DIMENSIONAL GRAIN ORIENTATION
AND PRELIMINARY RADIOGRAPHIC
STUDIES OF THE SANDSTONES
FROM THE FINGER LAKES STONE QUARRY

DIMENSIONAL GRAIN ORIENTATION AND PRELIMINARY RADIOGRAPHIC STUDIES OF THE SANDSTONES FROM THE FINGER LAKES STONE QUARRY

by

Jan Willem de Grijs

A thesis

Submitted to the Faculty of Arts and Science

in Partial Fulfilment of the Requirements

for the Degree

Bachelor of Science

McMaster University

May, 1971

ABSTRACT

Interbedded turbidite sandstones and shales of the Sonyea Group are exposed in the Finger Lakes Stone Quarry near Ithaca, New York. In 28% of the samples studied the orientation of the grains was not significantly different from a uniform distribution. These distributions included some that were bimodal and some obtained from a bed showing cross-stratification. In 60% of the samples the grain orientations could be considered parallel to the flute marks. As the top of the massive interval was approached the grain orientation became increasingly aligned with the flute marks. A difference of 14° was found between the vector means of the flute and tool marks.

Radiographs made of rock slabs cut from the samples used in grain orientation determinations frequently failed to show internal structures even though these were visible in the samples. A radiograph of one sample (02-08) showed cross-bedding, not visible in the sample or slab. The absence of internal structures in a radiograph do not exclude their being present.

ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to Dr. G. V. Middleton, his research supervisor, for suggesting the topic, his guidance and encouragement during the progress of research.

The following are thanked for their assistance:
Bob Anderson of Nuclear Physics for the Neutron Radiographs,
Don Falkiner for the preparation of thin sections and
Frank Tebay for help in producing X-ray radiographs.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
GEOLOGIC SETTING	2
THE FINGERLAKES LAKES STONE QUARRY	5
a) STRATIGRAPHIC VARIATION	5
b) SEDIMENTARY STRUCTURES	9
i) Flute Marks	9
ii) Tool Marks	9
iii) Internal Structures	9
c) FOSSILS	12
d) PETROLOGY OF THE SANDSTONES	12
GRAIN ORIENTATION	14
a) SELECTION OF SAMPLES	14
b) TREATMENT OF DATA	16
c) OPERATOR VARIATION	17
i) Consistency of Author During Study	17
ii) Discussion	18
d) IMBRICATION	28
e) RESULTS OF GRAIN ORIENTATIONS	
f) GRAIN ORIENTATION DISCUSSION	28
X-RAY TECHNIQUES	
a) INTRODUCTION	35
b) X-RAY PRINCIPALS	35
i) Film Focus Distance	37
ii) Exposure	37
iii) Kilovoltage	39
iv) Nature of the Sample	39

Page

c) X-RAY EQUIPMENT 40

d) X-RAY FILM 40

e) EXPERIMENTAL PROCEDURES 41

f) RESULTS 44

NEUTRON RADIOGRAPHY 46

CONCLUSIONS 47

REFERENCES CITED 48

LIST OF FIGURES

Figure		Page
1	Location and sketch map - Finger Lakes Stone Quarry	4
2	Measured sections	7
3	Lenses of sandstone in shale	8
4	Orientations	11
5	i. An example of cross-bedding in sandstone	13
	ii. Sole marks - showing flute marks	13
6	Graphs of grain orientations	23-27
7	Imbrications	29
8	Height above base versus deviation, for measured flute mark directions	33
9	Generation of focus spot	38
10	Exposure versus thickness	45

LIST OF TABLES

Table		Page
1	Modal analysis of sandstones	14
2	Duplicates by three operators	20
3	Analysis of variance: three operators	20
4	Replicates of two slides by author	21
5	Analysis of variance	21
6	Stastical data of grain orientations	22-23
7	Stastical data of imbrications	28
8	Mean grain orientations of individual beds and with known palaeocurrent directions	34
9	Thicknesses of individual rock slabs	41
10	Determinations of developing time	43

INTRODUCTION

Early studies of grain orientation of elongate sandgrains showed that the orientations were parallel to the current directions. Stanley (1963) showed that in the lower graded portion of the sandstone beds the orientations were sub-parallel and in current ripple and laminated intervals at right angles to the current direction. Onions (1965) found no relationship between the deviations or the measure of dispersion of the grain orientations with the height of the sample in the bed. Parkash (1969) found grain orientations to be stastically non-significant in the upper massive part in the proximal part of the bed. There was an increase in deviation of grain orientation from sole mark orientation upwards from the base of the bed.

The purpose of this study was to determine the grain orientation in sandstones and establish if there is any relationship between the current directions, determined from the sole marks. Previous studies have indicated that grain and sole orientations may be parallel (Smoor, 1960, McIver, 1961, McBride, 1962, Levé and Owen, 1969, Parkash, 1969) perpendicular (Basset and Walton, 1960, Bouma, 1962, Ballance, 1964) or oblique (Spotts, 1964, Spotts and Waser, 1964, Scott, 1967). Furthermore, it was the purpose of the present study to determine whether or not there were differences in the direction or dispersion of grain orientation between the massive and parallel laminated intervals of individual beds.

The Upper Devonian sandstones of the Finger Lakes Stone Quarry were chosen for this study. They are flat lying, show graded bedding, parallel laminations, ripple drift and cross-bedding both large and small scale and are interbedded with shales. From the assemblage of sedimentary structures it may be inferred that the sandstones were deposited by turbidity currents. Rock slabs cut from these beds were examined by means of x-ray techniques in order to determine whether or not internal structures, e.g. cross-bedding, were present in the apparently massive intervals.

GEOLOGIC SETTING

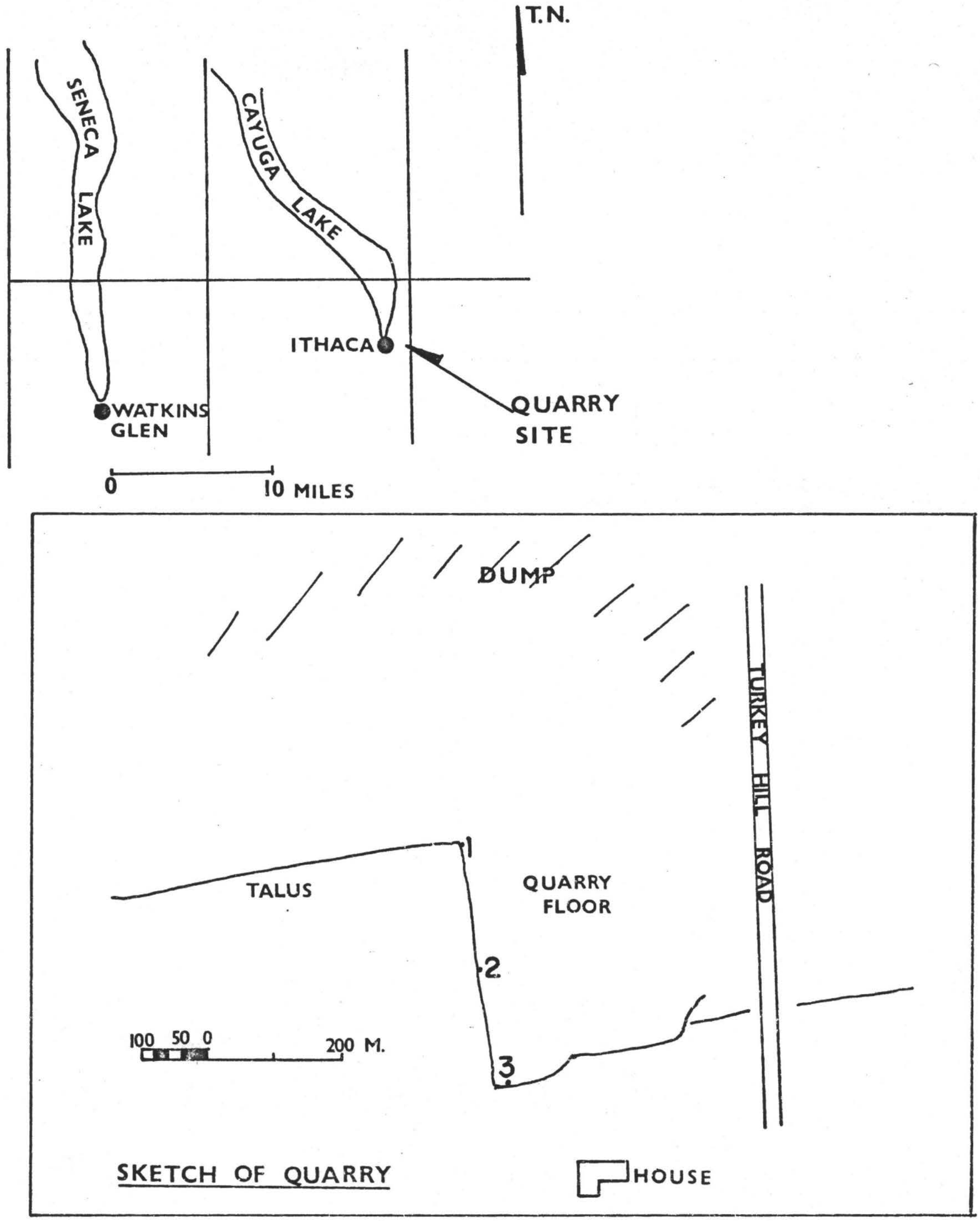
The Upper Devonian of New York State is made up of clastics of the Catshill Front.

The term "Portage" formation was used for many years to describe the alternating beds of shales and siltstones around Ithaca and was replaced by the Naples Group of the Middle Senecan Series (Keunen, 1956). The Naples Group in South Central New York State was subdivided into two formations, Middlesex and Sonyea, that are of late Devonian age and form a westward thinning wedge of clastics (Sutton, 1963). Walker and Sutton (1967) term the Sonyea as a group of the Senecan Series Finger Lakes Stage. Sutton et al (1970) divide the Upper Devonian of New York into a number of groups.

The major portion of the Upper Devonian of South Central New York State consists of approximately 2000 feet of shales and siltstones, the "Portage lithofacies" (Humes, 1960, Sutton, 1963). In the Ithaca region the Sonyea is synonomous with the Endfield (Humes, 1960).

The Finger Lakes Stone Quarry is believed by the author to lie in the Sonyea Group, though detailed stratigraphic correlation is required to ascertain to which member it belongs.

The Finger Lakes Stone Quarry lies some four miles east of Ithaca, New York. The quarry lies astride the Turkey Hill Road 2.4 miles from the junction of Highway 366 (Fig. 1).



1
2 MEASURED SECTIONS.
3

FIG. I: LOCATION AND SKETCH MAP-

FINGER LAKES STONE QUARRY.

THE FINGER LAKES STONE QUARRY

The quarry consists of alternating beds of fine grained sandstones and siltstones, and shales. The beds are flat lying. The greatest dip measured was $\pm 2^{\circ}$. The maximum exposed section in the quarry is about 10 meters thick. The sandstone beds are about 10-30 cms. thick though there are a large number of thinner beds forming lenses in the shales. The ratio of shale to sandstone is about 1:1. The sandstones generally show ripple marks, trace fossils, cross-bedding and internal structures. The base of the sandstones is sharp except for some bioturbation and shows sole marks. The palaeocurrent directions could not always be determined.

The shales are dark and extremely brittle. The base of the shale beds are generally deposited on a current ripple surface of the sandstones (Keunen, 1956) and frequently show signs of bioturbation.

Three short sections, 3.17, 2.51 and 2.35 in. were measured (Fig. 2). The height of the measured sections was restricted by the considerable amount of talus produced by active quarrying.

Two sets of near vertical joints, which persisted throughout the quarry, are present. They have average directions of strike 172° dip 87E and strike 117° dip 83N.

A number of concretions, up to 1 metre in diameter were observed. These are somewhat "Browner" than the adjacent greywackes and appear to be sideritic.

STRATIGRAPHIC VARIATION

Measured sections see Fig. 2. The ratio of sandstones to shales is 0.52 for all measured sections. The ratio increases from the northern to southern measured section, 0.45 to 0.61. The lateral extent of the individual sandstone horizons is variable some wedged out within 2 metres (02-04). None of the beds could be traced for more than 100 metres normal to the marks. On occasions the beds pinched out rapidly over a short distance even though they were of considerable thickness, e.g. bed 03-05 was 30 cms. thick and pinched out in approximately 1.5 metres. The pinch outs occurs when a relatively thick sandstone bed shows characteristics of scour and subsequently deposition of shales draped over the end of the beds. The beds were more continuous parallel to the sole marks and extended for at least 100 metres. The general character of the sandstone beds are long and lenticular.

The shales contain numerous lenses of silty and well cross-bedded sandstones. The lenses are up to 1.5 metres long and 5 cms. thick (average about 2 cms. thick), and interfinger with each other. Possibly they were produced by deposition from small Turbidity currents (Fig. 3).

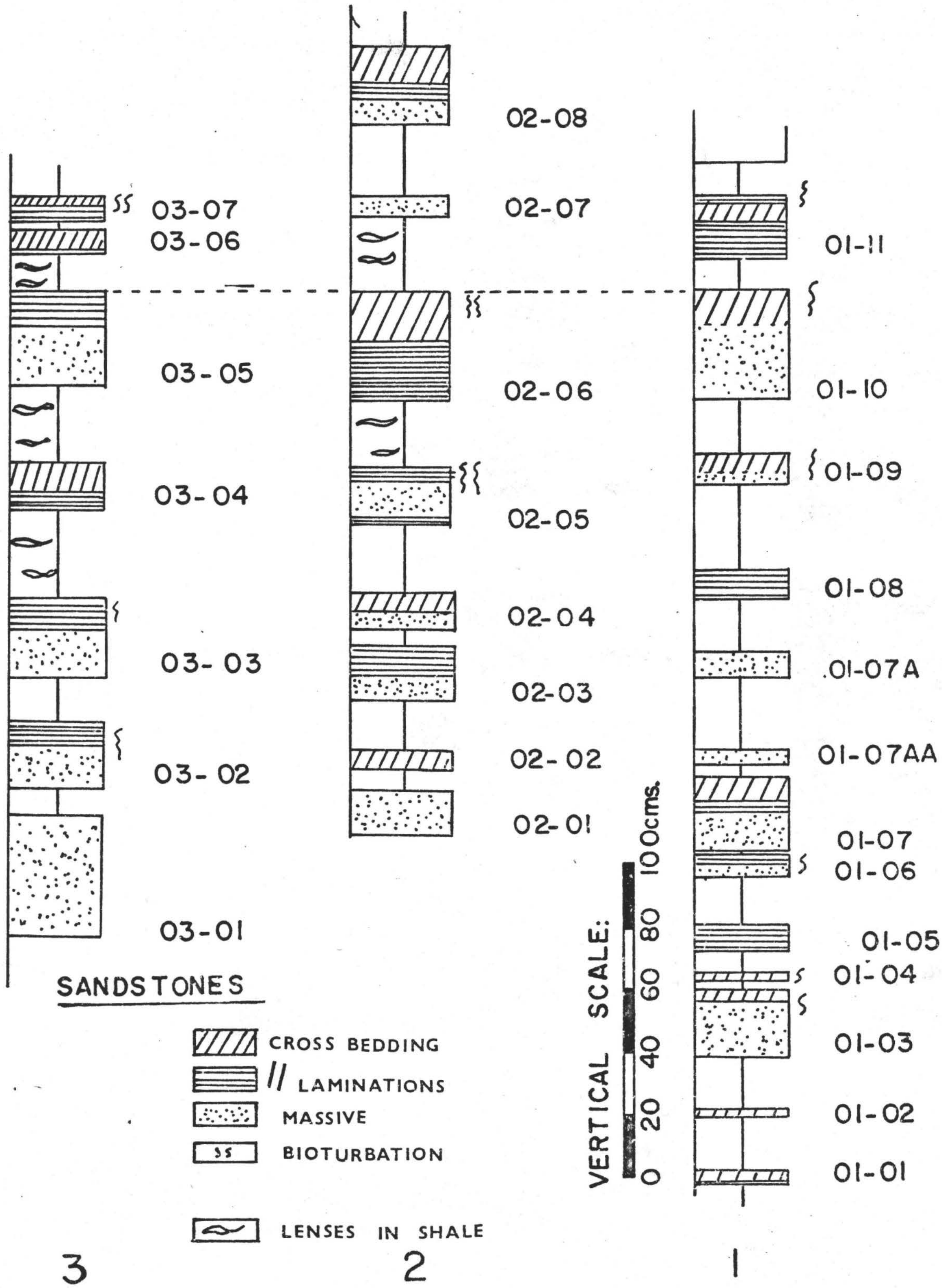


FIG. 2 : MEASURED SECTIONS

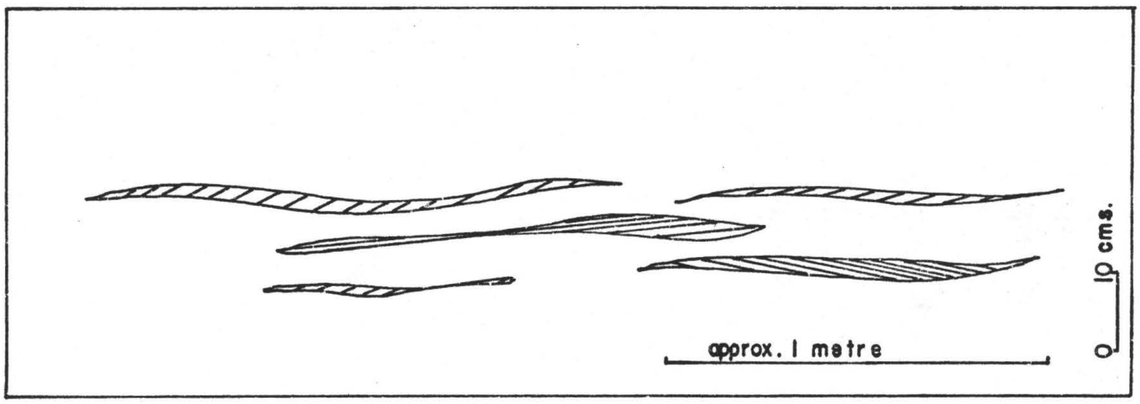


FIG.3 LENSES OF SANDSTONE IN SHALE.

They were found high in the measured sections and were more abundant in the southerly measured section.

SEDIMENTARY STRUCTURES

The sedimentary structures consist of sole marks namely flute and tool marks and internal structures. Current directions using sole marks were determined.

i) Flute marks

Whenever possible the orientation of the flute marks beneath the greywackes was determined. An average value was obtained in the field for each horizon, and this gave a resultant vector of 293° for the horizons measured (Fig. 4).

ii) Tool marks

Tool marks were found. An average value was obtained in the field for each horizon. Six measurements gave an arithmetic mean of 276°. The tool marks were small and formed by shell fragments. Large tool marks were also found but not *in situ*.

iii) Internal structures

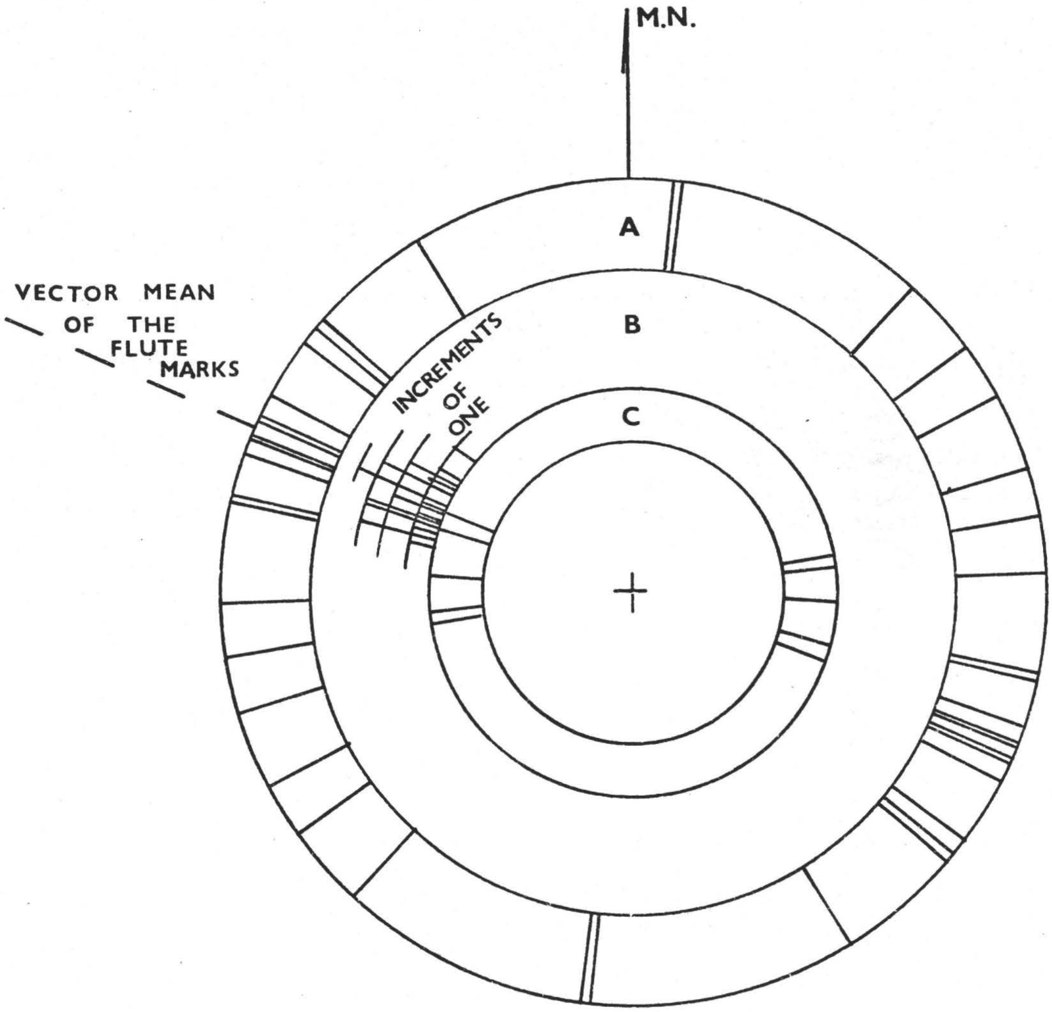
Sheldon (1928) describes the internal stucture for the sandstone horizons of the "Portage" formation around Ithaca:

ordinary ripple or large scale cross-bedding

minute cross-bedding

flat sedimentation

massive



A - GRAIN ORIENTATIONS

B - FLUTE MARKS

C - TOOL MARKS

ORIENTATIONS

FIGURE 4

Some of the sequences may be missing in individual beds according to Sheldon. This sequence approximates the widely used model of Bouma (1962):

e. pelitic interval

d. upper interval of parallel lamination

c. interval of current ripple lamination

b. lower interval of parallel lamination

a. graded interval

In the sections measured many of the intervals were missing but only one bed (02-05) apparently failed to fit the model having a sequence parallel laminated - passive - parallel laminated. A number of quarried blocks and occasional beds exposed in the quarry face had large scale low angle cross-bedding. In the measured sections this was seen for bed 02-08 after x-raying a slab cut from the sample 02-08 (Fig. 5).

FOSSILS

The following fossils were observed in the siltstones:

i) Plant remains preserved as small carbonaceour fragments.

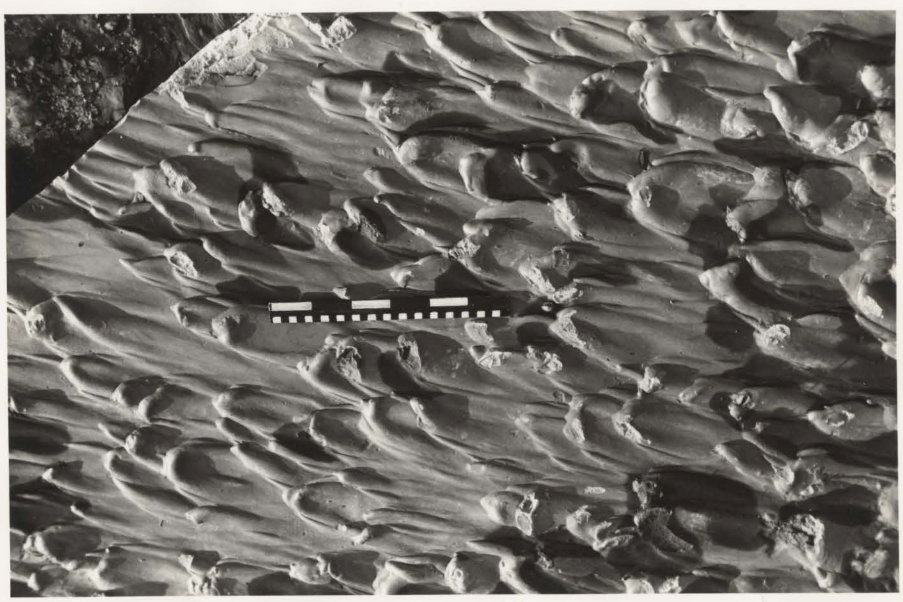
ii) Spirifers found but rare and no further identification was attempted.

iii) Lebensspuren found as vertical burrows and random trails along bedding planes. There are two distinct size of burrow (?Anthrophycus).

PETROLOGY OF THE SANDSTONES

The grain size of the sandstones tended towards silt size. The modal analysis of the minerals for a number of specimens was determined

i. An example of cross-bedding in sandstone.



ii. Sole marks - showing flute marks.

Fig. 5.

(Table 1). The quartz grains were polycrystalline and moderately well sorted. Calcite partially replacing the quartz. Only about 1% feldspar is present: some grains are highly altered and some moderately fresh.

Specimen	Quartz + Chart	Feldspar	Mica	Calcite	"Clays"	Opaques	Access -ories
01-07-19	58	2	13	9	14	3	1
01-07-13	54	2	16	5	20	3	-
02-07	58	2	18	12	17	2	1
03-05-02	68	-	12	11	10	1	1
03-05-03	67	-	14	5	7	4	-
MEAN	61	1.2	14.6	8.4	15.2	2.6	

CLAY - VERY FINE GRAINED MICAS

Table 1. - Modal Analysis of Sandstones.

The sandstones show slight grading upward in the massive interval, but due to the fine grained nature of the samples was not readily discernable.

GRAIN ORIENTATION

Selection of samples

Samples for grain orientation were selected from beds showing a general sequence of a massive interval grading into a parallel laminated interval. A number of thin sections were cut at approximately regular intervals from each of the chosen beds.

As each specimen was collected in the field the top and bottom and north magnetic direction were marked on it. If palaeocurrent directions were available for the bed being sampled they were measured using a

Brunton Compass.

Thin sectioning

Specimens to be used for grain orientation studies were positioned in a vice and cored perpendicular to the depositional surface at a position on the specimen chosen at random. The cores were 2.2 cms. in diameter and approximately 6 cms. in length. These were marked indicating top, bottom, the reference azimuth and "specimen" number.

Details for preparing mounted orientated thin sections are given in Onions (1965) and Martin (1965). Checks were made to determine the degree of accuracy of the reference azimuth. In the field the accuracy of the reference azimuth, marked on the specimen was $\pm 2^{\circ}$. Coring and preparation of the thin sections could add another $\pm 3^{\circ}$. The reference azimuth has a maximum possible error of $\pm 5^{\circ}$. It is of great importance that the specimens are always mounted the right way up on the slide otherwise readings of 180° minus "measured orientation" are obtained. Martin (1965) found seven slides out of 154 were inadevertently overturned during the preparation of these sections.

Measurement of the grain orientation

A petrographic microscope equipped with a cross hair ocular and mechanical point count stage were employed to measure the grain orientation. Only quartz grains were used in order to maintain uniformity of grain type and so decrease possible variations in hydrodynamic behaviour of the grains. The same procedure as previous grain orientation studies by Smoor (1960), Onions (1965), Martin (1965) and Parkash (1969) was used to permit comparisons with these earlier studies.

The East-West direction was used as the reference azimuth. The grains were selected by transversing in steps of 1 mm. North-South and 2 mm. East-West. If the entire thin section was covered and 100 grains had not been counted the East-West transverse was moved 1 mm. and subsequently 2 mm. after completion of the North-South transverse. The orientation was measured on those grains having an elongation ratio of less than 0.7. The elongation ratio is given by b/a, where "a" is the long axis of the quartz grain and "b" the longer intercept at right angles to "a". The elongation ratio was estimated visually with the aid of Smoor's figure (Smoor, 1960, p.17).

The same microscope and mechanical point count stage was used throughout the study. The magnification was 80X.

The number of grains counted was 100 per thin section. Smoor (1960) and Parkash (1969) found that 100 measurements were sufficient for grain orientation studies.

Treatment of Data

Grain orientation is measured as an azimuth in a plane. Using a computer programme (Martin, 1965) on a CDC 6400. The line of movement, that is the direction of palaeocurrent but not the sense, and the vector magnitude (L) expressed as a percentage was determined for ungrouped data. The line of movement gave values from 0-180^{o} and the vector magnitude can vary from 0%-100%, where 0% is a uniform distribution vector magnitude is a sensitive measure of dispersion of circular data and is independent of the origin (Curray, 1956). The Turkey Chi - square test (in Harrison, 1957) for preferred orientation was determined manually using a desk calculation. The standard deviation was determined using (Curray, 1956):

$Sc = 52.3 - 0.340L$ where empirical standard deviation was contrasted with the theoretical standard deviation derived from an infinite population.

The 95% confidence interval given by (Dixon and Massey, 1969) is:

$$\bar{x} - \frac{1.96\sigma}{\sqrt{N}} < \mu < \bar{x} + \frac{1.96\sigma}{\sqrt{N}}$$

where $\sigma/\sqrt{N}$ = standard deviation

N = number of observations

x = sampling distribution

μ = mean

OPERATOR VARIATION

In previous studies Smoor (1960) and Onions (1965) ran a series of experiments to determine the magnitude of operator error in grain orientation studies. The grain orientation of the slide AH4 was determined by three operators and two sets of 100 point counts obtained. The data was subjected to an analysis of variance (Dixon and Massey, 1969). A probability of α 0.1 was used.

The F was significant between operators (Tables 2 and 3) variance between operators is 41.3 giving a standard deviation of 6.4. The F test between point counts was non-significant.

CONSISTENCY OF AUTHOR DURING STUDY

The grain orientation of two slides was determined three times during the course of the study. The result (Tables 4 and 5) shows non-significant results between point counts. The variance between point counts was 21.0 giving a standard deviation of 4.6.

DISCUSSION

The results show a good measure of consistency between operators and replicate measurements. Smoor (1960), Onions (1965) and Martini (1965) found that the accuracy and consistency of grain orientation measurements is quite high.

RESULTS OF GRAIN ORIENTATION

Figure 6 shows the graphical results of the grain orientations, Table 6 gives the stastical data.

The relationship of the significant grain orientations for all sections in the sandstones to the sole marks tended to be parallel. Sixty percent of the measured grain orientations fell within $\pm 30^\circ$ of the vector mean for the sole marks and were considered to be parallel, 20% were oblique and 20% were perpendicular. None of the grain orientations from the parallel laminated intervals were perpendicular, 66% were parallel and the remainder were oblique. In the massive interval the perpendicular grain orientations were in the lower third of the beds. As the top of the massive interval was approached the grain orientations tended to be parallel to the flute marks (Fig. 7). The lower 1 cm. of the bed from the massive interval tended to have a bimodal distribution (beds 01-03, 01-07 and 02-05).

There was an overall even distribution of the deviations of the grain orientation about the vector mean of the flute marks. No clear trend in the dispersion could be determined from the grain orientation and the height above the base of the bed for example bed 01-07 there was a decrease and bed 01-06 there was an increase in dispersion.

Thin Section	#1		#2		
Operators	θ	L	θ	L	Δθ
G	26	55.2	25	53.6	1
B	13	37.1	12	50.0	1
W	20	35.1	13	41.4	7
				AVE	23

Table 2. - Duplicates by Three Operators.

Source of Error	SS	DF	MS	F	$F_{0.90}$
Between Operator Row Means	177.3	2	88.6	14.8	9.00
Between Point Counts Column Means	13.5	1	13.5	2.25	8.53
Residual	12.0	2	6.0		
Total	202.8	5			

Table 3. - Analysis of Variance: Three Operators.

	Point Count #1		Point Count #2		Point Count #3	
Thin Section	θ	L	θ	L	θ	L
01-07-03	112	36.3	109	39.6	97	42.1
AH4	20	35.1	13	41.4	13	36.1

Table 4. - Replicates of Two Slides by Author.

Source of Error	SS	DF	MS	F	$F_{0.9}$
Between Point Counts	121.3	2	60.7	3.25	9.00
Between Thin Sections	12330.7	1	12330.7	660.7	8.53
Residual	37.3	2	18.6		
Total	12489.3	5			

Table 5. - Analysis of Variance.

Table 6. - Statistical Data of Grain Orientations.

Specimen	Vector Mean	L	CHI^2	"SD"	95%	Structure	Thickness of Bed	Height of Specimen Above Base CMS.	Bimodal	Deviation from Sole Mark
01-01-01	103	44.0	41.5	37.3	7.3	// lam	5.5	0.5		-11
01-03-00	118	19.5	8.5	45.6	8.9	massive		0.5	YES	-2
01-03-01	6	59.0	69.6	32.2	6.3	massive		6		+76
01-03-02	130	4.0	3.5	50.9	10.0	massive	22 cms.	17		+10
01-03-03	88	35.5	21.4	40.2	7.9	massive		19		-32
01-05	102	26.8	14.4	43.2	8.5	// lam	8	5		
01-06-00	43	64.3	73.8	30.4	6.0	massive		3		
01-06-01	62	53.4	62.9	34.1	6.7	massive	13	5		
01-06-02	127	43.4	41.9	37.5	7.3	// lam		9		
01-07-00	67	48.9	37.4	37.3	7.3	massive		0.5		-55
01-07-01	112	36.6	27.4	39.9	7.8	massive		2		6
01-07-02	80	60.0	68.4	31.9	6.2	massive	23	12		-26
01-07-03	114	42.1	39.6	38.6	7.4	// lam		16		8
02-03	118	34.1	20.4	41.1	8.0	massive	17.5	1.5		-11
02-04	114	12.4	1.45	48.1	9.4	massive	11.5	2.4	YES	

Table 6. - Statistical Data of Grain Orientations (cont.)

Specimen	Vector Mean	L	CHI^2	"SD"	95%	Structure	Thickness of Bed	Height of Specimen Above Base CMS.	Bimodal	Deviation from Sole Mark
02-05-00	84	39.4	30.1	38.9	7.6	massive		0.5	YES	-21
02-05-01	7	49.0	47.9	35.6	7.0	massive	16	7		+82
02-05-02	7	45.0	30.1	37.0	7.3	// lam		14	YES	+82
02-06-00	54	41.6	35.0	38.2	7.5	// lam	34	7		
02-06-01	112	38.5	29.0	39.2	7.7	// lam		10.5		
02-07-00	110	42.2	38.6	38.0	7.4	massive	7	3		
02-07-01	85	37.0	27.2	39.7	7.8	massive		5.5		
02-08-00*	117	43.4	39.3	37.5	7.4	// lam	26	2		
02-08-01*	130	55.6	58.7	33.4	6.5	// lam		13		
03-03-00	181	45.1	37.7	37.0	7.2	massive	23	4		
03-03-01	114	42.4	34.8	37.8	7.4	massive		9		
03-05-00	73	52.0	46.9	34.6	6.8	massive	24	2		-35
03-05-01	NS	40.5	23.8	NS	NS	massive		7	YES	
#30	149	37.7	29.4	39.5	7.7	// lam				

* 02-08 is cross-bedded.

- dev ccw

+ dev cw

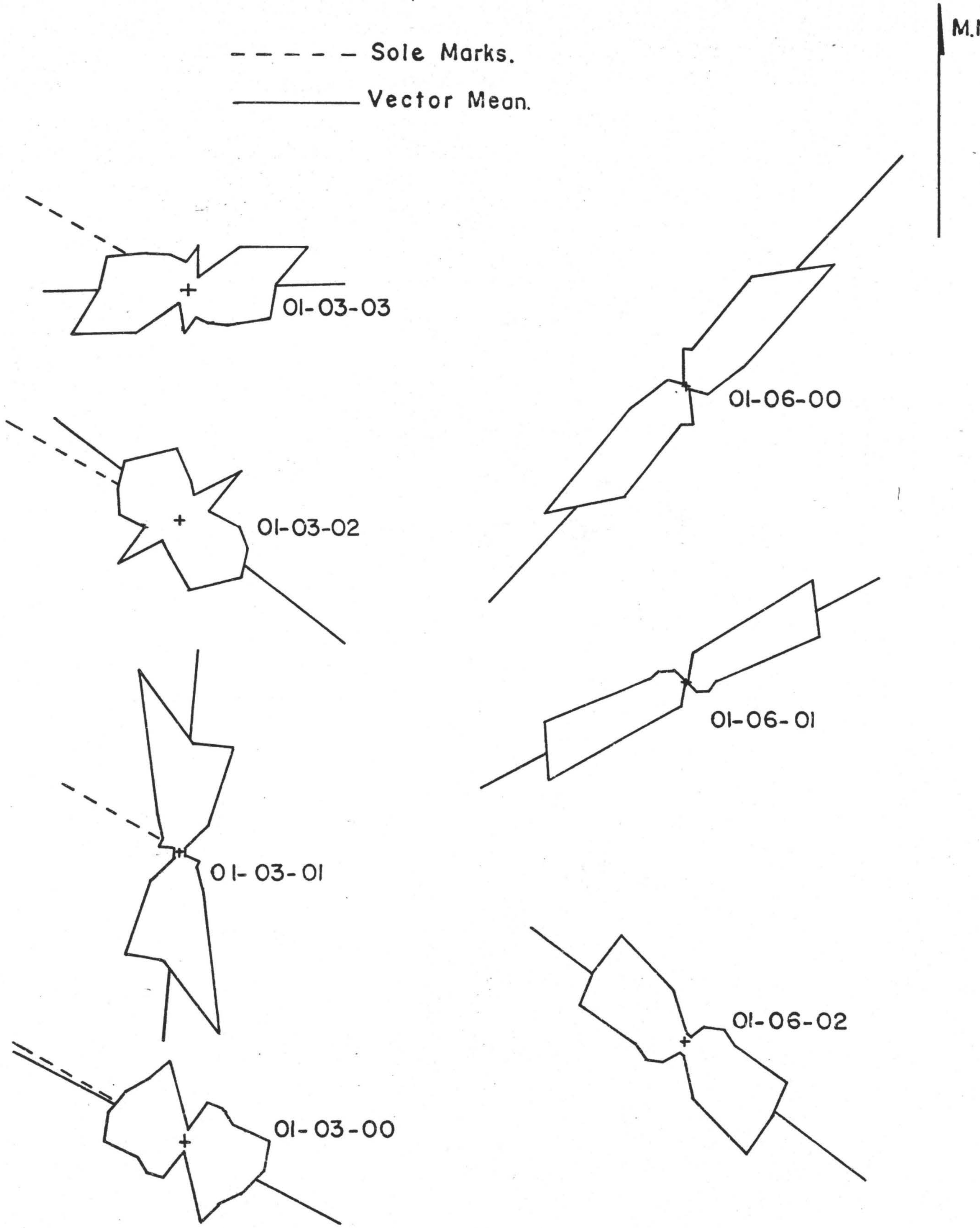


FIG.6: GRAPHS OF GRAIN ORIENTATIONS

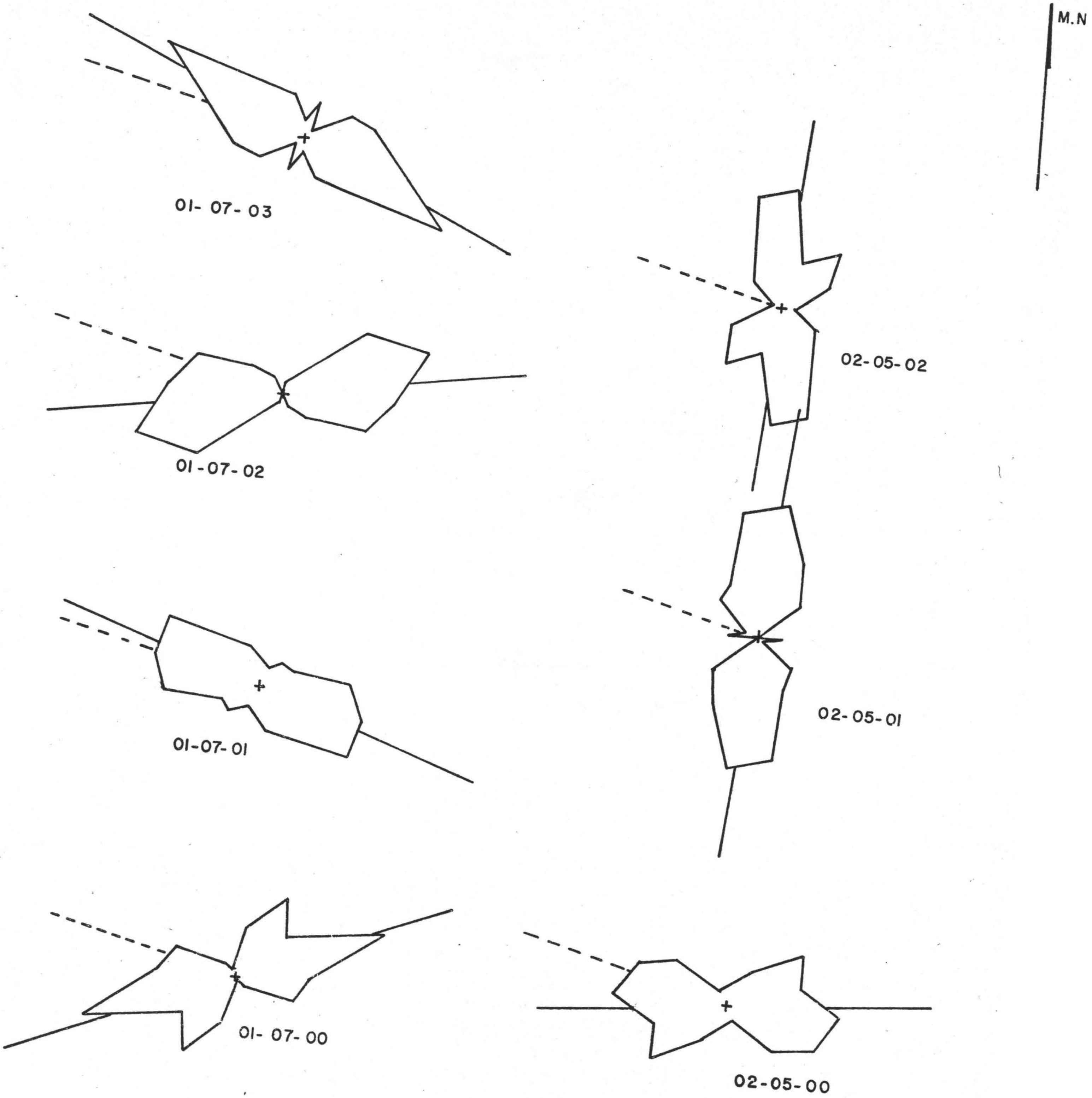


FIG. 6: CONT.

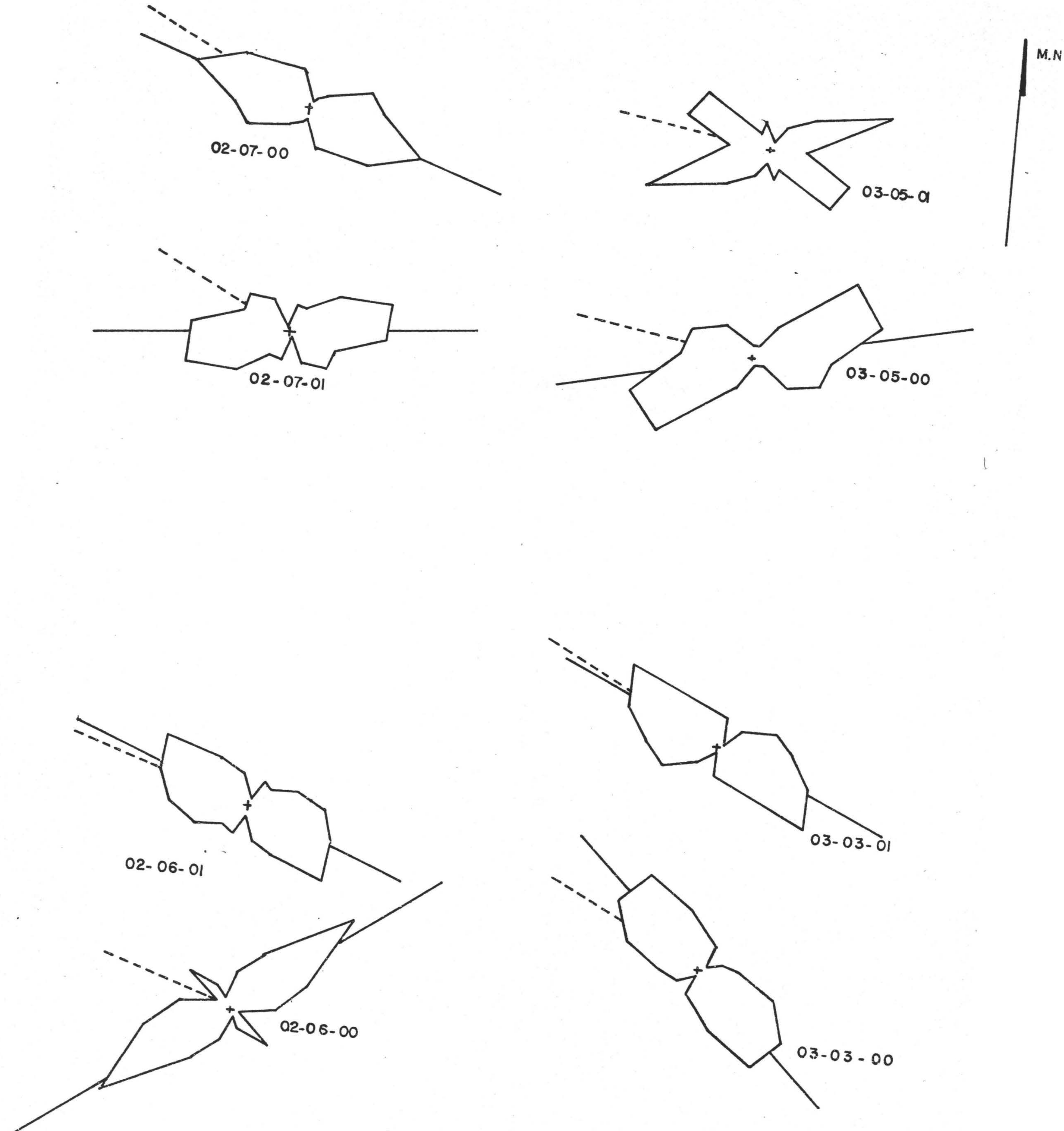

M.N
02-07-00
03-05-01
02-07-01
03-05-00
03-03-01
02-06-01
02-06-00
03-03-00

FIG.6: CONT.

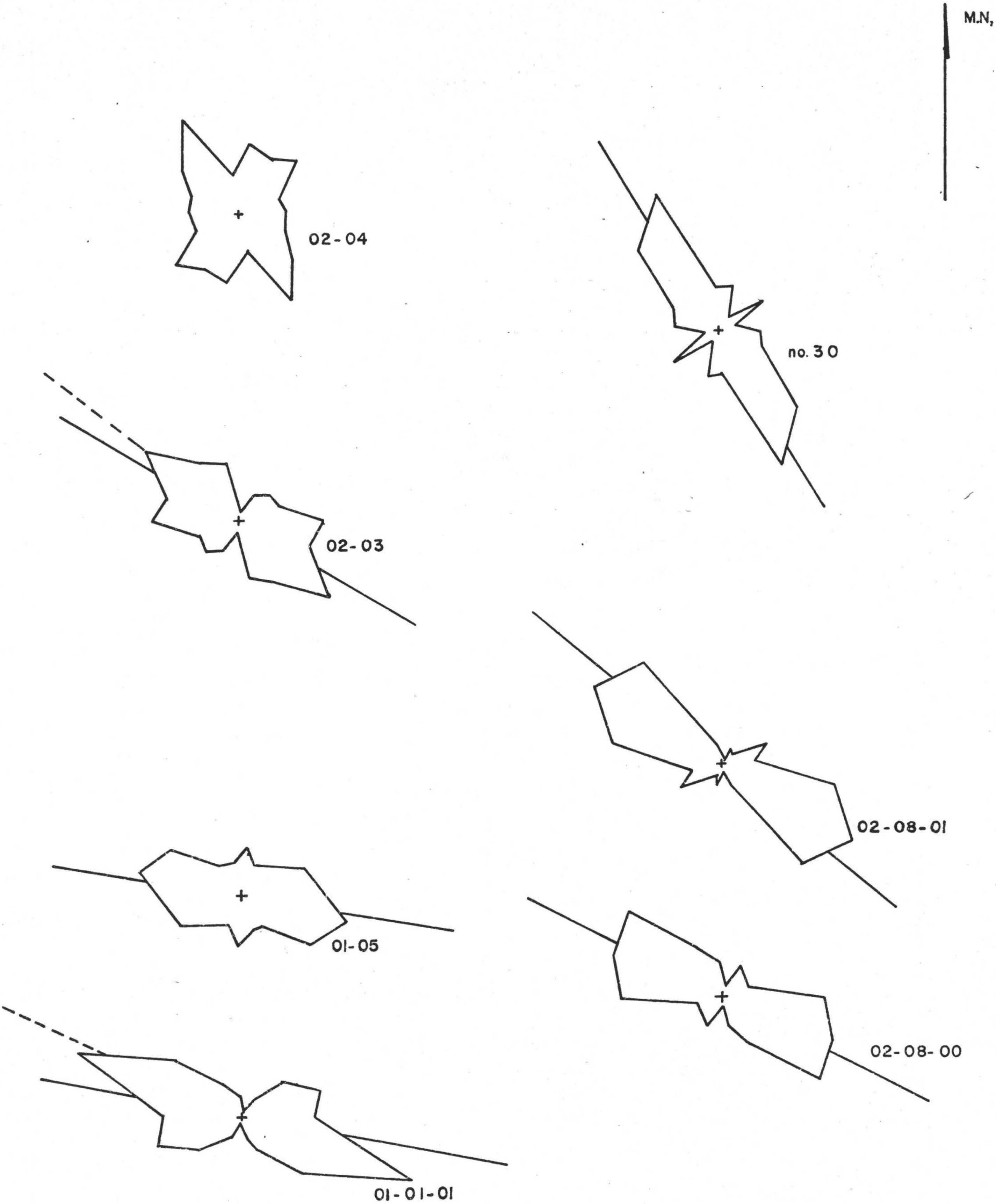
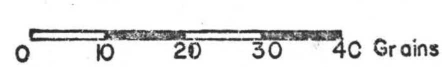

M.N.
02-04
no. 30
02-03
02-08-01
01-05
02-08-00
01-01-01

FIG. 6: CONT.


0 10 20 30 40 Grains

IMBRICATION

Four sections were cut parallel to the vector mean grain orientation direction and perpendicular to the bedding plane. The sections showed a low angle of imbrication (less than 20°) and were upcurrent (Table 8 and Figure 7).

Specimen	Vector Mean	L	CHI^2	"SD"	95%
01-07-01-I	20°	90.7	161	21.5	4.2
01-07-02-I	11°	90.6	160	21.5	4.2
02-05-01-I	9°	89.9	161	21.7	4.3
03-03-00-I	11°	80.9	124	24.8	4.9

Table 7. - Stastical Data of Imbrications.

The four thin sections for imbrication show a significant preferred orientation at the 95% level of confidence. These are all from the massive interval. Bed 01-07 shows a decrease in imbrication from the base up. This is based on two sections only. Specimen 03-03-00-I, near the base of bed 03-03, shows a relatively decreased imbrication as compared to the 20° found in 01-07-01-I which also occurs near the base.

GRAIN ORIENTATION DISCUSSION

The degree of grain orientation depends on the processes by which the particles come to rest. The following types of processes are found:

a) mass deposition

b) deposition from suspension

c) deposition from traction carpet.

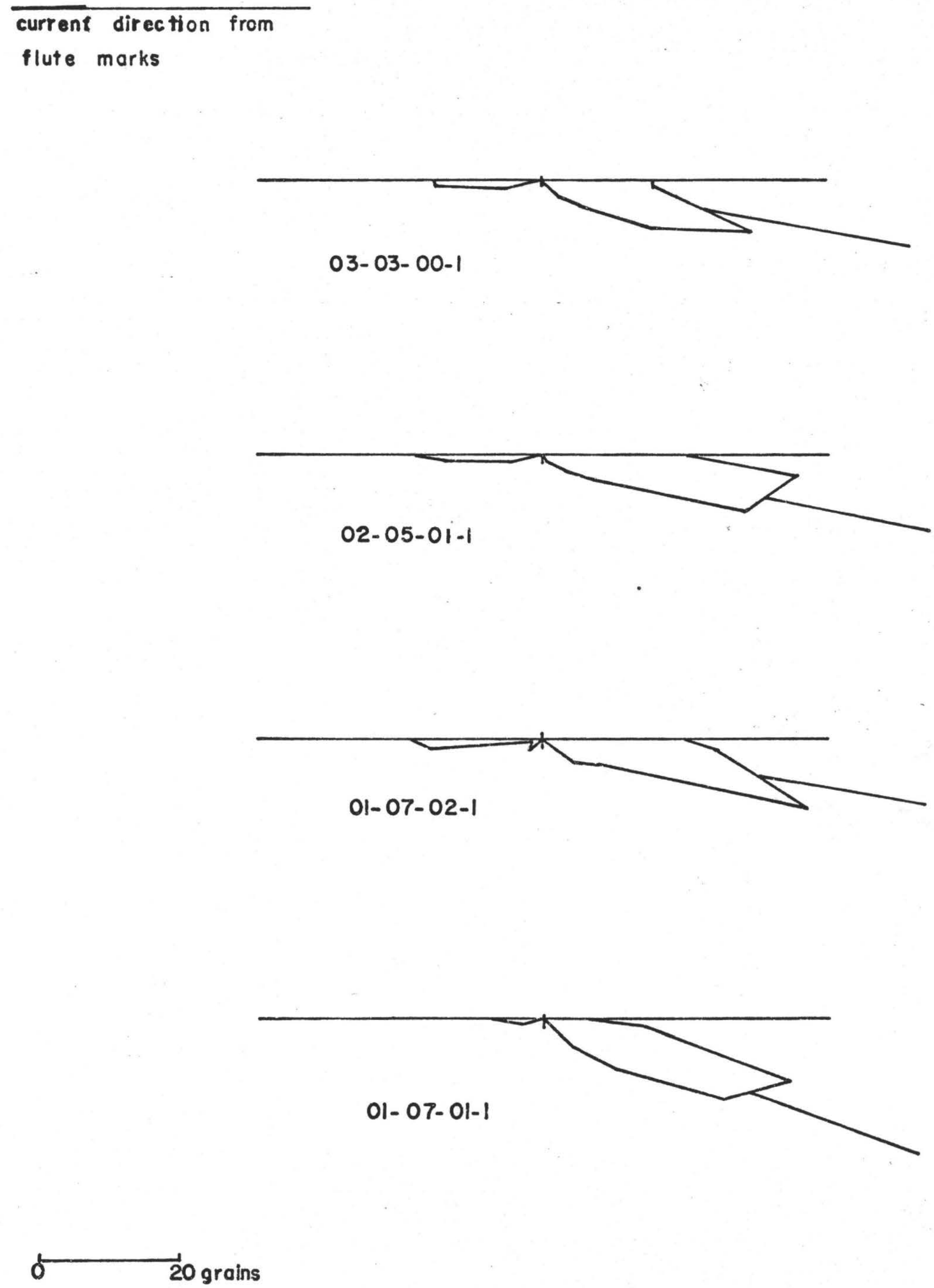


FIG. 8 IMBRICATIONS

Rusnak (1957) and Graf (1965) using theoretical considerations come to the conclusion that an elongate body will tend to set itself broadside to the relative motion. Gibbons (1969) states the necessity of initial investigation parallel to bedding for grain orientation may show two preferred directions especially when the imbrication is steep. In the four specimens examined for imbrication the angle was low, less than 20°, and upcurrent. Now because of the imbrication the bedding section is not a principal section of the fabric. Gibbons (1969) suggests that a measure of dispersion would be more meaningful in a section cut parallel to the internal structures. Grain orientation is dependent on the shape orientation and more basic data are required to study the geometry of imbricated fabrics.

The relationship between the grain orientation and sole marks have been studied and the following have been reported, parallelism, perpendicularism and obliqueism orientations of sand grains and sole marks (Parkash, 1969). Within individual beds considerable vertical and lateral variation occurs (Onions and Middleton, 1969, Colburn, 1968, Parkash, 1969).

In this study no attempts were made to establish lateral variations. Vertical variation was considerable in individual beds. The tendency in parallel laminated intervals was for grains to be aligned parallel to the sole marks. The massive interval showed increased alignment of grains with the sole marks in the sections from the top of the bed. These findings differ from Parkash (1969).

To determine what structures, if any, were present in the beds examined for grain orientation slabs were cut for X-raying. The radiographs showed only one sample having structures not seen in the hand specimen namely 02-08. The structure was large scale cross-bedding and the results for 02-08 are not considered valid (Gibbons, 1969) though the statistics were determined. It should be emphasized that even if no structures are seen in radiographs of massive beds it does not necessarily imply that the sediments are structureless.

The average of the deviations between the mean of the grain orientations and the flute marks was 18°, anticlockwise for those beds having measured flute mark directions. This difference is greater than expected from operator error (Table 8 and Fig. 8).

Alternative explanation for the deviation between the means of the grain orientations and flute marks can be considered to be one of the following or a combination thereof (after Parkash, 1970).

i) Coriolis forces

ii) "Ocean" currents flowing at an angle to the turbidity currents

iii) Topographic effects.

Before Coriolis forces can be considered it is necessary to know the position of the North Pole during the Upper Devonian. Irving (1964) gives a position by palaeomagnetic studies of approximately 32°N 120°E relative to the present position of New York State. This puts New York State in the Southern Hemisphere during the Upper Devonian. The Coriolis forces could have deflected the turbidity current anticlockwise.

The depositional basin was a shallow epicontinental sea (Colton, 1967) with Western New York being on the Western seaboard. The current directions in the epicontinental sea during the Upper Devonian were Northeast to Southwest (Colton, 1967). The cause of the deflection could be due to the sea currents. The initial turbidity current is marked by the flute marks, as this slowed tools and grains were deflected by the sea currents accounting for the deviations observed.

Hence both i) and ii) could be used as possible explanations for the observed deflections.

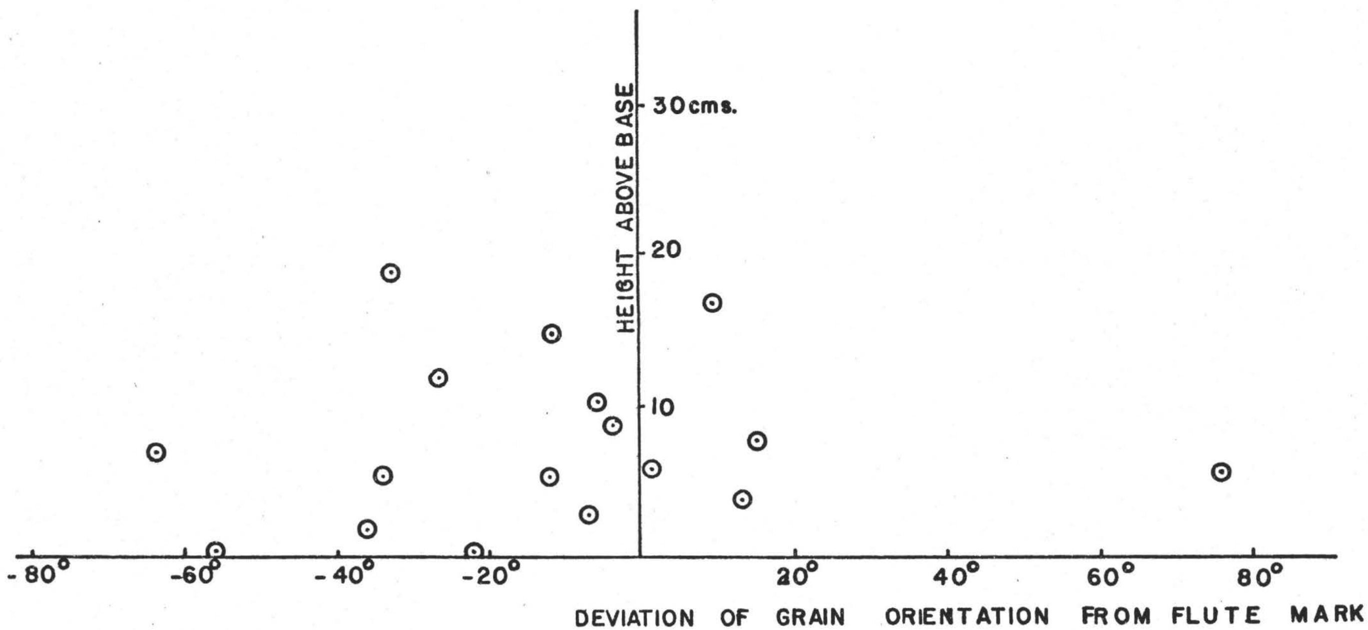


FIG.7. HEIGHT ABOVE BASE VERSUS DEVIATION.

Bed	Palaeocurrent direction	Grain Orientations	Mean of grain orientations
01-01-01	294° (114°)	103°	-
01-03	300° (120°)	6°,88°	-
01-07	286° (106°)	67°,112°,80°,114°	93°
02-03	309° (129°)	118°	-
02-05	285° (105°)	7°	-
02-06	297° (117°)	54°,112°	83°
02-07	298° (118°)	110°,85°	97.5°
03-03	297° (117°)	114°,131°	122.5°
03-05	288° (108°)	73°	-

Note: i) Only beds with measured palaeocurrent directions are included.

ii) Only significant grain orientations are included.

Table 8. - Mean grain orientations of individual beds and with known palaeocurrent directions.

The evidence for the influence of topography deflecting the latter stages of the turbidity currents is poor. Colton (1967) suggests original environments of frontal slope of a delta or a series of coalesced deltas advancing westwards during Devonian times. Only by precise location of these features can their influence on the turbidity currents be determined.

Further studies are required before the final solution can be found for deflections observed.

X-RAY TECHNIQUES

INTRODUCTION

The technique of making a photographic image by penetrating radiation such as X-rays or gamma rays is called radiography.

Prior to 1948 some European palaeontologists used radiography for the study and illustration of fossils (Schmidt, 1948). Hamblin (1962) was the first to use X-ray radiography in the study of structures in homogenous sediments using a medical X-ray unit. Subsequently, radiography was used to demonstrate the presence or absence of sedimentary structures in consolidated and unconsolidated sediments (Hamblin, 1965, 1967, Patchen, 1967, Bouma, 1969 and Fraser and James, 1969) and in the study of trace fossils (Farrow, 1966 and Frey, 1970).

In this study X-ray and neutron radiography were tried.

X-RAY PRINCIPALS

The photographic image is produced on a negative by the differential passage of radiation through a specimen. It is essentially a record of variation of density within the specimen. This leads to serious problems for if the definition and resolution are reduced to below a certain level no sedimentary structures will be observed on the negative, even though they may be present.

The amount of radiation emitted by an X-ray tube is dependant on the tube current, tube voltage and the time the tube is energized. Now if the voltage is kept constant the radiation emitted is directly proportional to the tube current multiplied by the time the tube is energized.

The tube current is a measure of the flow of electrons between the anode and cathode, in milliampees. The exposure time is either in minutes or seconds.

As the voltage increases the penetrating power of the X-rays emitted and their intensity also increases. This can frequently be a disadvantage for a decrease in contrast of the photographic image results. The intensity of an X-ray beam is controlled by the tube current.

The attenuation of radiation passing through a specimen is given by the difference between the radiation intensity before and after passing through the specimen. Hence:

$$I_1 = I_0 \, e^{-\mu d}$$

where I_1 = intensity after passing through the specimen

I_0 = original intensity

e = base of natural logarithms

d = thickness of the specimen

μ = linear attenuation coefficient which is obtained from the Bragg and Pierce equation:

$$\mu = Kt^3A^3$$

where K = proportionality factor

t = wave length of monochromatic radiation

A = atomic number of the material

The Bragg and Pierce equation is generally used in the X-raying of metals (Corney, 1963).

The quality of the photographic image produced after passage of radiation through a specimen is a function of several variables:

i) film focus distance

ii) exposure

iii) kilovoltage

iv) nature of the sample.

1. FILM FOCUS DISTANCE

The X-rays are generated in an X-ray tube and hit a target located between the cathode and anode producing a focus spot. (Fig. 9).

The focus spot must be kept small and should be less than 1 mm square (Bauma, 1969) this is to avoid giving "shadows" on the radiograph. The focus film distance is the distance between the focus spot and the film. The specimen must be kept as close as possible to the film. On emerging from the tube the X-rays form a 50^{o} core and the specimen should be at right angles to the X-rays. The focus film distance should be large. Hamblin (1962) uses distances greater than 24 inches.

The intensity of the X-rays drops with the increase in focus film distance by the inverse square law

$$I_1 = l_2 = d_2^{\,2} : d_1^{\,2}$$

where I_1 and I_2 are the intensities at a distance d_1 and d_2.

2. EXPOSURE

The exposure is given by

$$E = Mt$$

where M = tube current

t = exposure time.

The exposure is also dependent on the film focus distance (d) giving an exposure factor (EF)

$$EF = E/d^2$$

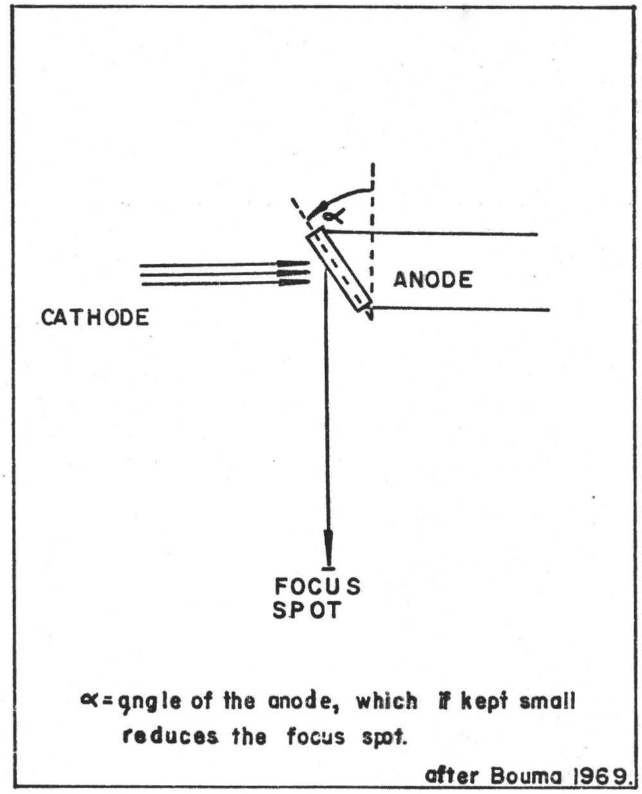


FIG. 9 GENERATION OF FOCUS SPOT.

3. KILOVOLTAGE

The kilovoltage must be kept as low as possible, but still high enough to penetrate the specimen, this was first reported by Schmidt (1948). At low kilovoltages two effects are important (Bouma, 1969):

i) the photoelectric effect results in the absorption of a photon by electrons in the specimen, this can be overcome by increasing the tube current.

ii) Compton effect results from a photon hitting an electron, being partially absorbed and continuing in another direction, this gives scattering on the radiograph. The increase in voltage decreases this effect.

4. NATURE OF THE SAMPLE

Only sandstones were examined. They were derived from three sources. Finger Lakes Stone Quarry, Chelmsford (Sudbury basin) and Gaspé.

Hamblin (1962) and Bouma (1969) have used both cores and plane parallel specimens. In establishing an exposure guide Patchen (1967), Bouma (1969) and Fraser and James (1969) used step wedges. No attempt was made using step wedges because of the difficulty in cutting them. Bouma (1969) found a linear relationship between increasing thickness when kilovoltage was kept constant. Bouma (1969) found that it was adequate to use two thicknesses, 3 and 9 mm., to construct an exposure chart.

Hamblin (1962,1967) suggests rough polishing of the cut sections for X-ray work to remove saw marks. This was not found to be necessary since careful cutting did not produce any saw marks.

The optimum thickness of plane parallel sections was found to be

3 mm. by Patchen (1967), Hamblin (1962,1967) and Bouma (1969). Thinner slabs of fine grained rocks do not yield enough subject contrast and the thicker slabs result in penetration problems and yield blurred images (Patchen,1967, Bouma, 1969).

X-RAY EQUIPMENT

The Philips-Muller Macrotank-K used was installed in a lead box (1/8" lead around the sides, door and top and 1/4" lead in the base, internal dimension 50" x 36" x 36"). The box allowed for adjustment in shelf height. For long exposures a water cooling system for the tube was available but was not required because of the relatively short exposure times. The door was fitted with a fail-safe switch to prevent accidental opening of the apparatus during activation of the tube.

X-RAY FILM

X-ray film differs from ordinary photographic film in that it has two emulsion layers on either side of the film (Bouma, 1969). This increases the film spread, gives greater contrast and speeds up processing and drying times.

In this study two X-ray film sorts were used, Ilford Industrial X-ray film G and Kodak Tri-X, the latter being a single emulsion film.

Kodak Rapid X-ray developer and Kodak X-ray fixer, obtained in concentrated form from the manufacturer, were used for Ilford Industrial X-ray Film G. Both were in use for processing X-ray diffraction film in the department and hence readily available. Kodak Tri-X was tried, using high resolution Kodak developer but yielded poor radiographs lacking in contrast.

The film used was 125 x 175 mm. in size and placed in a Lisco linen screen non ferrous cut film holder. The films were labelled by using lead markers during exposure and a record kept of exposure times, shelf height, amperage, kilovoltage and development time.

In developing X-ray film it is important to use tanks, instead of trays, because of the two emulsion layers. The film is suspended in the tank with a dip hanger and carefully agitated making sure it is always covered by fluid. The film was removed after developing time has elapsed, washed in water and fixed for 10 minutes. Then given a final washing in running water for 30 minutes, removed and dried at room temperature. The dry film was stored in a labelled envelope after removing any rough edges with a guillotine.

EXPERIMENTAL PROCEDURES

Rock slabs were cut from the specimens parallel to the sole marks. Two thicknesses were cut for each specimen, except for some cut serially with increasing thickness. The preferred thickness was 0.3 and 0.9 cms. (Bouma, 1969). These thicknesses were difficult to obtain and the slabs could only be cut to within 0.1 cms. Variations in thickness of individual slabs were extremely small (Table 9).

Thickness of Selected Specimens in cms. Measured Using Vernier Calipers	Mean and S.D. cms.
1. 1.09,1.09,1.09	1.09 + 0.00
2. 0.43,0.41,0.41,0.43,0.41	0.42 + 0.01
3. 0.95,0.92,0.89,0.92,0.95	0.926 + 0.022
4. 0.64,0.68,0.67,0.69,0.66	0.668 + 0.017

Table 9. - Thicknesses of Individual Rock Slabs.

The slabs were X-rayed using the Philips-Muller Macrotank-K. The slab was placed on the cut film holder. A test strip was produced by using a 1/4" thick lead screen(s) and moving the screen or screens according to the parameter being examined. A test strip given an easy method of comparing variations of a given parameter, e.g. exposure time for a given specimen.

Initial exposure times, amperage and kilovoltage and a development time of two minutes was used. Bouma (1969) gives some indication of expected values. The optimum development time was established by examining a number of exposures (Table 10).

The following parameters were then varied one at a time for a number of specimens cut from the same bed exposure time, kilovoltage, exposure time, shelf height and specimen thickness. Graphs of Log of exposure (mA. and minutes) versus thickness were constructed for specimens (Bouma, 1969). For example, specimens #30 and #31 (Fig. 10).

In medical X-ray work a large number of varying positions of the object are used. Specimen #31 was X-rayed at varying angles, that is the angle of the specimen with respect to the film. When the parallel laminations were close to or parallel (at 90° to the cut surface of the slab) with the X-rays the radiograph was sharp, as the angle between the two increased the radiograph showed the formerly sharply defined laminations becoming more and more hazy.

Specimens from each bed gave slightly differing graphs of exposure versus thickness. No other combination of parameters gave "straight line" graphs.

	Exposure Number	Developing Time in Mins.	"Clarity"
Specimen A	1	0.5	Lacks contrast
	2	1	Good
	3	1.5	Fairly good
	4	2	Too dark
	5	2.5	Black
Specimen B	1	0.5	Poor
	2	1	Fairly good
	3	1.5	Good
	4	2	Too dark
	5	2.5	Too dark

For constant kilovoltage 50
Milliamps 2
Exposure Time 2 mins.

Table 10. - Determination of Developing Time.

NOTE

i) Specimens A and B were two slabs cut from #31, thickness 0.4 and 0.9 cms., parallel and adjacent to each other.

ii) "Clarity" due to the expense and time involved in using optical scanning devices (Fraser and James, 1969), all observations were made visually and then compared with suggestions made by the x-ray technician.

RESULTS

Specimens which showed good parallel laminations, ripple drift and cross-bedding in cut slabs and were not excessively fine grained gave good radiographs. Very fine grained "dense" specimens required long exposure times relatively high kilovoltage and frequently failed to reveal or only partially revealed structure otherwise readily visible in hand specimens.

Specimens from the Cloridorme (Gaspé) with "dish structures" failed to show any structure on X-raying except for grading within the bed which is visible in the cut slabs.

Specimens from the Chelmsford Sandstone (Sudbury) showing sheet structures in hand specimens failed to show these on X-raying.

A number of supposedly massive beds when cut into slabs revealed parallel laminations visible to the naked eye, these were also seen in the radiographs.

Cores (2.2 cms. in diameter) and more or less uncut slab like specimens (up to 1.5 cms. thick) were also X-rayed but it was found that the irregular shadows produced by the specimens made any internal structures difficult to see in the radiograph even though they are readily visible to the naked eye.

Ilford Industrial X-ray Film G gave clear radiographs with very little grain and good contrast. Bouma (1969) states that Ilford Industrial X-ray Film G is the fastest available from Ilford, with high contrast and useful for thick objects. He did not use it in comparison with other films. The best shelf height was found to be ±80 cms., the amperage was set at 2 millamps.

For most specimens 35 kilovolts was found to be adequate, this

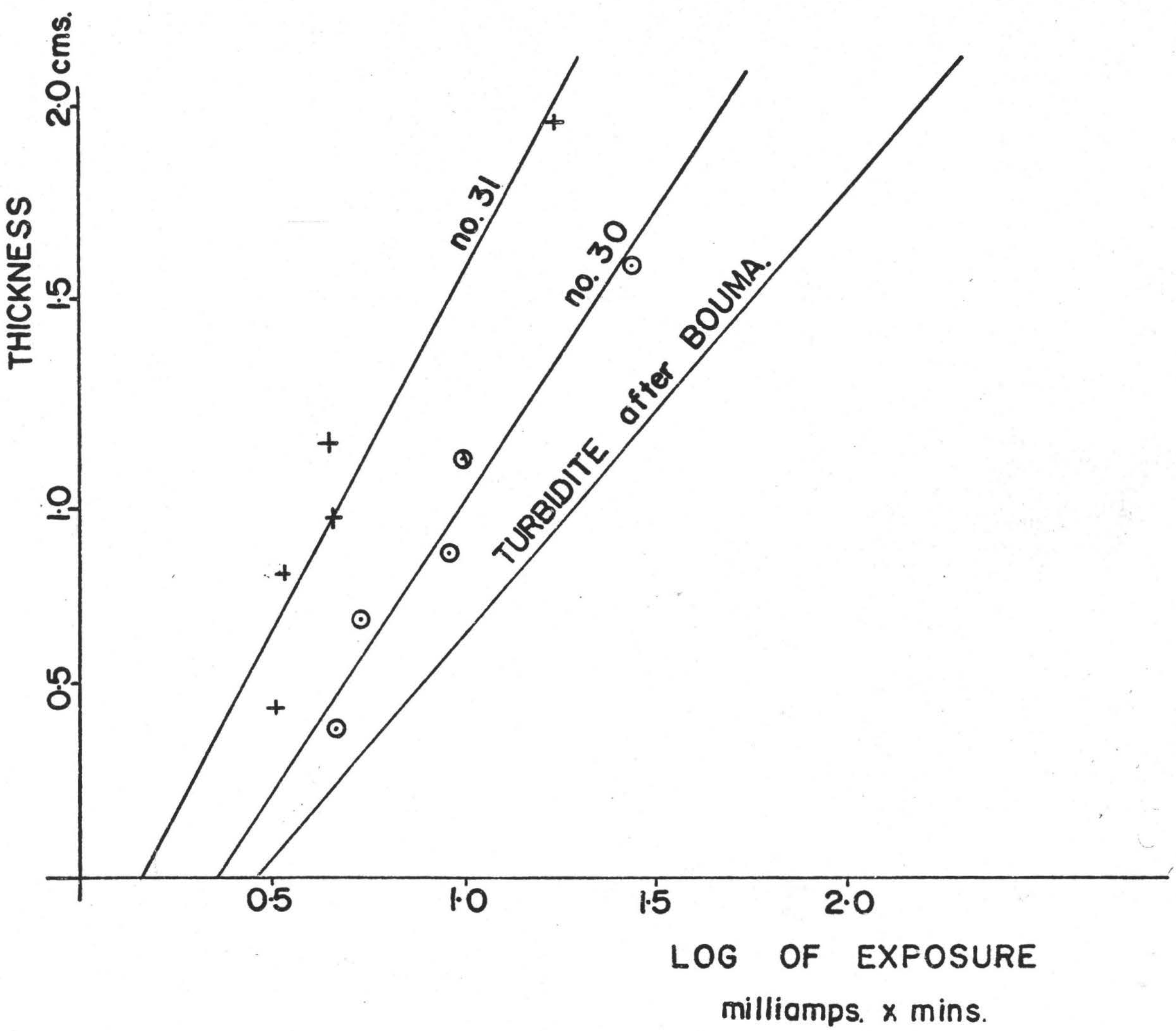


FIG. 10 : EXPOSURE VERSUS THICKNESS

is near the lower limits of the machine, but when dealing with very fine grained specimens the kilovoltage increased to 50 kilovolts. The higher kilovoltages gave radiographs with reduced contrast. Slabs less than 0.2 cms. thick are found to yield poor radiographs. For slabs between 0.2 and 2 cms. (the upper limit examined) no decrease or increase in contrast was seen. Hamblin (1962) found specimens 2-5 mm. thick gave the best results.

NEUTRON RADIOGRAPHY

An object placed in a neutron beam can produce a radiograph. Neutrons interact with nuclei producing a stable nuclear configuration. The "binding energy" released due to absorption of the neutron is used in detecting the occurrence of this event.

The neutrons are produced from a reactor though other non-reactor sources are available. These are passed through a collimator, the object being examined and through the photographic film onto a gadolium converter screen, used to facilitate detection. Neutrons have little direct effect on photographic emulsion. The gadolium screen has a high resolving power and when struck by neutrons release low energy particles resulting in a photographic image (Hawksworth, 1968).

The size of the radiographs was limited to the size of the port in the reactor initially 1.5" but later reduced to 1/2". The reactor flux was 1.5 kilowatts.

Neutron radiographs were made of several samples, these consisted of cores and slabs ranging from 0.9-0.1 cms., by reactor personnel. No internal structures were seen on the radiographs though these were readily visible on the specimens.

CONCLUSIONS

The use of one X-ray film type and standardization of technique simplifies dark room procedures and the taking of radiographs. All health regulations concerning X-ray work must be adherred to. The regulations vary from locality to locality (Lubenan et al, 1969).

Each sample requires differing exposure and kilovoltages which have to be determined before optimum results can be obtained. Bouma (1969) provides a good guide for establishing exposure factors for different samples of varying thickness.

If radiography shows homogenuity of the specimen being examined, this does not exclude the possibility that "structures" may not be present. These structures may have little absorption differences and may be well beyond the detection limits of the equipment being used.

Hamblin (1967) found good contrast was obtained from rocks containing quartz and calcite. Bouma (1969) and Frey (1970) found that lack of contrast in limestones resulted in no decent radiographs Similar results were found by Patchen (1967) for fine grained clastics. Radiographs were used by Baker and Friedman (1969) to determine structures in sea bottom sediments. Larson and Thiede (1971) found that good radiographs could be obtained for carbonates.

Studies using other rock types are required and the effects of the degree of compaction, diagenesis and average grain size require further investigation.

REFERENCES CITED

Baker, S.R. and Friedman, G.M. (1969) A non destructive core analysis technique using X-rays: Jour. Sedimentary Petrology, v.39, p.1371-1383.

Ballance, P. F. (1964) Streaked-out mud ripples below miocene turbidites, Puriri Formation, New Zealand: Jour. Sedimentary Petrology, v.34, p.91-101.

Bassett, D.A. and Walton, E.K. (1960) The Hell's Mouth Grits, Cambrian Greywackes in St. Tudwell's Peninsula, North Wales: Quart.Jour. Geol.Soc.London, v.116, p.85-110.

Bouma, A.M. (1962) Sedimentology of some flysch deposits: Elsevier Publishing Co., Amsterdam, 168p.

Bouma, A.M. (1969) Methods for the study of sedimentary structures: Wiley-Interscience, New York, 458p.

Colton, G.W. (1967) Late Devonian current directions in Western New York with special reference to Fucoides Graphica: Jour.Geol., v.75, p.11-22.

Corney, G.M. and Kocle, W.D. (1963) Film radiography, in McMaster, R.C., Ed., Non destructive testing handbook: Ronald Press Co., New York, v.1, sec.20, 51p.

Curray, J.R. (1956) The analysis of two dimensional orientation data: Jour.Geol., v.64, p.117-131.

Dixon, W.J. and Massey, E.J. (1969) Introduction to statistical analysis: McGraw-Hill Book Co., New York, 488p.

Farrow, G.E. (1966) Bathymetric zonation of Jurassic trace fossils from the coast of Yorkshire, England: Palaeogeography, Palaeoclimatology, Palaeoecology, v.2, 103-151.

Fraser, G.S. and James, R.T. (1969) Radiographic exposure guides for mud, sandstone, limestone and shale:Illinois State Geological Survey, Circular 443, 19p.

Frey, R.W. (1970) Trace fossils of Port Hays Limestone Member of Nobrara Chalk (Upper Cretaceous) West Central Kansas: University of Kansas Paleontological Contributions, Article 53, (Cretaceous 2), 57p.

Gibbons, G.W. (1969) Planar sections through imbricate-type fabrics: Jour.Geol., v.77, p.339-346.

Graf, W.H. (1965) The preferred orientation of an elliptical cylinder in a potential flow field: Jour.Geol., v.73, p.550-552.

Hamblin, W.K. (1962) X-ray radiography in the study of structures in homogeneous sediments: Jour. Sedimentary Petrology, v.32, pp.201-210.

Hamblin, W.K. (1965) Internal structures of "homogeneous" sandstones: State Geol. Survey of Kansas, Bull.175, part 1, 37p.

Hamblin, W.K. (1967) Exposure charts for radiography of common rock types: Brigham Young University Studies, v.14, p.245-258.

Harrison, P.W. (1957) New techniques for three dimensional fabric analysis and englacial debri containing particles from 3 to 40 mm. in size; Jour.Geol., v.65, p.98-105.

Hawksworth, M.R. (1968) An introduction to practical neutron radiography: X-ray Focus, v.8, No.3, p.23-29.

Humes, C.E. (1960) Geology of portions of the Ithaca and Watkins fifteen minute quadrangle: M.Sc. Thesis, University of Rochester, N.Y.

Irving, E. (1964) Paleomagnetism and its application to geological and geophysical problems: John Wiley, New York.

Kuenen, Ph.H. (1956) Problematic origin of the Naples rocks around Ithaca, N.Y.: Geologie en Mihnbouw (N.W. Jer.) 18e Jaargang, p.277-283.

Larsen, G. and Thiede, J. (1971) Sedimentary structures in Cambrian limestones studied by radiography: Lethiai, v.4, p.63-69.

Lené, G.W. and Owen, D.E. (1969) Grain orientation in a Berea sandstone channel at South Ammerst, Ohio: Jour. Sedimentary Petrology, v.39, p.737-743.

Lubenan, J.D., Davis, J.S., McDonald, J. and Gerusky, T.M. (1969) Analytical X-ray mazaros: Health Physics, v.16, p.739-746.

Martini, I.D. (1965) The sedimentology of the Medina Formation outcropping along the Niagara Escarpment (Ontario and New York State): Ph.D. Thesis, McMaster University, 420p.

McBride, E.F. (1962) Flysch and associated beds of the Martinsbury Formation (Ordovician), Central Appalachians: Jour.Sedimentary Petrology, v.32, p.39-91.

McIver, N.L. (1961) Upper Devonian marine sedimentation in the Central Appalachians: Ph.D. Thesis, Johns Hopkins University, 530p.

Onions, D. (1965) Dimensional grain orientation of Ordovician turbidite greywackes: M.Sc. Thesis, McMaster University, 102p.

Onions, D. and Middleton, G.V. (1968) Dimensional grain orientation of Ordovician turbidite greywackes: Jour.Sedimentary Petrology, v.38, p.164-174.

Parkash, B. (1969) Depositional mechanism of greywackes: Ph.D. Thesis, McMaster University, 238p.

Parkash, B. (1970) Down current changes in sedimentary structures in Ordovician Turbidite Greywackes: Jour.Sedimentary Petrology, v.40, p.572-590.

Patchen, D.G. (1967) Developing suitable X-ray radiographic techniques for thin rock slabs: Jour.Sedimentary Petrology, v.37, p.225-227.

Schmidt, R.A.M. (1948) Radiographic methods in paleontology: Amer. Jour.Sci., v.246, p.615-627.

Scott, K.M. (1967) Intra-bed palaeocurrent variations in a Silurian flysch sequence, Kirkcudbrightshire, Southern Uplands of Scotland: Scottish Journal of Geology, v.3, p.268-281.

Sheldon, P.G. (1928) Some sedimentation conditions in Middle Portage Rocks: Amer.Jour.Sci., v.215 (5th Ser., v.15) p.243-252.

Smoor, P.B. (1960) Dimensional grain orientation studies of turbidite greywackes: M.Sc. Thesis, McMaster University, 97p.

Spotts, J.H. (1964) Grain orientations and imbrications in Miocene turbidity current sandstones, California: Jour.Sedimentary Petrology, v.34, p.229-253.

Spotts, J.H. and Weser, O.E. (1964) Directional properties of a Miocene turbidite, California, in Developments in Sedimentary 3, Turbidites. Elsevier Publishing Co., Amsterdam, 264p.

Stanley, D.J. (1963) Vertical petrographic variability in Annot Sandstone turbidites: Jour.Sedimentary Petrology, v.33, p.738-788.

Sutton, R.G. (1960) Stratigraphy of the Naples Group (Late Devonian) in Western New York: New York State Museum and Science Service Bull. 380, 56p.

Sutton, R.G. (1963) Correlation of Upper Devonian strata in South Central New York: Penn.Geol.Survey, Bull. G-39, p.87-101.

Sutton, R.G., Bowen, Z.P. and MacLester, A.L. (1970) Marine shelf environments of the Upper Devonian Sonyea Group of New York: Geol.Soc.of Amer. Bull., v.81, p.2975-2992.

Walker, R.G. and Sutton, R.G. (1967) Quantitative analysis of turbidites in the Upper Devonian Sonyea Group, New York: Jour.Sedimentary Petrology, v.37, p.1012-1022.