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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

The Seventy-Ninth General Meeting of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, London, on Tuesday, May 13th, 1924, the Chair being taken by the President, Mr. H. Barringer, M.Inst.C.E., M.I.Mech.E., M.I.N.A.

The Secretary first read the names of the newly elected members, as follows :—

Members.—Walter Henry Coleman, Charles Oswald Frewen Jenkin, William Henry Westwood Lacey, Richard Mannaberg, Ernest Procter, Charles Ross, Sir John Bowring Wimble.

Transferred from Associate Member.—Cyrus Henry Perkins.

Associate Members.—William Ernest Victor Abraham, Sidney Martin Blair, Bruce McLean Craig, Wyndham Percy Jones, George Martin Lees.

Students.—Leonard John Ward, Major William Wilson.

Associates.—William Robert Lincoln.

The following paper was then read :—

The Geology and Oil Measures of South-West Persia.

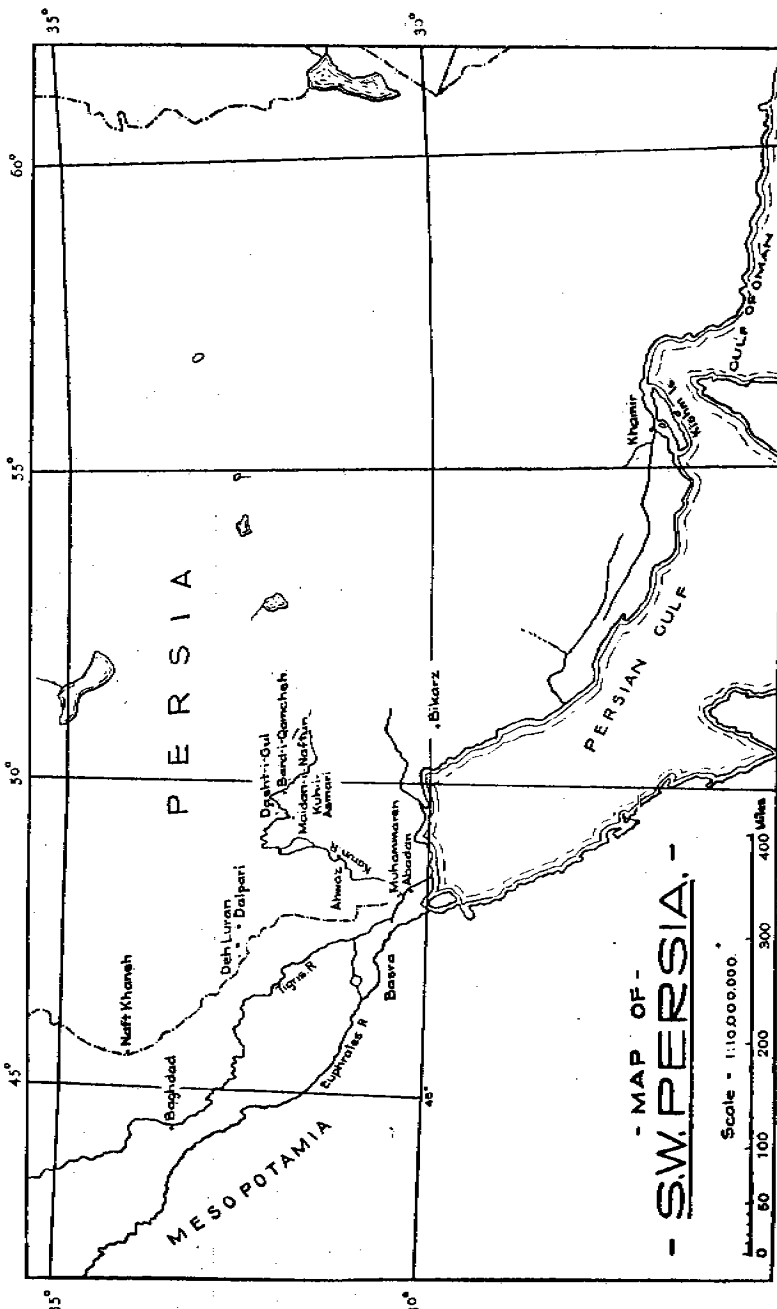
By R. K. Richardson, A.R.C.Sc. (Member).

Introductory.

The area forming the subject of this paper comprehends a long belt of petroliferous territory flanking the Persian Gulf on its eastern side and passing north-westwards through Arabistan and Bakhtiari Country into the Pusht-i-Kuh region of Luristan. It is bounded on the south-west by the desert lands of Persia and Mesopotamia, and on the north-east by the higher mountains of the Zagros arc.

Since Messrs. Mayo and Busk* delivered their paper before this Institution in 1918, much ground has been covered both in the field and laboratory. New regions and new rocks have come under the geological hammer, and much that was taken for granted, particularly in relation to the productive oil rock, has been the subject of revision.

* Some Notes on the Geology of the Persian Oilfields. *Journ. Inst. Petr. Techn*, V. No. 17, p. 3, 1918.



MAP OF S.W. PERSIA.

It can hardly be hoped, in the limits of this paper, to deal with the wealth of detail available, but it is proposed to review the geological features broadly and comprehensively, and the pertinent details of petroleum matters more particularly.

Before proceeding to the subject-matter the author desires to express his grateful thanks to colleagues of the Anglo-Persian Oil Company's Geological Staff, who have assisted in obtaining many of the data presented. Special reference will be made later to the valuable work of Dr. Douglas who has given much time and thought to the palaeontological determinations, and the author is indebted to him for the excellent illustrations of fossil forms.

Indebtedness must also be expressed to the Anglo-Persian Oil Company for having allowed the use of material from which this paper was compiled. In accordance with the rules of the Publication Committee of this Institution, the paper is written in the third person, but it should be clearly understood that the author accepts sole responsibility for opinions expressed and conclusions drawn, which may or may not be shared by colleagues or the Company.

Topographic Features.

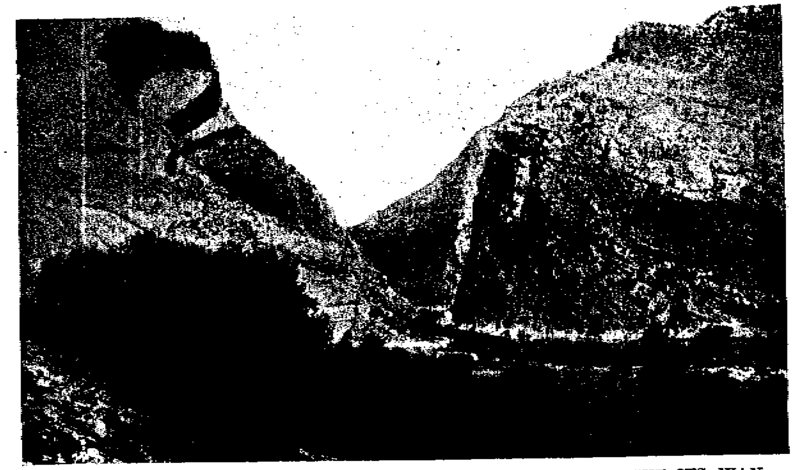
Proceeding north-eastwards from the line of the Persian Gulf and the great rivers of Mesopotamia—heirs to an extended gulf in recent geological times—one traverses, in general, before reaching the central Iranian Plateau, a land mass of three-fold altitude. Firstly, a belt of alluvial desert at sea-level or thereabouts; secondly, a series of parallel hill ranges displaying the variegated colours of the Fars rocks and newer deposits; and, lastly, a series of high mountains formed by the Asmari limestone and rocks of older age.

The relief of the area has a N.W.–S.E. orientation, in keeping with its geological character, and is cut transversely by deeply-incised drainage lines across the strike carrying the waters of numerous rivers debouching into the Tigris, the Shatt-el-Arab and the Persian Gulf.

The relation of land forms to geology is an intimate one. The valleys are frequently broad structural valleys and the higher altitudes the crests of structural arches of massive limestone.

The long black hogbacks and whalebacks, representing almost intact arches of limestone, are a characteristic of the region. The two limestone groups, which function as the indurated framework of the country are the Asmari and the Cretaceous limestones.

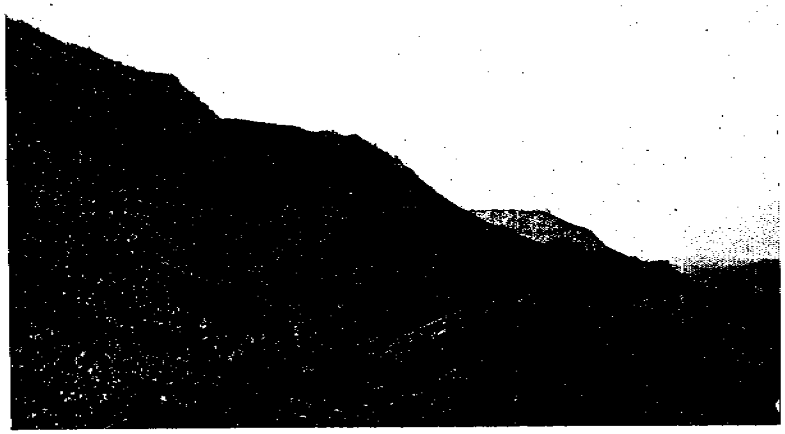
In the sub-montane tracts occupied by later Miocene and Pliocene deposits conditions are often found reversed. Here the broad synclinal areas containing hard massive conglomerates of



BARD-I-QAMCHEH. GORGE. THE KARUN RIVER HAS HERE CUT ITS WAY THROUGH A BIG ANTICLINAL ARCH OF ASMARI LIMESTONE.

SMALL "TANG" IN ASMARI LIMESTONE ON THE SLOPES OF THE KUH-I-KAMERUN.

BAKHTIARI CONGLOMERATE. TANG-I-DOULAB.



UPPER AND MIDDLE FARS ROCKS. DAREH-I-QIL.

the Bakhtiari period form the higher country, standing out as extensive tablelands.

A striking feature of Persian topography is the presence of deep clefts or "tangs" in the limestone arches running transversely across the strike. The origin of these has been the subject of much discussion involving two alternative lines of enquiry. It has been considered that they are tectonic lines due to disruption by bending forces during orogenetic movements.

The alternative view ascribes their origin to erosion by rivers, keeping pace with uplift, during mountain formation.

They are identical with similar phenomena on a grander scale in the Himalayas for which the latter explanation is generally accepted.

STRATIGRAPHY.

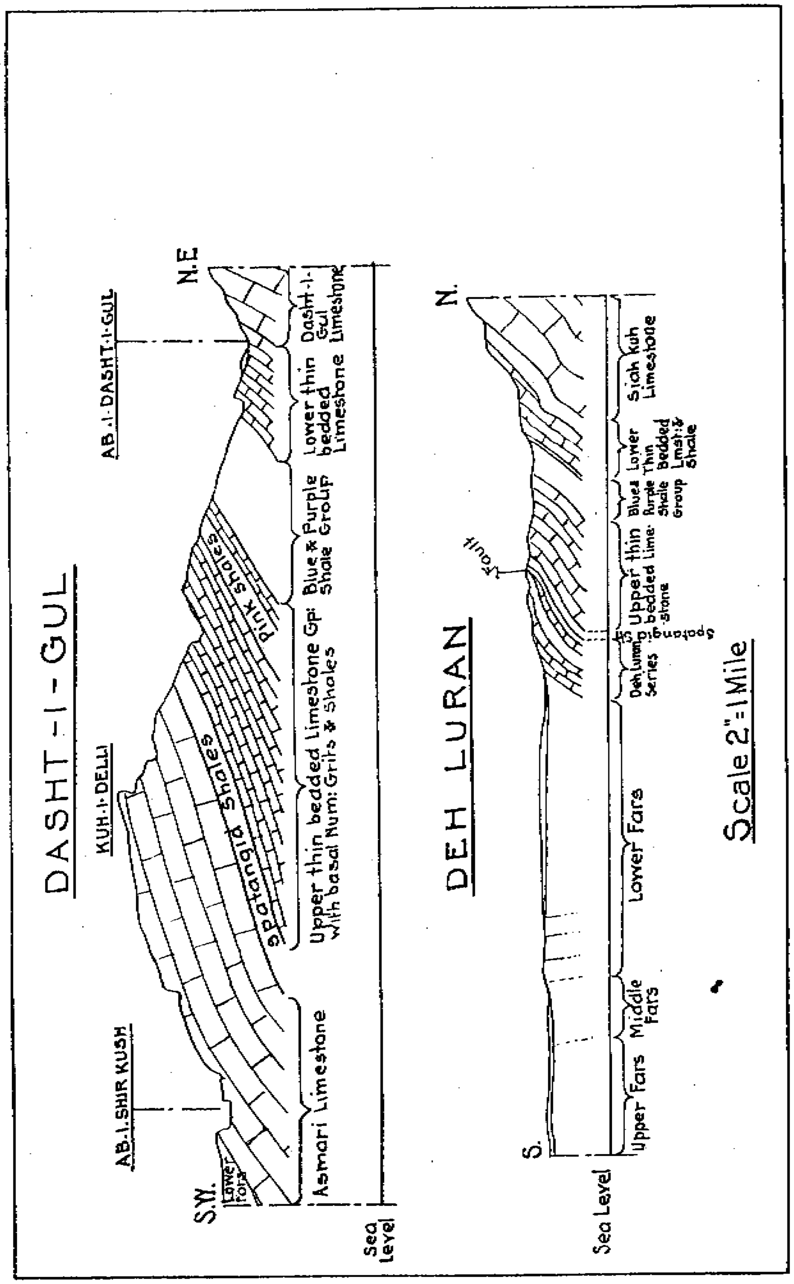
General.—Nature has facilitated geological enquiry in Persia in that she has laid bare, as on a dissecting table, the geological sequence stripped of superficial cover and disposed according to an order of grandeur and simplicity. It is fortunate that we have to deal with a succession in which individual members vary greatly in colour, hardness and other physical attributes.

While the sequence lends itself to divisibility into large and relatively simple units on lithological grounds alone, there is naturally some variation, particularly in thickness, from place to place. Considerable work has been done upon the Fars and newer rocks, but the older formations from the Asmari Limestone (Oligocene—Lower Miocene) to the Cretaceous had not, until recent years, been the object of close study.

The information about to be detailed relative to pre-Fars rocks rests upon three chosen sections, one in the North in the Deh Luran district of Pusht-i-Kuh, one in the centre typical of the oilfield region and Bakhtiari country generally, and one in the extreme South in the neighbourhood of Khamir, opposite Kishm Island in the Persian Gulf. These representative sections over widely separated areas, together with intermediate work, furnish stratigraphical scales from which a sound and general view of the geological sequence can be obtained.

For purposes of clarity and brevity it is proposed, with reference to pre-Fars rocks, to describe the central geological section in Bakhtiari country in detail, commenting on the others in passing. A glance at the correlation table will indicate their relations. Small overthrusts, glides, or crustal creep are largely responsible for a reduced thickness at Deh Luran.

In these general remarks on stratigraphy there is one point which should be made clear and that is, that when using European nomenclature to indicate age of respective groups, it must be



GEOLOGICAL SECTIONS DASHT-I-GUL AND DEH LURAN.

remembered that it applies in a general sense only. Europe is a long way from Persia and the geological periods of the latter, as represented by well defined rock groups, can only be expected to coincide roughly with European counterparts. If any system is to be made to fit the stratigraphical units of Persia the nomenclature and grouping of the Indian Geological Survey might in many respects be more suitable when modified to meet requirements.

Recent Deposits.—Deposits of high level gravels, silt and alluvial fans.

Bakhtiari Series.—This group, to which a Pliocene age is attributed, overlies the Fars Series unconformably. The discordance is strongly marked in some areas while in others it is less pronounced. The group consists of massive conglomerates, loose sands, and clays and has a maximum thickness of upwards of 15,000 ft.

The Fars Series.—The Fars Series covers many tens of thousands of square miles in Persia and largely occupies the submontane tracts of the region under consideration.

The relation between the basal, or gypseous group, of the Fars Series and the underlying Asmari Limestone has been given considerable attention. Overlap has been proved in some areas and in one or two rare instances unconformity is recorded. For the most part, however, over hundreds of miles of outcrop the junction has the appearance of being a conformable one. Detailed sections across the Maidan-i-Naftun oilfields show, however, a marked discordance between surface conditions and the Asmari Limestone, which is partly accounted for by overlap and proved lenticularity of deposits. It should be noted also that the junction of a hard, resistant limestone, such as the Asmari Limestone, with a soft gypseous series ready to become a semi-fluid under stress, provides ideal conditions for the development of slip planes and other phenomena which have possibly played their part during orogenetic movements.

The Fars Series has been divided into three sub-divisions, an upper arenaceous and red marl group, an arbitrary middle group, or passage series, combining the common features of the very distinctive upper and lower groups, and a lower gypseous series.

Upper Fars.—This is a sandstone and marl group several thousand feet in thickness of distinctive colour and appearance. The red tone of its outcrops and its general characteristics make it easily recognisable over immense distances with the naked eye.

The series consists of thick calcareous sandstones, red marls and shales, and a little veined gypsum.

Middle Fars.—This series is a passage group with arbitrary boundaries, and like most compromises it functions usefully while possessing many disadvantages. Its upper boundary is generally accepted as the first strong sandstone above which no bedded gypsum occurs while its lower boundary is usually a sandy limestone marking the cessation of continuous bedded gypsum and indicating the close of the period of intense desiccation which characterised Lower Fars times.

The group comprises sandy detrital limestones, calcareous sandstones, blue and red shales and occasional beds of gypsum. It varies in thickness from a few hundred feet to 2500 ft. and more, according to the area and views of the observer.

Lower Fars.—The Lower Fars or gypseous group consists essentially of bedded gypsum with intercalated red and blue shales and marls, salt, anhydrite, and occasional beds of detrital and secondary limestones.

It varies in thickness from relatively small dimensions on old shore lines, contiguous with the older outcrops, to 5000 ft. and more in other areas, which may represent centres of great structural basins containing desiccative seas in Lower Fars times.

The salt and anhydrite are rarely met with in natural outcrops. This may be due in some measure to the solubility of the one resulting in concealment, and the liability of the other to change, by hydration, into gypsum. Evidence would indicate, however, that the salt and anhydrite are rather features of the lower horizons of the Lower Fars. They are invariably met with, sometimes in quantity, intercalated with gypsum and shales in drilling wells on the Maidan-i-Naftun oilfield and in remote outside tests areas.

The detrital limestones are an interesting group of rocks occurring as very occasional beds in the series. They are sporadic in development and when present show rapid lateral variation in thickness. Under the microscope they are shown to be composed of rounded and irregular worn grains of older limestones in a calcite matrix. Quartz grains are sometimes found in them also, and the size of the limestone grains varies very considerably in samples from different areas. The limestones have often undergone partial change by secondary methods to calcite and aragonite.

The Asmari Limestone Series.—The name Asmari Limestone is derived from Asmari Mountain, a long dark whaleback rising, as a barren and relatively unbroken limestone arch, to a height of 4500 ft. above sea level. The mountain which is a structural arch lies some twenty miles South-east of the Maidan-i-Naftun oilfield.

The Asmari Limestone Series is a uniform group of massive to thickly bedded, hard, compact, brown, or grey-brown limestone, frequently of great purity and displaying little evidence of being an oil container in its natural outcrops. Rare bands of hard calcareous shales appear towards the base of the group.

It is a series which is widespread in occurrence and maintains its individuality, with some variation in thickness, over enormous tracts of country.

In the Bakhtiari district it has an approximate thickness of 2000 ft. Specific measurements made show 1800 ft. at Dasht-i-Gul and 2200 ft. in the region of the Bard-i-Qamcheh gorge. In the Deh Luran district of Pusht-i-Kuh (where the names Deh Luran Series, and Kalhur Limestone, have also been applied) it is a little over 600 ft. in thickness but overthrust strike faulting has reduced the original dimensions. A feature of note in this area is the irregular replacement of part of the group by secondary gypsum. In some cases a thickness of 200–300 ft. of beds has been replaced in this manner. The change, which appears to take place from below upwards, gives rise to a dull white form of gypsum lacking the well stratified, compact appearance of Fars gypsum and containing undigested fragments of limestone. It may here be remarked that Prof. de Boetsh holds the view that the gypsum within the Asmari limestone is primary and represents an alternation of lagoon conditions with normal deposition of limestones during the Asmari period. In the Kazarun district, some 200 miles S.E. of the oilfields, the thickness approximates to that in the Bakhtiari region, while further South at Khamir, the Khamir Limestone, with which it is correlated, averages some 600 ft. in thickness. In the type area at Asmari Mountain only the upper 400 ft. of beds is exposed, while on the Maidan-i-Naftun oilfield the rock lies under a cover of impervious Lower Fars deposits varying in thickness according to the part of the field upon which drilling is undertaken.

The rock is highly organic, being a richly foraminiferal limestone in which the bulk of the remains are only revealed upon microscopic examination.

The Asmari Limestone has now been proved by petrographic, palæontological, and stratigraphical evidence to be the productive oil rock of the Maidan-i-Naftun oilfield.

Chemical analyses of samples from outcrops in various parts of Persia, and of samples of the oil rock from wells drilled on the oilfield, which reveal notable features on comparison, are dealt with in a subsequent section.

Spatangid Shales.—This is a small well-defined group yielding an Eocene fauna and underlying the Asmari Limestone conformably. It consists of bluish-green splintery shales containing occasional bands of compact, fine grained argillaceous limestone. The group has an approximate thickness of 250 ft., but varies in different areas. It is represented in the Khamir region by the Micropsis shales. (Upper Khamir argillaceous group.)

Upper Thin Bedded Limestones.—Underlying the Spatangid Shales conformably this group is composed of hard, fine-grained, thinly bedded limestone, greyish white to faint brown in colour.

The group contains thin shale bands and passes imperceptibly into the Spatangid Shales above.

In the Dasht-i-Gul region an arenaceous limestone and calcareous grit phase, with intercalated pink shales and conglomerate, is developed at the base of the group. A rich and varied fauna was collected from this lower development, including several varieties of Assilina, orthophragmina, and nummulites.

The group in the Dasht-i-Gul region, including the arenaceous phase at its base (600 ft.), has an approximate thickness of 1600 ft., while in the Deh Luran region it is 900 ft.

The Blue and Purple Shales.—This group, underlying the Upper Thin-Bedded Limestones conformably, is a uniform series of soft purple and blue shales, apparently non-fossiliferous.

A few thin limestone bands appear towards the summit, however, and these upon microscopic examination reveal orthophragmina and other Eocene forms. An approximate thickness of 1200 ft. was recorded. The group in general is probably Eo-Cretaceous in age—*i.e.*, Lower Eocene-Danian.

The Lower Thin-Bedded Limestones.—This group follows the above with apparent conformity. It consists essentially of white, hard, thin-bedded limestones, weathering cream to grey. Intercalated bands of fissile purplish-blue shales occur towards the summit. The group has an approximate thickness of 1200 ft. in the Dasht-i-Gul region.

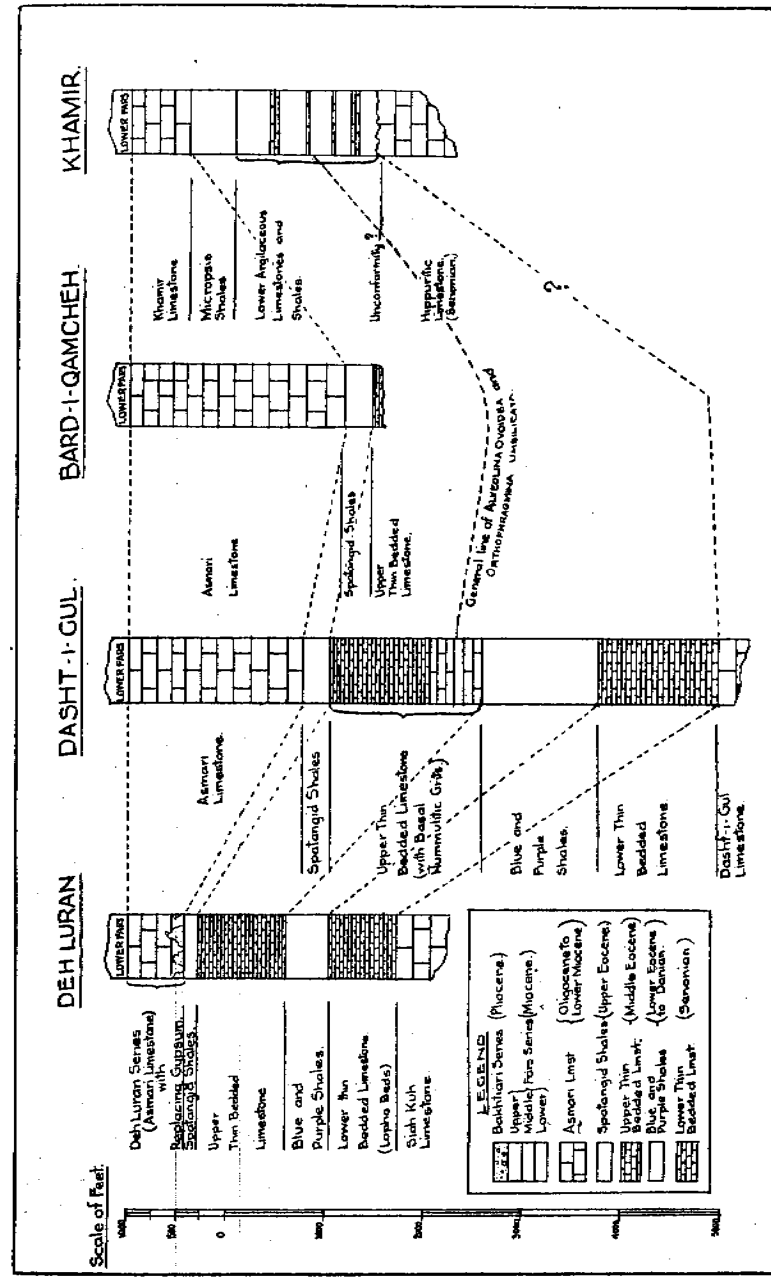
A rich Upper Cretaceous fauna was collected from the top of the corresponding group in the Pusht-i-Kuh region at Deh Luran, where the thickness is 700 ft.

The Dasht-i-Gul or Siah Kuh Limestone.—The lowest beds examined by us in the Bakhtiari country comprise a group of hard, compact, fine grained, massive to thickly bedded limestones which are brownish grey on a fresh fracture. The group, Cretaceous in age, is of unknown thickness, as only a few hundreds of feet are exposed in the core of a faulted fold at Dasht-i-Gul. In the Deh Luran district (Siah Kuh Limestone) a thickness of 500 ft. was noted but the base was not seen. The Series, which makes important topographic features, is tentatively correlated with the Hippuritic Limestone in the South at Khamir.

CORRELATION.

The attached table, embracing geological sequences in successive areas, represents a broad tentative correlation over a large part of Persia.

The correlation table is based primarily upon lithological and stratigraphical evidence collected during the past few years, and



GENERAL CORRELATION TABLE.

is in the main supported by palæontological determinations. It will be noted that the distinctive units chosen have maintained their individuality over extensive areas with little variation except in thickness. There are one or two features to which attention might be drawn. The groups in the Bakhtiari country are all represented at Deh Luran but have diminished in thickness.

In the South the groups are maintained with some variation in thickness, and slight variation in character below the Eocene shales—*i.e.*, the Lower Khamir argillaceous series, a group of argillaceous limestones and shales, embraces the thin-bedded limestones and the purple and blue shales of the regions to the North.

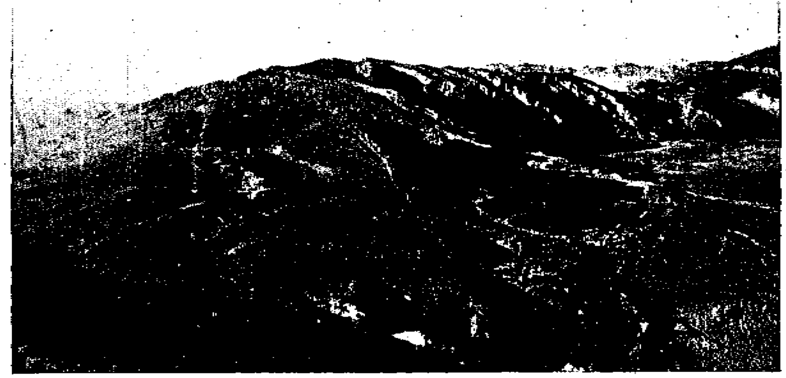
PALÆONTOLOGY.

During the last few years extensive fossil collections have been obtained and submitted to Dr. Douglas for examination. All identifications were made by him, and the author is indebted to him for the substance of the accompanying tables, which are based on his work.

There are several points to which attention might be drawn. The Asmari limestone and its equivalents in other areas have been given an age Oligocene-Burdigalian. This is a compromise between Field evidence and palæontological results. The lower part is probably Oligocene and the upper part Lower Miocene. This ubiquitous massive limestone, which is everywhere underlain conformably by Eocene shales and overlaid by Lower Fars gypsum, has yielded a fauna more typically upper Oligocene (Num. Intermedia) in the South, and more typically Lower Miocene (Lepidocyclina beds) in the North. It would appear probable that the Lower Fars-Asmari Limestone junction is not a true time-plane throughout Persia.

Mingling of the significant members of the two faunas has been found in intermediate areas. Dr. Douglas has suggested that conditions of desiccation bringing in Lower Fars deposits may have proceeded from South to North slowly, which offers a tentative explanation of the conditions observed.

Examination of a large number of rock slides prepared from the Asmari limestone shows a regular distribution of forms. The basal beds are characterised by lepidocyclina, cycloclypeus and amphistegina; the intermediate beds, forming the bulk of the sequence, by alternating zones of Heterostengina and Asmaria,

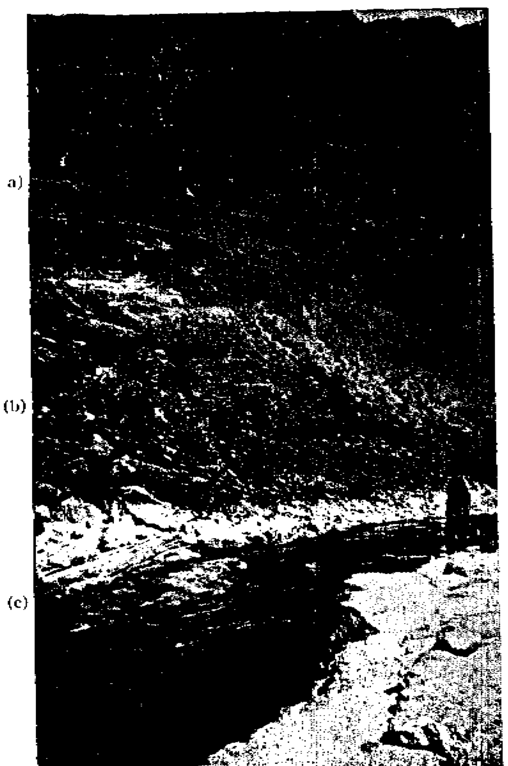


LOWER FARS ROCKS WITH DETRITAL LIMESTONES. ANDAKAH.

LOWER FARS OVERLYING ASMARI LIMESTONE. DASHT-I-QIL. BIKARZ AREA.

DEH LURAN SERIES (ASMARI LIMESTONE SERIES). SHOWING GYPSEOUS PHASE.

a)
(b)
(c)



ASMARI LIMESTONE (a) OVERLYING SPATANGID SHALES; (b) WITH UPPER BEDS OF UPPER THIN BEDDED LIMESTONES JUST EXPOSED; (c) BARD-I-QAMCHEH.

with alveolina and miliola; the upper beds with the alveolina-miliola fauna.*

The general ages of the groups are indicated in the attached tables :—

FOSSIL TABLE No. 1.

THE FOLLOWING FOSSILS HAVE BEEN FOUND IN THE FARS.

UPPER FARS. UPPER MIOCENE.	Gasteropods abundant. Miliola sp. Polystomella sp.	
MIDDLE FARS. MIDDLE MIOCENE.	Miliolina seminulum. " valvularis. " tricarinata. " linneiana. " alveoliniformis. " oblonga. " " Textularia agglutinans. " gibbosa. Spiroloculina excavata. " planulata. Lagena laevis. Globigerina conglobata. Polystomella craticulata.	Peneroplis carinatus. Pentellina chalmasi. Nodosaria cf. congobrina. " sp. Heterostegina depressa. Pecten (chlamys) multistriatus. Lithophagus lithophagus. Rotalia papillosa. Lamellibranch shells. Annelid tracks. Ostrea ?
LOWER FARS. LOWER MIOCENE.	Ostrea cf. multicostata. " virleti. " sp. multicarinata. " sp. Bulimina orata. Globigerina bulloides. Sigmoilina orata. Sphaeroidina bulloides. cf. Pecten soomrowensis. Venus (clausinella) sp.	

* Asmaria is a new and enigmatical form very prevalent in the Asmari limestone. In spite of its well-defined characters, experts are undecided as to whether it belongs to the animal or the vegetable kingdom.

Fossil Table 3.

	DEH LURAN.	*DASHT-I-GUL.*	*BARD-I-QAMCHEH.*	*KHAMIR.* (U. Argillaceous series.)
	Approx. 120—500 ft.	Approx. 250 ft.	Approx. 250 ft.	Approx. 450 ft.
SPATANGID SHALES. UPPER EOCENE.	cf. Balanophylla. Cardita aff. mutabilis. cf. Cyprina semilunaris. Globigerina bulloides. Pericosmus cf. nicaisei. Rotalia sp. Schizaster rimosus. Trochocyathus sp. Textularia sp. cf. Venus Gumberensis.		Ditremaster nux. Ditremaster (Hemiaster) forreatus. Spondylus cf. bifrons. Pericosmus. Schizaster.	Micropsis gagaria, Venustula.

	DEH LURAN.	DASHT-I-GUL.	MAIDAN-I-NAFTUN.	AS
	Approximately 600 ft.	Approximately 1800 ft.	Only 400 ft. tested by drill.	
ASMARI LIMESTONE SERIES. *OLIGOCENE TO BURDIGALIAN,*	*Macroscopic forms.* Arca aff. Burnesi, D'Arch. Cardita aff. Mutabilis. Cytherea aff. Incrassata. Echinolampas amplus, Fuchs. Echinolampas sp. Euspatangus cf. Rostratus, D'Arch. Ostrea pseudodigitalina, Fuchs. Pecten favrei, D'Arch. Pecten cf. Augustus, Fuchs. Psammechinus coronalis Lambet. Scutella paulensis, Agassiz. Turritella angulata, J. de C. Sow. Venus aff. Gumberensis, D'Arch. *Microscopic forms.* Miliolina (Abundant) Amphistegina cf. Hauerina D'Orb. Operculina. Heterostegina. Textularia. Lithothamnium ramosissimum. Ceriopora anomala, Abich.	*Macroscopic forms—2-300 ft. from summit* Flabellipecten expansus, Sowerby. Conus cf. antiqus, Lam. & ponderosus. Natica sp. Calliostoma (trochus) sp. *Microscopic forms.* *Upper Asmari Beds.* Miliolina cf. valvularis, Reuss. Pentellina sp. Spiroloculina sp. Nubecularia sp. Peneroplis sp. Textularia sp. Rotalia sp. Orbiculina adunca, Fichtel & Moll. *Upper Middle Asmari Beds* (approx.). Miliolids (isolated). Rotalia-like forms. *Middle Asmari Beds* (approx.). Miliolina cf. triquetra, Brady. Planispirina cf. celata, Costa. Spiroculina sp. Lithothamnium. *Lower Middle Asmari Beds* (approx.). Lepidocyclina cf. dilatata Michelotti. Cycloclypeus. Amphistegina. Asmaria nom. nov. *Lower Asmari Beds* (lowest 200 ft. approx.). Lepidocyclina sp. (abundant). Operculina sp. Heterostegina ? Globigerina. Polyzoa.	Alveolina cf. Melo, Fichtel & Moll. Alveolina cf. Ovulum Stache. Miliolina alveoliniformis, Brady. Miliolina seminulum, Zinne. Miliolina auberiana, D'Orb. Miliolina valvularis. Nonionina. Orbiculina ? Orbitolites ? Peneroplis. Polystomella. Rotalia. Textularia. Echinoid fragments.	Alveolina cf. Miliolina valv Miliolina alve Miliolina cf. t Textularia. Orbiculina. Nubecularia. Truncatulina. Planispirina c Polystomella. Reophax. Carpentaria. Asmaria, nom Lithothamniu Echinoid frag

N BEDDED LIMESTONE GROUP.

ossil Table 2.

...ri Mountain.		Bard-i-Qamcheh.	Kuh-i-Dira.	Khamir.
... 400 ft. exposed.		Approximately 2200 ft.	Approximately 1700 ft. exposed.	Approximately 600 ft.
o, Fichtel & Moll	Occur fre-quently	Alveolina cf. Melo.	Alveolina.	Astrocoenia ramosa Sow.
ris.		Heterostegina.	Miliolina alveoliniformis.	Carpenteria.
iformis, Brady.		Asmaria, nom. nov.	Miliolina auberiana.	Echinolampas cf. tumidopetalum, Gregory.
ietra.		Miliolids (abundant).	Miliolina valvularis.	Euspatangus cf. Formosus, de Loriol.
	occa-sional.	Amphistegina hauerina, D'Orb.	Peneroplis.	Exogyra persica sp. nov.
		Globigerina.	Polystomella craticulata.	Fistulana cf. egyptica, Opp.
		Peneroplis.	Rotalia papillosa.	Globigerina.
		Polystomella.	Textularia trochus, D'Orb.	Isastraea cf. irregularis, Duncan.
a costa.		Textularia.	Sphaeroidina bulloides, D'Orb.	Lithodomus sp. cf. Verbecki, Boettger.
		Sphaeroidina.	Nubecularia lucifuga, Defr.	Lithothamnium sp.
		Nonionina.	Sigmoilina.	Miliola seminulum.
		Ceriopora anomala.	Pentellina.	Miliola sp.
ov.	At lowest horizon exposed.	Rotalia.	Operculina (Heterostegina).	Nummulites intermedia, D'Arch.
		Lithothamnium ramosissimum.	Globigerina.	Nummulites fichtelis, Mich.
nts.		Nubecularia.	Carpenteria proteiformis, Goes.	Nummulites garansensis, Leym.
		Discorbina.	Amphistegina lessonii, D'Orb.	Nubecularia Boliviana.
		Truncatulina.	Lepidocyclina dilatata, Lem. & Douv (?)	Nubecularia sp.
		Miogypsina cf. Burdigalensis, Gumbel.	Nummulites intermedia, D'Arch.	Orbicella cf. Haimei, Abich.
		Echinoderm fragments.	Lithothamnium.	Ostrea cf. digitalina, Eich.
		Lepidocyclina dilatata var. elephantina.	Echinoid fragments.	Pachyseris murchisoni, Naime.
		Lepidocyclina dilatata, Michelotti.	" Cruciformis " nom. nov.	Phyllangia alveolaris.
		Lepidocyclina raulini, Lam & Douv.		Polystomella craticulata.
		Amphistegina lessoni D'Arch.		Pentellina sp.
		Cycloclypeus.		Pecten cf. Labadyei, D'Arch.
		Tinoporus.		Pleurotomaria sp.
		Pulvinulina.		Phasianella sp.
				Spines cf. Cidaris.
				Trochus cumulans.
				Turritella cf. Affinis D'Arch.

FOSSIL TABLE 4.

		DEH LURAN.	*DASHT-I-GUL.*	*BARD-I-QAMCHEH.*	*KHAMIR.* (Very argillaceous in this district.)
		Approx. 900 ft.	Approx. 1500 ft.	Less than 100 ft. exposed.	Approx. 1400-1500 ft. including Blue and Purple Shales.
UPPER THIN BEDDED LIMESTONE GROUP.	MIDDLE EOCENE.	Pericosmus sp. Schizaster sp. cf. rimosus.	(From basal grits). Assilina exponens. „ mamillata. „ spira. „ granulosa. Alveolina ovoidea. „ irregularis (nov). „ bulloides. Globigerina. Miliola cf. valvularis. „ cf. biloculina. Miliolina alveoliniformis. Lithothamnium sp. Nonionina sp. Nummulites gallensis. „ uroniensis. „ laevigatus. „ scabra. „ guettardi. Orthophragmina cf. umbilicata. Orthophragmina cf. nummulitica. Orbitolites sp. Pentellina sp. Rotalia sp. Textularia sp.	Algae (?) cf. Chondrites. Annelid tracks. Ditremaster nux. Pecten (chlamys) subdiscors. Pericosmus.	Alveolina ovoidea. Nummilites Biarritzensis. Orthophragmina Umbilicata. Globigerina sp. NOTE.—Upper thin bedded limestones and blue and purple shales are classed as one group in this region.

FOSSIL TABLE 5.

	DEH LURAN.	DASHT-I-GUL.	KHAMIR. (Lower Argillaceous Series.)
	410 ft.	1200 ft.	1400-1500 ft. including upper thin bedded limestones.
BLUE AND PURPLE SHADE GROUP. LOWER EOCENE. TO DANIAN.		Found in upper beds. Orthophragmina sp. Lithothamnium sp. Sphaeroidina dehiscens. Globigerina. Dentalium.	

FOSSIL TABLE 6.

	DEH LURAN.	DASHT-I-GUL.	KHAMIR.
	700 ft.	1200 ft.	
LOWER THIN BEDDED LIMESTONES (SENONIAN).	Baculites sp. Campanile. Cardium. cf. Echinoconus Carcharias. Goniopygus superbus. ,, cf. durandi. Hemipedina neemiae. Holectypus cf. inflatus. Hemiaster neomiae. ,, iranicus. Iraniaster cf. Douvillé. ,, Morgani. Membranipora sp. Natica sp. Ostrea (Lopha) Dichotoma. ,, ,, ,, var Persica. ,, ,, ,, ,, Rotunda (nov) ,, ,, sollier. ,, (Pycnodonta) vesicularis. ,, curvirostris. Orthopsis Morgani. Parapygus cf. inflatus. Pyrina orientalis. cf. Peterocera ornata. ,, ,, supercretacea. Pecten (Neithea) striatocostata. Pseudocatopygus longior. Pygurostoma Morgani. Plicatula hirsuta. Pleurotomaria cf. perspectiva. Spondylus subseratus. Salenia cossiaea. Terebratula Brossardi. ,, toucasi. Tricephalopora sp.	Globigerina.	

Fossil Table 7.

	DEH LURAN.	*DASHT-I-GUL.*	*KHAMIR.* (Hippuritic Lst.)
	500 ft. exposed.	200-300 ft. exposed.	1200 ft.
SIAH KUH LIMESTONE.	Nerinea cf. marrotiana. Radiolites. Trochosmilia compressa.	NO FOSSILS FOUND.	Caprinella doublieri (?) Durania laevis (?) ,, Mortoni (?) Sauvagesia praesharpei (?) ,, nicaisei (?) ,, Da Rio (?) (The Persian Hippurites are unusually large and many may be entirely new to science.)

Geological History and Tectonics.

Persia is pre-eminently a country of fold mountains. The grain of the country is north-west to south-east, and the fold lines and overthrust faults invariably have this orientation.

The Zagros arc and its associated ranges in Persia form part of a southern loop of the Great Alpine Himalayan belt which passes across Europe and Asia, and it is to this period of mountain building—the great Himalayan upheaval, in Tertiary times, that the system of folded structures and faults are due.

In considering the geological sequence, the absence of stratigraphical discordance over long geological periods, postulating continuous deposition and a period of relative quiescence from Senonian, to the end of Asmari times, is noted.

At the end of the Asmari period it is presumed the forces of upheaval manifested themselves and initiated the lines of subsequent elevation. The movement was obviously not very profound, but was sufficient to cause overlap and slight discordance between the Asmari limestone and the succeeding Fars deposits. At this period also climatic changes of a far-reaching character came into operation, resulting in a period of intense desiccation, during which the chemical deposits, salt, gypsum and anhydrite, of the lower Fars period were laid down. The order of deposition in a drying sea is considered to be gypsum, salt, other sulphates, other chlorides. It is understood that chemical proof is available that anhydrite instead of gypsum can be deposited in the presence of magnesium salts. Evidence of magnesium salts is abundant in analyses of water from Lower Fars rocks. Any disturbance of the salinity of the seas such as would be brought about by alternating periods of rainfall would cause an alternation of the salts in order of deposition, such periods of rainfall would also bring down sediments from which marls and clays would be formed. In areas sufficiently near to limestone masses, beds of detrital limestone would be laid down.

In the Maidan-i-Naftun oilfield the oil-bearing Asmari limestone is usually overlain by a zone of anhydrite ; this is succeeded by a zone of intercalations of salt, gypsum, rare anhydrite and shales. The salt zone is succeeded by further bedded gypsum, intercalcated red and blue shales and occasional detrital limestones.

The close of the period of desiccation is marked by the cessation of continuous bedded gypsum and the incoming of numerous detrital limestones, calcareous sandstones, and shales, with rare gypsum beds, of the Middle Fars sequence.

The Middle Fars is succeeded imperceptibly by the coarser, non-gypseous group of sandstones and marls of the Upper Fars period.

The history of Fars times is thus the gentle inception of the folding movement, a period of intense desiccation relieved at the end of Lower Fars times and followed by normal depositional conditions.

Of the boundaries of these desiccated inland seas of Lower Fars times little is known as geological investigations have not been carried sufficiently far afield. In South Persia, however, some fifty miles eastward of Bunder Abbas, at Minab, we have the Zindon Range which marks approximately the shore line of a Tertiary land surface to the east, and a Fars sea to the west. This ancient barrier of older rocks separated the highly saline Lower Fars seas in which a chemical series was laid down, from the more normal marine areas of Mekran and Persian Baluchistan where separate depositional conditions obtained.

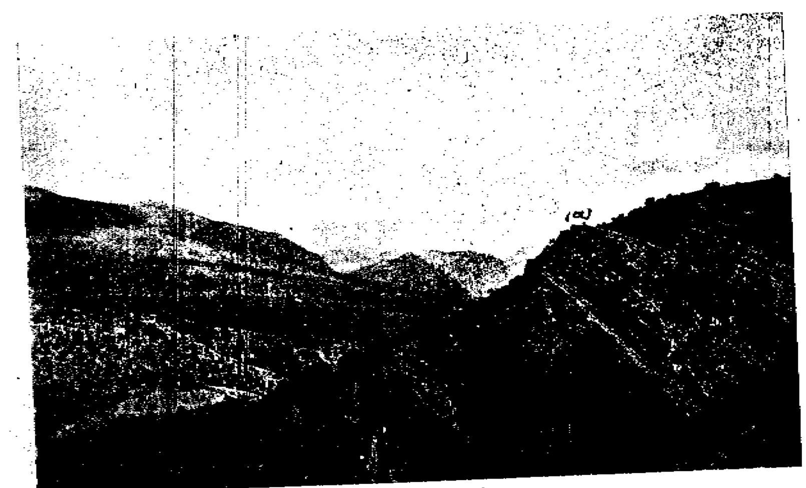
Folding movements may have continued slightly during Fars times, but, on the whole, the period was one of relative quiescence compared with the gigantic upheaval which took place at the end of the period. The close of the Upper Fars period is marked by intense orogenetic movements. It is the second phase of the earlier movement which defined geological trend lines at the end of Asmari times. Regional uplift on a grander scale obtained. The fold lines were emphasised, drainage lines steepened and concurrently with this, the newly-formed mountains were subjected to violent degradation. The enormous thickness of torrential conglomerates of the Bakhtiari period, lying unconformably on Fars rocks, bears witness to the severity of the processes involved.

This movement was probably continuous during Bakhtiari times, though with less violence, giving rise to the phenomenon of continuous unconformity which the Bakhtiari sediments display.

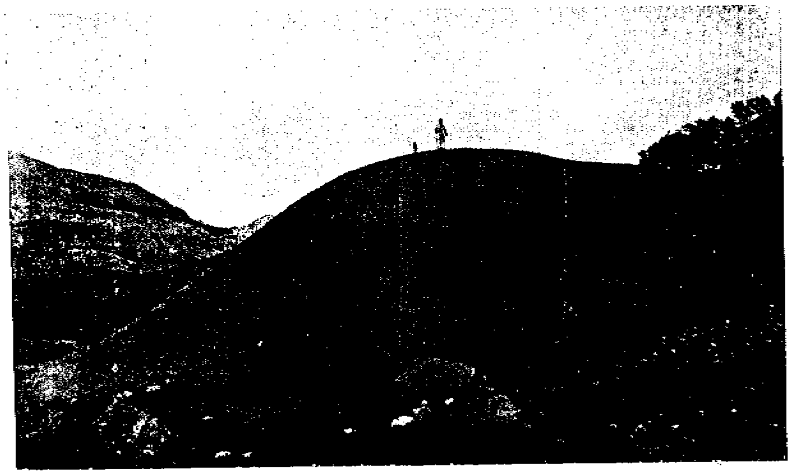
In post-Bakhtiari times the third phase of the movement, and probably the most severe, was initiated, leaving the stratal disposition more or less as it is to be found to-day. In this movement the rocks of the Bakhtiari period participated.

Earth movement appears to have been from north-east to south-west. In the higher mountains to the north-east the folds are more severe; passing south-westwards to the lower mountains the limestone ranges have frequently a somewhat steeper south-west limb and a gentle north-east limb; coming to areas where the softer Fars rocks are more prevalent we find the north-east limbs gentle and normal, while the south-west limbs are over-thrust and frequently obscured by transferred sheets of the upper fault blocks. The gypsum of the Lower Fars under the stress of folding forces has flowed, as a plastic mass, over the south-west limbs of numerous folds, and has frequently been driven over the younger Bakhtiari masses spreading over them amoeboid fashion, along thrust planes, but little removed from the horizontal. A

SEQUENCE DISPLAYING PART OF DEH LURAN SERIES (GYPSEOUS PHASE); SPATANGID SHALES (IN VALLEY IN FOREGROUND); UPPER THIN BEDDED LIMESTONES AND SIAH KUH LIMESTONE.



NUMMULITIC FACIES OF UPPER THIN BEDDED LIMESTONES A—A'. DASHT-I-GUL



PURPLE AND BLUE SHALES. DASHT-I-GUL.

SIAH KUH LIMESTONE. PUSHT-I-KUH

G. 2

traverse from the Persian Plateau, south-west, towards the plains shows the resulting structure clearly. Close folds are to be seen in the hard limestones of the north-east giving rise to gentler folds to the south-west. When the softer gypseous formations are reached the overthrust south-west limbs are manifested, while as we proceed further, even the softer rocks are less plicated until the gentle domes of such places as Kuh-i-Bang near Bushire indicate the last ripples of the spent forces.

Having dealt with the tectonics in general, a more detailed study of a particular area will follow when considering the structural features of the Maidan-i-Naftun oilfield.

In concluding this study of the geological history and tectonics of the region it may be mentioned certain structures characteristic of the southern part of the Persian Gulf. On Kishm Island, Henjam Island, Hormuz Island and other Gulf islands as well as on the Persian mainland in the region of Lingeh and Bunder Abbas, well-defined salt domes occur. The scope of this paper and the space available forbid more than a passing notice of these interesting structures.

The sequence of folding movements is shown in the following Table :—

Tabular representation of Geological movements.

	Pleistocene and recent deposits.	
3rd Phase of Himalayan upheaval.		Final grand upheaval at close of Bakhtiari Period.
	Bakhtiari Period. During which conglomerates and sands of non-marine origin were laid down under continued earth movement.	
2nd Phase of Himalayan upheaval.		Commencement of first big upheaval which continued throughout Bakhtiari times.
	Fars Period. A period of relative quiesence during which slight and gradual uplift—a continuation of the initial earth movement—may have occurred. Argillaceous deposits and chemical precipitates were laid down under conditions of intense desiccation relieved at the end when the older Fars rocks were laid down.	
1st Phase of Himalayan Movement.		Initiation of earth movement.
	Asmari Period. During which a great thickness of massive limestone was laid down.	

ORIGIN OF THE OIL.

Oil indications in Persia characterise rocks of all geological ages from the pre-cretaceous to pliocene. They are probably most abundant in the clastic and secondary limestones of the Lower Fars, as at Maidan-i-Naftun and Naft Khaneh, and near the Lower Fars—Asmari boundary, as at Dasht-i-Qil. Near Malamir they occur in the Bakhtiari series, while in the Deh Luran-Dalpari region they characterise most of the rocks from the Lower Fars to the Siah Kuh limestone. At Imam Hassan they occur in cretaceous shales. At Dareh-i-Qil they occur near the Middle-Lower Fars junction, and near Champeh in the Persian Gulf they occur along the plane of intrusion of a saline plug.

They are usually found in limestones, though they have often been observed in gypsum, sandstones, conglomerates and shales.

The origin of the oil in Persia is a matter requiring careful deliberation. Evidence is gradually accumulating which will need analysing and marshalling; but, above all, premature judgment is to be avoided. There are two alternative views:—

(*a*) An indigenous origin in the Asmari limestone.

(*b*) A Cretaceous origin followed by migration into the Asmari limestone.

The Upper Fars has also been suggested as a source of origin, but this view has not at present much evidence in its favour.

Initially it would be unscientific to neglect to search for the origin of the oil in the rocks at present containing it, unless it can be proved that the reservoir rock is incapable of producing the necessary organic matter.

It must be stated that the Asmari limestone or its equivalent in other areas provides, together with overlying Fars limestones, the most abundant and the most prolific oil-shows in the country, and at Maidan-i-Naftun the Asmari limestone yields oil in enormous quantities. It is a highly organic rock composed almost entirely of foraminiferal remains, and bulk for bulk is uniformly far richer in organic matter than any other formation examined.

The Asmari limestone is underlain by a thick body of blue shales, which would function as an impervious series obstructing migration from below, and is overlain by an impervious cap of Lower Fars gypsum, shales and anhydrite.

The alternative view that the oil originated in Cretaceous shales is due a full examination. There are many difficulties, however, in the way of its acceptance.

If it is a matter of evidence of association, then the indigenous theory of origin in the Asmari limestone has much more in its favour. Apart from this, however, there are grave objections to the theory on other grounds. If the oil of the Maidan-i-Naftun oilfield originated in Cretaceous rocks, by what means did it reach its present position? It has been suggested that the migration might have taken place along Tang lines, presumed super-fissures; but this view, against which much evidence is arrayed, is not generally accepted by geologists. There remains the method of direct upwards migration across the intervening sediments from Cretaceous shales to the Asmari Limestone. Difficulty is found in appreciating the *modus operandi* involved in this passage across some thousands of feet of thin-bedded limestones and shales, and we are entitled to ask, if this hypothesis is postulated, by what means the upward migration, through reputed impervious strata, was finally arrested in the rocks in which the oil is found at the present day? It is also anticipated that the oil in the Asmari Limestone would bear evidence as to its peregrinations, but in the many analyses of Persian oils no such evidence, so far as the author is aware, has been revealed.

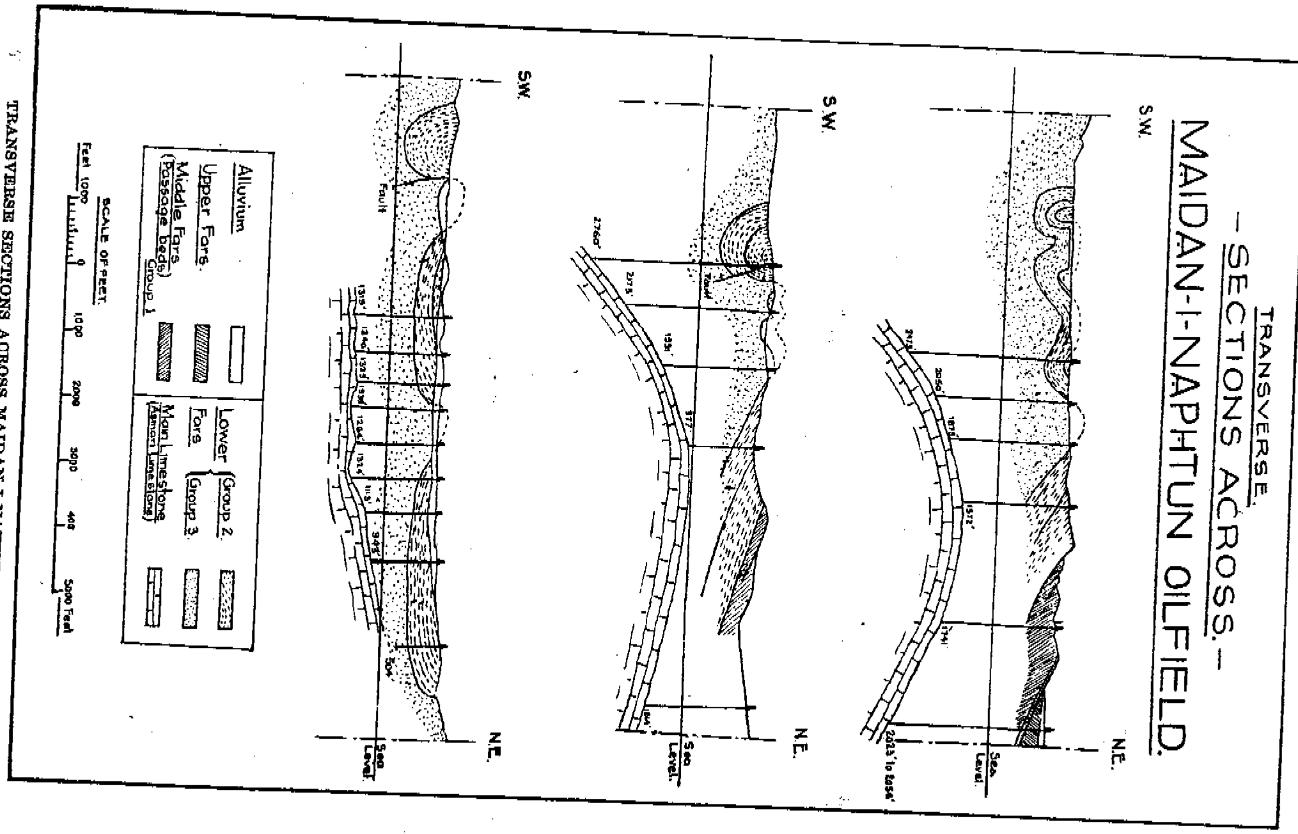
In postulating an indigenous origin for the oil in the Asmari Limestone at the Maidan-i-Naftun oilfield, the author does so without prejudice to the possibility of a Cretaceous origin for Cretaceous oil, and the chances of successful exploitation of such sources.

In the above the organic origin of the oil has been treated as axiomatic and the remarks have been chiefly concerned with this aspect and questions of migration. It may be stated, however, that if there is anything in the Limestone, gypsum, and hot water theory of the origin of petroleum, Persia offers a good field for study. For the benefit of supporters of this view it is noted that the Lower Fars limestones upon the oil field display secondary changes to calcite and aragonite. The presence of considerable aragonite, which postulates the action of heated water, is significant. Some of the author's colleagues have drawn attention to the striking association of these minerals with oil in other petroliferous areas in Persia.

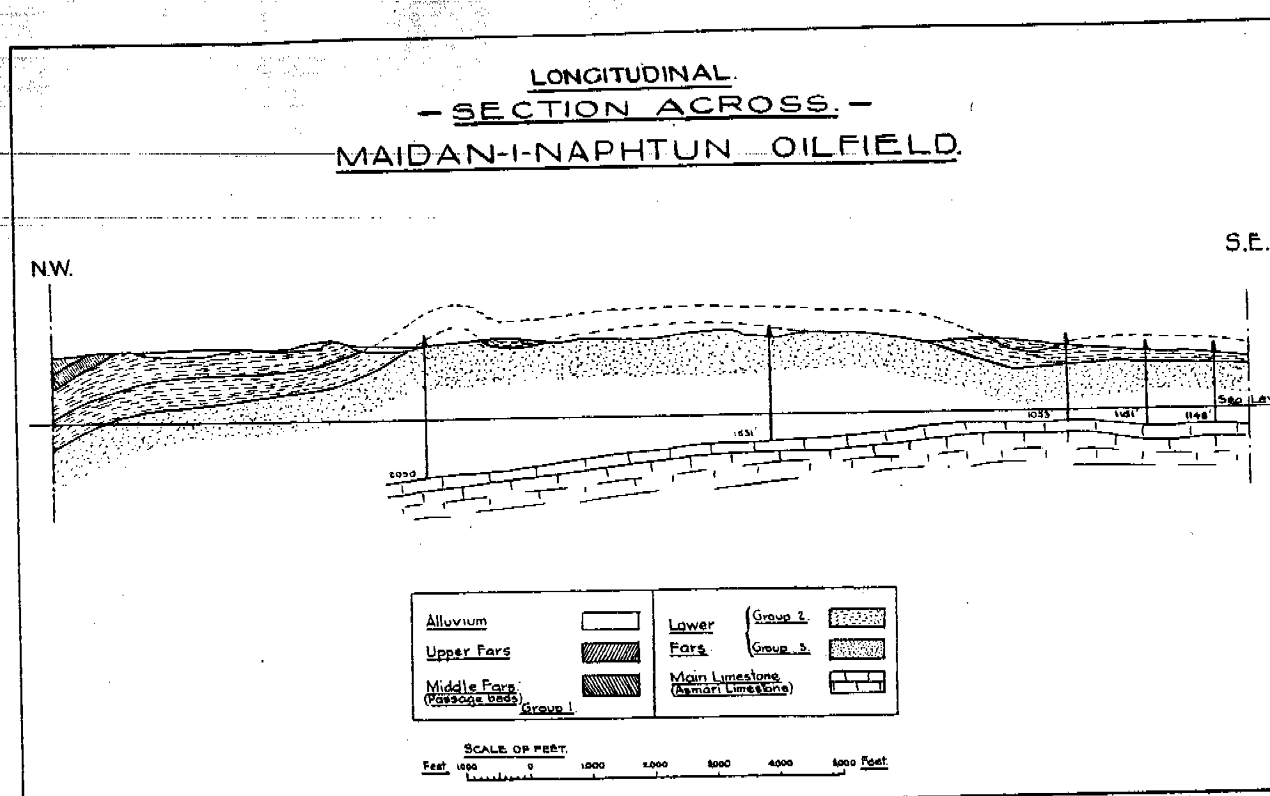
THE MAIDAN-I-NAFTUN OILFIELD.

The richness and sustained production of this remarkable oilfield make it one of the most important of the world's petroleum resources. It is situated approximately 140 miles N.N.E. of the Port of Abadan, on the Shat-el-Arab, to which place oil is transported by pipe-line.

The boundaries of the productive area are being continually widened by prospect wells, but the extent of its untapped reserves is still unknown. Production figures, which have already been published, representing the volume of oil extracted from a rela-



TRANSVERSE SECTIONS ACROSS MAIDAN-I-NAFTUN OILFIELD.



LONGITUDINAL SECTION ALONG MAIDAN-I-NAFTUN OILFIELD.

tively small number of wells, indicate the richness of the territory. These figures, however, are merely a measure of the progress of pipe-line, refinery and tanker construction, which afford at present the only limits to productivity:—

TOTAL ANNUAL PRODUCTION—MAIDAN-I-NAFTUN.

Year.	Crude Oil Gallons.	Equivalent Tons.
1912–13	21,896,714	82,629
1913–14	74,155,141	279,831
1914–15	101,889,665	384,489
1915–16	121,785,808	459,569
1916–17	174,544,131	658,657
1917–18	243,196,050	917,721
1918–19	293,199,729	1,106,414
1919–20	367,104,918	1,385,301
1920–21	468,693,795	1,768,656
1921–22	625,066,465	2,358,741
1922–23	788,209,802	2,941,081

Geological Features of the Oilfield.—Previous reference has been made to the general simplicity of the stratigraphic succession and the bold fold lines of the country. While this statement of first principles remains valid a detailed study of any particular area in Fars rocks, in relation to petroleum exploitation, involves the application of all the aids to geological inquiry.

The Maidan-i-Naftun Oilfield comprehends an anticlinal area in Fars rocks with a general axis running N.W.—S.E. Over the main area of the fold the Lower Fars or gypseous series is exposed. The North-Eastern flank of the anticline is relatively gentle, while the South-Western flank is completely obscured by an overthrust, the Tembi fault. The Lower Fars gypsum has been driven over the steep limb in the manner indicated in our study of tectonics.

It is one of the many anticlinal areas in Bakhtiari country displaying similar superficial characters in regard to stratigraphy and structure, but which lack the abundant oil seepages characterising the Maidan-i-Naftun area.

The main anticline is affected by a complicated system of minor folds. A glance at the detailed sections across the field will make this clear. These minor structures are open and simple in the central part of the area where they lie in relative proximity to the solid resistant Asmari mass below. To the South-West they become more compressed until both limbs achieve verticality. A zone of isoclinal and recumbent folds, with minor reversed faults follows, until the main thrust, the Tembi fault, is reached. The axes of these minor folds in the isoclinal region conform with the general strike line of the main anticline, but in the more openly folded, central part of the area they are often tortuous.

These plications of the Lower Fars series, which are probably the result of folding forces acting upon a soft and non-resistant series, are not reflected in the rigid Asmari massif below.

The view has been put forward that the minor folds may be due to a conversion of anhydrite to gypsum. The hydration of anhydrite involving an expansion, variously estimated at 25—50 per cent., would be capable of considerable local effects. The theory would, however, postulate that a large quantity, if not all, the Lower Fars gypsum was originally deposited as anhydrite. A zone of anhydrite is found overlying the main limestone in most wells, but its presence appears to be independent of distance from a possible zone of weathering. It is found both in shallow and in deep wells. While the possibility of chemical change from anhydrite to gypsum, resulting in local structures, cannot be denied, it is considered that the crumpling forces of post-Bakhtiari earth movements offer an explanation more acceptable, and more in accord with the general geological features of the problem.

The Lower Fars series overlies a broad Asmari massif of anticlinal character. Drilling results indicate that it has a gentle North-East flank and a slightly steeper South-West flank. It also pitches gently to the North-West.

A discordance between surface features in Fars rocks and the underlying Asmari limestone is clearly shown in the sections. It has the appearance of strong unconformity, but this view is misleading. Throughout Bakhtiari country the junction between the two groups at outcrop is a conformable one, and conformity with overlap probably represents the true relation of the groups. The effect of unconformity is due partly to minor folding in which the Asmari limestone has not shared. It is also partly due to proved lenticularity and to overlap of deposits. The nature of the junction—a soft gypseous series with a limestone mass—also offers excellent facilities for the development of slip planes during folding. Mr. H. G. Busk has recently put forward the view, with supporting evidence, that the junction is a slip or thrust of this character, a view that deserves the fullest consideration.

The Asmari limestone is met by the drill in most wells at depths from 1000—3000 ft., according to their positions relative to the anticlinal Asmari mass below. Indicators of the approach to the oil rock are usually slight gas or oil, and the presence of white powdered anhydrite in the drilling samples.

The Productive Oil Rock.—There are copious oil seepages on the Maidan-i-Naftun oilfield which almost invariably exude from the detrital limestones of the gypseous series. Oil shows are also found in Fars rocks above this horizon.

The detrital limestones of the Lower Fars series were for many years considered to be the productive oil rocks of the field. Investigation, however, during the last few years has conclusively proved that this is not the case. The microscope has revealed the oil rock to be, not a detrital limestone, but a highly foraminiferal rock of non-clastic character identical with the rock at Asmari Mountain. Stratigraphical knowledge, and drilling evidence, moreover, disallow the postulation of any other view. The supersession of the detrital limestone theory and the proof that the productive oil rock is the Asmari limestone has changed the outlook of petroleum geology relative to the oilfield, and a very much larger productive area is assured than was formerly thought to be the case.

Dolomitisation.—The Asmari limestone, which has been noted under stratigraphy to be hard and compact in natural outcrops, has been rendered a porous reservoir rock by dolomitisation and other agencies.

Dolomitisation is the change by metasomatic processes of a limestone comprised mainly of calcium carbonate to a rock composed of calcium magnesium carbonate. The change, theoretically, involves a reduction in volume of over 12 per cent. and a fissured, cavernous, or loose rubbly structure is a frequent result of the process. It is generally regarded that magnesium chloride is the active substance in solution which establishes this change, and even in our present-day analyses of Lower Fars waters from wells a high magnesium chloride content is registered.

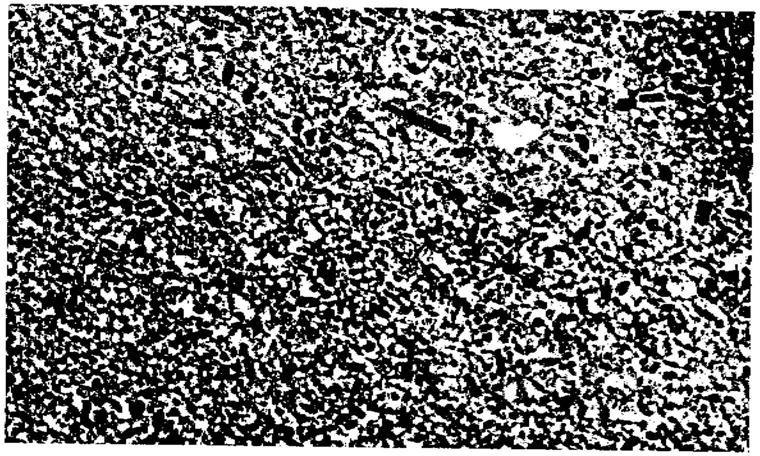
Dolomitisation has affected the Asmari limestone from end to end of the field, as the analytical tables will show. In the region of the Central Maidan at Naftun the rock is a pure dolomite, the magnesium and calcium constituents being present in almost correct molecular proportions. Other analyses show dolomitisation in varying degrees, but it yet remains to be seen whether the degree of dolomitisation will prove a measure of productivity in any particular well, as has been claimed in some American fields where a limestone reservoir obtains.

The author is indebted to Professor Hugo de Böckh for a valuable discussion on the subject of the dolomitic and cavernous nature of the Asmari limestone. He has indicated the probability that under the lagoon conditions obtaining at the end of the Asmari period the limestone was attacked by magnesium chloride and magnesium sulphate in solution resulting, by complex processes, involving the leaching out of calcium carbonate, in the formation of the cavernous dolomite termed "Rauchwacke," which is frequently associated with gypsum and salt formations. The resulting dolomite, it is claimed, apart from any porosity induced by dolomitisation alone, is thereby rendered highly porous, or even cavernous, by the changes involved.

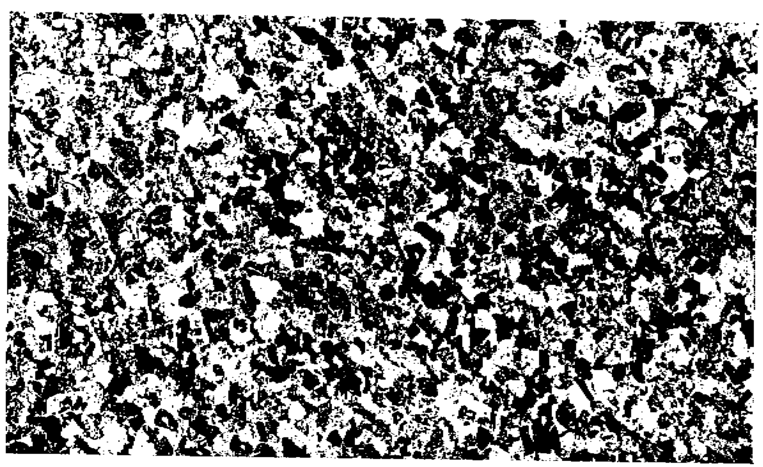
The following tables display analyses of the Asmari limestone

HIPPURITIC LIMESTONE (RIGHT). KHAMIR.

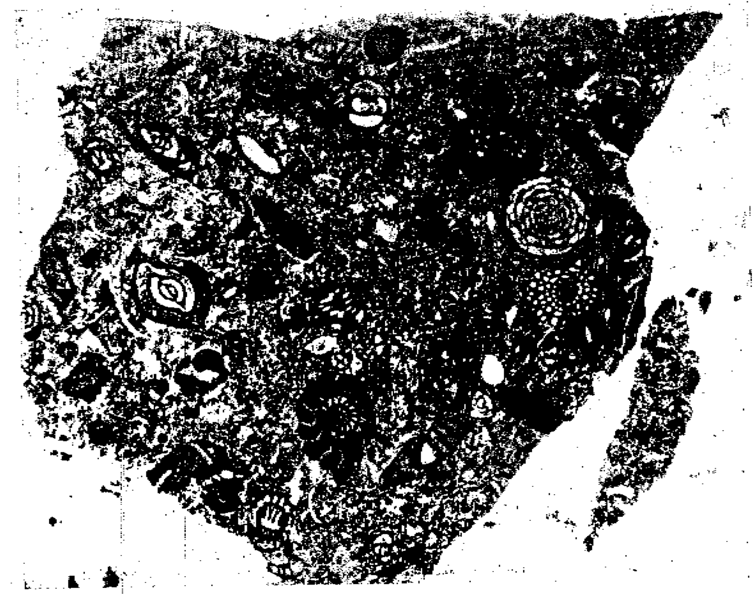
SALINE PLUG OF HORMUZ SERIES (LEFT) INTRUDED THROUGH UPPER FARS (RIGHT). NAMAKDAN, KISHM ISLAND



PHOTOMICROGRAPH OF DETRITAL LIMESTONE. LOWER FARS SERIES. MAIDAN-I-NAFTUN.

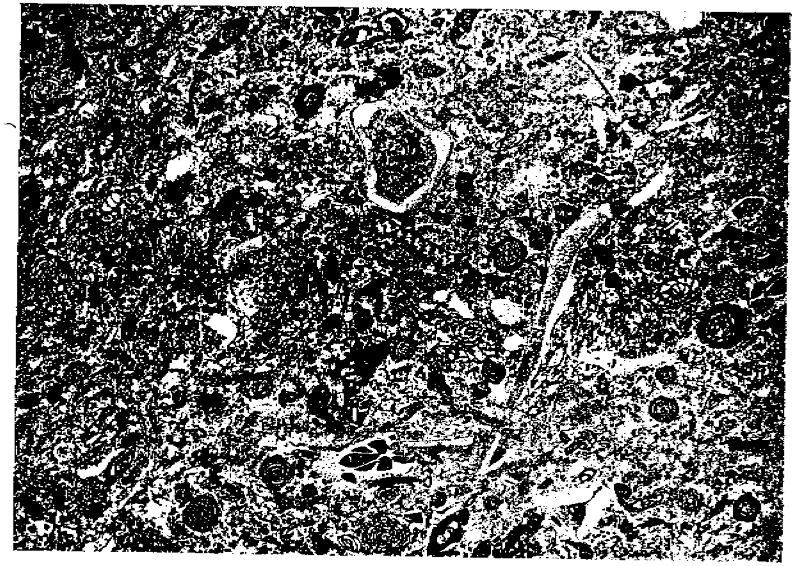


PHOTOMICROGRAPH OF SANDY DETRITAL LIMESTONE. LOWER FARS SERIES. DAREH-I-QIL.

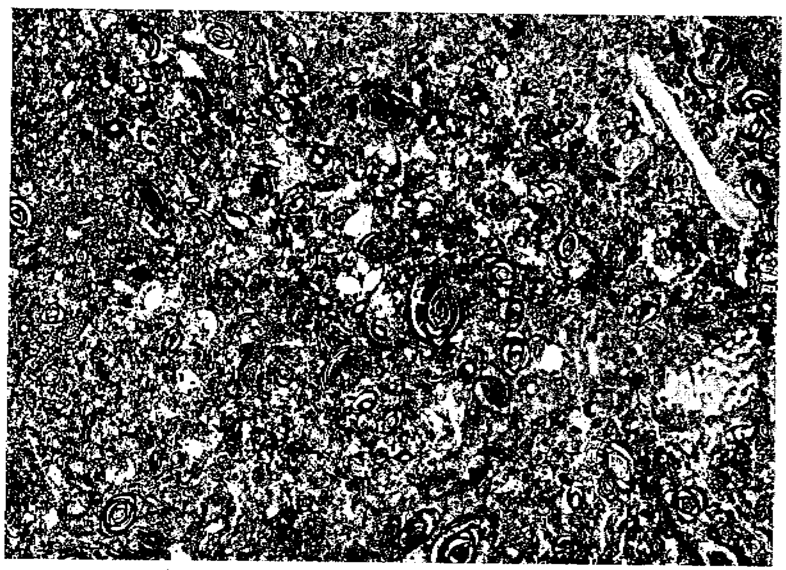


PHOTOMICROGRAPH OF OIL ROCK (ASMARI LIMESTONE). MAIDAN-I-NAFTUN. DISPLAYING ALVEOLINA CF. MELO AND MILIOLINE FORMS, ETC.

PHOTOMICROGRAPH OF OIL ROCK (ASMARI LIMESTONE). MAIDAN-I-NAFTUN. DISPLAYING MILIOLINE FORMS, ETC.



PHOTOMICROGRAPH OF ASMARI LIMESTONE ; UPPER BEDS. ASMARI MOUNTAIN. DISPLAYING ALVEOLINA CF. MELO, MILIOLINE FORMS, TEXTULARIA, ASMARIA, ETC.



PHOTOMICROGRAPH OF ASMARI LIMESTONE. UPPER BEDS. DASHT-I-GUL. DISPLAYING MILIOLA CF. VALVULARIS, TEXTULARIA, PENEROPLIS, PENTELLINA, ORBICULINA, ADUNCA, ETC.

made at outcrop, for comparison with analyses of the oil-bearing Asmari limestone at Maidan-i-Naftun. It may be mentioned here that some analyses of the Asmari limestone at outcrop, from the Bikarz area, where samples were collected in the vicinity of extensive oil seepages were, unlike those in the first table, highly dolomitic.

ANALYTICAL TABLES.—1.

Analysis of four samples of the Asmari Limestone from Outcrops.

	Asmari Mountain.		Bard-i-Qamcheh.	
	1.	2.	3.	4.
	%	%	%	%
Moisture	·05	3·74	·06	·12
Silica	4·21	2·70	4·19	3·19
Iron and Aluminium	·64	2·75	3·88	1·19
Calcium Sulphate	—	·42	1·53	·53
Calcium Carbonate	93·35	87·28	88·11	94·36
Magnesium Carbonate	1·72	3.54	2·27	·19

ANALYTICAL TABLES.—2.

Analyses of samples of the oil-bearing Asmari Limestone.

	Maidan-i-Naftun (8 Wells).			
	1.	2.	3.	4.
	%	%	%	%
Moisture	·73	·51	·40	·54
Bituminous Matter	1·46	·40	·79	·66
Silica	4·83	3·95	3.34	4·85
Iron and Aluminium	2.22	2·85	1·55	2·94
Manganese	·83	·66	·27	1·37
Calcium Sulphate	·34	1·33	1·15	1·42
Calcium Carbonate	48·94	49·09	49·97	47·90
Magnesium Carbonate	40·65	41·21	42·52	40·32
	5.	6.	7.	8.
	%	%	%	%
Moisture and Organic Matter	·98	·41	·60	4·55
Silica	3·58	5·75	2·90	8·49
Iron and Aluminium	1·80	2·68	1·40	2·85
Manganese	·19	·12	—	—
Calcium Sulphate	5·41	16·86	3·40	19·96
Calcium Carbonate	50·86	43·71	79·50	42·72
Magnesium Carbonate	37·15	30·34	12·20	21·43

In one particular well a series of four analyses were made from drilling samples of the oil rock selected at different depths. They revealed a decrease in the dolomitic content from above downwards.

In concluding this study of the Oil-Field region it may be stated that the Maidan-i-Naftun area has never been troubled by water, it has never registered a dry hole, and the limits of the productive area have nowhere yet been proved, though a continuous policy of marginal extension by test wells has been in operation for several years.

DISCUSSION.

The President said he was sure the members would agree that they had listened to a very interesting paper full of valuable information set out in an exceedingly clear manner, and he had no doubt it would lead to a valuable discussion. The question of the origin of petroleum was touched upon, and looking at the list of fossils and the micro-photographs it appeared to him that they might have some bearing on that subject.

Dr. Hugo de Böckh, in opening the discussion, said that it had not been his intention to speak, as he was only a visitor, but, having been asked, there were one or two comments which he wished to make. The paper touched on many scientific questions, but to discuss them all would take far too much time. It had recently been his privilege to spend some time in Persia, and he saw there a very characteristic feature. In Persia, a Miocene reservoir rock, containing great quantities of hydrocarbons, is overlain by the Lower and Middle Fars Series which contain gypsum and also, in addition, some hydrocarbons.

Hoppe-Seyler has demonstrated the following reaction:—

$$CaSO_4+CH_4=CaCO_3+H_2S+H_2O.$$

If pulverised gypsum is put into a tube and methane passed through it, a gas is obtained which already contains H_2S. In this way gypsum is a very changeable rock.

If folding, faulting, or erosion open up the way for hydrocarbons they will come in contact with and change the gypsum. H_2S, on becoming partially oxidised, gives off native sulphur. In the pluvial period of the Diluvium there was much water and strong erosion.

The escaping gases agitated the water which contained sulphates, amongst them magnesium sulphate.

Complicated interaction set in, resulting in the various rocks of so-called "secondary action."

Mr. Richardson has referred to aragonite occurrences. It has been pointed out that all the waters of the Lower Fars contain magnesium sulphate. Having magnesium sulphate in solution and a temperature exceeding 29° C., aragonite, and not calcite, is deposited. In most other countries the deposits which are overlying and containing rocks saturated with hydrocarbons do not contain as much gypsum as those in Persia, so that there is no possibility of such interactions taking place.

Hydrocarbons do not attack clays, marls, or sandstones, and, according to the prevailing conditions, we get mud volcanoes, gas shows, oil shows, H_2S, and native sulphur. In Persia we find

"secondary action" resulting in different types of sinter deposits. It can be observed clearly how these sinter deposits are principally confined to diluvial terraces formed during the pluvial period. Of course, the waters circulating in the rocks would contain, more or less, H_2S, which could act on $CaCO_3$. Calcium hydrosulphide would be formed, and calcite, gypsum, and sulphur are then deposited.

Another question which was touched upon by Mr. Richardson is the porosity of the dolomitised Main Limestone. This porosity is due not so much to dolomitisation itself as to the leaching out of $CaCO_3$ during dolomitisation, or, in certain cases, at a later stage. It is often said that dolomitisation results in a porous rock, owing to the fact that by taking two molecules of $CaCO_3$ and replacing one molecule by $MgCO_3$ we obtain the double salt dolomite, $CaMg\ (CO_3)_2$, which will occupy as much space as one $CaCO_3$ molecule plus one $MgCO_3$ molecule. This would mean 12·2 per cent. less space. In this calculation the hexagonal modification of $CaCO_3$—calcite—is taken, but we have the more unstable modification of $CaCO_3$—aragonite—forming the shells of some animals. As aragonite has a greater specific gravity, the "shrinkage" would be only a half. Moreover, we know of dolomites—dolomitised limestones—which are quite dense rocks, and it must be pointed out that in the Alps and Carpathians, for instance, magnesites occur which have been formed into carboniferous limestones. They should show a greater porosity, but they are absolutely compact, dense rocks. All the points connected with the process of dolomitisation have not yet been cleared up, but dolomite can be formed in different ways. In many cases we have not only a simple replacement of one molecule of $CaCO_3$ but also very complicated interactions, and the formation of the double salt dolomite can take place even by adding material to $CaCO_3$.

The dolomitised Main Limestone was formed under lagoonal conditions and is often associated with gypsum, as can be proved in several sections.

Very complicated interaction takes place in the concentrated sea water of lagoons. It will not be the $MgCl_2$ which acts but the magnesium sulphate. Moreover, ammonium salts will play an important rôle. According to Murray and Irvine warm sea water contains much more ammonium salts than cold sea water, and we must expect warm sea water in lagoons where gypsum even is deposited. CO_2, derived from decaying organic material, will also be present.

It would be very interesting to study the question on lines similar to those of Van't Hoff's work on the different salts of the Permian salt deposits.

Dolomites connected with gypsum and salt beds display a characteristically cavernous structure. There is a framework of more or less dolomitised limestone, and between this framework are cavities, the walls of which are covered with dolomite crystals.

The framework does not fix the true porosity, and, as the late Mr. Whealler has shown, in accordance with the action previously mentioned, this framework would frequently have a porosity of only 1–7 per cent., and only half of this in the case of aragonite.

A good cavernous reservoir rock—such as the German "Rauchwacke"—is the result of the leaching out by solution, which takes place in lagoons, of certain parts of the limestone.

The transformation of parts of the limestone into dolomitic limestone, or sometimes into pure dolomite, is only one part of the processes resulting in a cavernous rock.

Mr. E. H. Cunningham-Craig said he desired, in the first place, to take the opportunity of congratulating the author upon his very comprehensive and well-balanced paper. He had shown a masterly grasp of the matter. He could confirm almost everything the author had said. Personally he remembered very well that when he first mapped the Maidan-i-Naftun field it was quite obvious that the minor structures that were seen at the surface would not continue to any great depth. It became perfectly obvious that a solid hard mass was lying underneath on the north-eastern side of the field, and probably at a very much greater depth on the south-western flank. He made up his mind that that hard mass could be nothing but the Asmari Limestone, but he did not realise that the Asmari Limestone would be the reservoir oil rock, that it would have been honeycombed by secondary changes, and so made into one of the most prolific oil rocks that was known. He was more concerned at that time with the detrital limestones, which were also affected very seriously and were made very strongly cavernous. He thought perhaps the author had not attached quite sufficient importance to those detrital limestones, which occurred very sporadically. In some places they were found very thick, and they then thinned out rapidly in each direction, passing into calcareous muds or even calcareous sands, thinning and finally disappearing. The existence of that limestone meant that some limestones in the immediate vicinity—he said "immediate vicinity" because they were so locally developed—were being denuded at the time the Fars Series was being formed. If a limestone was being denuded it was most likely that the limestone was the Asmari Limestone. Therefore, in the places in which the limestones were found very thick and very locally developed one might expect to find the surface of the Asmari limestone underneath considerably affected by denudation; and quite possibly that denudation had enabled the solutions which had caused those complicated secondary actions to attack that limestone the more rapidly. In that connection he desired to mention a curious point which the author had not mentioned. Some six or seven years ago he was sent four specimens of limestone, one of Asmari limestone and three which were labelled as the "main oil rock" from three different wells in the field. The Asmari limestone was fairly typical, showing the fossil forms which had been shown on the slides that evening. Another specimen was a highly crystalline and very cavernous dolomite, which consisted mostly of crystals of dolomite. The other two specimens were fine detrital limestones. Whether they occurred just on top of the Asmari limestone or not he did not know; he did not know from what depth they came in the well, but they were sent to him as the "main oil rock" from those three different wells. He thought it quite possible, therefore, that, in certain localities at any rate, on the top of the denuded mass of Asmari limestone, considerable deposits of detrital limestone might occur also, which, of course, would be dolomitised as well as the underlying Asmari masses. The author had very wisely stated with regard to the question of the origin of the oil that it could not yet be determined. Various theories existed as regard its origin, one which had not been mentioned being that oil was also indigenous to the Fars Series. That, he believed, was a point which Prof. de Böckh had not overlooked. Oil was to be found in a great many different horizons in Persia, and he believed they would certainly find oil indigenous to the upper Fars in other parts of Persia. He looked at the question in the following way. Although oil might have been formed in Cretaceous rocks it might have migrated, because it could migrate with the greatest ease if it were given sufficient time. Oil could migrate through limestone without leaving the slightest trace. It was only when colloidal beds were met with that the oil or part of it was seized upon; and that part which went through became filtered and therefore gave evidence of its migration. Given sufficient time, oil would migrate to enormous distances through rocks like limestone, and even shales and sandstone and anything that was not markedly colloidal. Every oil-shale field in the world gave evidence of that kind. The fact that oil was found in the Asmari limestone he looked upon simply as showing that the limestone when it was affected by secondary action was the best reservoir; that oil wherever it came from would always find the best reservoir and would stay there until it was washed out by water, or extracted by man, or removed in some other way. Although he did not wish to dogmatise upon the origin of the oil at Maidan-i-Naftun, he considered that it was the reservoir that must be looked for first, and when there was a reservoir in the Asmari limestone it was known that it made an exceedingly prolific oil rock.

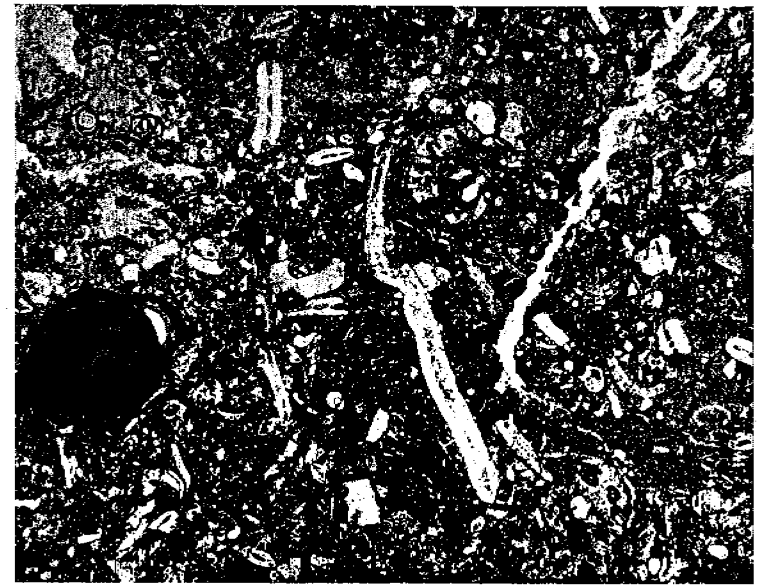
Mr. S. Lister James desired to identify himself with the very appreciatory remarks Mr. Cunningham Craig had made in regard to the paper. He thought it could be stated that the author himself deserved the credit for making the most important discovery of the identity of the main reservoir rock, the Asmari limestone. As had already been stated, it was previously thought that the main reservoir rock was one of the detrital limestones similar to those exposed at the surface, and in the early days there was no occasion to look further for the main source. Only the results of a very few wells were available for drawing a conclusion, and the slight irregularity of depth was then easily and plausibly explained by lenticularity—lenticular bands of the detrital limestone. But, as drilling continued, the difficulties of accepting that theory were accentuated. According to the Company's records, it was Prof. S. J. Shand who first suspected that the Asmari limestone was the real reservoir rock; but Prof. Shand only being in the Company's service a short time it remained for the author to develop that theory. Probably, for all he knew, the author might have formed that theory quite independently, but at any rate he carried it to finality, which was the main thing, by carefully examining a very numerous collection of slides made by himself or under his personal direction, and clearly demonstrating that there was no other course than to accept the Asmari limestone as the main reservoir rock. His important conclusions were confirmed palæontologically by Dr. J. A. Douglas. That discovery had marked a very great step in petroleum geology in Persia, and it had thrown an entirely new light on prospecting work in all parts of the country. It was necessary, in view of those results, to review their ideas of outside test areas with that fresh knowledge as a basis; that was the main fact that had to be depended upon. Prof. de Böckh had now brought them a great step forward in pointing out the association between the oil in the Asmari limestone and the development of a lagoon facies; and those were the two main facts upon which they now based their search for other fields.

Mr. T. G. Madgwick said that although he had no personal knowledge of Persia he desired to ask a few questions. In discussing the origin of the oil the author had referred to oil indications and oil shows. He would like to know which of those terms referred to seepages, and whether the author included bituminous matter in rocks as an oil indication. In describing the geological succession the author had frequently referred to a brown colorisation. Was that colour due to bituminous matter of any kind

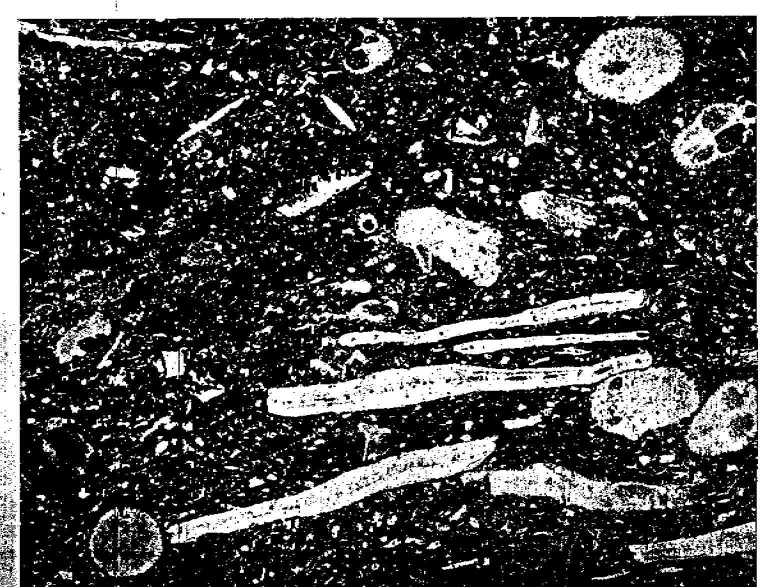
whatever. Further, the Asmari limestone was referred to as a highly organic rock. Was that because it contained tests of foraminifera, or because it had actual bitumen or any carbonaceous matter in it. He was very much interested in the suggestion that had been made that the Tang lines were lines of possible migration from depth. It would be interesting to know if those lines showed up in any way in the distribution of the oil underground or in the gas pressure, or whether they had any influence at all on the dolomitisation underground. The question of dolomitisation was a very important one upon which the author had thrown much light. The author evidently associated the occurrence of oil with dolomite, but he would like to know whether the author regarded the two as one phenomenon. It was not easy for him to imagine how the lagoon water could circulate through a massive limestone apparently to some depth, particularly if that limestone had not been fissured, and where there was a continually growing accumulation of more or less impervious sediments on top. That was a case in which core drilling would throw light on the actual occurrence, and perhaps the author had carried out experiments in that respect already. Some very interesting slides had been shown bearing on the significant fact recorded of the gypseous alteration of limestone. He noticed that the particular case described occurred in a faulted area and the author claimed that the alteration took place from below. That was certainly an occurrence which deserved the fullest investigation possible, and he would like to know whether the author considered it as something connected with the general process of dolomitisation. He also asked if there was any possibility of it having occurred on a larger scale prior to the deposition of the Fars group, and whether the resulting gypseous limestone, which would naturally be easily eroded, had played any part in the source of the gypsum in the Fars series. *Apropos* of that, he thought he might mention an occurrence in Sinai in which there was a Miocene limestone containing a very high percentage of gypsum, the partial erosion of which might very conceivably havf contributed a good deal to the gypsum deposits in that part oe Egypt. Did the author think any similar process had occurred in Persia? He did not say that the Sinai occurrence was necessarily an alteration from below, as he had not considered it from that point of view. He also asked whether there were any seeps in the places where the gypsum occurred, and whether the occurrence of aragonite referred to was at all pronounced in the same locality. It was perhaps rather an unfair question to ask the author whether he were in doubt on the question of the organic hypothesis of oil, but would he raise the curtain further on the interesting discussions he had evidently been involved in with regard to the limestone, gypsum and hot water hypothesis.

Mr. Gordon Pitt said he did not know whether it was fortunate or unfortunate that whenever a geological paper or a paper with a geological trend was read before the Institution sooner or later the discussion seemed to direct its attention to the vitally important question of the origin of oil. He took it that the author's general observations in the paper, particularly in regard to the extraordinarily amazing list of identified animal remains which were mentioned, might be read in the light of supporting the animal origin of oil. One point had occurred to his mind several times, particularly during the remarks of their distinguished guest, Prof. de Böckh. The theories as to the animal, vegetable or purely inorganic origin of oil were usually definitely geological theories on the part of a geologist or definite chemical theories on the part of a chemist. The paper indicated most clearly that a man who was capable of bringing forward a reasonably tenable theory on either of those subjects must be immersed in his own particular branch of the subject. Therefore the problem very often was looked at from a prejudiced or biased point of view. The suggestion that had been made in regard to the ammoniacal condition of a solution when dolomitic changes were taking place furnished some information that might be overlooked. In forming a conclusion in regard to the animal theory on the one side and the vegetable theory on the other, an indication of that kind might be most valuable, because, apart from anything else, during the natural process of the production of oil from either an animal or a vegetable source certain chemical changes or chemical conditions were set up which were purely temporary, which left no final trace at all, and which would be likely to be overlooked by the geologist and might be overlooked or wrongly translated by the chemist. If it were remembered that animal material in undergoing the chemical changes which it must undergo in order to produce oil would unquestionably produce more ammonia than would be produced by a vegetable material, under corresponding conditions it might throw a certain amount of light on the subject, although the final evidence of that ammoniacal condition having obtained had entirely disappeared.

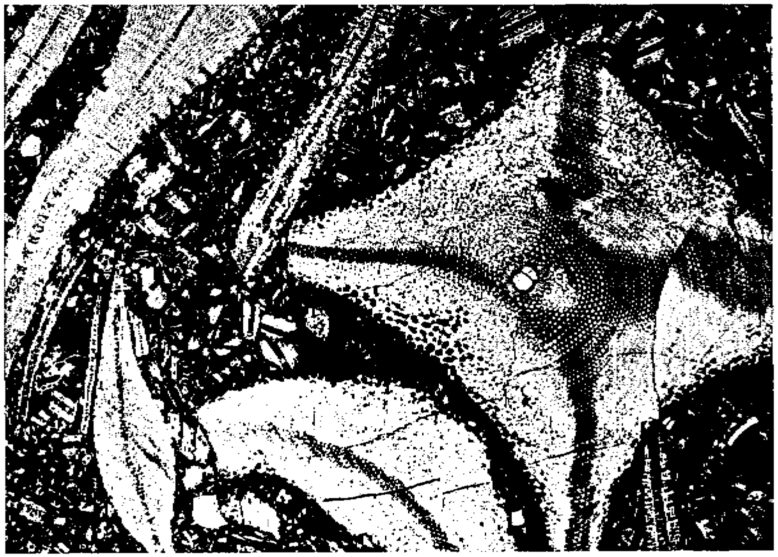
Mr. T. Dewhurst said that it must be admitted that great progress had been made since Messrs. Mayo and Busk read a paper to the Institution on the geology of Persia in 1918, owing to the excellent reconnaissance and detailed mapping of all members of the staff, and to the palæontological work of Dr. Douglas. The evolution of knowledge concerning the geology of Persia had recently been accelerated by the stratigraphical work of Prof. de Böckh. The members of the Geological Staff of the Anglo-Persian



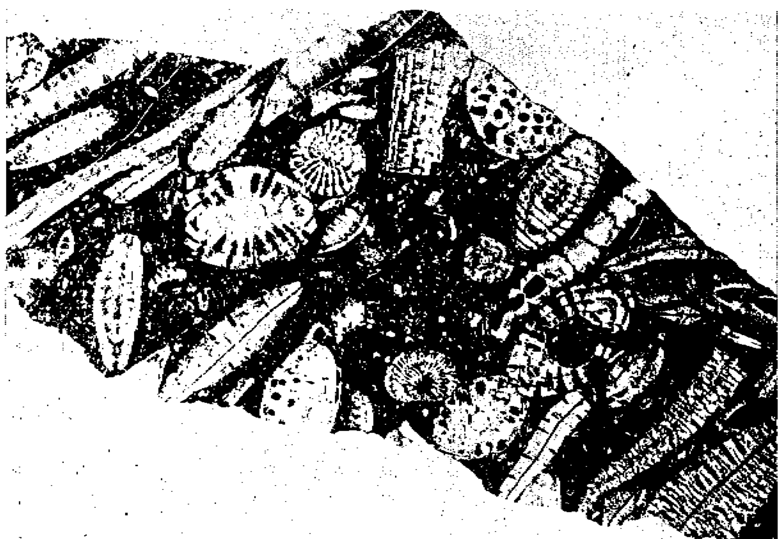
PHOTOMICROGRAPH OF ASMARI LIMESTONE (UPPER MIDDLE BEDS). BARD-I-QAMCHEH. DISPLAYING ALVEOLINA CF. MELO, MILIOLINE FORMS, LITHOTHAMNIUM AND HETEROSTEGINA.



PHOTOMICROGRAPH OF ASMARI LIMESTONE (MIDDLE BEDS). BARD-I-QAMCHEH. DISPLAYING HETEROSTEGINA AND ASMARIA.



PHOTOMICROGRAPH OF ASMARI LIMESTONE ; BASAL BEDS. BARD-I-QAMCHEH. DISPLAYING AXIAL AND EQUATORIAL SECTIONS OF LEPIDOCYCLINA.



PHOTOMICROGRAPH OF ROCKS FROM NUMMULITIC PHASE ; BASAL BEDS UPPER THIN-BEDDED LIMESTONE. DASHT-I-GUL. DISPLAYING ASSILINA, ORTHOPHRAGIMA AND NUM. GALLENSIS.

Oil Company had, in particular, hammered their way into the older geological formations of Persia, and had also raised some of the formations in the stratigraphical scale. For example, the Asmari formation had been shown to be mainly of Miocene agé, while in the original paper it was considered to be older. Another important step in the progress of knowledge had been the recognition of the Asmari limestone as the main oil container, while further light had been thrown on the question of the Asmari-Fars unconformability. He agreed with the remarks of Mr. Cunningham-Craig in the latter connection. The recognition of the true age of the Asmari limestone had rather caused geological opinion to swing to the opposite extreme, and instead of postulating a big gap between the Asmari and Fars formations, to dispense with that gap altogether. The tendency now was to ascribe all the observed effects (such as those shown in the case of Maidan-i-Naftun, where there was striking discordance between the superficial Fars structures and the underground structure of the Asmari) to overlap, differential yielding to earth movement, and to the slipping and sliding of Fars beds down the slopes of Asmari cores. However, the detrital limestones of the Lower Fars suggested probable exposure and erosion of the Asmari limestone. Further, at Khamir, the Lower Fars, or beds with a Lower Fars facies, rested with some evidence of discordance on lower members of the Asmari limestone. Furthermore, in one section there was even a conglomerate at the base of the Lower Fars, indicating at least local unconformability. The lack of evidence of discordance in some sections might be deceptive. For example, in the Salt Range of India the Nummulitic Hill limestone was overlain by the Kamlials, and it was possible to examine the junction between these formations for miles without seeing any physical evidence of discordance. However, it was clear from palæontological and other evidence that the Charat series and the whole of the thick Murree series were missing, and that there was a big gap in the succession. Although palæontological evidence would not allow of a big stratigraphical gap between the Asmari and Fars formations, the apparent physical conformity in some sections might be deceptive. He therefore suggested that the observed effects between the Asmari limestone and the Fars should be ascribed to a plurality of causes—unconformability, overlap, differential yielding to earth movement, and the slipping and sagging of the soft Fars beds around Asmari cores. There seemed to be a lack of harmony between the various conclusions of the paper ; there was no definite underlying thesis or conception or hypothesis. For example, the suggested conformability of the Asmari and the Fars was not correlated with the table showing the history of the earth movement to which the region had been subjected. Again, the postulate that the oil is indigenous to the

Asmari was not supported by the evidence as to the chemical and physical conditions under which the limestone was deposited. This lack of cohesion between the various conclusions and suggestions put forward constituted the main criticism of the paper. It was perhaps unnecessary to enlarge on the point made by Mr. Cunningham-Craig, with which he agreed, that the Asmari limestone may b; the oil-container merely because it is a porous reservoir rock. Apart from the fact that there were many organic remains in the limestone, there was no more reason, from the evidence given in the paper, to believe that the oil was of Asmari origin than there would be to assume in the case of a sandstone field that the oil was formed in the oilsands. From the evidence of the paper, the porous Asmari limestone seemed to have no more claim to be considered as a source rock than had an oil-sand. There was no attempt to show that the conditions under which the limestone was deposited were favourable for the formation of oil. For several years he had suspected that the oil was formed in the Lower Fars inland seas and lagoons, and had migrated *via* the plane of unconformability and overlap into the porous portions of the Asmari limestone. This view was based largely on the existence of inland seas in Lower Fars times, on the fact that the most prolific seepages in Persia occurred in the Lower Fars detrital limestones and near the Asmari-Fars boundary, and on analogy with the Punjab oil occurrences. The Nummulitic Hill limestone of the Punjab resembled the Asmari limestone. There was unconformability and overlap of the Lower Charat beds, which were analagous to the Lower Fars, and like them were deposited under inland sea conditions. The analogy between the geology of the two regions was therefore striking. Geologists were agreed that in the case of the Punjab the oil was formed in the Lower Charat beds, and had migrated *via* the plane of unconformability and overlap into adjacent formations. The above-mentioned view of the origin and migration of oil in Persia was much strengthened by the completeness of the analogy with the Punjab. It would be very difficult, if not impossible, to eliminate that hypothesis. In any case, the postulate of indigenous Asmari oil required for its acceptance much more evidence than had been presented in the paper. It would seem to involve earth movement during the Asmari period, with the formation of an inland sea or lagoonal facies of the Asmari limestone. It was readily conceivable that under such conditions oil would have been formed in the Asmari limestone as well as in the Lower Fars beds, but the paper did not contain evidence in favour of the existence of such conditions. It was still more improbable, on the evidence submitted, that the whole of the oil in the Asmari limestone was indigenous to that

formation, and much more evidence should have been given before that hypothesis was formulated.

Mr. R. K. Richardson, in reply, said that Mr. Cunningham-Craig had referred to the particular samples of oil rock that were sent to him. Personally, although he had prepared some hundreds of slides, he had not seen anything in the nature of a detrital limestone from the main oil horizon. The particular specimen that Mr. Cunningham-Craig referred to, which was practically a pure dolomite displaying some crystalline matter, came from the central Maidan. Slides made from rocks in the central Maidan did not display many remains ; they were practically all altered.

Mr. Cunningham-Craig said he desired to emphasise that two of the samples were not from the central Maidan area but from the south-eastern area.

Mr. Richardson, continuing, said he could not think what they could be. He had made slides from the oil-bearing limestone out of every well, and they practically all showed those particular remains and a non-detrital character.

Mr. Cunningham-Craig said that all he knew was that they were the specimens sent to him.

Mr. Richardson, in reply to Mr. James, said he desired to emphasise that credit of priority for the suggestion that the Asmari limestone was the productive oil rock was due to Prof. Shand. The evidence submitted, in some respects, however, militated against the theory, which was subjected to criticism. He had carried on Prof. Shand's early work and brought it to a conclusion, removing at the same time the difficulties which stood in the way of its initial acceptance.

In answer to Mr. Madgwick, he said that the brown colour of the rocks mentioned in the paper was not due to organic matter ; it was simply the natural colour. When he referred to the Asmari limestone as being highly organic he was referring particularly to the actual remains. With regard to possible tang lines, the evidence on the oilfield in regard to oil production, gas pressures and dolomitisation of the oil rock bore no relation to linear direction. He had put forward in the paper two alternative views with regard to the occurrence of gypsum in pre-Fars formations. There was distinct evidence in Persia of widespread secondary action, not merely in the Asmari limestone but in the Fars limestones and in the Hippuritic limestone of the South. Gypsitisation had taken place along joints in the Hippuritic limestone and in some cases in Fars rocks as at Marmatain ; for example, whole beds 10–30 ft.

thick had been almost entirely changed to gypsum. If they were given a blow with a hammer they crumbled into a dust of fine gypsum and fragmentary limestone; they were full of cavities and consisted largely of gypsum, which was obviously secondary after limestone. The source of the gypsum in the Fars was not secondary at all; it had been laid down as a primary deposit in the desiccated seas of Fars times. The association of aragonite with oil seepages was an extraordinary occurrence in Persia. It had been noted by geologists in the south and in the north; it occurred in the Maidan-i-Naftun oilfield, and it was certainly a very intriguing occurrence. He understood that what Mr. Pitt desired to know in the remarks he had made was whether he was in favour of the animal origin of oil. As a matter of fact, on the basis of evidence at present available, he was distinctly in favour of an indigenous animal origin for the oil in the Asmari limestone; but it was necessary to put the other views forward because, as he had stated in the paper, it was absolutely essential to preserve an open mind. Objections could be brought against all hypotheses particularly upon such a debatable subject, but he considered an hypothesis involving an indigenous origin in the Asmari limestone fraught with the least difficulties. Conclusive evidence did not exist, and it was necessary to keep an open mind about the whole question. He was in entire agreement with the remarks Mr. Dewhurst had made with regard to the plurality of causes accounting for conditions at Maidan-i-Naftun. He considered the actual discordance was due to a number of causes which he had already indicated in the paper. Although he had pointed out the conformable nature of the Fars Asmari junction over hundreds of miles of mapped outcrop he had already stated that a condition of conformity with overlap represented the actual initial nature of the junction. With regard to the physical relations of the two groups in reference to earth movement, the cohesion between the two was distinctly shown in the table in regard to tectonics. Formation of fold lines at the end of Asmari times, and gradual uplift during Fars times, with attendant overlap of deposits against the flanks of rising Asmari masses, were indicated in the table referred to. Mr. Dewhurst had commented that, apart from the fact that there were many organic remains in the limestone, there was no more reason to believe that the oil was of Asmari origin than there would be to assume in the case of a sandstone field that the oil was formed in the oilsands. He considered, however, that the origin of the oil could not be contemplated apart from the abundant organic remains. Their presence was an integral part of the hypothesis. He had put forward in the paper an hypothesis in regard to the origin of the oil. Mr. Dewhurst was in possession of as much information as he was on that subject.

PHOTOMICROGRAPH OF ROCK FROM NUMMULITIC PHASE; BASAL BEDS UPPER THIN-BEDDED LIMESTONE. DASHT-I-GUL. DISPLAYING ALVEOLINA OBLONGA, ORBITOLITES, ORTHOPHRAGIMA AND NUM. URONIENSIS.

The President thought the Institution was to be congratulated on the fact that at the last meeting of the Session such an exceedingly interesting paper had been read. All the speakers who had taken part in the discussion had referred to its excellence. He had much pleasure in asking the members to pass a most hearty vote of thanks to the author of it.

The resolution was carried with acclamation and the meeting terminated.

Mr. W. G. Weeks subsequently wrote :—I agree entirely with Mr. Dewhurst's remarks that insufficient evidence has been adduced to justify our regarding the Asmari limestone as the origin of the oil it contains. Mr. Richardson's description of the limestone—" a highly organic rock composed almost entirely of foraminiferal remains "—would apply very well to the chalk, in the whole enormous mass of which, so far as I am aware, no trace of oil has been found ; so that the mere presence of multitudes of tests proves nothing.

I should like to ask Mr. Richardson whether he has ever considered the spatangid shales as the possible mother-rock of the oil. The occurrence of this 250 ft. of shales, lying conformably between limestones, suggests the approach and retreat of a coast-line, some river-mouth in which supplied the material for the shales. Since, during the Palæogene, the Mediterranean Sea was much larger than it is now, extending far to the east of the Caspian, there was sea to the north-west, north, and north-east of the Persian area, and the river, whose mouth discharged the spatangid shale material, presumably came from the south-west, south, or south-east.

Palæogeographical researches indicate that, in the Cretaceous and Palæogene, a great trough lay to the east of the African land-mass, its axis running from a point north of Madagascar across the Arabian Sea and Baluchistan to the then eastern extension of the Mediterranean. The trough appears usually to have been submerged by a southward-trending arm of the ancient Mediterranean ; but, at some time early in the Eocene, it is thought to have been above sea-level for a while. During the period of emergence it would have been drained by a northward-flowing river which might very well have been the one which supplied the material for the shales.

This river, both in its attitude to the climatic zones and in size, would have been closely comparable with the Nile. Now it has been estimated that the Nile brings down annually, in solution alone, about 1,700,000 tons of organic matter. It is probably no exaggeration, therefore, to say that our hypothetical river might have delivered into the sea, along with its load of inorganic material, a quantity of the order of 5,000,000 tons a year of dissolved and finely comminuted suspended organic matter. The inorganic material, certainly, would have been deposited round about the delta; and it is not unreasonable to suppose that it would have carried down with it at least some of the organic. I suggest that this precipitated organic matter was the primary material of the Asmari oil.

The hypothesis obviously needs a good deal of confirmation by field observation and otherwise. I believe, however, that it does not contradict any known observation, and it has the merit of reconciling the views of those who advocate an Asmari origin because of the difficulty they find in understanding how, otherwise, the oil got there, and of those who cannot accept that theory.

STUDENTS' SECTION, LONDON BRANCH.

The Third General Meeting of the Students' Section, London Branch, was held at Aldine House, Bedford Street, Strand, W.C. 2, on Tuesday, December 18th, 1923, at 6 p.m.

Mr. H. G. Austin (Chairman), in opening the meeting, stated that, owing to Messrs. C. O. Graham and F. E. J. Foxall-Smedley's absence abroad, which necessitated their resignation on the Committee, it was decided to fill their places, and Mr. L. W. Marrison had been selected to fill one vacancy, the other being left open until later.

Mr. A. B. Miskin was then called upon to read his paper, an abstract of which follows, entitled :—

The Iodine Values of Cracked Gasolines,

by A. B. Miskin.

This paper embodies the results of some research on the iodine values and other properties of the olefines in cracked, untreated, motor spirit.

Dr. Dunstan very kindly supplied the three samples which were examined—Ramage vapour phase cracked spirit, Ramage spirit once distilled over dried, unburnt clay, and soda treated, and A.D.H. cracked gas oil.

Before proceeding further it will be necessary to outline the chemistry of these oils, for the benefit of those students who are not chemists.

Five hydrocarbon types are found in these oils—namely, Paraffins, *e.g.*, methane CH_4. These do not react with ordinary reagents at room-temperature, or with halogens in the dark. Next in order of stability are the aromatics, *e.g.*, benzene C_6H_6, which resemble the paraffins in their behaviour, except in that they dissolve in 98 per cent. sulphuric acid. Thirdly, there the olefines, *e.g.*, ethylene C_2H_4. These compounds are characterised by one "Double bond" and hence are less stable than paraffins. They combine with 80 per cent. sulphuric acid and with halogens even in the dark. Fourthly, there the diolefines, which are similar to the olefines, but have two double bonds, are less stable and will dissolve in weaker acid. Finally, acetylenes are found in cracked oils. Acetylenes have a treble bond, are very unstable and will combine with sodium to form acetylides. It is possible that diolefines also react in this manner.