

## THE PERMIAN SYSTEM AS AN OIL AND GAS RESERVOIR IN IRAN, IRAQ AND ARABIA,

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### ABSTRACT

Permian strata form thick sequences in the Middle East, especially through south Iran and adjacent Iraq and, to a lesser extent, in eastern Arabia. Apart from basal sandstones previously considered as Carboniferous, the Permian System in these areas consists predominantly of carbonate formations. These formations have all the characteristics of favourable reservoir rocks. They represent thick, fractured, limestone-dolomite sequences and are often foetid, oily or bituminous in outcrop. Significant gas production has been obtained from these Permian strata in the Dammam Field and at Bahrain for many years. In recent years, very large gas fields have been discovered in Permian strata of south Iran and, especially in Coastal Fars at Kangan, Dalan, Nar, Kuh-e Aghar and Kuh-e Mand, as well as in the Persian Gulf (e.g. Pars C structure). These large gas reserves are of great significance in the future development of Iran.

The thick Permian carbonate sequences of south Iran, now known as the Dalan Formation (NIOC Geological Sub-Committee July 1976), were formerly referred to as the Khuff Formation, a much thinner stratigraphic unit of Permian carbonates, which occurs in Arabia. Stratigraphic and paleontological analysis of many Permian sections shows that prospective strata are almost invariably Upper Permian.

The importance of the Permian sequence in Iran, Iraq and Arabia is that it concordantly underlies almost every known productive oilfield structure, as well as the majority of prospective ones. The Permian Dalan and Khuff formations, thus represent a very extensive hydrocarbon reservoir and, wherever possible, drilling should be continued to test these formations. In the thicker sequences of south Iran, much of the section is made up of highly fossiliferous, fusulinid and coral limestones with considerable associated dolomitization. These Permian reef type limestones are an attractive prospect as reservoir rocks because they are:

1. conformably involved in major oilfield structures and many large unproved, anticlines.
2. mostly capped by Triassic marls and evaporites.
3. are significantly fractured and dolomitized with secondary porosity.
4. are mostly organic limestones and thus potential source and reservoir rocks.
5. often oily or bituminous in outcrop and already known to produce gas in at least seven major oil fields.



Figure 1

## I. THICKNESS OF PERMIAN SEDIMENTS.

Thickness of sediments belonging to the Permian System and their lateral variations in this regard, are fundamental to the consideration of these strata as potential hydrocarbon reservoirs. From consideration of measured surface and subsurface sections of Permian sediments in south-east Turkey, northern Iraq, south Iran, the Persian Gulf, Oman and Saudi Arabia, a general picture of their thickness distribution can be obtained. Some thirty stratigraphic sections of the Permian from drilled wells and surface sequences represent the basic data for thickness interpretation. (see enclosures 1 to 6). Although a large number of surface sections are available, there is very little data on the thickness of the Permian underlying most of Iraq, the Persian Gulf and large areas of Saudi Arabia. Apart from the 5 wells at Bahrain (characterized by Awali 88) and the Idd-el-Shargi 12 Deep Test, information on the Permian in the Persian Gulf area is scarce, although it has been penetrated in Dammam 45, Iminoco 1, and Sharjah 1, as well as in the Pars C field. In Saudi Arabia, only about 6 wells near the Persian Gulf have penetrated the entire Jurassic and entered older strata. It is not known how many of these have reached Permian formations. In all of Iraq only the Mosul Petroleum Company well, Atshan 1, is known to have drilled into Permian strata. No wells have reached these beds by deep drilling in Kuwait and the Neutral Zone.

Despite the paucity of stratigraphic information and lack of deep wells over large parts of the Middle East Permian sedimentary province, a rough isopach map can be constructed as shown in text figure 2. This map shows isopachs at 1000 ft intervals for the total Permian section as known in Iraq, south Iran and Arabia. In Baluchistan and bordering the central Iranian Plateau, isopach lines are interpretive and do not show the effects of later Mesozoic-Cenozoic tectonic disturbances, metamorphism and intrusion.

Major regional variations in thickness are apparent from this generalized isopach map. They can be summarized as follows:

1. Arabian Shelf — an area with sediments less than 2000 ft. thick between the Arabian Shield on the west, and central Iraq and the southern Persian Gulf on the east. This area is at least 500 miles wide, with a deep, south-west embayment towards the Yemen. It consists of fairly uniform Upper Permian formations, namely the Khuff Limestone and lower Sudair Shale. However, an underlying coarse, clastic unit, the Wajid Sandstone, is irregularly developed mostly in the embayment between the Arabo-Nubian and Arabo-Somali massifs.

2. Oman-Fars Basin - There is a basin of thick Permian carbonates in eastern Oman. It continues towards the north-west in the Ru'us al Jibal and the Iranian provinces of Laristan, coastal Kerman and interior Fars. In these areas, it contains Permian sediments from 2500 ft. to 3500 ft. thick, which are mainly Upper Permian carbonates but include arenaceous sediments on the north-east margin of the old Qatar structural high. The greatest thickness of Permian strata known in the Middle East is from the eastern Oman Mountains where they are over 5900 ft. at Jebel Akhdar and 5500 ft. at Saih Hatat. In both these sections, the base of the Permian is not exposed. However, large parts of these sequences are metamorphosed to varying degrees due to the intrusion of Late Cretaceous ophiolites and basic igneous rocks.

Thus, the thickest known sections in the Oman Mountains are of little interest for petroleum prospects. The occurrence of this thick Permian sequence in eastern Oman is evidently due to continued subsidence and sedimentation in that area throughout the Permian. In Iran, Iraq and most of Saudi Arabia, the Permian sedimentary section belongs mostly to the Upper Permian, while that of eastern Oman contains both lower and upper parts of the system.

Although most older rocks are obscured by a widespread Neogene cover in the Makran, the appearance of thick Permian carbonates in the north of the Bampur Basin is probably related to the subsiding Oman Basin. At present, however, the Permian of Iranian Baluchistan is represented by patches surrounded by later metamorphism and intrusion.



3. Kurdistan-Luristan Basin. This is an area extending from northern Iraq to south-west Iran in which the Permian sediments are generally thicker than 2500 feet. In stratigraphic sections near Khorramabad, the Permian System attains a thickness of up to 4000 ft. The outline of this basinal area of thick carbonate sedimentation is bounded on the south-west by the Arabian Shelf, and on the north-east by the tectonized area of the Iranian Plateau. It is thought that it extends southwards through Khuzestan within an early development of the Dizful embayment. Towards the north-west, the Kurdistan-Luristan Basin grades into a shallower trough of predominantly Permian carbonates in south-east Turkey. In a south-east direction, however, the basin is terminated by a structural high with much reduced Permian thicknesses.

4. Qatar-Bahrain area. Extending northwards from Qatar and Bahrain is a tongue-like extension of the thinner Permian sedimentation characterising the Arabian Shelf. This area seems to be a sedimentary reflection of a structural high referred to as the Qatar Arch, which is known to have a marked effect on Mesozoic sedimentation in south Oman, north-east Arabia and the central Persian Gulf. Throughout this northward prolongation of the thinner shelf sediments from the Arabian Foreland into south Iran, the Permian strata are less than 2,000 feet thick. Most available sections indicate thickness below 1,500 ft.

Consideration of thickness changes in the Permian sediments of the Middle East are a basic part of their evaluation as potential reservoir rocks. Not only can the areas of thicker, more favourable sediments be indicated, but convergence of strata can also be shown.

Areas which are considered to have the most favourable Permian sediments from point of view of thickness are:

- a. west and south-west of the Oman Mountains.
- b. from interior Fars to Coastal Kerman.
- c. in Kurdistan - Luristan and the Dizful embayment.

However, it is noteworthy that Permian sediments through most of the Arabian Shelf exceed 1,000 feet in thickness. This is quite sufficient thickness for a hydrocarbon reservoir, particularly as most of the section is composed of dolomitized and fractured limestones of the Khuff Formation.

Convergence, or wedge-out, in the Permian sediments is an important feature in the formation of stratigraphic traps and in influencing the accumulation of oil along the margins of the thick basinal areas.

## II. PERMIAN LITHOFACIES.

Changes in Permian lithofacies are of major importance in the evaluation of Permian strata as prospective reservoir rocks for oil and gas in Iran and adjacent areas. A general subdivision of sediments has been made on the basis of dominant lithological type, as shown on the accompanying regional map (Plate 3) are, firstly, marine sediments including:

- a. Thin, shelf carbonates
- b. Thick, basinal carbonates
- c. Predominant shales and marls (lutites)
- d. Predominant sandstones (arenites)
- e. Predominant coarse clastics (rudites and poorly sorted arenites)

and, secondly, continental sediment known only from small areas on the northern edge of the Arabian Shield.

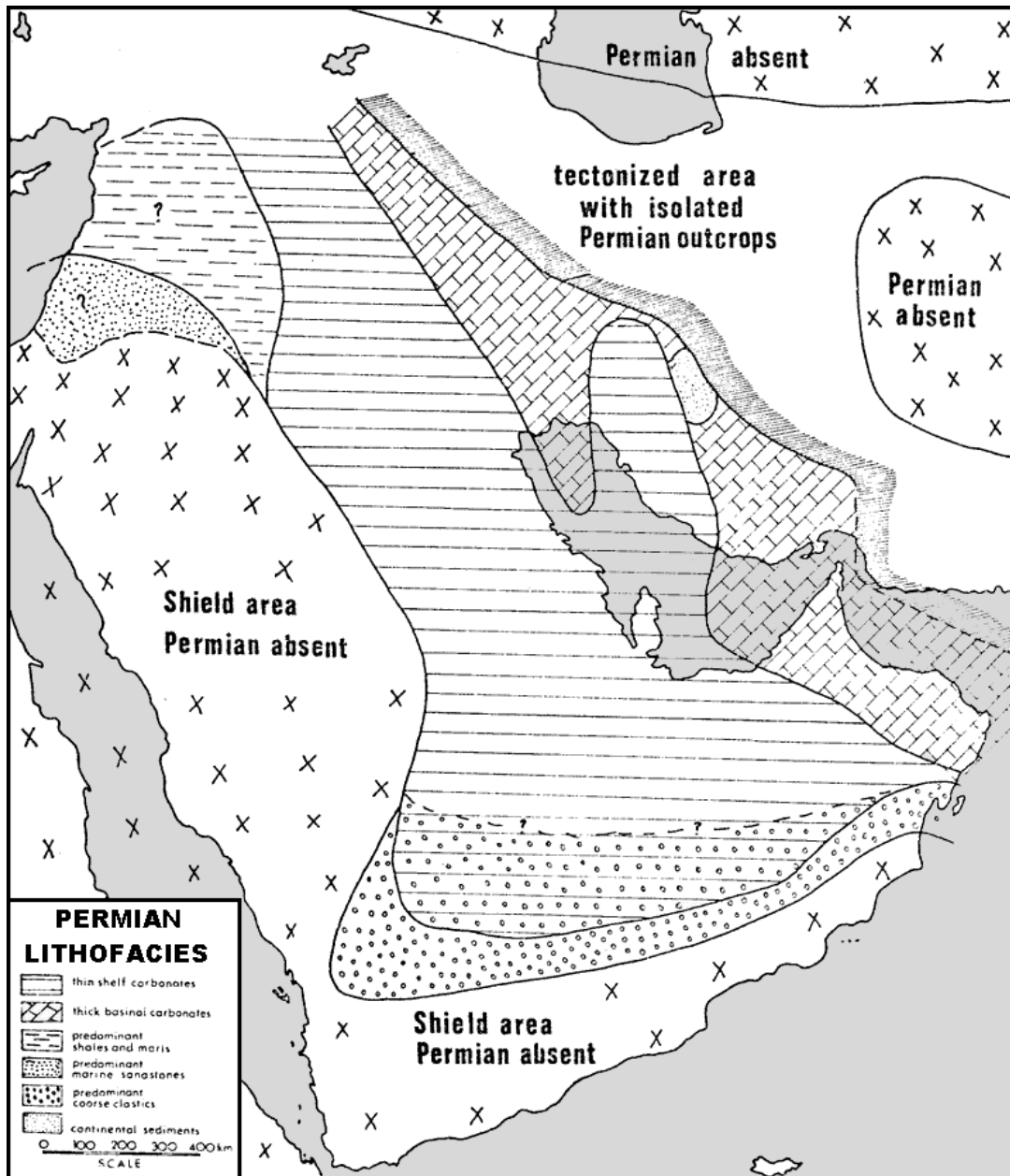


Figure 3

### III. PERMIAN BIOFACIES.

A diagrammatic biofacies cross section for the Upper Permian interval is given in text figure 4. It attempts to show the relationships between biofacies, environment and tectonic elements in deposition between the Hejaz and the Iranian Plateau.

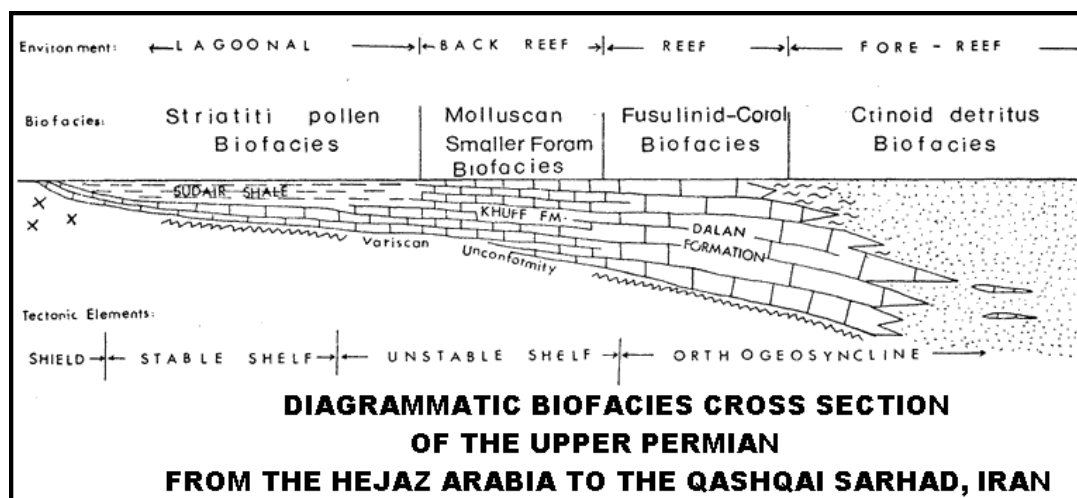


Figure 4

### IV. THE TYPE PERMIAN SUCCESSION.

The standard stages used here are all from the areas of Murchinson's type Permian, in the province of Perm, on the west flank of the Urals. They form a complete sequence of Permian units in stratigraphic succession in the Uralian miogeosyncline, where sedimentation continued from Late Carboniferous with no significant break.

In descending stratigraphic sequence, these Permian time-rock subdivisions are:

- Tatarian Stage
- Kazanian Stage
- Kungurian Stage
- Artinskian Stage
- Sakmarian Stage

Where fusulinid, ammonoid and coral assemblages have been identified from stratigraphic sections in the Middle East it is possible to refer the sediments to the standard Permian stages. This enables correlation to be made between Permian sequences in different areas and provides information on the continuity and duration of time represented by prospective Permian reservoir rocks. Since various stage names have been used to subdivide the Permian a chart is given (text figure 5) showing their comparison.

### TYPE PERMIAN SUBDIVISIONS AND CORRELATIVE STAGES

SYSTEM	SERIES	PERMIAN STAGES (WORLD WIDE SCALE)	STAGES IN URALS	WEST TEXAS	SALT RANGE PAKISTAN	TIMOR	GERMANY	
P E R M I A N	UPPER PERMIAN	DORASHAMIAN	TATARIAN	OCHOAN	UPPER	CHIDERU	ZECHSTEIN	
		DJULFIAN				JABBI		AMARASSI
		PUNJABIAN				KUNDGHAT		
		KAZANIAN	KAZANIAN	CAPITAN	KALABAGH	BASLEO		
		KUNGURIAN	KUNGURIAN	WORDIAN	MIDDLE	VIRGAL	TAE WAI	UPPER ROTLIEGEND
	LOWER PERMIAN	BAIGENDZINIAN	ARTINSKIAN	LEONARDIAN	LOWER	KATTA AMB	BITAUNI	LOWER ROTLIEGEND
		SAKMARIAN	SAKMARIAN	WOLFCAMPIAN		SPECKLED SANDSTONE	SOMOHOLE	
		ASSELIAN						

Figure 5

#### V. LITHOSTRATIGRAPHY OF THE PERMIAN IN IRAN.

Although the Permian is thickly developed and outcrops in many areas of the Zagros Ranges in south Iran, it has only recently been subdivided into named lithological units. This is largely because most measured sections show a continuous carbonate sequence for the Permian, which is difficult to divide into mappable units. One feature, which the Permian sections of south Iran exhibit in common, is the occurrence of conformable sandstones at their base. By convention, these relatively thin basal sandstones have been distinguished as Carboniferous. However, they probably represent the beginning of Late Permian sedimentation as suggested by overlying interbedded sandstones and fossiliferous sandy limestones of definite Upper Permian age. In an article on the Permian in south Iran, Harrison (1937) remarks that its basal part in the Zagros is a rusty coloured, false-bedded, calcareous grit, which passes upwards into dark massive limestone.

### CORRELATION CHART OF PERMIAN FORMATIONS IN THE MIDDLE EAST

TIME, ROCK UNIT SYSTEM	AREA STAGE	CORRELATION CHART OF PERMIAN FORMATIONS IN THE MIDDLE EAST								REVISED PERMIAN STAGES	
		SOUTH-EAST TURKEY	NORTH IRAQ	NORTH IRAN	SOUTH IRAN	SAUDI ARABIA	NORTH OMAN	NORTH-EAST OMAN	SOUTH-EAST OMAN (Hugf)		
PERMIAN	TRIASSIC	SCYTHIAN	BEDUH SHALES	MIRGAMIR FORMATION	ELIKAH FORMATION	DASHTAK FORMATION KANGAN FM.	UPPER SUDAIR	GHAIL LIMESTONE	UMAILI FORMATION		
	UPPER PERMIAN	TATARIAN	INBIRIK FORMATION	QARARI FORMATION	NESEN FORMATION	DALAN FORMATION	LOWER SUDAIR SHALE	HAGIL LIMESTONE	QAMAR LIMESTONE		DORASHAMIAN
		KAZANIAN		SATINA FM. ZINNAR FORMATION		BASIC IGNEOUS DYKES & SILLS	KHUFF FORMATION				DJULFIAN
		KUNGURIAN		HAZRO FORMATION						FARAGHUN FM.	BIH DOLOMITE
	MIDDLE PERMIAN	ARTINSKIAN		UNNAMED LIMESTONES ?							KUNGURIAN
		SAKMARIAN				WAJID SANDSTONE			HATAT PHYLLITES	LUSABA LIMESTONE	BAIGENDZIAN
	LOWER PERMIAN								H AUSHI FORMATION		SAKMARIAN
											ASSELIAN
	CARBONIFEROUS	UPPER									
		LOWER		HARRUR LIMESTONE	UNNAMED L. CARBONIFEROUS LIMESTONE						

Figure 6

A four-fold subdivision can be noted in most of the Permian sections in south Iran. As a general rule the descending sequence is as follows:

- |  |   |
|--|---|
| <p>Upper Dalan Formation</p> <p>Middle Dalan Formation (Nar Member)</p> <p>Lower Dalan Formation</p> <p>Faraghun Formation</p> | <p>i. - Limestones, relatively thick bedded, with some thin dolomite interbeds.</p> <p>ii. - Anhydrite, massive, with some interbedded dolomite.</p> <p>iii. - Limestone, dark, well-bedded to massive, with some dolomites towards the top.</p> <p>iv. - Alternating dark, fossiliferous limestones, with sandstones and marls forming the lowermost part of the sequence.</p> |
|--|---|

The total thickness of these units in the Zagros Ranges is from 1400 feet to more than 3500 feet. The Permian is 3380 ft thick in coastal Fars.

This type Permian succession can be seen in the sections at Ushtarun Kuh & Pul-e Zarreh. A somewhat similar lithostratigraphic succession can be observed at Kuh-e Dinar, & less clearly at Kuh-e Faraghun.

The upper dolomitic part of the Permian is largely replaced by clastics in some of the Permian sequences in interior Fars. This is noticeable in the Kuh-e Dinar section, where there are 250 feet of interbedded marls and calcareous shales at the top of the Permian succession. It is even more apparent at Siah Kuh, north of Abadeh, where the uppermost 52 feet of the Permian consist of sandstones, quartzites, and some sandy limestones. These clastics are part of a north-eastward change to arenaceous facies, which takes place to the north of Shiraz. At Kuh-e Safid, the Permian is thus represented by a lithostratigraphic succession consisting almost entirely of sandstones and siltstones over a thickness of 3550 feet, with only a few thin limestone bands. This type of arenaceous Permian sequence is quite unusual in south Iran, and occurs in strongly tectonized areas of little or no interest for petroleum prospects. In general, the lithostratigraphy of the Permian in south Iran presents an almost continuous limestone-dolomite sequence.

## VI. SURFACE OIL OCCURRENCES IN PERMIAN STRATA. OIL INDICATIONS IN PERMIAN OUTCROPS.

There are numerous occurrences of hydrocarbons in surface exposures of Permian strata in the Middle East. All of them are of a minor nature and there are no 'live' seepages, springs or mud volcanoes, such as characterize younger petroliferous strata.

The various types of occurrence of 'dead' oil in surface outcrops of the Permian in this region can be classed as follows:

- a. bituminous sands
- b. oily limestones and dolomites
- c. dark, foetid, organic limestones.

Some known Permian surface occurrences of these types are discussed below:

1. Sandstones impregnated with bitumen and heavy oil occur at two intervals near the top and bottom of the Permian Hazro Formation at its type locality on the Hazro uplift in south-east Turkey. Similar bituminous sandstones were encountered at the base of Permian in Raman 14, but it is debateable whether they are Permian or Devonian. Despite extensive field mapping of Permian formations in south Iran and Oman, no bitumen occurrences have been noted either in carbonates or in the possible Permian sandstones, which immediately underlie them. The outcropping bituminous sandstones at Hazro, in south-east Turkey, are unusual in that they occur at the base of the Permian overlying a major unconformity.
2. Oily limestones and dolomites are fairly frequent in surface outcrops in the Zagros Ranges of south Iran. At Ushtarun Kuh, such limestones and dolomitic limestones occur frequently in the Upper Permian section. They have a strong oily to gasoline-like smell, suggesting light oil impregnation.  
In the Alexandretta Gulf Basin of southern Turkey, instances of light oil in fissures of Permian limestones are reported by Tasman and Egeran (1951). Local traces of petroleum are also known from outcrops of Permian rocks in Oman (Morton 1959) and are believed to be from the carbonate sequences in the Ru'us al Jibal.
3. Dark, foetid limestones are common among the Permian sequences exposed in the Zagros Ranges in northern Oman. They have a definite sulphurous odour, particularly on breaking along a fresh surface. Because of the intimate occurrence of sulphur with practicably all crude oils (in amounts from 0.1% by weight) these sulphurous limestones are considered as evidence of the former presence of oil, or oil-field water. Dark foetid limestones of this type are recorded from the top of Permian section at Saih Hatat in the Oman Mountains.

Thus, it can be seen that there are frequent indications of oil in Permian outcrops. Although they are of a minor nature, they show that these strata can contain oil and that they are considered sufficiently significant to justify exploration for oil in buried Permian formations.

## VII. PRODUCTION FROM PERMIAN STRATA.

Oil production is not yet known from subsurface Permian strata. A number of offshore wells in the eastern Persian Gulf are considered to have encountered Permian. These include Idd-el Shargi 12, Iminoco 1, Farsi Petroleum Company B-1 and Sharjah 1, as well as potentially productive gas wells in the Pars "C" structure.

Gas production has been proved from 5 deep wells at Bahrain. These include well No. 52 drilled in 1949 to 10,077 feet, well No. 88 drilled in 1951 to 11,085 feet and well No. 128 drilled to 11,985 feet

during 1955. In all these wells, fractured oolitic, detrital and dolomitic limestones of the Khuff Formation were found to contain gas under considerable pressure. Gas occurs in several Permian zones and has been produced from these five deep wells since at least 1955 to supply the fields pressure maintenance project at Bahrain. Main production in that field is from the Middle Cretaceous Wasia Formation and Permian gas is used to repressurize this reservoir. In 1963, there were 179 flowing oil wells at Bahrain and 5 gas wells from Permian with a total annual gas flow of 8020 million cubic ft. On available data, it appears that these Permian gas wells at Bahrain each average in excess of 4 million cubic ft of gas per day. This deep gas production in Bahrain Island is vital to increased oil production in a field, which has been developed since 1932.

In Saudi Arabia, numerous stratigraphic tests are believed to have encountered the Permian Khuff Formation. However, only one well drilled on structure is known to produce from the Permian. This is Damman 43, a deeper-pay wildcat in the Damman Field, completed during 1957 as a high-pressure gas producer in the Dhahran Zone of the Permian Khuff Formation. Although Damman 43 was drilled to a total depth of 10,224 ft., it produces gas from the Upper Permian between depths of 8492 ft to 8596 feet (Aramco Report of Operations 1957). This zone lies more than 3000 feet below the oil-producing members of the Arab Zone in the Damman Field. It is the oldest geologic formation proved to contain a hydrocarbon accumulation in Saudi Arabia. The well produces a relatively small quantity of gas to make up requirements for the Aramco Dhahran industrial gas system.

The competition of this gas from Damman 43 is as follows:

Nitrogen	7.0%
Carbon dioxide	8.0%
Hydrogen sulphide	0.6%
Methane	83, 0%
Ethane & heavier hydrocarbons	1.4%

This is a dry gas with a low percentage of heavier hydrocarbons. It has relatively large amounts of carbon dioxide and nitrogen, which decrease its inflammability and B.T.U. value. There is also a small but significant amount of hydrogen sulphide, which makes it unsuitable as a public fuel, although adequate for industrial purposes. New gas discoveries in the Permian of the Persian Gulf are reported to have been made from the B, F and G structures, as well in large amounts from the Pars "C" structure. In addition, Permian gas production is now known from Dalan, Nar, Mand and Kuh-e Agah, all in coastal Fars.

The deep wells at Bahrain and Dammam are the only ones currently producing from the Permian in the Middle East. Nevertheless, they prove the presence of substantial hydrocarbons in the rocks of this system. Recent discoveries in Iran and the Iranian offshore emphasize the importance of the Permian as a major reservoir. Bahrain Petroleum Company is now actively using Permian gas for its aluminium industry.

#### VIII. CHARACTERISTICS OF PERMIAN RESERVOIR ROCKS.

Amongst the Permian formations encountered in the Middle East, several have little or no potential as reservoir rocks. These include the metamorphosed sediments of the Hatat Phyllites in northern Oman, the impervious argillaceous rocks of the lower Sudair Shale and the poorly sorted coarse clastics of the Wajid Sandstone.

It is the predominantly carbonate rock units of the Permian, which constitute the most important actual and potential reservoir rocks in Iran, Iraq and Arabia. These include the Khuff Formation of Saudi Arabia, the Qarari, Zinnar and Chia Zairi formations of Iraq, the Hagil Limestone, Bih Dolomite, Qamar Limestone and Asfar Formation in northern Oman, and, particularly, the Upper Permian Dalan Formation in southern Iran and the Persian Gulf. In these carbonate formations, permeability throughout the rock unit is generally low, but there are well-developed zones of

secondary porosity, dolomitization and fracture porosity.

The gas producing Khuff Formation, as known at Bahrain and Dammam, is not uniformly permeable. As seen in the Awali 88 well, it contains numerous impervious bands of anhydrite and anhydritic limestone. The permeable zones are believed to be related to secondary porosity in dolomitized and oolitic portions of the upper part of the Khuff Formation.

In Saudi Arabia, there are numerous impervious cream-coloured marls and red and green gypsiferous clays in the upper half of the Khuff, separating permeable dolomites and dolomitic limestones.

Fracture and joint porosity might be expected to be more significant as reservoir characteristics where the thick carbonate formations of south Iran, north Iraq and north Oman are involved in folding. Numerous fractures, as well as both vertical and bedding-plane joints, are observable in outcrops of massive limestones in the Zagros Ranges of south Iran. In this area, there are considerable thicknesses of light grey dolomites and dolomitic limestones towards the top of the Permian sequence, which have significant secondary porosity. The Harrur and Ora sections of northern Iraq both have about 100 feet of sandy, oolitic limestones in the uppermost part of the Permian, which should present favourable reservoir properties. Similar cross-bedded, oolitic limestones occur in the upper 72 feet of the Permian Harbol Formation, in south-easternmost Turkey, where they underlie the argillaceous Goyan Group of Triassic age. These oolitic limestones are thick bedded to massive and smell slightly foetid on broken surfaces.

In northern Oman, very thick dolomite successions, such as the 2100 feet thick Bih Dolomite at Jebel Hagab, provide much intergranular porosity and appear to have excellent reservoir characteristics.

The significance of limestones and dolomite as reservoir rocks can be gauged from the fact the greatest concentration of large oil fields in the world is in the Middle East. Most of the production is from limestone reservoir rock. Several pools contain 5 billion barrels or more each. There is little physical difference between the Oligo-Miocene Asmari Limestone, the Jurassic limestone of the Arab Zone, and the Permian limestones, which concordantly underlie them. So far, however, only gas production has been proved from the Permian carbonates of the Middle East, especially in South Iran and the Persian Gulf.

## IX. THE CAP ROCKS FOR PERMIAN RESERVOIRS.

1. Impervious cap rocks, or roof rocks, for actual and potential Permian hydrocarbon reservoirs exist in several stratigraphic positions. These are:

- i. conformably overlying the Permian
- ii. unconformable on the Permian
- iii. within the uppermost Permian
- iv. within the remainder of the Permian System.

Prospective Permian carbonate reservoir rocks are, in general, well provided with overlying and interbedded impervious strata, which could serve as a cap rock. An exception to this is northern Oman and south-eastern Iran, where thick Permian carbonates pass upwards into dolomites or thinner bedded limestones and dolomites of the Lower Triassic. In this case, the continuous Upper Permian-Lower Triassic carbonate sequence may act as a single prospective reservoir for which the first potential cap rock would be the evaporites of the Triassic Dashtak Formation in south-east Iran. In surface exposures in the Oman Mountains, possible capping strata are not so obvious, as even the Jurassic and Middle Cretaceous continue as carbonates. However, in the Fahud 1 well a thin horizon of anhydrites and dolomitic limestones occurs immediately above the Permian, which could provide a possible cap rock in the area south-west of the Oman ranges.

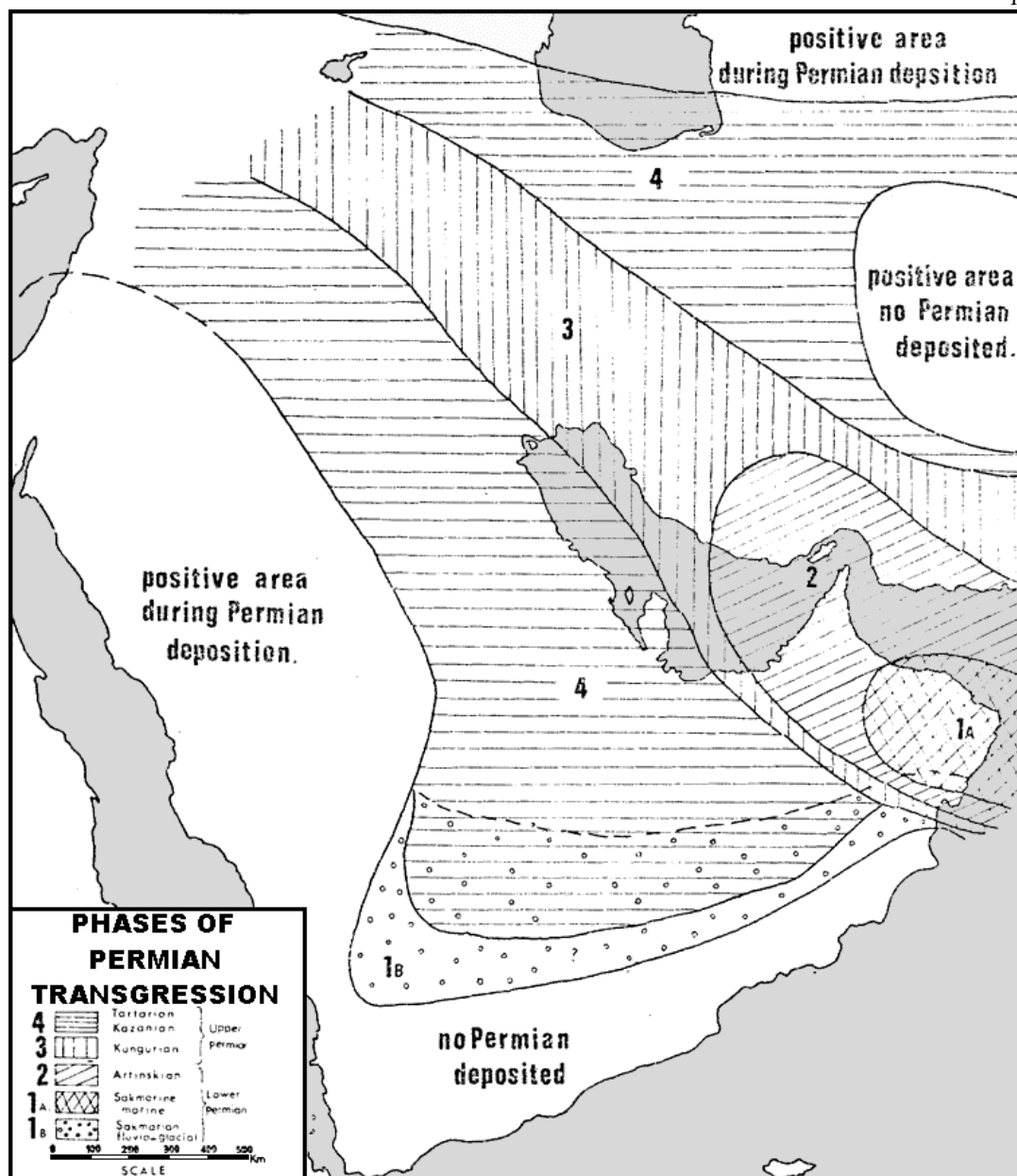


Figure 7

- i. cap rock conformably overlying the Permian.

The situation in which impervious strata are found conformably overlying the Permian System offers the most favourable cap rock conditions. This is found in south-eastern Turkey, northern Iraq and most of south Iran, where argillaceous rock units of the Triassic immediately overlie the Permian carbonate sequences. In surface sections and wells in south-eastern Turkey, the argillaceous Goyan Group of Triassic age rests conformably on the Permian Inbirik and Harbol formations. Soft marls, marly limestones and red-brown to purplish shales predominate in the lower part of the Goyan Group and form an excellent impervious cap rock for the underlying prospective reservoir rocks of the Permian.

In northern Iraq, surface exposures of Upper Permian carbonates at Chalki, Ora and Harrar grade upwards into argillaceous and calcareous beds of the Mirga Mir Formation. The latter consists of some 656 feet of thin-bedded, grey and yellow, marly limestones and shales with slump beds and recrystallization breccias. The Mirga Mir Formation is Lower Triassic and of Early Werfenian age. It conformably overlies the massive Permian carbonates of the Chia Zairi Formation and could form an effective cap rock for them. Overlying the Mirga Mir is a more argillaceous Lower Triassic formation, known as the Beduh Shale. It consists of 210 feet of red-brown and purplish shales and marls with minor thin ribs of limestone and certainly represents an impervious cap rock.

Most of the Permian sections in the Zagros Ranges of south Iran are also conformably overlain by Lower Triassic Marls. This is seen at Pul-e Zarreh in the Bakhtiari country, as well as at Kuh-e Dinar in the Qashqai Sarhad. The thickness of these Triassic marls in the Kuh-e Dinar section is at least 450 feet, including a few thin, intercalated, dolomitic limestones. In coastal Fars, the basal Dashtak shale member occurs together with Triassic evaporites capping both the Kangan and Dalan formations.

Throughout most of the areas underlain by Permian carbonates in Saudi Arabia there is also a conformable cover of brick red and dark red massive shale up to 380 feet thick. These impervious beds, known as the Sudair Shale, are partly Triassic but also extend into the Upper Permian. They form an effective cap rock for the Khuff Limestone.

ii. cap rocks unconformably overlying Permian.

There are only a few minor cases where potential Permian reservoir rocks are overlain unconformably by considerably younger impervious strata. They are mostly marginal to the main areas of Permian sedimentation in southern and south-eastern Arabia. One such instance is in Dauka 1, northern Dhofar, where a reduced section of the Permian Khuff Formation 200 feet in thickness is overlain unconformably by grey green and chocolate brown shales of the Lower Cretaceous Thamama Group. The unconformity is non-angular one (i.e. disconformity) and, since the Permian carbonates are present in an up-dip, wedge-out, the presence of any overlying impervious strata could be of significance as a roof rock.

iii. cap rock within the uppermost Permian.

The lower Sudair Shale, which palynological studies have shown to be Permian, forms an extensive cap rock within the uppermost Permian for the known Khuff carbonate reservoir. The thickness of the lower Sudair is 164 feet at its type sequence in the south-eastermost Rub' al Khaki. It is believed to thin gradually towards the north-east.

iv. other cap rocks within the Permian System.

It appears that relatively impermeable zones within the Permian carbonate sequences are almost as important as overlying impervious cap rock formations. Thus, several zones have tested gas in the Permian Khuff Formation at Bahrain. These represent zones of dolomitization and secondary porosity within the Khuff and are thought to be separated by impermeable layers of dense, microcrystalline limestone, anhydritic limestones and a few thin anhydrite layers. They can be seen on the accompanying lithological log of the Permian in Awali 88. Evidently, Aramco have also recognized and named separate permeable zones within the Permian carbonates, as they refer to production of gas from the Dhahran Zone of the Khuff Formation in Dammam No.43. In Saudi Arabia, there are known to be thin layers of cream-coloured marls and green gypsiferous clays in the upper half of the Khuff. They probably act as permeability barriers or cap rocks within this dominantly carbonate formation.

In southwest Iran, several stratigraphic sections show the presence of impermeable marls and shales within the Permian. At Pul-e Zarreh, there is a marl unit 125 feet in thickness in the middle of some 3000 feet of Permian limestones and dolomites. Similar units of grey and brown shale occur in the

Permian at Ushtarun Kuh.

The Chia Zairi Limestone of northern Iraq also contains a marl-dolomite unit some 200 feet thick in the middle of the Permian carbonate sequence. This unit is known as the Satina Formation and could presumably act as a cap rock for the fossiliferous limestones of the Zinnar Formation.

#### X. SOURCE ROCKS OF PERMIAN HYDROCARBONS.

Since Permian carbonates in the Middle East contain considerable gas in at least seven fields, as well as minor surface oil indications, there must be source rocks from which these hydrocarbons have been derived. There is a common conception that dark, organic shales have been the source rocks for most sand or carbonate reservoirs. In the Middle East, however, the overwhelming predominance of carbonate rocks and extreme scarcity of dark organic shales, coupled with the immense oil reserves in carbonate reservoirs, suggests that much of the oil may be indigenous to these reservoirs. In considering the origin of Arabian Jurassic oil in the upper Jubaila and Arab 'D' member, Steineke, Bramkamp and Sander (1958) have concluded that it has come either from these carbonates themselves, or from carbonate muds of the lower Jubaila. It is most probable that hydrocarbons found in similar Permian carbonate reservoir rocks have also originated there. The limestones of the Permian System in Iran, Iraq and Arabia are richly fossiliferous and have clearly contained much organic material at the time of burial. In addition, a regional Variscan unconformity immediately underlies the Permian carbonate formations in the Middle East. There are virtually no underlying shale source rocks. For the most part, the Permian limestones and dolomites of Arabia rest unconformably on clastics of the Older Paleozoic strata, such as the Cambrian Saq Sandstone, or other clastics like the Wajid Sandstone, which would provide most unprospective source rocks.

In southern Iran, Lower Paleozoic clastics directly underlie the Permian. Beneath the Permian carbonates in Oman, one finds either Lower Permian clastics or Ordovician sandstones. Thus, the known formations beneath the Variscan unconformity in Iran, Iraq and Arabia are not considered to have been source beds for Permian hydrocarbons.

It is conceivable that oil and gas have found their way into the Permian reservoir rocks by lateral migration from some point where they unconformably overlie dark shale source beds.

This has most probably been the case with the bitumen impregnated sandstones at the base of the Permian Hazro Formation in south-east Turkey. These bituminous sandstones rest unconformably on the Siluro-Devonian Handof Formation, a 2950 feet thick, shaly section with locally bituminous black shale intervals. Thus, it is probable that bitumen in the basal Permian sequence at Hazro is derived from source beds beneath the unconformity. Elsewhere in the thick Permian carbonate formations of the Middle East, gas and oil are probably indigenous as underlying strata are mostly older Paleozoic clastics unlikely to be the source rocks of Permian oil.

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Aramco, [1957].- Report of Operations.

Aramco Staff, [1959]- "Ghawar Oil Field, Saudi Arabia." Amer. Assoc. Petroleum Geologists, Bull. 43, No.2.

Boeckh, H. de, Lees G.M., & Richardson F.D.S. [1929]- "Contribution to the Stratigraphy and Tectonics of the Iranian Ranges." In: Gregory J.W. "The Structure of Asia."

Brinkmann, R. [1959]- "Abriss der Geologie, Bd.2, Historische Geologie." 8th Edition, Ferdinand Enke Verlag, Stuttgart.

Dominguez, J.R. [1965]- "Offshore Fields of Qatar." Fifth Arab Petroleum Congress, Cairo.

- Douglas, J.A. [1936]- "A Permo-Carboniferous Fauna from South-west Persia (Iran)." *Palaeontologia Indica*, n.s., vol. XXII, No. 6.
- Douglas, J.A. [1950]- "The Carboniferous and Permian Faunas of south Iran and Iranian Baluchistan." *Palaeontologia Indica*, n.s., vol. XXII, No. 7.
- Dunnington, H.V., Wetzel R., & Morton, D.M. [1956]- "Mesozoic & Palaeozoic." In: "Iraq." Fasc. 10a, vol. 111, Asia. *Lexique Stratigraphique International*; Editor L. Dubertret.
- Elias, M.K. [1937]- "Depth of Deposition of the Big Blue (Late Paleozoic) Sediments in Kansas." *Geol. Soc. Amer., Bull.*, vol. 48, pp. 403-432.
- Gignoux, M. [1955]- "Stratigraphic Geology." W.F. Freeman and Company, San Francisco.
- Gussow, W.C. [1954]- "Differential Entrapment of Oil & Gas: A Fundamental Principle." *Amer. Assoc. Petroleum Geologists, Bull.*, vol. 38, No. 5.
- Hadley, D.G. & Schmidt, D.L. [1974]- "Non-glacial origin for conglomerate beds in the. Wajid Sandstone of Saudi Arabia." *U.S.G.S. Saudi Arabian Project 174*, p. 1-27.
- Harrison, J.V. [1937]- "The Permian of South Iran." (Abstr.) 17th International Geol. Congress, Moscow.
- Hellal, A.H. [1965]- "On the Occurrence and Stratigraphic Position of Permo-Carboniferous Tillites in Saudi Arabia." *Geologische Rundschau*, Bd. 54.
- Henson, F.R.S. [1951]- "Observations on the Geology and Petroleum Occurrences of the Middle East." *Proc. Third World Petroleum Congress, Section 1, The Hague*.
- Hemer, D.O. [1965]- "Application of Palynology in Saudi Arabia." *Fifth Arab Petroleum Congress, Cairo*.
- Huang, T.K. [1932]- "Permian Corals of Southern China." *Pal. Sinica, Ser. B*, vol. VIII, Fasc. 2.
- Hudson, R.G.S. [1958]- "Permian Corals from Northern Iraq." *Palaeontology*, vol. 1, part 3.
- Hudson, R.G.S. [1959]- "The Permian and Trias of the Oman Peninsula, Arabia." *Geol.Mag.*, vol.97, No.4.
- Hudson, R.G.S. & Sudbury, M. [1959]- "Permian Brachiopods from south-east Arabia." *Notes Mém. Moyen Orient*, vii.
- Miklukho-Maklay, A.D. [1963]- "Verkhni Paleozoi Srednei Azii." (Upper Paleozoic of Central Asia) pp. 1-328, Published by Leningrad University.
- Morton, D.M. [1959]- "The Geology of Oman." *Fifth World Petroleum Congress, Proc. Section 1, New York*.
- N.I.O.C. Geological Subcommittee [1976]- "Permo-Trias Rock Stratigraphic Nomenclature in South Iran." (unpublished), Tehran.
- Schmidt, G.C. [1964]- "A review of Permian and Mesozoic formations exposed near the Turkey/Iraq border at Hanbol." *Bull. Mineral Research. & Exploration Inst. of Turkey*, No. 62, pp. 103—119.

Steinecke, M., Bramkamp, R.A., & Sander, N.J. [1958]- "Stratigraphic Relations of Arabian Jurassic Oil." In: "Habitat of Oil." A.A.P.G. Symposium.

Tasman, C. & Egeran, N. [1951]- "The Oil Possibilities of Turkey." Third World Oil Congress, Proc. Section 1, The Hague.

Termier, H. & Termier, G. [1960]- "Paléontologie Stratigraphique." Masson and Cie, Paris.

Picard, L. [1964]- "Oil Exploration in Israel."

Pokorny, V. [1967]- "Geology of Syria." Damascus.

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The Permian system as an oil & gas reservoir in Iran, Iraq & Arabia. Proc. Second Iranian Geological Symposium, Tehran, p. 161-201, 7 text-figs. 1-7, 6 enclosures.

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