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REPORT TITLE	
LITHOLOGY OF INTERVAL 3600 - 4040 (TD) 30/7-3 BOREHOLE	
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SUMMARY

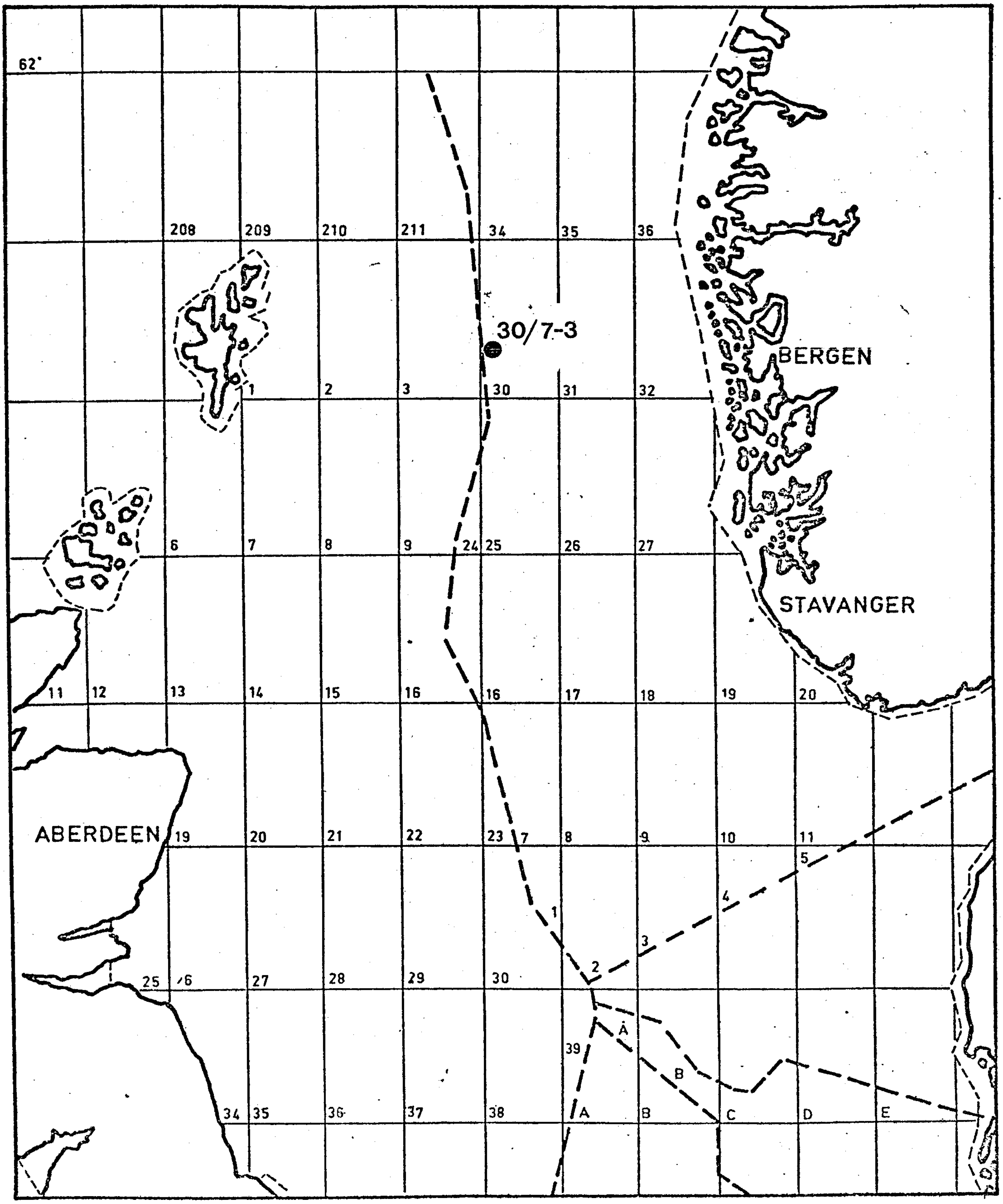
The interval 3600 - 3900 consists of coccolith limestone with no significant variations in lithology. From 3905 - 3925 is a transition to "crusts" presumably a type of shale with distinctive hackly surface features, and a puzzling internal structure. The "crust" interval extends from 3930 - 3985, below which shales and limestones become dominant. An additional lithology is thin wafers of cemented volcanic glass (vitric tuff) which extends from 3800 - 4023, peaking at 3937 - 3945. The lithologies and observations on the core (3918 - 3925) suggest deposition in quiet water below wave base.

KEY WORDS

Lithology

North Sea

LOCALITY MAP



INTRODUCTION

Forty-two samples in the interval 3600 - 4040 (TD) were washed, sieved into 0.125 - 2.0 and > 2.0 mm fractions, and dried. The cuttings were examined by: 1. binocular microscope, 2. thin-sections and 3. x-ray diffraction. On the basis of (1) four lithological groups based on descriptive parameters were set up. These types were further studied by (2) and (3).

In addition, the cored interval from 3918.5 - 3924.9 was also studied, with 1. direct observation and binocular microscope, 2. thin-sections, 3. x-ray diffraction, and 4. palynology.

DISTRIBUTION OF LITHOLOGIES

The four lithologic types defined and interpreted below, limestone, shale, crusts and wafers, allow a lithologic subdivision of the well into four parts (Fig. 1).

1. 3600 - 3900, LIMESTONE DOMINATED
   Mainly limestone with shale coming in at 3740 and wafers coming in at 3800. Shale increases in abundance towards the base.

2. 3905 - 3925, TRANSITION
   Transition with decreasing limestone (calcite) content and increasing content of "crusts". An affinity between shale and "crusts" is suggested by the concommitant dying out of shale.

3. 3930 - 3985, "CRUST" DOMINATED
   Although the significance of the "crust" appearance is not known, this rock type is dominant in the interval, increasing down to 3960, peaking at 3960 - 3985, and decreasing sharply below, giving way to shale and limestone. Wafers peak at 3937 - 3945.

4. 3990 - 4040 (TD), MIXED
This interval appears to mark a return to normal sediments with the increase in limestone, especially towards the base of the well, and shale. Wafers are detected nearly to the base of the well, 4023, but an origin as downfall cannot be ruled out.

CUTTINGS

Description

The four lithological types are 1. limestones, 2. shales, 3. "crusts", and 4. "wafers".

1. LIMESTONES are mainly grey, also coffee brown and tan, or greenish grey in color. They are very fine grained, occasionally granular in appearance, with variable amounts of small forams, and scattered euhedral pyrite crystals. There are occasional calcite spar fragments, and a belemnite fragment was seen at 3780.

Thin-section: staining with alizarin red proves a calcite composition. The limestones are composed mainly of calcisiltite, with recognisable coccoliths, suggesting that they consist largely of coccolith debris with a variable quantity of admixed forams. Minor terrigenous components include quartz silt and mica flakes. These occasionally have a corroded appearance. Large euhedral calcite crystals are scattered about in some chips. Diagenesis of these limestones can only be observed with regard to the forams and other large sparry calcite fragments. The nannofossil matrix cannot be examined in detail with the optical microscope. Forams, as well as the euhedral calcite crystals are either filled with coarse sparry calcite, or empty. Thus forams have in some cases been filled with spar, or tests and calcite crystals (of uncertain origin) were dissolved during diagenesis.

Figure 1. Distribution of lithologies. Ages based on accompanying paleontological report.

Symbols:

_ Lithologic type chosen for thin-section or X-ray diffraction analysis.

0 dominant (> approx. 90%)

X abundant (approx. 30-90%)

\+ common (approx. 5-30%)

: present (< approx. 5%)

Depth	Thin-section/ X-ray	Lst	Shale	Crusts	Wafers	Interval	Age
3600		0					Turonian
3620		0					- - - - -
3640		0					
3660		0					
3680	X-r	0	:				
3720		0					
3740		0	:				Cenomanian
3750		X	+				
3780		0	:			Limestone	
3800	T-s + X-r	0	:		:		
3815	T-s	0			:		
3830	T-s	0	:		:		- - - - -
3850		0	:				
3860	T-s	0					
3875	T-s	X	+		:		
3895	T-s	X	+			————	
3900	T-s	0	:		:		Upper
3905		X	:		:		Albian
3910		X	+		:		
3915		X	+			Transition	
3920		X	+	X	:		
3925		+	+	X	:	————	
3930		:	+	X	:		- - - - -
3937		X	+	X	+		
3945	X-r	X	:	X	+		
3950		+		X	:		
3955		+	:	X	:		
3960		:		0	:		
3965	T-s + X-r			0			
3970	X-r	:	:	0	:	Crusts	
3975		+	:	0	:		
3980	X-r			0	:		
3985	X-r	+	:	0	:		
3990		+	:	X			
3995		+	:	X			Middle
4000		X	+	X	:	————	Albian
4005	X-r	+	+	X			
4010		X	+	X		Mixed	
4013		+	X	X			
4020		X	+	+	:		
4023		:	X	+	:		
4040		0	+				

X-ray diffraction: Limestones were not specifically examined by this method, but some shales and calcareous shales displayed calcite peaks indicating a small calcite content (3800, 3970).

2. SHALES are fissile, dark grey to black. They grade into less fissile calcareous shales and marlstones, as well as the unusual "crusts" described below.

Thin-section: calcareous shales show the presence of well aligned clay flakes, occasionally interlaminated with limestone, and with some forams (3875 B, 3895 A).

X-ray diffraction: a qualitative examination of diffractograms suggests the following mineral composition in order of decreasing abundance: illite and mixed layer clay, quartz, albite, kaolinite and chlorite (3680, 3800, 3970, 4005). Calcite may be present (3800, 3970). Further details are given in appendix 1. Additional information about shales is also provided in the core description.

3. CRUSTS refer to cuttings with a hackly or intensely fractured surface texture. They are mostly grey to black, and have a crusty or volcanic appearance. Crusts occur mostly as flakes or elongate rods up to 3 mm wide and 1 cm long. Occasionally an internal structure having a meniscus-septate pattern is detectable.

Thin-section: shows that most fragments have a distinct curved septate-like structure (Fig. 2), caused by variations in color. The composition is mostly of tiny clay minerals and additional undeterminable fine grained material.

X-ray diffraction: interpretation of diffractograms indicates the presence of the following minerals in decreasing order of abundance: illite and mixed-layer clay, quartz, albite (3965, 3980, 3985), with small amounts of kaolinite and chlorite in the lower two samples.

4. WAFERS are a very distinct component occurring as thin parallel-sided plates and having a light brown to yellow surface color. A brief reaction with HCl indicates a coating of calcite. Because of its hardness and other physical properties, wafers tend to occur in the > 2 mm fraction in pieces larger than the other lithologies.

   Thin-section: mostly silt-sized angular fragments of isotropic material, mainly transparent, also yellow, reddish and brown. Sorting is poor. There are very rare quartz and feldspar grains and books of clay minerals (3815 B, 3875 D). The younger sample also included nannofossils. One fragment also contains rosettes of fibrous radiating material, possibly calcite.

   X-ray diffraction: shows only a weak reflection from calcite, suggesting that the bulk of the material is amorphous.

<u>Interpretation</u>

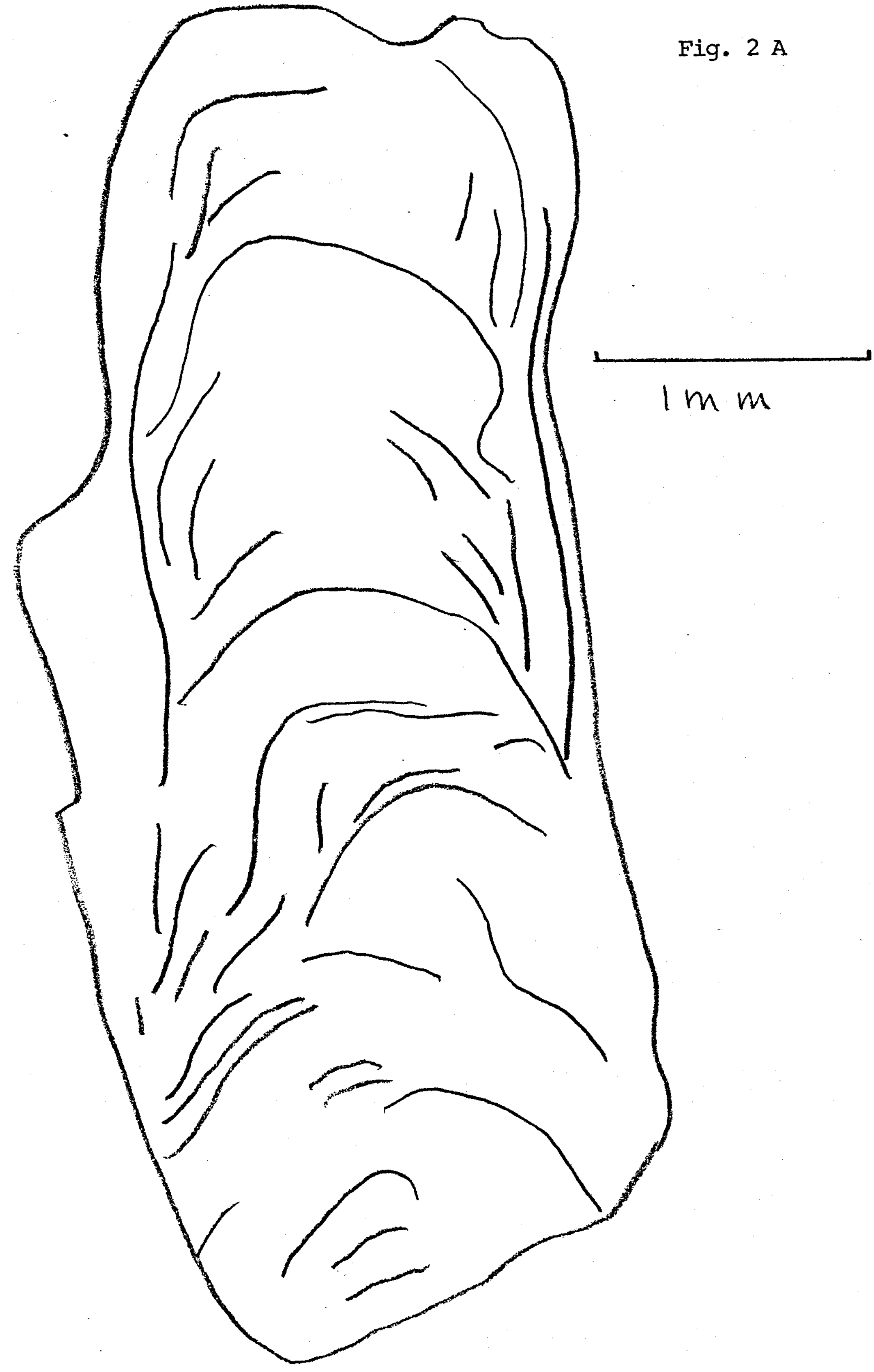
The interpretation of the four lithotypes is based on the data supplied above.

1. LIMESTONES formed in quiet water below wave base. There was minor clastic terrigenous input into the basin. Abundant coccoliths attest to favorable conditions for coccosphere growth and preservation. Diagenesis observed in thin-section suggests minor solution and reprecipitation of calcite. The nature and extent of coccolith diagenesis is unknown. There is no apparent dolomitisation or silicification.

2. SHALES formed by deposition of clay and fine silt also in a very quiet environment, however with input from a clastic source. The calcite and nannofossil content indicate that deposition of terrigenous clastics and intrabasinal (allochem) carbonates took place simultaneously. The well-aligned clay flakes also parallel the

Fig. 2 A - E. Sketches of "crust" cuttings in plane light picked from sample 3965. The lines indicate dark bands. Magnification approx. x 40.

Fig. 2 A



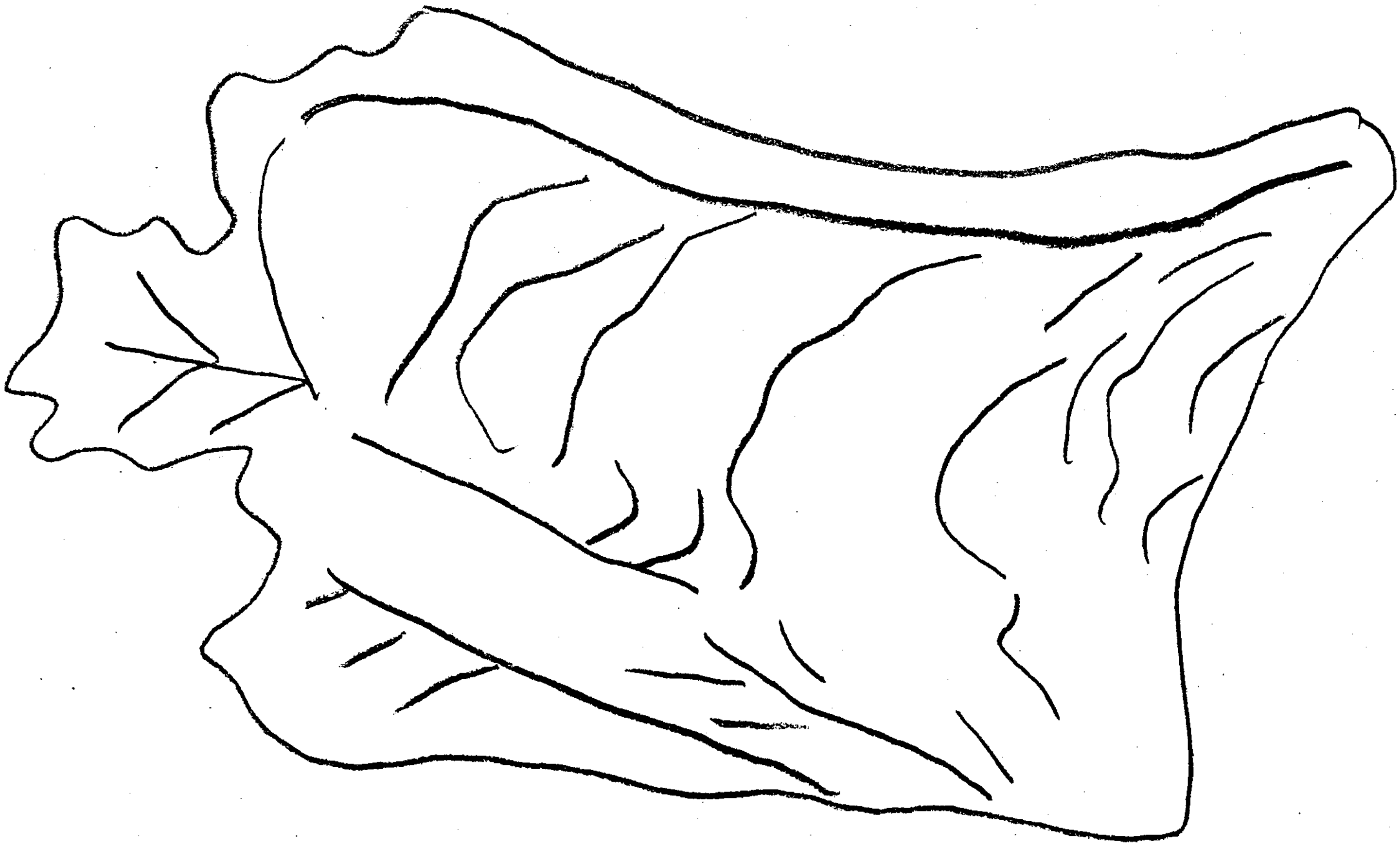
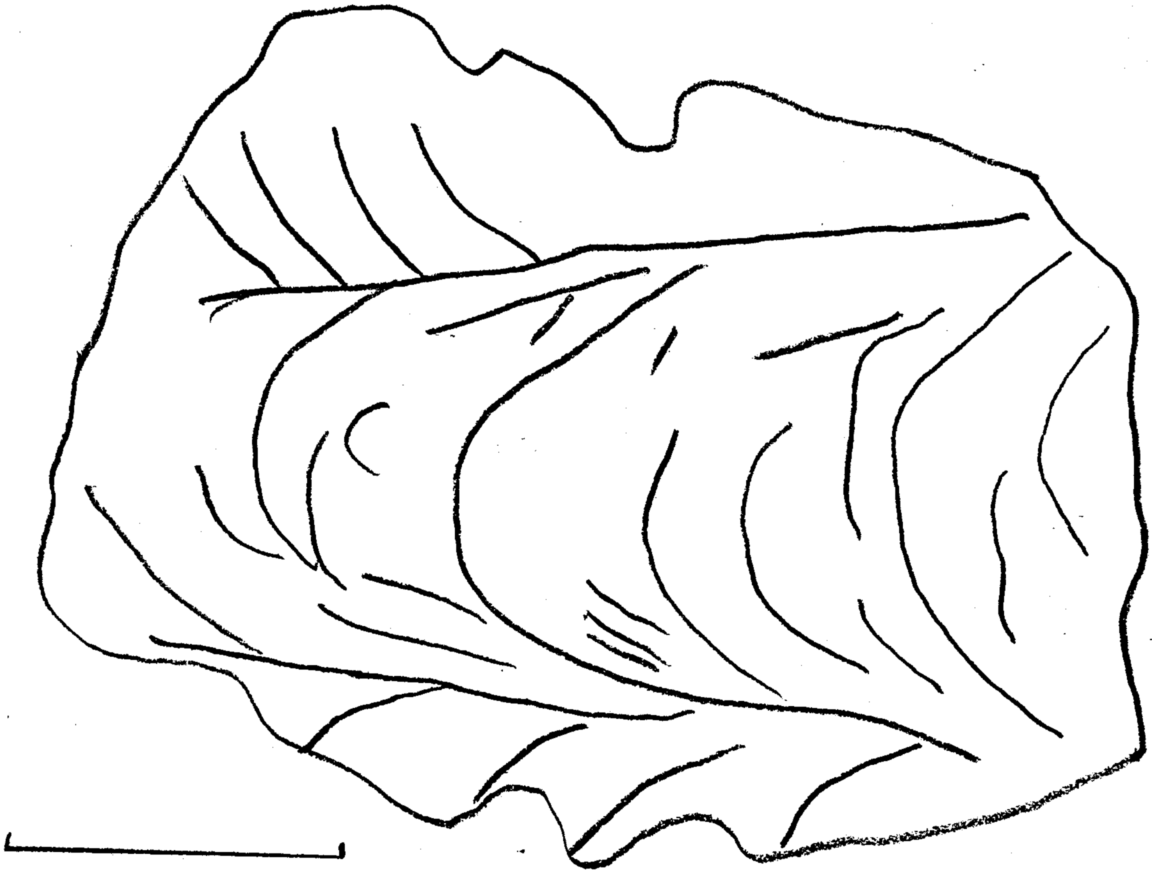


Fig. 2 B



1 mm

Fig. 2 C

Fig. 2 D

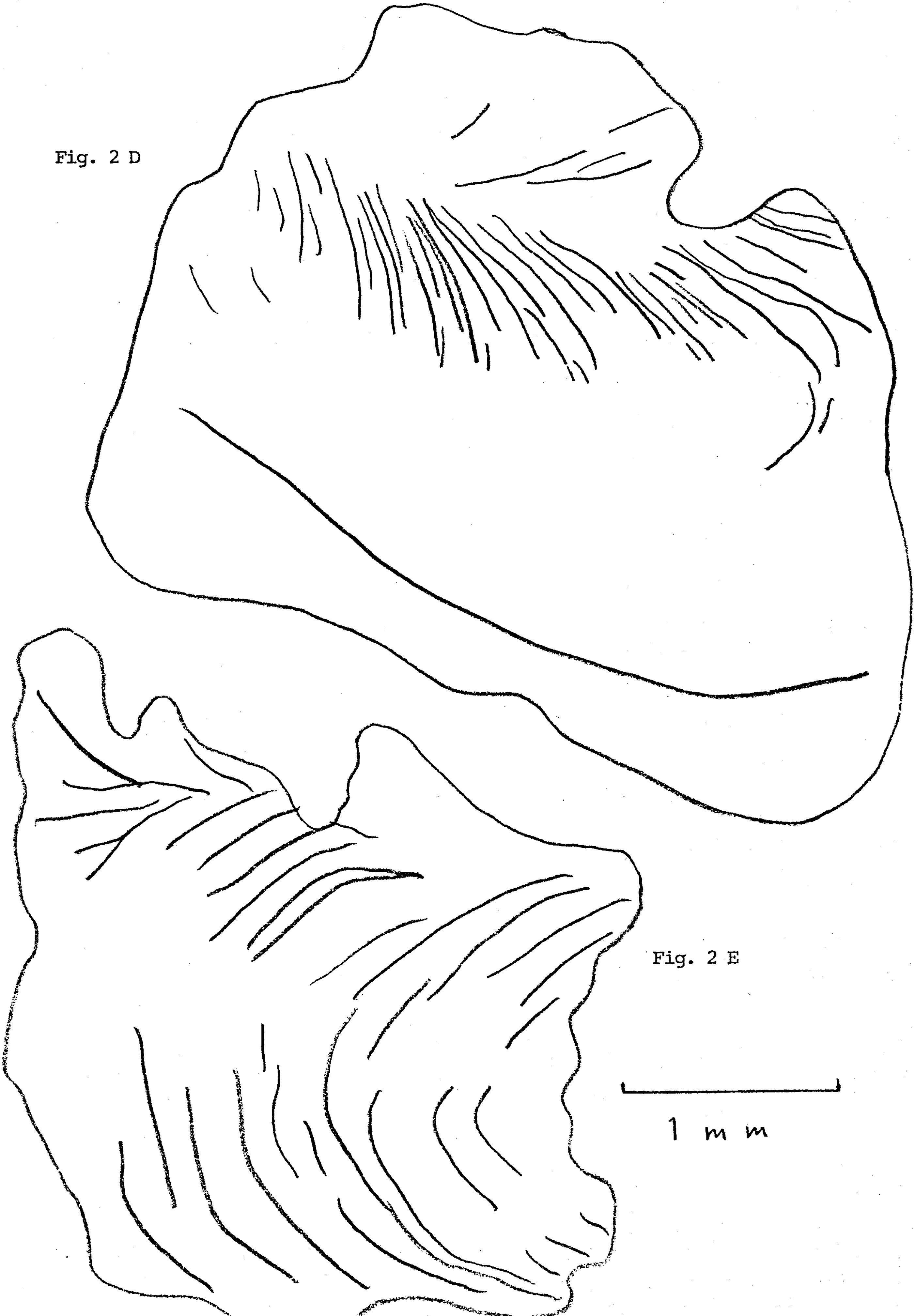


Fig. 2 E

lamination and presumably caused the fissility.

3. CRUSTS are of uncertain origin. They superficially resemble volcanic material, but the structure in thin-section is not similar to those known from previous studies, including accretionary lapilli, flow bands, or perlitic cracks.

The curved septate structure is similar to certain burrow fills, particularly to those formed in coastal sediments by crustacean activity, however, these are usually larger, 1 - 3 cm across. However, careful inspection of the cored section (described below) revealed abundant examples of burrow structures about the same size as the "crust" structures, some of which show concentric lamination in section. If some of these crusts are burrow fills, several points are raised: 1. the burrow fills must be harder than the surrounding sediment to occur as discrete fragments (the internal structure is related to the external form as seen in the thin-section), 2. the crusts appear to have lower kaolinite-chlorite composition than normal shales, and 3. this still does not explain the unusual hackly surface texture of the crusts.

The latter feature might be explained by an originally different clay mineral composition, subsequently altered by diagenesis and burial. There is nevertheless no strong evidence here pointing to a volcanic origin.

4. WAFERS, due to their isotropy and amorphous structure appear to be a well-preserved vitric (glass) tuff, partly cemented by calcite. The fine grain size suggests great distance from the volcanic source, or upwind location from the source.

CORE

Description

The entire core extends from 3918.5 to 3924.9 m, divided into 7 sections.

Color: dark grey, with some grey-green levels. Tan carbonate nodules and beds.

Grain size: mostly clay with some silt. Scattered very fine sand grains are presumed to be forams. Two possible intraformational breccia horizons contain pebble sized material.

Composition: apart from a few isolated carbonate concretions (dolomite) and limestone beds the core consists of calcareous silty claystone. Variations in color may be due to changes in carbonate content, this increasing with lighter color.

Sedimentary structures: bioturbation seen as patchy variations in color and grain size is the dominant structure. Often a concentric pattern is preserved. Inclination of burrows is variable. A few burrows are filled with brown carbonate. The tops of a few carbonate concretions are also burrowed.

Parallel stratification is the next most abundant structure. It is most apparent where bioturbation is absent. A few thin intervals, up to several centimeters thick are massive, showing no internal structures, while other zones show gentle grading brought out by rows of very fine sand grains (probably forams).

Additional structures include a convex up bivalve shell which rests on silty clay, but the upper part of the area under the shell is filled with clay. This is a geopetal filling.

Two breccia beds, 2 and 8 cm thick occur just below 3921. These consist of fragments of mudstone and claystone, partly calcareous. The fragments are angular, plate shaped, and are oriented with a dip of about 10^{o} to the stratification in the core.

Fossil content: apart from burrows, thin shells, usually convex down are scattered in several parts of the core. Some of these appear to be flattened and substantially crushed. One thick shelled bivalve was observed, convex up. Most of these appear to be isolated shells.

Carbonate beds: carbonate beds up to 6 cm thick and thinner concretions and stringers occur sporadically throughout the core (total thickness a few per cent of the core length). Many of these are bioturbated, lenticular, and have gradational and sharp boundaries. A couple showed thin fractures filled with sparry calcite. The carbonate beds have a distinct brown color. A dolomite composition for some is suggested, based on the limited reaction to HCl. However, a primary origin for others is shown by calcite composition (alizarin red stain) with presence of coccoliths in thin-section (core section 5).

X-ray diffraction: was carried out on a breccia, and on a normal bioturbated part of the core. The results (3921 A, 3921 B, see appendix 1) show that the bioturbated shale contains much more calcite than the breccia. Otherwise, the composition is similar to that of other shale cuttings reported above.

Palynology: A palynological study of one of the breccia layers in the core was carried out to compare it with the palynology of other parts of the well basedon cuttings. The abundance of "reworked" Middle Paleozoic marine palynomorphs is noteworty (Appendix 2). The good preservation of these older forms suggests that they have been extracted from pebbles of Middle Paleozoic shale. These were eroded and transported into the basin and deposited among Late Albian sediments.

Intepretation

The fine grain size of allochthonous clastic material, and the absence of sedimentary structures due to transport by traction currents indicate that deposition was largely from suspension in very quiet water.

The abundance of bioturbation indicates that conditions for the presence of a burrowing fauna were favorable, there was circulation of bottom waters with renewal of oxygen and organic matter. The occasional thin massive or parallel stratified beds suggest sudden rapid deposition. Some of these beds have forams concentrated at the base suggesting slight reworking or settling out of suspension from currents. In particular the intraformational breccia beds suggest lateral mass transport, possibly some kind of slump. The geopetal structure suggests that bottom currents contained both fine silt and clay, but under the protection of the shell only clay was deposited. Bioturbation of carbonate beds suggests a primary origin for these. There was some dolomitisation, apparently limited to lenticular bands.

The general absence of a coarse terrigenous fraction suggests deposition away from a shoreline, while the fine grain size and absence of characteristic sedimentary structures suggests a moderate to great depth of water, with little current movement.

APPENDIX 1

MINERALOGICAL ANALYSIS BY X-RAY DIFFRACTION

The minerals identified in each sample are listed in probable order of decreasing content. The sign = indicates no appreciable difference between content of two minerals. Also provided is the identification of the rock type by binocular microscope.

CUTTINGS

3680	(shale) illite + mixed-layer, quartz, albite, kaolinite = chlorite.
3800	(shale) illite + mixed-layer, quartz, albite, kaolinite = chlorite, calcite.
3945	(wafer) small amounts of calcite.
3965	(crust) illite + mixed-layer = quartz, albite.
3970	(calcareous shale) quartz, illite + mixed-layer, albite, kaolinite = chlorite, calcite.
3980	(crust) illite + mixed-layer, quartz, albite, small amounts kaolinite = chlorite.
3985	(crust) quartz, illite, albite (+ small amounts K-feldspar?), small amounts kaolinite and/or chlorite.
4005	(shale) illite + mixed-layer, quartz, albite, kaolinite = chlorite.

These data are inconclusive with regard to a possible volcanic origin for some of the samples. No direct evidence (smectite, zeolites) was found.

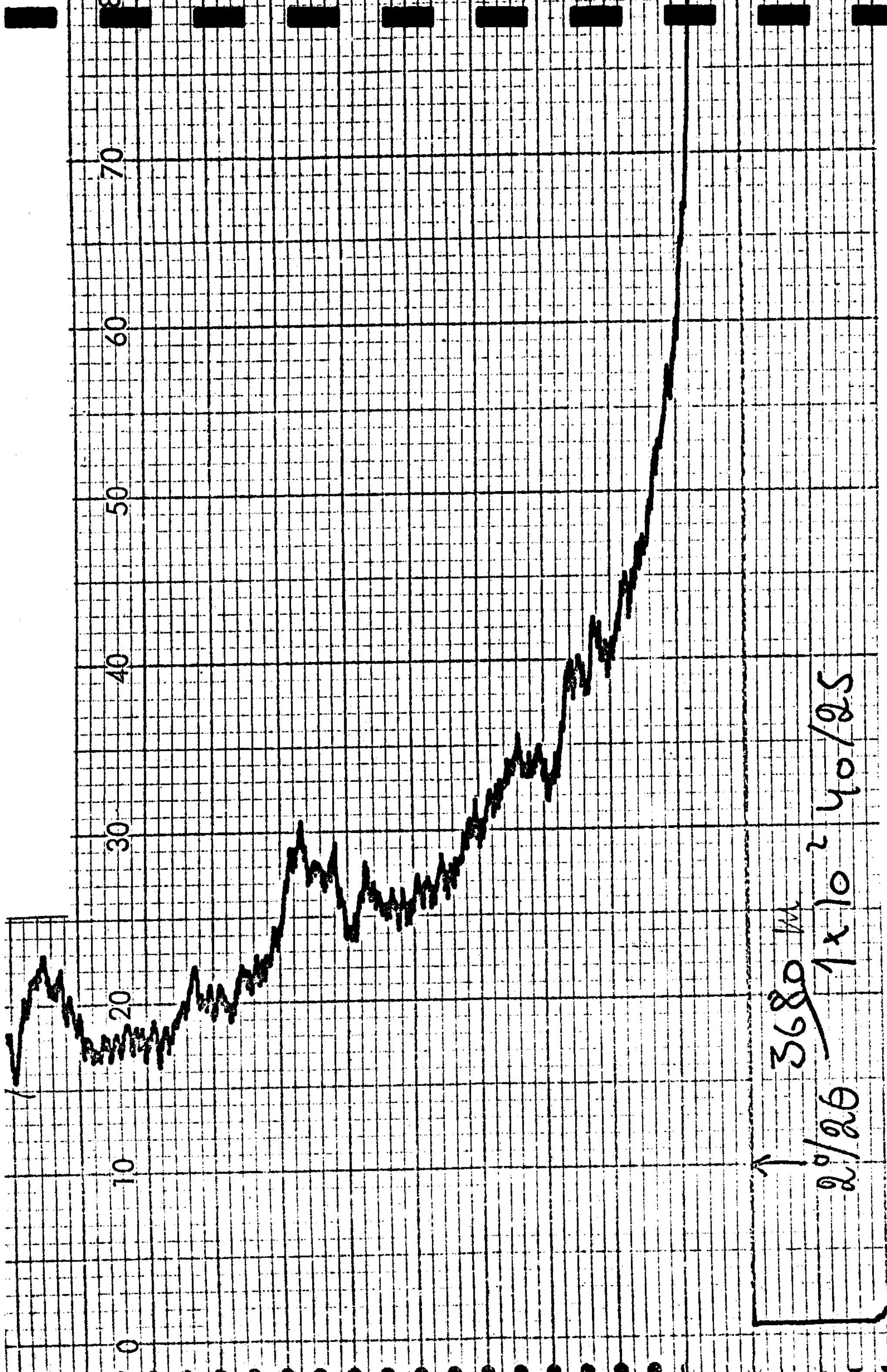
CORE

3921 A (bioturbated shale) calcite, illite + illite-mixed-layer (disordered), albite = quartz, chlorite, kaolinite.

3921 B (breccia) illite + illite-mixed-layer (disordered), calcite, quartz = albite, chlorite = kaolinite.

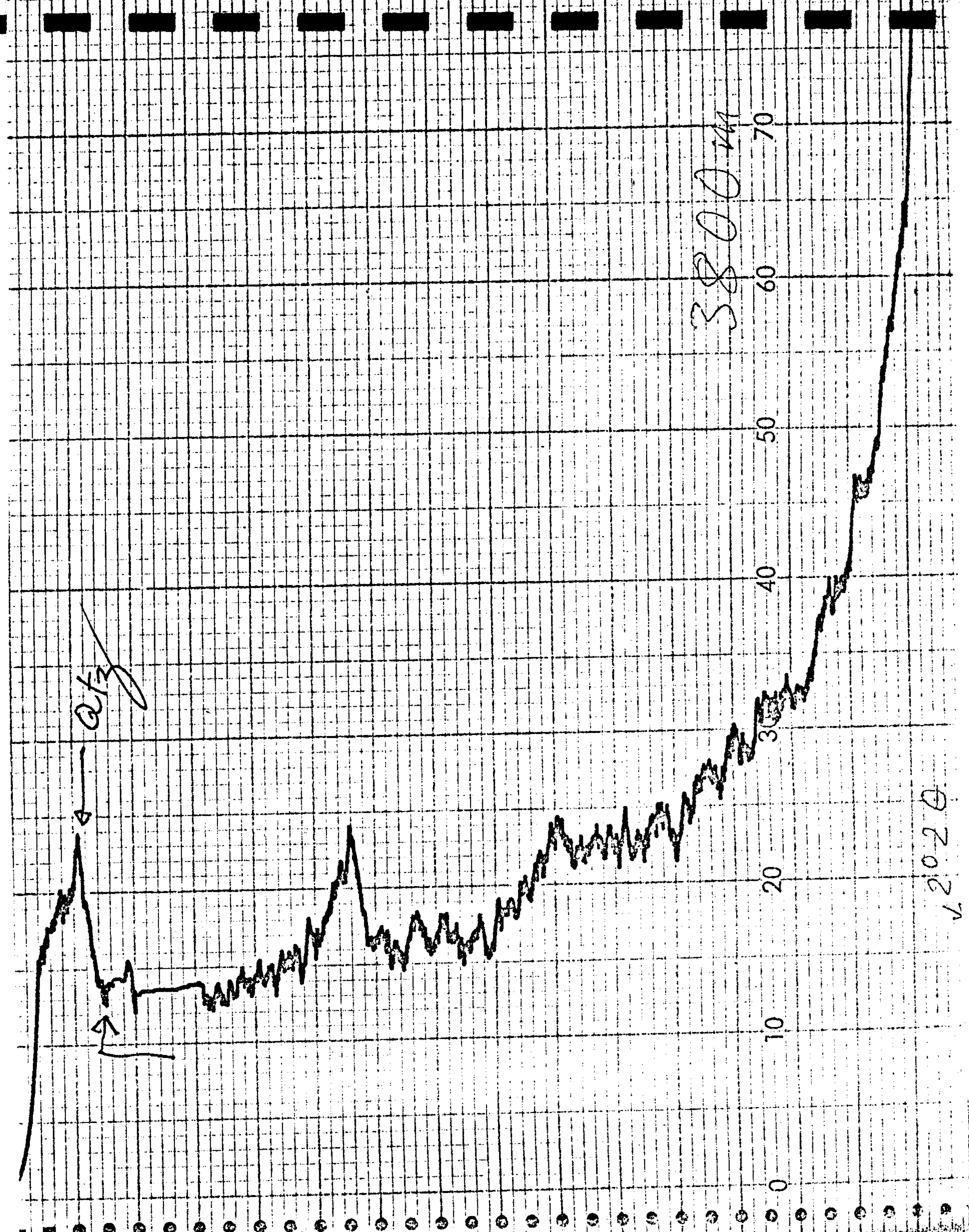
The only significant difference between the two samples is in the calcite content. The high calcite content in the bioturbated shale places the core in the transition zone between the limestone interval and the crust interval.

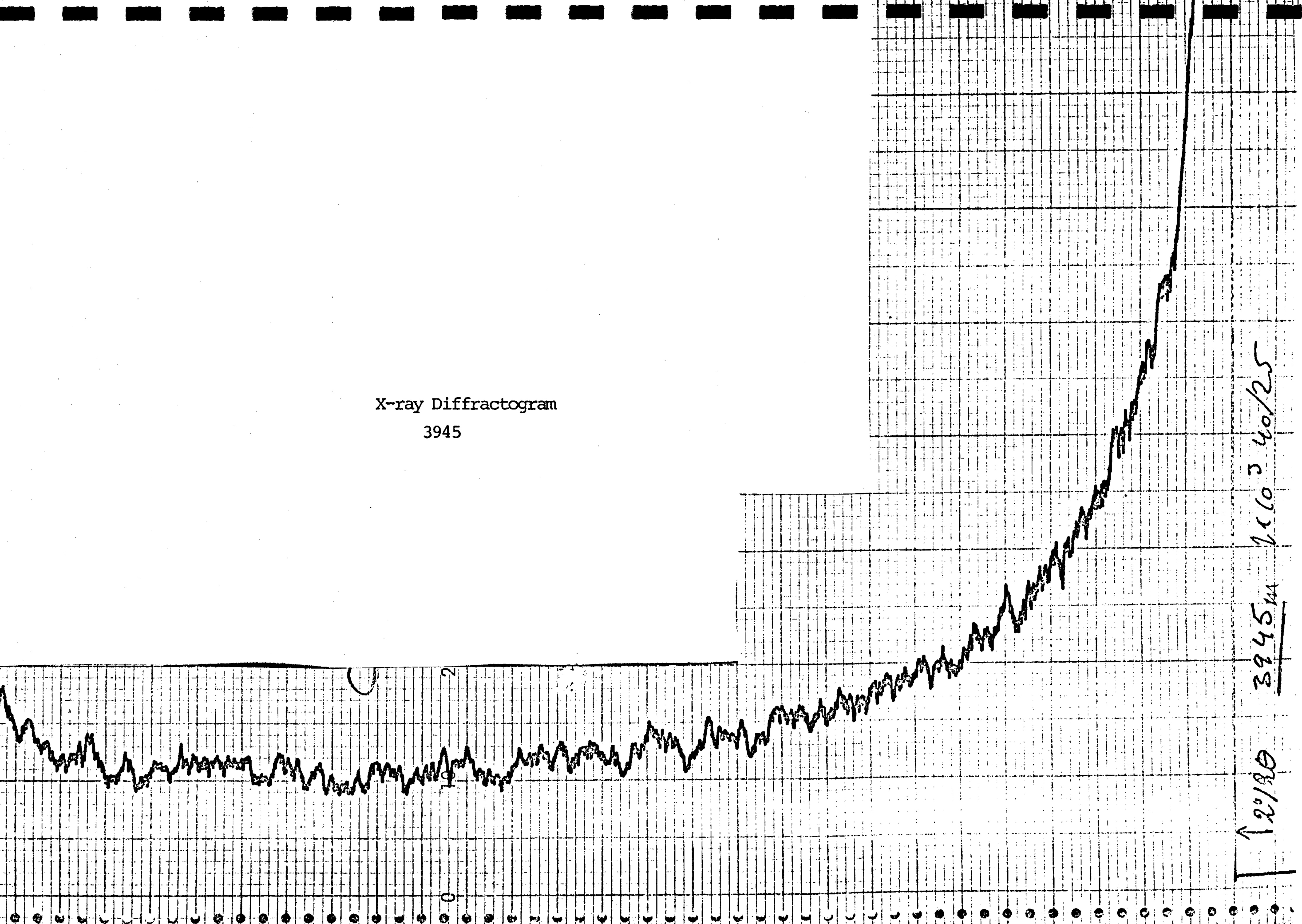
X-ray Diffractogram
3680



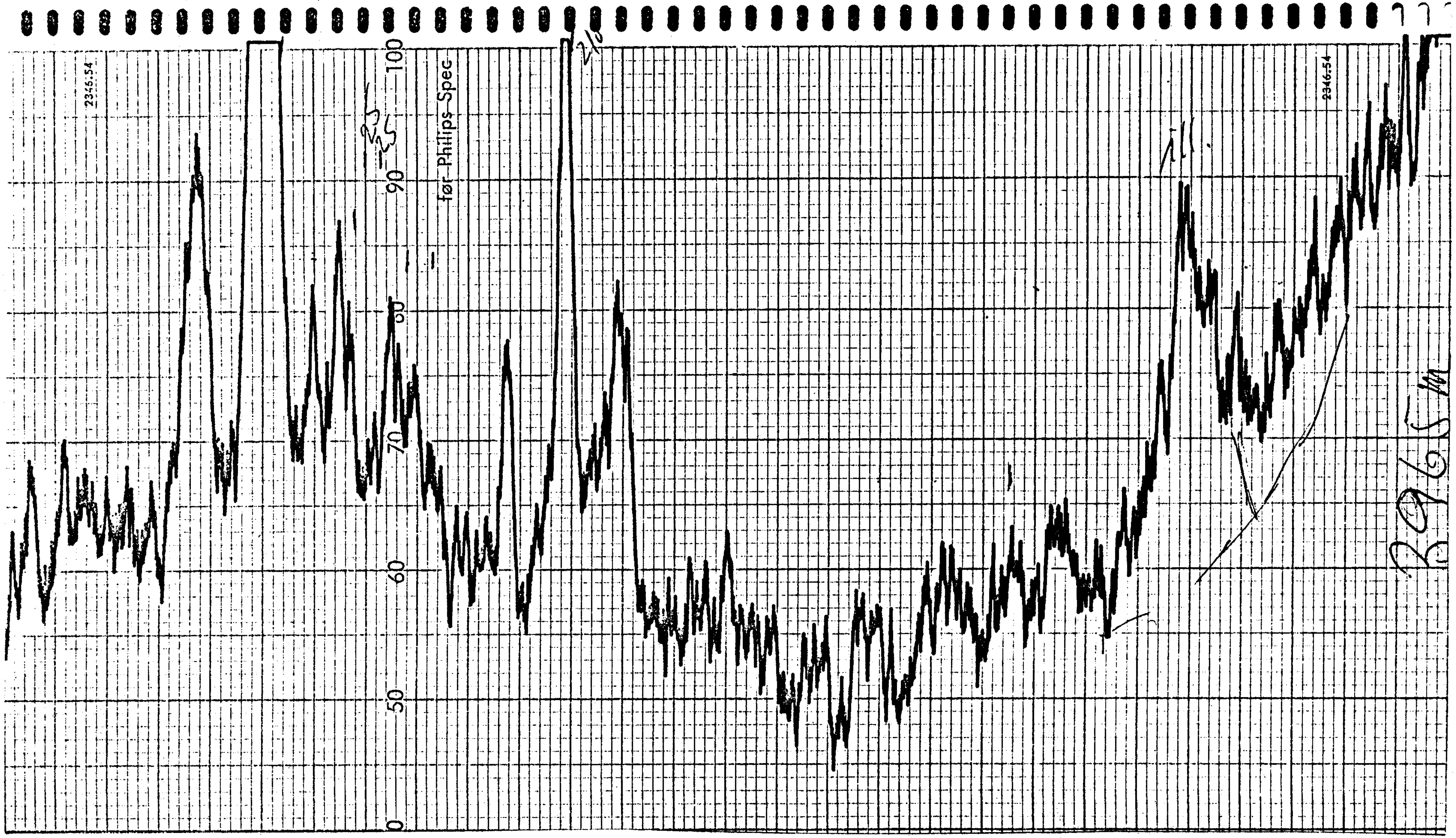
X-ray Diffractogram

3800



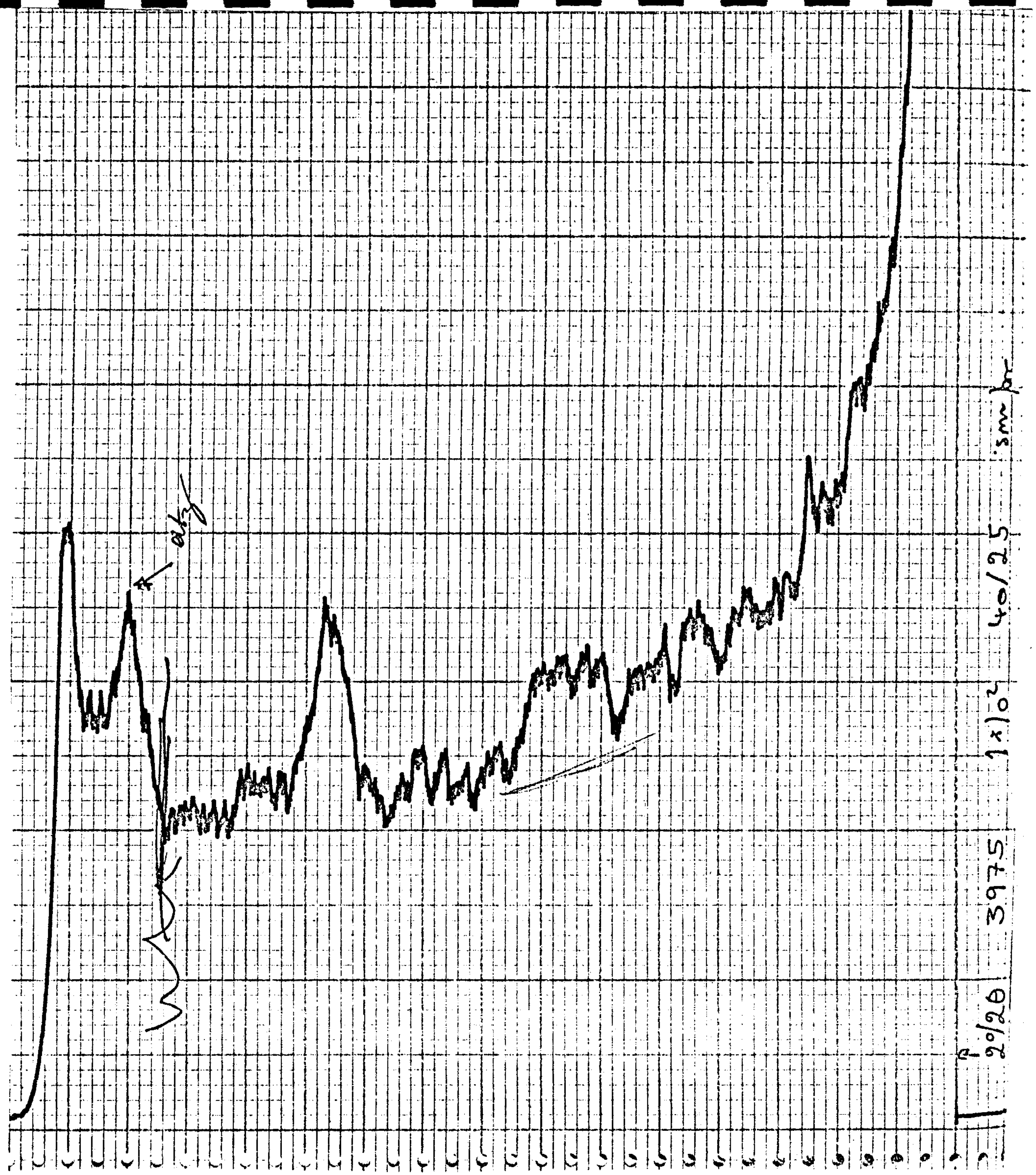


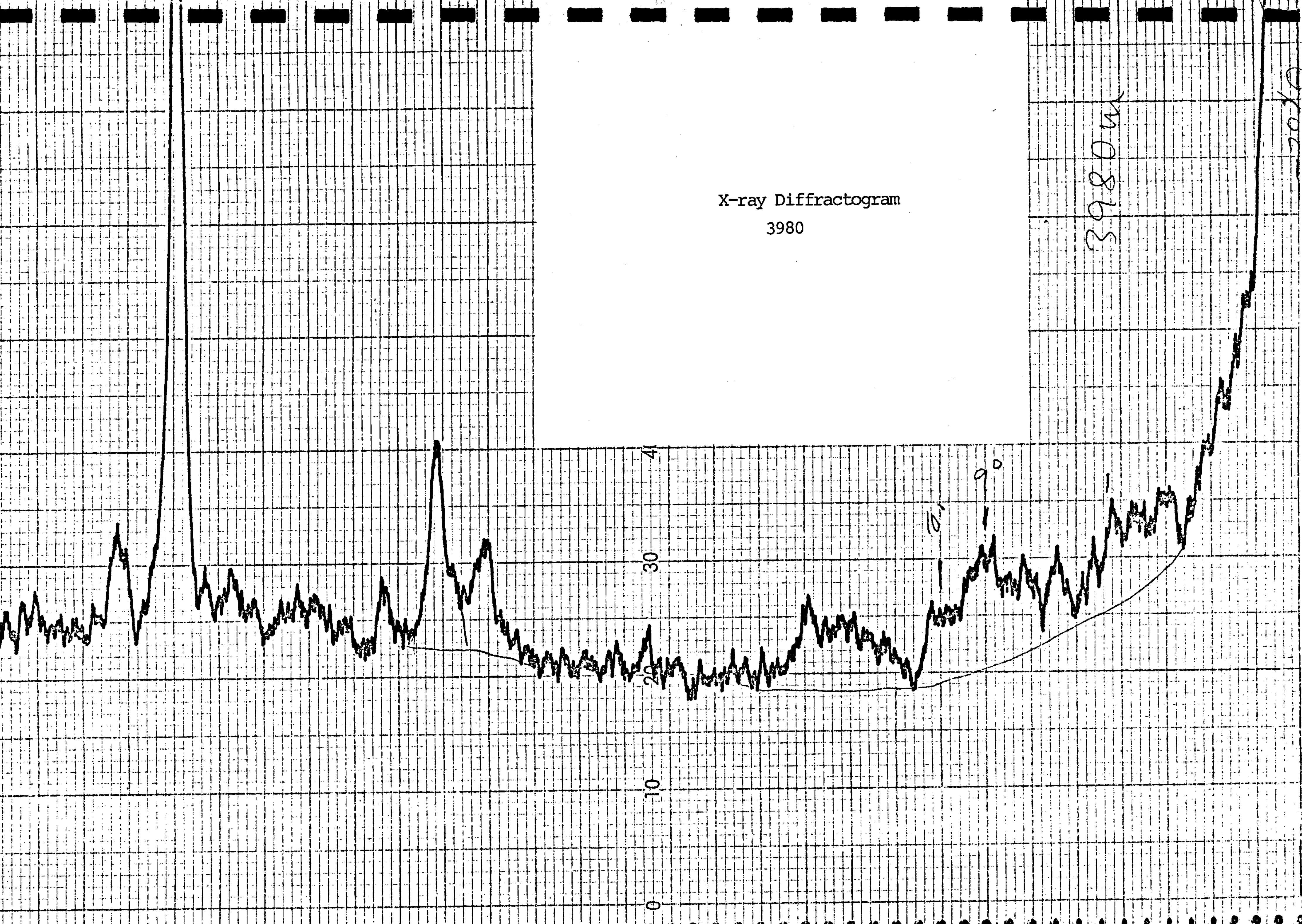
X-ray Diffractogram
3945



X-ray Diffractogram 3965

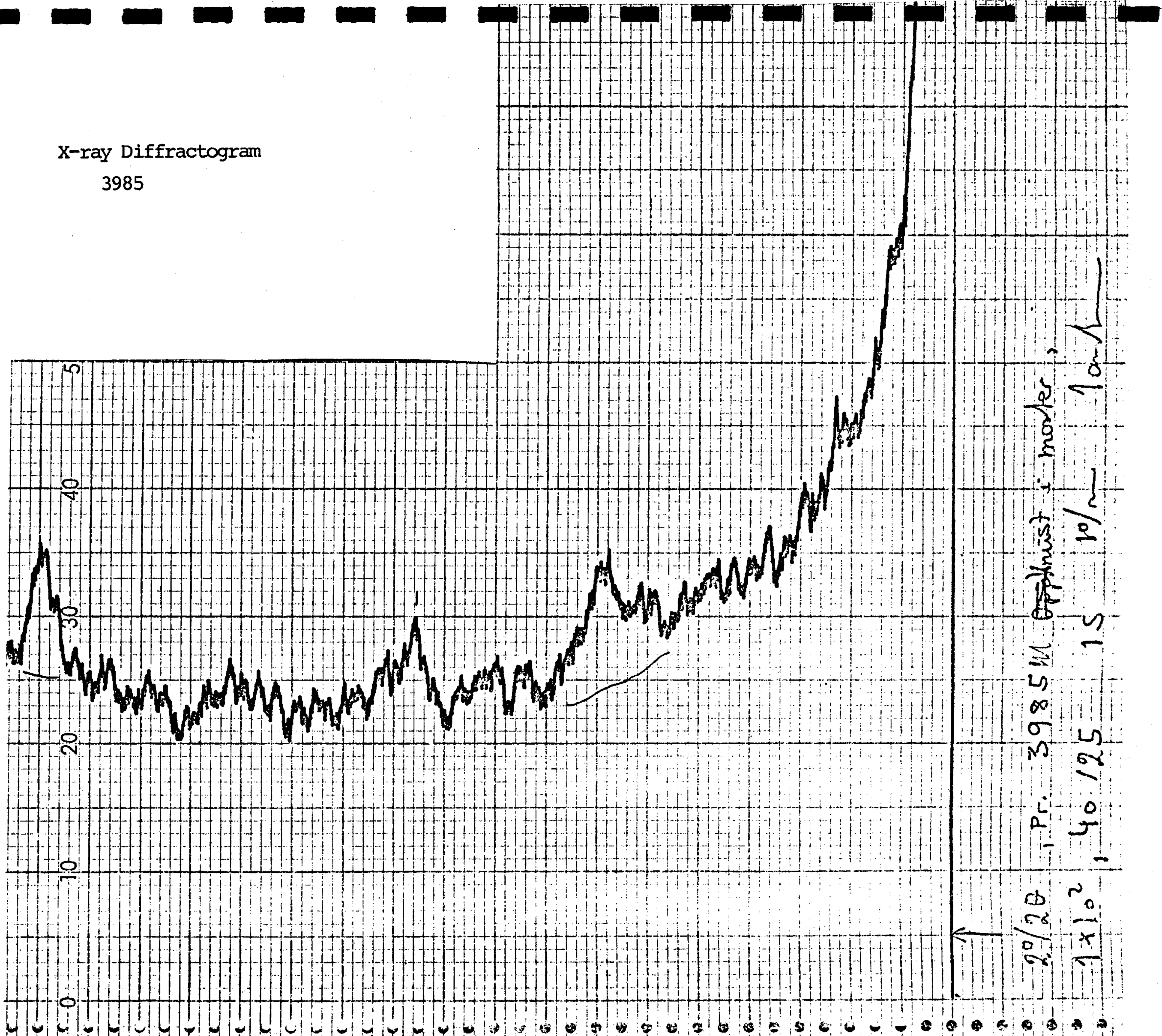
X-ray Diffractogram
3975

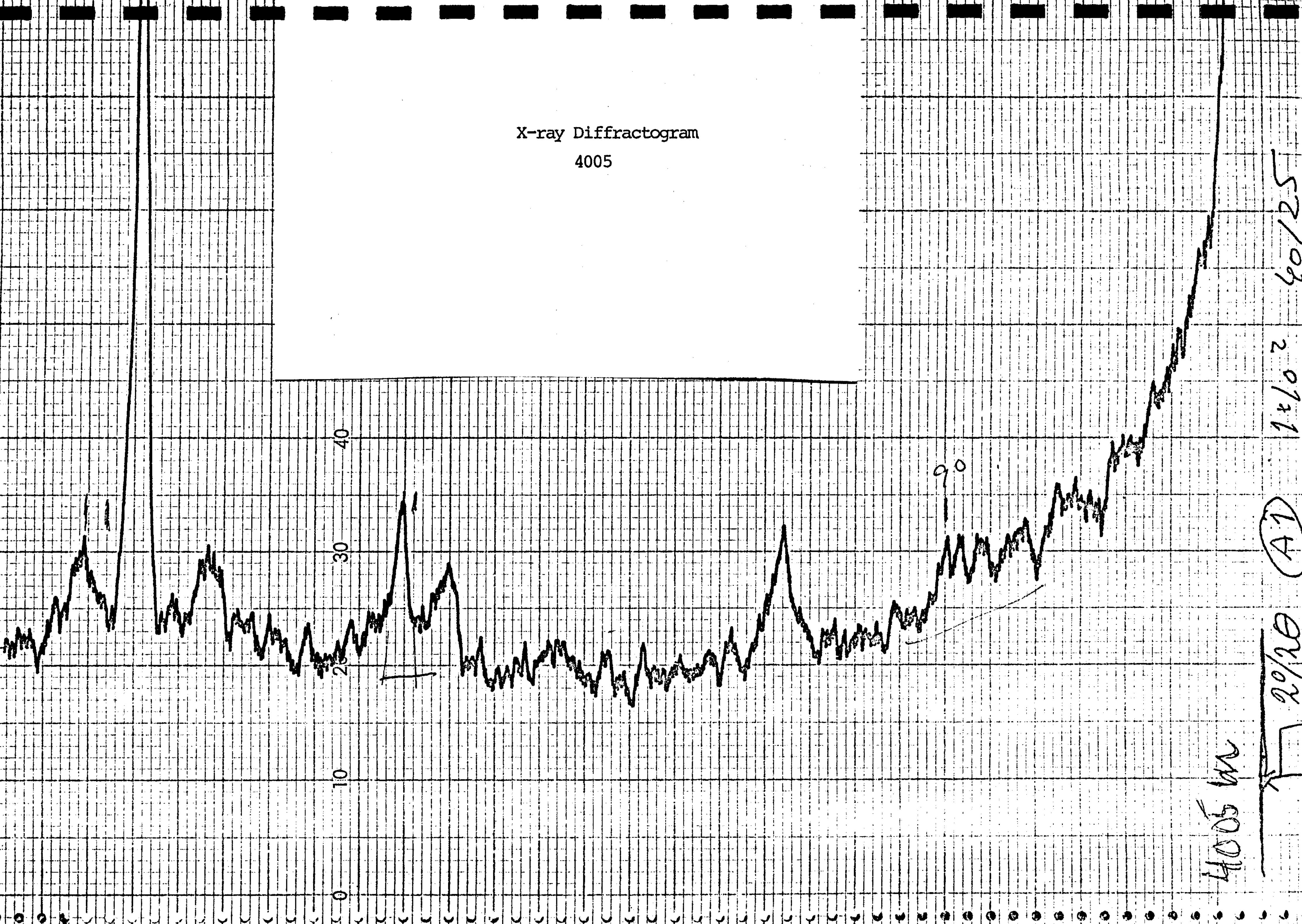


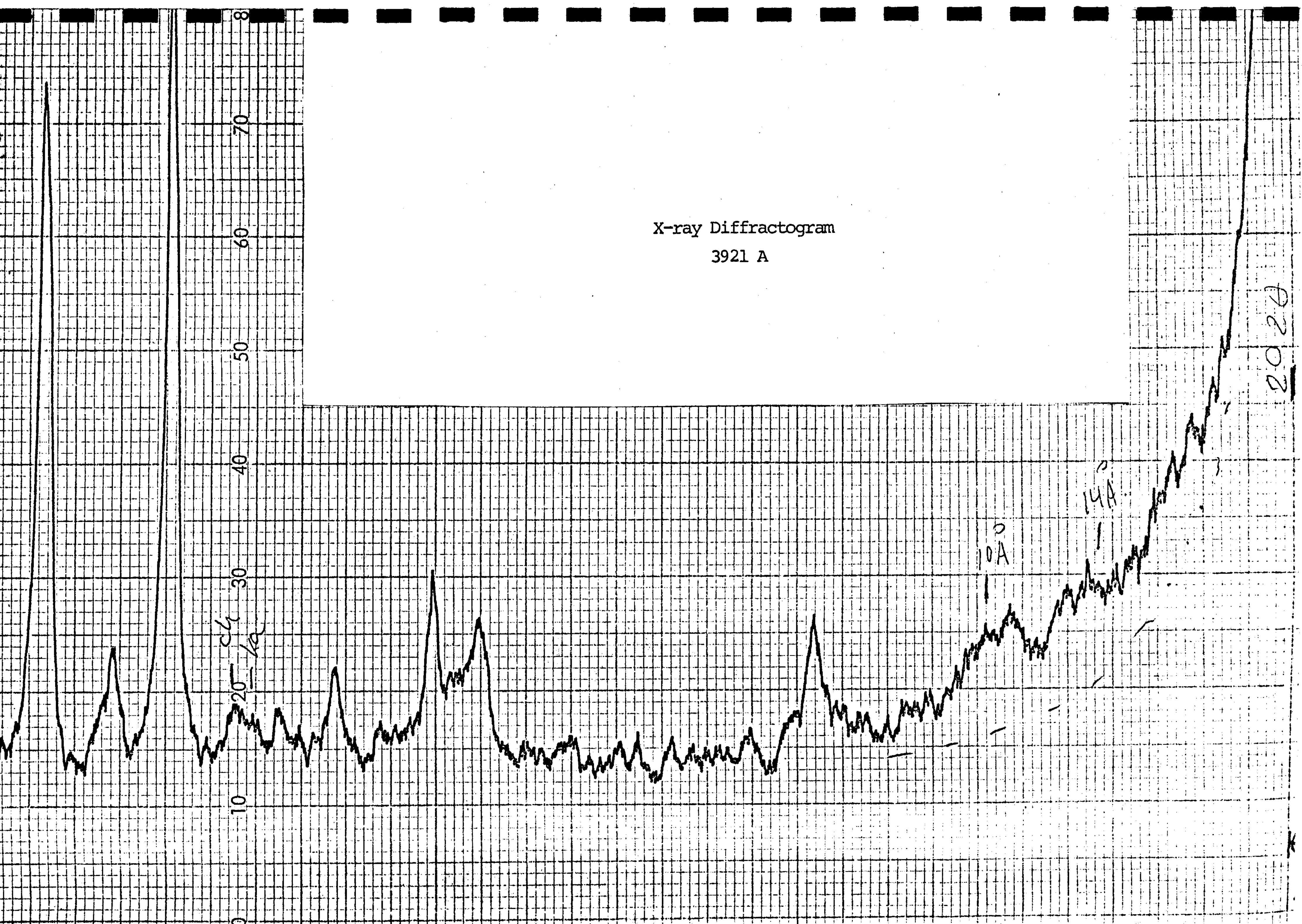


X-ray Diffractogram
3980

X-ray Diffractogram
3985

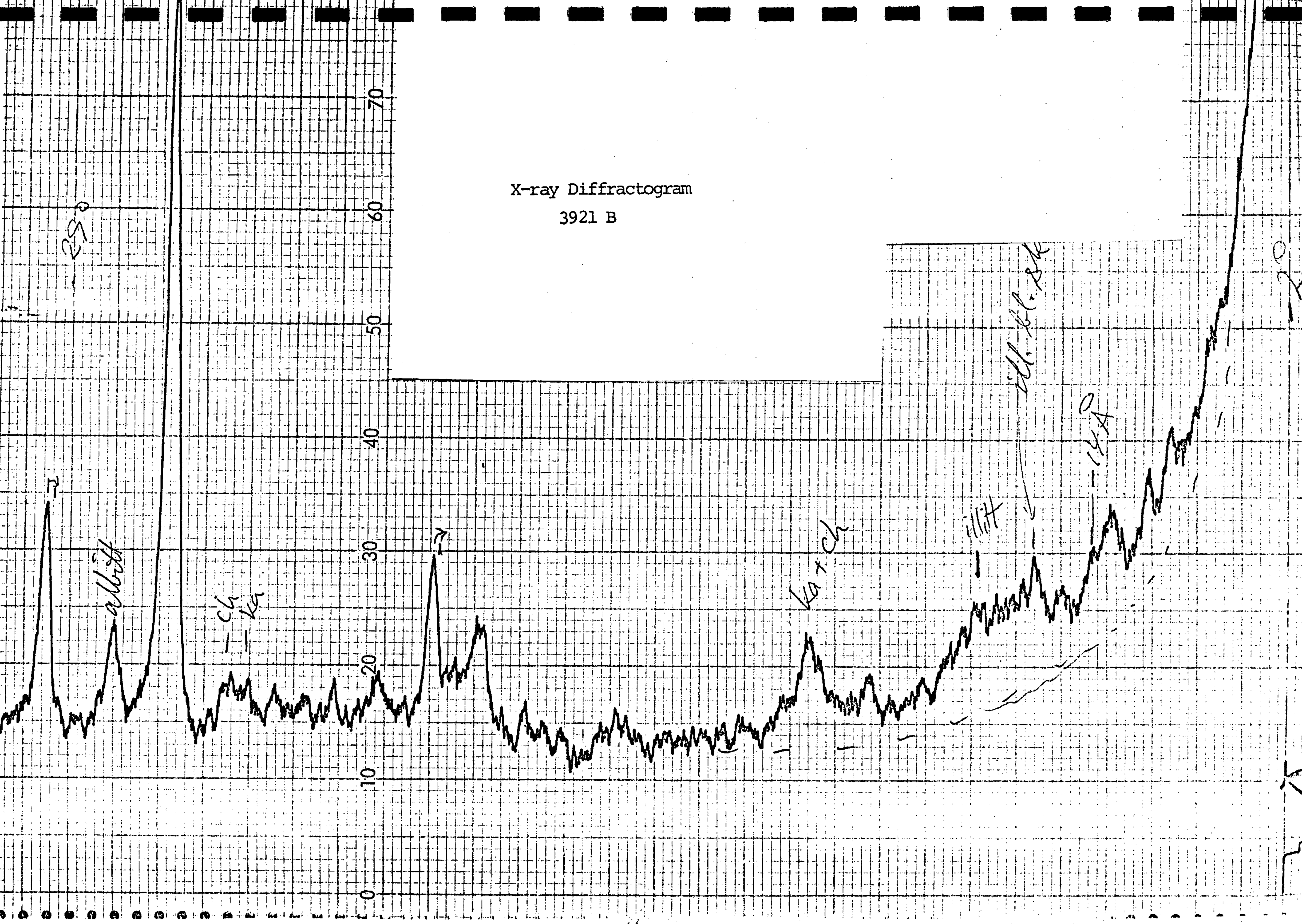



X-ray Diffractogram
4005
40
30
20
10
0
A1



X-ray Diffractogram

3921 A



X-ray Diffractogram
3921 B

APPENDIX 2

PALYNOLOGY OF CORE SAMPLE AT 3921

This sample was chosen for a study of reworking. Small pebbles are clearly visible in the core section at this level. Results are summarised below.

1. The indigenous palynological assemblage is dominated by Late Albian dinoflagellate cysts (see biostratigraphic report). There are few acritarchs or spores and the assemblage is of open marine character.

2. Reworked material consists largely of black more or less opaque fragments. These make up over 60% of the total palynological assemblage (indigenous forms included). Occasional poorly preserved and abraided Devonian spores were also recorded. Late Jurassic - Early Cretaceous reworking was also recorded, though somewhat infrequently.

3. Detailed examination revealed organic structures in some of the fragments. Numerous examples of Tasmanites sp., a marine Pracinophycid algae were recorded. These have a high thermal maturation index (ca. 3.9) in common with reworking observed throughout the Cretaceous.

4. Other fragments, lacking definite organic structures are more difficult to identify, though the morphology of some fragments is remeniscent of chitinozoa and scolecodonts. This would support a Middle Palaeozoic age. The degree of fragmentation varies and it is not possible to positively identify the fragments as chitinozoa. However, chitinozoa are easily fragmented under normal (i.e. non-recycled) conditions. Some specimens of Tasmanites sp. show only minimal signs of abrasion.

Interpretation

If the black coalified fragments are contemporaneous with the Devonian spores then a marine Middle Palaeozoic source is proposed for some of the sediment deposited during Late Albian times. The occurrence of Tasmanites sp. indicates that the source of the sediment was nevertheless marine sedimentary rocks.

The abundance of resedimented palynological material further indicates that this marine sedimentary source was rich in organic matter.

The preservation of organic structures and the minimal abrasion observed in carbonised (and therefore relatively brittle) specimens of Tasmanites sp. suggests that very little transport has taken place. It seems unlikely that the specimens would survive active transport. The small pebbles observed in hand-specimen may therefore be the source of this material.