conditions. (Eh less than 0.02; after Berner, 1971). The absence of fossils reflects an absence of life or is probably the result of very low preservation potential in such conditions.

As in many of the other cores the fine grain size is indicative of fairly low energy conditions of sedimentation. The planar laminated beds may reflect quiesent conditions whereby grains in suspension could settle out differentially, causing the observed textural and mineralogic sorting.

The crossed-laminations throughout most of the core, however, are suggestive of a flow regime in which tractional grain flow was an important factor. Parallel laminations can also develop in high flow regimes, however the type of sedimentation usually produces parting lineation and there is no evidence of such structure in the core.

Unlike most of the other cores, the feldspar content is quite high. Fine grained feldspars are subject to fairly rapid weathering alteration. Therefore, their preservation in this rock is indicative of a relative immaturity of the sediment, given the probable warm, humid climate (discussed later). The environment of deposition is probably not very distant from the source.

The oxidizing conditions, lack of fossils and immaturity of the sediment suggest that these sediments were deposited under terrestrial conditions. The low energy, episodic sedimentation conditions could occur in lacustrine, floodplain, or deltaic, or any one of a number of terrestrial environments, however, one core does not provide the control necessary to determine the large scale geometric relations needed to distinguish these environments.

SUMMARY OF INTERPRETATION AND HISTORY OF DEPOSITION

INTRODUCTION

With a good comprehension of the various depositional environments represented at specific times and locations throughout this Lower Paleozoic succession, an attempt at constructing a regional analysis of the basin of deposition and its geologic history is made possible. Such an analysis should involve discussion of the regional setting, climate, sediment source and burial history. Unfortunately, not all of these criteria can be used in this analysis because of serious limitations imparted by the fact that the samples are cores and the sample control was limited. The seismic control was a decided advantage in circumventing some of the sampling problems.

One common aspect of all the cores studied, with the exception of the red beds (cores 77-011-2 and 77-011-3), is their marine nature. Evidence of this lies in the presence of marine fossils of one type or another. Acritarchs are the chitinous body parts of otherwise relatively unknown organisms. They were probably planktonic and as such are not environmentally indicative other than the fact that they are of marine origin. In addition, many of the cores contain marine brachiopod (Chonetid) and bryozoan fragments, which further attest to the marine aspect. Finally, some of the diagenetic minerals are thought to be of marine origin only. Although many of these factors are only circumstantial evidence, when considered in their entirety the probability of their representing a marine environment is greatly enhanced.

A second dominant aspect of this sequence is the fine grained nature of the sediments. This seemingly ubiquitous aspect is illustrated in the ternary diagram (Fig. 17). The grain size, among other environmental indicators, is an important factor with respect to environmental interpretation.

In addition to the ?Devonian terrestrial rocks, a number of shallow marine (shelf depth) lithofacies have been recognized from the study of ten cores. These environments can be classified more generally as Restricted Shelf, Normal Shelf, and Terrestrial facies (Fig. 18) according to the same basic guidelines used by Morris, (1977).

BITUMINOUS AND RESTRICTED MARINE SHELF LITHOFACIES

Morris (1977) recognizes a restricted shale and bituminous shale facies of typical shallow marine seas. The restricted shale facies is generally lacking structures indicative of a high current regime or a diverse benthic assemblage. The bituminous mud facies contains unbiotur-

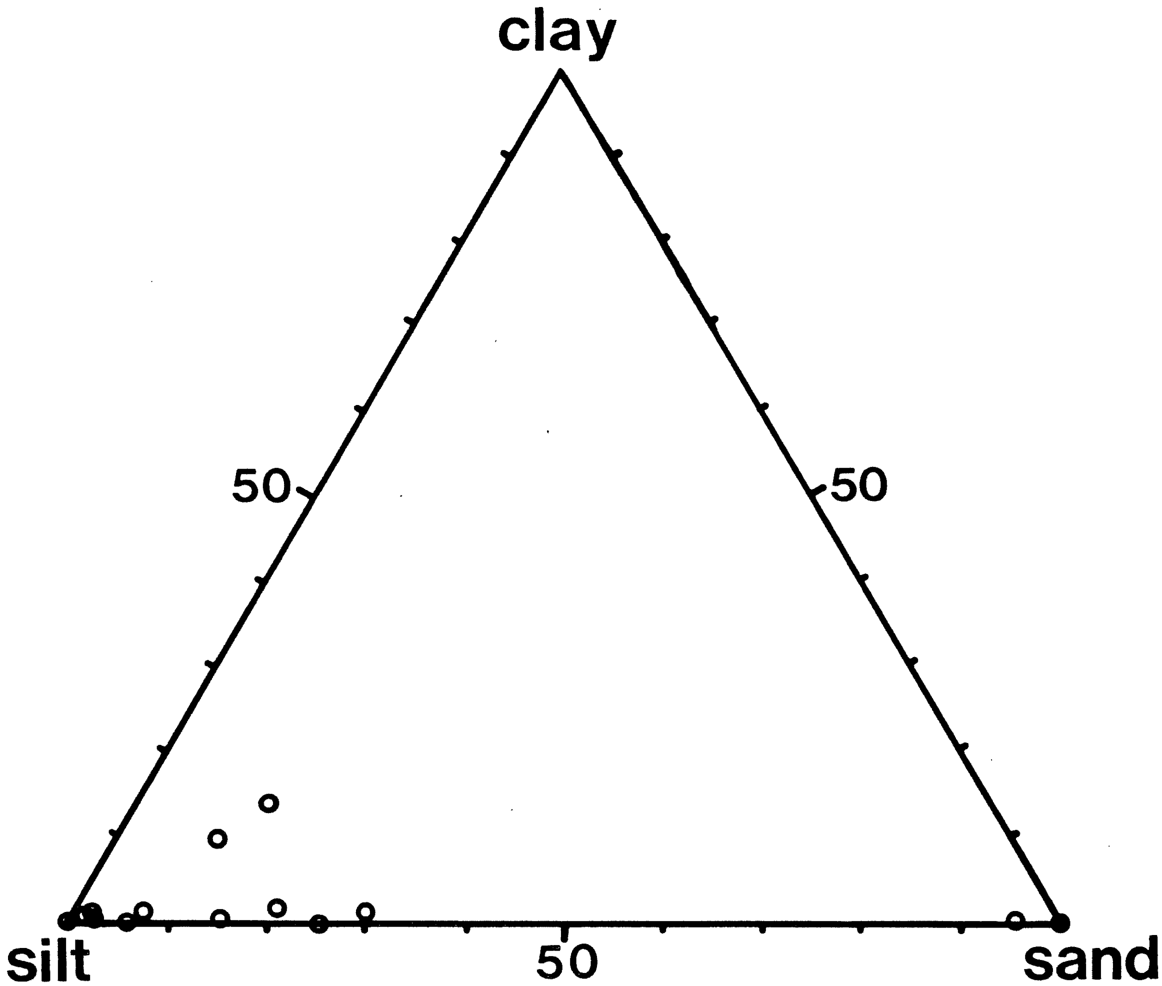


Figure 17.

Grain size analyses from eight cores illustrating the fine grained aspect of the lower Paleozoic sequence.

FACIES	BIVALVE GROUPS	TRACE FOSSILS	BENTHIC FORAMINIKRA	CONCRETIONS	ENVIRONMENTAL INTERPRETATION
NORMAL SHALE	EPIFAUNAL AND INFAUNAL SUSPENSION-FEEDERS, INFAUNAL DEPOSIT-FEEDERS	*CHONDRITES,* HORIZONTAL BURROWS	COMMON	SIDERITIC AND CALCAREOUS	Sea water Abundant O_2 / Mild oxidizing conditions / Reducing conditions / Sediment
RESTRICTED SHALE	DOMINANT INFAUNAL DEPOSIT-FEEDERS	FEW HORIZONTAL BURROWS	RARE	CALCAREOUS	Sea water Abundant O_2 / Reducing conditions / Sediment
BITUMINOUS SHALE	DOMINANT EPIFAUNAL SUSPENSION-FEEDERS	NONE	NONE	PYRITIC CALCAREOUS	'Soupy' layer / Sea water Abundant O_2 / Abundant H_2S / Reducing conditions / Sediment

Figure 18

A classification of shale facies and criteria for their recognition. (from Reading, 1978, after Morris, 1977) bated sediment with well developed laminae rich in kerogens and only specialized epifauna.

The Lower Ordovician black shale (core 77-011-32) has evidence of low oxidation potential, weak current activity and some infauna suggesting that it may be in the realm of restricted mud facies rather than the bituminous lithofacies.

The ?middle Silurian black shales (cores 77-001-7 and 77-011-8) have textural and compositional evidence for conditions of quiescence, uniform sedimentation and low oxidation potential and associated lack of epifaunal activity. This interpretation suggests an environment of deposition very similar to the Bituminous Mud (or shale) facies described by Morris.

NORMAL SHELF FACIES

The normal mud facies consists of mudstone and claystone with a diverse benthic assemblage of burrowing and epifaunal organisms. (Morris, 1977) Many of the cores have attributes which may be indicative of a specific depositional process within a normal shelf environment. However, interpretation of shallow marine lithofacies solely in terms of the dominant physical depositional process is difficult because these processes may be operational in any one of a a number of specific normal shallow marine environments. Other factors such as facies geometry, alternation and stratigraphic succession aid greatly in such interpretation. In this study, such data are lacking so only a general attempt is made at lithofacies classification. The rocks can be classified as forming in a storm dominated, storm influenced and nearshore or bank environment of a normal marine facies. Normal shelf environments of various types recur much more often in the sequence than do other environments. Therefore, based on probability, it is reasonable to suggest that much of the section was deposited under normal shelf conditions.

The cyclic sequences in core 77-011-13-B are the most strongly suggestive of storm deposition. The sequences of shell lag, parallel lamination, and bioturbated sediment in core 77-011-23-B record initial storm erosion, deposition and post storm reworking indicative of a storm dominated lithofacies.

Cores 77-011-11 and 75-009-25 also have cyclic units probably of storm related origin. They are not regular or well defined suggesting that the environment of deposition was only subtly influenced or more remote from the major storm (or ?tidal) influence.

Sedimentary structures and bioturbation style in the Late Silurian siltstones (77-011-22) indicate relatively dynamic conditions of current flow and sedimentation throughout the core. Little can be said as to whether they might have been tidal or oceanic currents rather than storm (wind or wave induced) currents.

The Late Ordovician siltstones and fine sandstones (core 75-009-24-A) belong to a fairly shallow water facies. The ooids and the trace fossils both indicate turbulent water conditions whereas the chamosite probably is an indicator of warm (25°C) and shallow water. The presence of secondary siderite among the ooids suggests exposure to quite well oxygenatated conditions whether at the time of deposition or as a diagenetic process. The rocks probably formed in a sub-littoral zone, possibly some distance from an area of sediment influx; for example on the flanks of an isolated bank.

TERRESTRIAL

The ?Devonian redbeds represented by cores 77-011-2 and 77-011-3 present little concrete evidence of their depositional environment. Their red colour indicates oxidizing conditions but it is not clear if the colour is pre-, syn-, or post-depositional. Although the general nature of the hydraulic regimes during deposition can be ascertained, it is difficult to relate them to a specific environments. Core 77-011-2 is the coarser grained and more texturally immature of the two and has small mud chips suggesting local derivation of sediment. The above considerations, together with the fact that these cores are barren of fossils, tend to favor an inferred terrestrial origin.

HISTORY OF DEPOSITION

Figure 19 illustrates the lithologies and environmental interpretations through time of the ten samples from both central and southern study areas. Sample stations are located along or projected onto continuous seismic profiles on which stratigraphic thicknesses are based (Fig. 20).

The base of the central study area is represented by the Late Ordovician black shales of the bituminous shale facies (core 77-011-8). One thousand metres up sequence is the Late Ordovician fine sandstone and siltstone from a coastal or bank environment (core 77-009-24-A). Above this is the fissile siltstone which developed under normal marine shelf conditions in Middle Silurian (Wenlockian) time (core 77-011-11). Soon after (but still in Wenlockian time) black shales were deposited in a bituminous shale facies (core 77-011-8). By ?Late Silurian time, conditions were back to a normal shelf (storm influenced) environment represented by the siltstones in core 75-009-25. Considerably further (1,000 m) up sequence are the red sandstones of ?terrestrial origin and above these are the red siltstones. These two

	Central Study Area	Southern Study Area
Devonian ?	#3 Terrestrial ?	
	#2 Terrestrial ?	
	#25 Normal Shelf (storm influenced)	
Silurian	#7 Restricted Shelf	#22 Normal Shelf
	#11 Normal Shelf (storm influenced)	#23-B Normal Shelf (storm influenced)
	#24-A Bank or Coastal	
Late Ordovician	#8 Restricted Shelf	
Early and Lower Ordovician	Coastal (Wabana)	#32 Restricted Shelf
Cambrian	? Coastal (Bell Island)	

Figure 19

Depositional environments through time in the central and southern study areas showing possible corralitives.

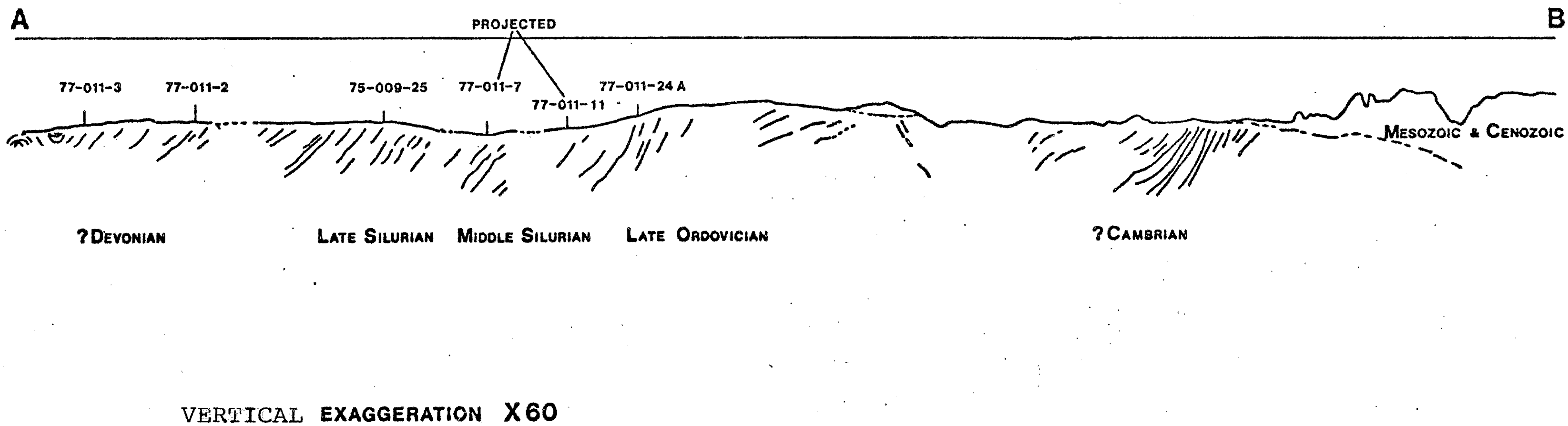


Figure 20.

Line drawing of profile A--B (see Fig. 1.) as interpreted from air gun seismic record, showing core locations (including those projected from north of the line) and ages. Cambrian rocks have not been sampled from the offshore succession however this profile illustrates the presence of sediments probably of this age. The great thickness of rock above the Late Silurian sample suggests a Devonian age for samples 77-011-2 and 3. (after King, <u>et al</u>, in preparation) samples at the top of the sequence are probably Devonian in age and prossibly represent a general shallowing (?basin filling) and emergence (?uplift) of the area.

Thus, the stratigraphic column of the central study area shows considerable facies variation through time with little apparent pattern to the sequence mainly because of the sparsity of the column.

Several indirect climatic indicators are present in this succession. Large and thick basinal shale accumulations usually develop in humid climates where prolific drainage systems can provide a basin with abundant source material (Potter _et al_, 1980).

The fine sandstone and siltstone of core 75-009-24-A probably contains the best climatic indicator in the succession. As noted earlier, chamosite occurrences in recent sediments are confined to warm (25° to 27°) marine waters and within ten degrees latitude of the equator.

A tropical or subtropical environment is further substantiated by the Ordovician Pangaeic reconstruction of Boucot and Gray (1979) based on lithofacies and biogeographic data.

The Devonian (?) redbeds at the top of the sequence are good indicators of a climatic regime which results in the production of abundant hematite. Today, this does not occur to any extent in cold climates, however, redbeds are common in warm environments. The Pangaeic reconstruction for Lower Devonian time (Boucot and Gray) shows this area in mid-latitudes and Morel and Irving (1978) place the Newfoundland area in 20^{o}S latitudes. Both these are consistent with the indications from the redbeds.

In summary, although these rocks lend little conclusive evidence of climatic conditions, additional evidence further suggests that this Lower Paleozoic sequence developed in a warm, humid climate in tropic to mid-latitudes throughout the depositional period.

The stratigraphic sequence in the southern study area begins in Early Ordovician time with black shales that probably developed as a restricted marine shale facies. Although this is the lowermost sample in the sequence, seismic records indicate that the sequence continues at least 2,000 m below this sample point but a Mesozoic-Cenozoic cover prevented sampling. The sequence could conceivably continue down to the Cambrian. The next sample up sequence is the ?Silurian (core 77-011-23-B) grey siltstones deposited in a storm dominated marine shelf facies. The Silurian siltstones about 400 m up sequence are a part of a normal shelf facies that was probably current dominated. As in the sequence from the central study area, samples are too sparce to build a complete geologic history.

King *et*. *al*. (in preparation) have estimated the total thickness of this succession at approximately 8,000 m. Bedrock dip is usually 1° to 3° and most structural features are very broad. It is not clear from studies to date whether the 8,000 m of sediment were deposited in a vertical sense, or in a very gently sloping progradational sense. The former requires a basin considerably deeper than the latter. A basin 8,000 m deep is certainly a possibility however the presence of Precambrian basement on the Avalon Peninsula and the shallowing of identical rocks in the vicinity of the Virgin Rocks and Eastern Shoals (King *et* *al*) could be an indication that the total vertical thickness of the Lower Paleozoic succession is less than the strategraphic thickness.

REGIONAL CONSIDERATIONS

INTRODUCTION

This Cambro-Silurian (?Devonian) succession is seen from seismic control to be continuous over a vast area (approximately 15,000 sq.km), representing a much more expansive and thicker section of shallow marine sediments than is present as spotty deposits on the Avalon Peninsula, Nova Scotia, and New Brunswick. It is an integral part and in fact the main body of the Avalon Platformal sediments. Correlations between the offshore section and the much better understood land geology help establish the extent of various facies through time and enhance the picture of the geologic history of the Canadian Avalon platformal sediments.

REGIONAL CORRELATIONS

Cambrian

Cambrian strata of the Avalon Platform are mainly shales with minor sandstones and limestones (Poole et. al., 1970). This dominance of shales is a prominent feature of the offshore sequence as well. The land sequences are mainly of shallow water marine deposition similar to the offshore succession as interpreted here.

Cambrian strata of the Avalon Platform are confined to Precambrian graben and synclinoria and are usually simply folded or broken by normal faults (Poole et al, 1970). Cambrian sediments in eastern Newfoundland are thickest in the Trinity Bay area where over 1,200 m of shales and minor limestones of the Elliots Cove Group were deposited. This sequence comprises alternating red and green shales and minor limestone, locally important manganese beds, grey and black shales and siltstones and very minor volcanics. Similarly, in Cape Breton Lower Cambrian grey, green, and red shales and siltstones of the Codrum and Canoe Brook Formations were deposited in a shallow marine environment. In Southern New Brunswick over 300 m of dark grey and black shales with minor sandstone and limestone make up the St. John Group.

None of the core samples in this study are of Cambrian age, however, reflection seismic profiles illustrate that the sequence continues down section to the east but could not be sampled because of a considerable thickness of Mesozoic-Cenozoic cover (Fig. 10).

Because the offshore section is known from seismostratigraphic relations alone, no lithologic correlations can be made with the land geology.

Ordovician

Tremadocian grey and black shales of the Clarenville Formation conformably overlie Upper Cambrian shales and minor limestones of the Elliots Cove Group at Trinity Bay (Poole, et al, 1970). These Tremadocian rocks are located on the west side of the Avalon platform, west of Trinity Bay, however, to the east, in Conception Bay, 600 to 900 m of Clarenville shale is believed to underlie the Tremadocian and Arenigian strata on the islands of the bay (Poole, 1970).

On Cape Breton Island, 400 m of grey shale with graptolites were deposited during the Tremadocian and Arenigian. (Poole et al, 1970) Similarly at Saint John, a 30 m sequence of thinly bedded black shales containing Tremadocian graptolites overlies similar Upper Cambrian rocks and is succeeded by black graptolitic shales of Arenigian age. At the same time (Arenigian) black shales were deposited in the offshore section immediately south of the Avalon Peninsula (core 77-011-32). These newly recognized black shales in the offshore section lend further to the striking fact that the Avalon Platformal sediments of Early Ordovician age are unfailingly black or grey shales.

In the Conception Bay area this widespread restricted environment passed upward into a more normal (oxidizing) environment in Arenigian time while restricted conditions still remained to the south and in Cape Breton and New Brunswick. There is no record to indicate when restricted conditions terminated in these latter areas.

The Bell Island Group overlies the Clarenville shales in Conception Bay, forming three islands comprised of 1,000 m of grey, brown and greenish micaceous sandstone, siltstones and shales with minor hematite beds. The conformably overlying Arenigian Wabana Group has been studied in detail by Hayes (1915). The sequence consists of approximately 300 m of grey, brown and greenish shales, siltstones and micaceous sandstones. These rocks are of interest because of the oolitic hematite and chamosite beds which have been mined quite extensively. A shallow water and coastal environment of deposition for the Wabana Group is indicated by numerous features such as cross bedding, ripples, mudcracks, oolites and presence of chamosite, hematite and siderite. This section coincides with a poorly sampled area of the offshore above core 77-011-32, so it is not known if a similar environment extended offshore.

Middle to Late Ordovician

Middle to Late Ordovician rocks are not well known on the land areas of the Avalon Platform with the possible exception of the Browns Mountain Group of northern mainland Nova Scotia (Poole *et al*, 1970). (Their age has been a subject of controversy and it is possible that these rocks are of Precambrian age (Keppie, 1978).) Provided they are of Ordovician age they are of particular significance because they contain oolitic beds and *Lingula* both of which are good shallow water indicators (Williams, 1914).

Of the Middle to Late Ordovician samples in the offshore section, the lowermost is a black shale (core 77-

011-8). Nothing is known of the spatial or temporal extent of this restricted facies. The uppermost sample of Late Ordovician age, (core 75-009-24-A) is representative of a sub-littoral environment. It is of interest to note its environmental similarities with the Iron Formation of the Browns Mountain Group, especially with respect to the oolite occurrences. Actual lithologies are not correlatable however physio-chemical conditions must have been similar. This may be indicative of similar environments.

Silurian

Avalon platformal sediments of Silurian age have not been recognized in Newfoundland, however, the Arisag Group on the north shore of Nova Scotia is a thick, complete Silurian to Lower Devonian sequence mainly of shales deposited disconformably on Ordovician rocks. Studies on these rocks (Cant, 1979) have shown that much of the section was deposited in storm dominated shallow marine environments. Cant interpreted considerable lithologic variations as being the result of different water depths and energy levels within shallow marine environments that graded between storm, current and tide dominated facies.

The only other Avalon Platformal rocks of Silurian age make up the Middle River Group which occurs in eastern cape Breton. The Group consists of sandstones and conglomerates which were deposited unconformably on Cambrian rocks.

Worth noting are the Silurian paralic slates, quartz arenites, paraconglomerates and volcanics of the White Rock and Kentville Formations overlying the Cambro-Lower Ordovician Meguma Group. The significance of these occurrences to the regional correlations is to some degree uncertain because the Meguma platform has been transported and does not necessarily have Avalonian affinities.

Most of the Silurian cores (77-011-11, 77-011-23, 77-011-22) in the offshore section indicate storm or current dominated facies of a normal shelf environment. This environment shows certain similarities to the shallow water storm dominated environments recognized by Cant (1979) in the Arisig rocks.

A black shale (core 77-011-7) appears to occur stratigraphically between the other Silurian samples and thus represents a restricted environment of limited temporal extent and unknown regional distribution. The fact that a restricted environment was encountered three times over a time span from Early Ordovician to Middle Silurian is indicative of a cyclical pattern of normal to restricted environments in the study area. Because three different successions were encountered in a sparcely sampled section, the probability is high that it is even more repetitive than the present facts indicate. Similar environmental distributions occur in the widespread epiric sea of the Jurassic in Europe (Morris, 1977).

Devonian

Rocks of Devonian age on land areas of the Avalon Platform are only known in Nova Scotia. Lower to Middle Devonian strata occur in Arisag, as a continuation of the Silurian sequence. These include marine siltstone, shale, slate, sandstone and minor limestone of the Stonehouse Formation succeeded by fluviatile and deltaic red and green sandstone, siltstone and shale of the Knoydart Formation and a thick sequence of fluviatile sediments of the River John Group.

In Southeastern Cape Breton, Middle Devonian conglomerates, sandstones, shale and tuff of the McAdam Lake Formation overlie rocks of probably Ordovician age, which in turn rest on Cambrian strata. The McAdam Lake rocks are all of fluviatile origin. In southern Nova Scotia Ludlowian rocks of the Kentville Formation are conformably overlain by slates, siltstones, quartzites and limestones of the Lower Devonian Torbrook Formation. These are believed to represent normal shallow water conditions of deposition, however, associated iron formation beds are probably nearshore deposits. These Early Devonian strata of Nova Scotia generally reflect a change from marine to terrestrial condition of deposition and this pattern appears to have occurred in the offshore section as well.

The redbeds sampled in the offshore succession are thought to be of terrestrial origin. As discussed earlier, although these cores were barren of diagnostic fossils for age dating, seismic data show a thick sequence of conformable relations well above the position of the youngest dated core (Silurian) so the redbeds are inferred to be of Devonian age. These strata are confined to an area along the north-south oriented synclinal axis (Fig. 20).

REGIONAL ENVIRONMENT -- MARGINAL OR EPEIRIC SEA?

This study has illustrated the extensive distribution of the Avalon Platformal sediments and the shallow marine aspect of deposition which persisted from Cambrian to Silurian time. An understanding of the local character of the rock and its environment of deposition does not entirely fulfill the criteria necessary to distinguish whether the large scale regional environment was similar to a typical modern continental shelf or an epeiric sea on a stable craton. Such a study requires a view of the broad extent of the platformal sediments.

A discussion of lithologic and environmental correlatives in Atlantic Canada has illustrated the regional aspect of the succession. Just as the Atlantic Canada corelatives do not always represent continuation of actual lithologies and facies, oversea correlations are noted simply to illustrate the great extent of rocks of this platformal nature. The extensive offshore succession on the Grand Banks helps tie together the otherwise spotty occurrences of the Avalon platformal sediments in Atlantic Canada and helps attach a greater significance to their presence, especially in terms of overseas correlations. The offshore sequence bounds closely on major structural discontinuities (Glooscap Fault System, Collector Anomoly) and could have very close affinities to the overseas platformal sediments.

Several authors including Rast (1976, 1980) have established reasonable correlations of the Avalonian Precambrian rocks and their platformal sediments with sections in Massachusetts, Wales and the English Midlands. Similarities with the Precambrian and Lower Paleozoic sequence of the Moroccan Meseta in Northwest Africa suggest that this may also belong to the same continental block (Piqué, 1981). Continuities are recognized between the Moroccan rocks and those in Eastern Spain and Brittany and these rocks possibly delineate the eastern margin of the Avalonian rocks (Piqué, 1981).

Lower Paleozoic continental reconstructions indicate that the Avalonian craton would have been expansive with a length exceeding 4,000 km and up to 1,500 km wide. If one can assume shallow marine sedimentation over much of this area than there is a strong indication that a large epeiric sea was located on the Avalon craton. The possibility of a deep intra-cratonic trough does not negate the concept of an expansive, albeit dicontinuous epeiric sea. A further argument for epeiric sea deposition is the stability of the platform through time. A craton can also provide a stable environment which is far from zones of greater tectonic activity near plate margins. This would help explain how much of the section escaped serious deformation.

One of the more striking aspects of the Avalon platformal sediments was the widespread anoxic environment represented by the black and grey shales of the Cambrian. It is difficult to envisage widespread and relatively long lived restricted conditions on a continental shelf open to oceanic ciruclation. Widespread black shales of shallow marine origin are not common in the geologic record. One analogue is the bituminous shale facies that developed over large areas of the European northwest epeiric basin in Jurassic times. These deposits developed as a result of restricted circulation, causing oxygen depletion in tranquil basins.

Although none of the above arguments provide definitive evidence in support of the argument for an epeiric sea, they nevertheless favour such a view.

CONCLUSION

Limits set by the size and number of samples from this Lower Paleozoic succession put constraints on the type of conclusions which can be drawn from this study. The inferences on depositional environments are not made solely on the basis of observations from individual samples but rather in light of a consideration of the regional setting and the seismo-stratigraphic control. Conclusions regarding paleoenvironments are based on interpretation and as such are subject to change pending the acquisition of more data.

The Summary of Interpretations deals with conclusions for individual cores and will not be repeated here except to note that a range of lithologies does occur, all of which (except for the redbeds) are compatable with deposition under shallow marine conditions.

In summary, the study of ten bedrock cores from the offshore area and continuous seismic profiles show that generally conformable deposition of shallow marine sediments (mainly siltstones) occurred over an area greater than 15,000 sq km from Early Ordovician to Late Silurian time and probably well before this (as rocks of probable Cambrian age are seen on the seismic profiles).

In Early Ordovician time it is probable that restricted shallow marine conditions prevailed over a vast area. Late Ordovician and Silurian siltstones have evidence of deposition in more dynamic and well oxygenated conditions and probably represent a predominance of a normal shallow marine environment. Some degree of cycling between normal marine and restricted circulation conditions may have occurred. Redbeds of probable Devonian age are interpreted to be of terrestrial origin and as such further substantiate the trend to terrestrial conditions noted on the land succession. A few climatic indicators in these rocks give indication of a warm, humid climate, compatible with paleomagnetic findings.

Correlations between the offshore succession and the Avalon platformal sediments on land (in Atlantic Canada) indicate that general trends in depositional environments through time are similar in the offshore and land geology.

The question of whether the succession was deposited in a marginal or epeiric sea is addressed because it is of considerable significance to the tectonic history of the area, especially as the extent of the Avalon platformal sediments is greater than previously recognized.

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APPENDIX I

CLASSIFICATION OF TRACE FOSSILS

Ichnological classification concepts (Simpson, 1975) are based on the fact that trace fossils are:
1. sedimentary structures; 2. traces of organic activity; and 3. the produce of specific organisms. Three separate classifications apply to these three aspects. The first which is concerned with sedimentary structures is essentially morphological. It is the Toponomic classification, desribing mode of preservation. The second, which is concerned with traces of activity by organisms is the Ethological or behavioral classification. The third classification uses the normal biological nomenclature to distinguish phylogenies of trace fossils (Taxonomic).

Mode of Preservation

Seilacher (1964) classified trace fossils as relief figures. He distinguished full reliefs, semi-reliefs and cleavage reliefs with endogene and exogene forms and top (expigene) and bottom (hypogene) forms. Definitions of these terms are shown in Table 2, and figure 2 illustrates schematic examples. Processes such as "stuffing" a part of a tunnel with waste materials, "mining" for nutrient rich soil, and sediment sorting are incorporated into this

Table 2

Classification of Trace Fossils (Seilacher, 1964)

1. Full relief: bioturbation structure preserved within a stratum.

2. Semirelief: bioturbation structure preserved at a lithological interface: boundary reliefs and cleavage reliefs.

   A. Boundary relief: semirelief not involving cleavage preservation: hyporeliefs and epireliefs.

      (1) Hyporelief: boundary relief occuring on the sole of a stratum; relief may be concave or convex.

      (2) Epirelief: boundary relief occurring at the top of a stratum; relief may be concave or convex.

   B. Cleavage relief: semirelief in which subsurface laminae are deformed during production of the surficial trace; parting of these laminae (as by weathering fissility) reveals vertical repetition of a given lebensspur, any isolated specimen of which resembles a single boundary relief.

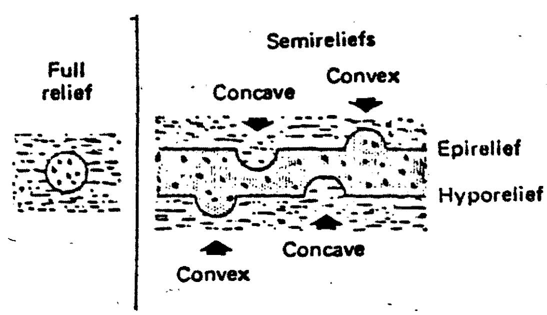


Figure 2

Classification of Trace fossils as relief features
(adapted from Seilacher, 1964)

classification. Various diagenetic processes and complete bed restructuring as a result of biogenic activity are also placed under the heading "mode of preservation".

Behavioral Activity

An ethotogical classification describing simple behaviorial activities is the most popular system of trace fossil classification (Seilacher, 1964 b). Seilacher distinguished five categories which are based on interpreted activities of the producing organism. (see figure 3)

1. Resting Trace - imprints on a soft substrate that reflect the weight distribution and outline of a temporarily resting organism.
2. Crawling Trace - Tracks and trails with signs of mode of locomotion.
3. Grazing Trace - Patterns on or within the substrate left by benthic organisms in search of food in the sediment.
4. Feeding Trace - Temporary burrows or other traces of deposit feeders which may form complex patterns as they mine the sediment. Patterns may be radial, spiral, branching or "U"-shaped.
5. Dwelling Structures - Permanent or semi-permanent burrows dug as dwelling places for benthonic organisms. They are predominantly cylindrical with lined walls for additional strength.

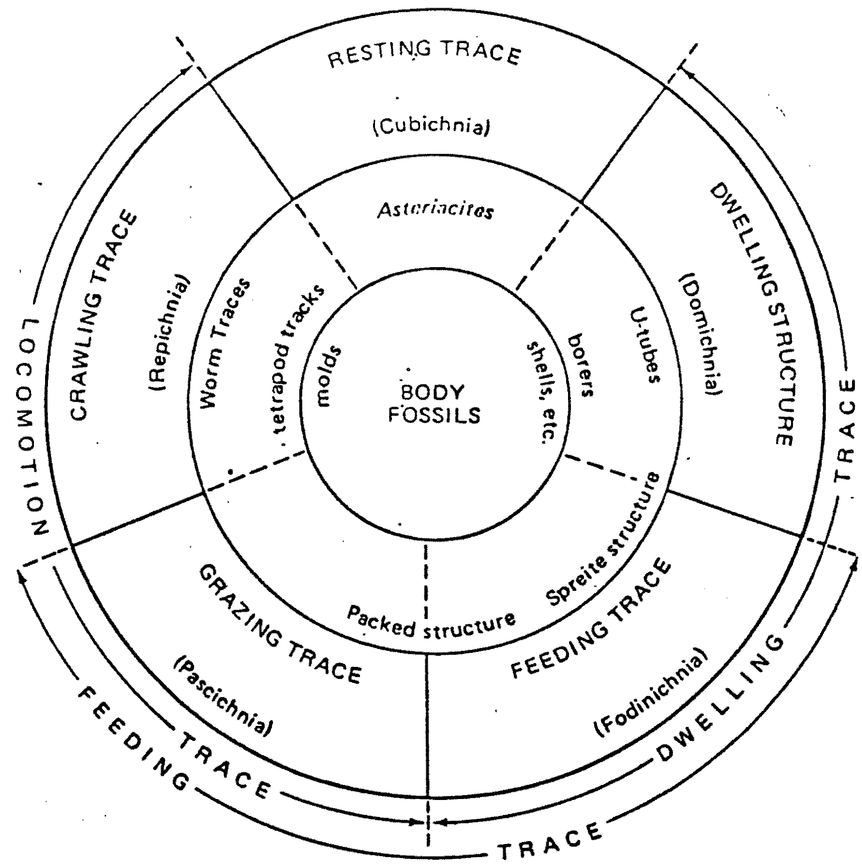


Figure 3

Ethotogical Classification of trace fossils showing five main behavioral activities, their relation to one another and to body fossils. See description in text. (from Seilacher, 1964).

Taxonomic Classification

Historically, trace fossils were named according to the classical Linnean binomial system because they were believed to be body fossils. As the true nature of trace fossils was discovered, the formal procedures of botanical or zoological nomenclature were applied rather loosely. The tendency in ichnology is to define ichnogenus and ichonspecies. The ichonogenus usually reflects a characteristic behavior pattern and the species, a less striking morphological trait.

Degree of Bioturbation

The amount of bioturbation that a sediment has undergone is dependant on the rate of sedimentation and the density of the organisms and their diversity. The degree of bioturbation may give an insight into the conditions of sedimentation. Reineck (1963) used a scheme whereby the amount of bioturbation is quantified, in percentage terms, according to the degree of destruction of primary sedimentary structures. This is illustrated in Table 3.

Table 3

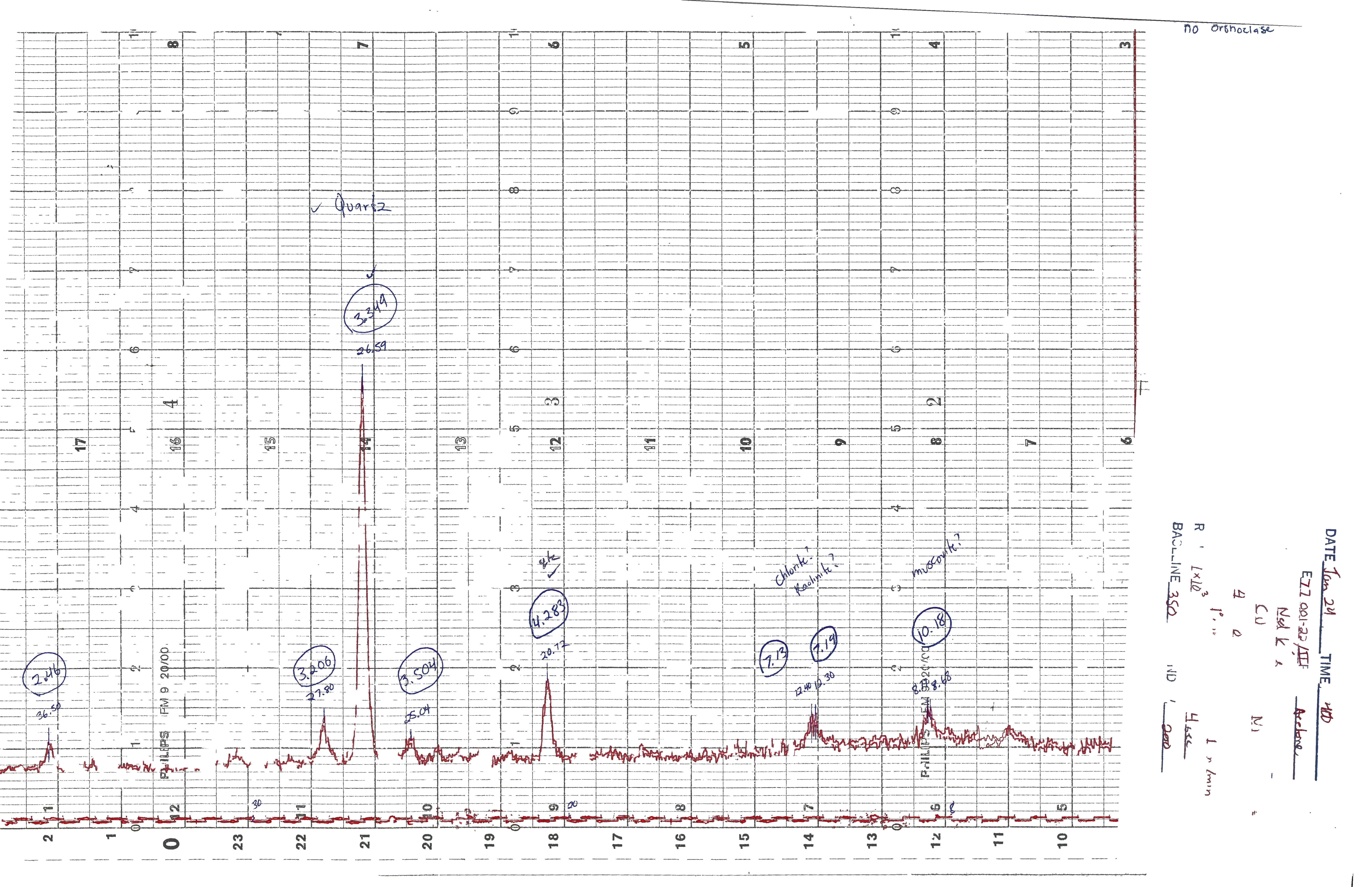
Grade	Degree of bioturbation (%)	Classification of bioturbation
0	0	No bioturbation
1	1– 5	Sporadic bioturbation traces
2	5–30	Weakly bioturbated
3	30–60	Medium bioturbated
4	60–90	Strongly bioturbated
5	90–99	Very strongly bioturbated, but rest of inorganic bedding still recognizable
6	100	Completely bioturbated

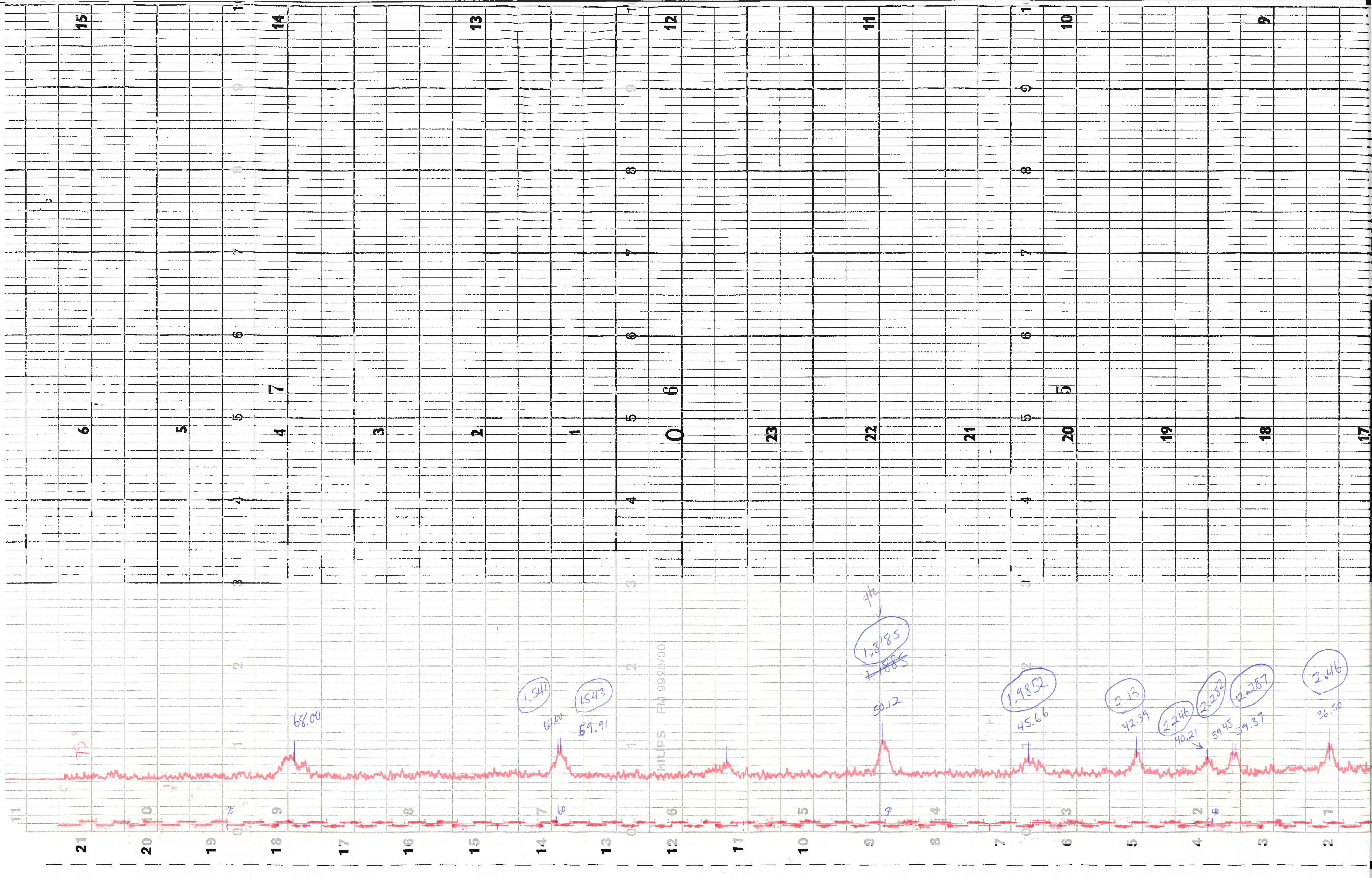
Classification of bioturbation depending on primary bedding destruction (Reineck, 1963)

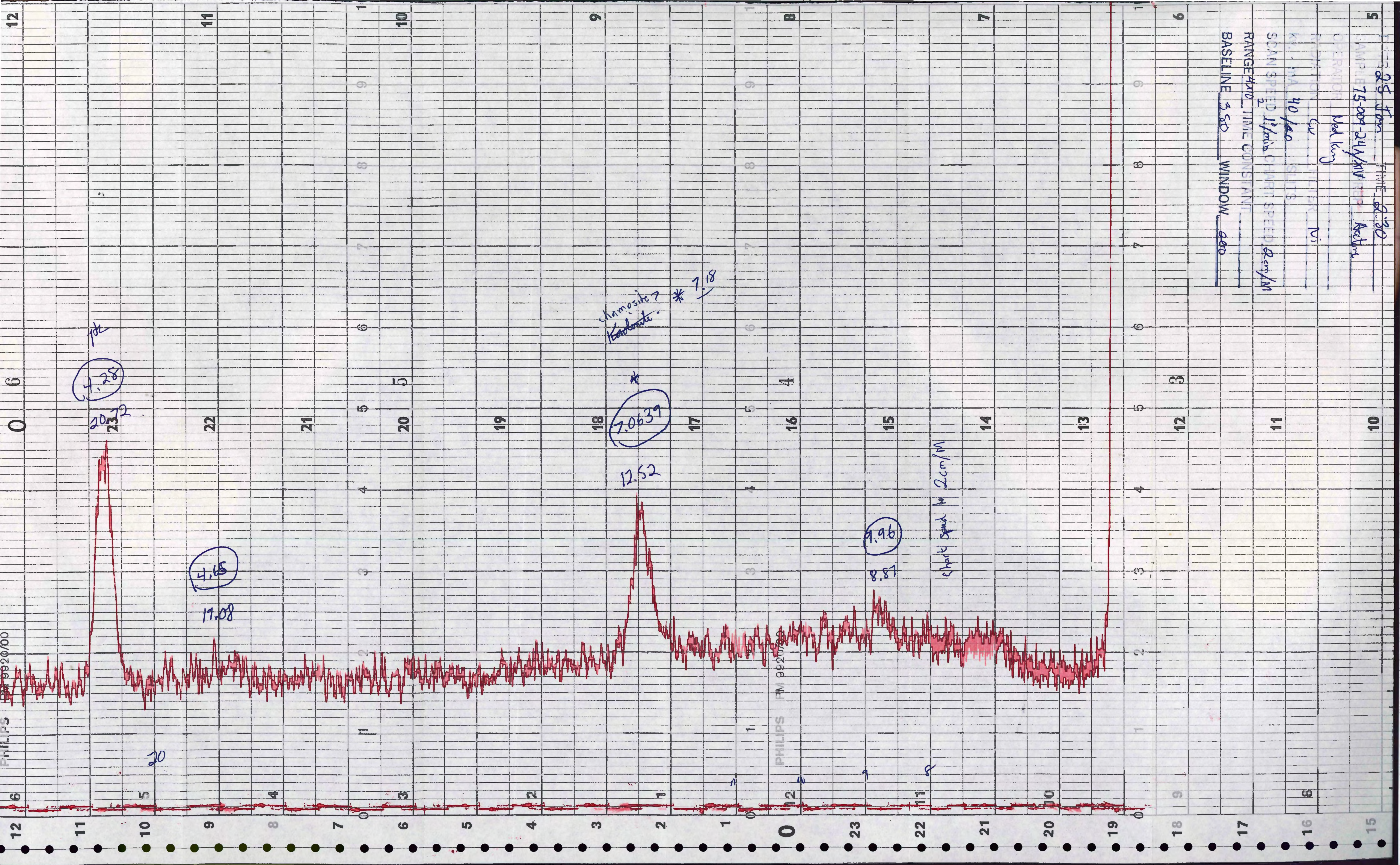
APPENDIX 2

X-RAY DIFFRACTION SPECTRAL PLOTS

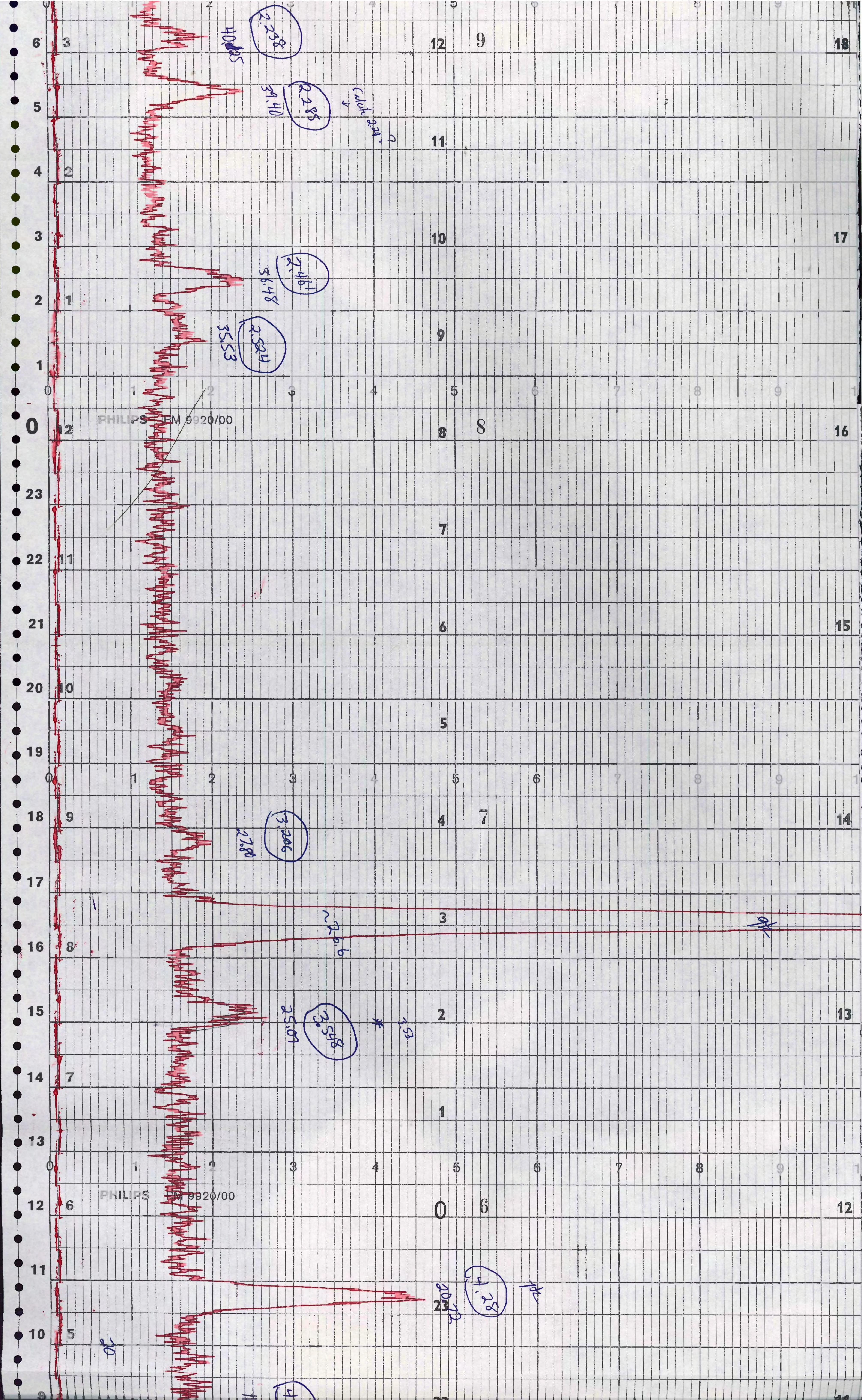
Whole rock analysis was performed on each sample after grinding to a powder (in acetone) with a mortar and pestle and allowed to dry on a glass slide. This analysis was performed to obtain positive identification of chamosite, siderite, hematite, and muscovite and to check for presence of otherwise unidentified feldspar and clay minerals.

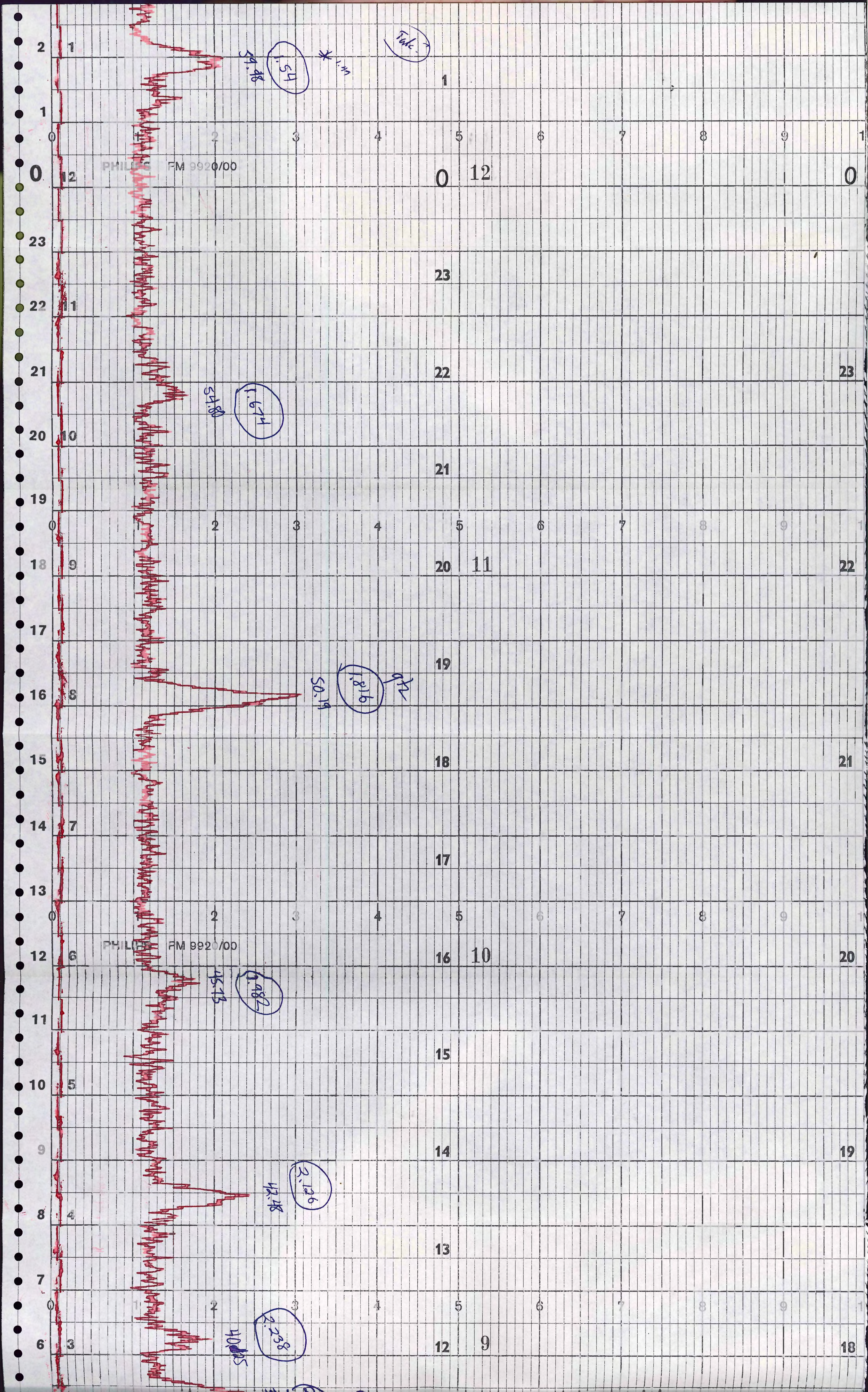

no Orthoclase
Quartz
3.349
26.59
4.283
20.72
3.206
27.80
3.504
25.04
2.46
36.50
7.13
7.19
12.40
12.30
Chlorite?
Kaolinite?
10.18
8.68
muscovite?
PHILIPS
FM 9 20/00
DATE
TIME
BASELINE 350


PHILIPS PM 9920/00
75°
68.00
1.541
60.00
1543
59.91
1.8185
~~1.1885~~
50.12
1.9852
45.66
2.13
42.39
2.246
40.21
2.282
39.45
2.287
39.37
2.46
36.50



PHILIPS
PM 9920/00
TIME 2:30
OPERATOR Ned King
SCAN SPEED 1°/min CHART SPEED 2cm/M
RANGE TIME CONSTANT
BASELINE 3.80 WINDOW 0.00
7.28
20.72
4.65
19.08
chamosite?
~~Kaolinite~~
* 7.18
7.0639
12.52
4.96
8.87
chart speed to 2cm/M


PHILIPS PM 9920/00
2.238
2.283
39.40
2.461
36.48
2.524
35.53
3.206
27.80
3.548
25.07
4.28
20.72
PHILIPS PM 9920/00


PHILIPS PM 9920/00
1.54
59.98
1.674
54.80
1.816
50.19
PHILIPS PM 9920/00
0.982
45.13
3.126
42.48
2.238
40.25

DATE Jan TIME 12:00

SAMPLE 77-011-3/XII PREP Acetone

OPERATOR Ned King

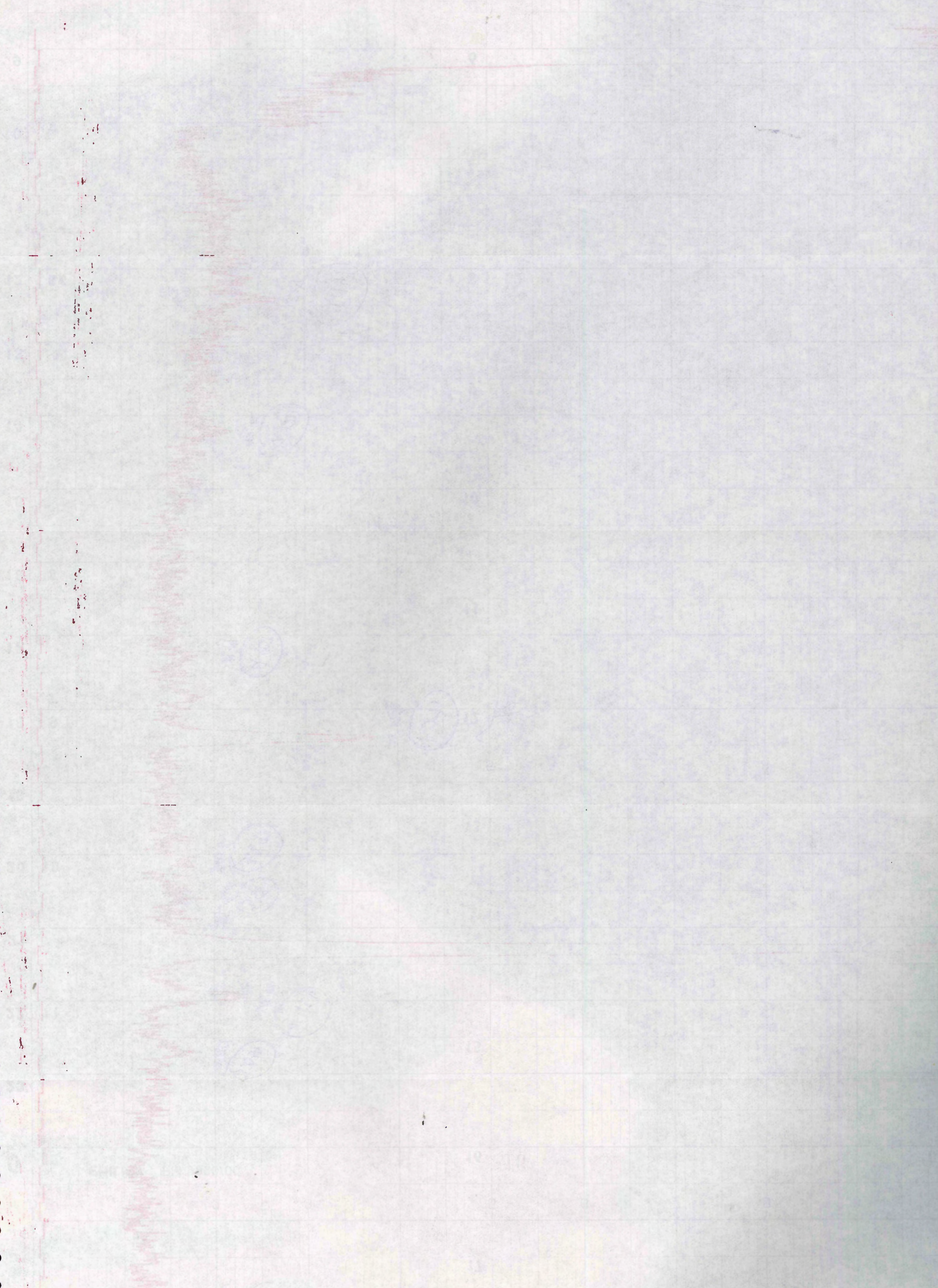
RADIATION Cu FILTER Ni

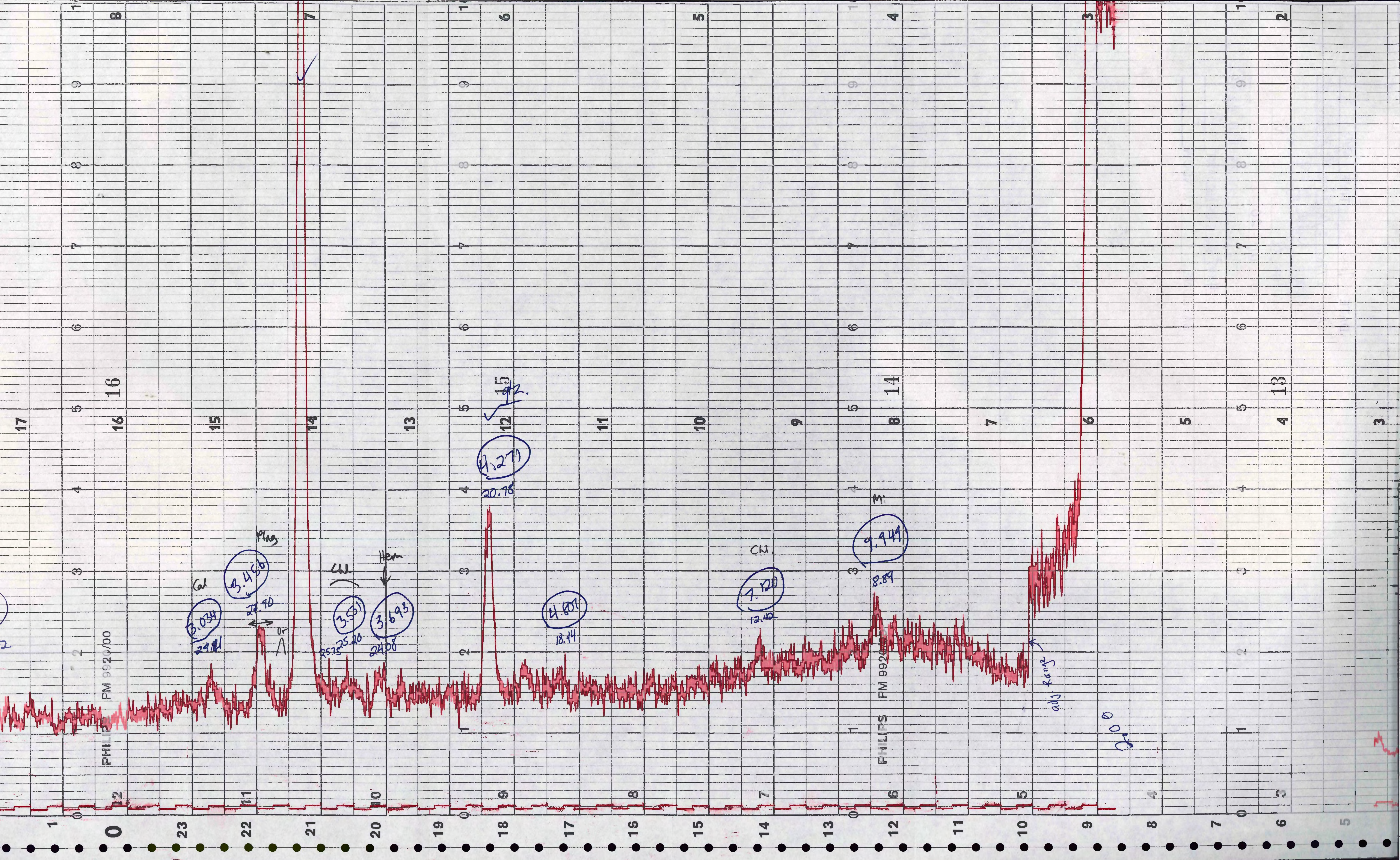
kv. - mA 40 - 20 SLITS

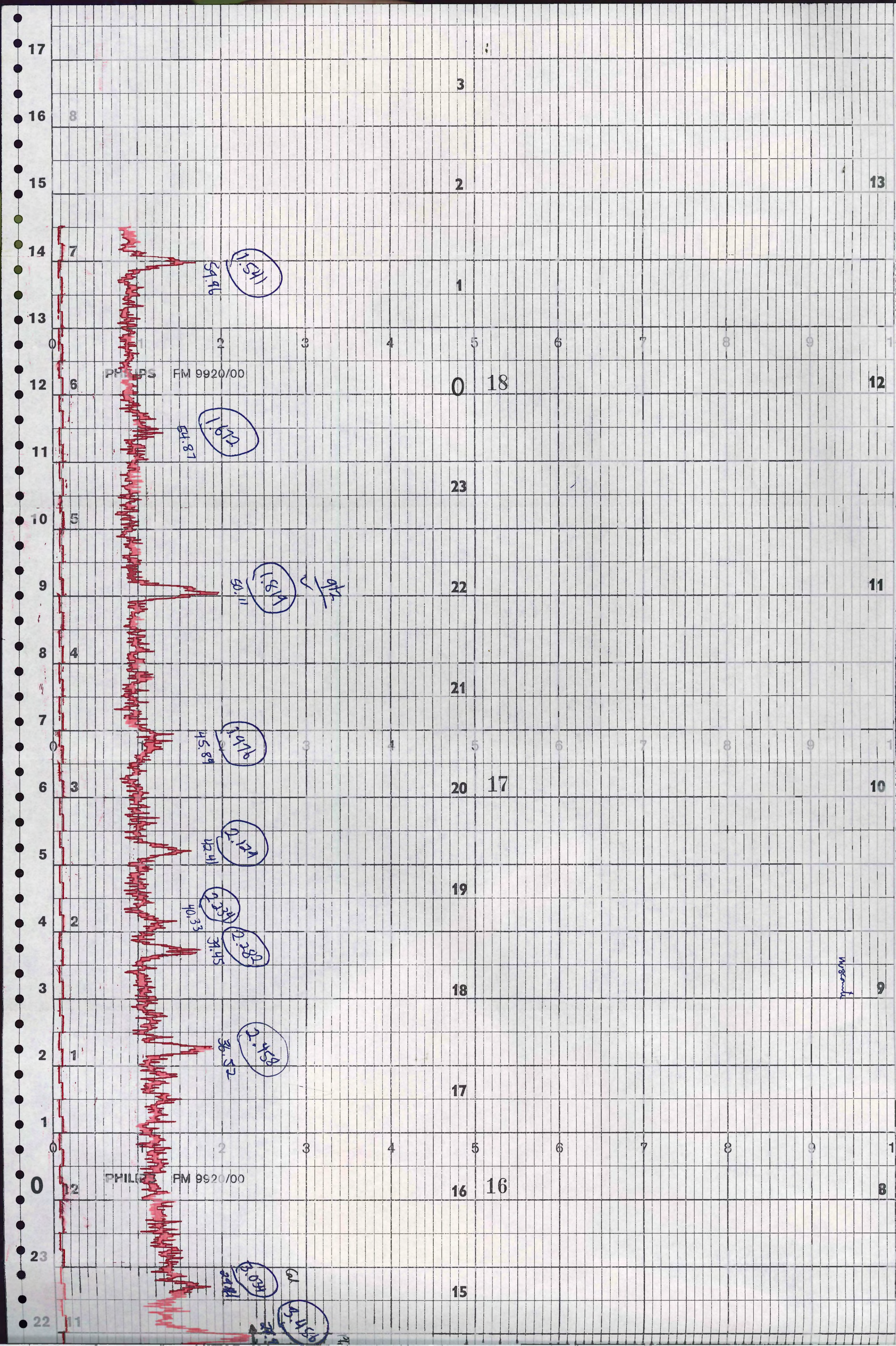
SCAN SPEED CHART SPEED 1 cm/sec

RANGE 4×10^2 TIME CONSTANT

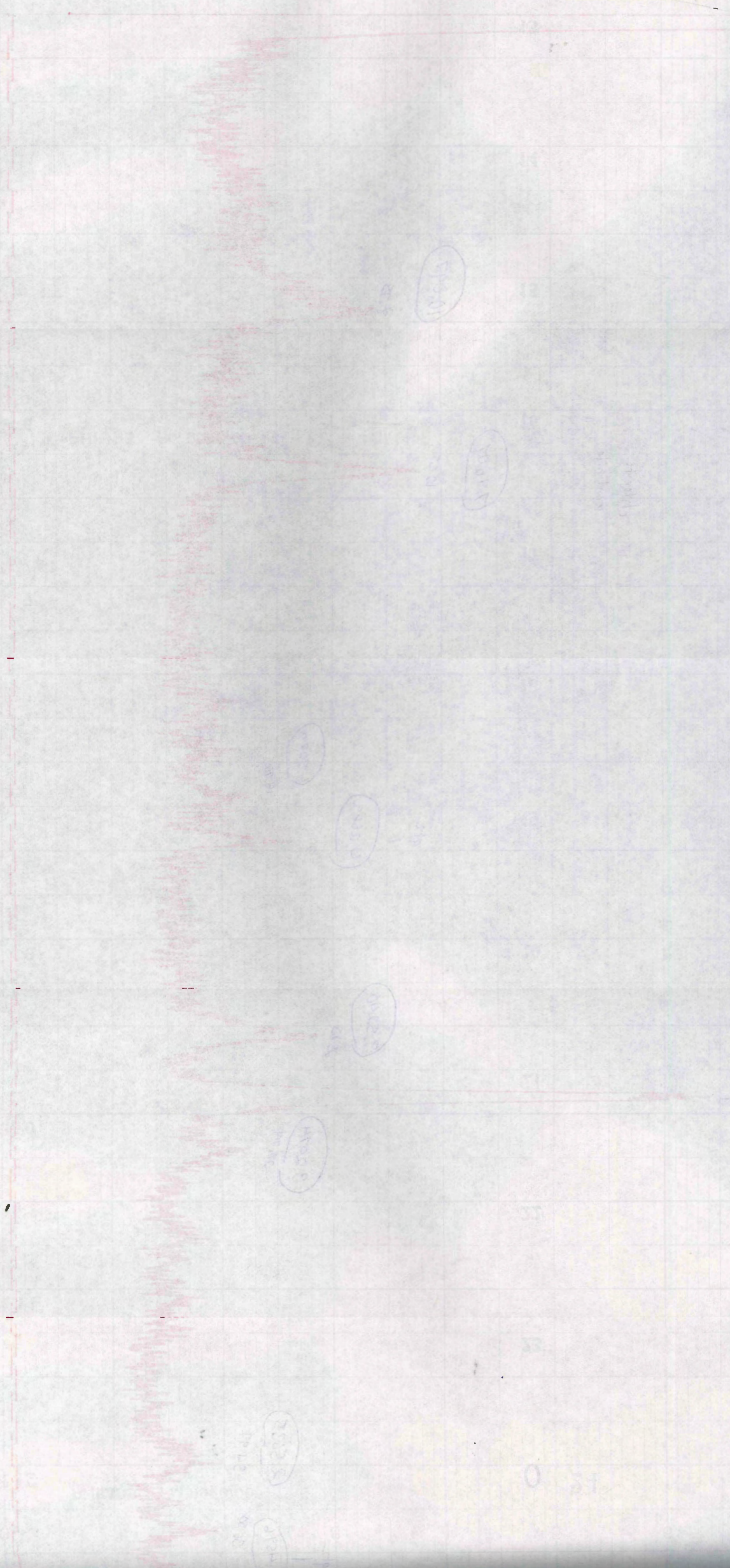
BASELINE WINDOW

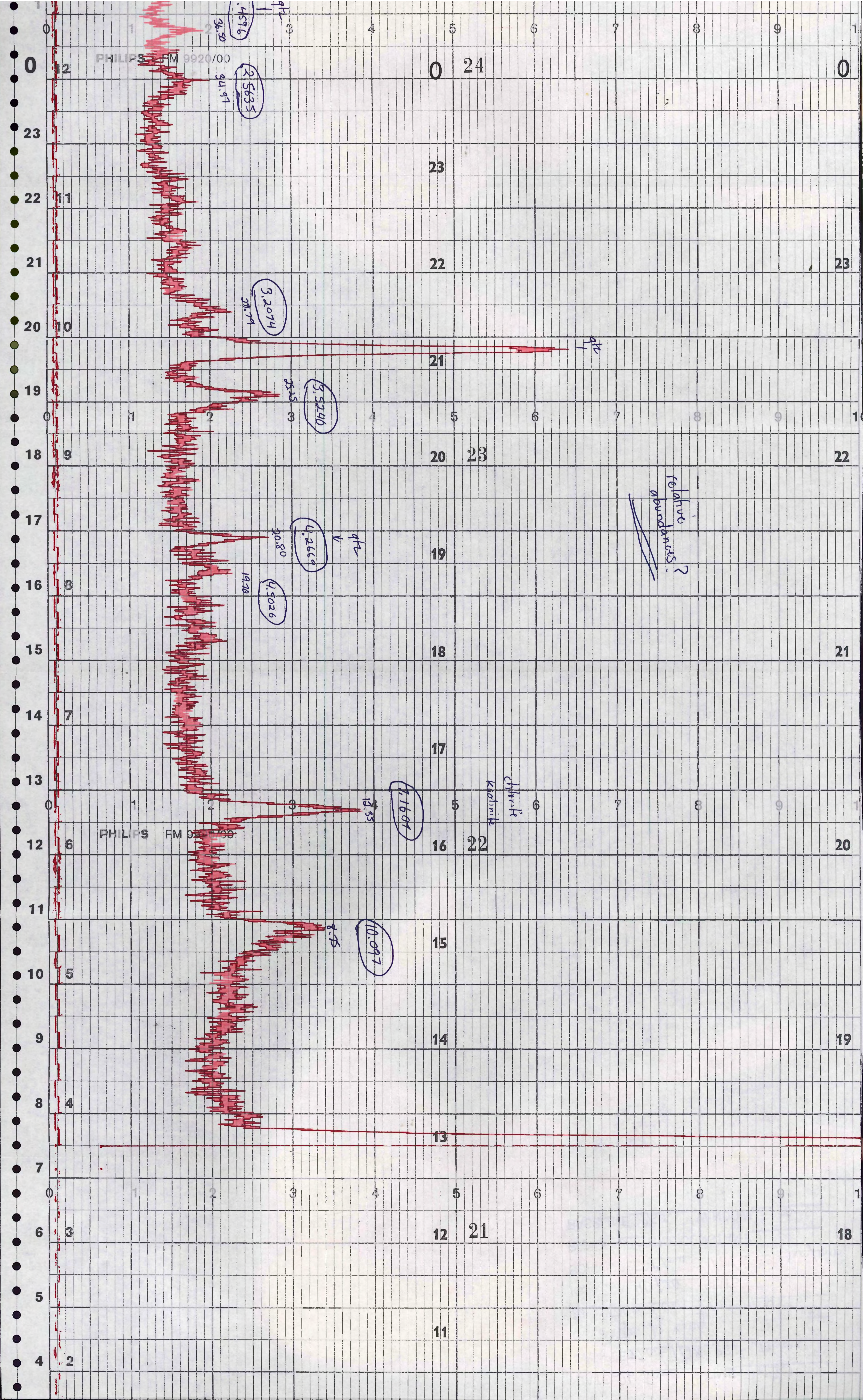


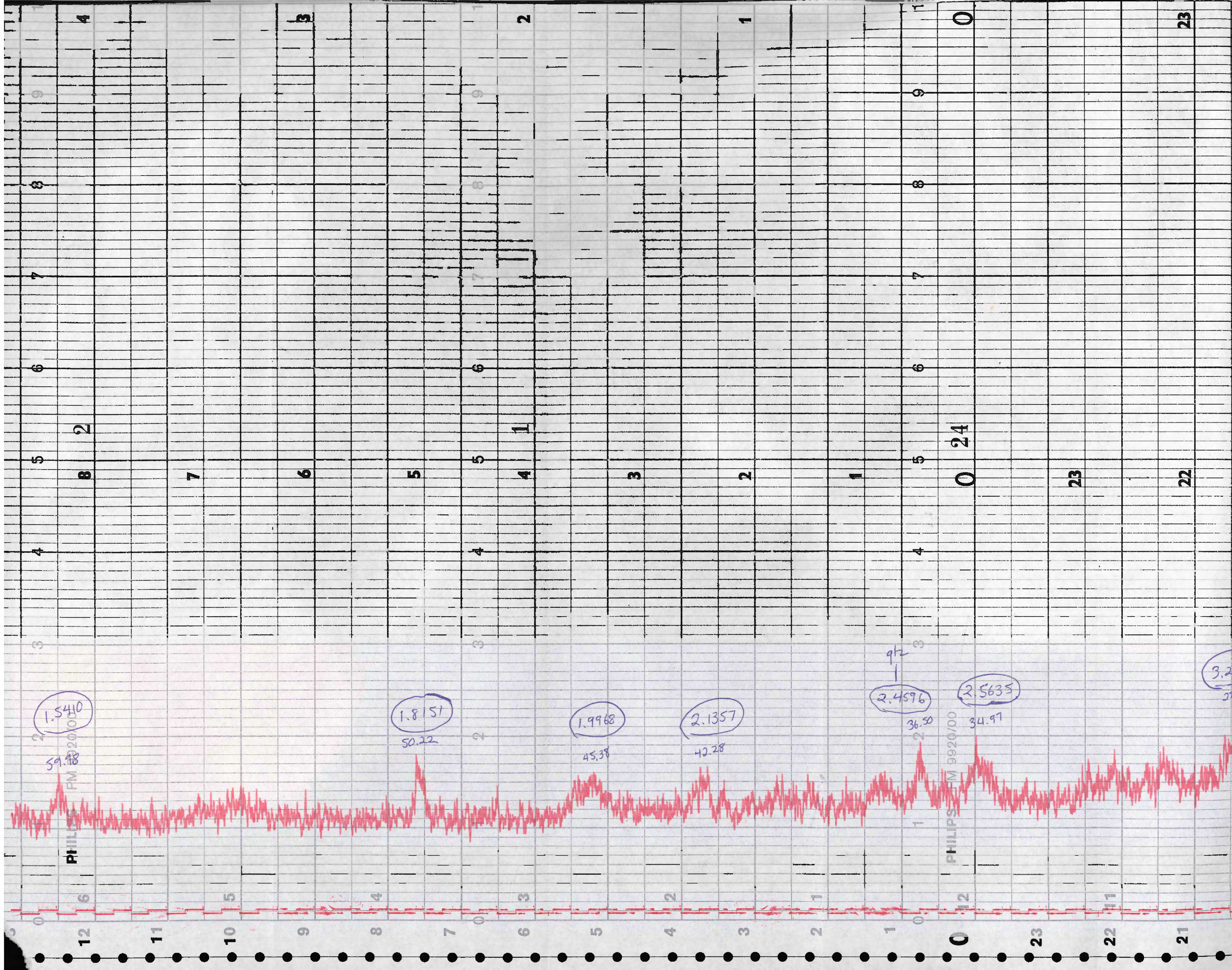

Cal
3.034
Plag
3.456
Or
Chl
3.531
25.20
Hem
3.693
24.08
Qtz.
4.271
20.78
4.807
18.44
Chl.
7.120
12.42
Mi
9.949
8.89
adj range
PHILIPS
PM 9920/00


PHILIPS PM 9920/00
1.541
59.96
1.672
54.87
1.819
50.11
1.976
45.89
2.124
42.41
2.234
40.33
2.282
39.45
2.458
36.52
3.034

DATE 26 Jan TIME 4:30
SAMPLE 77-011-11/IX PREP Acetone
OPERATOR N. King
RADIATION Cu FILTER Ni
kv. - mA 40/20 SLITS
SCAN SPEED 1°/min CHART SPEED 1cm/min
RANGE 4x10^2 TIME CONSTANT
BASELINE 350 WINDOW 200

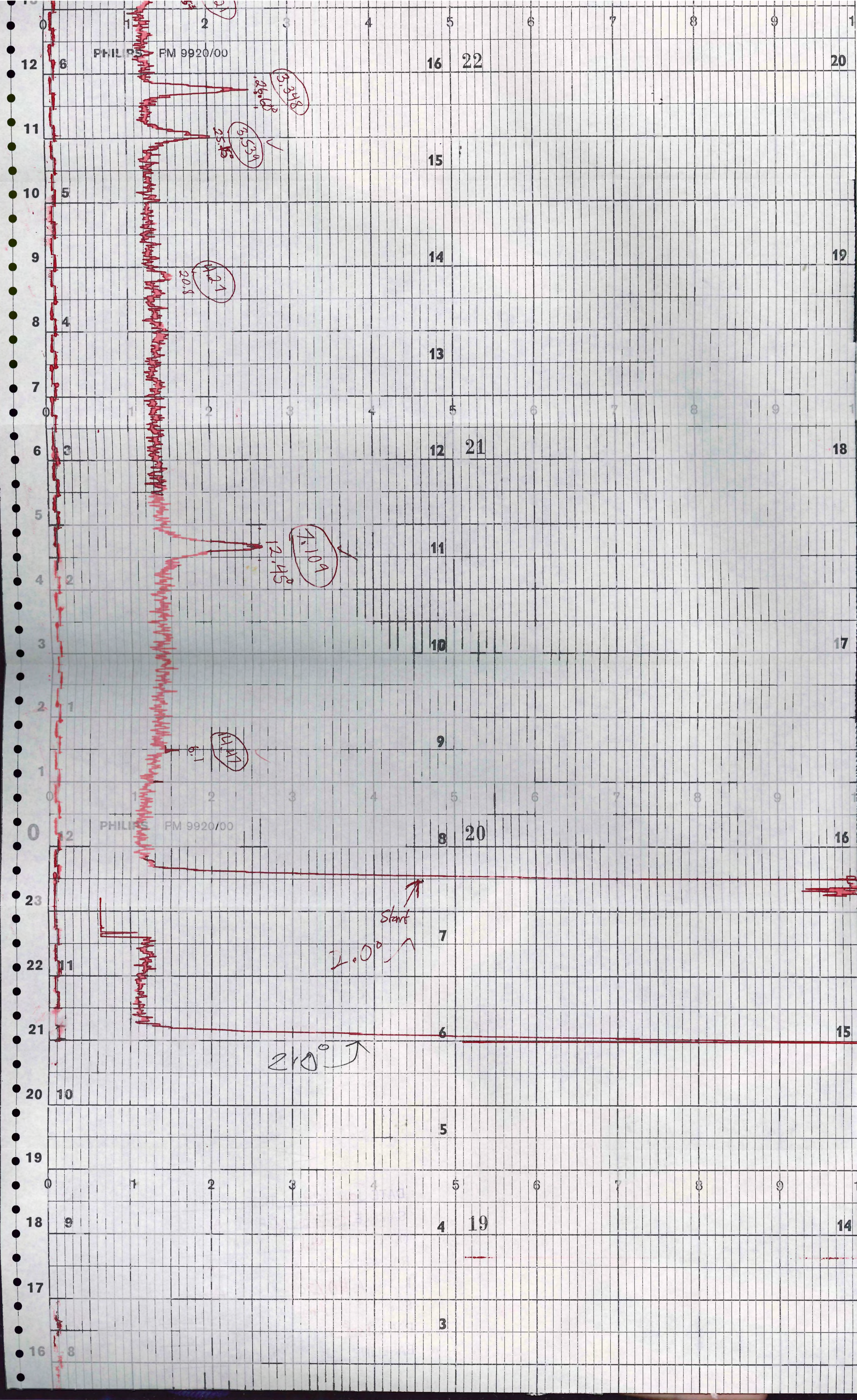


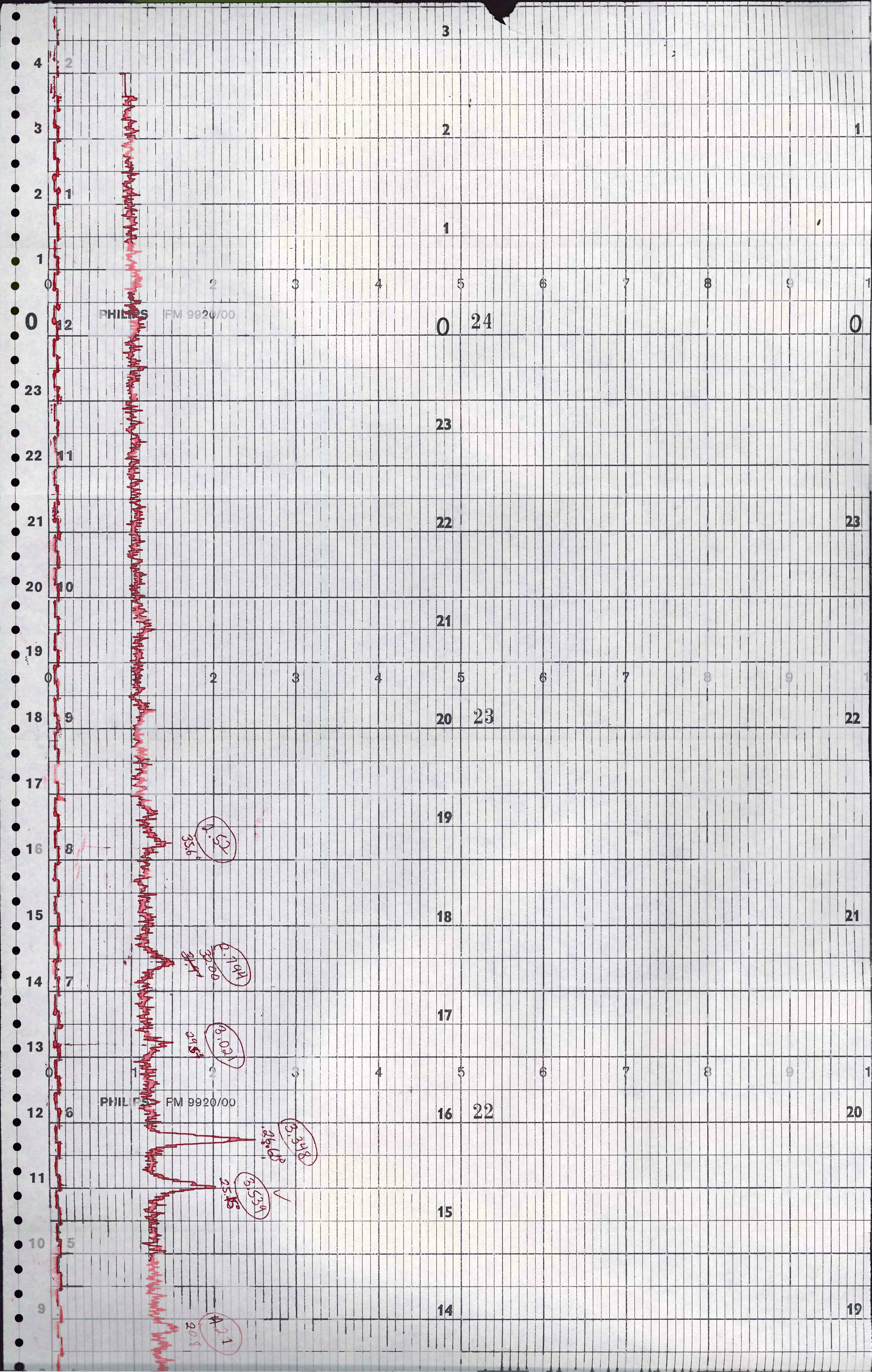

PHILIPS PM 9920/00
qtz
2.5635
3.2074
3.5246
4.2669
4.5026
7.1601
10.097
chlorite
kaolinite
feldspar abundances?


1.5410
59.98
1.8151
50.22
1.9968
45.38
2.1357
42.28
qtz
2.4596
36.50
2.5635
34.97
PHILIPS
PM 9920/00

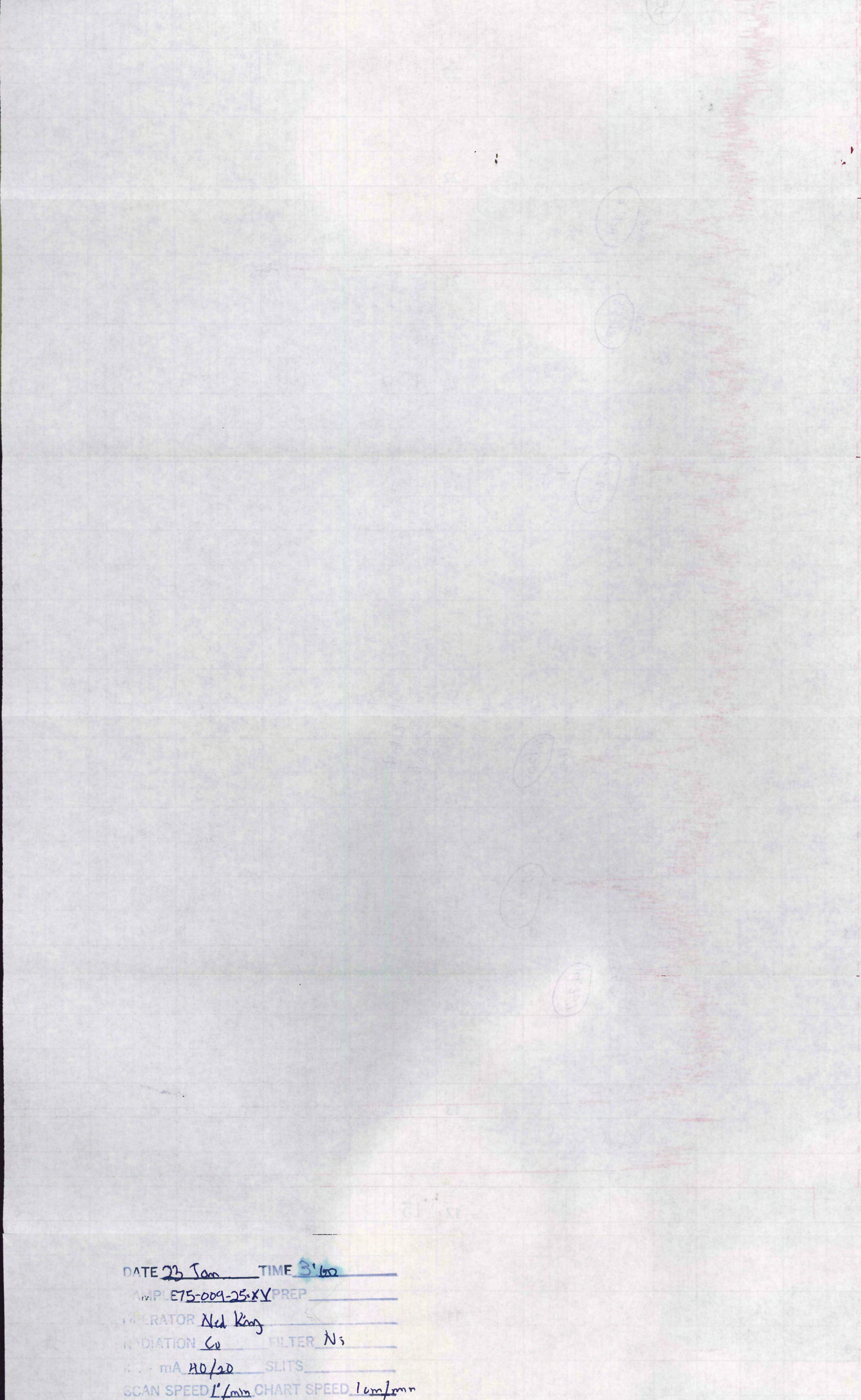
20-58.4

DATE Jan 24 TIME 3:00
SAMPLE 75-009-24-A/I PREP Acetone
OPERATOR Ned King
RADIATION Cu FILTER Ni
kv. · mA 40/20 SLITS ~~1cm/min~~
SCAN SPEED 1°min CHART SPEED 1cm/min
RANGE 1×10^3 TIME CONSTANT 4 sec
BASELINE 350 WINDOW 200


PHILIPS PM 9920/00
3.348
26.60°
3.539
4.21
20.8
7.109
12.45°
6.1
Start
2.0°
PHILIPS PM 9920/00



PHILIPS PM 9920/00
2.52
35.6
2.794
32.00
3.021
3.348
26.60
3.539
25.15
4.21
20.8



DATE 23 Jan TIME 3'00

SAMPLE E75-009-25-XY PREP

OPERATOR Ned King

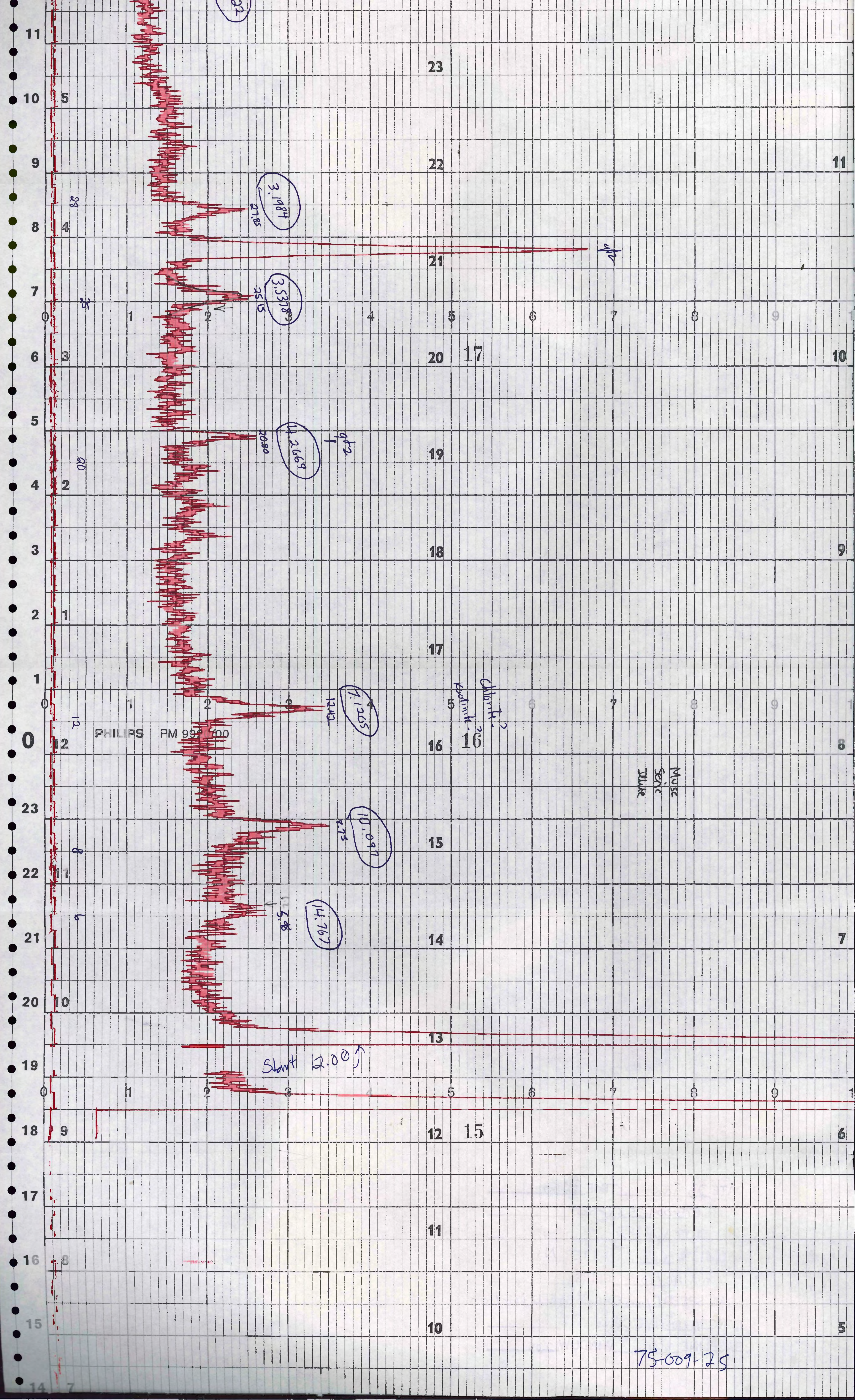
RADIATION Cu FILTER Ni

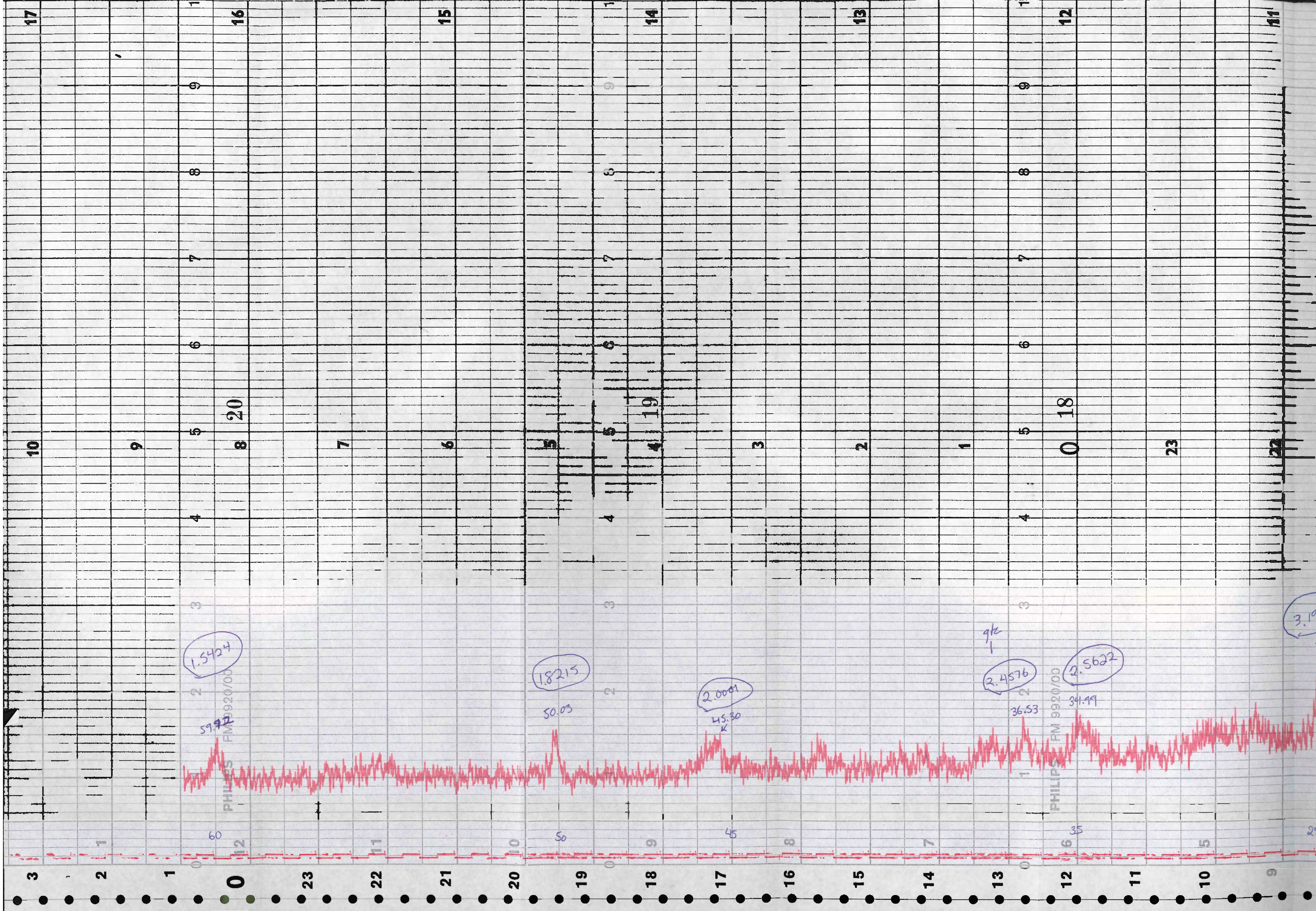
KV - mA 40/20 SLITS

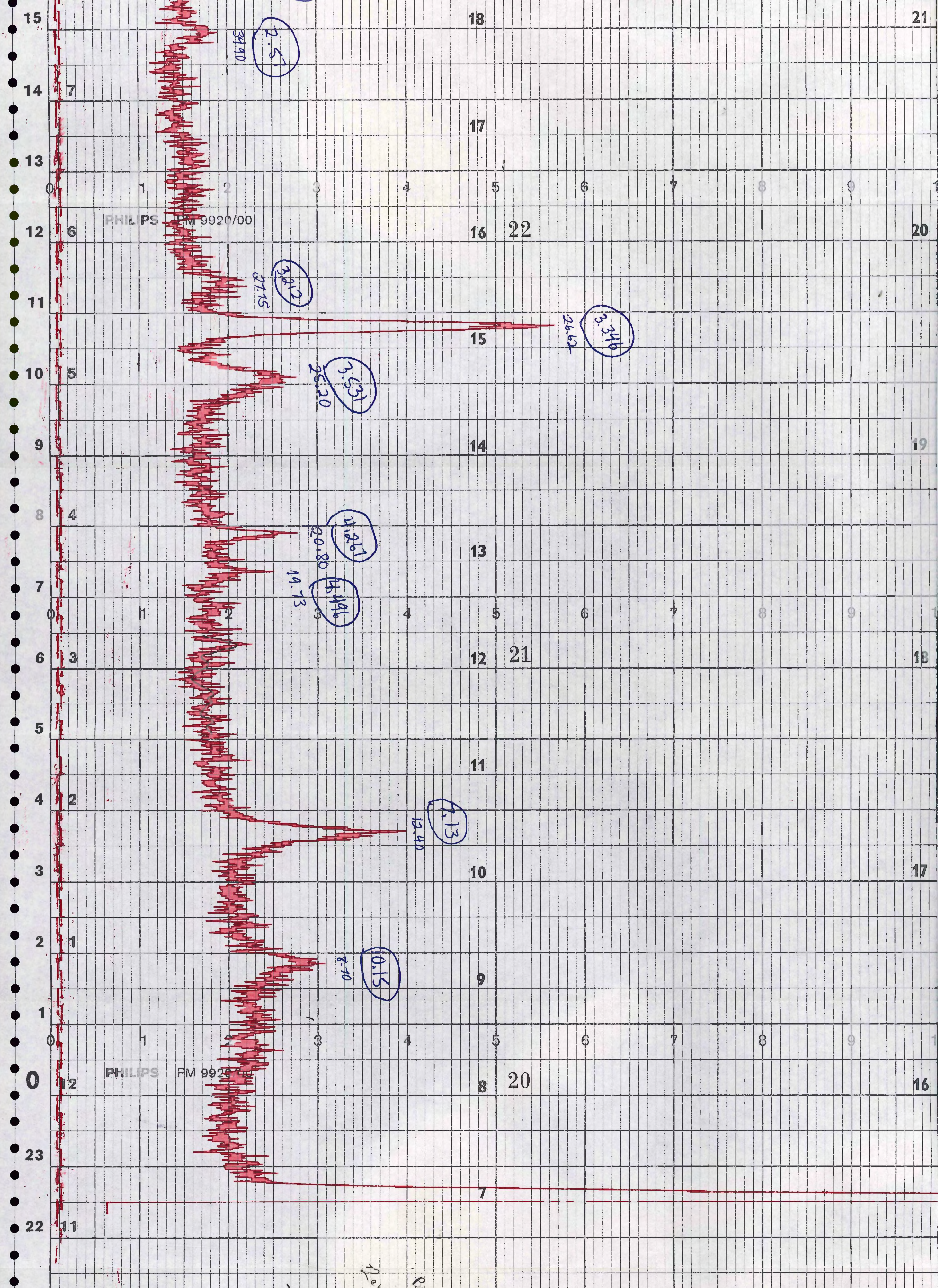
SCAN SPEED 1°/min CHART SPEED 1cm/min

RANGE 4×10^2 TIME CONSTANT

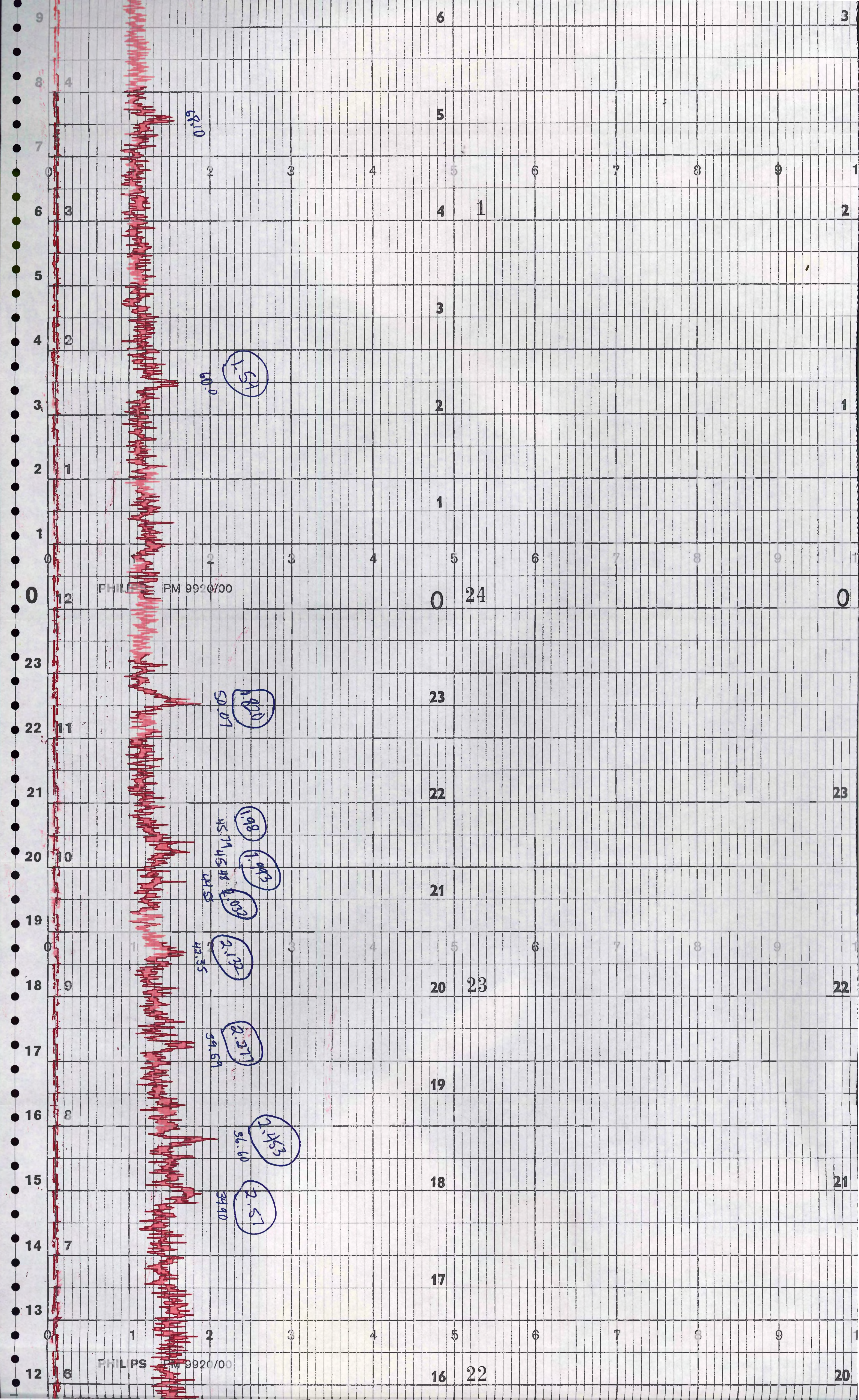
BASELINE 350 WINDOW 200

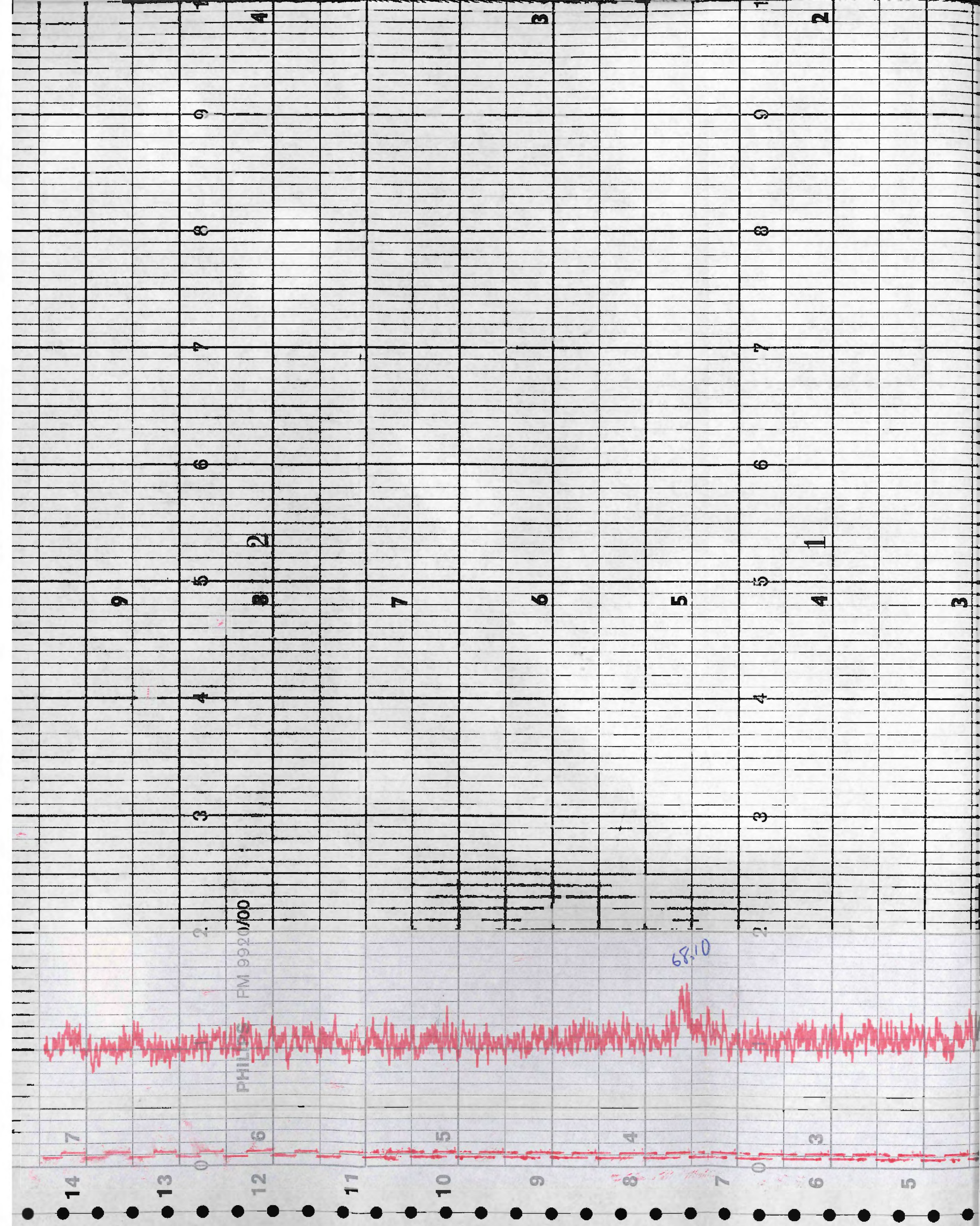

3.1984
27.85
3.5378
25.15
4.2669
20.80
qtz
7.1205
12.42
Chlorite?
Kaolinite?
PHILIPS PM
Musc
Seric
Illite
10.097
8.75
14.767
5.98
Start 2.00
75-009-25


1.5424
59.92
1.8215
50.03
2.0001
45.30
2.4576
36.53
2.5622
34.99
PHILIPS PM 9920/00



DATE Jan 26 TIME 1:30
SAMPLE 77-011-32/II PREP Acetone
2nd try
OPERATOR Ned King
RADIATION Cu FILTER Ni
kv. mA 40/20 SLITS
SCAN SPEED 1°/min CHART SPEED 1 cm/sec
RANGE 4x10 TIME CONSTANT
BASELINE 350 WINDOW 200


PHILIPS PM 9920/00
1.54
1.98
2.32
2.37
2.57
PHILIPS PM 9920/00


68,10