PETROGRAPHY OF THE BASAL CRETACEOUS SANDSTONES
OF CENTRAL LEBANON

By

Sharif B. Wakim

1968

"Submitted in partial fulfillment of the requirements
of the Degree of Master of
Science/in the Geology Department of the/American University
of Beirut/Beirut, Lebanon."

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Date 5 Febr. 1968

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Abstract

The formation known in Lebanon as the "Basal Cretaceous Sandstone" consists largely of medium-grained arenites. The present study shows that these are well-sorted oligomict quartz sandstones, and indicates that they were deposited partly in shallow marine and partly in nonmarine conditions. KANAAN's hypothesis (1966) of a delta meets with some minor difficulties, and consideration is given here to the effect of the transgressive Lower Cretaceous sea which, aided by the ample tides of the Tethys, may have considerably modified the deltaic character of the accumulation.

The great purity of the detrital fraction of these sandstones argues against a direct derivation from the metamorphic rocks of the Arabian shield. A study of the heavy mineral content and comparison with the older sandstones of Jordan confirms this impression and at the same time suggests a possible source; further stratigraphic evidence is needed before any positive conclusions can be drawn as to provenance, however.

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1. INTRODUCTION

The Cretaceous of Lebanon begins with a sandstone formation which represents here the so-called "Nubian Sandstone" (RUSSEGER, 1837) of Egypt and the surrounding countries. (See SHUKRI and SAID, 1945, 1946; SAID, 1962; BURDON, 1959; Lexique Stratigraphique International.) In Lebanon these basal Cretaceous sands lie (with local disconformity) on the limestones of the Upper Jurassic, and give way in turn to an alternation of sands and neritic limestones; the latter contain a fauna of Barremian or Aptian age, and are considered as lower Aptian by DUBERTRET and VAUTRIN (1937). The sands proper, which culminate locally in a horizon of calcareous pisoliths, reach a maximum thickness of some 380 m in the neighbourhood of Jezzine (KANAAN, 1966), thinning out across the northern and eastern frontiers of Lebanon and finally disappearing. DUBERTRET (1933) described them under the heading "Neocomian" but later (1963) points out that they are the littoral deposits of the Cretaceous transgression as it moved eastwards across the Jurassic land surface, and as such need not define a particular stage. In any case their poverty in fossils makes it wellnigh impossible to date them precisely.

Lebanon, together with Palestine and parts of Syria and Jordan, lies on the unstable margin of the Arabian shield (MITCHELL, 1959), characterized by the Judaea-Lebanon and Moab-Antilebanon ranges with the Dead Sea rift between. The geologic history of the whole region is one of slow epeirogenic uplift of the central part of the shield with peripheral downwarping or oscillations. In Lebanon these events are recorded in

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prolonged carbonate deposition interrupted by a brief emergence in the late Jurassic;[1] during the transgression which succeeded the latter were laid down the terrigenous deposits which fill the limestone "sandwich" to which the stratigraphic column in Lebanon may be crudely likened.

KANAAN (1966) gives a detailed stratigraphic account of the Basal Cretaceous Sandstone in his study of its sedimentary structures and facies variation. The object of the present study has been to bring further evidence to bear on Kanaan's work insofar as it relates to the following questions:

a. Environment of deposition;
b. Medium of transportation;
c. Provenance.

2. PETROGRAPHY

Arenaceous beds predominate in the Basal Cretaceous Sandstone; a study of the nine sections measured by KANAAN and the present writer and described in Kanaan (1966) shows that sandstones make up between 60 and 90 percent of the formation, averaging 75 percent. Because no elutriator was available for fine granulometry, sampling for granulometric work was restricted mainly to these medium-grained beds.

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[1] The region now occupied by Mt Hermon may have remained above the sea since that time.

2.1 Coloration

Shades of ochre, brown, red and violet characterize the Lower Cretaceous and cause it to stand out in pleasing contrast to the dull grey limestones above and below. These colours, due to the presence of iron oxides in varying amounts, reach their strongest development in the basal sands and their associated volcanic horizons. Much of this ferruginous material appears to have been deposited in recent times from ground water evaporating at the surface; it is not uncommon for outcrops rich in ferruginous cement to give way in depth to pale coloured or even white uncemented material, as an occasional unwary engineer has discovered to his cost. However a number of locally persistent ferruginous horizons, here and there suggestive of ancient land surfaces, indicate that some iron oxide was also deposited contemporaneously. In some localities (the most important being Aghmid near Ain Zhalta) outcrops of white sand are quarried for glass manufacture.

Locally, the argillaceous beds may reach thicknesses of several meters. They are generally coloured grey, occasionally darkened by the presence of organic material.

2.2 Granulometry

88 samples were selected for granulometric study from sandstone beds in seven localities. (Sample locations are shown in Fig. 1, p. 4; levels sampled are indicated on the stratigraphic sections, Plates IX-XX.) The samples were disaggregated (with the help of hydrochloric acid and stannous chloride where necessary) and hand sieved, using a series of sieves with

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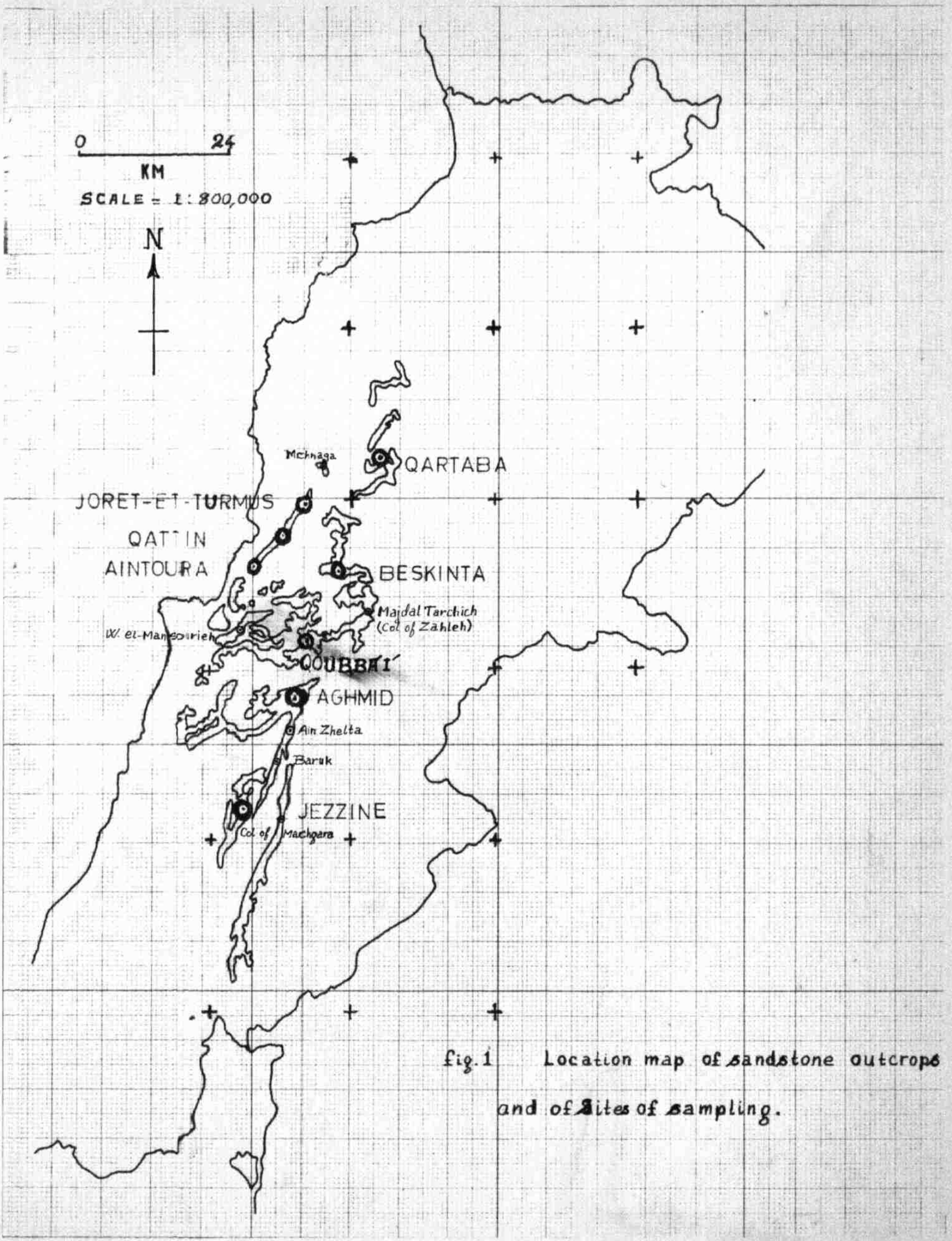

fig. 1 Location map of sandstone outcrops and of sites of sampling.

openings of 3360, 1680, 840, 420, 210 and 105 microns. The percentages by weight of the different fractions are given in Table I (pp 6-8) and shown graphically on the histograms in Fig. 2 (p. 9).

A good discussion of statistical approaches to granulometry is given by KRUMBEIN (1939). In the present study histograms have been retained (in spite of their disadvantages) to give a rough visual impression of grain size distribution, but for the quantitative treatment cumulative frequency curves and quartile statistics were adopted for the following reasons:

> 1) A preliminary treatment using moment statistics failed to reveal any parameters of use for defining correlatable horizons or expressing regular horizontal variations;[1)]
>
> 2) The composition of the finest fraction ($< 105\mu$) being unknown, the frequency distributions are "open-ended": a disadvantage in calculating moments;
>
> 3) The mathematical operations of quartile statistics are simple and rapid.

The application of quartile statistics to sedimentary problems has been developed by TRASK (1930, 1932) and KRUMBEIN (1936a, 1936b, 1939); the following brief discussion is taken mainly from Krumbein (1939).

The cumulative frequency curve (see for example Fig. 3), as its name implies, is a plot of the cumulative frequency (in this case weight percent) of the independent variable (grain diameter). Thus 50 percent of the sample described by Fig. 3 would be held back by a sieve of aperture 1 mm. The values of the median (Md) and the two quartiles (Q_1, Q_3): or, for

. . .

[1)] The mean diameter in samples taken from the section at Aghmid did in fact show a negative correlation with depth below the top of the formation. See p. 28 and Appendix.

Table I

Grain Size Distribution

Sample No.	Locality	Class intervals and frequencies(1)							Quartile parameters				
		<3.25	3.25- 2.25	2.25- 1.25	1.25- 0.25	0.25- -0.75	-0.75- -1.75	-1.75- -2.75	Md_φ	$Q1_\varphi$	$Q3_\varphi$	QD_φ	SK_φ
10	Beskinta	6	10	42	34	6	1	-	1.26	0.95	1.90	0.43	+.17
12	"	7	32	43	16	2	-	-	2.00	1.50	2.55	0.53	+.03
16	"	5	9	20	53	13	-	-	0.85	0.50	1.60	0.55	+.25
17	"	17	20	51	13	-	-	-	1.90	1.50	2.75	0.63	+.23
21	"	18	29	38	13	2	-	-	2.20	1.55	2.95	0.70	+.05
37	Aghmid	10	15	23	34	14	3	1	1.20	0.50	2.25	0.88	+.18
38	"	7	7	15	34	24	12	1	0.55	-0.35	1.50	0.93	+.03
42	"	13	20	34	28	4	-	-	1.70	1.05	2.60	0.76	+.13
43	"	7	14	51	26	1	-	-	1.65	1.30	2.10	0.45	0.00
44	"	4	8	31	52	6	-	-	1.15	0.85	1.65	0.40	+.10
46	"	15	52	24	8	1	-	-	2.55	2.00	3.05	0.53	-.03
47	"	3	8	58	28	2	1	-	1.55	1.15	1.85	0.35	-.05
48	"	7	14	53	25	1	-	-	1.55	1.25	2.10	0.43	+.13
50	"	9	25	49	15	1	-	-	1.90	1.45	2.55	0.55	+.10

---

1) See footnote at the last page of this Table.

Table I (Cont'd.)

Sample No.	Locality	Class intervals and frequencies(1)							Quartile parameters				
		<3.25	3.25-2.25	2.25-0.25	1.25-0.25	0.25--0.75	-0.75--1.75	-1.75--2.75	Md_φ	$Q1_\varphi$	$Q3_\varphi$	QD_φ	SK_φ
51	Aghmid	7	16	36	34	8	-	-	1.40	0.95	2.15	0.60	+.15
52	"	4	25	65	5	-	-	-	1.95	1.60	2.35	0.38	+.03
54	"	5	19	51	24	2	-	-	1.65	1.25	2.20	0.48	+.08
57	"	15	33	40	11	1	-	-	2.20	1.60	2.85	0.63	+.03
58	"	12	20	52	15	1	-	-	1.95	1.45	2.45	0.50	0.00
59	"	19	20	48	12	1	-	-	2.00	1.60	2.85	0.63	+.23
60	"	9	18	36	31	5	1	-	1.55	0.95	2.35	0.70	+.10
63	"	4	9	43	41	2	-	-	1.35	1.10	1.90	0.45	+.10
65	"	18	38	39	5	-	-	-	2.35	1.95	3.00	0.53	+.13
66	"	16	41	25	19	-	-	-	2.45	1.55	3.05	0.75	-.15
67	"	4	13	73	9	-	-	-	1.85	1.55	2.15	0.30	0.00
70	"	9	30	55	6	-	-	-	2.10	1.75	2.45	0.35	0.00
74	"	19	24	33	21	3	-	-	2.05	1.30	2.90	0.80	+.05
75	"	7	22	61	10	-	-	-	1.90	1.55	2.35	0.40	+.05
77	"	12	57	18	10	2	-	-	2.65	2.00	2.90	0.45	-.20
81	Qartaba	6	11	53	30	1	-	-	1.45	1.15	1.95	0.40	+.10
83	"	4	13	60	22	-	-	-	1.60	1.30	1.95	0.33	-.03
84	"	3	4	15	51	23	3	-	0.65	0.20	1.15	0.48	-.03

Table I Cont'd.)

Sample No.	Locality	Class intervals and frequencies(1)							Quartile parameters				
		< 3.25	3.25-2.25	2.25-0.25	1.25-0.25	0.25--0.75	-0.75--1.75	-1.75--2.75	Md_φ	$Q1_\varphi$	$Q3_\varphi$	QD_φ	SK_φ
85	Qartaba	2	9	28	40	20	1	-	1.00	0.35	1.70	0.68	+.03
86	"	4	46	43	7	1	-	-	2.25	1.90	2.60	0.35	0.00
87	"	1	4	63	30	1	-	-	1.45	1.15	1.65	0.25	-.05
89	"	5	14	32	40	9	-	-	1.30	0.75	2.00	0.63	+.08
91	"	6	38	44	12	1	-	-	2.00	1.60	2.60	0.50	+.10
92	"	3	8	33	44	11	1	-	1.15	0.75	1.60	0.43	+.03
99	Qattin	10	24	56	10	0	0	0	2.05	1.55	2.45	0.45	-.05
101	"	18	25	38	17	1	0	0	2.05	1.40	2.90	0.75	+.10
102	"	10	14	38	37	1	0	0	1.45	1.10	2.20	0.55	+.20
106	"	16	29	34	19	1	0	0	2.10	1.40	2.90	0.75	+.05
111	"	12	21	51	16	0	0	0	1.90	1.45	2.45	0.50	+.05
113	"	6	8	69	15	1	0^+	0	1.50	1.30	1.85	1.28	+.08
116	Aintoura (Jeita)	5	18	55	21	0^+	0	0	1.75	1.35	2.20	0.43	+.03
117	"	18	34	34	18	2	0^+	0	2.30	1.65	3.00	0.68	+.03
118	"	3	23	56	16	2	0^+	0	1.85	1.35	2.25	0.45	-.05
119	"	6	12	52	26	3	0^+	0	1.60	1.15	2.10	0.48	+.03
120	"	9	22	48	19	2	0^+	0	1.85	1.35	2.40	0.53	+.03
121	"	3	9	54	27	6	0^+	0	1.45	1.05	1.90	0.43	+.03

Table I (Cont'd.)

Sample No.	Locality	Class intervals and frequencies(1)							Quartile parameters				
		<3.25	3.25-2.25	2.25-0.25	1.25-0.25	0.25--0.75	-0.75--1.75	-1.75--2.75	Md_φ	$Q_{1\varphi}$	$Q_{3\varphi}$	QD_φ	SK_φ
122	Aintoura (Jeita)	4	12	48	35	1	0^+	0	1.45	1.05	1.95	0.45	+.05
123	"	9	32	46	13	1	0	0	2.00	1.45	2.65	0.60	+.05
124	"	6	32	43	18	1	0^+	0	2.00	1.45	2.55	0.55	0.00
125	"	6	15	43	36	2	0^+	0	1.55	0.95	2.10	0.58	-.03
126	"	5	31	44	18	2	0^+	0	1.95	1.40	2.45	0.53	-.03
127	"	17	24	33	25	1	0^+	0	1.95	1.20	2.85	0.83	-.08
129	"	2	11	76	10	1	0	0	1.75	1.55	1.95	0.29	0.00
130	"	13	24	37	22	5	0^+	0	1.85	1.20	2.70	0.75	+.10
131	"	7	11	35	40	6	0^+	0	1.25	0.90	1.90	0.50	+.15
133	"	3	18	77	3	0^+	0	0	1.95	1.85	2.15	0.15	+.05
140	Jouret Et Turmus	8	27	44	18	2	0^+	0	1.95	1.35	2.55	0.60	0.00
143	"	17	23	33	22	4	0^+	1^-	1.95	1.25	2.85	0.80	+.10
144	"	15	32	34	17	1	0^+	0	2.15	2.90	1.45	0.73	+.03
145	"	14	16	39	28	3	0^+	0	1.65	1.15	2.45	0.65	+.15
151	"	20	45	22	11	2	0^+	0	2.55	1.95	3.05	0.55	-.05
155	"	14	33	40	12	1	0^+	0	2.20	1.65	2.80	0.58	+.03
156	"	13	28	40	17	3	0^+	0^+	2.05	1.45	2.70	0.63	+.03

Table I (Cont'd.)

Sample No.	Locality	Glass intervals and frequencies(1)							Quartile parameters				
		< 3.25	3.25- 2.25	2.25- 0.25	1.25- 0.25	0.25- -0.75	-0.75- -1.75	-1.75- -2.75	Md_φ	$Q1_\varphi$	$Q3_\varphi$	QD_φ	SK_φ
182	Jezzin	20	18	38	21	3	0^+	0	1.85	1.30	2.95	0.83	+.28
185	"	10	67	20	3	0^+	0	0	2.60	2.30	2.90	0.30	0.00
189	"	19	60	20	0^+	0^+	0	0	2.70	2.35	3.10	0.38	+.03
192	"	15	19	38	24	3	1	0	1.85	1.20	2.60	0.70	+.05
193	"	10	17	35	36	1	0^+	0	1.50	1.00	2.35	0.68	+.18
202	"	3	8	42	46	2	0	0	1.35	0.85	1.85	0.50	0.00
205	"	7	49	35	7	2	0^+	0	2.40	1.90	2.80	0.45	-.05
210	"	8	38	43	9	1	0^+	0	2.25	1.70	2.65	0.48	-.08
212	"	4	7	70	17	2	0^+	0	1.50	1.35	1.80	0.23	+.08
214	"	6	4	66	23	1	0	0	1.55	1.25	1.75	0.25	-.05
215	"	20	59	17	4	0^+	0	0	2.75	2.55	3.15	0.35	0.00
217	"	7	5	58	29	1	0^+	0	1.45	1.20	1.75	0.28	+.02
219	"	9	21	18	24	24	3	0^+	1.15	0.15	2.45	1.15	+.15
222	"	18	32	42	8	0^+	0	0	2.25	1.85	2.90	0.53	+.13
224	"	8	53	29	9	1	0^+	0	2.45	1.85	2.85	0.50	-.10
226	"	7	32	57	4	0^+	0	0	2.15	1.95	2.35	0.20	0.00

Table 1 (cont'd.)

Sample No.	Locality	Class intervals and frequencies(1)							Quartile parameters				
		<3.25	3.25- 2.25	2.25- 0.25	1.25- 0.25	0.25- -0.75	-0.75- -1.75	-1.75- -2.75	Md_φ	$Q_{1\varphi}$	$Q_{3\varphi}$	QD_φ	SK_φ
228	Jezzin	9	40	47	4	0^+	0	0	2.25	1.90	2.65	0.38	+.03
233	"	2	16	67	15	1	0^+	0	1.65	1.25	2.10	0.43	+.05
234	"	5	8	26	26	27	8	0	0.85	-.15	1.80	0.98	+.05
235	"	13	26	39	18	5	0^+	0	1.95	1.35	2.65	0.65	+.05
236	"	11	9	28	48	4	0^+	0	1.20	0.90	1.95	0.33	+.23

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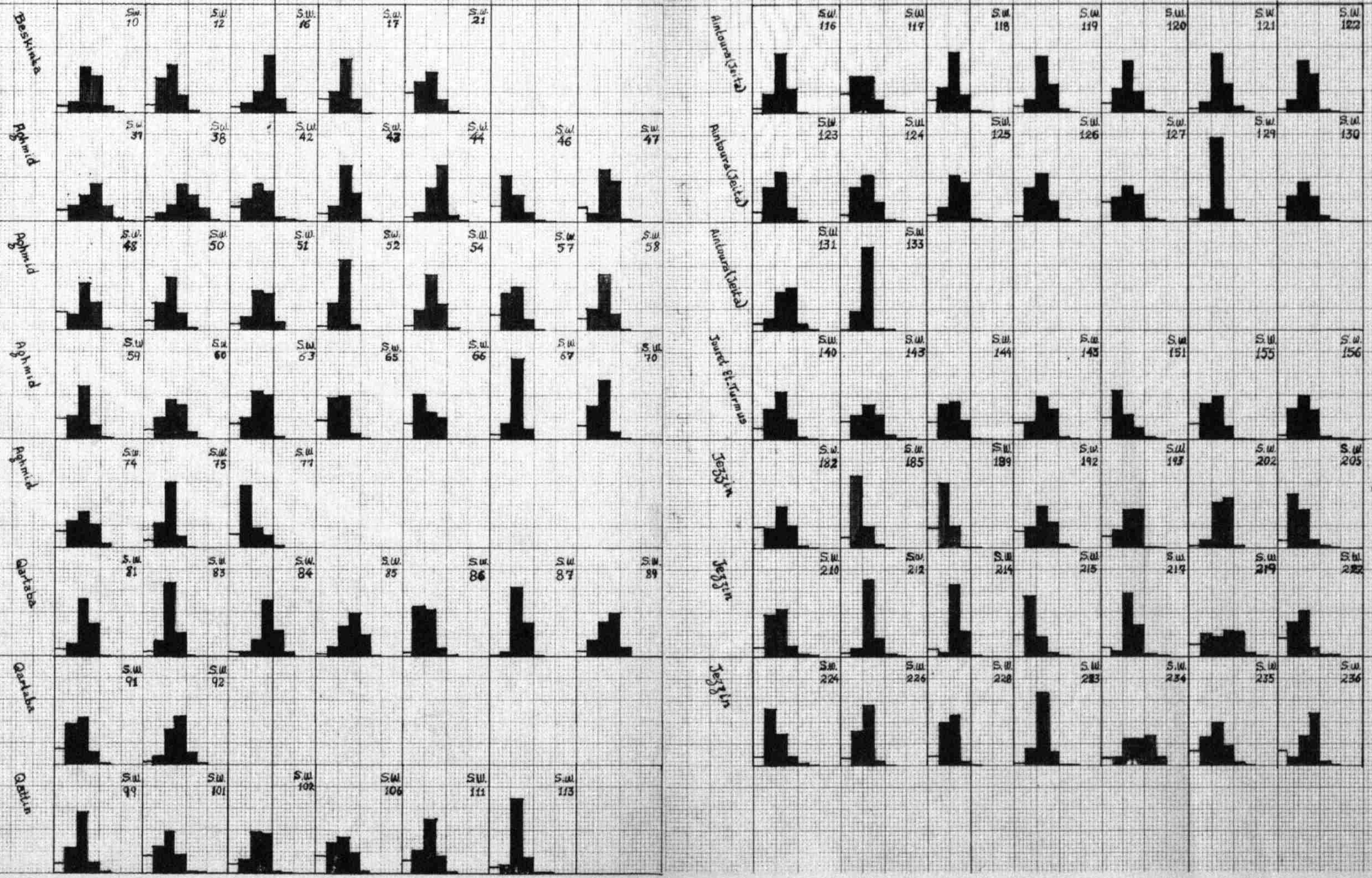
1) Class intervals in φ-units; frequencies in wt. percent of sample.

fig. 2 _ Histograms of granulometric distributions of 88 samples from sandstone beds. Each subdivion of horizontal scale is one φ-unit, except the unshaded subdivision which covers all class intervals finer than 3.25 φ-units. The vertical scale is 100%.



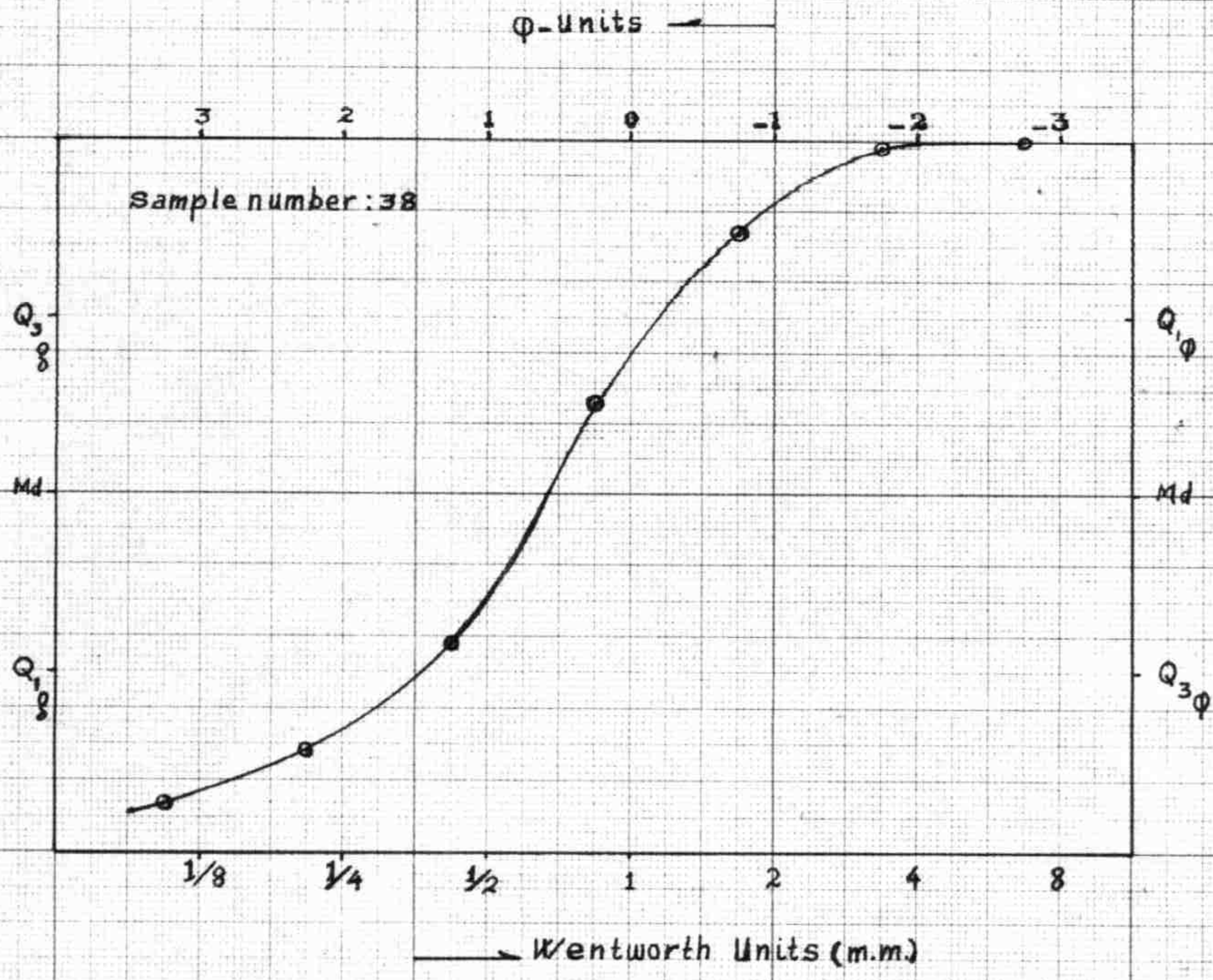


fig. 3 — Representative cumulative curve. In this example, 14 % of the sample are trapped by a sieve with holes 1.68 m.m. in diameter, and 30% by a sieve of aperture 1 mm.

that matter, of any percentile: can be read directly from the curve.1) Arithmetic measures of spread and skewness are easy to interpret and are given by:

$$\text{quartile deviation } (QD_a) = \tfrac{1}{2}(Q_3 - Q_1) \; ; \tag{2.1}$$

$$\text{skewness } (Sk_a) = \tfrac{1}{2}(Q_3 + Q_1 - 2Md) \; . \tag{2.2}$$

Geometric measures are to be preferred, however, as they are dimensionless and consequently independent of the units employed:

$$QD_g = (Q_3/Q_1)^{\frac{1}{2}} \; ; \tag{2.3}$$

$$Sk_g = (Q_3 Q_1/Md^2)^{\frac{1}{2}} \; . \tag{2.4}$$

(QD_g is also known as Trask's sorting coefficient.) The logarithms of the geometric parameters are still more convenient, being easier to calculate and (because they form an arithmetic progression instead of a geometric one) more readily interpreted:

$$\log QD_g = \tfrac{1}{2}(\log Q_3 - \log Q_1) \; ; \tag{2.5}$$

$$\log Sk_g = \tfrac{1}{2}(\log Q_3 + \log Q_1 - 2.\log Md) \; . \tag{2.6}$$

<u>The φ-scale</u>

KRUMBEIN (1936b) pointed out the advantages of transforming the logarithmic scale of diameters normally employed in granulometry to a

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1) Throughout this discussion and in the treatment of the data themselves we will follow the convention of always assigning the numerically higher value to the third quartile, irrespective of the units used or of their significance. (See Krumbein, (1939). p. 564.)

linear one using the relationship

$$\varphi = -\log_2 d , \tag{2.7}$$

and developed the so-called φ-scale. Each unit on the φ-scale corresponds to a division of the Wentworth scale:

Wentworth scale (diam. in mm)	..1/32..	1/16..	1/8...	1/4...	1/2...	1....	2....	4....	8..
φ-scale (units)	.. 5	.. 4	.. 3	.. 2	.. 1	.. 0..	-1..	-2..	-3..

The negative sign is introduced merely to provide positive φ-values in that part of the scale most often used with arenaceous sediments. Quartile deviation and skewness may now be measured by:

$$QD_\varphi = \tfrac{1}{2}(Q_{3_\varphi} - Q_{1_\varphi}) \quad ; \tag{2.8}$$

$$Sk_\varphi = \tfrac{1}{2}(Q_{3_\varphi} + Q_{1_\varphi} - 2Md_\varphi) \quad . \tag{2.9}$$

When the cumulative curve is plotted with grain size expressed in φ-units the statistical treatment becomes a matter of the greatest simplicity; the φ-parameters are readily convertible to geometric ones if need be:

$$d = 2^{-\varphi} \quad ; \tag{2.10}$$

$$QD_g = 2^{QD_\varphi} \quad ; \tag{2.11}$$

$$Sk_g = 2^{-Sk_\varphi} \quad . \tag{2.12}$$

Fig. 4 (p. 13) is a chart showing diameters in mm equivalent to φ-units in the range -2 to +4.

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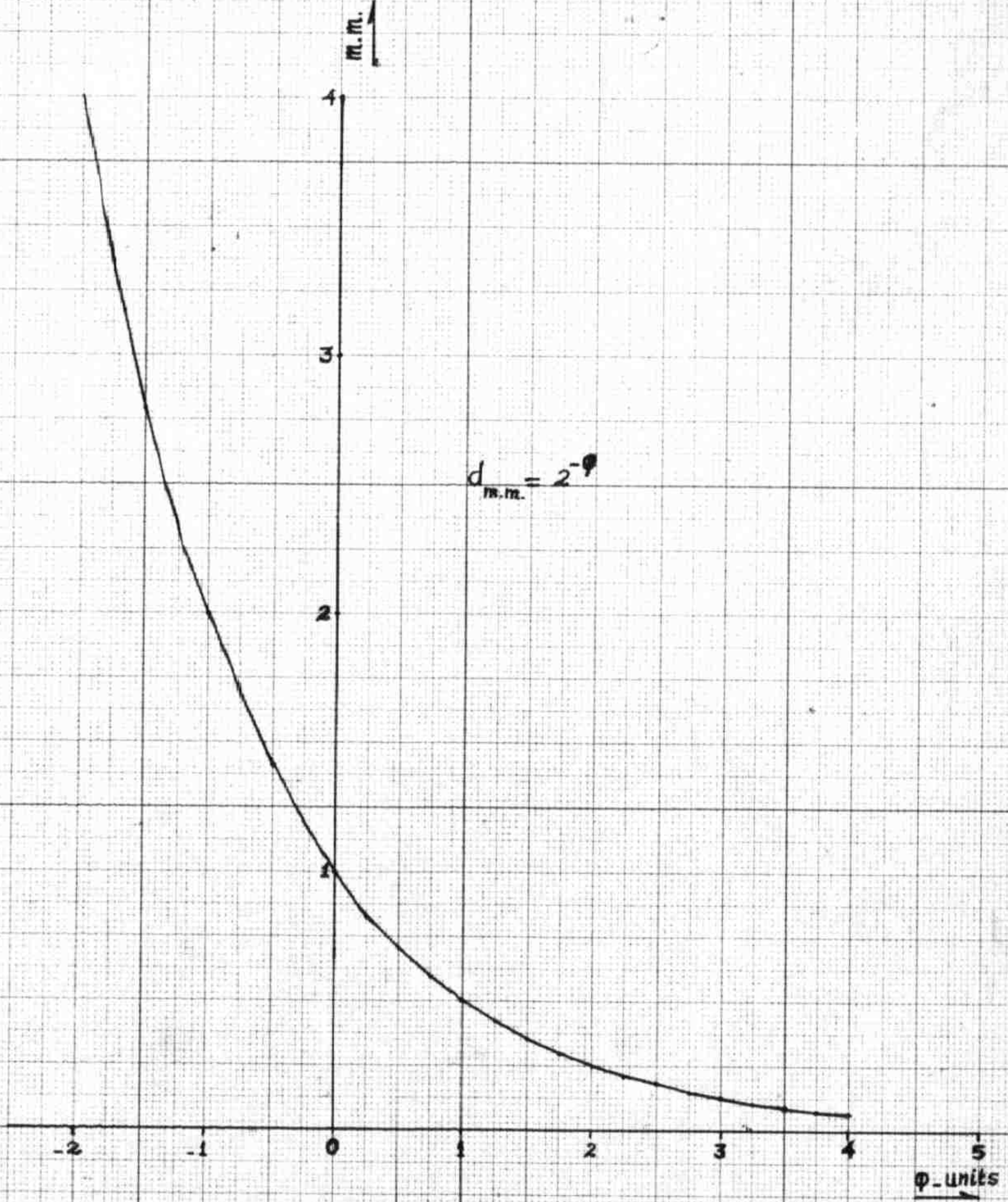

fig. ~~5~~ 4

φ to m.m. transformation curve

The results are summarized in histograms (Figs 5-7) showing the respective frequency distributions of median diameter, quartile deviation and skewness. The average values and spread of these three parameters turn out to be:

	Mean	standard deviation
Md_φ	1.77	0.45
QD_φ	0.52	0.18
Sk_φ	+0.03	0.08

It thus appears that the samples studied represent medium-grained arenites according to the definition of BERNARD <u>et al</u>. (1961). The mean quartile deviation of 0.5 corresponds to a geometric parameter of 1.4, which is in good agreement with the value of 1.2 found by SHUKRI and SAID (1945) for the Nubian Sandstone of Egypt. These are homogeneous deposits by any standards: TRASK (1932, cited by KRUMBEIN, 1938) considers 2.5 as the upper limit for well sorted material.

Rather more than one-third of the samples are free from appreciable skewness; the remainder of the population shows a variation between -0.25 and +0.25 with a slight bias towards positive values. The narrowness of these limits (equivalent to geometric parameters of 0.83 and 1.2 respectively), together with the pronounced central tendency expressed by the mean and standard deviation, indicates that the deposit as a whole is characterized by log-normal grain-size distributions.

Some idea of the variation of QD_φ and Sk_φ over the samples studied may also be had from the examples of cumulative curves given in Figs 8 and 9 (pp 18 and 19).

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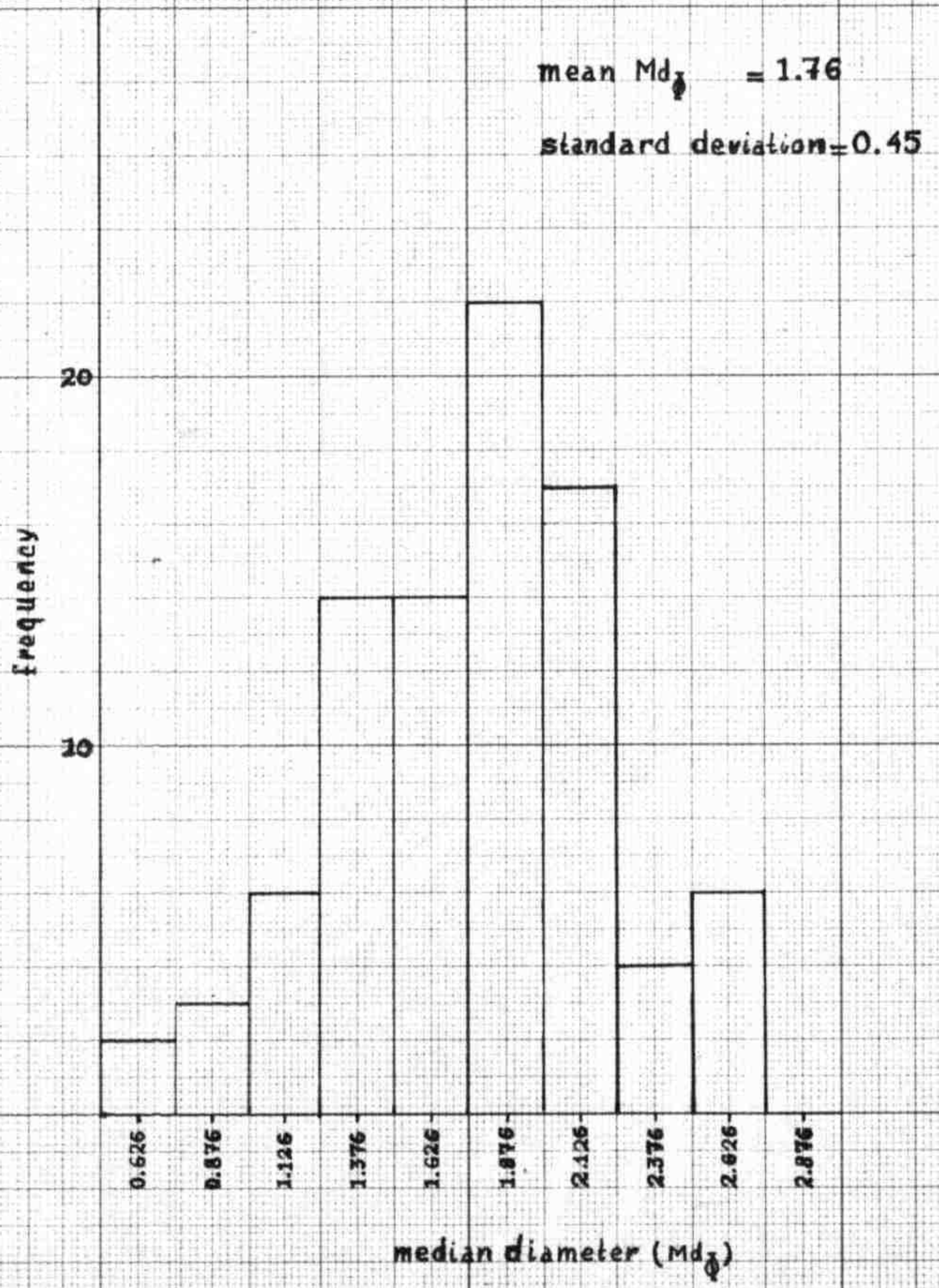
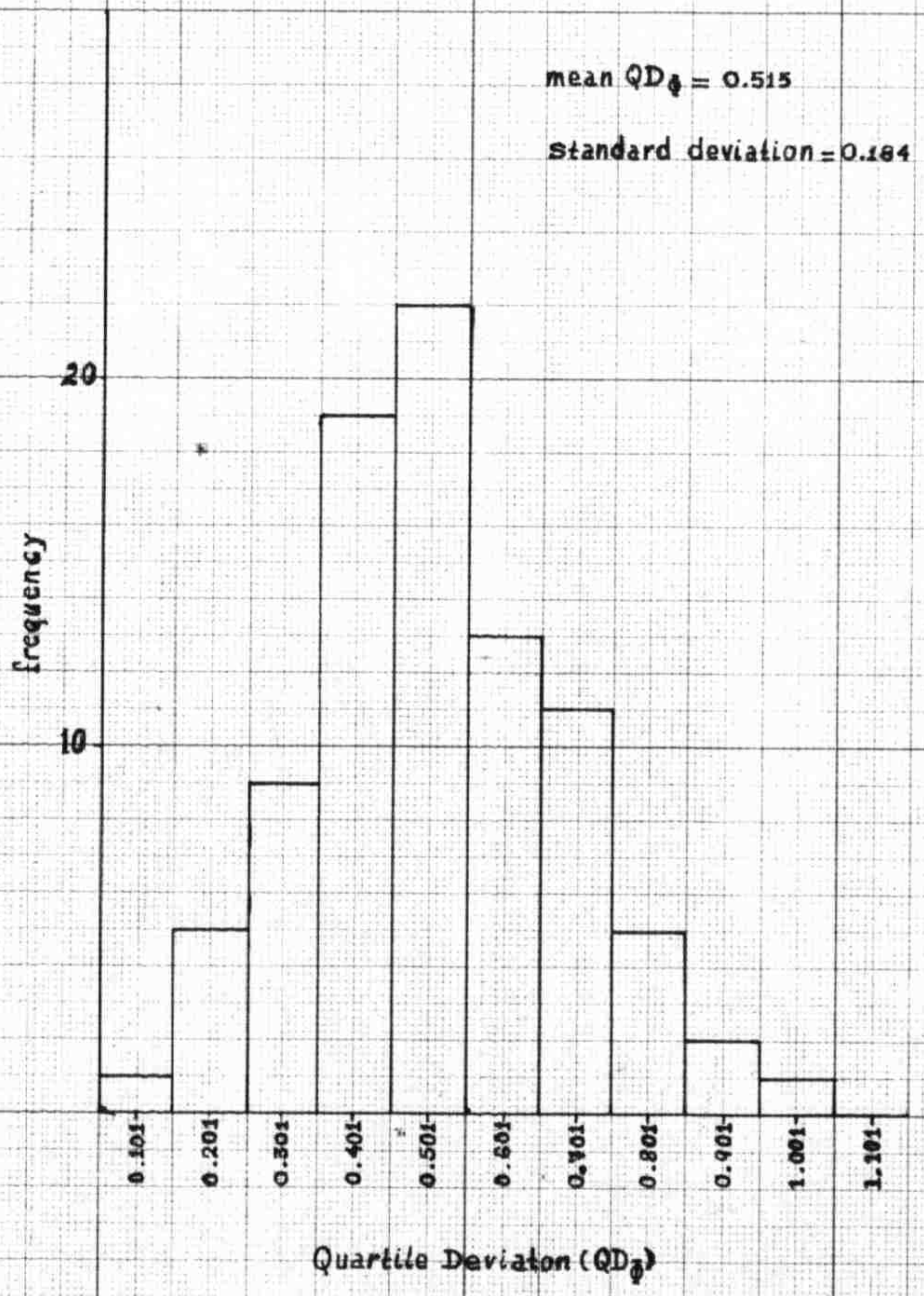


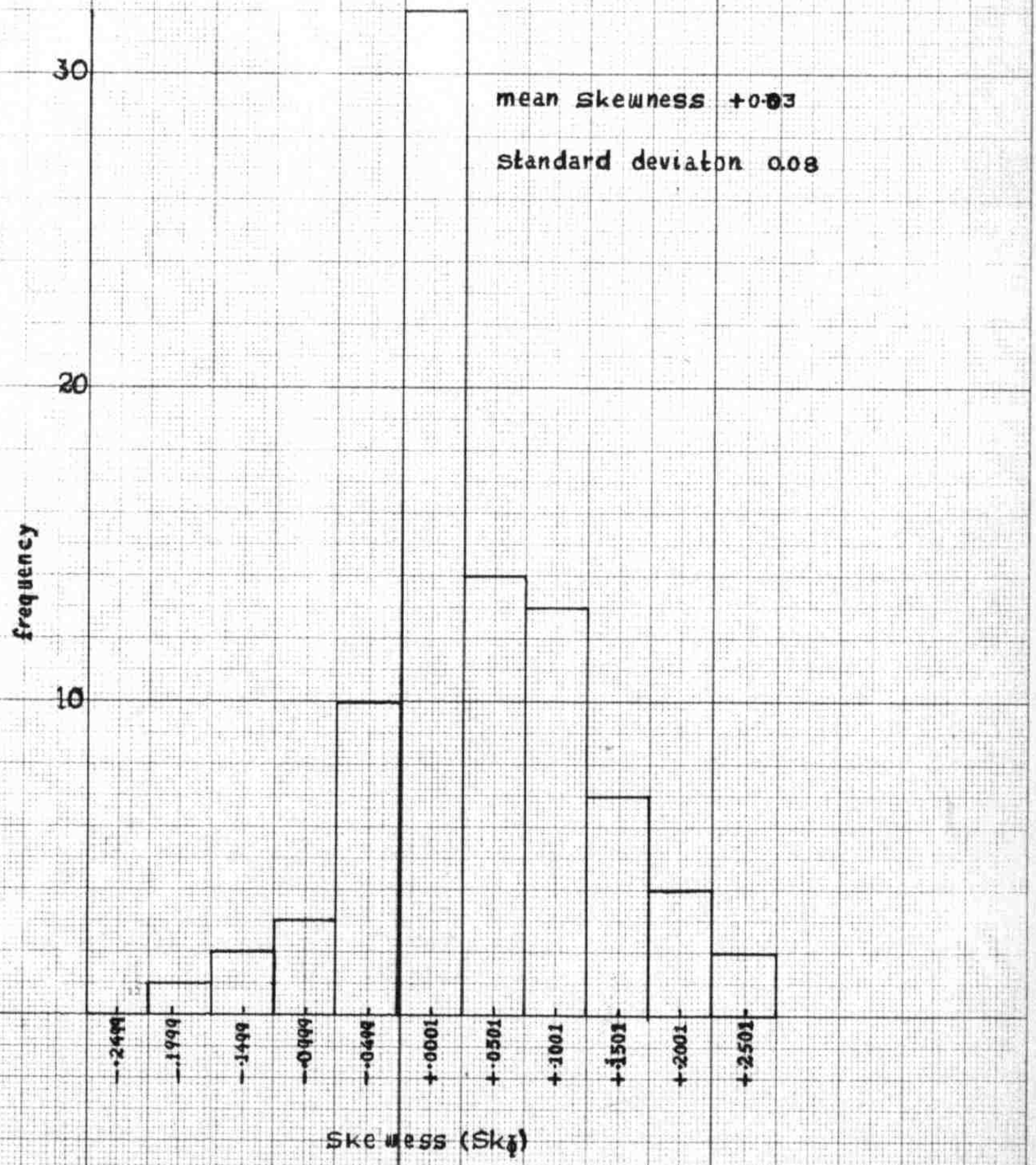
Fig ~~#~~5 Histogram of median diameters, measured in Φ units, ~~of sandstone beds~~



mean QD_ϕ = 0.515

standard deviation = 0.184

fig.9 6 Histogram of logarithmic quartile deviation ~~of sandstone beds~~



mean skewness +0·03

standard deviaton 0.08

fig. 7 frequency distribution (histogram) of skewness ~~of sandstone beds.~~

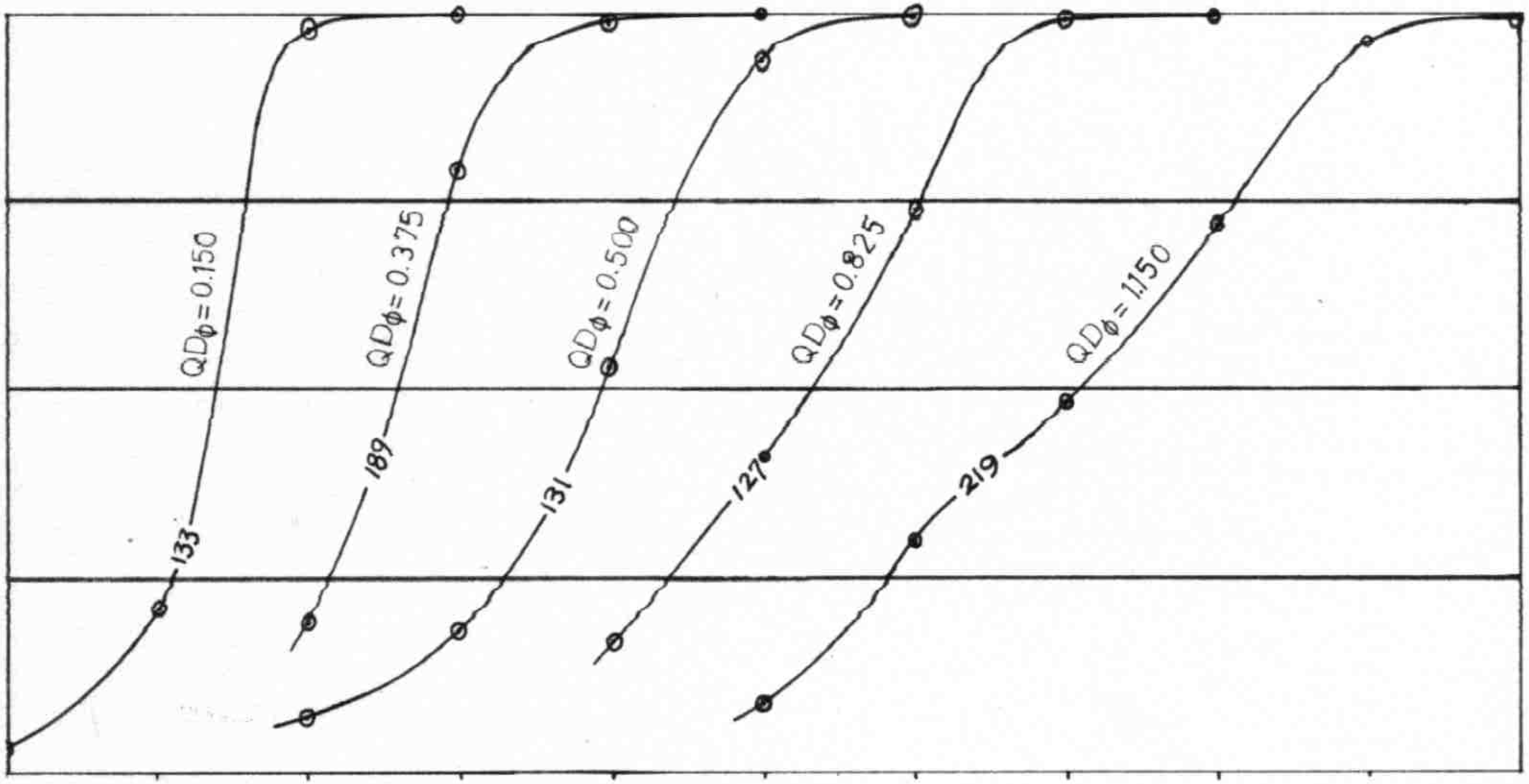


Fig. 8 Cumulative frequency distribution curves showing successively variations in sorting. Curve 219 shows also bimodality.

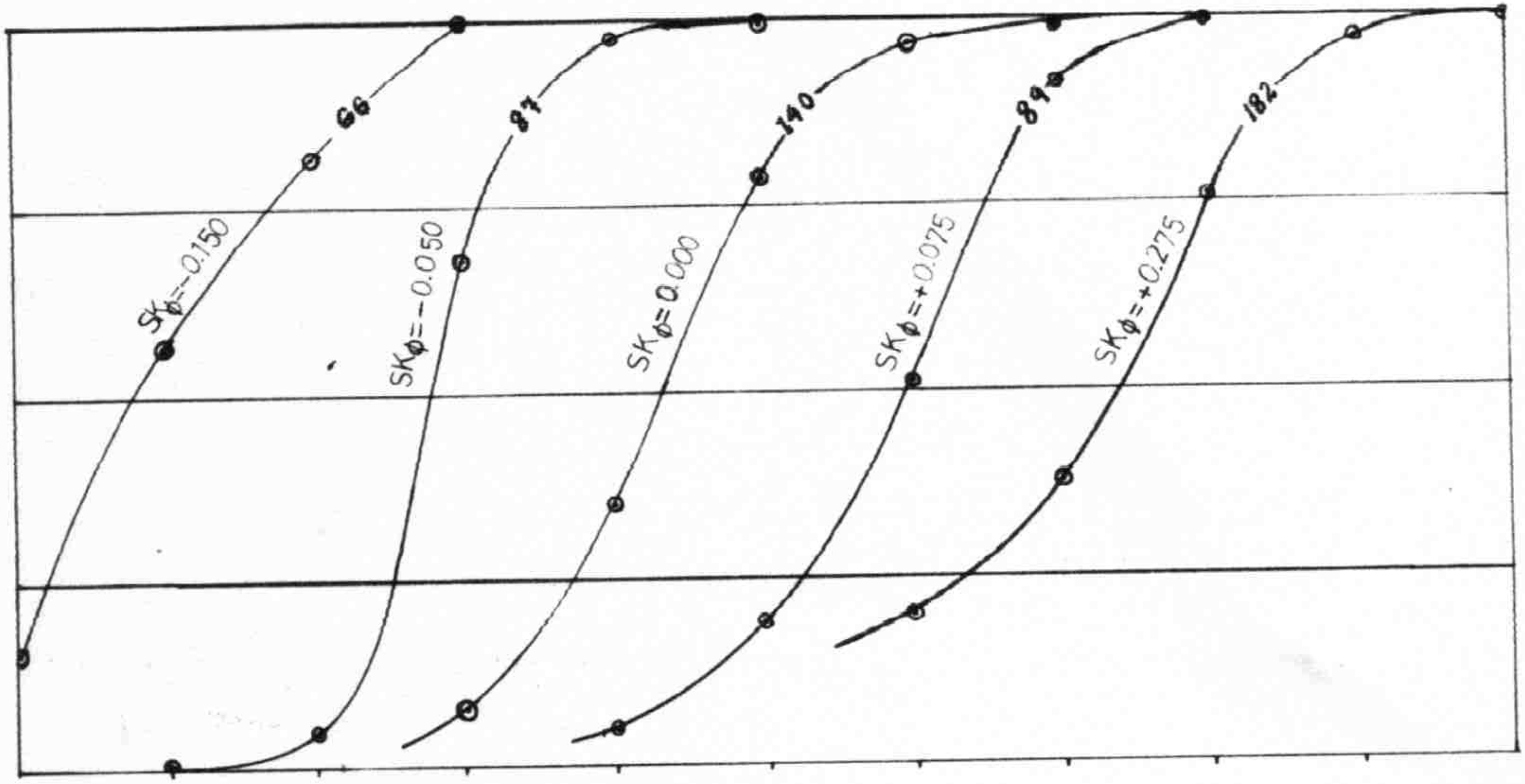


Fig. ~~10~~ 9 Cumulative frequency distribution curves showing successively variations in skewness from very skewed positive to very skewed negative.

2.3 Thin sections

85 samples were studied in thin section; most of them were taken from well-cemented sandstones or carbonate beds, but a few poorly-cemented samples were sectioned after impregnation with Lakeside 70 thermoplastic cement.

Arenites

These range from siltstones to coarse sandstones; the majority are reasonably well sorted. Quartz is the only common mineral in the detrital fraction, though here and there some detrital calcite was found (Sample No. 22, Plate IIa). The cement is generally ferruginous, though carbonate cement is common in the neighbourhood of carbonate beds. Silica was encountered as cement in two samples only (Nos 54 and 71). There appears to be some positive correlation between grain size and degree of rounding (see Plates IIIc; IVa, b). The smaller, angular fragments are distributed over a wide range of samples, often occurring among predominantly well-rounded grains (see for example Plate IIc; Plate IVa, b). Some samples, however, consist mainly of small, well-sorted, angular fragments of fine sand grade or smaller (Plate IIId). Lamination and minor cross-bedded structures were observed in some slides (Samples 16, 19, 152; Plate IIIa, b).

The quartz generally shows wavy extinction; in some grains optical discontinuities are found. Evidence of secondary growth is rare. Here and there fractures are seen, sometimes developed along the rhombohedral cleavage directions, with a filling of ferruginous cement (Plate IVd). Sometimes the grains are traversed by rows of minute inclusions, too small to identify; larger inclusions are also present in apparently random arrangement: zircon, rutile and magnetite are the commonest minerals occurring in this way. The main accessory minerals observed were tourmaline, zircon and rutile.

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Carbonate rocks

Several samples of the pisolithic rocks from the uppermost part of the formation were sectioned; these are described in Section 2.6. The other carbonate beds studied are limestones of rather variable character. Recrystallization or partial dolomitization has doubtless obliterated fossil remains in many of these; where they survive the fossils are often vaguely outlined and difficult to identify. Quartz is a common constituent of these rocks, which may grade vertically or horizontally into carbonate-cemented sandstones. Some are oolitic; most are coloured brown by varying proportions of ferruginous material. Samples from Beskinta (Nos 2, 3, 4) contained an appreciable amount of glauconite (partly oxidized) in the form of pellets (coprolites?) and vermiform structures suggestive of organic remains (see Plates V and VI).

Faunal remnants representing the following groups were recognized: echinoids (Beskinta); Foraminifera (Jezzine); gasteropods, pelecypods. About six specimens of Choffatella decipiens were observed in thin sections of Samples 205 and 206 from Jezzine.

2.4 Heavy minerals

Bromoform separations were carried out on 49 samples from the seven localities. The heavy mineral fraction of these samples, between one and five parts per thousand, showed no systematic variation in either its horizontal or its vertical distribution. Its average composition, determined by counting about eleven thousand individual grains, is shown in Table II (p. 22) and Fig. 10 (p. 23). In the latter are also plotted some characteristics of accessory detrital minerals normally found in sediments. Of the non-opaque minerals present, tourmaline is by far the most abundant; all the minerals present in significant amounts are relatively stable

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chemically and, with the exception of chlorite, harder than quartz.

TABLE II

Composition of the heavy mineral fraction (non-opaque) of the Basal Cretaceous Sandstone of Lebanon. Based on random counts made on 49 samples from 7 localities. 11,000 grains counted.

Mineral	Percent Frequency
Tourmaline	60
Zircon	9.0
Rutile	8.8
Chlorite	8.2
Topaz	3.8
Anatase	1.9
Disthene	1.5
Biotite	0.9
Glaucophane	0.5
Others*	5.4
	100

*Garnet, basaltic hornblende, corundum, beryl, cordierite, apatite, andalusite, fluorite, brookite, idocrase, monazite, in quantities less than one-half percent.

2.5 Clay Minerals

X-ray powder photographs were made from 16 samples taken mainly from argillaceous beds and the finest fractions ($< 105\mu$) of some sandstones. A de Wolff-Guinier camera was used and the samples were ground with glycerol before exposure. The results are summarized in Table III (p. 24). Quartz and kaolinite proved to be the main constituents of most of these samples, with locally some illite. A white clay taken from a sandstone bed at

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Fig. 10 — Multivariable diagram showing the frequency of the heavy minerals of the Cretaceous sands of Central Lebanon as related to the physical & chemical properties of these minerals.

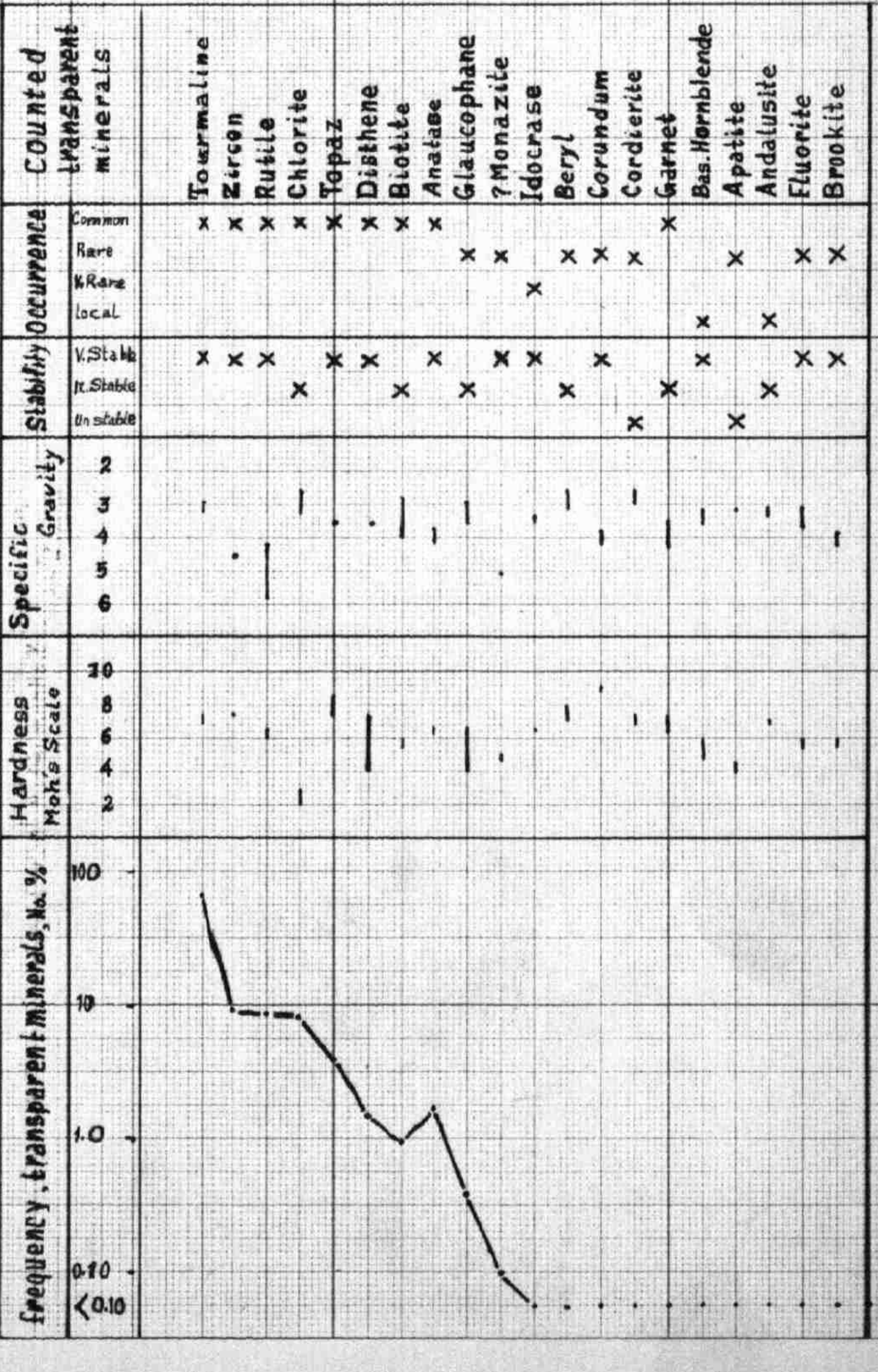

TABLE III

Basal Cretaceous Sandstone: minerals identified by x-ray diffractometry

Sample	Locality	Rock type	Nature of sample	Principal minerals
6	Beskinta	Sandstone	Fraction <105µ	Quartz (abundant); kaolinite
14	Beskinta	Sandstone	Fraction <105µ	Quartz (abundant) Kaolinite (trace)
15	Beskinta	Argillaceous	Clay	Quartz (abundant) Kaolinite (abundant)
17	Beskinta	Sandstone	Fraction <105µ	Quartz (abundant) Kaolinite (abundant)
20	Beskinta	Sandstone	Fraction <105µ	Quartz (abundant) Kaolinite
21	Beskinta	Sandstone	Fraction <105µ	Quartz (abundant) Kaolinite
30	Aghmid	Sandstone	Fraction <105µ	Quartz (abundant) Kaolinite Ferruginous matter
31	Aghmid	Sandstone	Fraction <105µ	Quartz (abundant) Kaolinite (traces)
59	Aghmid	Sandstone	Fraction <105µ	Quartz (abundant) Kaolinite (abundant)
199	Jezzine	Argillaceous	Clay	Quartz (trace) Kaolinite (abundant) Illite
207	Jezzine	Argillaceous	Clay	Quartz (trace) Kaolinite (abundant) Illite (abundant)
221	Jezzine	Argillaceous	Clay	Quartz (abundant) Kaolinite (abundant)
236	Jezzine	Argillaceous	Clay	Quartz (abundant) Kaolinite (abundant)
A	Machnaqa	Sandstone	Small lens of white clay	Quartz Kaolinite 11.2Å phase (abundant)
B	Ain Zhalta	Sandstone	Small pellets of grey clay (see text)	Quartz (abundant) Kaolinite (abundant)
C	Baruk	Sandstone	same as B	Quartz (abundant) Kaolinite (abundant)

Machnaqa (Sample A) consisted largely of a mineral with a basal spacing (when glycerated) of 11.2 Å. This does not correspond to any of the interstratified minerals listed by MILLOT (1964); that which it most

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nearly approaches is a mixed-layer illite-vermiculite with a spacing (when glycerated) of 12 Å.

Small grey argillaceous pellets of various sizes up to 3 mm long are sparsely but rather widely distributed in the arenaceous beds. Two of these (Samples B and C) when examined by x-ray diffractometry proved to consist of quartz and kaolinite. It is characteristic of these pellets that they are always roughly the same size as the quartz grains among which they occur. Might they represent feldspar grains deposited along with the quartz and subsequently weathered? Some examples can be seen in Plate I.

2.6 Concretionary structures

The concretionary structures of the Basal Cretaceous Sandstone can be divided into two main categories: pisoliths (mainly calcareous but ranging to almost entirely ferruginous in composition) and non-pisolithic ferruginous concretions of various types (generally consisting of haematite, hydrated ferric oxide or pyrite).

Pisoliths

As mentioned earlier (p. 1), the upper limit of the sandstone is marked locally by beds of pisoliths which attain in places (e.g. Aghmid, see Plate XII) a total thickness of about 15 m. In most localities where they occur the pisoliths are of predominantly calcareous composition, but at Qubbai' (see location map, Fig. 1) and in several localities studied earlier by the present writer they are ferruginous. Good examples of the calcareous type are found at Aghmid (Plates VII and VIII). They are generally roughly spherical or spheroidal in shape, often deformed, and vary from oolite size to several cm in diameter, with a large proportion between ½ and 1½ cm.

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Each pisolith is built up of concentric layers about a central core, generally a quartz grain or an aggregate of quartz grains, less often a fragment of a shell. The layers are of finely crystalline calcite, often delicately lobate in outline, and are differentiated from one another by iron stains. They are often discontinuous (Plate VIIb), perhaps owing to growth now on one side, now on another, as the developing pisolith was rolled about by currents or waves. The first few layers are usually irregular, following the outline of the nucleus. In a number of examples (for instance the pisolith marked (A) in Plate VIII) a group of "cores", each with its system of concentric layers, shows that a pisolith in its early growth coalesced with one or more neighbours to form a common nucleus about which continued growth has formed a single, larger individual.

Ferruginous concretions

A large variety of concretionary ferruginous bodies is found in the Basal Cretaceous Sandstone. Some, occurring as irregular sheets of impure haematite roughly concordant with the bedding, may represent ancient topographic surfaces where iron-bearing ground water, evaporating after rising through the capillary spaces of the sand, deposited a ferruginous crust. Others, filling joint systems, may have originated in recent times by deposition in the zone of oxidation above the ground water table. The exposure illustrated in Plate Ib shows shallow cracks in the surface of a sandstone bed filled with fine-grained, coherent ferruginous material: possibly fossil mud cracks. Most of the concretions however are of more compact form, either indistinct pseudomorphs after wood fragments or, more frequently, masses of irregular shape which may or may not have replaced other materials. When broken they quite commonly reveal a nucleus of pyrite, implying that they have grown from accumulations of this mineral by oxidation. Pyrite concretions are frequently found associated with lignite, which

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evidently has protected them against oxidation.

2.7 Lignite and sundry fossil remains

Plant remains are common throughout the formation. In the medium- to coarse-grained sands they are generally preserved as ferruginous pseudomorphs (see above, 2.6), but in silty and argillaceous beds offering protection against oxidation lignite is found, occasionally (as at Bzebdine) in quantities that have in the past encouraged an exploitation which, unfortunately, did not prove profitable. Well-preserved fern fronds are sometimes found with these lignites, and occasionally amber, the latter having been recovered as well-formed droplets near the quarries of Homsiyeh (Jezzine), accompanied by the fresh- or brackish-water pelecypod Unio. It has been reported from the University of Tübingen, where samples of the amber are now being studied, that it contains an insect fauna.

Dark, well-laminated shales occur in a number of localities: those at Mejdel Tarchich and the Col of Zahle were found to contain ostracods, and in addition yielded appreciable quantities of oil when treated with ether. In the calcareous beds were found (in addition to the remains listed in Section 2.3 above) Foraminifera, fish teeth and (near Jezzine) Rhizocorallium, the filled-in burrows or bore-holes of shallow-water marine organisms. A fish tooth was also discovered in a sandstone bed at Machnaqa.

3. DISCUSSION

3.1 Environment of deposition

The granulometric results show that the Basal Cretaceous Sandstone of Lebanon is an essentially uniform deposit, comparable in grain size

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and degree of sorting with the Nubian Sandstone of Egypt (SHUKRI and SAID, 1945). But whereas Shukri and Said concluded that their samples represented a beach deposit, the evidence in Lebanon points to a more complex environment. The occurrences of undamaged fern fronds and amber droplets point to at least temporary or local nonmarine conditions, and (though open to question) the evidence of contemporary land surfaces (see above, p. 26) supports this view. The occurrences of lignitic shales with Unio (at Jezzine) and of oil-bearing shales with ostracods (Col of Zahle and Mejdel Tarchich) are suggestive of brackish lagoons, some of them with well-developed euxinic bottom conditions; the predominance of kaolinite in the samples taken from argillaceous beds (see Table III) might mean either a continental or a euxinic marine environment, but its occurrence in the arenaceous samples as well points rather to the former. Finally the carbonate beds with their varied evidence of marine conditions: glauconite, fish teeth, oysters and echinoid spines: bear infrequent but unequivocal witness to the presence of the sea.

KANAAN concludes on the basis of sedimentary structures and facies variations that the Basal Cretaceous Sandstone is a fluvio-deltaic deposit. This interpretation is in good agreement with the ambivalent character of the formation revealed by the present study, but meets with difficulties when we look for something of the general sedimentological pattern traditionally expected of deltas. In an ideal delta we might expect, in working down a vertical section at a given locality, to observe at least some trends in petrography and facies variation that could be associated with our progress from topset through foreset to bottomset strata: above all a tendency towards finer grain sizes and more frankly marine deposits. Although a supplementary study of the Aghmid section (see Appendix) did show a negative correlation between grain-size and

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depth below the top of the formation, this could not be confirmed satisfactorily at any of the remaining six localities sampled, some of which even showed a positive correlation; and for the rest it cannot be claimed that any coherent facies trends are observable.

This apparent lack of organization need not deter us, however, if it is remembered that we have to consider the development of a delta, not in terms of a stationary sea level, but against the background of a marine transgression. The succession of beds at any point now becomes purely a matter of competition between subsidence and sedimentation: and although in the extreme landward and seaward parts of the delta intact sequences of topsets and bottomsets (respectively) may be maintained, the region in between may present almost any imaginable succession of deposits (subaerial and subaqueous) interfingering with one another or separated by minor unconformities. TWENHOFEL (1926), in his classic treatise, gives a good illustration (Fig. 59, p. 598) of this type of situation, and cites as an example the Coal Measures of Indiana.

This picture of a growing delta in a rising sea, with now one, now the other in temporary ascendancy, is superimposed on a larger one in which the transgression slowly gains on the sedimentary pile, finally overwhelming it and beginning another era of carbonate deposition heralded by neritic limestones and, locally, the pisoliths. The almost total absence of conglomerates1) in the Lower Cretaceous of Lebanon

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1) A few local conglomerates occur in the neighbourhood of Mt Hermon; cp. footnote on p. 2.

bespeaks a flat shore and hinterland, and there is evidence (see KANAAN, 1966) that the climate was warm and humid: we may picture a seascape of wide, nearly horizontal beaches swept by the breakers of the Tethys, whose tides must have been many times ampler than those of the Mediterranean. Through the gently shelving hinterland a river system flows slowly over a great flood plain on which grows a rich sylvan vegetation. Sand bars formed by the waves enclose lagoons of brackish water. At other times the sea, encroaching on the delta, tears up its surface to sort and redistribute the alluvium with each ebb tide, carrying the fine material away to form offshore deposits.

A curious feature of the current-bedded layers described by Kanaan is the unusually sharp contact of the foresets of each bed with the truncated top of the bed beneath. Kana'an considers whether this might be explained by high current velocities: a condition unlikely to obtain very often in the distributaries of a delta above high water mark. Kanaan's studies also show that the transporting currents have flowed in a generally westerly direction: whereas considering the situation of Lebanon with respect to the Arabo-Nubian shield as a whole, it would seem more reasonable to expect the rivers to have flowed northward. But iff the current bedding was laid down, not by the rivers which transported the sand from the interior but by the ebb tides of a sea lying to the west, both these paradoxes disappear.

3.2 Medium of transportation

When we turn to consider the possible agents of transportation from the source area, the direct evidence seems meagre. True, if there was a delta there must have been a river; but it would be reassuring to have

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some independent confirmation of this. Kanaan has explained the cross-bedding of the sands in terms of fluvial deposition; but having suggested that tidal currents are more likely to have been responsible, we can hardly appeal to his arguments now that we are in need of a river. Sand grains are notoriously equivocal about how they were transported, as a study of sedimentological literature readily shows. We are moreover here confronted with deposits of which a considerable part is likely to have been modified by the action of waves on the sea shore: the treatment to which it is no doubt largely indebted for its excellent sorting characteristics. Two indications of fluvial transport are worth mentioning: 1) the largest fraction of the sand (> 3.4 mm), though quantitatively unimportant, contains grains as much as 7 mm in diameter: a larger size than could normally be carried by wind over appreciable distances but could very well be transported by traction in a mature river at flood time; 2) the deposits of well-sorted, angular material referred to on p. 20 suggest river-transported sands that escaped reworking by the sea, perhaps by burial in the delta topsets to a depth that placed them beyond the reach of the transgressive waves when these regained ascendancy over the land.

The difficulty of finding direct evidence on transportation is added to by the probability, as will be seen below, that these sands are themselves derived from a pre-existing sandstone formation.

3.3 Provenance

Mineralogically, the Basal Cretaceous Sandstone is characterized by the absence of unstable components. Quartz is the only major detrital constituent; and tourmaline makes up 60 percent of the heavy mineral fraction, followed by zircon and rutile, 9 percent each. Chlorite is the only mineral present in appreciable quantities whose stability leaves anything to be desired, and it is doubtful whether this was really transported or derived from local basaltic volcanism contemporaneous with the sands.

The absence of unstable minerals might be due to prolonged working by waves in a littoral environment; but in that case we should look for a more varied heavy mineral fraction in those parts of the deposit which clearly have not been on the beach: for example the lignitiferous sands. We are thus left/to consider the mineralogical composition in relation to the medium of transportation and the source rocks. Whilst there is no doubt that prolonged transportation by rivers can result in very considerable attrition of feldspar grains, amphiboles and other relatively unstable components, it is not usual for these to be eliminated completely in one cycle of erosion. The dune sands of the Netherlands, for instance, though transported over the length of the Rhine, contain a much richer assortment of accessory minerals (ter MEULEN, unpublished work) than is the case here. It is commonly believed that the sands of Lebanon have their origin in the metamorphic rocks of the Arabo-Nubian shield: a perfectly reasonable supposition, considering the geographical and tectonic relations of the two areas. But if these sands were first generation derivatives of the shield, should we not expect to find at least some feldspars among the quartz and some amphiboles among the heavy minerals? In all the material examined (127 thin sections and 11,000 heavy mineral grains) were found only two grains of alkali feldspar and less than ten of basaltic hornblende.

We might therefore consider the possibility of indirect derivation from the Arabian shield by erosion of some intermediate deposit: Kanaan has suggested a sand desert dispersed by a change of climate from dry to wet. Might not

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an older part of the Nubian Sandstone itself have been this "intermediate source"? BENDER (1963) describes the Cambrian sandstones of Quweira in southern Jordan as containing gravels and beds of arkose; the principal heavy minerals are zircon, hornblende, tourmaline and rutile: here are more of the characteristics we should expect of a deposit directly derived from the metamorphic shield, on which, indeed, the formation lies in direct contact. LILLICH's (1964) work on the E coast of the Dead Sea describes rocks of essentially similar character. Lower Cretaceous sands are present in both these areas, making it unlikely that they provided material for the Basal Cretaceous Sands of Lebanon; but E of Damiye Bridge in the Jordan Valley (AVINIMELICH 1945, cited by BURDON, 1959) Bathonian limestones of the Zarqa Group are covered by Cenomanian marls. A more attentive study of this disconformity might reveal a possible source of our Basal Cretaceous Sandstone; the present politico-military situation requires the postponement of this till happier times.

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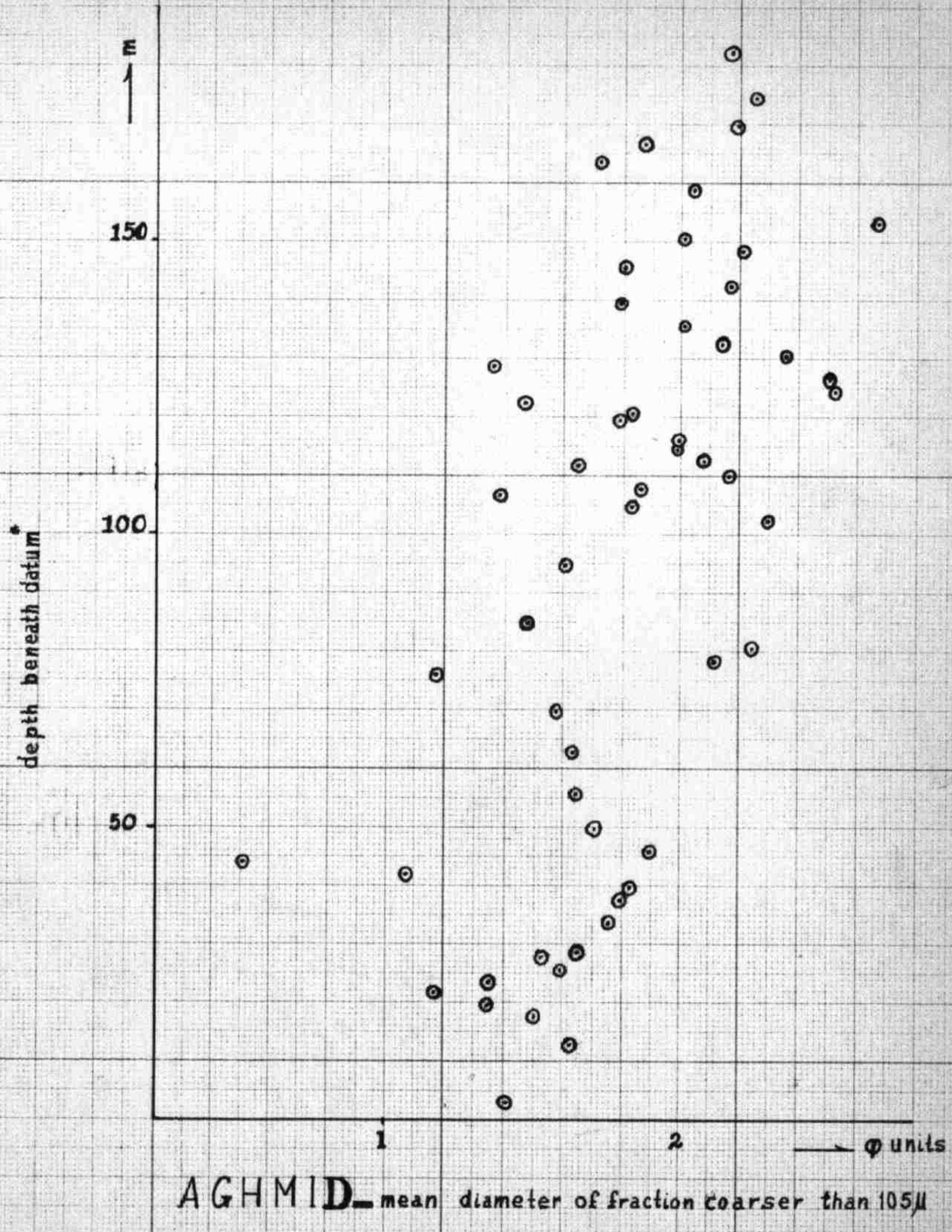
Appendix I



AGHMID – mean diameter of fraction coarser than 105μ

* Datum is the top of the Basal Sandstone as defined by the top of the pisoliths.

Plate I

a. White clay pellets. Possible weathering products of felspar grains. Section of Beskinta. x½.

b. Mud cracks associated with an old soil profile. Section of Ma'aser Ech-Chouf.

c. Looking northward from Douma. Basalt flows lying disconformably on Jurassic limestone and covered in turn by sandstone of the Lower cretaceous.

Plate II

a. Sandstone with carbonate detrital grains, (the greyish grains in the picture). Upper part of the section of Qoubbai.
Sample No. 22. x4.

b. Sandstone showing relatively coarse subrounded to subangular grains and ferruginous cement.
Sample No. 16. Section of Beskinta. x15.

c. Sandstone showing rounded coarse and angular fine grains with ferruginous cement and calcitic veins.
Sample No. 27. Section of Aghmid. x15.

PLATE I

a

b

c

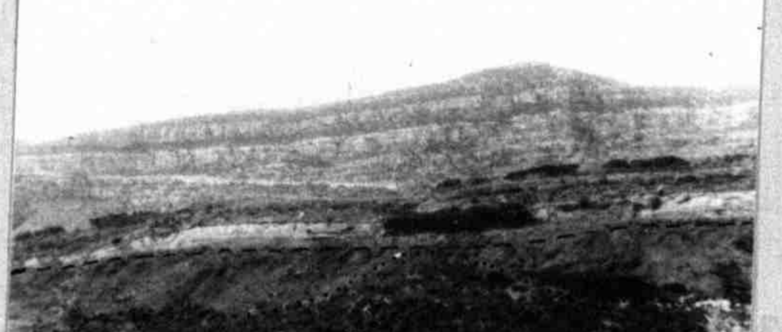
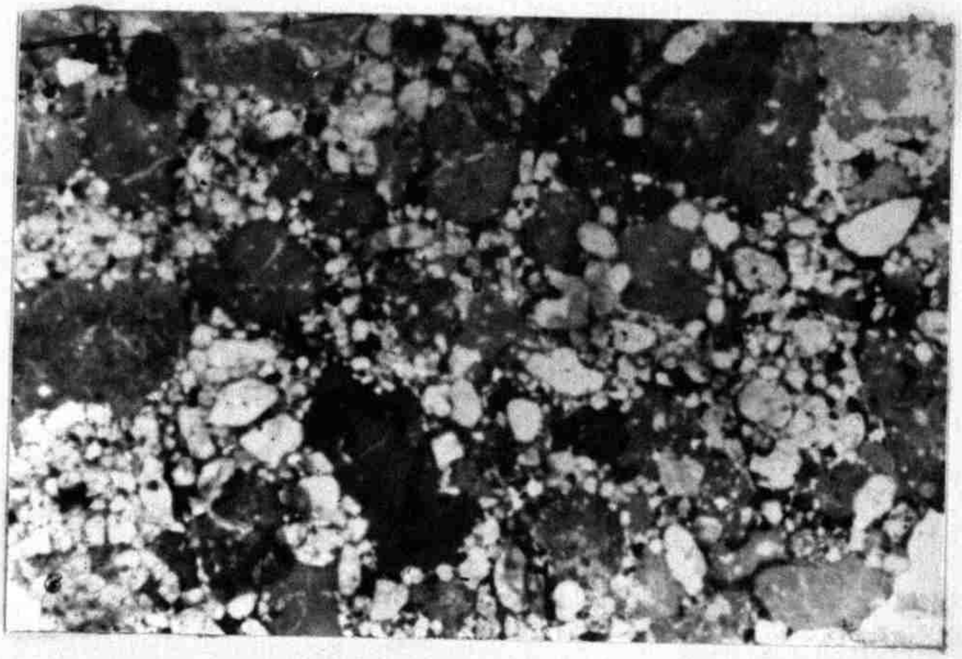


PLATE II



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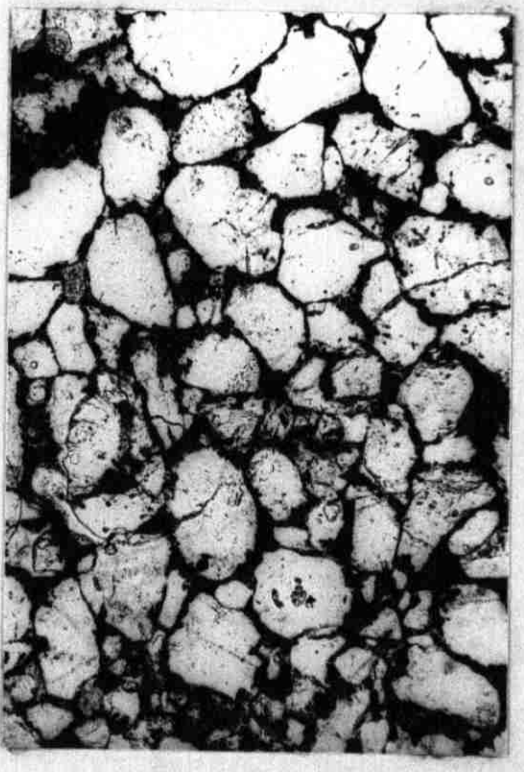

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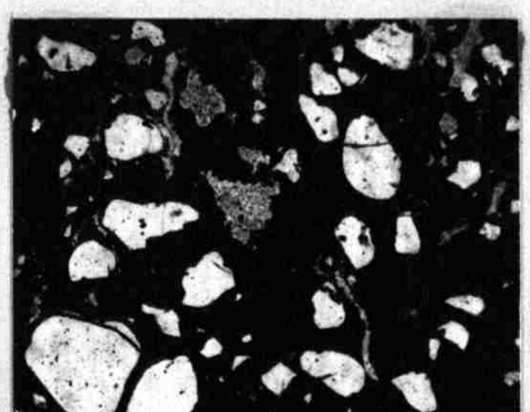


c

Plate III

a. Very fine sand and silt laminations bedded with Lignite, showing a pattern of differential compaction.
Sample No. 19, Beskinta section. x4.

b. Same sample as above enlarged to show the relation of the silt to the lignite and bedding. x30.

c. Same sample as above enlarged showing sand-silt relation. x30.

d. Fine sand. Angular well sorted grains
Sample No. 1, base of Beskinta section. x15.

PLATE III

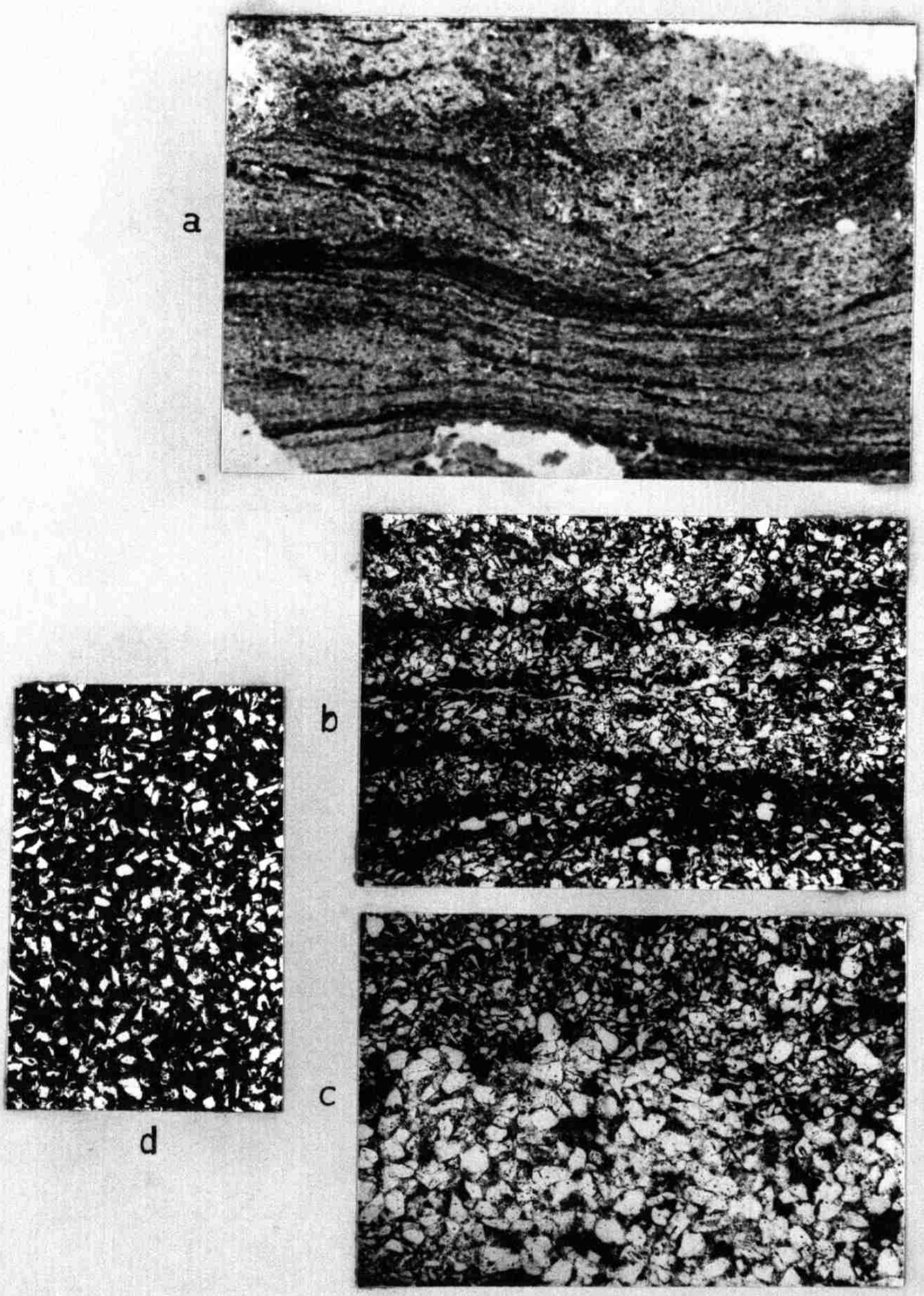


Plate IV

a. Badly sorted quartz sand showing variations in rounding. One grain shows acicular inclusions. Sample No. 31D, Aghmid section. x30.

b. From same sample as above: proportionately less cement. Note ferruginous Oolite, lower left. x30.

c. A tourmaline grain showing fractures and rounding. Sample No. 11B. Beskinta section. x30.

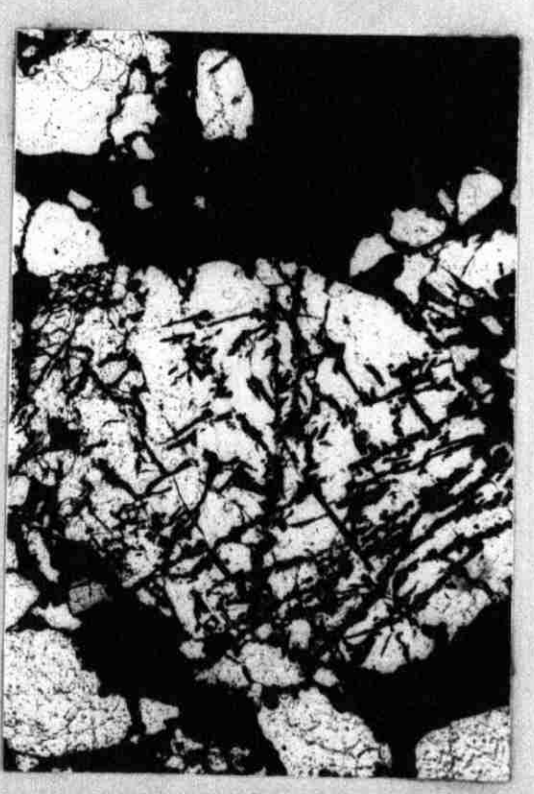
d. Rhombohedral cleavage of a quartz grain. Cleavage planes filled with iron oxide (see text p. 20). Sample No. 11B, Beskinta section. x30.

PLATE IV

a

b

c



d

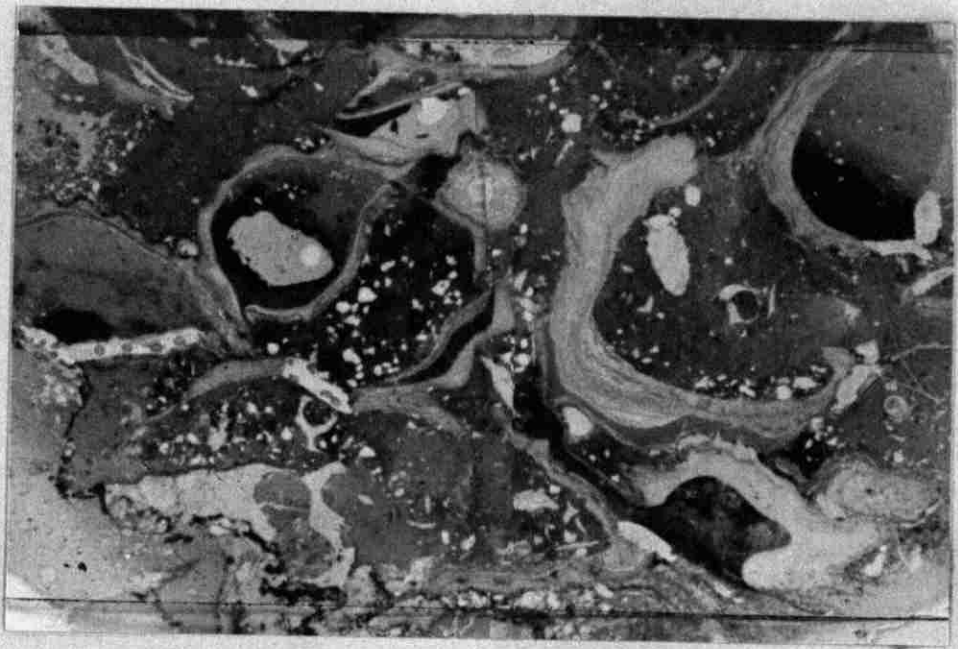
Plate V

a. Fossiliferous sands with oysters and Perna etc. Above the pisoliths of Jezzin.
Sample No. 173, x2½.

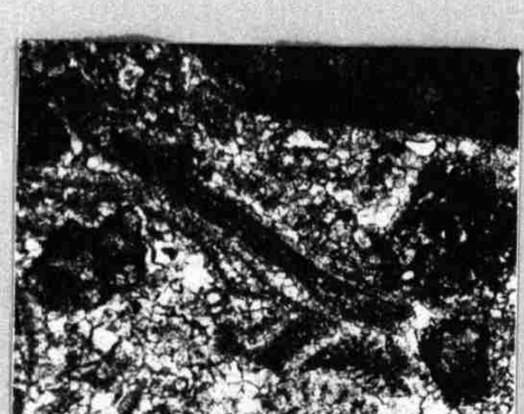
b. Limestone with echinoid spines and other fossil remains. Bottom of Beskinta section.
Sample No. 2, x20.

c. Fossiliferous silicified sandy limestone with forams from the upper part of the section of Qoubbai.
Sample No. 22, x50.

PLATE“V”



a



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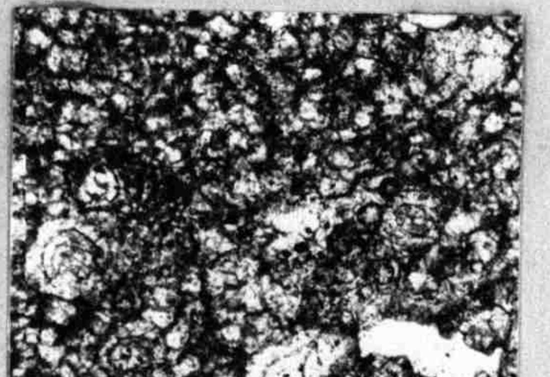
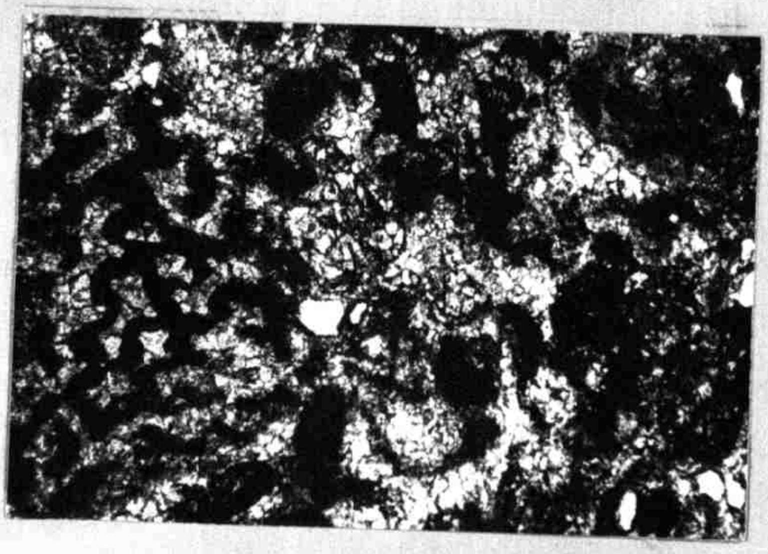
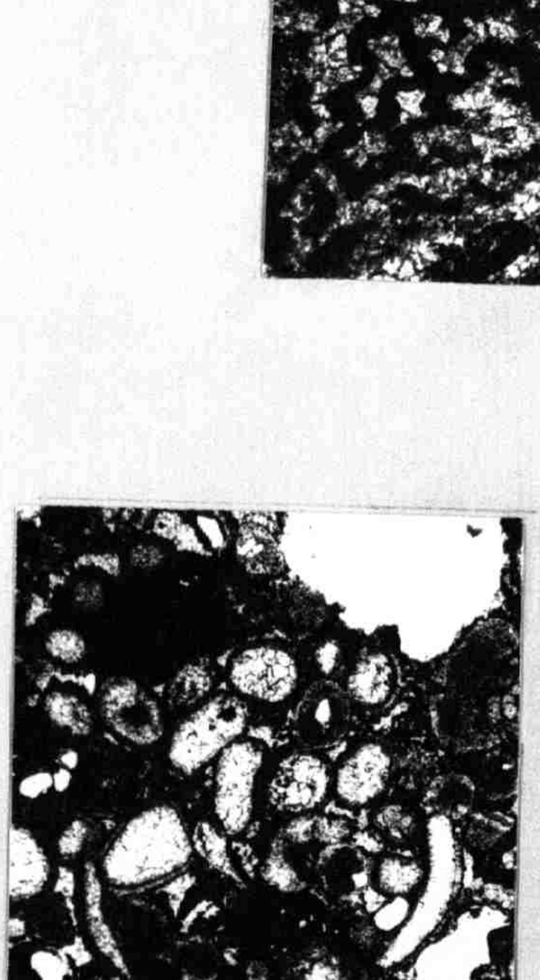


c

PLATE VI



a



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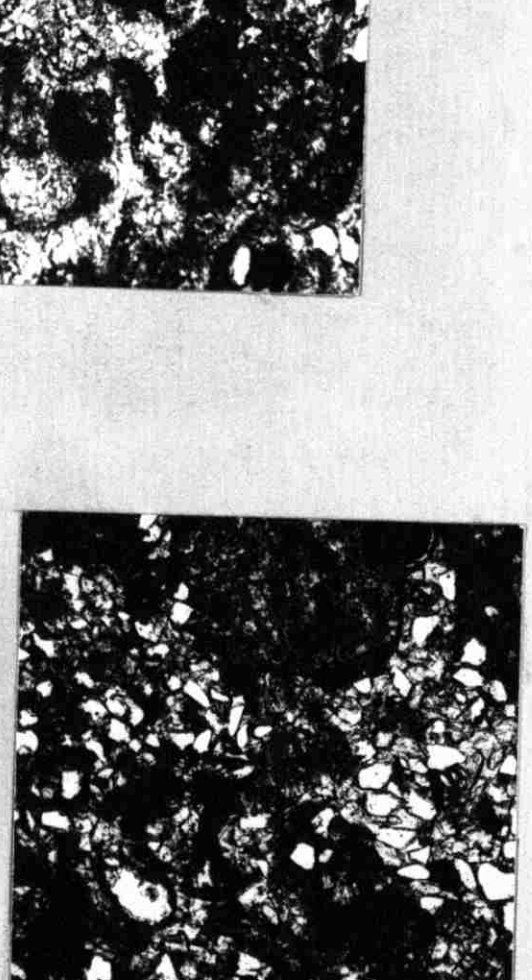
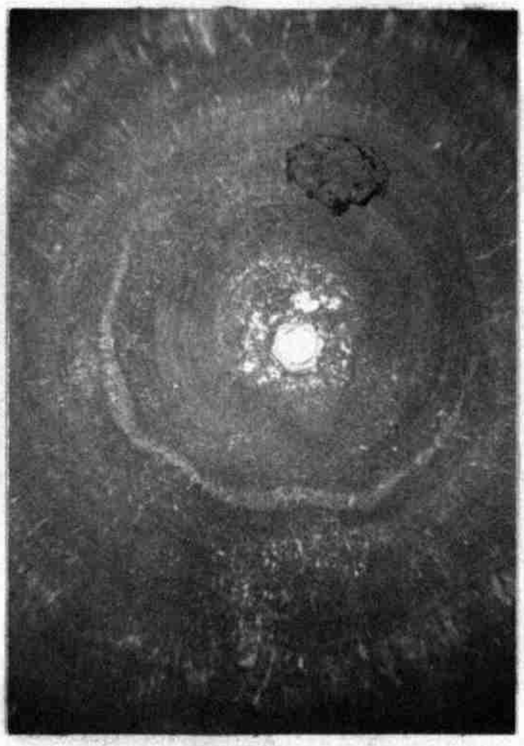


c

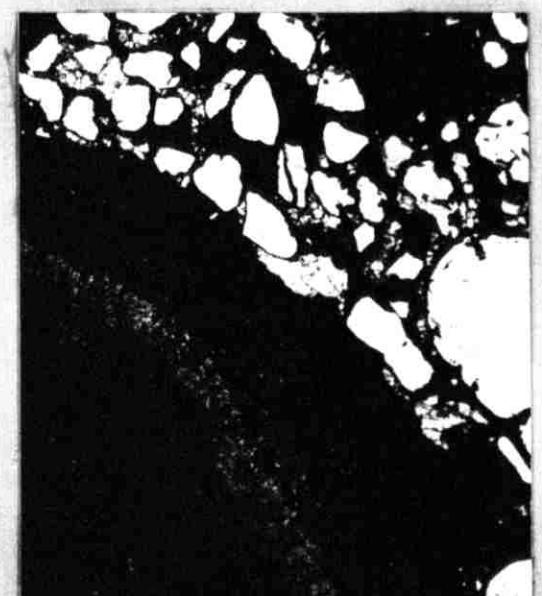
PLATE VII

a



b

c



d

Plate VI

a. Limestone with veriform structure of Glauconite. Sample No. 2, near the base of the section of Beskinta. x15.

b. Limestone with calcitic glauconitic spherulites of Oolitic dimensions. The slide also shows some rather fine boreholes and a few quartz grains.
Sample No. 3, near the base of the section at Beskinta. x15.

c. Limestone with more of quartz grains than (b). Sample No. 4, just above sample 3. Beskinta. x15.

Plate VII

a. Pisolith showing calcitic core and asymmetrical growth of concentric rings. The core is probably a recrystallized shell fragment.
Sample No. 29, top of the section of Aghmid. x15.

b. Pisolith with the carophytoid core. The section shows a semicircular wedging growth ring (see text p. 26).
Sample No. 26, top of Aghmid section. x15.

c. Pisolith with large irregular core and lobate growth layers. Sand grains in contact with outer part of the pisolith have embedded themselves in the periferv by solution of the calcite.
Sample No. 29, top of Aghmid section. x15.

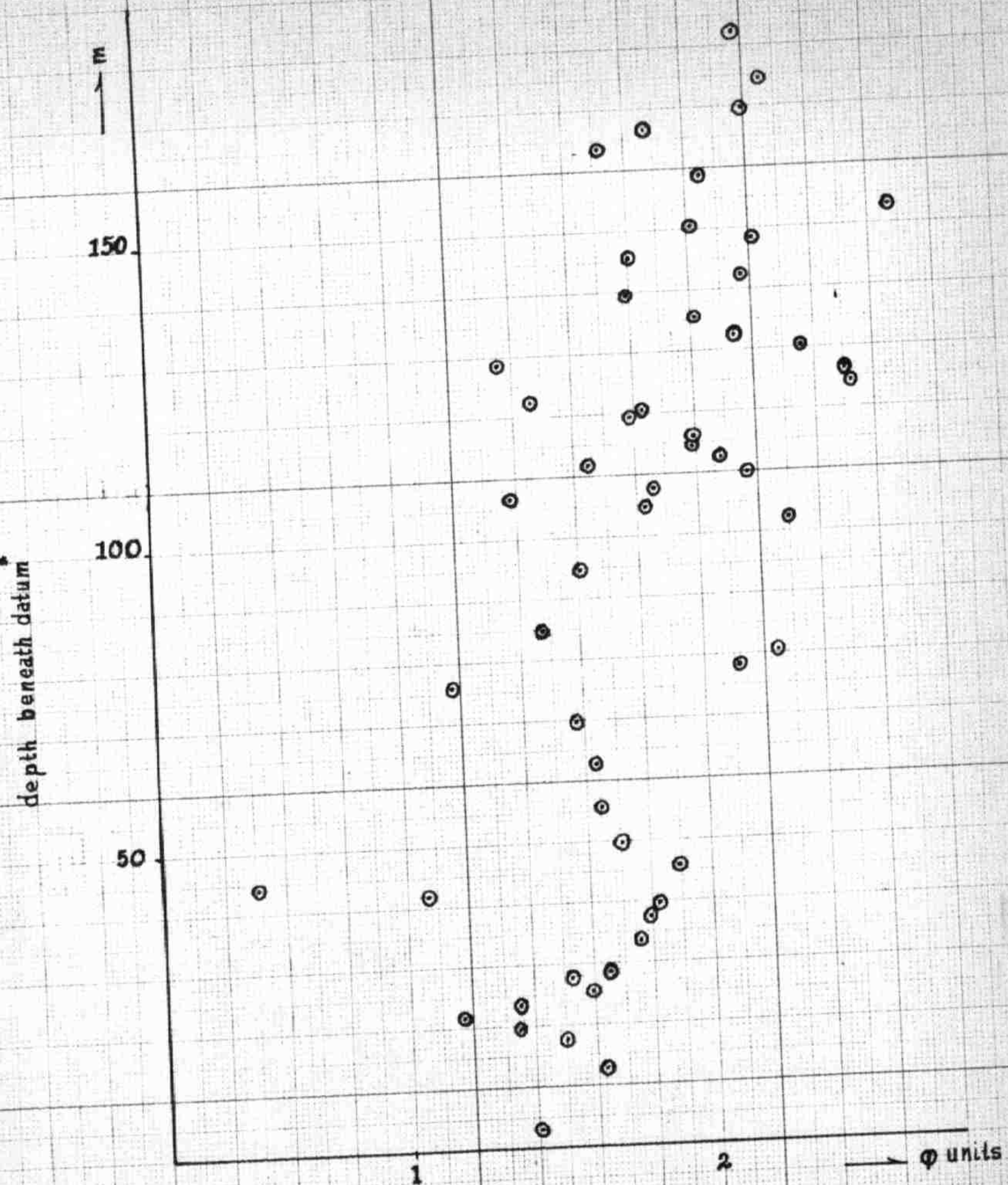
d. A Ferruginized pisolith with remnants of calcite left shown as rings of white specks in the dark body of the pisolith. Sand grains are aligned round the pisolith but have not penetrated it.
Sample No. 31D. Aghmid. x12½.

Plate VIII

a. Pisoliths of different shapes and sizes in a matrix of sand grains cemented with iron oxide. (A) indicates two coalesced cores at the micro-stage of development.
Sample No. 29, Aghmid section. x2½.

PLATE VIII

Appendix I



AGHMID – mean diameter of fraction coarser than 105μ

* Datum is the top of the Basal Sandstone as defined by the top of the pisoliths.

Plate IX

LEGEND

FOR ALL STRATIGRAPHIC SECTIONS IN TEXT

PLATE [XV]

CONGLOMERATE

SANDSTONE

ARGILLACEOUS SANDSTONE

MARLY SANDSTONE

PISOLITIC SANDSTONE

SANDSTONE WITH PYRITE NODULES

SANDSTONE WITH CARBONOCEOUS MATERIAL

CLAY AND SHALES

LIGNITES

MARLS

LIMESTONES

OOLITIC LIMESTONE

SANDY LIMESTONES

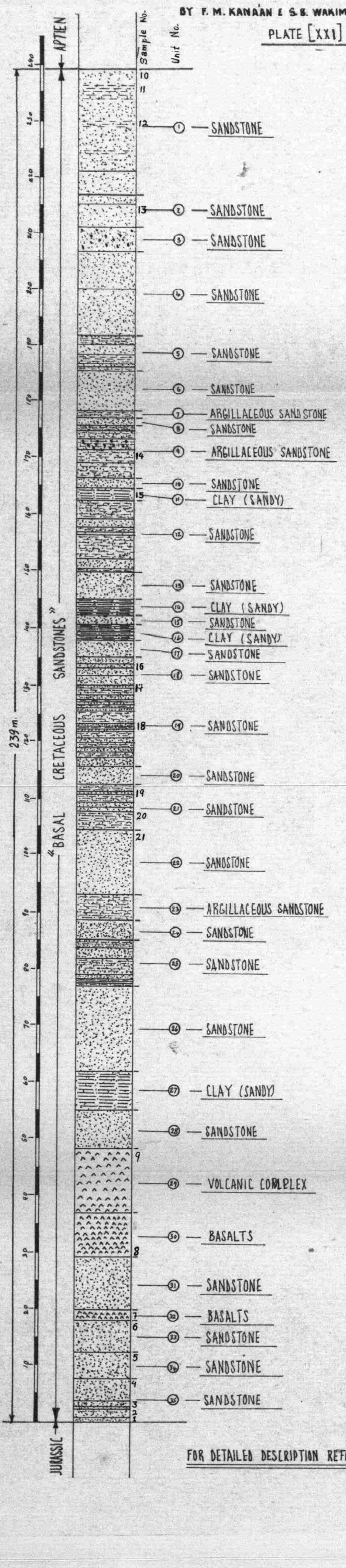
VOLCANICS - BASALT, TUFF, CHOLLATE CLAYS

Plate X

STRATIGRAPHIC SECTION
«BASAL CRETACEOUS SANDSTONES» OF CENTRAL LEBANON
LOCALITY OF BESKINTA

BY F. M. KANA'AN & S. B. WAKIM, SUMMER, 1965

PLATE [XXI]



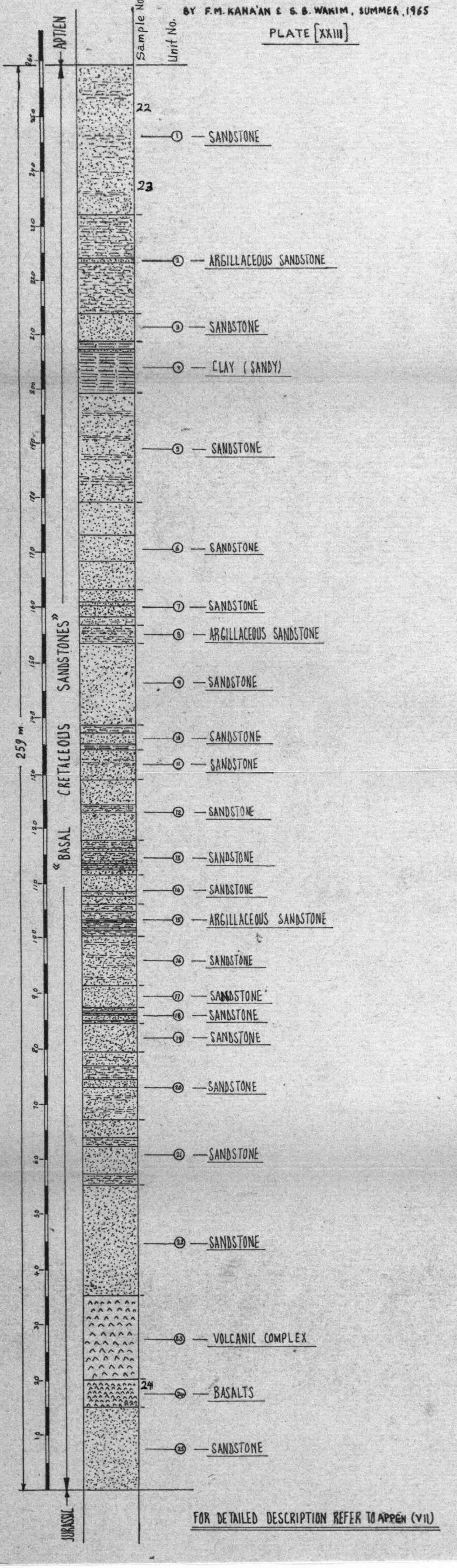
FOR DETAILED DESCRIPTION REFER TO APPEN. (V)

Plate XI

STRATIGRAPHIC SECTION
"BASAL CRETACEOUS SANDSTONES" OF CENTRAL LEBANON
LOCALITY OF QUOBAI'

BY F. M. KANA'AN & S. B. WAKIM, SUMMER, 1965

PLATE [XXIII]



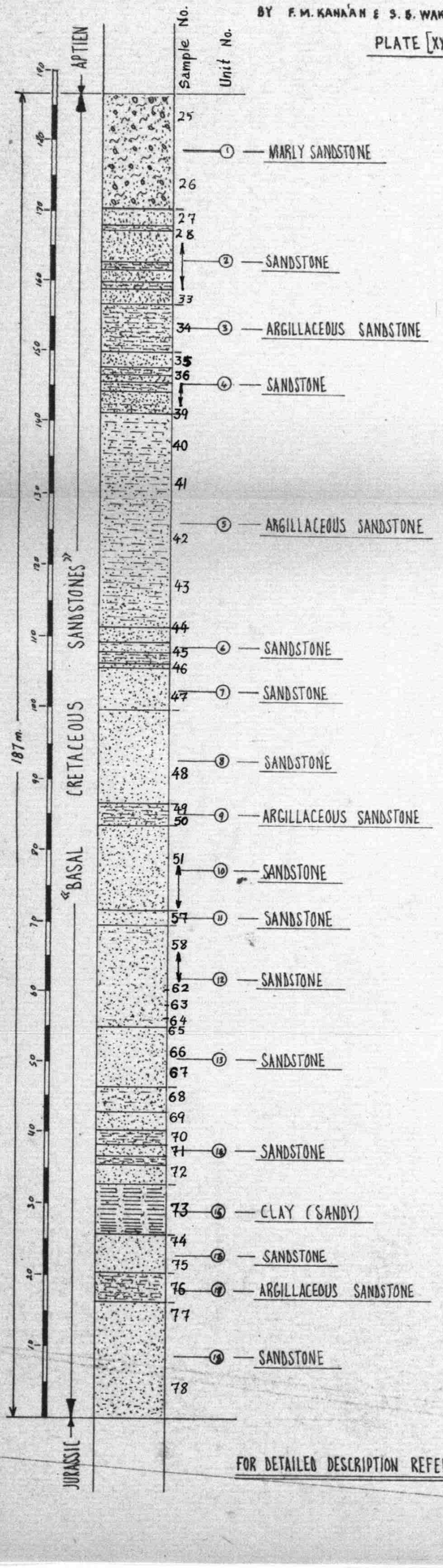
FOR DETAILED DESCRIPTION REFER TO APPEN (VII)

Plate XII

STRATIGRAPHIC SECTION
“BASAL CRETACEOUS SANDSTONES” OF CENTRAL LEBANON
LOCALITY OF AGHMID

BY F. M. KANA'AN & S. S. WAKIM, SUMMER 1965

PLATE [XXIV]



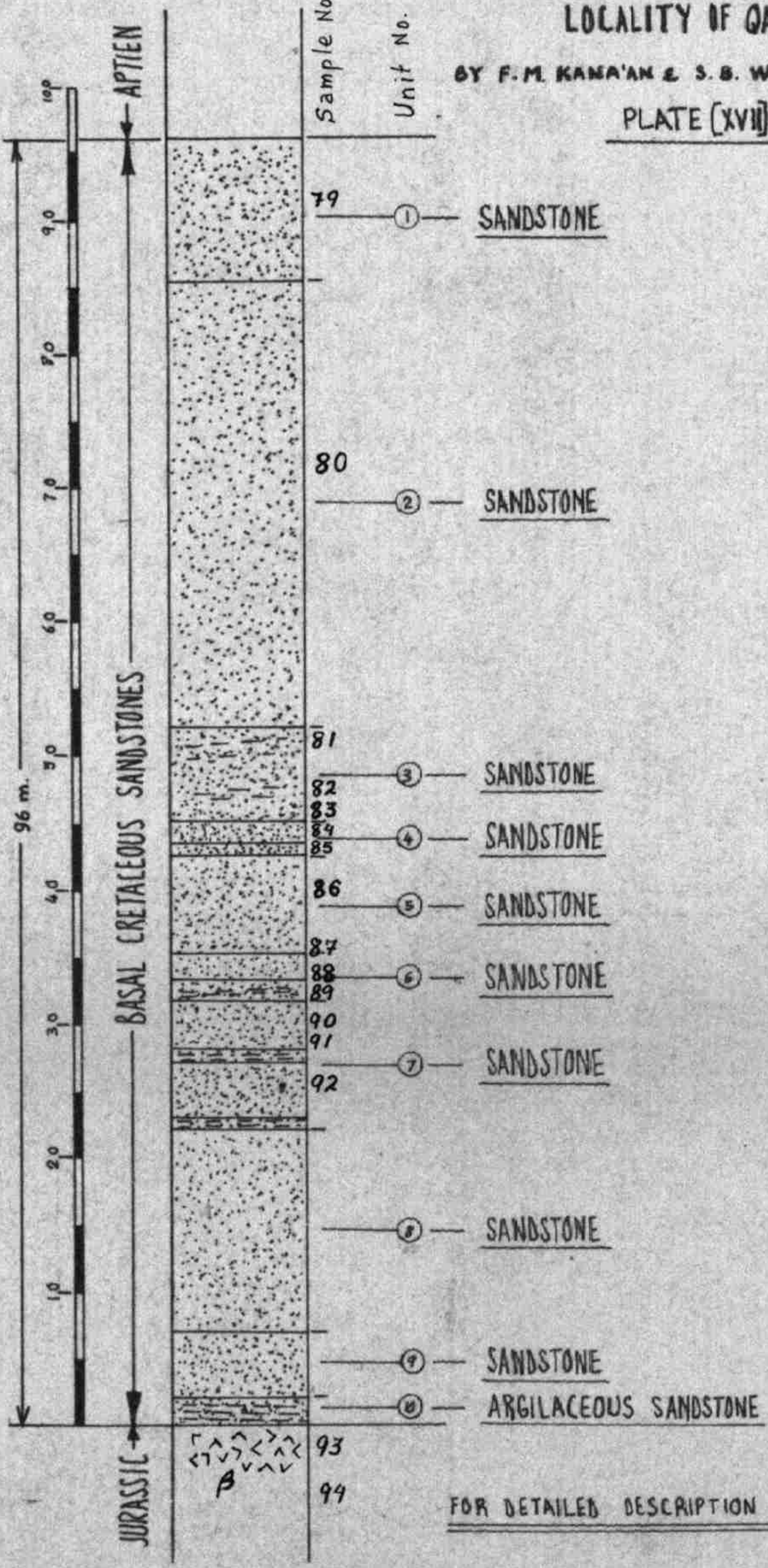
FOR DETAILED DESCRIPTION REFER TO APPEN (VIII)

Plate XIII

STRATIGRAPHIC SECTION
«BASAL CRETACEOUS SANDSTONES» OF CENTRAL LEBANON
LOCALITY OF QARTABA

BY F. M. KANA'AN & S. B. WAKIM, SUMMER 1965

PLATE (XVII)



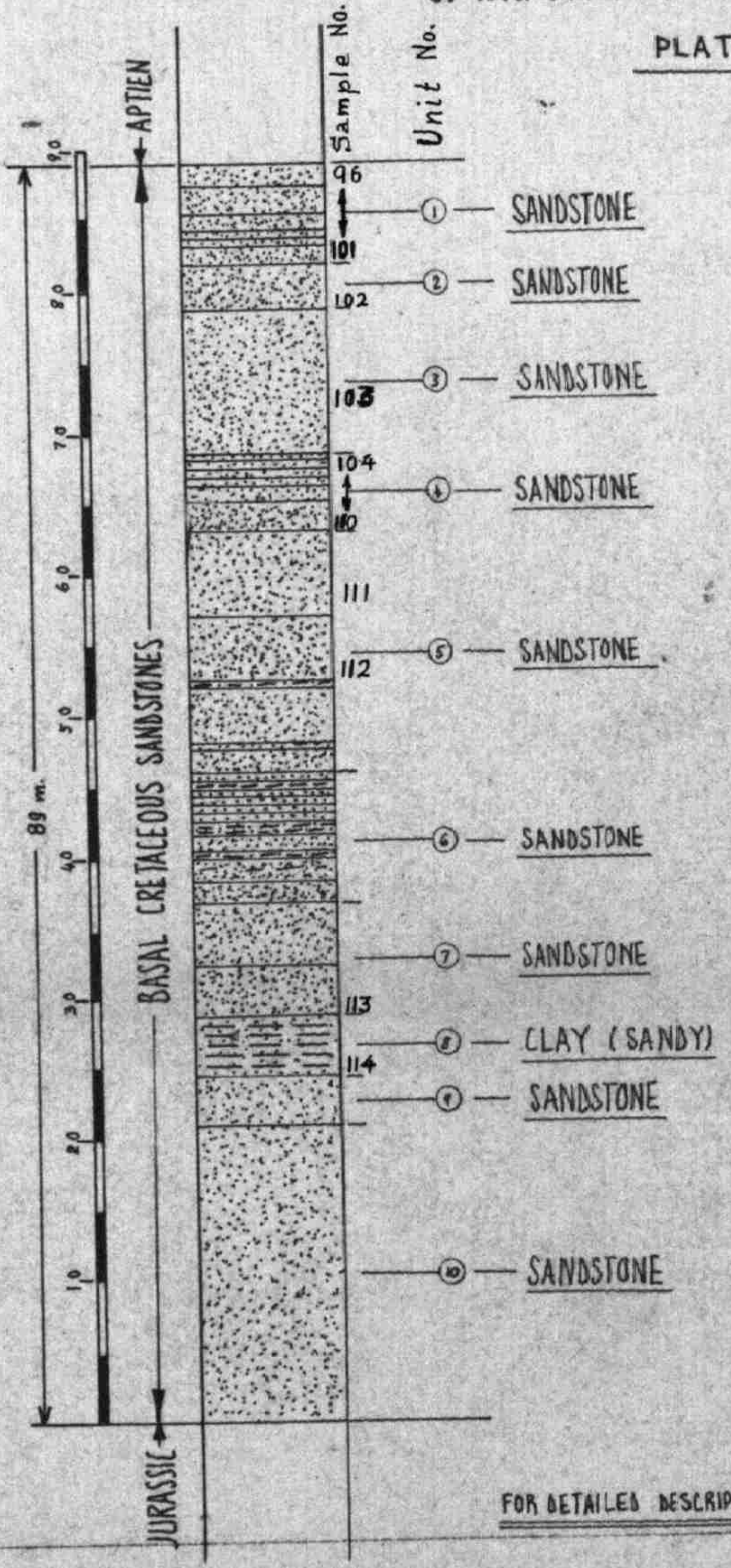
FOR DETAILED DESCRIPTION RERER TO APPEN. (I)

Plate XIV

STRATIGRAPHIC SECTION
«BASAL CRETACEOUS SANDSTONES» OF CENTRAL LEBANON
LOCALITY OF QATTIN

BY F.M. KANA'AN & S.B. WAKIM, SUMMER 1965

PLATE [XIX.]



FOR DETAILED DESCRIPTION REFER TO APPEN (III)

Plate XV

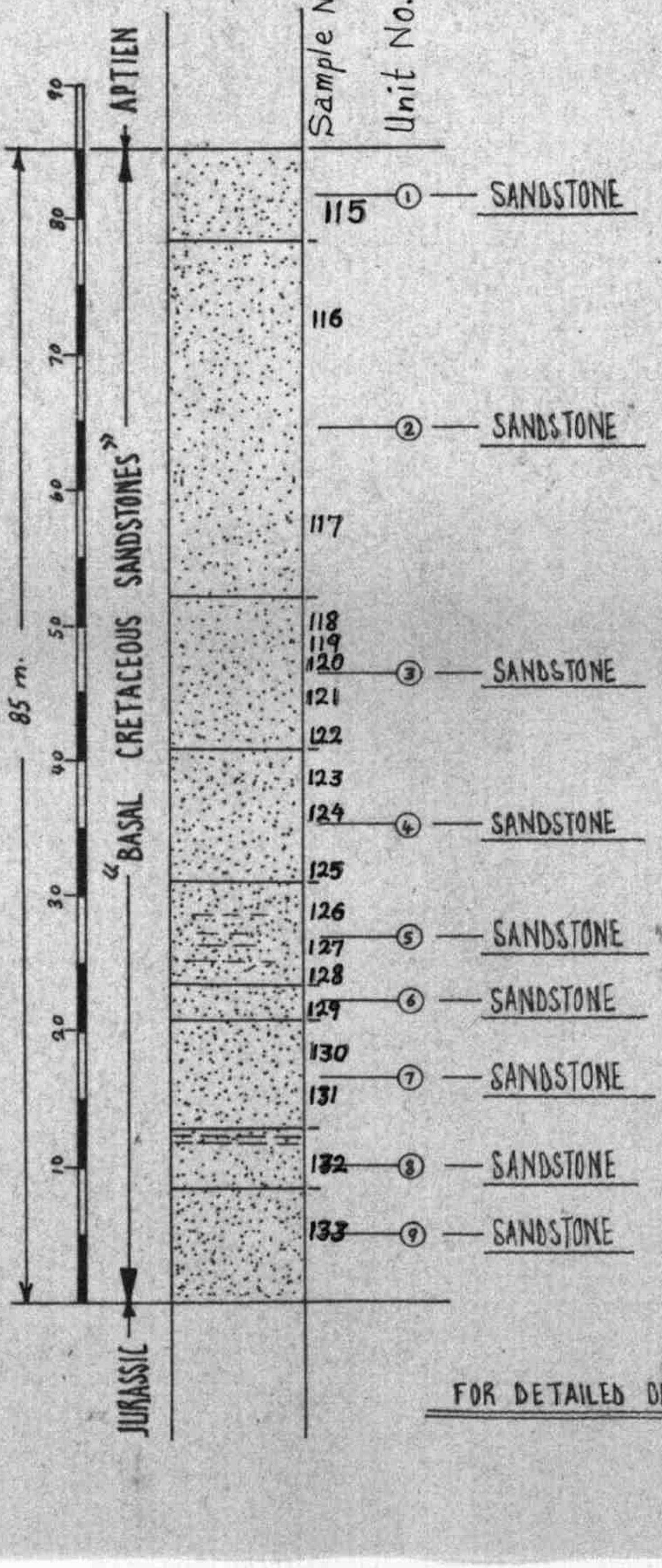
STRATIGRAPHIC SECTION

"BASAL CRETACEOUS SANDSTONES" OF CENTRAL LEBANON

LOCALITY OF AIN-TOURA

BY F. M. KANA'AN & S. S. WAKIM, SUMMER, 1965

PLATE [X X]



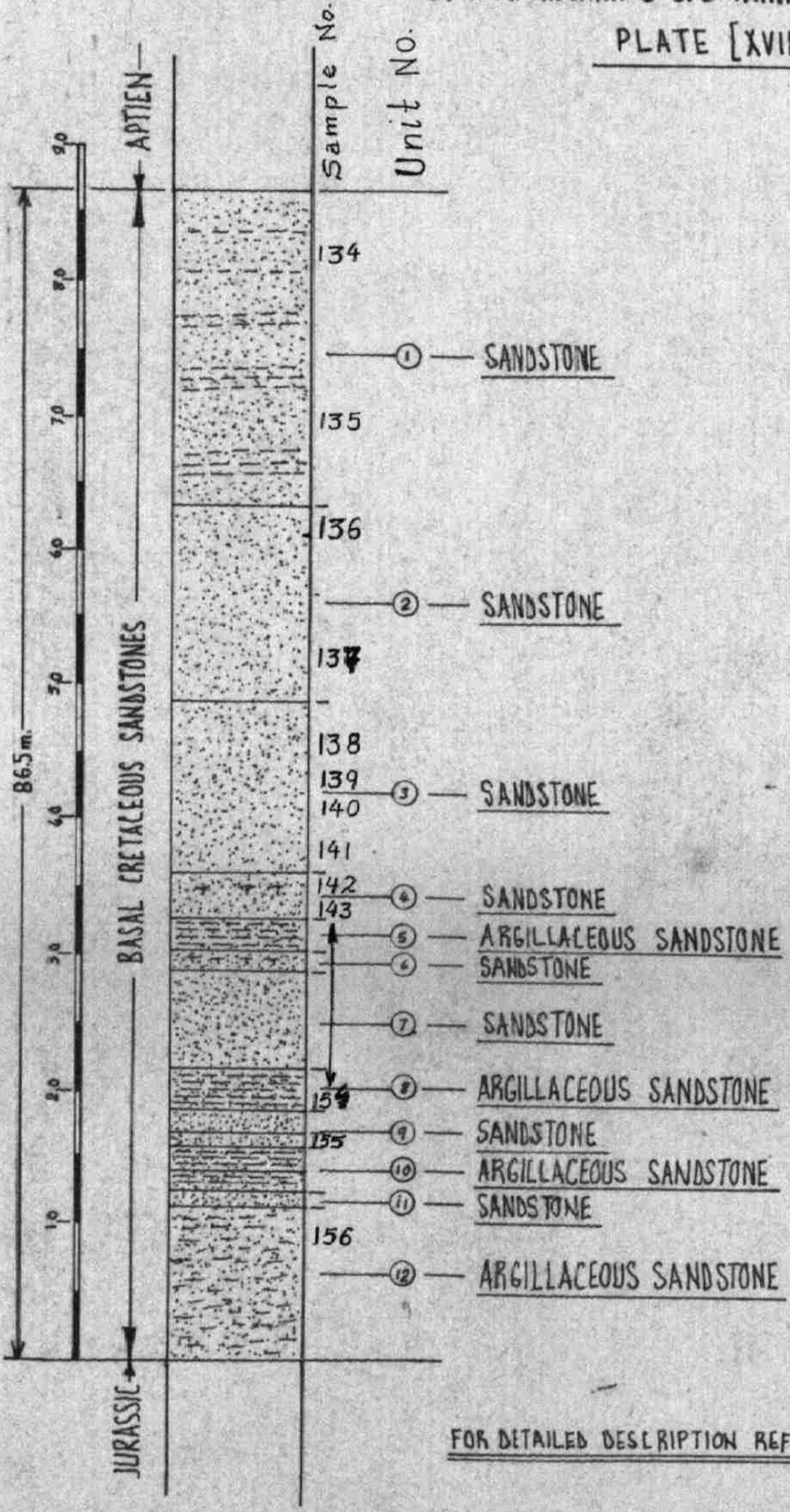
FOR DETAILED DESCRIPTION REFER TO APPEN. (W)

Plate XVI

STRATIGRAPHIC SECTION
«BASAL CRETACEOUS SANDSTONES» OF CENTRAL LEBANON
LOCALITY OF JOURET EL-TORMOS

BY F. M. KANA'AN & S. B. WAKIM , SUMMER, 1965

PLATE [XVIII]



FOR DETAILED DESCRIPTION REFER TO APPEN. (II)

LOCALITY OF JEZZINE

BY F. M. KANA'AN & S. B. WAKIM, SUMMBR, 1965

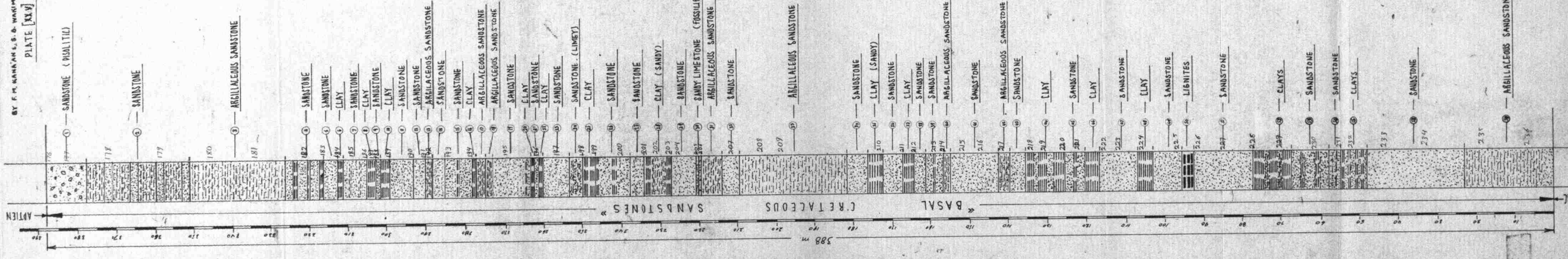
PLATE [XXV]

STRATIGRAPHIC SECTION - "BASAL CRETACEOUS SANDSTONES" OF CENTRAL LEBANON

LOCALITY OF JEZZINE

BY F. M. KANA'AN & S. B. WAKIM, SUMMER, 1946

PLATE [XXV]



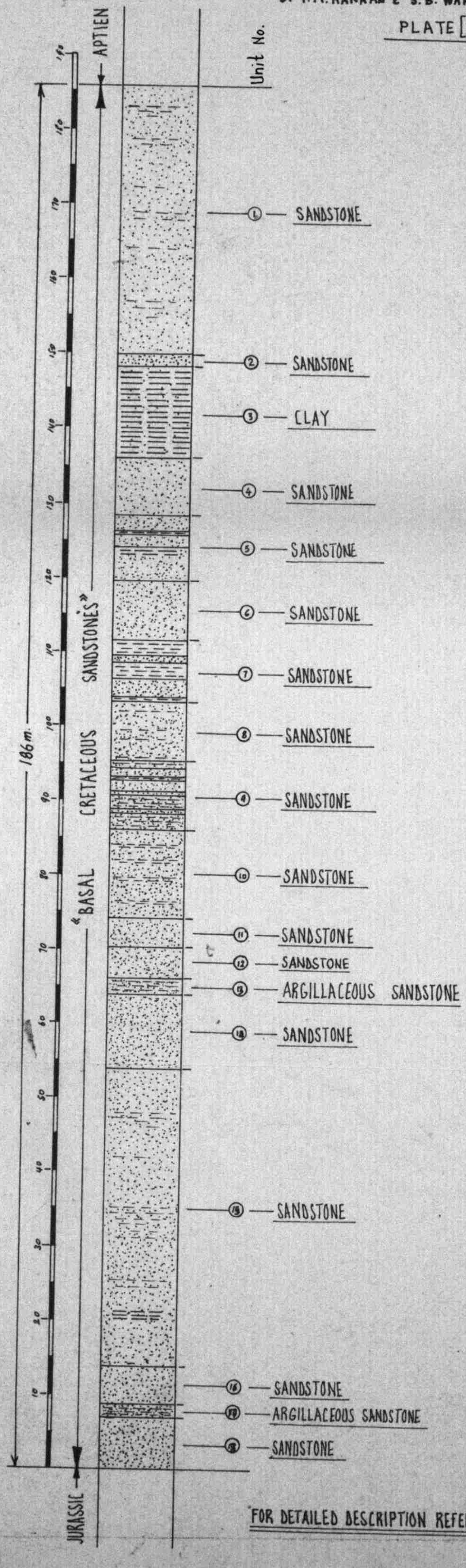
- FOR DETAILED DESCRIPTION REFER TO APPEN (IX)

Plate **XVIII**

STRATIGRAPHIC SECTION
"BASAL CRETACEOUS SANDSTONES" OF CENTRAL LEBANON
LOCALITY OF MAJDAL-TARCHICH

BY F.M. KANA'AN & S.B. WAKIM, SUMMER, 1965

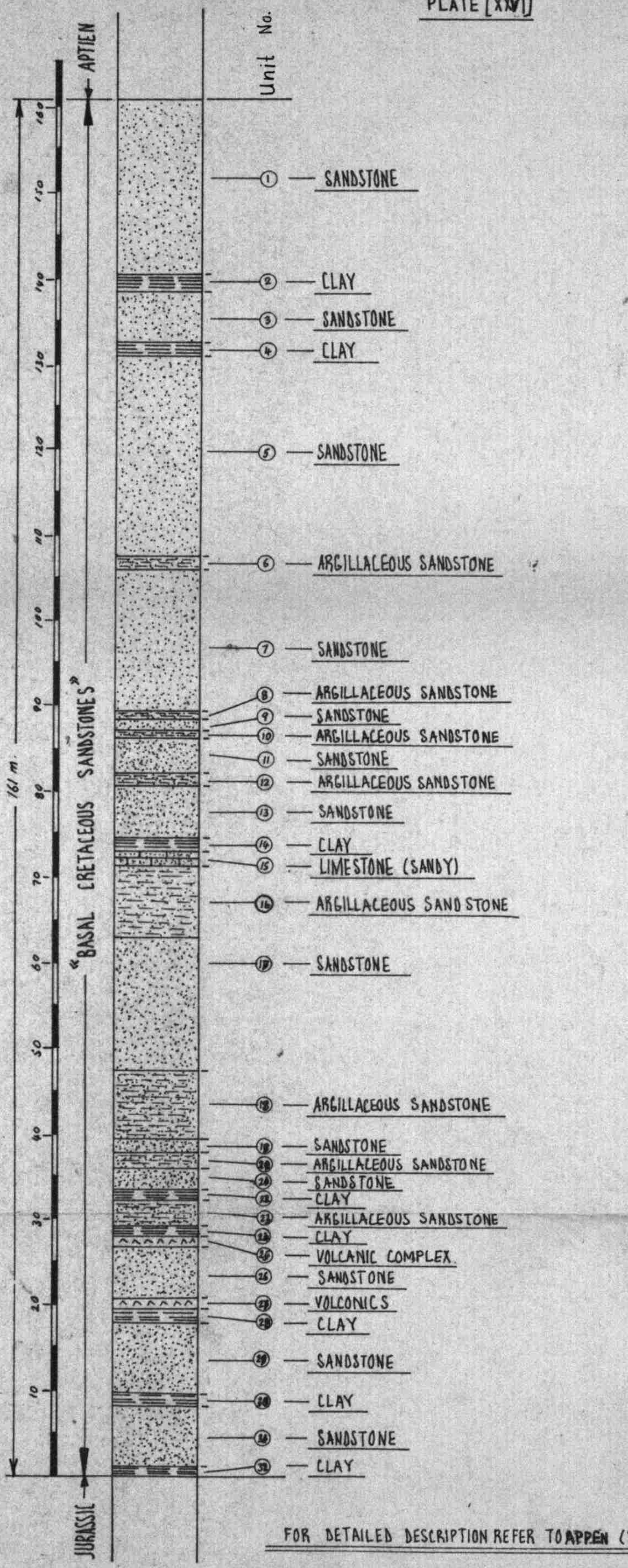
PLATE [XXII]



FOR DETAILED DESCRIPTION REFER TO APPEN (VI)

Plate XIX

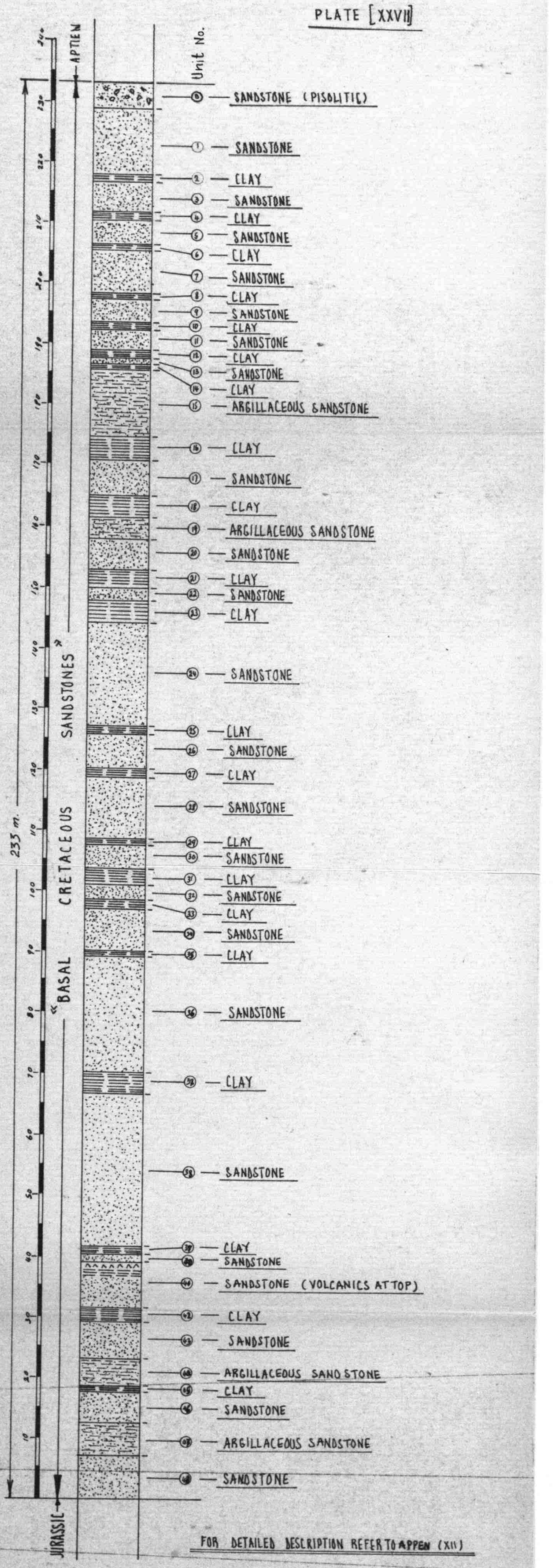
STRATIGRAPHIC SECTION
"BASAL CRETACEOUS SANDSTONES" OF CENTRAL LEBANON
LOCALITY OF W-AL-MANSOURIEH
PLATE [XVI]



FOR DETAILED DESCRIPTION REFER TO APPEN (XI)

Plate XX

STRATIGRAPHIC SECTION
"BASAL CRETACEOUS SANDSTONES" OF CENTRAL LEBANON
LOCALITY OF ~~COLE~~ COLE de OF MALHGHARA
PLATE [XXVII]



FOR DETAILED DESCRIPTION REFER TO APPEN (XII)