

Cretaceous Subsurface Geology of the Middle East Region

Louis Christian
International Consultant

ABSTRACT

A regional structure contour map at Near Top Cretaceous is based on hundreds of well tops from extensive bibliographic references from throughout the Middle East. This structure map shows strong basin asymmetry. Major faults are shown in outcrop and/or suspected at basement or intermediate levels, based in part on gravity and magnetics modeling, published and in 'open file' studies. Major uplifts associated with several super-giant oil and gas fields are clearly indicated even at the shallow Cretaceous level (Ghawar Anticline, Qatar Arch, Burgan-Khuraib Trend, etc.), even at a very regional scale with a contour interval of 1,000 feet. Isopach maps of Upper, Middle, and Lower Cretaceous are contoured at intervals of 500 feet. Each of these three isopach maps is overprinted in color to show generalized lithofacies trends. Lower and Middle Cretaceous deltaic sandstone fairways on the western shelf provide excellent reservoir rocks for a trend containing many of the world's very largest oil fields. Somewhat more basinward, predominantly carbonate facies include oil reservoirs in the Upper, Middle, and Lower Cretaceous. Deepest facies lie beneath the Zagros Foothills Belt in coastal Iran and eastern Iraq. This is particularly true for the Upper Cretaceous, where Coniacian to Maestrichtian thick, deep basinal shales, cherts, clastic turbidites, and slumped exotic blocks of ophiolites mark the northeastern border of the Late Cretaceous basin as it approaches the Main Zagros Fault and an assumed subduction zone underthrusting the Iranian Plate or Eurasia.

INTRODUCTION

The reservoirs of many super-giant oil fields of the Middle East are Lower to Middle Cretaceous deltaic sandstones. Some examples are Kuwait's Burgan field with 86 billion barrels of oil (BBO), Saudi Arabia's Safaniya (32 BBO and the largest offshore field in the world) and Iraq's Majnoon (30 BBO). Table 1 and Figure 1 show the largest 33 Middle East oil fields.

Lower and Middle Cretaceous carbonate reservoirs also account for huge oil reserves in such fields as Iraq's Rumaila (22 BBO), Abu Dhabi's Zakum (17 BBO) and Saudi Arabia's Zuluf (14 BBO). Upper Cretaceous carbonate reservoirs also contain giant oil reserves in such fields as Dubai's Fateh (6 BBO) and Abu Dhabi's Shah (3 BBO).

Out of a total of 33 Middle East oil fields with ultimate recoverable reserves greater than about 5.0 BBO, 17 have Cretaceous reservoirs (Figure 1 and Table 1). Most of the super-giant oil fields in the Middle East are trapped in large anticlines or faulted anticlines (Aramco Staff, 1959; Bou-Rabee, 1986; Beydoun, 1988; Edgell, 1991, 1992; Carman, 1996). This is specifically true for the giant and super-giant Cretaceous oil fields which are identified in the oil productive Cretaceous fairway shown on Figure 1. Approximate reserves are rounded to the nearest billion barrels (Adasani, 1965; Schlumberger, 1975; Ibrahim, 1983, 1984; Beydoun, 1988; Brennan, 1990, 1991; Ivanhoe and Leckie, 1993).

In spite of the importance of the Cretaceous Middle East petroleum system there have been only limited published regional maps of Cretaceous structure, isopachs, and lithofacies distribution. Most of the published regional maps are areally limited, or include only sparse or out-of-date well control (e.g. Kaymen-Kaye, 1970; Murriss, 1980; Koop and Stoneley, 1982).

Regional maps are important tools in exploration. Isopach and lithofacies maps not only indicate important reservoir fairways along which large structural closures are productive but also areas with

Table 1
Super-Giant Middle East Oil Fields

| Top 33 Ranked Oil Fields | Country | Primary Reservoir | Billions Recoverable Barrels |
|---------------------------------|----------------|---|-------------------------------------|
| Ghawar | Saudi Arabia | Upper Jurassic carbonates | 90 |
| Burgan | Kuwait | Lower Cretaceous sandstone | 86 |
| Safaniya | Saudi Arabia | Lower Cretaceous sandstone | 32 |
| Majnoon | Iraq | Lower Cretaceous sandstone | 30 |
| Rumaila | Iraq | Cretaceous carbonates | 22 |
| Zakum | Abu Dhabi | Lower Cretaceous carbonates | 17 |
| Kirkuk | Iraq | Tertiary, Cretaceous carbonates | 17 |
| Manifa | Saudi Arabia | Lower Cretaceous, Upper Jurassic | 15 |
| Umm Shaif | Abu Dhabi | Lower Cretaceous, Upper Jurassic carbonates | 14 |
| Zuluf | Saudi Arabia | Lower Cretaceous carbonates | 14 |
| Ahwaz | Iran | Tertiary, Cretaceous carbonates | 13 |
| Abqaiq | Saudi Arabia | Upper Jurassic carbonates | 13 |
| Khurais | Saudi Arabia | Upper Jurassic-Paleozoic carbonates | 12 |
| Marun | Iran | Tertiary-Upper Jurassic carbonates | 12 |
| Berri | Saudi Arabia | Upper Jurassic-Paleozoic carbonates | 11 |
| Gachsaran | Iran | Tertiary, Upper Cretaceous, Lower Cretaceous | 11 |
| East Baghdad | Iraq | Lower Cretaceous sandstone | 10 |
| North Field | Qatar | Permian carbonates-Devonian sandstone? | 10? + gas |
| Bu Hasa | Abu Dhabi | Lower Cretaceous carbonates | 9 |
| Kuh-e Mand | Iran | Tertiary-Cretaceous carbonates | 9? |
| Agha Jari | Iran | Tertiary-Cretaceous carbonates | 9 |
| Raudhatain | Kuwait | Upper Cretaceous-Lower Cretaceous | 8 |
| Khafji | Kuwait | Lower Cretaceous sandstone, carbonates | 7 |
| Qatif | Saudi Arabia | Upper Jurassic, Middle Jurassic carbonates | 6 |
| Marjan | Saudi Arabia | Upper Cretaceous, Lower Cretaceous, Jurassic carbonates | 6 |
| Bab | Abu Dhabi | Lower Cretaceous carbonates | 6 |
| Fateh | Dubai | Upper Cretaceous carbonates | 6? |
| Sabriya | Kuwait | Upper Cretaceous carbonates, Lower Cretaceous sandstone | 5 |
| Asab | Abu Dhabi | Lower Cretaceous carbonates | 5 |
| Zubair | Iraq | Upper Cretaceous carbonates, Lower Cretaceous sandstone | 5 |
| Shaybah | Saudi Arabia | Lower Cretaceous carbonates | 5 |
| Dukhan | Qatar | Upper Jurassic, Middle Jurassic carbonates | 5 |
| Abu Sa'fah | Saudi Arabia | Upper Jurassic carbonates | 4 |

Note: About 80 to 90 Middle East oil fields have greater than one billion barrels of ultimate recoverable oil. Of the top 33 super-giants (greater than about five BBO) 17 have Cretaceous reservoirs.

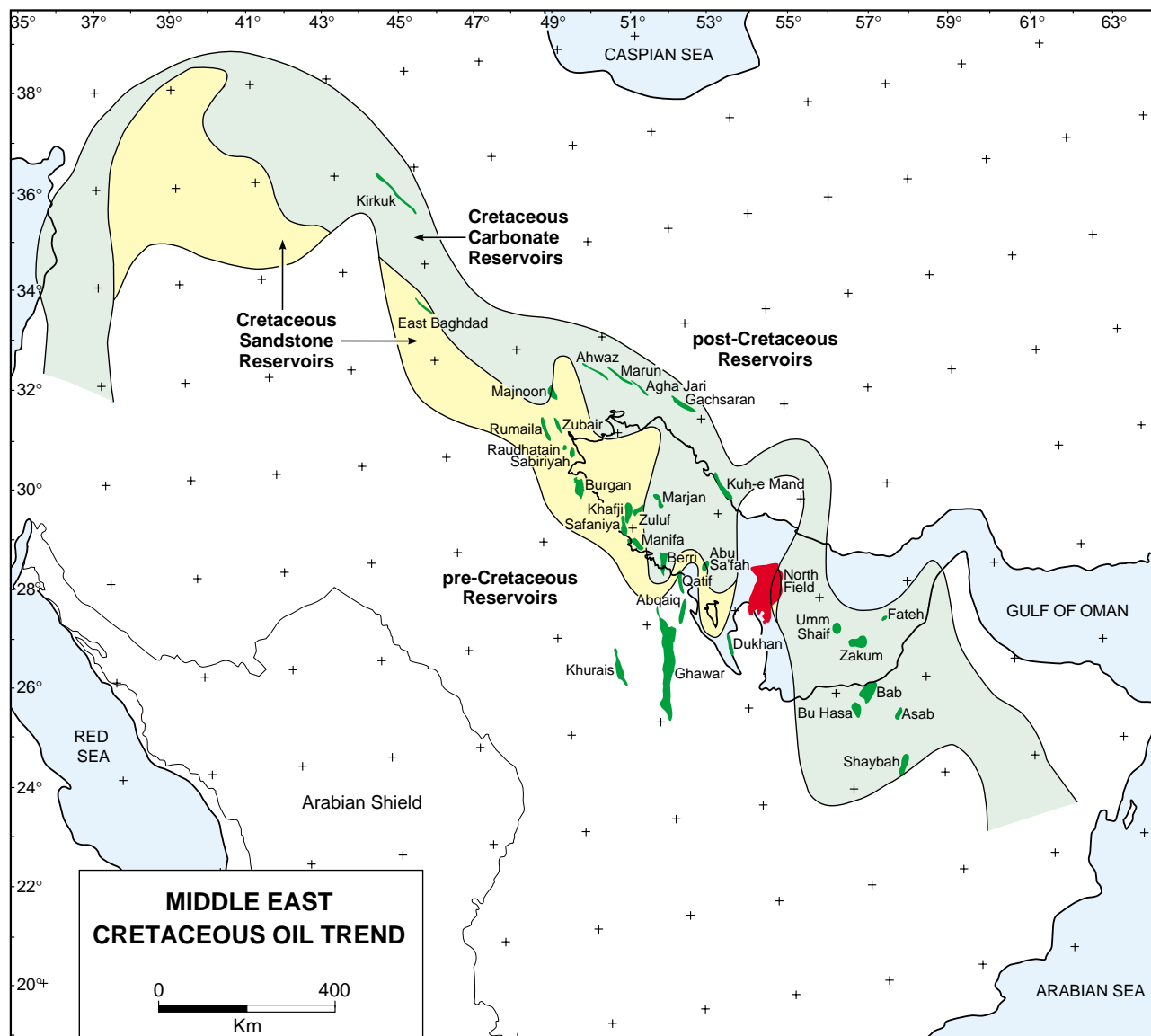


Figure 1: Cretaceous oil field trends include 17 of the 33 ‘Super-Giant’ Middle East oil fields, as well as dozens of other major and lesser oil fields from Oman northwesterly to Turkey. Most of the super-giants are trapped in large anticlines or faulted anticlines within identified productive Cretaceous fairways, but stratigraphic trap potential may also be inferred from isopach-lithofacies maps.

stratigraphic trap potential. They may show key sub-basins where good source rocks are developed. They may also be used to gain a better understanding of tectonic activities, growth history, petroleum migration pathways and timing of trap formation.

In this paper regional maps of the Near Top Cretaceous structure are shown for a contour interval equal to 1,000 feet (ft). Also shown are isopachs (contour interval = 500 ft), with generalized lithofacies patterns for the Lower, Middle and Upper Cretaceous. The maps are based on several hundred wells published in the international geological literature. Also stratigraphic and structural sections and detailed isopach, facies and structure maps of small local areas helped provide control for overall regional patterns.

CRETACEOUS LITHOSTRATIGRAPHY OF ARABIAN GULF

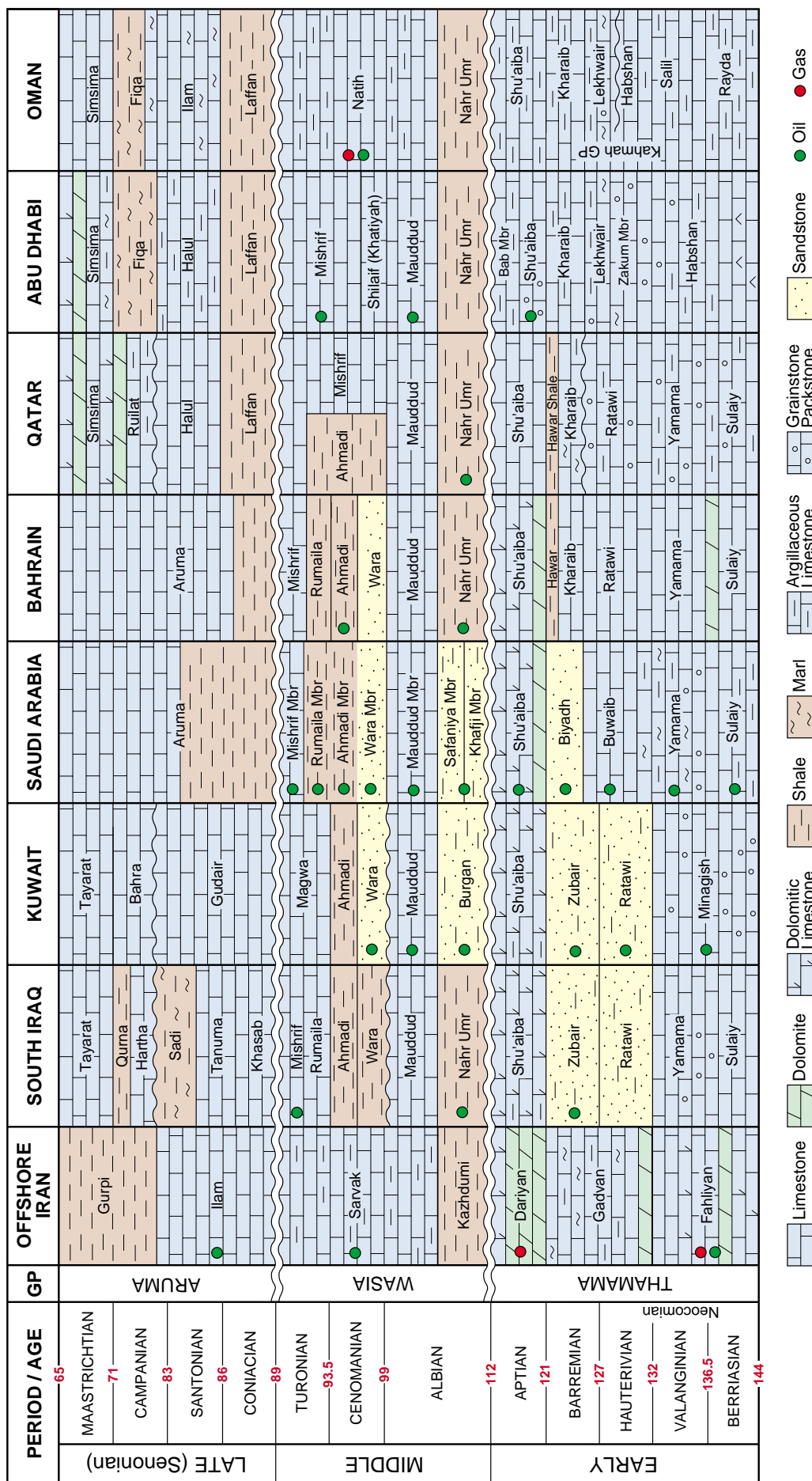


Figure 2: Comparative stratigraphic columns, from Iraq southeast to Oman, showing the Coniacian Laffan-Basal Aruma and equivalents as regional seals overlying Mishrif and equivalent carbonate reservoirs. The Albian Nahr Umr is the regional seal for the Shu'aiba-Upper Thamama carbonate and sandstone reservoirs (modified after Alsharhan and Nairn, 1986, 1988 and 1990).

Standard international Cretaceous subdivisions normally group Berriasian to Albian stages in the Lower Cretaceous, while Cenomanian to Maestrichtian stages are grouped traditionally in the Upper Cretaceous. However, for purposes of this study, the Nahr Umr shale is recognized as a regionally significant upper seal for the Aptian Shu'aiba/Upper Thamama carbonate reservoir rocks (Alsharhan and Nairn, 1990; Alsharhan, 1994). The Coniacian Laffan/Aruma/Tanuma formations and equivalents are recognized as being similarly important regional upper seals for the Turonian Mishrif and equivalent oil reservoirs (Carman, 1996).

For this reason, the European (French) subdivisions of Upper, Middle, and Lower Cretaceous are used in this study, as shown in Figure 2.

REGIONAL STRUCTURE

Gross regional structure of the Middle East Basin, the richest oil and gas province in the world, is reasonably well known (Dubertret and André, 1969; Brown, 1972; Iranian Geological Survey, 1976; Murriss, 1980; Demidov, 1981; Lovelock, 1984; Beydoun, 1988). Near Top Cretaceous structure contour map (Figure 3) shows very clearly:

1. The Precambrian Shield and Central Arabian Arch region west of Riyadh.
2. The shallow east to northeast sloping 'shelf side' of the basin (Rigo de Righi and Cortesini, 1964; Koop and Stoneley, 1982; Le Nindre et al., 1990).
3. The deepest part of this very asymmetrical basin beneath the Zagros Foothills Foldbelt of coastal Iran and eastern Iraq on the east side of the Arabian Gulf (Dubertret and André, 1969; Brown, 1972; Morris, 1977; Setudehnia, 1978; Demidov, 1981).
4. A northern "Mesopotamian Sub-basin" and a southern "Rub' Al-Khali Sub-basin" and a broad positive centrally located structural region composed of several individual highs (Qatar-South Fars Arch, Ghawar Anticline, and Burgan-Khuraish Trend, in particular) on which are found several of the largest oil and gas fields on our planet (Edgell, 1989).
5. In northern Iraq fold axes change direction from northwest to westerly, becoming southwesterly in northern Syria and in adjacent parts of southeast Turkey (Ponikarov et al., 1967).
6. Several types of fault patterns and mini-rift basins of differing ages complicate the northern part of the basin, especially in southeast Turkey and Syria (Cline, 1989; Çemen and Ediger, 1990; Çançar, 1990-93; Tür-Kan Petroleum, 1991; Christian, 1992; de Ruiter et al., 1994).
7. In a very regional sense the left-lateral Dead Sea Fault, trending southwesterly through Lebanon, Palestine and Jordan (Dubertret, 1967; Freud et al., 1970; Gvirtzman and Weissbrod, 1984) and the Main Zagros Fault, with right-lateral as well as thrust component (Gidon et al., 1974), trending northwesterly through Iran and Iraq, form a conjugate pair related to Late Cretaceous-Tertiary northward subduction of the Arabian Plate beneath Eurasia along the Taurus Mountains Thrust Zone (Fairbridge and Badoux, 1960; Brinkman, 1976; Hatcher et al., 1981).
8. Inferred from Bouguer gravity, magnetotelluric sections, limited well data and subcrop patterns, basement faults are shown trending northwesterly through Central Saudi Arabia and western Iraq (Sallomy and Al-Khatib, 1986a, 1986b; Johnson and Stewart, 1993; Stewart et al., 1996). Northerly trending 'basement faults' also appear to form the western boundary of the Ghawar, Khuraish, and Qatar highs (Edgell, 1989, 1991, 1992; McGillivray and Husseini, 1992; Johnson and Stewart, 1993; Christian, 1994b). Some of these faults are confirmed by seismic data, although Saudi Aramco and former Aramco personnel claim major offsets are in Triassic or older and tend to die out upward and may even be undetectable at Cretaceous/Jurassic levels (McGillivray and Husseini, 1992; Johansson, 1997).

9. In western Iraq faults of similar northwest strike are inferred from gravity and magnetic data (Sayyab and Valek, 1967; Abbas, 1983; Ministry of Geology, Moscow, 1984; Alomari and Alnaib, 1986). Seismic and well data are at present too sparse to confirm these faults.
10. The above faults, as well as graben faults in Jordan, are all, more or less, parallel to the Najd Fault System exposed in the Arabian Shield, and also nearly parallel to the Main Zagros Fault of Iran. Although Zagros faulting is supposed to be primarily young, it seems likely that all of these faults of similar strike may be inherited from pre-Hercynian or perhaps even Precambrian structural

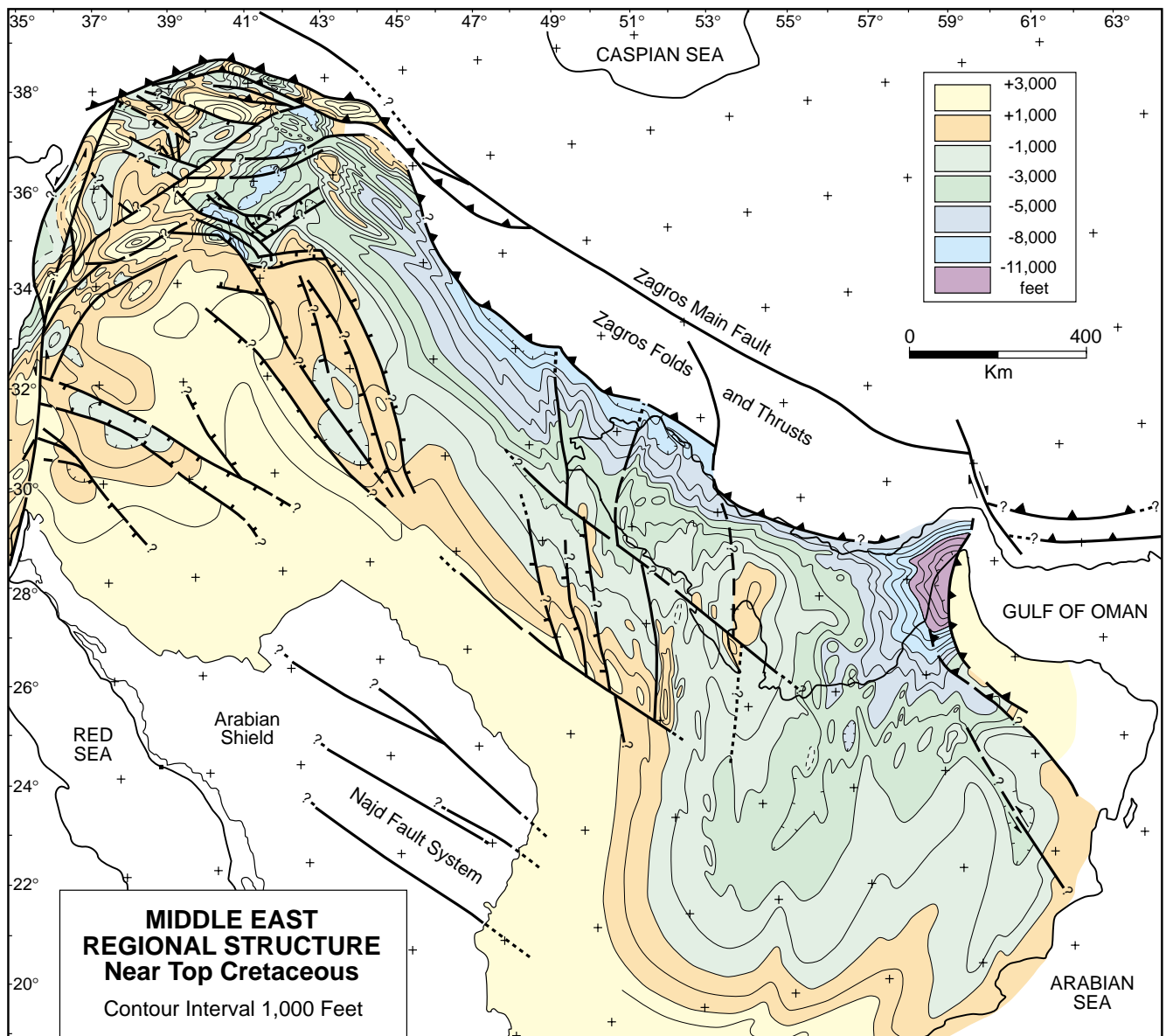


Figure 3: Regional structure, near Top Cretaceous, showing asymmetrical basin with maximum depths to basement in eastern Rub' Al Khali sub-basin near the mouth of the Gulf, and in the eastern part of the Mesopotamian sub-basin. Giant oil productive anticlines and faulted anticlines are prominently displayed even at a regional scale. Lesser rift basins and inverted rifts complicate the northwestern part of the area. Established fault patterns and suspected faults based on gravity and magnetics suggest additional prospective structural trends.

trends, and have been reactivated at various times with, in some cases, demonstrated reversals in the direction of strike-slip motion (Agar, 1987; Husseini, 1988; Jackson and McKenzie, 1988; Christian, 1994a).

11. The Zagros Fold and Thrust Belt shown in Iran is too complex to be contoured at the Cretaceous level at this map scale (Académie des Sciences de L'U.R.S.S., UNESCO, 1981; Berberian and King, 1981); but major (super-giant) oil and gas fields are indicated, with outcrop structure based on Ion et al. (1959), Slinger and Crichton (1959), U.N. Economic Commission for Asia and Far East (1963) and Geological Survey of Iran (1976-77).

Abundant Top Cretaceous well points have been published in the Rub' Al-Khali region of southern Saudi Arabia, Oman and Yemen, but the Top Cretaceous horizon is too shallow to show the deeper structures which produce oil in this region (Soliman and Shamlan, 1982).

LOWER CRETACEOUS ISOPACH-FACIES

Very generalized Lower Cretaceous isopachs are drawn with a contour interval of 500 ft. The superimposed color pattern indicates major lithofacies trends (Figure 4).

Shallow marine deltaic sandstone facies on the western shelf side of the basin include major oil producing reservoirs in Iraq, Kuwait and Saudi Arabia (pre-Aptian/pre-Shu'aiba Zubair and Biyadh formations). Eastward these sands shale-out basinward and become largely replaced by carbonates in Abu Dhabi and adjacent areas, where the carbonates include major oil reservoirs in the Thamama Formation and equivalents. Zubair sands productive at Kifl, in Central Iraq, suggest the Lower Cretaceous deltaic sands are prospective at least 400 kilometers (km) north of the Kuwait border along trend with established production (Figures 1 and 4) in an area of very inadequate exploration. There is as yet no facies evidence of Zagros folding nor subduction at this early stage.

MIDDLE CRETACEOUS ISOPACH-FACIES

Figure 5 maps Middle Cretaceous isopachs, also with a 500 ft contour interval and the same color scheme, to show generalized facies distribution patterns. Enormous oil reserves are contained in the extensive deltaic sands mapped in Saudi Arabia, Kuwait and Iraq in the western and central parts of the greater Middle East Basin (Burgan, Khafji, and Safaniya reservoir sands).

Major oil is also produced from overlying carbonates (Mishrif-Rumaila-Mauddud reservoirs), especially in Iraq, United Arab Emirates, and adjacent areas. The existence of Middle to Lower Cretaceous reservoir sands at East Baghdad field extends these subsurface porosity objectives to at least 450 km north of the Kuwait border. Structural leads within this stratigraphic trend should be well worth seismic investigation and drilling.

Restricted rift deposits with thick evaporites are found in the Levant, extending northeastward from Syria toward Mosul, in northern Iraq (a late stage of the old Triassic-Jurassic rift system where thick evaporite and carbonate sequences have been well described by Dubertret (1967), Druckman (1974), Bach Imam et al. (1980), Beydoun (1981), Bach Imam (1985) and May (1991). Post Cretaceous inversion of this rift basin created the Palmyra Foldbelt in Syria and smaller mini-rift inversions extending east-northeast into northern Iraq (Tel Hajar, Abd El Aziz, Sinjar Anticline).

These Middle Cretaceous rocks still seem to be 'pre-Zagros folding' except that a thick deep basinal turbidite facies with exotic blocks (Boote et al., 1990) exists in the foredeep immediately west of the Oman Mountain Front (Figure 5).

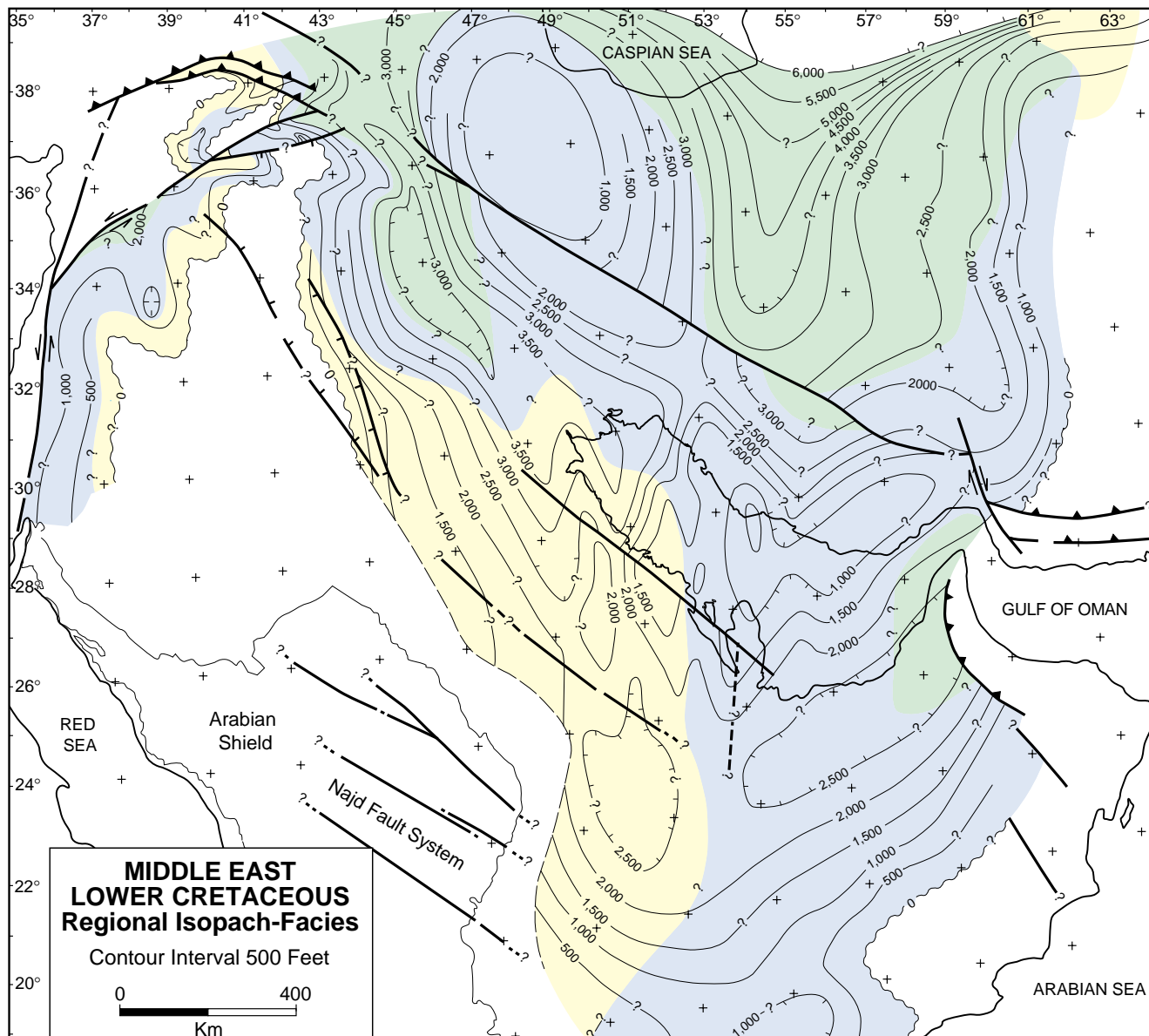
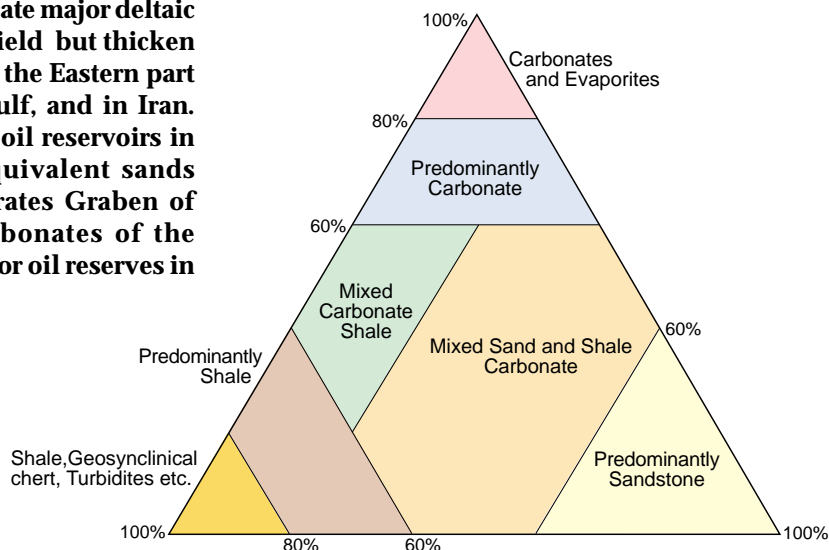


Figure 4: Lower Cretaceous regional isopachs are drawn with a contour interval of 500 feet. Superimposed color patterns indicate major deltaic sand facies fringe the Arabian Shield but thicken into shale and carbonate facies in the Eastern part of the Arabian Peninsula, the Gulf, and in Iran. Zubair sandstones are important oil reservoirs in southern Iraq and Kuwait. Equivalent sands produce oil in the Upper Euphrates Graben of Eastern Syria. Equivalent carbonates of the Thamama Formation contain major oil reserves in Abu Dhabi and adjacent areas.



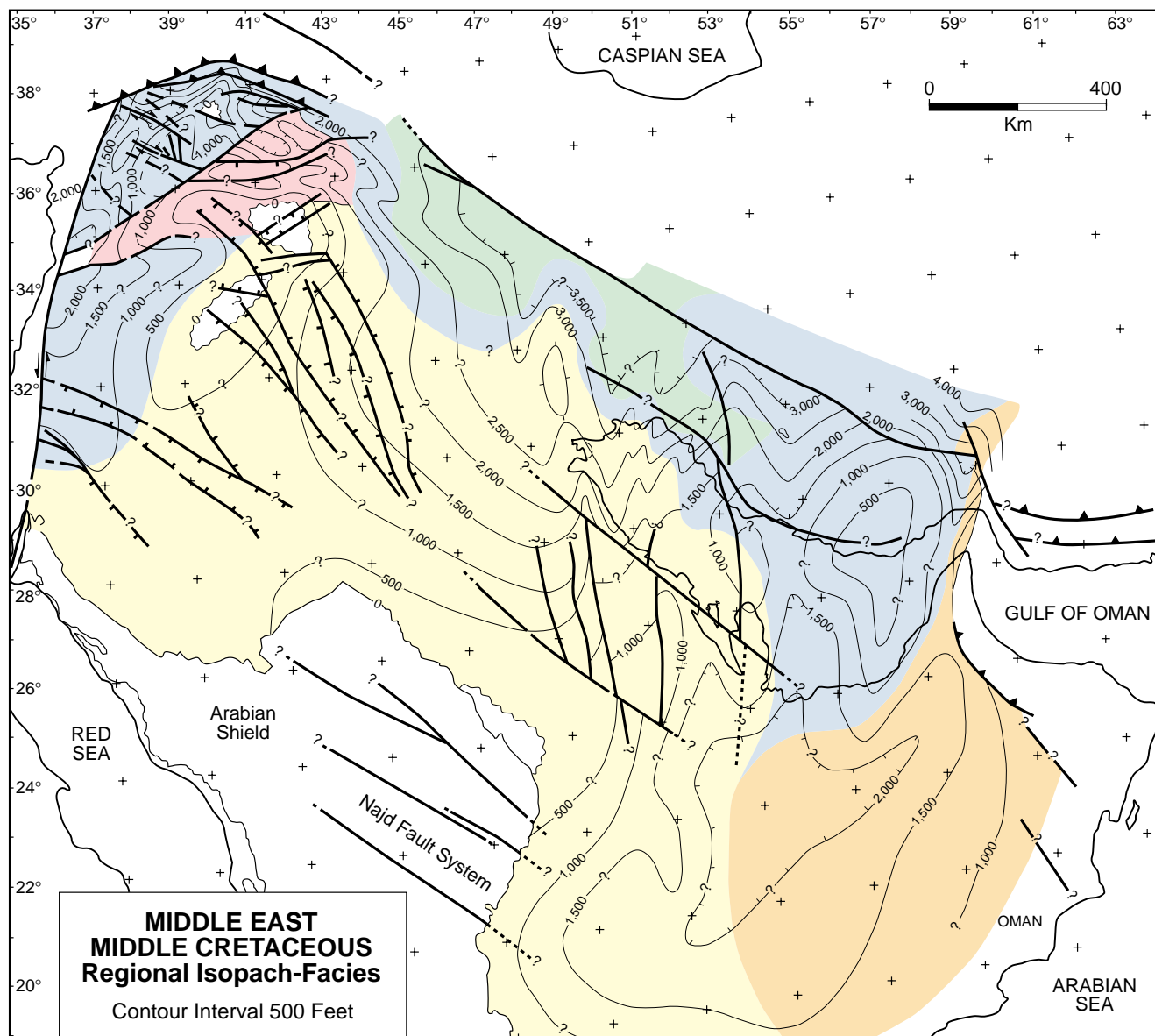


Figure 5: Middle Cretaceous regional isopach and lithofacies. Enormous oil reserves are found in the sandy western shelf of the Middle Cretaceous Basin of Iraq, Kuwait and Saudi Arabia (Nahr Umr, Burgan, Kafji and Safaniya reservoirs). Northeast-trending evaporite-rich rift deposits are found in Syria and Iraq. The overlying Mishrif carbonates also include large oil reserves. Perhaps the greatest future potential exists along a 450-kilometer long Middle to Lower Cretaceous sandstone fairway from Kuwait northwestward through Central Iraq in an area of meager geophysical and drilling activity.

Facing page: Lithofacies legend systems with sandstone and shale end members tend to dominate the western shelf of the Cretaceous isopach-facies maps (see Figures 4, 5 and 6), while carbonate and shale end members are more usual in the central and eastern parts of the Arabian Gulf Basin. Carbonate-evaporite facies and deep marine (bathyal to abyssal) turbidite-chert-shale-ophiolite facies are color coded as local extremes of the predominantly carbonate or predominantly shaley facies.

UPPER CRETACEOUS ISOPACH-FACIES

Figures 2 and 6 indicate Late Cretaceous transgressive facies systems, reversing the extensive regressive deltaic sandstone developments of the Middle Cretaceous. Not only is there very little basin margin sandstone development in the west, but also open marine shelf to deeper marine shales and carbonates predominate over most of the greater Middle East Basin. Locally deeper silled basins (Coniacian Karabogaz Formation, for instance) preserved organic-rich source rocks, although much of the Cretaceous reservoirs are actually charged with Jurassic-sourced oil (Dunnington, 1967; Avedisian and Hammosh, 1970; Ala et al., 1980; Harput et al., 1982; Bordenave and Burwood, 1990; Harput and Ertürk, 1991).

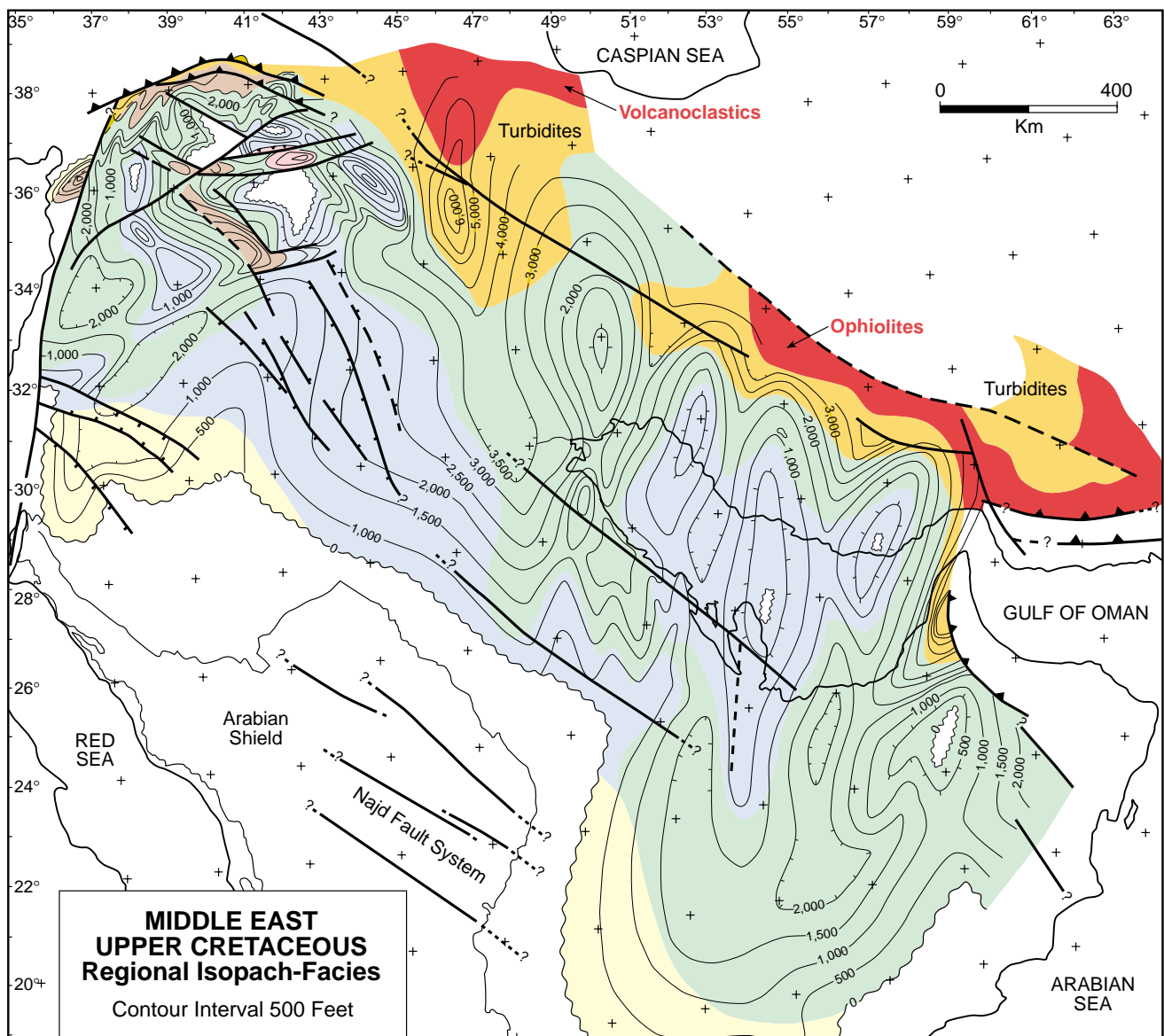
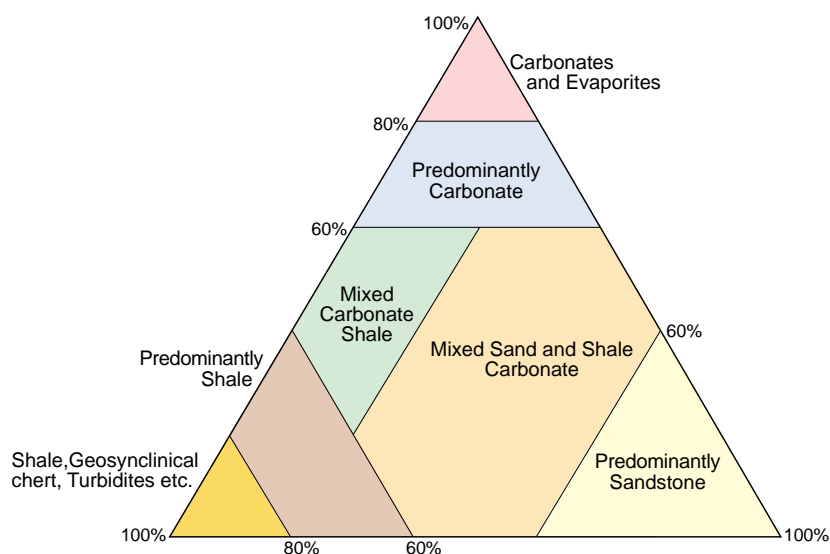


Figure 6: Upper Cretaceous regional isopach-facies systems are markedly transgressive (Coniacian to Maestrichtian), with extensive shaley basinal facies and local reef developments in northern Iraq, southeast Turkey, Qatar and the Emirates. Ultra-deep marine turbidites were for the first time being subducted beneath Iran. Between Coniacian and Maestrichtian time, early stages of the northwest trending Zagros folding and thrusting began in a significant manner. The Zagros Orogeny continued and even accelerated through Quaternary time.



A deepening marine pulse in Coniacian time probably reflects downwarping and northeastward tilting of the Arabian Plate accompanying subduction beneath the Iranian/Eurasian Plate (Erdogan and Akgül, 1981; Soylu, 1991). Shale seals critical to the trapping of numerous Mishrif and Mishrif-equivalent oil fields represent this marine deepening pulse in the Gulf region (Laffan Shale), Iraq (Tanuma Shale), and southeastern Turkey (Karabogaz Formation), as has been suggested by Karig and Kozlu (1990) and Christian (1992). Detailed stratigraphic and subcrop patterns controlling reservoir distribution immediately below this level need further investigation in the United Arab Emirates and Oman (Harris and Frost, 1984; Jordan et al., 1985; Pascoe et al., 1994).

Although old relict north-south isopach trends are still evident on Figure 6, northwesterly trending shallow reef trends parallel to the Zagros Fault in western Iran, eastern Iraq, and northeastern Syria are evident, such as the proposed Suwaidah-Ain Zalah-Alan-Kirkuk trend (Weber, 1963; Nikolayevskiy, 1972; Christian, 1992). Closer to the subduction zone along the Zagros and Taurus Mountain Fronts, thicker and deeper marine facies include shales, red radiolarian cherts, turbidite clastics, and detached slide blocks of serpentines. A similar association of deep bathyal or abyssal lithofacies has been observed being overthrust along the Oman Mountain Front (Alsharhan, 1995; Boote et al., 1990).

These rocks, of Coniacian to Maestrichtian age, undoubtedly were deposited during an early stage of northwest striking Zagros folding, accompanying the Arabian Plate's subduction beneath Iran. Between Coniacian and latest Cretaceous time, then, is bracketed the moment when the Zagros Orogeny first began in a major way. Subduction continued well into the Paleocene and Eocene along the Zagros and Oman Mountain Fronts, and to some extent even into the Oligocene and Early Miocene, particularly at the northern margins of the basins beneath the Taurus Mountains in southeastern Turkey (Académie des Sciences de l'U.R.S.S., UNESCO, 1981; Snyder and Barzangi, 1986). Zagros folding has continued to the end of the Tertiary and even Quaternary.

Local mini-rift basins in Turkey, Syria and northwestern Iraq were particularly active during Late Cretaceous: the Upper Euphrates Rift in Syria, Anah Graben in Iraq, and the Tel Hajar-Abd El Aziz Rift in Syria-Iraq (Youash and Naoum, 1970; Leonov et al., 1986; Leonov et al., 1989); the Abba-Furat mini-rift in Syria (de Ruiter et al., 1994); and the Akçakali Graben in southeastern Turkey (Tardu et al., 1987).

With access to more composite electric and lithologic well logs than are now available, much more detailed net isolith and/or lithofacies percentage contours would permit great improvements in Figures 4, 5, and 6.

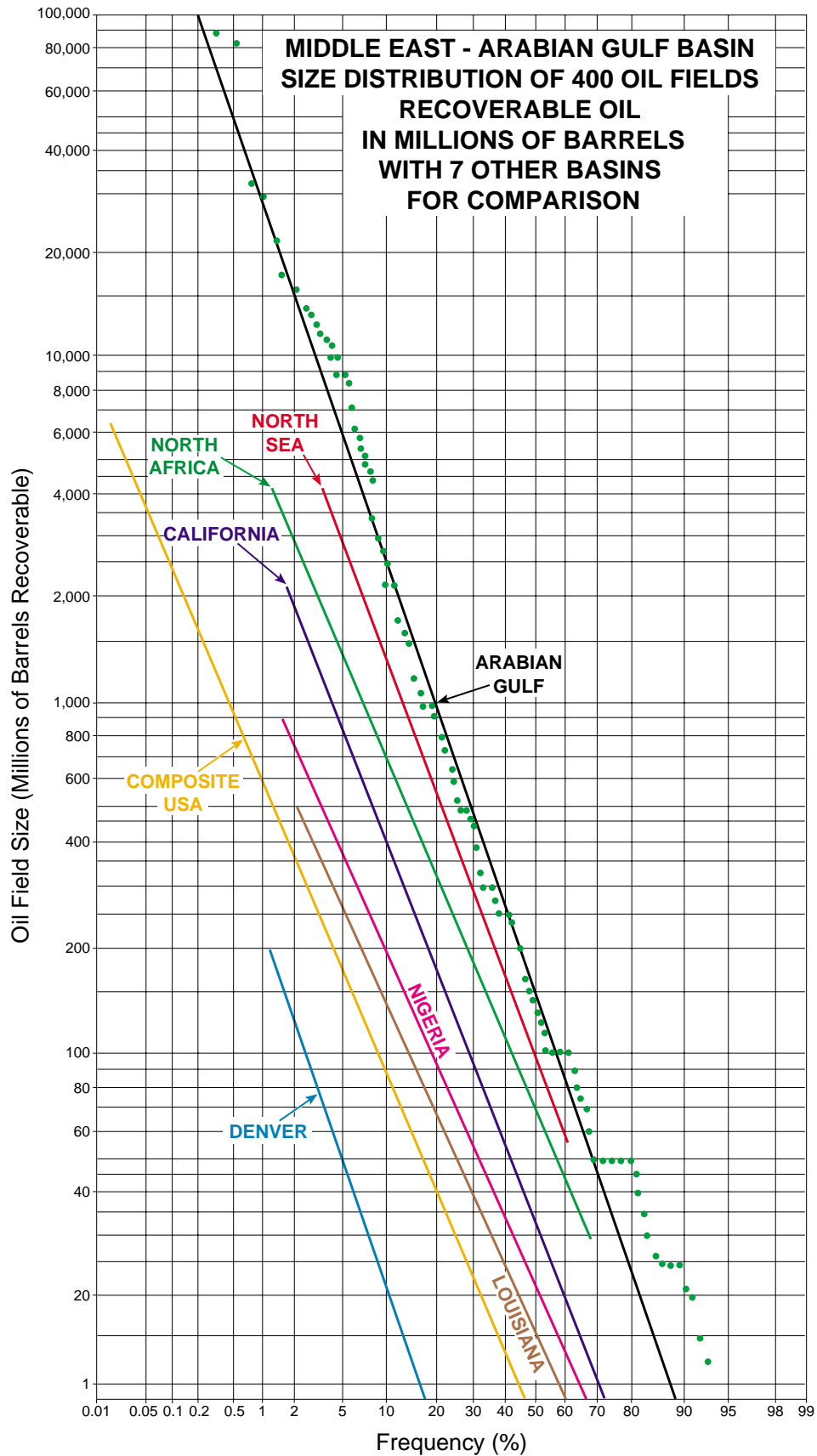


Figure 7: Size distribution of 400 Middle East oil fields, plotted on logarithmic probability paper. Median (50 percentile) reserve size is 150 million barrels. Median field sizes for Saudi Arabia, Iraq and Iran, if plotted individually, would be even larger.

CONCLUSION

The regional Cretaceous structural and isopach/lithofacies maps of the Middle East provide a unique overview of the major tectonic and stratigraphic developments in the leading petroleum basin of the World. The structural map of the Near Top Cretaceous and the Upper Cretaceous isopach show that most of the tectonic elements of the region, including the main anticlinal trends with oil fields remained active during and after the Late Cretaceous. The isopach and lithofacies maps of the Lower, Middle and Upper Cretaceous indicate the development of broad intra-shelf basins along the Cretaceous platform which controlled the regional distribution of lithofacies.

Figure 7 shows the reserve size distribution of 400 oil fields in the Arabian Gulf region, ranked and plotted on logarithmic graph paper. The 50 percentile (median) reserve size for the Middle East is 150 million barrels (MMBO). Similar individual plots for Iraq, Iran and Saudi Arabia, separately, would show median reserve sizes in the 250 to 500 MMBO range. Simplified plots for several lesser oil provinces are shown for comparison (Christian, 1994b).

Vast future potential in the Middle East can be forecast for Cretaceous reservoirs, as for rocks of certain other ages. Perhaps the greatest potential for new giant-sized oil fields in the Middle East lies along a 400-kilometer trend of inadequately explored Lower Cretaceous Zubair sandstone and Middle Cretaceous Khafji-Safaniya sandstone deltaic shelf edge "fairways" between Burgan in Kuwait and Baghdad in central Iraq (Jamil, 1978; Jawad Ali and Aziz, 1993; Christian and Johnston, 1995).

ACKNOWLEDGMENT

The author thanks Professor Abdulrahman Alsharhan for inviting this paper for *GeoArabia*, the referees and the editor for their useful suggestions. Gulf PetroLink redrafted the final figures.

REFERENCES

- Abbas, M. 1983. *Bouguer Gravity Map of Iraq*. Directorate of General Geological Survey and Minerals Investigations, Baghdad.
- Académie des Sciences de L'U.R.S.S., UNESCO, CCGM, Direction Générale des Géodésie et de Cartographie (Congrès Géologie Internationale) 1981. *Carte Tectonique Internationale de L'Europe et des Régions Avoisnantes*. Feuille 16, 2^e Éd., Moscow.
- Adasani, M. 1965. *The Greater Burgan Field*. Fifth Arab Petroleum Congress, Kuwait, p. 19-27.
- Agar, R. 1987. *The Najd Fault System Revisited: A Two-way Strike-Slip Orogen in the Saudi Arabian Shield*. Journal of Structural Geology, v. 9, no. 1, p. 41-48.
- Ala, M., R. Kinghorn and M. Rahman 1980. *Organic Geo-chemistry and Source Rock Characteristics of the Zagros Petroleum Province, Southwest Iran*. Journal Petroleum Geology, v. 3, p. 61-89.
- Alomari, M. and S. Alnaib 1986. *Basement Configuration from Gravity Modelling in Iraq*. Journal of the Geological Society of Iraq, v. 19, no. 10, p. 1304-1318.
- Alsharhan, A. 1994. *Albian Clastics in the Western Arabian Gulf Region: A Sedimentological and Petroleum Geological Interpretation*. Journal of Petroleum Geology, v. 17, no. 3, p. 279-300.
- Alsharhan, A. 1995. *Sedimentology and Depositional Setting of the Late Cretaceous Fiqa Formation in the United Arab Emirates*. Cretaceous Research, v. 16, p. 39-51.
- Alsharhan, A. and E. Nairn 1990. *A Review of the Cretaceous Formations in the Arabian Peninsula: Part III. Upper Cretaceous (Aruma Group), Stratigraphy and Paleogeology*. Journal of Petroleum Geology, v. 13, p. 247-266.

- Arabian American Oil Co. (ARAMCO) Staff 1959. *Ghawar Oil Field, Saudi Arabia*. American Association of Petroleum Geology, v. 43, no. 2, p. 434-454; various other informal and verbal communications.
- Avedisian, A. and A. Hammosh 1970. *Oil gravity and Age Variations in Middle East Crudes*. Journal of the Geological Society of Iraq, v. 3, no. 1, p. 41-53.
- Bach Imam, I. 1985. *Precisions Nouvelles sur l'âge Triassique, et non Jurassique de la Majeure Partie des Formations Évaporitiques et Dolomitiques des Forages de l'Est Syrien*. Revue de Paléobiologie, Genève, v. 4, no. 1, p. 35-42.
- Bach Imam, I., I. Khoja and J. Sigal 1980. *Note sur l'âge Principalement Triassique des Formations Évaporitique et Dolomitique du Mésozoïque Inférieure des Forages de l'Est Syrien*. Journal of the Geological Society of Iraq, v. 13, no. 1, p. 155-160.
- Berberian, M. and G. King 1981. *Towards a Paleogeography and Tectonic Evolution of Iran*. Canadian Journal of Earth Sciences, v. 18, p. 210-265.
- Beydoun, Z. 1981. *Some Open Questions Relating to the Petroleum Prospects of Lebanon*. Journal of Petroleum Geology, v. 3, no. 3, p. 303-314.
- Beydoun, Z. 1988. *The Middle East: Regional Geology and Petroleum Resources*. Scientific Press Ltd. (U.K.), 292 p.
- Boote, D., D. Mou and R. Waite 1990. *Structural Evolution of the Suneinah Foreland, Central Oman Mountains*. In Robertson et al., *The Geology and Tectonics of the Oman Mountains Region*. Geological Society Special Publication no. 49, p. 397-418.
- Bordenave, M. and R. Burwood 1990. *Source Rock Distribution and Maturation in the Zagros Orogenic Belt: Provenance of the Asmari and Bangestan Reservoir Oil Accumulations*. Advances in Organic Geochemistry, Organic Geochemistry, v. 16, no. 1-3, p. 369-387.
- Bou-Rabee, F. 1986. *The Geology and Geophysics of Kuwait*. University of South Carolina Ph.D. Dissertation, 150 p.
- Brennan, P. 1990. *Greater Burgan Field*. American Association of Petroleum Geologists, Treatise of Petroleum Geology, Structural Traps, v. 1, p. 103-127.
- Brennan, P. 1991. *Raudhatain Field-Kuwait*. American Association of Petroleum Geologists, Treatise of Petroleum Geology, Structural Traps, v. 5, p. 187-210.
- Brinkman, R. 1976. *Geology of Turkey*. Elsevier, Amsterdam. 158 p.
- Brown, G. 1972. *Tectonic Map of the Arabian Peninsula, Scale 1:4,000,000*. U.S. Geological Survey Map AP-2.
- Çançar, S. 1990-1993. Verbal communications and numerous maps, geophysical and well data, and correlation charts.
- Carman, G. 1996. *Structural Elements of Onshore Kuwait*. GeoArabia: Middle East Petroleum Geosciences, v. 1, no. 2, p. 239-266.
- Çemen, I. and V. Ediger 1990. *The Bozova Strike-Slip Fault of Southeast Turkey: An Example of a Reactivated Thrust Fault*. Türkiye 8 Petrol Kongresi, Ankara, p. 169-179 (in Turkish).
- Christian, L. 1992. *Subsurface Geology of Turkey-Syria-Iraq Border Area*. Private Consultant's Report, 40 maps, 95 p.

- Christian, L. 1994a. *Projection of Triassic, Permian and Carboniferous Isopach Trends from Arabia Across the Persian Gulf into Iran, and Proposed Sinistral Displacement of Permian Isopachs along the Main Zagros Fault*. Geological Survey of Iran, Scientific Quarterly Journal, v. 3, no. 11, Spring 1994, p. 63-79.
- Christian, L. 1994b. *Distribution of Super-Giant Middle East Oil Fields in Three Distinct Classes of Structural Traps*. December 1994 Meeting of Dallas Geological Society International Group.
- Christian, L. and D. Johnston 1995. *Super-Giant Oil Fields and Future Prospects in the Middle East*. American Association of Petroleum Geologists Bulletin, Abstract, v. 79, no. 6, p. 907.
- Cline, R. 1989. Notes from paper "Thayyem Field Discovery: Syria's Euphrates Graben" delivered at Houston Geological Society International Exploration Meeting in Houston, 17 May 1989.
- Demidov, V. 1981. *Osobyennosti Formirovaniya Struktur Mesopotamskovo Progiba isklona Arabiskoi plit*, Mosk. O-VA Ispytatyelyei Prirody OTD Geol., v. 56, no. 3, p. 45-48 (in Russian).
- Druckman, Y. 1974. *The Stratigraphy of the Triassic Sequence in Southern Israel*. Geological Survey of Israel, Bulletin 64, Jerusalem.
- de Ruyter, R., P. Lovelock and N. Nabulsi 1995. *The Euphrates Graben of Eastern Syria: A New Petroleum Province in the Northern Middle East*. In M.I. Al-Husseini (Ed.), Middle East Geosciences, GEO'94. Gulf PetroLink, Bahrain, v. I, p. 357-368.
- Dubertret, L. 1967. *Remarques sur le Fossé de la Mer Morte et ses Prolongements au Nord Jusqu'au Taurus*. Revue de Géog. Physique et de Géol. Dynamique, v. 9, fasc. 1, p. 3-16.
- Dubertret, L. and C. André 1969. *Carte Orographique et Cartes Tectoniques de la Péninsule Arabique*. Musée Nationale d'Histoire Naturelle, Notes et Mémoires sur le Moyen-Orient, Tome X.
- Dunnington, H. 1967. *Stratigraphical Distribution of Oil Fields in the Iraq-Iran-Arabia Basin*. Journal Institute of Petroleum, v. 53, no. 520, p. 129-161.
- Edgell, H. 1989. *Geological Framework of Saudi Arabia Groundwater Resources*. 1st Saudi Symposium on Earth Sciences, Jeddah, J.K.A.U., Earth Sciences, v. 3, p. 267-286.
- Edgell, H. 1991. *Proterozoic Salt Basins of the Persian Gulf Area and their Role in Hydrocarbon Generation*. Precambrian Research. Elsevier Science Publishers BV, Amsterdam. v. 54, p. 1-14.
- Edgell, H. 1992. *Basement Tectonics of Saudi Arabia as Related to Oil Field Structures*. In M. Richards et al. (Ed.), Basement Tectonics. Kluwer Academic Publishers, Netherlands. p. 169-193.
- Erdogan, L. and A. Akgül 1981. *An Oil Migration and Re-entrapment Model for the Mardin Group Reservoirs of Southeast Anatolia*. Journal of Petroleum Geology, v. 4, no. 1, p. 57-75.
- Fairbridge, R. and H. Badoux 1960. *Slump Blocks in the Cretaceous of Northern Syria*. Geological Society of London Proceedings, pt. 1581, p. 113-117.
- Freud, R., Z. Garfunkel, I. Zak, M. Goldberg, T. Weissbrod and B. Derin 1970. *The Shear Along the Dead Sea Rift*. Philosophical Transactions, Royal Society of London, A. 267, p. 107-130.
- Gidon, M., F. Berthier, J. Billiault, B. Halbronn and P. Maurizot 1974. *Sur les Caractères et l'Ampleur du Coulissement de la "Main Fault" dans la région de Borujerd-Dorud (Zagros Orientale, Iran)*. Comptes rendus des Séances de l'Académie des Sciences, Paris, Sér. D., v. 278, p. 421-424.
- Gvirtzman, G. and T. Weissbrod 1984. *The Hercynian Geanticline of Helez and the Late Palaeozoic History of the Levant*. In J. Dixon and A. Robertson (Eds.), The Geological Evolution of Eastern Mediterranean. Geological Society of London, p. 177-186.

- Harpur, B. and O. Ertürk 1991. *The Organic Geochemical Evaluation of the 9th and 10th Districts of S.E. Anatolia*. Journal of Southeast Asian Earth Sciences, v. 5, no. 1-4, p. 421-428.
- Harpur, B., F. Goodarzi and N. Bozdogan 1982. *A Preliminary Source Rock Analysis Study in Southeast Turkey by Using Organic Petrographical Techniques*. Sixth Petroleum Congress of Turkey, p. 33-49 (in Turkish).
- Harris, P. and S. Frost 1984. *Regional Unconformities and Depositional Cycles: Cretaceous of the Arabian Peninsula*. In J. Schlee (Ed.), *Interregional Unconformities and Hydrocarbon Accumulations*. American Association of Petroleum Geologists, Memoir 36, p. 67-80.
- Hatcher, R., I. Zietz and R. Regan 1981. *Sinistral Strike-Slip Motion on the Dead Sea Rift: Confirmation from New Magnetic Data*. Geology, v. 9, p. 458-462.
- Husseini, M. 1988. *The Arabian Infracambrian Extensional System*. Tectonophysics, v. 148, p. 93-103.
- Ibrahim, M. 1983. *Petroleum Geology of Southern Iraq*. American Association of Petroleum Geologists Bulletin, v. 67, p. 97-130.
- Ibrahim, M. 1984. *Geothermal Gradients and Geothermal Oil Generation in Southern Iraq: A Preliminary Investigation*. Journal of Petroleum Geology, v. 7, no. 1, p. 77-86.
- Ion, D., S. Elder and A. Pedder 1959. *The Agha Jari Oil Field, Southwest Persia*. Third World Petroleum Congress, Section I, p. 162-186.
- Iranian Geological Survey and National Iranian Oil Co. 1976. *Tectonic Map of Southwest Iran, with Structural Contours on Top of Jurassic*. Teheran.
- Ivanhoe, L. and G. Leckie 1993. *Global Oil, Gas Fields, Sizes Tallied, Analyzed*. Oil and Gas Journal, 15 February 1993, p. 87-91, and personal communications, 1992-1993.
- Jackson, J. and D. McKenzie 1988. *The Relationship Between Plate Motions and Seismic Moment Tensors, and the Rates of Active Deformation in the Mediterranean and Middle East*. Geophysical Journal, v. 93, p. 45-73.
- Jamil, A. 1978. *Hydrochemical and Hydrodynamic Zones and the Probable Direction of Water Flow within Zubair Reservoir of Zubair and Rumaila Oil Fields (Southern Iraq)*. Geologisches Jahrbuch, Hannover, D. 25, p. 199-211.
- Jawad Ali, A. and Z. Aziz 1993. *The Zubair Formation, East Baghdad Oil Field, Central Iraq*. Journal of Petroleum Geology, v. 16, no. 3, p. 353-364.
- Johansson, F. 1997. Personal communications.
- Johnson, P. and I. Stewart 1993. *USGS Open File Report 93-5, Jiddah. Magnetic Anomalies and Basement Structure in Central Arabia*. p. 1-29.
- Jorden, C., R. Connally and H. Vest 1985. *Middle Cretaceous Carbonates of the Mishrif Formation, Fateh Field, Offshore Dubai, U.A.E.* In P. Roehl and P. Choquette, *Carbonate Petroleum Reservoirs*. Springer Verlag. p. 426-442.
- Karig, D. and H. Kozlu 1990. *Late Palaeogene-Neogene Evolution of the Triple Junction Region Near Maras, South-central Turkey*. Geological Society of London Journal, v. 147, p. 1023-1034.
- Kamen-Kaye, M. 1970. *Geology and Productivity of Persian Gulf Synclinerium*. American Association of Petroleum Geologists Bulletin, v. 54, no. 12, p. 2371-2394.

- Koop, W. and R. Stoneley 1982. *Subsidence History of the Middle East Zagros Basin, Permian to Recent*. Philosophical Transactions, Royal Society of London, A305, p. 149-168.
- Le Nindre, Y.-M., J. Manivit and D. Vaslet 1990. *Géodynamique et Paléogéographie de la Plate-Forme Arabe du Permien au Jurassique*. Document du BRGM no. 192, Histoire Géologique de la Bordure Occidentale de la Plate-Forme Arabe, v. 2, 273 p.
- Leonov, Y., K. Makarem and T. Zaza 1986. *Olistostrome Origin for Rocks in the Core of the Abd-el-Aziz Anticline, Syria*. Geotectonics, v. 20, no. 2, p. 142-145 (translation from Russian).
- Leonov, Y., S. Sigachev, M. Otri, A. Yusef, T. Zaza and T. Sauaf 1989. *New Data on the Paleozoic Complex of the Platform Cover of Syria*. Geotectonics, v. 23, no. 6, p. 538-542 (translation from Russian).
- Lovelock, P. 1984. *A Review of the Tectonics of the Northern Middle East Region*. Geological Magazine, v. 121, no. 6, p. 577-587.
- May, P. 1991. *The Eastern Mediterranean Mesozoic Basin*. American Association of Petroleum Geologists Bulletin, v. 75, no. 7, p. 1215-1232.
- McGillivray, J. and Husseini, M. 1992. *The Paleozoic Petroleum Geology of Central Arabia*. American Association of Petroleum Geologists Bulletin, v. 76, no. 10, p. 1473-1490.
- Ministry of Geology, U.S.S.R. 1984. *Gravimetric Map of Africa-Middle East, Sheet 3, Scale 1:5,000,000*. Moscow.
- Morris, P. 1977. *Basement Structure as Suggested by Aeromagnetic Surveys in Southwest Iran*. Iran Petroleum Institute, Proceedings of the Second Geological Symposium Iran, p. 294-307. Teheran.
- Murris, R. 1980. *Middle East: Stratigraphic Evolution and Oil Habitat*. American Association of Petroleum Geologists Bulletin, v. 64, p. 597-618.
- Nikolayevskiy, A. 1972. *Upper Cretaceous Petroleum-bearing Reef Complex in Northeastern Syria*. Geologiya Nefti i Gaza, v. 9, p. 71-76 (in Russian).
- Pasco, J., N. Evans and T. Harland 1995. *The Generation of Unconformities within the Mishrif and Laffan Formations of Dubai and Adjacent Areas: Applications to Exploration and Production*. In M.I. Al-Husseini (Ed.), Middle East Geosciences, GEO'94, Gulf PetroLink, Bahrain, v. 2, p. 749-760.
- Ponikarov, V., V. Kazmin, I. Mikhailov, A. Razvaliyev, V. Krashennnikov, V. Kozlov, E. Souliidi-Kondratyew and V. Faradzhev 1967. *The Geological Map of Syria*. Explanatory Notes. U.S.S.R. Mission in Syria.
- Rigo de Righi, M. and A. Cortesini 1964. *Gravity Tectonics in Foothill Structure Belt of Southeast Turkey*. American Association of Petroleum Geologists Bulletin, v. 48, p. 1911-1937.
- Sallomy, J. and H. Al-Khatib 1986a. *Basement Tectonics in the Al-Salman Area, Southwestern Desert, Iraq*. Arabian Journal of Science and Engineering, v. 11, no. 1, p. 77-85.
- Sallomy, J. and H. Al-Khatib 1986b. *Analysis of Gravity and Magnetic Data in the Study of the Structure and Tectonics of the Arar Area, Southwestern Desert, Iraq*. Arabian Journal of Science and Engineering, v. 11, no. 3, p. 213-224.
- Sayyab, A. and R. Valek 1967. *Patterns and General Properties of the Gravity Field of Iraq*. XXIII International Geological Congress, Prague, v. 5, p. 129-142.
- Schlumberger 1975. *Well Evaluation Conference, Saudi Arabia*. Chapter 1, p. 9-25 (by Arabian American Oil Co.).

- Setudehnia, A. 1978. *The Mesozoic Sequence in Southwest Iran and Adjacent Areas*. Journal of Petroleum Geology, v. 1, no. 1, p. 3-42.
- Slinger, F. and J. Crichton 1959. *The Geology and Development of the Gachsaran Field, Southwest Iran*. Fifth World Petroleum Congress, Proceedings, Section I, p. 349-375, New York.
- Snyder, D. and M. Barazangi 1986. *Deep Crustal Structure and Flexure of the Arabian Plate Beneath the Zagros Collisional Mountain Belt as Inferred from Gravity Observations*. Tectonics, v. 5, no. 3, p. 361-373.
- Soylu, C. 1991. *Oil Source Rocks in the Adiyaman Area, Southeast Turkey*. Journal Southeast Asian Earth Sciences, v. 5, no. 1-4, p. 429-434.
- Soliman, F. and A. Shamlan 1982. *Review on the Geology of the Cretaceous Sediments of the Rub'al Khali, Saudi Arabia*. Cretaceous Research, v. 3, p. 187-194.
- Stewart, I., T. Connally and J. Copley 1996. *Stratigraphic Interpretation of Magnetotelluric Data in Central Saudi Arabia*. GeoArabia: Middle East Petroleum Geosciences, v. 1, no. 1, p. 52-63.
- Tardu, T., T. Baskurt, A. Güven, A. Dincer, M. Tuna and U. Tezcan 1987. *Structural and Stratigraphic Aspects of Akçakal Graben and its Hydrocarbon Potential*. Türkiye 7 Petrol Kongresi, Ankara, p. 35-49 (in Turkish).
- Tür-Kan Petroleum Ltd. 1991. Correlation of Lithostratigraphic Rock Units in SE Turkey and Northern Syria-Iraq, and other maps, charts, geophysical data, source rock maturation data, well data, etc. (unpublished data; northern end of basin).
- U.N. Economic Commission for Asia and Far East 1963. *Case Histories of Oil and Gas Fields in Asia and Far East*. Mineral Resources Development Services, Bangkok, no. 20, p. 118.
- Weber, H. 1963. *Ergebnisse Erdölgeologischer Aufschlussarbeiten der DEA in Nordost-Syrien*. Erdöl und Kohle, v. 16, p. 669-682.
- Youash, Y. and A. Naoum 1970. *General Geology of Sinjar Area*. University of Baghdad Bulletin, College of Science, v. 11, p. 136-150.

ABOUT THE AUTHOR

Louis Christian's career began with Chevron in Bakersfield and Los Angeles. After three years in Manila with Anglo-Philippine Oil and Mobil Oil as Senior Geologist and Field Party Chief, he was posted by Mobil to Libya and Tunisia for several years as Staff Geologist, Planning Analyst and Exploration Supervisor. Following a three-year assignment with Mobil Oil Indonesia, Christian spent several years as Associate Geological Advisor in Mobil's International New Ventures Group in Dallas and was involved with Australia, China, Iraq, Abu Dhabi and other Middle East areas. In 1987-88, Christian was International Advisor to Nelson Bunker Hunt in Dallas. In 1988-89 he directed Middle East New Ventures studies for Anschutz Overseas Corporation in Denver and Dallas. Since 1990 Christian has continued Middle East exploration consulting, advising Summit Exploration, Enron, Arco, Amoco, Transworld, BHP, Mosbacher Energy, Mobil and Tür-Kan Petroleum Ltd. In 1990-91, he compiled a five-volume study on subsurface geology and oil potential of the Turkey-Syria-Iraq border area. Christian holds BSc and MSc degrees in Geology from Stanford University.



Manuscript Received 14 May, 1997

Revised 6 July, 1997

Accepted 21 July, 1997