PETROGRAPHY OF THE MESOZOIC BASALTS OF LEBANON

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Samir Musa Kuttayneh

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To my Parents

in gratitude for constant help

and encouragement

FOREWORD

Like all others, this thesis is the fruit of a cooperative enterprise, and I am glad of this opportunity to acknowledge the help I have received in its preparation.

My thanks go first to the Department of Geology for a two-year Assistantship during which I carried out the work now reported, for the use of equipment and facilities without which it could not have been brought to completion; and not least for the advice and help I have received at all times from the different members of the staff, especially Dr. B. GREGOR, who directed my steps towards making this work possible.

The photomicrographs were made with a camera lent to me by the Department of Biology. The Director of the Agronomic Research Institute at Tell Amara authorised the Chemical Laboratory there to analyse samples of basalt for me, and the analyses were carried out by Mr. Michel SAHYOUNI with patience and skill. Monsieur Alain GUERRE, Adviser to the Lebanese Geological Survey, kindly supplied me with samples of Tertiary basalts from North Lebanon, and my colleague Mr. Jawad SA'D brought me a sample from the Lower Cretaceous of Syria.

I am indebted to my colleague Mr. Sharif WAKIM for many fruitful discussions and occasional companionship in the field. Miss Mary FIDANIAN and Miss Sonia ADROUNI typed and retyped the MS faithfully and uncomplainingly, and Miss Berjouhi ADROUNI prepared it for binding. To all of these and to many others whose friendship and encouragement I have enjoyed, I offer sincere thanks.

The purpose of these studies was to present a descriptive account of the Mesozoic basalts of Lebanon; and if I have been tempted by curiosity to speculate on their possible significance in a problem that has baffled two generations of petrologists, I have done so in all humility and without any pretensions to advancing a tectonomagmatic theory on so slender a foundation.

Beirut, 21 May 1967. SAMIR M. KUTTAYNEH

ABSTRACT

A study of 400 samples from three volcanic horizons has shown that the Mesozoic basalts of Lebanon belong to the alkaline olivine-basalt suite generally associated with tension, rifting and block faulting movements of the continental crust. A supplementary study of some samples of the Tertiary basalts of North and South Lebanon reveals close similarities between these and the Mesozoic groups.

These findings are in accordance with the tectonic history of Lebanon since late Jurassic times, and emphasize the region's relationship with the African rift system. It is tentatively suggested that olivine basalts are derived by local melting in the mantle under zones of tension, in contradistinction to tholeiites which work their way up through the crust in places where this has been thinned and weakened by assimilation into underlying accumulations of molten mantle material.

C O N T E N T S

INTRODUCTION

The Lebanon, together with the northern end of Jordan and a part of western Syria, forms a volcanic province whose record goes back to early Jurassic times (basalts of Mt Hermon) and ends only with the lavas of the Houran, the last of whose volcanoes were still active about 4000 years ago. Basalts, pyroclastics and their derivatives occur at three principal horizons in the Mesozoic of Lebanon: one in the Kimmeridgian and two in the Lower Cretaceous. The first of these latter is generally considered to be of Neocomian age; the second spans the interval middle Aptian-lower Albian.

1. Kimmeridgian

The Jurassic of Lebanon consists for the most part of a monotonous sequence of dolomitic limestones of relatively shallow-water facies, relieved near the top in central and north Lebanon by a volcanic horizon in the Kimmeridgian (DUBERTRET, 1955). Here basalt alternates with calcareous tuff, chocolate-brown marls and a blue neritic limestone weathering to ochre at the outcrop. This volcanic complex attains a thickness of nearly 200 m in north central Lebanon (RENOUARD, 1951), and forms a fertile, gentlysloping verge around the steep walls of the barren valleys below, which supports a considerable agricultural and fruit-growing community. It is overlain by a grey compact limestone of upper Portlandian age (the so-called "falaise de Bikfaya"), up to 60 m thick, with large flint

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nodules and a benthic fauna. In the central and western parts of the country this is succeeded in turn by more beds of neritic limestone which finally alternate with and give way to the sands of the Lower Cretaceous; farther inland the sands generally lie directly on the falaise de Bikfaya.

The field relations of these Upper Jurassic volcanics in north central Lebanon have been described by an-NADI (1966). They appear to represent the approximately synchronous activity of a group of vents whose successive outbursts are marked by intermittent laterites and pyroclastics, the latter often unstratified, interbedded with the basalts. This, together with the neritic character of the associated limestones, suggests a shallow marine environment in which the volcanics were temporarily built up above sea level: a situation reminiscent of the Carboniferous volcanism in the Midland Valley of Scotland (CRAIG, 1965). In some places, particularly in the Tannourine-Hasroun area of North Lebanon, these Upper Jurassic basalts attain a thickness of 100 to 150 m and extend right up to the base of the Cretaceous sandstones, the falaise de Bikfaya being absent. Whether volcanic activity has extended here into Portlandian times, or the sands have been deposited on the eroded surface of the Kimmeridgian, is hard to tell. Radiometric dating of selected outcrops of these basalts might help considerably in elucidating the details of late Jurassic and early Cretaceous history in Lebanon.

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2. Neocomian-Aptian

Basalts, tuffs and laterites occur in the Lower Cretaceous sandstone at various places. Northward of Beirut the outcrops are fairly abundant and generally occur in the lower half of the sands, whereas to the south they are much sparser and almost invariably near the top. The lack of any continuous correlatable horizon within this formation makes it difficult to say whether within each of these separate regions the basalts of this group are strictly contemporaneous with one another or not.

Most authors, including ZUMOFFEN (1926), HEYBROEK (1942) and DUBERTRET (1955) have regarded the Lower Cretaceous sandstone as being of Neocomian age. This assumption is no doubt justified at least for central and western Lebanon, where a gradual and gently oscillating transition from the neritic limestone of the upper Portlandian (as exemplified by Heybroek's section of the Damour Valley) suggests that the terminal Jurassic regression stopped short of the present coastline; however, the direct superposition of the sands on the falaise de Bikfaya and even on the Jurassic basalts in other parts of the country throws some doubt on the assumption that the base of the sandstone is everywhere of the same age. This formation, apparently continuous with the Nubian Sands to the south, lenses out to the north and east across the Syrian frontier; its maximum recorded thickness is about 300 m at Jezzine (KANA'AN, 1966).

3. Aptian-Albian

The Neocomian-Aptian sandstone is succeeded by two transgressive

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formations: a neritic limestone rich in benthic fossils, with sandy intercalations, surmounted by a more decidedly marine horizon about 60 m thick which forms a prominent escarpment all over the country: the "falaise de Jezzine" (Dubertret, 1955). Above this, further neritic limestones with here and there thick sandstone intercalations betray a new regression, whose reversal is eventually marked by the Albian marls and their gradual transition to the deeper-water facies of the Cenomanian.

These epeirogenetic movements of the later Aptian have been accompanied by a new period of volcanic activity, which appears to have completed the record of Mesozoic volcanism in Lebanon: for though Middle and Upper Cretaceous limestones cover about one-half of the country's 11,000 km^2, no volcanics contemporaneous with these have yet been described. Like their predecessors, the Aptian-Albian basalts are concentrated in north central Lebanon, reaching their maximal development in the Laklouk-Hadeth area where thick flows are found both below and above the falaise de Jezzine.

A schematic section through Bcharreh and the Cedars (Fig. 1, after DUBERTRET 1955) shows, grosso modo, the stratigraphic relations of the Mesozoic basalts.

Although no major unconformity has been observed between the basalts and the sedimentary formations now enclosing them, the frequent presence of laterites and unstratified pyroclastics, and the absence of definitely identifiable pillow-lavas, suggest that subaerial

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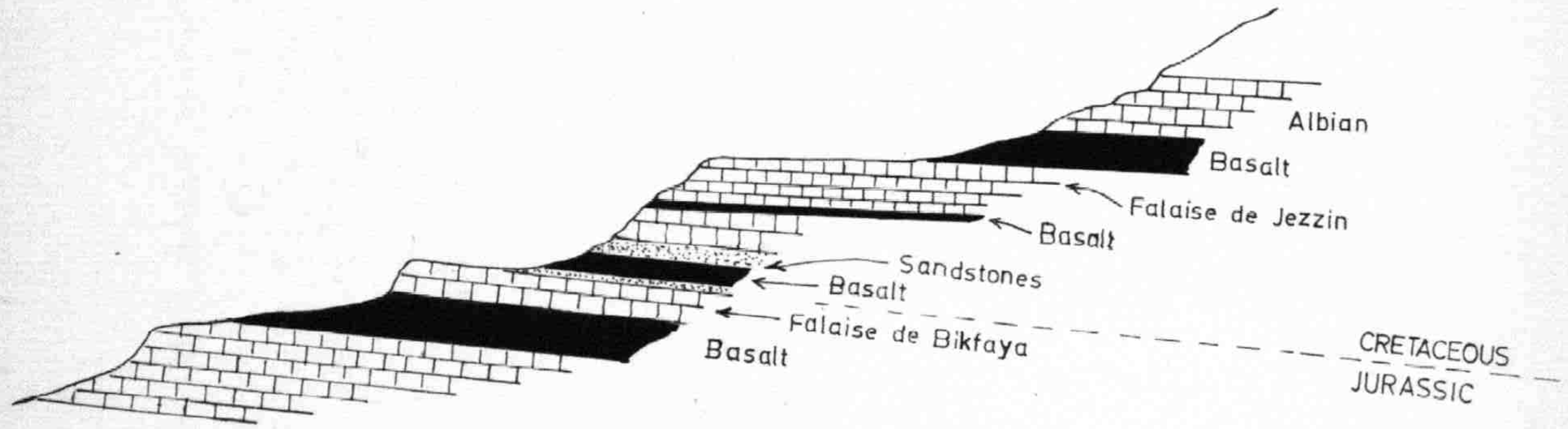

Fig.1 Schematic section to show stratigraphic relations of the basalts.

(After Dubertret, 1955; slightly modified.)

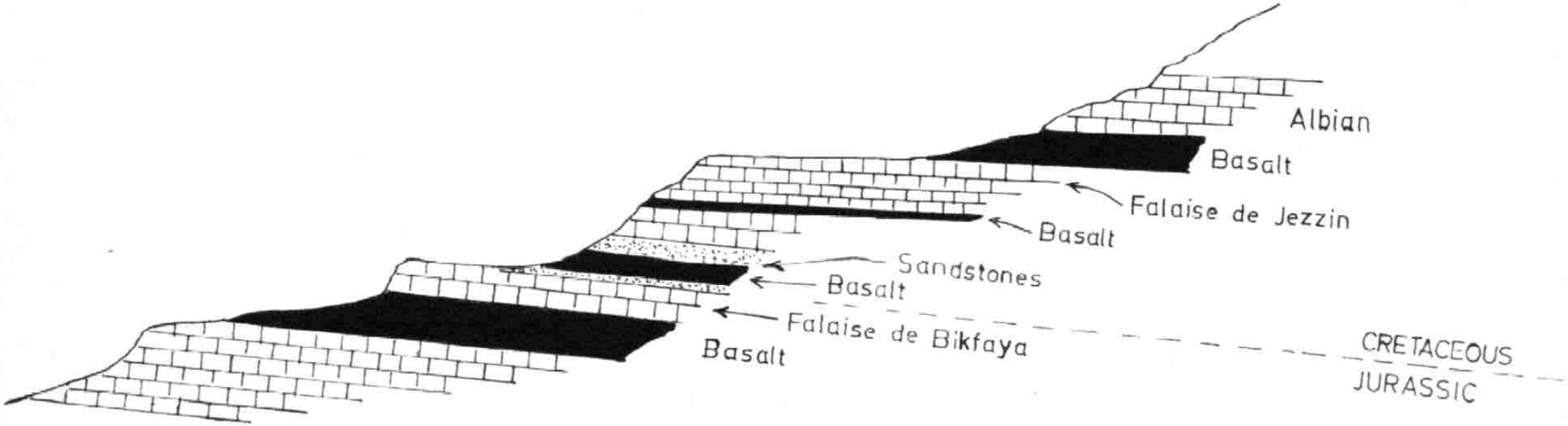

Fig.1 Schematic section to show stratigraphic relations of the basalts.

(After Dubertret, 1955; slightly modified.)

eruption was common in all three of the episodes here described; there are, however, notable exceptions, such as the thick limestone tuffs of Boka'ata (Kimmeridgian), and we are led to imagine a generally horizontal surface of deposition, never far above or below sea level, relieved here and there by deeper basins in which contemporaneous marine deposits could accumulate.

Centres of activity

All of the volcanic vents so far reported are exposed in Jurassic rocks. an-NADI (1966) has described four: two at Kartaba, one at Abboud and one at Bala'a. A fifth, the most southerly so far described, is found at Aintoura. A sixth vent has been found by the present writer in the Jurassic at Harissa (Tannourine district), and a seventh in the Aptian of Basloukit, to the N of Ehden (see location map, Fig. 2)[1]. The vents are characteristically filled with volcanic limestone breccias, tuffs which spread out and interdigitate with the associated lava flows, and basaltic rocks in various stages of decomposition. Minor intrusions in these latter are briefly described below.

The continuity of Upper Jurassic and Lower Cretaceous volcanic horizons in the neighbourhood of the Kartaba vents, together with the marked concentration of activity at all horizons in the central and northern part of the country, encourages the supposition that here the Cretaceous lavas mark a reactivation of the same centres which supplied the Upper Jurassic ones. Sandstone blocks in the main

1) Endpaper

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Kartaba vent (an-NADI, 1966), though they have not been definitely identified with the Lower Cretaceous Sandstone, add force to this suggestion.

No volcanic vents are known to the S of Beirut; in this region the Jurassic, less completely exposed than in the N, bears practically no trace of igneous activity, and (as mentioned higher, p 3) the Lower Cretaceous volcanic series is represented by sparse outcrops of basalt and tuff near the top of the sandstone and occasionally in the neritic Aptian limestone just above it. A thick deposit of pyroclastics at Zhalta, SW of Jezzine, suggests that this area was a centre of Lower Cretaceous activity in southern Lebanon.

Intrusive rocks

Diabase dykes are not infrequently found within the vents, particularly in the larger of the two vents at Kartaba where they are intruded into a filling of mixed basalt, pyroclastics and diabase boulders. If the same vents in fact supplied both the Jurassic and the Cretaceous lavas, these dykes could represent feeders of the Neocomian and Aptian volcanoes. Some boulders of gabbroid texture and composition were also found in the main Kartaba vent, although no outcrop could be located in situ. Possibly these boulders have been carried up from some deeper intrusive formation.

Here and there in the Lower Cretaceous sands, where the bedding is locally obscured by landslides or soil cover, discordant relations may be suspected between basalt and sandstone. Such is the case of the basalt of the N. Abou-Zibleh (Plate 48), whose outcrop rises steeply up the valley side in spite of the generally horizontal position of the sediments in this area. Boulders of diabase found in the valley of the N. Chekfita where the river runs through the sandstone lend credence to the supposition of dykes in this formation.

In several places where basalt is exposed in the Mesozoic rocks these are fractured by E-W trending faults of a system which extends over most of the country and cuts across outcrops of the Vindobonian. It is not possible to say whether these faults, active perhaps already in Jurassic times, provided an outlet for the Mesozoic lavas; but since the lavas themselves are generally truncated by the faults with which they are associated, this suggestion does not seem very plausible. The only place where discordant relations were observed between basalt and country rock in the neighbourhood of a major fault is the Aintoura vent.

Methods and Techniques

About 110 of the more accessible outcrops were studied, a total of some 400 samples being taken. Fresh outcrops in road cuts and quarries were selected wherever they could be found; but a certain amount of material had unavoidably to be taken from weathered exposures. Because of the irregular distribution of the better outcrops, and the frequent presence of natural obstacles such as escarpments or steep valley-sides, no rigid sampling scheme was followed, the only aim being to secure a reasonably even coverage of

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each of the three horizons studied. The sites are approximately identified on the location map (Fig. 2)[1]; their respective coordinates on the Levant Grid are given in the Appendix.

300 thin sections were made from the samples. At first water was used in the grinding process; but when the slides were put to dry, the ground chips would often peel off the glass. This was thought to be due to shrinkage of hydrated minerals in the more strongly altered samples, and the difficulty was overcome by substituting kerosene for the water. The sections were studied with an ordinary polarising microscope at magnifications up to 450 diameters. Neither point counter nor universal stage being available, primitive m methods of modal analysis had to suffice: the relative areas covered by the different constituents were estimated by eye, and the plagioclases were determined by the maximum extinction angle on (010) (method of Michel-Levy). The sizes of some of the larger crystals were estimated with the help of an eyepiece micrometer. The terms used to describe texture and fabric are those defined by HEINRICH (1956).

KIMMERIDGIAN

Megascopic characters

The freshly cut surfaces of the hand specimens vary in colour from bluish black through greyish black, olive grey and greenish grey to dusky yellow-green[2]. The variation is no doubt largely

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[1] Endpaper

[2] Colours listed in the Geological Society of America's Rock Colour chart, 1963.

due to weathering, the fresher rocks being blackish and the weathered ones tending towards the lighter colours. The macro-textures vary from aphanitic to phaneritic[2]. In many specimens olivine (especially when altered), magnetite, chlorite and sometimes augite can be seen. In the coarser-grained rocks the plagioclase crystals glitter and sparkle when the hand specimen is turned. Nodules and veins of chlorite, greenish zeolite and white calcite are not uncommon, and some samples are stained with reddish bands of iron oxide. Vesicular and amygdaloidal basalts, the amygdules consisting mainly of calcite, are quite frequent. The smooth, freshly-cut surface of an aphanitic specimen shows a patchy pattern of yellowish alteration products and irregular black spots in a greyish-black groundmass. The weathered surfaces vary in colour from yellowish-brown through light brown to almost black. Where weathering is advanced ("spheroidal" weathering), grey-brown, friable shells of alteration products (mainly carbonates and clay minerals) with yellowish-brown spots and stains (hydrated iron oxides) cover the surviving blocks and nodules of basalt. The laterites are maroon to dark reddish-brown, with occasional lighter patches. When freshly broken, they often present lustrous surfaces reminiscent of slickensides.

Microscopic characters

The textures of the Kimmeridgian basalts range from holocrystal-

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2) The terminology used here to describe texture and fabric is that followed by HEINRICH (1956).

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line granulitic (which predominates) to vitrophyric. The majority of them are porphyritic (cf. an-NADI, 1966), with olivine and subordinate augite, labradorite or andesine phenocrysts from 0.5 to 5 mm in diameter. The plagioclase is generally labradorite with a composition between An_{50} and An_{68}. Plagioclase phenocrysts of high An-content tend to occur in a matrix of low An-content, and vice versa. For example, the basalt of Diman (Table I) has labradorite phenocrysts (An_{54}) in a matrix consisting largely of andesine (An_{44}).

No particular distributional trend was observed in either the texture or the composition of these rocks. Their microscopic characters and mineralogy are summarized in Table I , and their average composition is given here below.

Essential minerals of the Kimmeridgian basalts

Mineral	Vol. percent (mean of 56 samples)	Standard deviation
Plagioclase[1]	35	5
Angite[2]	27	5
Olivine[2]	22	5
Magnetite + ilmenite	7.5	2
Others (by difference)	8.5	-

Accessory and secondary minerals; weathering products

(excluding friable weathered surfaces)

Apatite, basaltic hornblende, biotite, chlorite, iddingsite, serpentine, haematite, carbonates, zeolites, clay minerals, ? eliachite.

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1) Average composition of plagioclase = An_{54} (unweighted mean of 56 individual samples); standard deviation = ±5.

2) Including pseudomorphous alteration products.

Mineralogy

A. Plagioclase (An_{35}-An_{65}). The crystals are mostly lath-shaped and rarely exceed 1.75 mm in length, the phenocrysts occasionally attaining 3 mm. Albite twinning is prevalent; Carlsbad-albite and Carlsbad twins (slide 050)[1] are less common. Small Baveno twins are occasionally seen (slides 004, 249). Some of the larger phenocrysts are euhedral to subhedral, untwinned, and show oscillatory zoning (slides 035, 276; plate 22). The tendency for calcic phenocrysts to be accompanied by andesine in the ground mass and vice versa has already been mentioned, and can be observed in slides 050 and 058. The An content shows a normal frequency distribution (Fig. 3) with a mean composition of An_{54} and a standard deviation of ± 5.

The plagioclase is often altered to sericite, calcite, chlorite and accumulations of argillaceous-looking material of low birefringence, and the crystals are sometimes cracked and corroded; deuteric processes and weathering have no doubt both contributed to these changes.

B. Augite. Colourless to pale brown augite occurs as poikilitic phenocrysts, sometimes of pinkish-brown colour suggesting the presence of titanium (plate 1). Prisms are elongated parallel to the c-axis and sometimes show a basal parting (malacolite); more commonly a parting parallel to (100)(diallage). Zoning is common, and can be seen as a darkening towards the rim of the

[1] Numbers refer to thin sections kept in the Mineralogical Museum, American University of Beirut.

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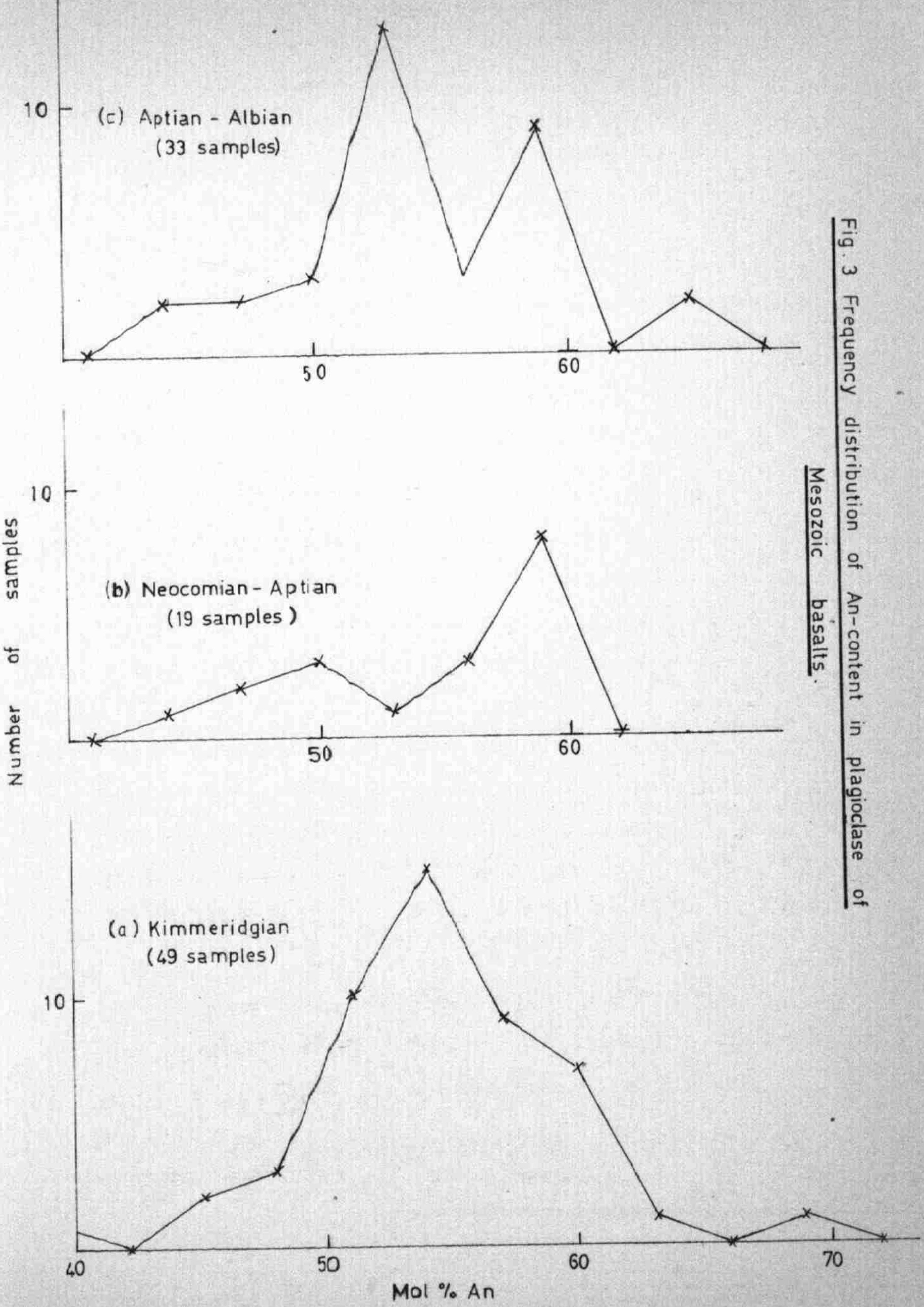

Fig. 3 Frequency distribution of An-content in plagioclase of Mesozoic basalts.

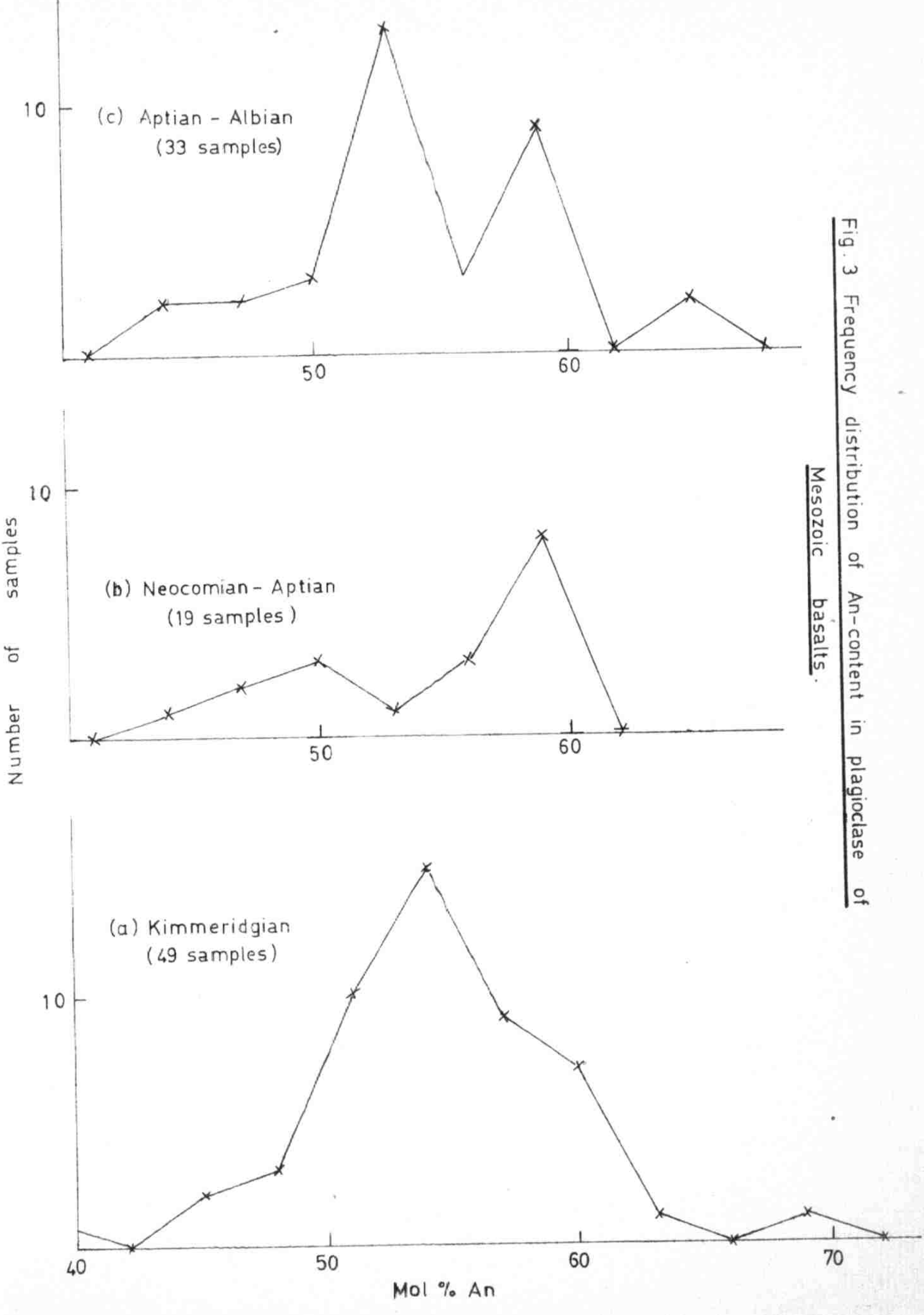

Fig. 3 Frequency distribution of An-content in plagioclase of Mesozoic basalts.

section (plate I), indicating enrichment in iron. Twinning parallel to (100) is often present (plates 7). 7) crystals are generally fractured, the cracks containing a green, non-pleochroic alteration product (?chlorite).

Augite occurs in the groundmass as anhedral grains and short, squat prisms, sometimes with "hour-glass" structure. Many of these have extinction angles of less than 45°, suggesting that some pigeonite may be present.

C. <u>Olivine.</u> Olivine is present in all the Kimmeridgian basalts, occurring mainly as subhedral to euhedral phenocrysts, often poikilitic, up to 4 mm in diameter (plates 13 - 18). Tabular development parallel to (100) is common. Zoned olivine is present in one section (slide O44), where the crystals consist of a cloudy core surrounded by a clear, colourless rim. Pseudomorphs of serpentine (antigorite) are widespread, and in some specimens little remains of the original mineral. Iddingsite is present as an alteration product in some cases. Granules of olivine occur in subordinate amounts in the groundmass.

The composition is mainly forsteritic, as evidenced by:

1. Positive interference figure;
2. Large axial angle;
3. Predominance of antigorite among the alteration products;
4. Scarcity of secondary magnetite.

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Nevertheless, some of the olivine has a negative sign and smaller axial angle, and is associated with iddingsite alteration rims and cores, indicating a composition nearer to the fayalite end of the series.

The more drastically altered specimens show occasional magnesite or calcite, opaque minerals and even quartz (slide 257) (plate 19). Resorption rims are common in the phenocrysts, especially in the neighbourhood of minor "intrusions" of plagioclase and granular augite. The granular olivine of the groundmass is often fresh in rocks where the phenocrysts are partially or even completely altered. In the rocks of hyalopilitic texture, medium-sized to large euhedral phenocrysts of fresh olivine are found.

D. <u>Magnetite and ilmenite.</u> Since with the equipment available it is not always possible to distinguish these two minerals from one another, they have been included together in the quantitative estimates (Table I). Magnetite usually shows triangular, square or rhombic sections; ilmenite tends towards a more skeletal development. Dust and granules occur in the groundmass of the fine-grained and vitreous basalts; elongated particles are more characteristic of the ophitic textures. Haematite and chlorite sometimes occur as rims, and a few of the olivines have threads of magnetite particles in the sinuous serpentine of their altered parts. Magnetite threads and granules also occur in some of the augite phenocrysts.

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NEOCOMIAN-APTIAN

Megascopic characters. The Neocomian basalts do not markedly differ in appearance from the preceding group. Spheroidal weathering is more common, and the rocks tend to assume a greenish colour which on microscopic examination proves to be associated with the occurrence of chlorite (slide 178). A section of a spheroidally-weathered boulder from Qubbay shows veins of secondary minerals radiating from the centre. These rocks are characteristically porphyritic; at Machgara there is an outcrop where phenocrysts of olivine and augite protrude from an aphanitic groundmass. Diabase boulders in the valley of the N. Chekfita show black elongate crystals (possibly of ilmenite) altering to a whitish powder on the weathered surface. Many of the Neocomian basalts are completely lateritised, which explains the relatively small number of samples (20) studied.

Microscopic characters. The microscopic characters and mineralogy are summarised in Table II. The group is generally porphyritic with medium-sized olivine and augite phenocrysts. The textures range from holocrystalline granulitic to hypocrystalline intersertal; some specimens are ophitic. The plagioclase laths are on the whole longer than those of the Kimmeridgian, and a few of the samples are of frankly diabasic character and consequently are likely to be related to the Aptian-Albian group of extrusives rather than those of the supposed Neocomian. Carbonate xenoliths have been found (slide 145 , Ba'tara), surrounded by calcite,

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diopsidic augite and chlorite.

The basalts in the neighbourhood of the Damour Valley are characterised by accessory nepheline (reported by HEYBROEK, 1942) and sometimes albitised plagioclase with isotropic patches of (?) analcime.

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The average composition of this Neocomian group is given below:

Essential minerals of the Neocomian basalts

Mineral	Vol. percent (mean of 20 samples)	Standard deviation
Plagioclase[1)]	57	3
Augite[2)]	24	5
Olivine[2)]	19	4
Magnetite + ilmenite	6	2
Others (by difference)	14	-

Accessory and secondary minerals; weathering products (excluding friable weathered surfaces)

Apatite, nepheline,[3)] albite,[3)] (?) analcime,[3)] serpentine, iddingsite, zeolites, chlorite, haematite, carbonates and clay minerals.

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1) Average composition of plagioclase = An_{54} (unweighted mean of 19 samples); standard deviation = ± 5.

2) Including pseudomorphous alteration products.

3) Damour valley group (See below, p. 19).

Mineralogy

A. Plagioclase (An_{44}- An_{60}). Laths up to 2 mm long are characteristic, but anhedral grains sometimes occur interstitially. Labradorite also occurs as phenocrysts up to 4 mm long, sometimes with Carlsbad or pericline twinning (slide 284). The plagioclase of the Neocomian basalts differs from that of the Kimmeridgian ones in two respects: first, the composition of the phenocrysts, when these are present, tends to follow that of the groundmass (cf. p. 10); secondly, although in the two groups the plagioclase composition is identical so far as the mean and standard deviation go, the An-content of the Neocomian plagioclase has a bimodal frequency distribution (Fig. 3) with peaks at An_{50} and An_{59}, in contrast with the normal distribution in the Kimmeridgian rocks (p. 12). The 19 samples studied here can be divided into one group of 6, all from the Damour Valley vicinity, with a mean composition of An_{58} (standard deviation ± 1.4), and another of 13 with a mean composition of An_{53} and a standard deviation of $\pm$ 5.

B. Augite. The augite does not differ materially from that of the Kimmeridgian basalts (q.v., p. 12). The phenocrysts are from 1.5 to 3.5 mm in diameter, and frequently include granules of olivine as well as plagioclase in the ophitic texture. Six-sided cross-sections are common.

C. Olivine. Olivine, mainly of forsteritic composition, occurs as phenocrysts from 1 to 4.5 mm in diameter, some of them enclosing feldspar laths. Antigorite, iddingsite, carbonate (?magnesite) and

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quartz pseudomorphs are common (plates 20). Granules of olivine are also found in the groundmass (plate 24).

D. Magnetite and ilmenite. These minerals occur as in the Kimmeridgian basalts (q.v., p. 14); ilmenite tends to develop long crystals in the ophitic rocks.

The Damour Valley group

As shown above, the basalts in the Neocomian of the Damour Valley and its immediate neighbourhood have substantially more calcic plagioclase than the other basalts of the Lower Cretaceous sands; using the Fedorov stage de NEVE (in HEYBROEK, 1942) obtained a mean An-content of 62 percent from five samples taken in this region. Other distinguishing features of these rocks are the presence of nepheline (E of Al-Bnayeh, valley of the N. Chekfita; HEYBROEK, 1942), sodalite and natrolite (valleys of N. Chekfita and N. Abu-Zebli; ibid.), albitized plagioclase with (?)analcime, and sometimes tree-like crystals of ilmenite altering to leucoxene (cf. p. 15 above). All of the six samples studied have ophitic textures.

APTIAN-ALBIAN

Megascopic characters

The Aptian-Albian basalts are similar in general appearance to the foregoing groups, except for a tendency towards finer grain and more frequent development of vesicles and amygdules (plates 28,33).

Microscopic characters

These rocks are generally fine-grained holocrystalline granulitic to hypocrystalline vitrophyric; ophitic and intersertal textures are common. The basalts of Jaj are medium-grained ophitic, those of Laklouk fine-grained hyalopilitic, and those near the Basloukite vent are vitrophyric. All are porphyritic, the phenocrysts usually being olivine, occasionally augite. Plagioclase phenocrysts are rare, and the plagioclase laths are on the average shorter than those of the Kimmeridgian and Neocomian.

The microscopic characters and mineralogy are summarised in Table III; the average composition is given below.

Essential minerals of the Aptian-Albian basalts

Mineral	Vol. percent (mean of 38 samples)	Standard deviation
Plagioclase[1)]	37	6
Augite[2)]	26	4
Olivine[2)]	20	6
Magnetite + ilmenite	9	2
Others (by difference)	8	-

1) Average composition of plagioclase =An_{55} (unweighted mean of 33 individual samples); standard deviation = $\pm$ 5.

2) Including pseudomorphous alteration products.

Accessory and secondary minerals; weathering products

(excluding weathered surfaces)

Apatite, basaltic hornblende, chlorite, iddingsite, serpentine, haematite, carbonates, zoisite, zeolites, quartz and clay minerals.

Mineralogy

A. Plagioclase (An_{44}- An_{78}). Generally similar to that of the preceding groups. Laths are up to 2 mm long. Albite and Carlsbad-albite twinning. Some of the larger euhedral crystals show progressive zoning. Bytownite phenocrysts occur at Tell Al-Mazra'a (slide 237).

A bimodal frequency distribution (Fig. 3) is again found, with peaks at An_{53} and An_{59}; but this does not appear to be regionally correlated.

B. Augite. Colourless to pale brown. Occurs mainly in the groundmass, occasionally as pinkish-brown ophitic phenocrysts (?titan-augite) from 1.5 to 2 mm in diameter. One large euhedral phenocryst of 3 x 6 mm can be seen in slide 113. Diallage is observed in slide 119; zoning and twinning are common, and "hour-glass" structure is often seen in the grains of the groundmass. A reaction rim can be seen in slide 270, and a partially resorbed border in slide 117 (plate 11).

C. Olivine. Colourless, largely forsteritic, Occurs mainly as phenocrysts from 0.25 to 3.0 mm in diameter, with imperfect cleavage parallel to (010). Commonly altered to serpentine, but generally fresh im the fine-grained hyalopilitic rocks. Pseudomorphs containing carbonate, chlorite and quartz are common. Partial resorption and penetration by plagioclase and granular augite are sometimes seen.

D. Magnetite and ilmenite. Present in all the rocks. Elongated crystals of (?) ilmenite are characteristic of the ophitic textures; small granules are evenly distributed in the groundmass of the hyalopilitic and vitrophyric rocks. An octahedron can be seen in slide 141. Magnetite grains sometimes surround augite and olivine.

PLIOCENE

For comparison with the three groups of Mesozoic basalts, 6 samples from the Pliocene were studied: 5 from the extensive flows of North Lebanon and one from the Mardjayoun district in the south.

Megascopic characters

The Pliocene basalts are typically greyish in colour, weathering to a yellowish brown. They are generally vesicular, with vesicles ranging upwards from 1 mm in diameter, sometimes with carbonate amygdules. They are for the most part phaneritic; large olivine phenocrysts and partial pseudomorphs of iddingsite can easily be seen with the naked eye.

Microscopic characters

These basalts are of medium-grained granulitic texture with large olivine phenocrysts (up to 7 mm diameter), many of them altered to iddingsite (Plate 35). The olivine is less rich in magnesium than that of the Mesozoic groups. Augite occurs as small prismatic granules in the groundmass, and is browner than the augite of the Mesozoic basalts. Zoned phenocrysts are found in the Mardjayoun basalt (slide 315). The plagioclase is fresh and clear, considerably less calcic than in the preceding groups. Square and rhombic sections of magnetite grains can be seen in the groundmass, and small granules sometimes surround the augite crystals (slide 315). The vesicles are often filled with calcite, sometimes with aragonite: the latter suggesting that the amygdules formed while the rock was still hot. The average composition is as follows:

Essential minerals in the Pliocene basalts

Mineral	Vol. percent (mean of 6 samples)	standard deviation
Plagioclase[1)]	37	4
Augite	28	2
Olivine	22	5
Magnetite + ilmenite	9	3
Other (by difference)	4	-

Accessory and secondary minerals

(?)Apatite, iddingsite, haematite, calcite, aragonite

The microscopic characters and composition of the individual samples are summarised in Table IV. Except for the more sodic plagioclase and their better state of preservation, these Pliocene basalts are remarkably similar to their predecessors of the Mesozoic.

1) Composition of plagioclase = An_{48}; standard deviation = $\pm$ 1.

CHEMICAL ANALYSIS

Mr. Michel SAHYOUNI, of the Agronomical Research Institute at Tell Amara (Rayak) has kindly undertaken to analyse 6 of the Mesozoic samples (4 from the Kimmeridgian, one from the Lower Cretaceous sands at Dara and one from the upper Aptian at Tell Al-Mazra'a), as well as a sample from the Pliocene of Kwaichate (N of Halba). Though still incomplete at the time of writing (Al_2O_3, H_2O^+ and P_2O_5 still requiring to be determined), these analyses already demonstrate the low silica content, and relative to this the high alkali-lime ratio, of all the rocks analyzed:

Partial chemical analyses of Lebanese basalts[1)]

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	P_2O_5
1. Kimmeridgian, N. ed-Dahab	45.6	2.16	N.D.	3.61	10.4	10.8	9.36	3.16	0.72	N.D.
2. Kimmeridgian, Bala'a	45.0	2.60	N.D.	3.78	10.6	14.8	9.39	3.26	0.72	N.D.
3. Kimmeridgian, Qartaba	44.1	2.03	N.D.	3.54	11.5	10.8	9.53	3.20	0.56	N.D.
4. Kimmeridgian, Es-Sfire	41.6	2.90	N.D.	5.85	11.2	6.55	9.81	4.09	0.98	N.D.
5. Neocomian, Dara	45.1	2.03	N.D.	7.69	6.72	9.88	9.25	2.34	0.36	N.D.
6. Aptian-Albian Tell Al-Mazra'a	40.3	3.86	N.D.	7.01	9.84	7.56	10.8	3.13	0.85	N.D.
7. Pliocene, Kwaichate	45.1	2.50	N.D.	8.89	6.36	12.3	5.88	3.16	0.61	N.D.

1) Analysis by Mr. Michel Sahyouni, Agronomical Research Institute, Tell Amara.

These results are in quite good agreement, so far as they go, with an analysis of the Neocomian diabase of Abey (de SITTER-KOOMANS in HEYBROEK, 1942) and a group of analyses of Tertiary basalts of Jordan in BURDON (1959), and suggest that the basalts in the whole area have maintained a more or less uniform chemical composition from late Jurassic until Recent times.

The mineralogy and chemical composition of all the basalts here studied characterise them as belonging to the alkaline olivine-basalt association (TURNER and VERHOOGEN, 1960; BARTH, 1962). Their uniformity precludes the preparation of variation diagrams to determine the alkaliline index (PEACOCK, 1931); but the alkali, lime and silica contents correspond fairly closely with BENSON's (1944) weighted average for the Pliocene association of E Otago Province in New Zealand, well known as an example of the continental alkaline olivine-basalt association. The relevant data are given below:

Comparison of Lebanese volcanics with the Pliocene volcanics of E Otago Province, New Zealand

Lebanon[1]	SiO_2	$Na_2O + K_2O$	CaO
1. Kimmeridgian (4 samples)	44.0	4.18	9.52
2. Neocomian-Aptian	45.1	2.70	9.25
3. Aptian-Albian	40.3	3.98	10.8
4. Pliocene	45.1	3.77	5.88
5. Average (1-4)	43.6	3.66	8.85
Otago[2]			
Weighted average (Moderately-deformed Sub-Province)	46.2	5.08	9.58

1) Analyses by Mr. Michel Sahyouni.

2) From BENSON (1944).

.../...

DISCUSSION

We have thus to consider the following findings:

1. The Mesozoic volcanics of Lebanon are all alkaline olivine-basalts;
2. The available data on Pliocene basalts in the area indicate that these are closely related in composition to the Mesozoic ones.

The alkaline character of these rocks underlines Lebanon's tectonic history of block faulting and epeirogenetic movement since late Jurassic times. It would be interesting to study the Lower Jurassic basalts of Hermon and see whether they too tell the same story. Seen in this light, the copious Tertiary and Recent outpourings to the north and south of the country remind us of its relationship with the African rift system, where the association of alkaline rocks with crustal rifting is seen at its most dramatic.

The petrogenesis of the calcic rocks, if not directly demonstrable, can at least be explained by the hypothesis of sialic assimilation (BARTH, 1961) or even the melting down of sediments (as in the well known experiments of WINKLER and von PLATEN, 1960;1961). But the two main non-orogenetic suites present a more difficult problem. If alkali olivine-basalts and tholeiites (flood basalts) both come from the subcrustal regions, how are we to account for the difference between them?

The explanation of the former as products directly tapped from the mantle is satisfactory enough; but the differentiation of tholeiites on such a scale as we find in the Tertiary of India and the western United States would surely require a magma reservoir so vast that it would melt its way through the crust before the olivine could sink to the bottom. Is it not simpler to suppose that this is exactly what happens, except that the iron and magnesium, instead of separating as olivine, react with the melted sial to form pyroxenic magma which then wells up through swarms of dykes in the thinning remnants of the crust?

If this were indeed so, we should expect tholeiitic outpourings to be associated with thinning of the crust: as, for example, in the Columbia-Snake River plains, the Lake Superior region and the Deccan (where the base of the lavas is below sea level). In the continental alkaline provinces, on the other hand, the crust should retain the thickness it had prior to the eruptions; for otherwise assimilation of sialic material would neutralise the alkaline magma. Here magma is generated when and where the pressure is reduced by tensional faulting, and rises directly along the fractures. This is in keeping with the considerable topographic elevation of the East African plateaux, which are approximately in isostatic equilibrium (HOLMES, 1965); the same is true of the Black Forest and the Vosges flanking the Rhine graben (GOGUEL, 1957).

The Lebanon and Antilebanon are high mountains, reaching 3000m on the summits of Hermon and Qornet Es-Saouda; yet their maximum isostatic gravity anomalies (+80 and +100 milligals respectively; PLASSARD and STAHL, 1957) indicate that they are at least partially compensated, so that we may assume a crustal thickness of at least 35 km. Here, then, we have apparently a third example where intermittent flows of continental alkalic rocks are associated with an unthinned, block-faulted crust.

<u>Tabulated N - S Petrography of Kimmeridgian Basalts</u>

<u>Table I</u>

Locality	Slide No.	Fabric: Texture	Fabric: Max. Diam. of Phynocr. in mm. Oliv.	Augt.	Lab.	And.	Approx. length of Plag. lath in mm.	Modal composition (percent): Lab.	And.	Augt.	Oliv.	Mag. + Ilm.	Others
es-Sfire	174	Holocr. Gran.	1.00	-	-	-	0.25	An60 35	-	25	15	10	15
Blouza	161	Holocr. Gran.	4.00	-	-	-	0.05	-	Ab60 30	30	25	10	5
Blouza	262	Holocr. Gran.	1.00	-	-	-	0.25	An50 50	-	20	15	3	17
Hadchite	259	Hypocr. Hayl.	1.50	-	-	-	1.00	An60 45	-	20	25	9	1
Bcharri	249	Holocr. Gran.	4.00	-	-	-	1.50	An54 30	-	30	20	7	13
Bcharri	259	Hypocr. Hayl.	1.50	-	-	-	0.25	-	Ab54 45	30	20	5	-
Hackleh	249	Hypocr. Inter.	1.50	-	-	-	0.25	An50 40	-	30	10	7	13
Bazoun	245	Hypocr. Hayl.	2.00	-	-	-	0.50	-	Ab52 40	30	15	7	8
Hasroun	33	Holocr. Gran.	1.50	-	-	-	0.75	An54 40	-	25	25	7	3
E. of Diman	35	Hypocr. Hayl.	5.00	-	-	-	1.50	An50 40	-	25	20	7	8
Diman	39	Hypocr. Hayl.	1.50	3.00	An54 2.5 x 0.5	-	0.25	10	Ab56 25	30	20	7	8
Brisat	41	Holocr. Gran.	2.00	-	-	-	1.50	An50 40	-	25	25	5	5

(Table I cont'd.)

Locality	Slide No.	Fabric: Texture	Fabric: Max. Diam. of Phynocr. in mm. Oliv.	Augt.	Lab.	And.	Approx. length of Plag. lath in mm.	Modal composition (percent): Lab.	And.	Augt.	Oliv.	Mag + Ilm.	Others
Brisat	42	Hypocr. Inter.	2.00	-	-	Ab54 1.00	0.25	An54 45	-	20	20	5	10
N. of Harisa	43	Holocr. Gran.	0.50	-	-	-	0.25	An64 30	-	20	25	5	10
Harisa	49	Holocr. Gran.	1.50	-	-	-	1.50	An58 40	-	30	20	6	3
Harisa	50	Holocr. Gran.	1.50	-	-	Ab62 2.00	0.125	An60 30	5	30	25	5	5
Almseil	51	Holocr. Gran.	1.25	-	-	-	0.25	An54 30	-	35	20	10	5
Kharhel	58	Holocr. Gran.	1.25	1.00	-	Ab65 0.25	V.fine	An50 25	10	30	25	8	2
Ghatine	59	Holocr. Gran.	0.50	-	-	-	1.00	An54 30	-	30	20	3	17
Bala'a	67	Holocr. Gran.	1.00	2.50	-	-	1.00	An54 35	-	25	25	7	8
Bala'a	61	Holocr. Gran.	1.00	-	-	-	2.00	-	Ab52 30	20	30	7	13
Ain Al-Batrak	71	Holocr. Inter.	0.75	-	-	-	0.25	An58 35	-	25	15	5	20
Qartaba	73	Holocr. Inter.	1.00	-	-	-	0.25	An54 35	-	30	15	10	10

(Table I cont'd.)

Locality	Slide No.	Fabric: Texture	Fabric: Max. Diam. of Phynocr. in mm.: Oliv.	Augt.	Lab.	And.	Approx. length of Plag. lath in mm.	Modal composition (percent): Lab.	And.	Augt.	Oliv.	Mag + Ilm.	Others
Qartaba	75	Holocr. Oph.	1.00	-	-	-	0.50	-	Ab52 35	15	20	10	20
Qartaba	78	Holocr. Oph.	1.25	-	-	-	2.25	An60 35	-	30	20	5	10
Qartaba	81	Holocr. Gran.	1.75	-	-	-	0.50	An54 35	-	30	25	5	5
Qartaba	83	Holocr. Oph.	0.75	-	-	-	1.75	An54 35	-	30	25	5	5
Qartaba	86	Holocr. Oph.	1.00	-	-	-	1.50	An54 35	-	30	20	7	8
Qartaba	91	Holocr. Oph.	1.00	-	-	-	1.50	An58 35	-	25	25	7	8
Qartaba	103	Holocr. Oph.	0.75	-	-	-	1.50	An54 35	-	30	25	5	5
Mazra'at As-Syad	108	Holocr. Oph.	0.75	-	-	-	2.00	An54 40	-	25	25	7	3
Abboud	105	Holocr. Oph.	1.00	-	-	-	2.00	An54 35	-	30	25	7	3
Ain Ed-Delbeh	218	Holocr. Gran.	0.50	-	-	-	0.125	An54 30	-	25	30	10	5
Ain Al-Bardeh	216	Holocr. Gran.	1.00	-	-	-	0.50	An60 35	-	25	25	4	11

(Table I cont'd.)

Locality	Slide No.	Fabric: Texture	Max. Diam. of Phynocr. in mm.: Oliv.	Augt.	Lab.	And.	Approx. length of Plag. lath in mm.	Modal composition (percent): Lab.	And.	Augt.	Oliv.	Mag + Ilm.	Others
Mayrouba	213	Holocr. Oph.	2.00	-	-	-	1.50	An52 40	-	25	20	8	7
Beit Al-Mahdi	208	Holocr. Gran.	2.00	-	-	-	1.50	An60 40	-	20	25	8	7
W of Bekata	206	Hypocr. Hayl.	0.50	-	-	-	0.125	An58 30	-	30	25	6	9
Bekata	204	Holocr. Gran.	0.50	-	-	-	0.25	An56 30	-	30	20	7	13
Ehmij	18	Holocr. Gran.	0.75	-	-	-	0.25	-	Ab51 25	30	25	7	13
Ehmij	17	Holocr. Gran.	1.00	-	-	-	0.125	An50 30	-	40	15	12	3
Almate	13	Hypocr. Inter.	0.50	-	-	-	0.25	An50 30	-	30	25	10	5
Es-Souaneh	7	Hypocr. Inter.	1.50	-	-	-	0.25	An58 35	-	30	20	7	8
Es-Souaneh	12	Hypocr. Inter.	0.75	-	-	-	0.25	An54 30	-	30	20	10	10
Machnaqua	4	Hypocr. Hayl.	1.50	-	-	-	0.125	An50 40	-	20	20	10	10
Yahshoush	191	Hypocr. Hayl.	1.50	-	-	-	0.25	An60 35	-	30	25	7	3

(Table I cont'd.)

Locality	Slide No.	Fabric: Texture	Fabric: Max. Diam. of Phynocr. in mm. Oliv.	Augt.	Lab.	And.	Approx. length of Plag lath in mm.	Modal composition (percent): Lab.	And.	Augt.	Oliv.	Mag. + Ilm.	Others
Jouret - et-Tormos	198	Holocr. Oph.	1.00	-	-	-	0.50	An50 35	-	25	25	5	10
Nehr-Ed-Dehab	200	Holocr. Oph.	2.00	-	-	-	1.00	An68 35	-	30	25	5	5
Aramoun	276	Hypocr. Hayl.	2.5	-	-	-	1.50	An58 50	-	20	20	7	3
Aintourah	180	Holocr. Gran.	1.50	-	-	-	1.00	An60 35	-	20	20	5	20
Marjaba	170	Hypocr. Hayl.	1.50	-	An54 1.50	-	0.75	An50 45	-	30	10	5	10
Marjaba	171	Holocr. Gran.	1.00	1.00	An64 3 x 0.25	-	0.75	-	Ab56 25	30	20	5	20
Bhersaf	282	Holocr. Oph.	2.00	-	-	-	0.75	An54 30	-	30	25	8	7
Dlaibeh	306	Holocr. Gran.	2.50	1.50	-	-	1.00	An56 40	-	25	20	5	10
Arbaniyeh	307	Holocr. Gran.	2.50	-	-	-	0.75	-	Ab56 35	25	20	7	13
Bhannes	184	Holocr. Gran.	2.00	-	-	-	1.25	An56 40	-	20	10	5	25
Mar Mousa	188	Holocr. Gran.	2.00	-	-	-	1.00	An50 35	-	25	20	5	5

Tabulated Petrography of Neocomian Basalts

Table II

Locality	Slide No.	Fabric: Texture	Max. Diam. of Phynoc. in mm.: Oliv.	Max. Diam. of Phynoc. in mm.: Augt.	Max. Diam. of Phynoc. in mm.: Lab.	Max. Diam. of Phynoc. in mm.: And.	Approx. length of plag. lath in mm.	Modal Composition (percent): Lab.	And.	Augt.	Oliv.	Mag. Ilm.	Others
Al Mrouj	187	Holocr. Gran.	2.00	1.50	An54 1.25	-	1.00	10	Ab52 25	30	20	10	5
Al Mrouj	186	Holocr. Gran.	1.50	1.00	An54 2.00	-	-	15	Ab56 25	25	15	7	13
Darah	281	Holocr. Gran.	1.00	-	-	-	1.50	-	Ab50 40	20	20	6	14
Darah	208	Holocr. Gran.	1.50	-	-	-	1.50	-	Ab52 35	30	25	5	5
Beskinta	178	Holocr. Gran.	1.50	-	-	-	2.00	-	Ab56 45	-	-	5	50
Falougha	305	Holocr. Gran.	2.00	-	An54 1.50	-	0.50	10	Ab52 25	30	15	5	15
Qurnayel	166	Holocr. Gran.	1.50	-	-	-	0.75	An58 30	-	30	15	5	20
Al Qala'a	164	Holocr. Gran.	1.50	-	An58 1.25	-	0.25	20	Ab52 20	20	30	5	5
Chbaniyyeh	162	Holocr. Gran.	2.00	-	An60 2.00	-	0.25	15	Ab52 25	30	20	8	2
Qubbay'	160	Holocr. Gran.	1.00	-	-	-	1.00	An58 40	-	25	15	5	15

Table II (Cont'd.)

Locality	Slide No.	Fabric: Texture	Fabric: Max. Diam. of Phynoc. in mm. Oliv.	Augt.	Lab.	And.	Approx. length of plag lath in mm.	Modal Composition (percent): Lab.	And.	Augt.	Oliv.	Mag. Ilm.	Others
Abey	322	Holocr. Oph.	1.00	-	-	-	0.75	An58 35	-	20	20	7	17
*E. of Albnayeh	330	Holocr. Oph.	1.50	-	-	-	1.50	An60 40	-	20	15	5	20
*E. of Albnayeh	324	Holocr. Oph.	1.50	-	-	-	1.00	An58 35	-	25	20	5	15
*Shakfita River	328	Holocr. Oph.	1.50	-	-	-	1.00	An58 35	-	30	15	5	15
Nahr Abu-Zebli	321	Holocr. Oph.	1.50	-	-	-	0.75	An60 40	-	30	20	5	5
+Kafr Fakhoud	320	Holocr. Oph.	1.50	-	-	-	0.75	An56 35	-	30	15	5	15
Maysaloun (Syria)	313	Holocr. Oph.	2.00	-	-	-	1.00	-	Ab56 35	30	20	5	10
Machghara	284	Holocr. Gran.	4.00	-	An54 4.00	-	0.50	-	Ab50 40	20	20	10	10
Machghara	283	Hypocr. Inter.	4.50	200 x 3.50	-	-	0.50	An60 30	-	30	20	10	10
Ba'tara	145	Holocr. Gran.	1.00	-	-	-	1.00	-	Ab56 35	20	30	8	7

* With 5 percent nepheline

\+ With 7 percent Albite

Tabulated N - S Petrography of Aptian-Alpian Basalts

Table III

			Fabric					Medal composition (percent)					
Locality	Slide No.	Texture	Max. Diam. of Phynocr. in mm. Oliv.	Augt.	Lab.	And.	Approx. length of Plag. lath in mm.	Lab.	And.	Augt.	Oliv.	Mag. + Ilm.	Others
Hrar	241	Holocr. Oph.	3.00	-	-	-	1.25	An58 25	-	25	30	5	15
Hrar	244	Hypocr. Hayl.	1.00	-	-	-	0.25	An54 30	-	30	20	10	10
Tall Al-Mazra'a	237	Holocr. Oph.	1.00	-	An78 2.50	-	0.50	An56 35	-	30	25	5	5
Tall Al-Mazra'a	238	Hypocr. Inter.	0.50	-	-	-	0.125	An54 30	-	25	25	10	10
Beit Younes	239	Holocr. Gran.	2.00	-	-	-	2.00	An58 35	-	25	30	7	3
Beit Younes	240	Holocr. Gran.	1.50	-	-	-	0.75	An60 35	-	30	25	5	5
Beit Ayyoub	234	Holocr. Gran.	1.00	-	-	-	1.00	An54 30	-	30	25	8	7
Beit Mounther	029	Hypocr. Inter.	2.50	-	-	Ab54	0.25	An56 30	-	30	25	10	5
Ejbbe	273	Hypocr. Hayl	2.00	-	-	Ab52	0.50	An60 35	-	20	20	10	15
Basloukit	271	Hypocr. Vitr.	1.00	-	-	Ab56	V.fine	An54 25	-	30	20	10	15
Basloukit	270	Hyp. Vitr.	0.25	-	-	-	V.fine	-	Ab52 40	25	15	10	10
Ehden	265	Hypocr. Hayl.	3.00	-	-	-	0.25	An57 50	-	20	20	8	2

(Table III cont'd.)

Locality	Slide No.	Fabric: Texture	Max. Diam. of Phynocr. in mm.: Oliv.	Augt.	Lab.	And.	Approx. length of plag. lath in mm.	Modal composition (percent): Lab.	And.	Augt.	Oliv.	Mag + Ilm	Others
Kafr Sghab	263	Vitreous	-	-	-	-	-	An52 30	-	30	-	20	20
Kafr Sghab	264	Hypocr. Hayl.	3.00	-	-	-	0.25	An50 40	-	30	15	7	8
Tartij	025	Holocr. Oph.	1.50	-	-	-	1.00	An64 30	-	30	25	5	10
Tartij	027	Holocr. Oph.	2.00	-	-	-	1.00	An60 35	-	25	20	10	10
Tartij	019	Holocr. Oph.	1.00	-	-	-	2.00	An54 35	-	30	20	7	8
Jaj	021	Holocr. Oph.	1.00	-	-	-	1.00	An53 30	-	25	30	7	8
Kebraye	147	Hypocr. Inter.	3.00	-	-	-	1.00	An64 35	-	30	25	8	2
Kebraye	149	Holocr. Gran.	1.00	-	-	-	1.00	An60 35	-	30	20	10	5
Kebraye	154	Hypocr. Hayl.	0.50	-	-	-	0.50	-	Ab56 25	20	35	5	15
Laqlouq	119	Hypocr. Hayl.	0.50	-	-	-	0.25	-	Ab56 35	30	15	10	10
Laqlouq	120	Hypocr. Hayl.	0.25	1.00	-	-	0.25	An60 35	-	25	10	10	20
Laqlouq	121	Hypocr. Hayl.	1.50	-	-	-	0.25	An54 30	-	20	15	15	20
Laqlouq	123	Holocr. Gran.	2.00	-	-	-	1.50	An60 35	-	20	25	5	15

(Table III cont'd.)

Locality	Slide No.	Fabric: Texture	Fabric: Max. Diam. of Phynocr. in mm.: Oliv.	Augt.	Lab.	And.	Approx. length of Plag. lath in mm.	Modal composition (percent): Lab.	And.	Augt.	Oliv.	Mag. + Ilm.	Others
Laqlouq	124	Hypocr. Hayl.	0.50	2.00	-	-	1.50	An60 35	-	20	25	5	15
Laqlouq	125	Hypocr. Hayl.	0.25	1.50	-	-	0.30	An60 40	-	20	20	5	15
Laqlouq	127	Hypocr. Hayl.	0.25	1.50	-	-	0.50	An52 45	-	30	5	8	12
Ain Niha	109	Holocr. Oph.	1.25	-	-	-	1.00	An55 35	-	30	25	7	3
Ain Niha	111	Holocr. Oph.	2.00	-	-	-	1.00	An56 30	-	30	20	10	10
Ain Al Alaq	113	Hypocr. Hayl.	1.00	3 x 6	-	-	0.50	An54 40	-	30	10	10	10
Ain Al Alaq	117	Holocr. Hayl.	0.50	-	-	-	1.25	An50 30	-	35	20	7	8
Ain Al Alaq	118	Hypocr. Hayl.	0.50	1.50	-	-	0.75	An50 45	-	25	10	10	10
Ain Meyfouk	133	Hypocr. Inter.	1.00	-	-	-	0.50	-	Ab54 45	-	-	10	45
Ain Meyfouk	135	Hypocr. Inter.	1.00	-	-	-	0.50	An54 30	-	30	20	18	17
Ain Meyfouk	141	Holocr. Oph.	2.5	-	-	-	1.00	An54 30	-	25	20	10	15
Abadiyye	156	Holocr. Oph.	1.00	-	-	-	1.50	An52 30	-	20	30	8	12
Cole of Zahle	182	Holocr. Gran.	1.00	-	-	-	0.75	An58 45	-	20	20	5	10

Tabulated Petrography of Some Tertiary Basalts

Table IV

		Fabric					Approx. length of Plag. lath in mm.	Modal Composition (percent)					
Locality	Slide No.	Texture	Max. Diam. of Phynocr. in mm.					Lab.	And.	Augt.	Oliv.	Mag.+ Ilm.	Others
			Oliv.	Augt.	Lab.	And.							
Halba	225	Hypocr. Oph.	1.50	-	-	-	0.75	-	Ab52 40	30	20	8	2
Koehlock	293	Holocr. Gran.	4.00	-	-	-	1.50	-	Ab50 35	30	25	7	3
Freidice	287	Holocr. Gran.	2.00	-	-	-	1.25	-	Ab52 30	25	20	7	18
Freidice	304	Holocr. Gran.	7.00	-	-	-	1.75	-	Ab52 35	25	30	7	3
Tlail	230	Holocr. Gran.	4.00	-	-	-	1.00	-	Ab52 40	30	20	10	-
Mardjayoun	315	Hypocr. Gran.	3.00	2.00	-	-	0.25	-	Ab52 40	30	15	15	-

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Plate 1: Zoned augite; outer rim more brownish,
from Kharhel, (slide No. 058), x 150. **Kimmeridgian.**

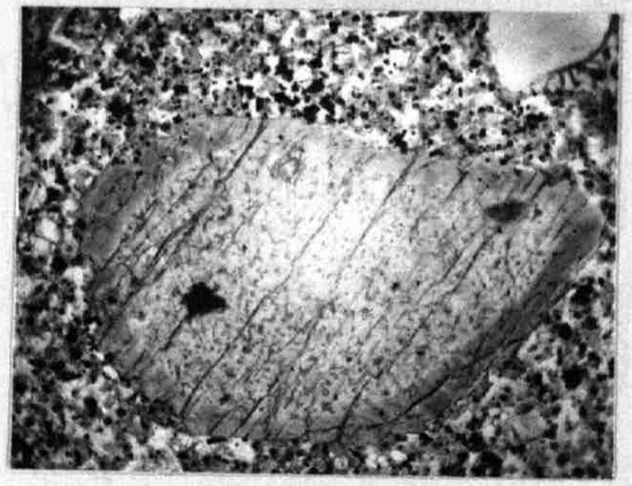
Plate 2: Zoned prismatic augite (air bubble in the centre).
from Al-Mseil, (slide No. 051), x 150.
Kimmeridgian.

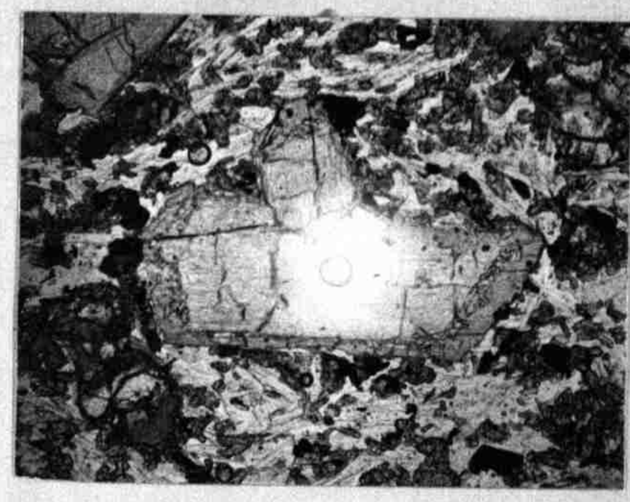
Plate 3: Poikilitic augite with cleavage,
from Machghara, (slide No. 283), x 75. Neocomian.

Plate 4: Augite in a haylopilitic texture,
from Ain Al-Alaq, (slide No. 118), x 50.
Aptian.

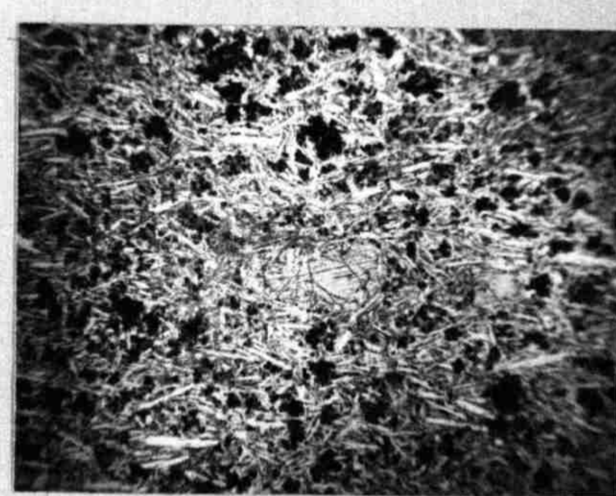
Plate 5: Diallage augite,
from Laqlouq, (slide No. 127), x 150. Aptian.

Plate 6: Twinned 8-sided augite in a fine-grained
haylopilitic texture.
from Ain Al-Alaq, (slide No. 118), x-nicols, x 50.
Aptian.


Plt. 1


Plt. 2


Plt. 3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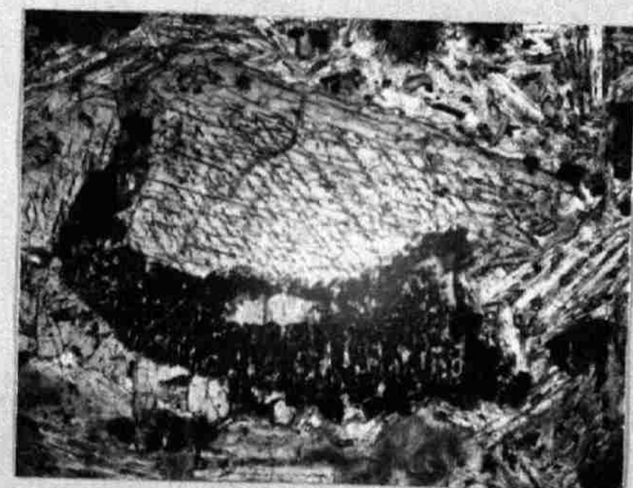

Plt. 5


Plt. 6

Plate 7: Twinned augite, Kimmeridgian,

from Brisat, (slide No. 042), x-nicols, x 150.

Plate 8: Phenocrysts of olivine, augite, and andesine,

from Harisa, (slide No. 050), x-nicols, x 50.

Kimmeridgian.

Plate 9: Ophitic texture,

from Hrar, (slide No. 243), x 150. Aptian.

Plate 10: Ophitic texture with olivine,

from Mazra'at As-Sayyad, (slide No. 108), x 50.

Kimmeridgian.

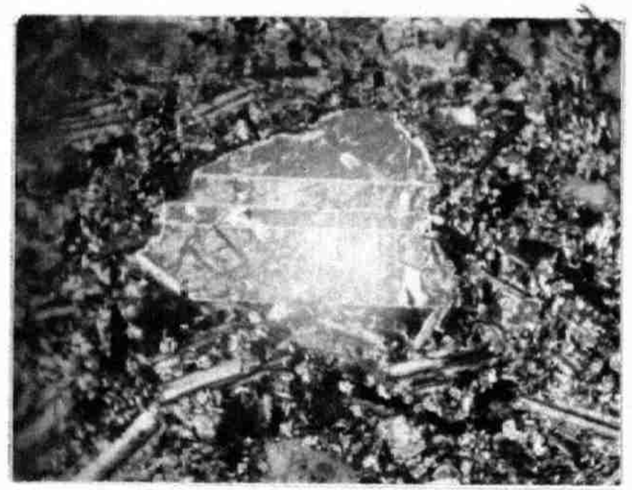
Plate 11: Resorbed euhedral augite, Aptian,

from Ain Al-Alaq, (slide No. 117), x-nicols, x 50.

Plate 12: Eight-sided poikilitic augite,

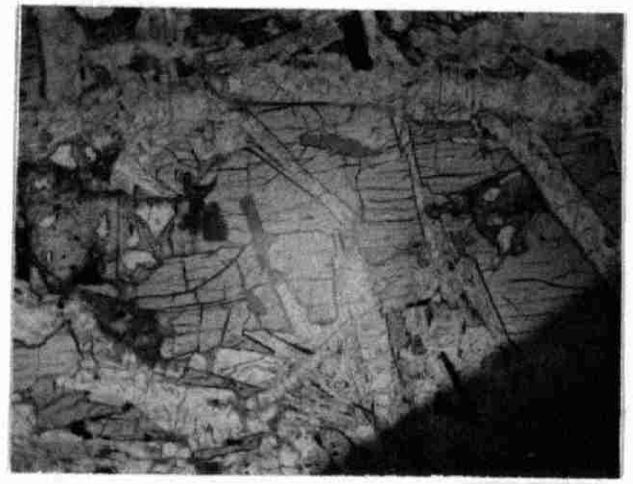
from Ain Al-Alaq, (slide No. 117), x 150.

Aptian.



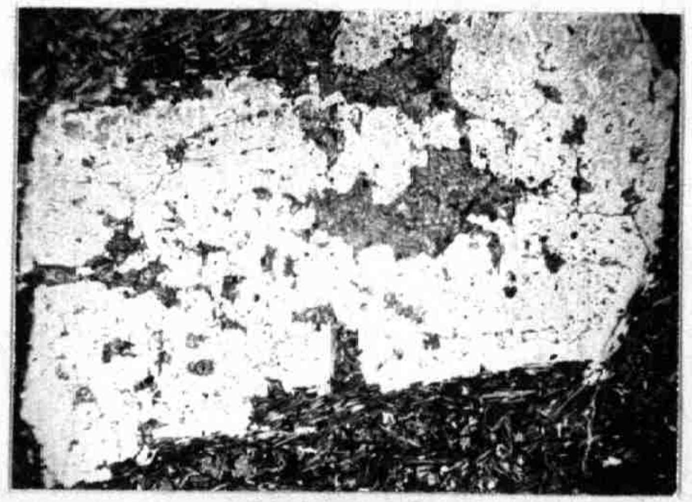
Plt. 7

Plt. 8



Plt. 9

Plt. 10



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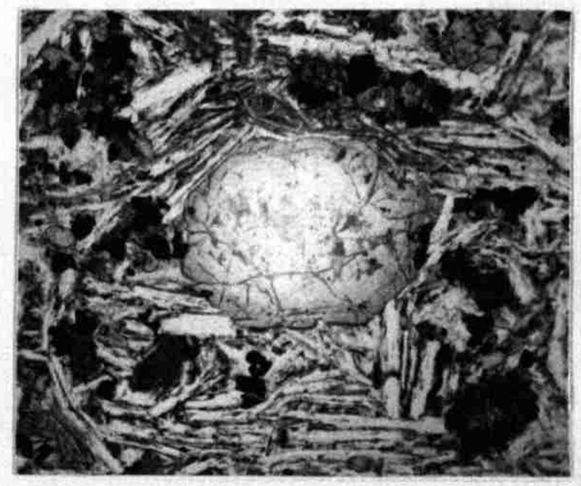


Plt. 12

Plate 13: Prismatic olivine, Kimmeridgian,
from Machnaqa, (slide No. 004), x 50.

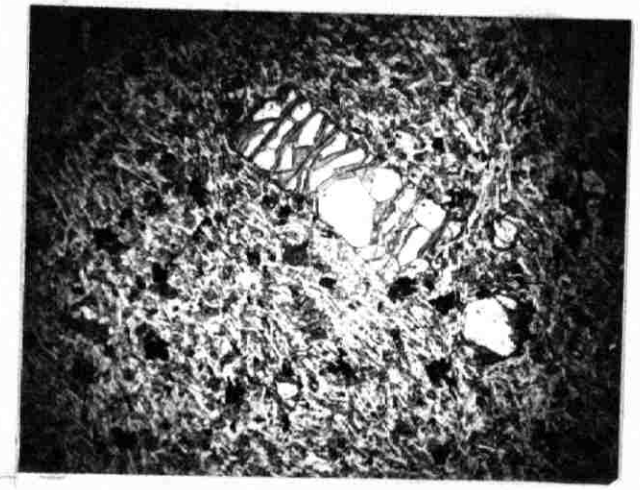
Plate 14: Rather fresh olivine,
from Kharhel, (slide No. 058), x 150.
Kimmeridgian.

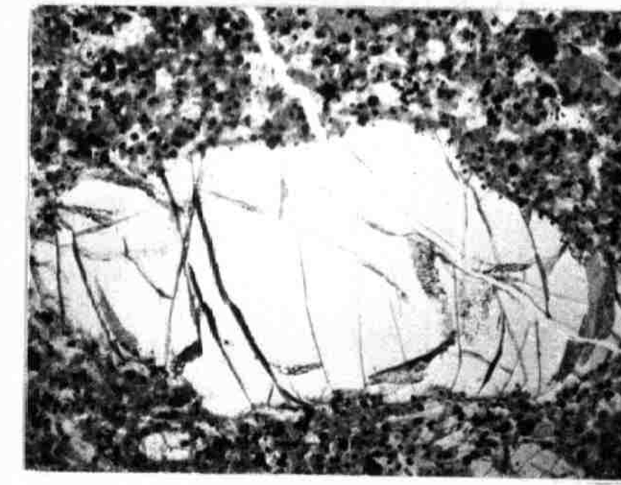
Plate 15: Olivine, Aptian,
from Kafr Sghab, (slide No. 264), x 150.

Plate 16: Six-sided olivine,
from Hadchit, (slide No. 259), x 50.
Kimmeridgian.

Plate 17: Olivine with antigorite alteration rims,
from E of Diman, (slide No. 035), x 150. Kimmeridgian.

Plate 18: Olivine (left) and pseudomorphs after olivine
(right, near rock surface),
from Bala'a, (slide No. 067), x 50.
Kimmeridgian.


Plt. 13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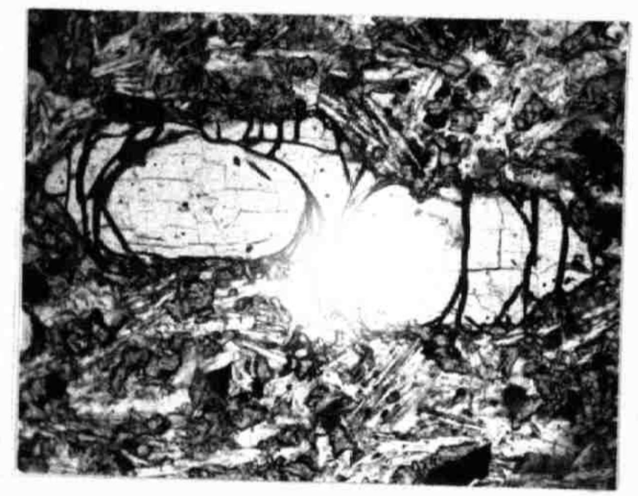
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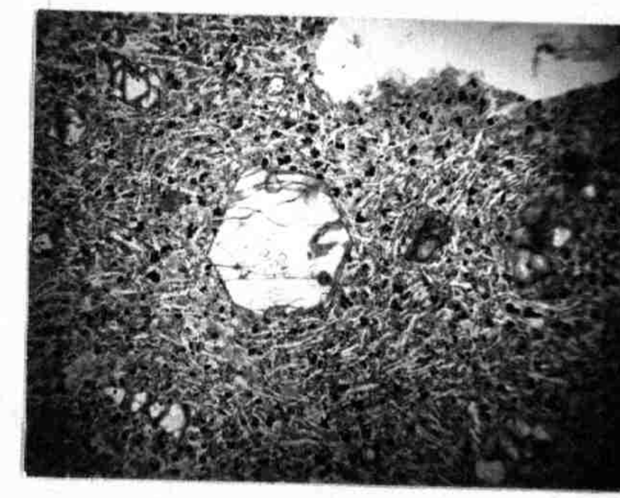
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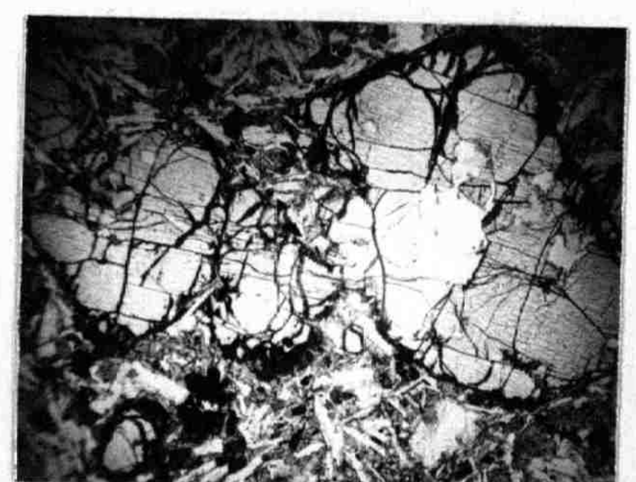

Plt. 17

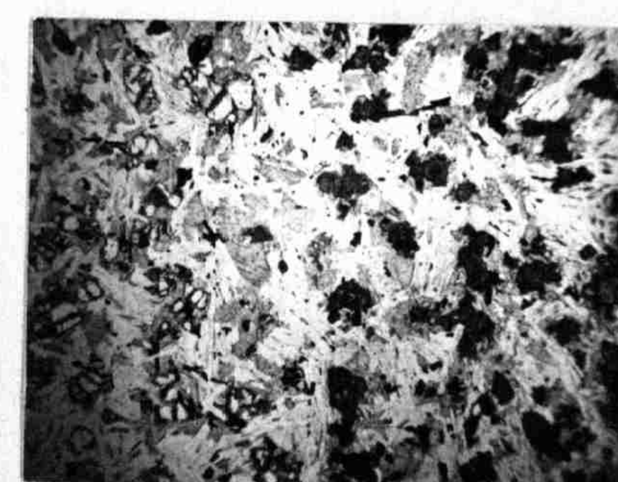

Plt. 18

Plate 19: Calcite and quartz in a pseudomorph after olivine, from Bcharreh, (slide No. 257), x 150. Kimmeridgian.

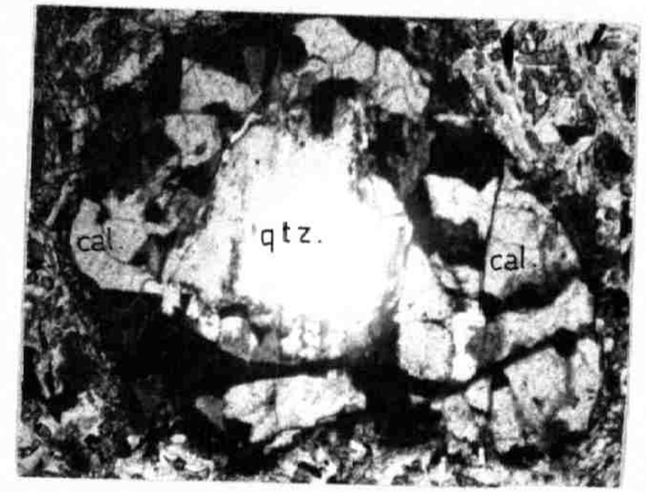
Plate 20: Quartz, iddingsite, and magnetite in a pseudomorph after olivine, from Batara, (slide No. 145), x 50. Neocomian.

Plate 21: Zoned plagioclase, Neocomian, from Batara, (slide No. 145), x-nicols, x 150.

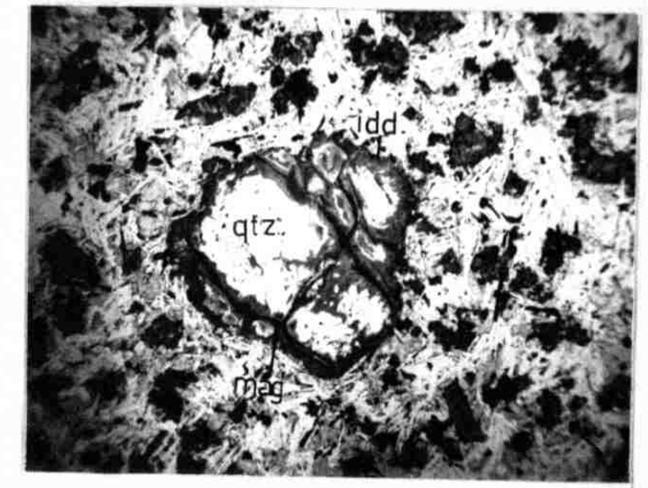
Plate 22: Zoned euhedral plagioclase, from Al-Mseil, (slide No. 051), x-nicols, x 150. Kimmeridgian

Plate 23: Labradorite, Neocomian, from Machghara, (slide No. 284), x-nicols, x 50.

Plate 24: Granulitic texture, from Dara, (slide No. 281), x-nicols, x 50. Neocomian.

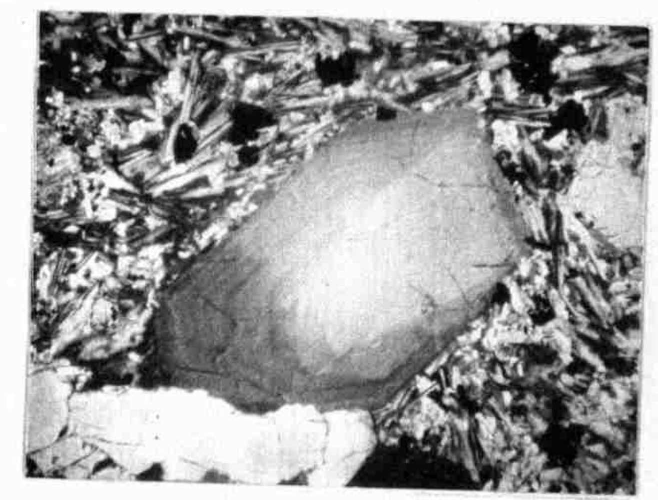


Plt. 19



Plt. 20


Plt. 21


Plt. 22


Plt. 23


Plt. 24

Plate 25: Gabbro showing diallage, labradorite, and chlorite, from Qartaba vent, (slide No. 104), x 50.

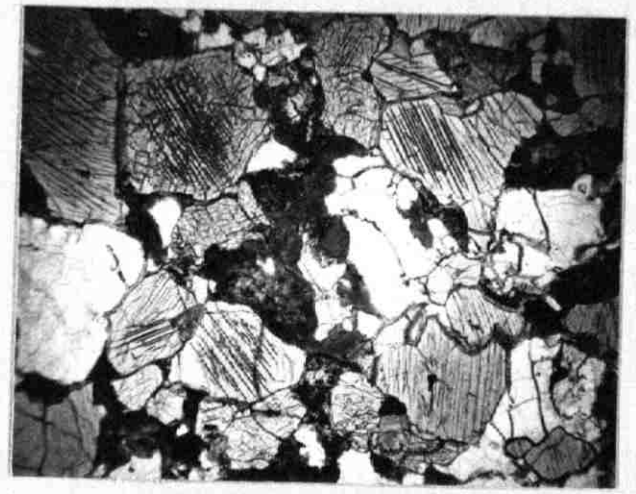
Plate 26: Labradorite, augite, and olivine phenocrysts, from Machghara, (slide No. 284), x-nicols, x 50. Neocomian.

Plate 27: Labradorite phynocrysts, Kimmeridgian, from Marjaba, (slide No. 170), x-nicols, x 50.

Plate 28: Calcite amygdale, from Basloukit, (slide No. 269), x-nicols, x 50. Aptian.

Plate 29: Calcite vein in Aptian basalt, from Ain Meyfouk, (slide No. 133), x 50.

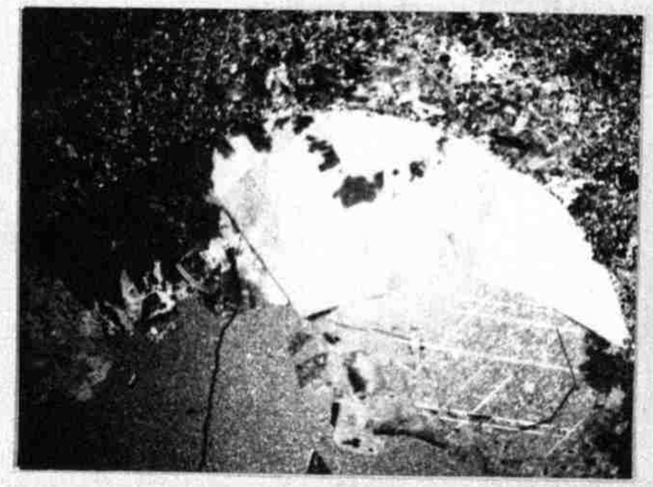
Plate 30: Calcite vein in Aptian basalt, from Basloukit, (slide No. 269), x 50.



Plt. 25

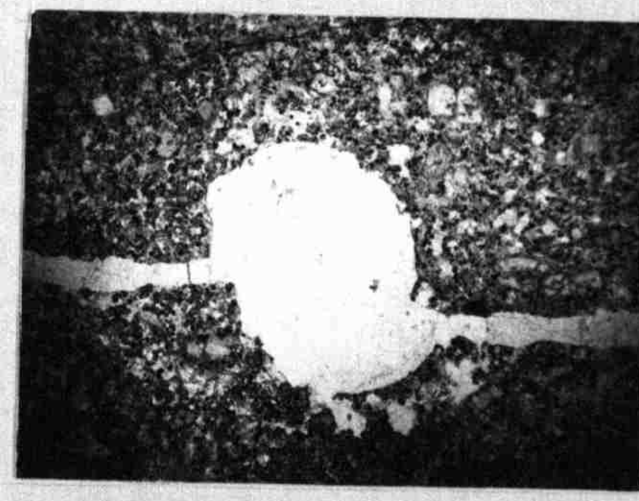
Plt. 26

Plt. 27



Plt. 28

Plt. 29



Plt. 30

Plate 31: Xenocryst with reaction rim in Aptian basalt, from Kebraye, (slide No. 147), x 150.

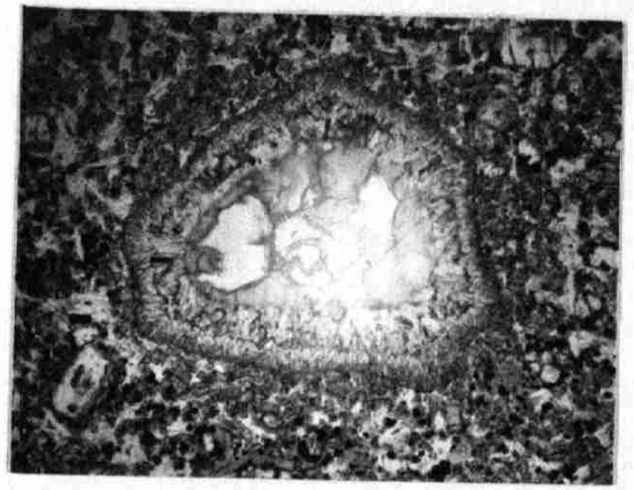
Plate 32: Zeolite Amygdale in Neocomian basalt, from Machghara, (slide No. 284), x 50.

Plate 33: Calcite in Aptian basalt, from Hrar, (slide No. 244), x-nicols, x 50.

Plate 34: Carbonate xenolith surrounded by diopsidic augite, from Batara, (slide No. 145), x 50. Neocomian.

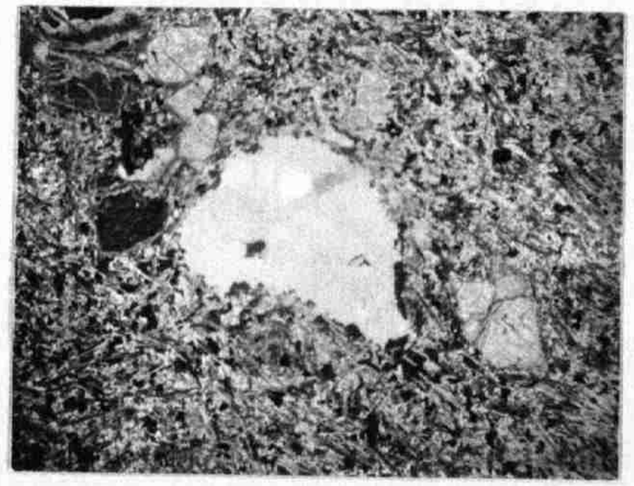
Plate 35: Olivine altered to iddingsite, Pliocene, from Tlail, (slide No. 230), x 50.

Plate 36: Plagioclase showing Baveno twinning, from Halba, (slide No. 225), x-nicols, x 150. Pliocene.

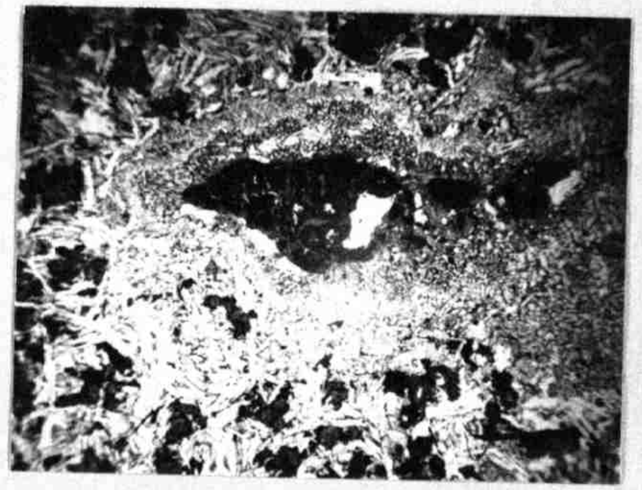


Plt. 31

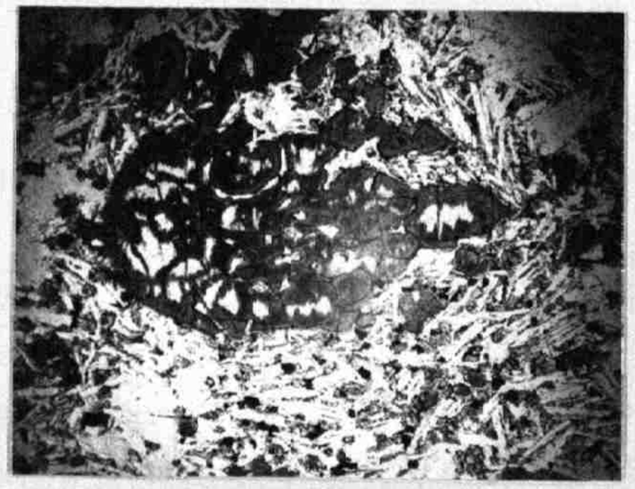
Plt. 32



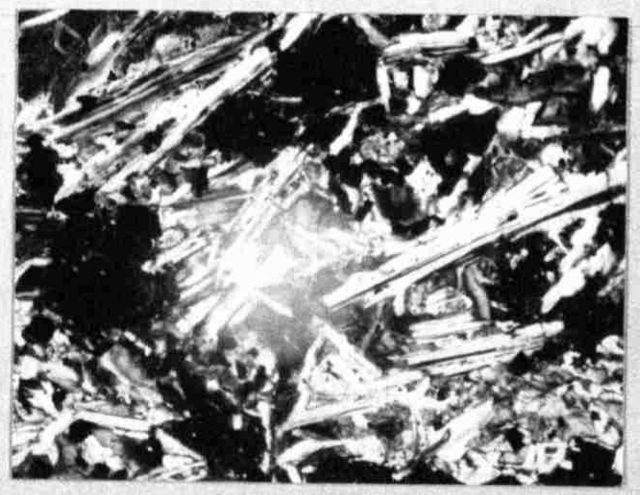
Plt. 33



Plt. 34



Plt. 35



Plt. 36

Plate 37: Coarse and fine grained diabase dykes, Qartaba vent, Qartaba.

Plate 38: Qartaba vent, volcanic materials in contact with Kimmeridgian limestone, Qartaba.

Plate 39: Basloukit vent.

Plate 40: Harisa vent.

Plate 41: Basalt covered by Albian limestone in Kebraye.

Plate 42: Basalt over and below falaise de Djezzine, Harisa.

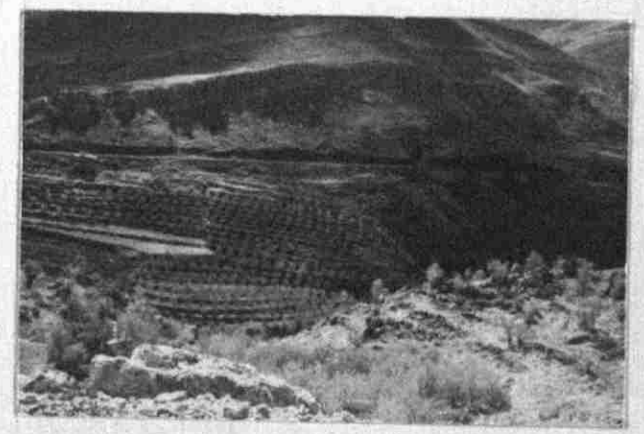
Plt. 37

Plt. 38

Plt. 39

Plt. 40

Plt. 41



Plt. 42

Plate 43: Basalt showing columnar jointing, Hackleh. Kimmeridgian.

Plate 44: Basalt outcrop, Bhannes, Kimmeridgian.

Plate 45: Basalt boulders in volcanic agglomerate, Harisa vent, Harisa.

Plate 46: Completely weathered basalt, Qartaba. Kimmeridgian.

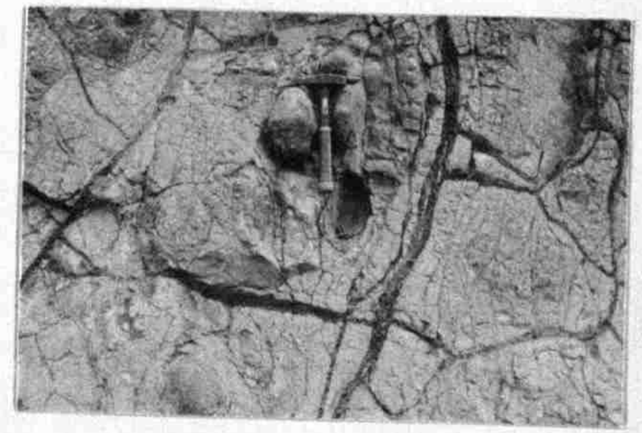
Plate 47: Spheroidally weathered basalt, Beit Younes. Aptian.

Plate 48: Basalt outcrop, valley of Nahr Abu-Zebli. Neocomian.

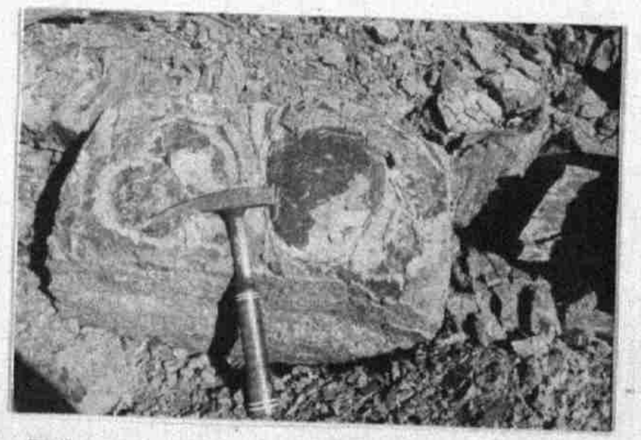
Plt. 43

Plt. 44

Plt. 45



Plt. 46



Plt. 47

Plt. 48

APPENDIX

Localities sampled and their Levant Grid coordinates[1)]

Kimmeridgian

Locality	Sheet	E	N	No. on Index map (fig. 2)
Abboud	Qartaba	162.5	240	25
Ain Al-Bardeh	Qartaba	153	232	36
Ain Al-Batrak	Qartaba	161	243	24
Ain Ed-Delbeh	Qartaba	153.5	232.5	35
Aintourah	Zahle	154	217	43
Al-Mseil	Qartaba	170	250.3	19
Aramoun	Jbail	147.3	231	34
Arbaniyeh	Beyrouth	145.7	215.5	65
Bala'a	Qartaba	164.3	249	20
Bazoun	Qartaba	175.5	255.3	near 13 [2)]
Bcharreh	Baalbek	176.5	256	13
Beit Al-Mahdi	Qartaba	153	230.8	38
Bekata, W of	Jbail	150	292.3	66
Bhannes	Beyrouth	144	219.4	63
Bhersaf	Beyrouth	145	220	near 63[2)]

1) Refer to Carte Geologique du Liban au 1:50.000.

2) Some locality numbers have been omitted from the index map owing to lack of space.

Kimmeridgian - cont'd

Locality	Sheet	E	N	No. on Index map (fig. 2)
Blouza	Tripoli	171	258	11
Brisat	Qartaba	171.5	262.2	14
Chatine	Qartaba	167	250.3	near 16[1]
Diman	Qartaba	173	255.5	near 15[1]
Dlaibeh	Beyrouth	146.5	216.4	64
Ehmij	Qartaba	157	243	29
Es-Souaneh	Qartaba	154.5	239.7	31
As-Sfire	Sir Ed-Danie	182	272.5	4
Hackleh	Qartaba	176	255.5	near 13[1]
Hadchite	Tripoli	174	257	12
Harisa (N)	Qartaba	170.4	250.7	19
Hasroun	Qartaba	173.7	255.6	near 14[1]
Joret Et-Tormos	Jbail	149	233.7	33
Kharhel	Qartaba	169	250.2	near 19[1]
Machnaqa	Qartaba	154.6	239.2	near 31[1]
Mar Mousa	Beyrouth	146.4	218	42
Marjaba	Beyrouth	152	220	40
Mayrouba	Qartaba	154	238	38
Mazra'a As-Sayyad	Qartaba	162.5	240.6	near 25[1]

1) See footnote 2) on p. (i).

Kimmeridgian - cont'd.

Locality	Sheet	E	N	No. on Index map (fig. 2)
Nahr Ed-Dahab	Jbail	148.7	233	near 33[1]
Qartaba	Qartaba	161	239.5	25
Yahshoush	Jbail	151	236.3	32

Neocomian

Locality	Sheet	E	N	No. on Index map (fig. 2)
Abey	Jezzine	131.2	200.6	54
Al-Mrouj	Beyrouth	151.8	219.5	41
Al-Bnayeh, E of	Jezzine	133.8	200.3	55
Batara	Qartaba	163.3	246.8	34
Beskenta	Zahle	155.3	223.4	67
Chbaniyyeh	Beyrouth	148.4	209.7	48
Dara	Zahle	160.7	218.	44
Falougha	Beyrouth	151.2	211.2	49
Kafr Fakhoud	Jezzine	132.9	197	58
Machghara	Jezzine	139.4	175.5	59
Maysaloun(Syria)	Zebdani	180.5	184.	62
Nahr Abu-Zebli	Jezzine	140.3	200.9	57
Nahr Chakfita	Jezzine	135.2	201	56
Qubbay	Beyrouth	146.8	258.9	49
Qurnayel	Beyrouth	150	213.4	45

---

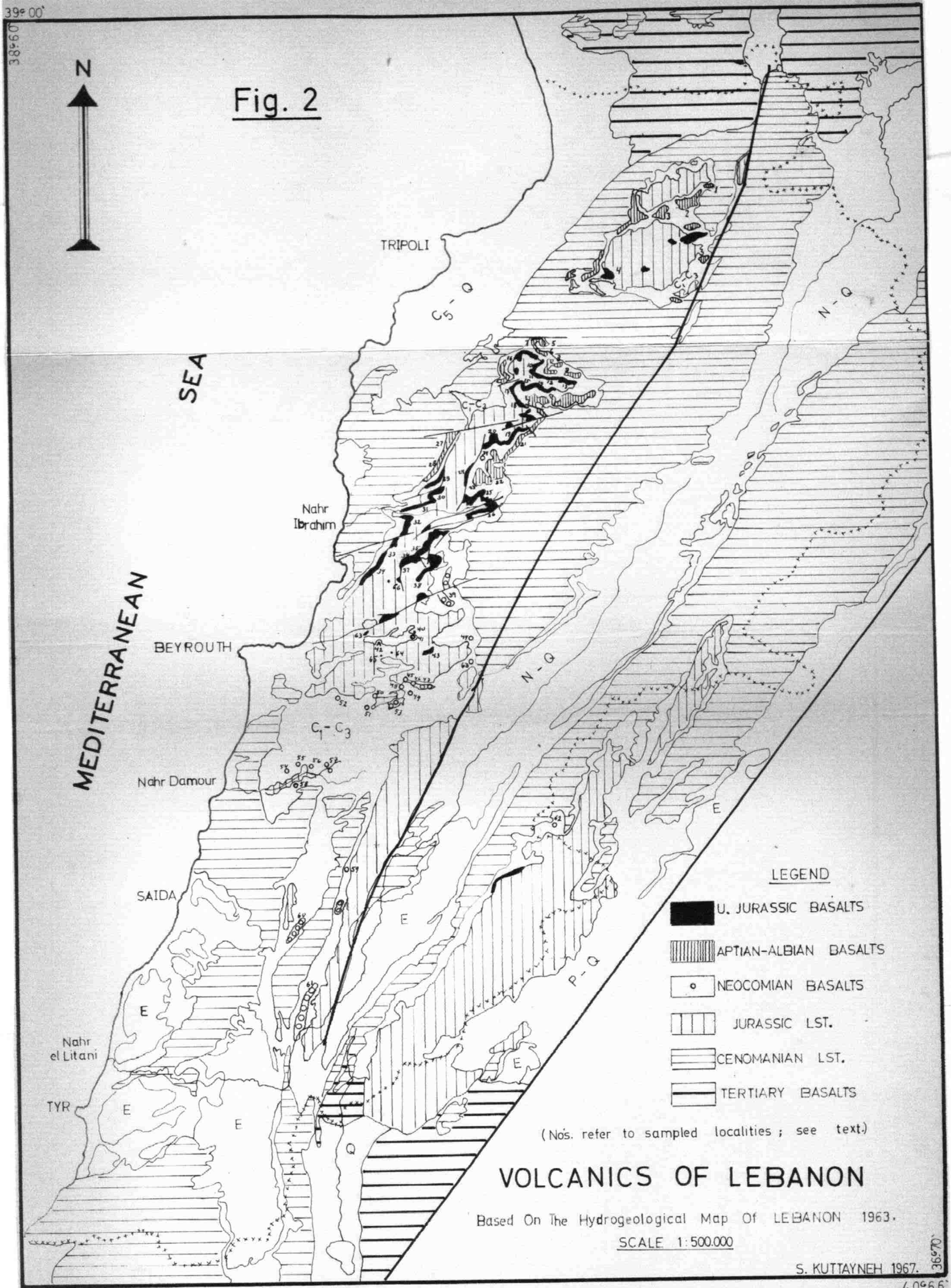
1) See footnote 2, on p. (i).

Aptian - Albian

Locality	Sheet	E	N	No. on Index map (fig. 2)
Abadiyyeh	Beyrouth	140.2	211.2	52
Ain Al-Alaq	Qartaba	163	242	near 23[1)]
Ain Meyfouk	Qartaba	162.5	244.7	near 23[1)]
Ain Neha	Qartaba	162	241.8	near 23[1)]
Basloukit	Tripoli	171.2	263	5
Beit Ayyoub	Sir Ed-Danie	191	281	2
Beit Mounther	Tripoli	167.5	257.5	16
Beit Younes	Sir Ed-Danie	190	281	near 2[1)]
Col of Zahle	Zahle	161	214.3	63
Ehden	Tripoli	173	269	6
Ejbbè	Tripoli	171	263.3	7
Hrar	Sir Ed-Danie	187.2	280.2	3
Jaj	Qartaba	158	247.5	28
Kafr Sghab	Tripoli	173	259.8	8
Kebraye	Qartaba	168.5	248.8	21
Laqlouq	Qartaba	164.9	246.5	23
Tall Al-Mazra'a	Sir Ed-Danie	199	282.5	1
Tartij	Qartaba	159.3	249.7	27

1) See footnote 2 on p. (i).

Fig. 2



VOLCANICS OF LEBANON

Based On The Hydrogeological Map Of LEBANON 1963.

SCALE 1:500.000

S. KUTTAYNEH 1967.

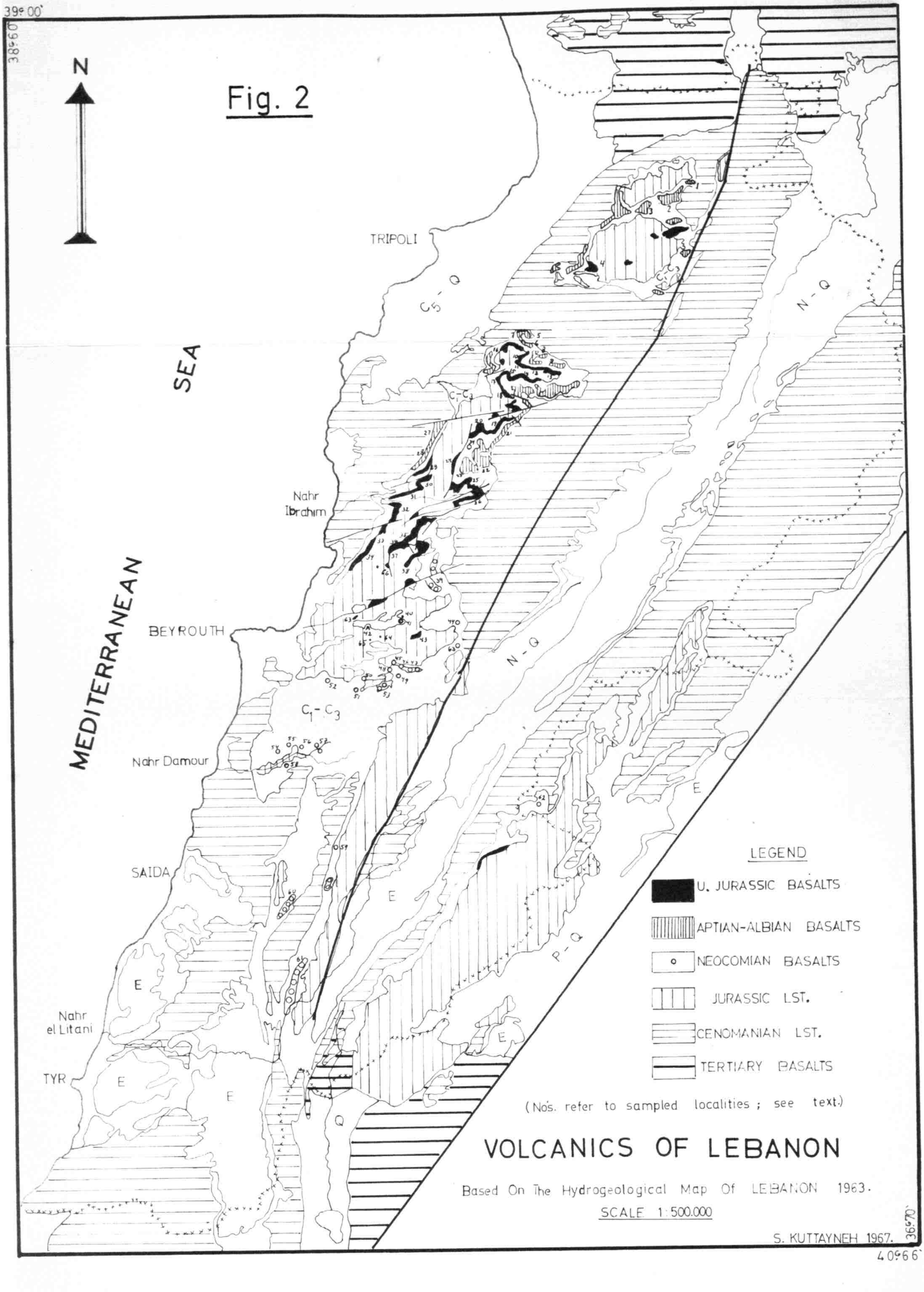

39° 00'
38° 60'
N
MEDITERRANEAN
SEA
TRIPOLI
Nahr Ibrahim
BEYROUTH
Nahr Damour
SAIDA
Nahr el Litani
TYR
C5 - Q
C1 - C3
N - Q
P - Q
E
Q
LEGEND
U. JURASSIC BASALTS
APTIAN-ALBIAN BASALTS
NEOCOMIAN BASALTS
JURASSIC LST.
CENOMANIAN LST.
TERTIARY BASALTS
(No's. refer to sampled localities ; see text.)
VOLCANICS OF LEBANON
Based On The Hydrogeological Map Of LEBANON 1963.
SCALE 1:500.000
S. KUTTAYNEH 1967.
36° 70'
40° 66'

Fig. 2