بازسازی نقشه‌های هم‌ضخامت و (هم) رخساره پالئوزوئیك در ایران و شبه‌جزیره عربستان

نوشته: لوئیس کریستین *

چکیده

در این بررسی نقشه‌های توزیع (کنونی) رخساره‌های سنگی همراه با بازسازی Palinspastic چینه‌های کامبرو- اردویسین، سیلورین، دونین و کربنیفر برای گستره‌ای از خاورمیانه با گسترش عرضی حدود ۲۰ درجه از جنوب خاوری ترکیه تا شمال یمن و با گسترش طولی حدود ۲۰ درجه از اورشلیم تا (تنگه) هرمز تهیه شده است.

هدف اصلی از این بررسی عبارت است از تعیین گسترش ناحیه‌ای سنگ‌های منشاء نفت پالئوزوئیک، که می‌دانیم در سیلورین زیرین دارای شیل‌های گراپتولیتی سیاه‌رنگ غنی از مواد آلی بوده، و سنگ‌های مخزن ماسه‌سنگی پالئوزوئیک، که اغلب در کربنیفر و دونین خوب تا عالی و در کامبرو- اردویسین کم و بیش خوب تا نامطلوب هستند.

گام بعدی از این مطالعه بازسازی هرچه بیشتر الگوهای چینه‌شناختی ناحیه‌ای پالئوزوئیک در دو سوی گسلهٔ اصلی زاگرس است که به سبب جابه‌جایی راستالغز متنوع با سن‌های گوناگون تا کنون امکان‌پذیر نشده است. این بازسازی در شرایطی صورت می‌گیرد که رویدادهای دگرگونی و فعالیت‌های آذرین درونی متعدد ایران مرکزی الگوهای رسوبی ناحیه‌ای بسیار واضح را تحت تأثیر قرار داده‌اند.

Abstract

Present day isopach and lithofacies distributions as well as palinspastic reconstructions for strata of Cambro- Ordovician, Silurian, Devonian, and Carboniferous ages are mapped for an area in the Middle East extending approximately 20 ^{o} of latitude from S. E. Turkey to N. Yemen and about 20 ^{o} of longitude from Jerusalem to Hormuz.

The primary purpose of this study is to document the regional extent of Paleozoic petroleu*m source rocks*, which in the Lower Silurian are known to contain richly organic black graptolitic shales, and Paleozoic sandston*e reservoir rocks*, which are often good to excellent in the Carboniferous and Devonian, and fair to relatively poor in the Cambro- Ordovician.

A second objective is to reconstruct as much as possible older Paleozoic regional stratigraphic patterns across the Main Zagros Fault, undeterred by strike slip offsets of several kinds and ages, and in spite of metamorphic and intrusive igneous episodes in Central Iran which tend to mask what would otherwise have been fairly obvious regional sedimentary patterns.

Introduction

The region studied covers an area of about 2400 x 2400 kilometers (1500 x 1500 miles) from S. E. Turkey to the borders of Yemen and Oman, and from the Central Arabian Arch- Arabian Shield to the Caspian Sea- Kopet Dagh and Iranian border with Afghanistan (Figure 1).

This huge area has been studied geologically, both at the surface and in the subsurface, for 75 years or more, in some areas in very great detail, by national and international oil companies, government geological surveys, and academics. A complete bibliography would include more than 1000 entries.

Paleozoic Isopach and Facies Reconstructiouns of Iran and the Arabian Peninsula

By: Louis Christian *

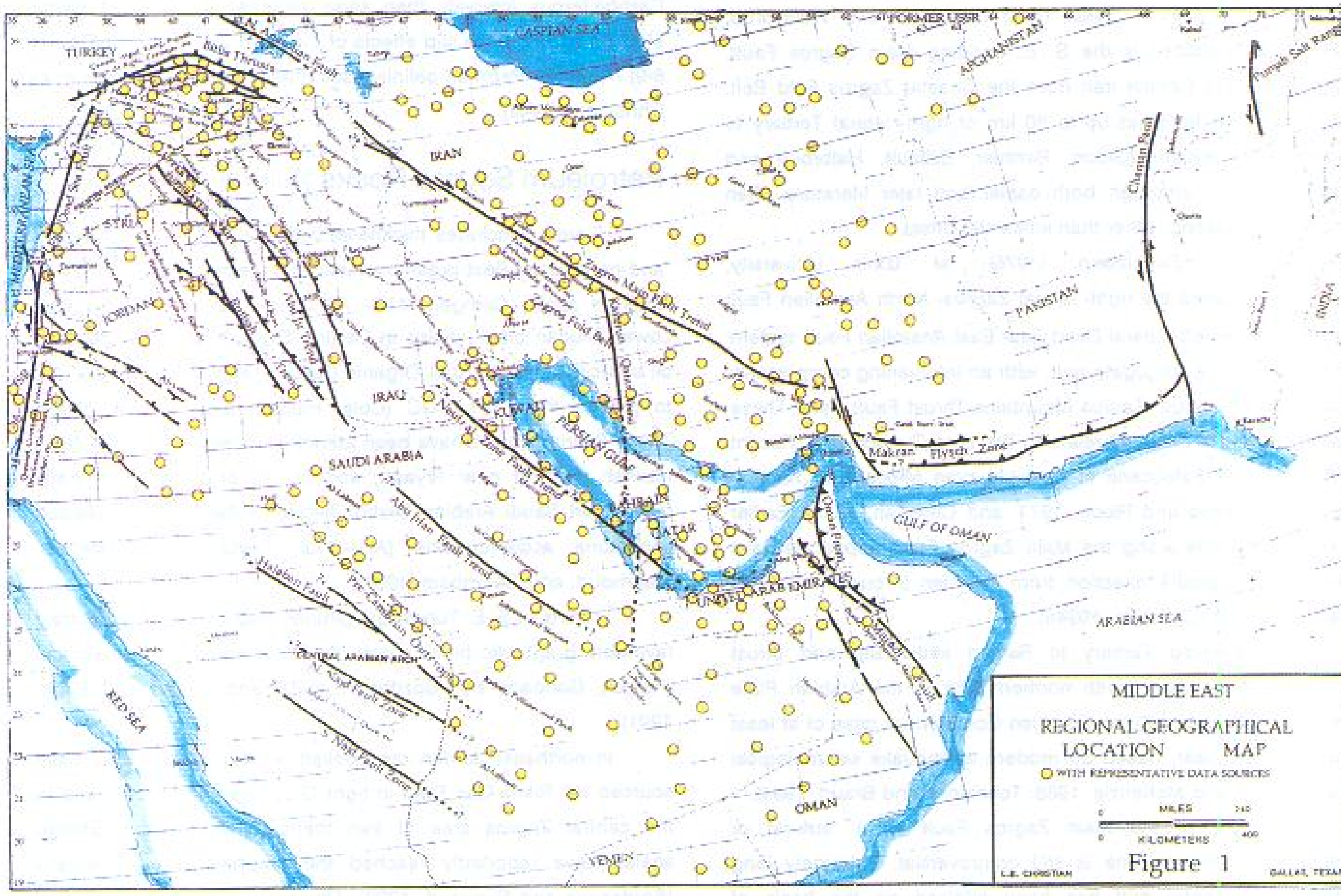


Figure 1

Methodology

Results of local geological studies have been correlated and mapped across a dozen international boundaries and organized rationally on a regional scale. Between 100 and 200 stratigraphic formation names are used in the various countries of the Greater Middle East to define lithologic units which very often have simple counterparts across international borders. Simplifications herein will sacrifice some local accuracy and detail in order to better analyze regional stratigraphic patterns and structural history.

The *Location Map* (Figure 1) indicates many of the previously published sources of data (Wells, outcrop sections, and detailed local isopach, facies or structural maps). Most of the data were plotted and contoured on 1:1,000,000 or 1:2,000,000 scale base maps, drafted and colored at 1:4,000,000, and photographically reduced to 1:16,000,000 for this paper. The appendix to this paper includes a color key to the regional facies patterns which have been mapped. Isopach contours are in kilofeet.

Regional Structure

Figure 1 also shows the well documented Dead Sea Fault, with more than 100 km of left- lateral displacement,trending S.W. through Lebanon, Israel and the Gulf of Aqaba (Freund, Garfunkel, Zak, Goldberg, Weissbrod, and Derin, 1970; Hatcher, Zeitz and Regan, 1981; Quennel, 1959, 1984; Gvirtzman and Weissbrod, 1984). Also indicated is the S. E. trending Main Zagros Fault, which separates Central Iran from the Coastal Zagros Fold Belt. This long linear fault has up to 60 km of right- lateral Tertiary to Recent displacement (Gidon, Berthier, Billiault, Halbroun and Maurizot, 1974), although both earlier and later literature often emphasize thrusting rather than strike slip offset.

Professor Brinkmann (1976), at Izmir University, conveniently called the right- lateral Zagros- North Anatolian Fault System and the left- lateral Dead Sea- East Anatolian Fault system two elements of a conjugate pair, with an intervening compressive zone (the Bitlis- South Taurus Mountains Thrust Fault Belt). These three tectonic elements all relate to the Late Cretacous to Recent perhaps mostly Paleocene or possibly even Miocene to Recent- stress field (Braud and Ricon, 1971, and Christian, 1991). Earlier strike slip motions along the Main Zagros Fault appear to have been in the opposite direction from Permian through Middle or Late Cretaceous (Christian, 1994a).

The observed Tertiary to Recent strike slip and thrust elements are consistent with northern drift of the Arabian Plate and subduction beneath the Eurasian Continent at rates of at least 1 to 2 cm per year, based on modern earthquake seismological data (Jackson and McKenzie, 1988; Tchalenko and Braud, 1994).

Treatment of the Main Zagros Fault as a "suture" or Continental Collision Zone is still controversial. Extremely long distance continental drift has been inferred on the basis of paleomagnetic data (Sengor et al, 1988, Dercourt et. al, 1986; Scotese et. al, 1979; Scotese and McKerrow, 1990; and Beydoun, 1991). But Kashfi (1985, 1988) and others indicate Mesozoic, Paleozoic and even pre-Cambrian rock types are so nearly identical on opposite sides of the *"Zagros Suture"* that the integrity of the greater Middle East Sedimentary Basin on both sides of the Zagros Main Fault seems likely.

No resolution of these apparently conflicting observations is attempted here other than to point out that other faults, farther to the east, such as those bordering the Sanandaj- Sirjan Zone in Central Iran, seem to be associated with much larger *"continental"* displacements than is the case for the Zagros Fault (Alavi, 1994). If long distance continental drift and subduction are for the moment ignored, nevertheless large scale *strike slip* offsets of differing amounts, differing directions, and differing reliability, seem to exist along the Main Zagros Fault.

And so thicknesses and facies are simply contoured as smoothly as possible on both sides of the Zagros Fault for each of the four stratigraphic age intervals (Figures 2-5). Palinspastic maps for the same Cambro- Ordovician, Silurian, Devonian and Carboniferous intervals then show regional stratigraphic trends eliminating the strike slip effects of the Main Zagros Fault (Figures 6-9). A similar Permian palinispastic map was presented earlier by Christian (1994a).

Petroleum Source Rocks (Silurian)

Figure 3 includes thicknesses of total Silurian- both source and nonsource. Best organic content has been found in the Lower Silurian (Cole, Carrigan, Abu- Ali, Tobey, and Halpern, 1994). Lower Silurian black shales in Central Saudi Arabia include such oil source rock with Total Organic Carbon ranging from about 2% to greater than 10% TOC (Cole, Halpern and Aoudeh, 1995). These Silurian shales have been identified as sources for the giant Hawtah oil field near Riyadh, and for 10 or 12 other recently discovered Saudi Arabian Carboniferous or Permo-Carboniferous sandstone accumulations (Abu- Ali, Franz, Shen, Monnier, Mahmoud, and Chambers, 1991).

In parts of S. E. Turkey the Silurian also includes moderately favorable graptolitic black shales thermally within the oil window (Harput, Goodarzi and Bozdogan, 1982, and Harput and Ertük, 1991).

In northeast Jordan overcooked Silurian shales may have sourced the Risha Gas Field in tight Ordovician sandstone, and in the central Zagros area of Iran thermally overmature Silurian shales have reportedly reached the graphite zone (!) locally (Bordenave and Burwood, 1990). Obviously regional variations in Silurian thermal maturity in the Middle East require close attention (Christian, 1994c, 1995).

Paleozoic Oil and Gas Reservoir Rock Potential

Cambro-Ordovician sandstones or quartzite generally have low (2% to 6% or so) porosity and poor permeabilities. However, local porosity enhancement by weathering and/or fracturing may

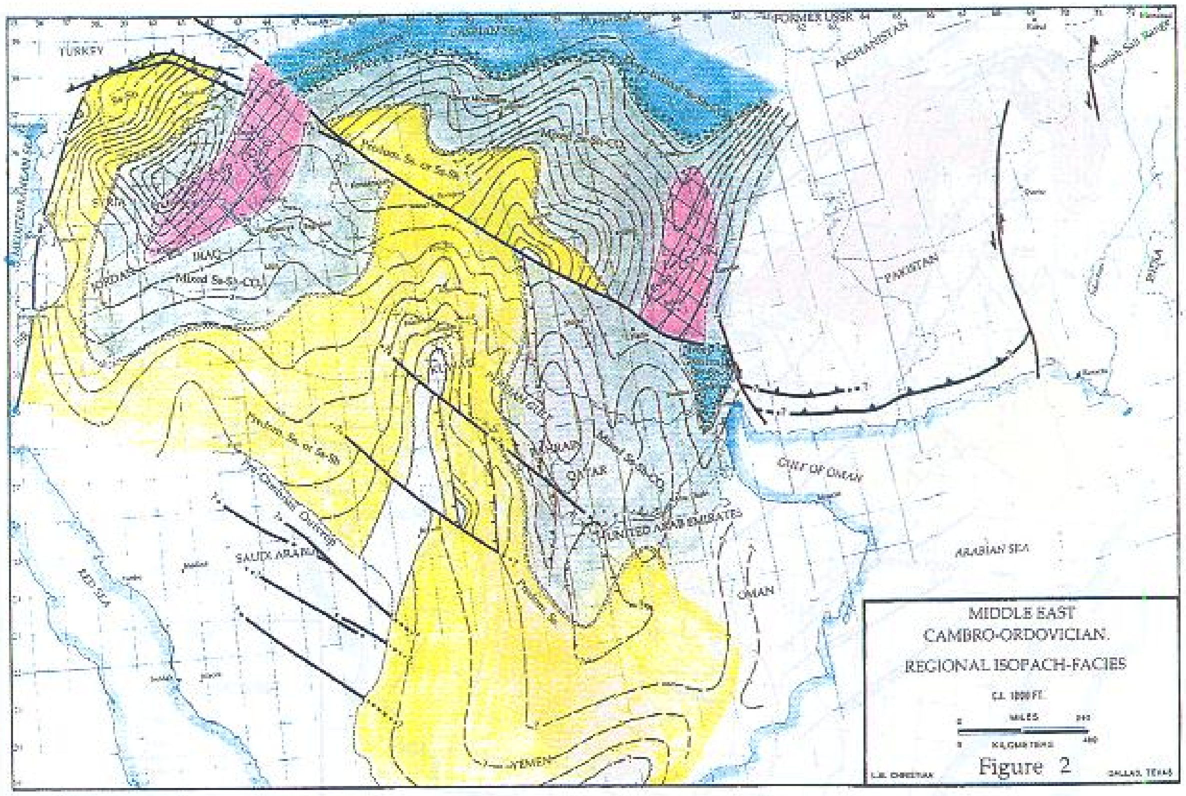
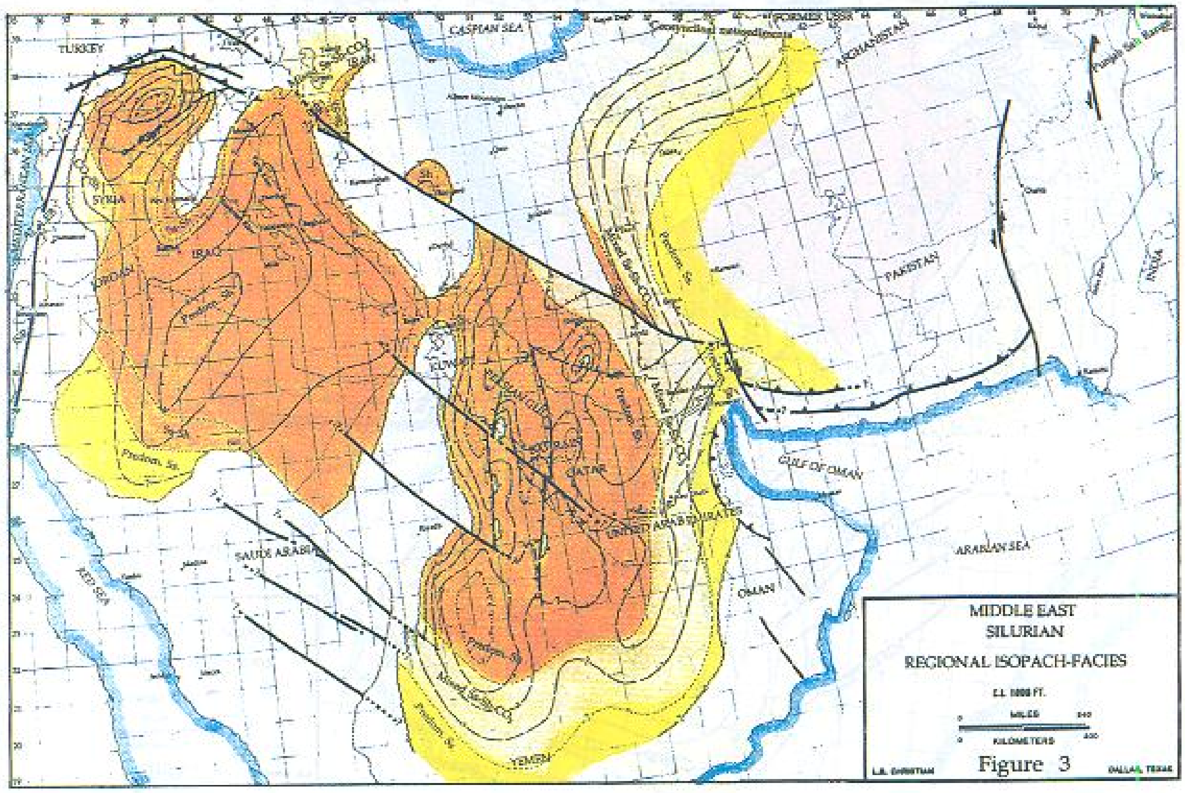


Figure 2



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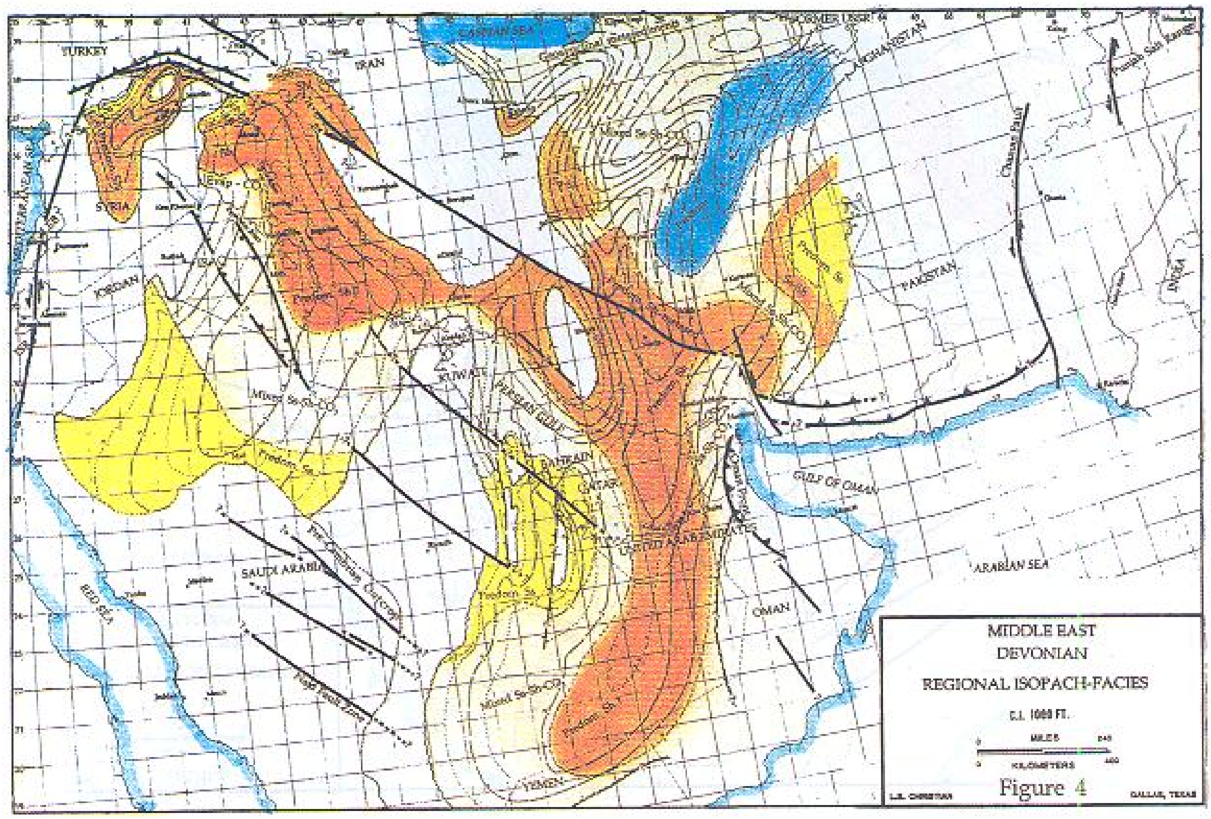
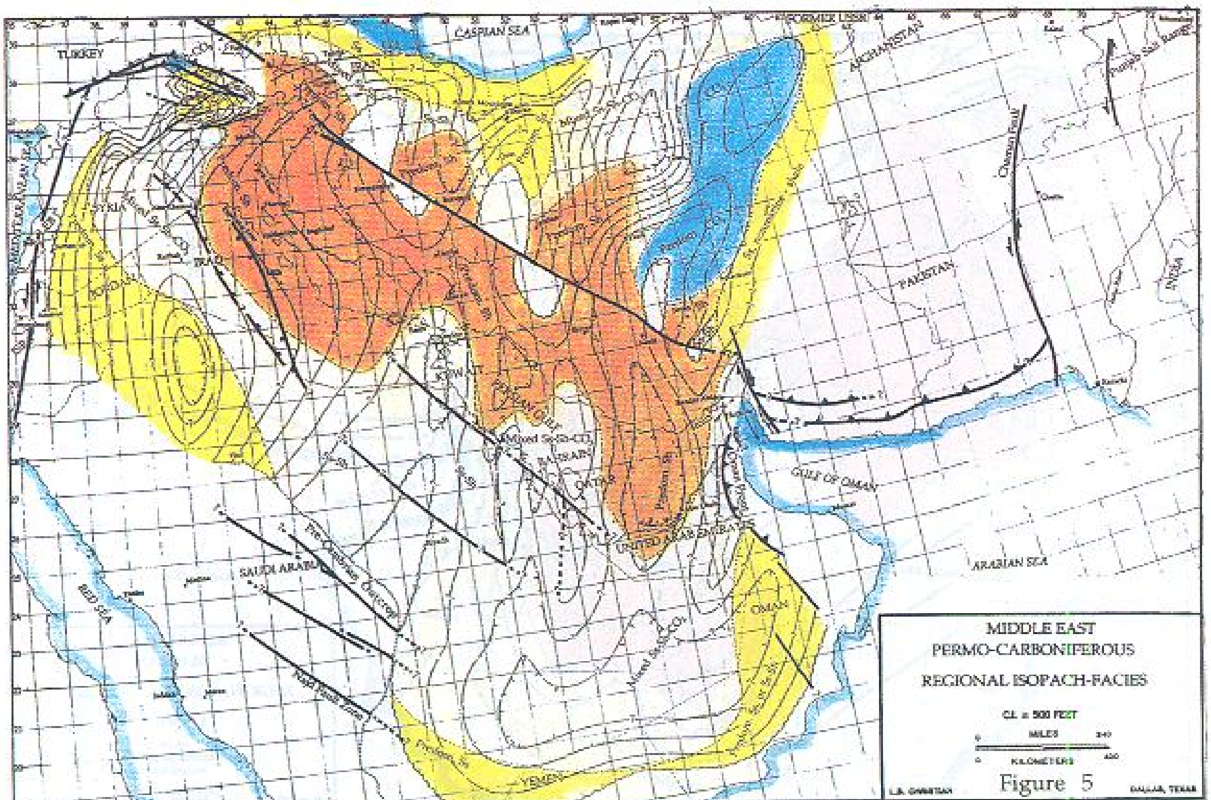


Figure 4



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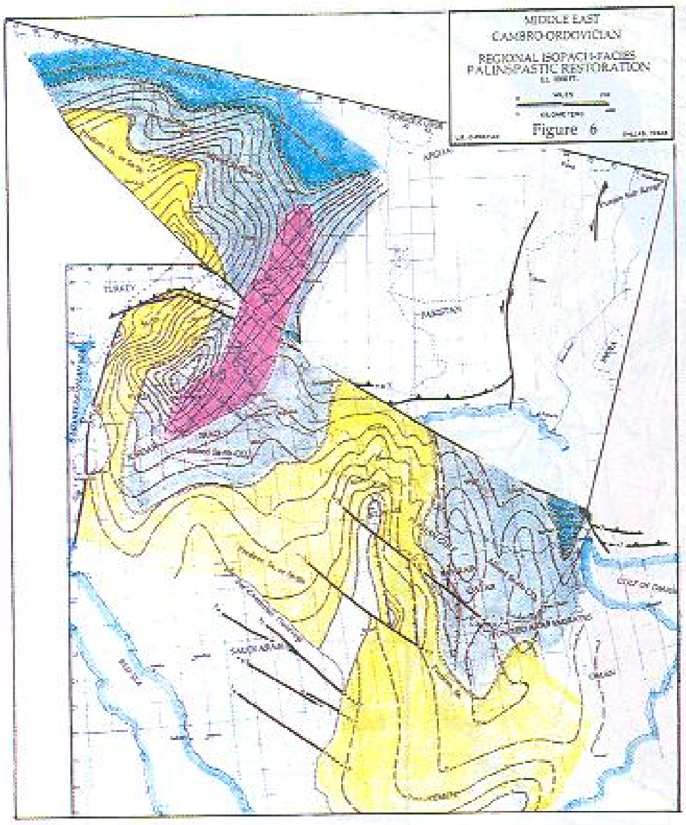
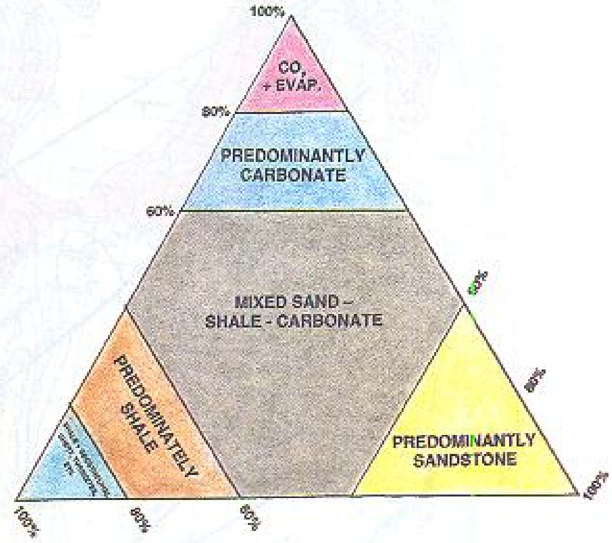
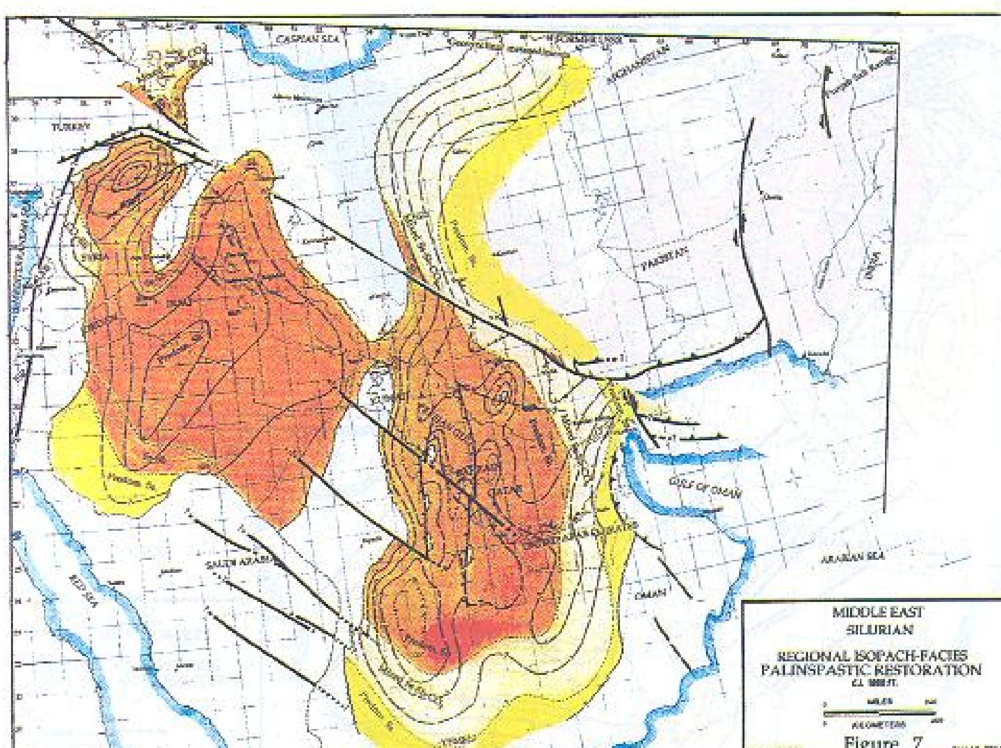


APPENDIX



LITHOFACIES
LEGEND USED IN THIS STUDY



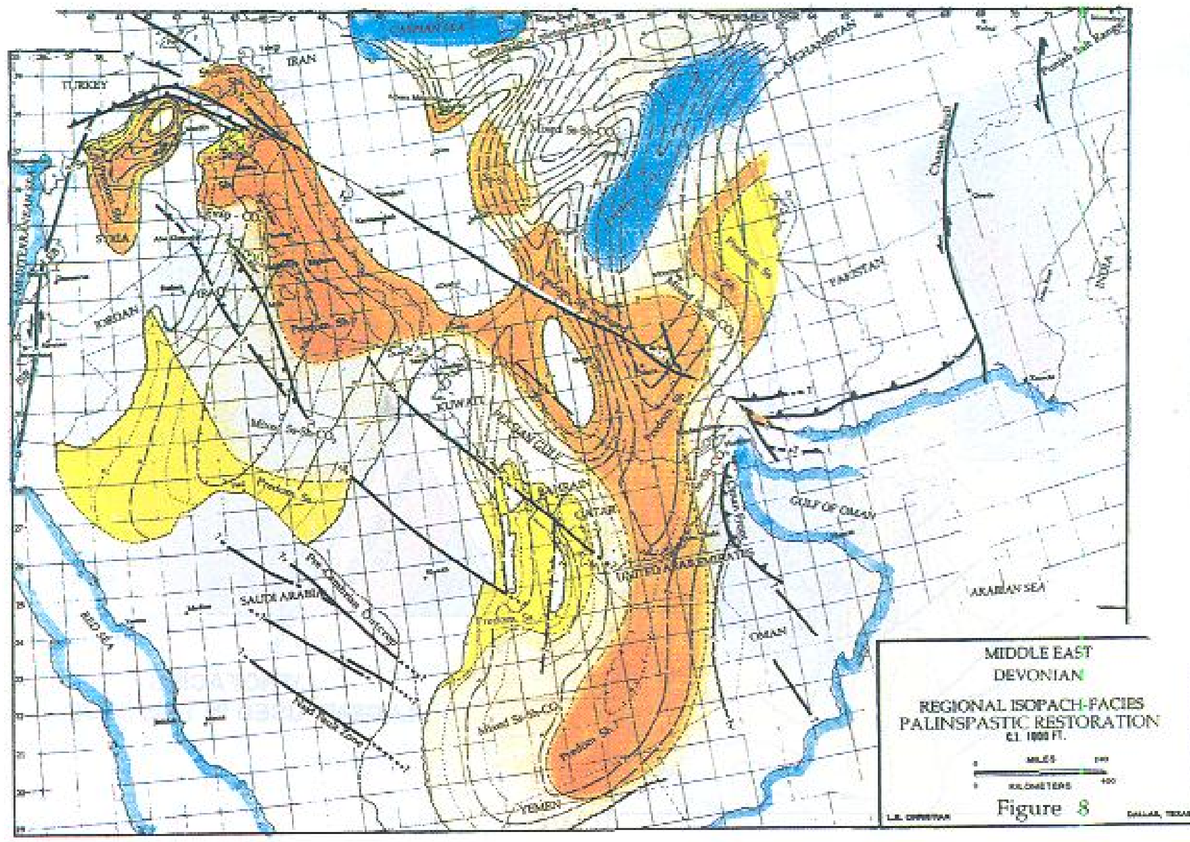


Figure 8

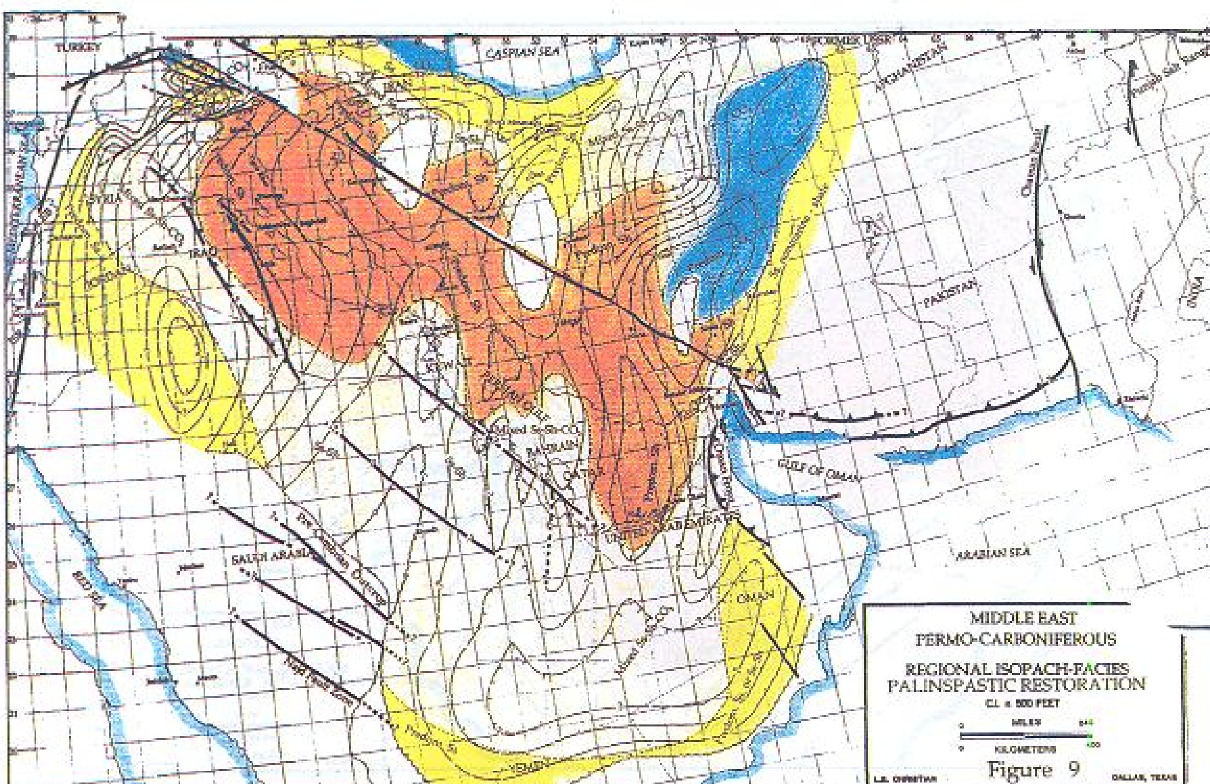


Figure 9

be expected at unconformity surfaces and in faulted structures. Similar Cambro-Ordovician rocks in Libya and Algeria, in large structural traps with high vertical relief, are capable of billion barrel plus oil or oil equivalent reserves (Amal, Hassi Messaoud, etc.). So these older, relatively tight, reservoirs can still be rationally explored, given appropriate structural conditions. Figure 2 shows regional thickness and facies of these rocks throughout the Middle East.

Devonian sandstone reservoirs have higher potential than is generally recognized. The Shell Barbes Deep Test in S. E. Turkey reportedly tested up to 2,000 BOPD from probable Devonian sandstone (Katin Formation). Devonian sandstones are also known to contain gas and liquids beneath the Super Giant North Field, offshore Qatar. One Shell well in the Ras Qirtas- Matbakh area has sonic log porosities averaging about 18% in the Devonian, and FTT gas and liquids were recovered but not tested open hole, because of high pressures which could not be safely controlled by available blow- out preventers. Figure 4 indicates regional distribution of Devonian thicknesses and facies in the Middle East. Higher sand percent facies in Qatar- Bahrain- N. W. Saudi Arabia, derived from the west, look more promising than the deeper, shalier facies which probably underlies most of the Zagros Fold Belt.

Carboniferous- L. Permian sandstone oil reservoirs have already been established as major producers near Riyadh, Saudi Arabia, in recent years (see Figure 5 for regional isopachs and facies). Porosity and permeability are highly variable, but favorable reservoir conditions have been observed in some wells as far north as S. E. Turkey. By year end 1994 the Hawtah oil field, south of Riyadh, had begun production at 150,000 BOPD from Permo-Carboniferous sandstones (Ferguson and Chambers, 1991). By the end of 1995 or early 1996 production from Hawtah had exceeded 220,000 BOPD (Oil and Gas Jour., etc., 1991- 1996). A Dozen or so other Saudi Arabian pre-Khuff clastics fields south of Riyadh will eventually also be produced, or are being developed. It is quite apparent that we are in the early stages of a new Permo-Carboniferous and older oil play which probably will extend northward through Iraq and eastward toward Qatar and the United Arab Emirates.

Upper Permian Khuff Formation carbonate reservoirs in North Dome (offshore Qatar) are currently being developed as the world's largest offshore gas field. The Iranian equivalent (Dalan Formation) also contains world class gas reserves on the other side of the Gulf. Christian (1994b) included a regional Middle East isopach map of this stratigraphic unit. Average porosities are usually rather low (often 6 to 9% or less), but total Upper Permian reservoir thicknesses can in some cases exceed 1,000 feet. Even given mediocre reservoir properties, with great productive thicknesses and very large structural traps (9,000 km2 at North Field, offshore Qatar), recoverable reserves can be enormous.

North Field reserves have been estimated in various Oil and Gas Journal issues (1991- 1996) and elsewhere, to be at least 150 to 250 TCFG. In an OPEC Bulletin, Al Sahlawi (1992) estimated gas in place to be 500 TCF, and recoverable gas as a very conservative 150 TCF. The implied 30% recovery factor seems far too low for a deep, high pressure gas field. If 80% recovery is assumed for such a deep high pressure accumulation, recoverable reserves would be estimated at 400 TCFG with about 13 BBC, based on gas/ liquid ratios in old wells drilled by wells drilled by Wintershall.

If deeper Devonian sandstones also prove to be productive in large parts of the structure these ultimate recoverable estimates at North Dome could perhaps *be doubled* (see discussion of Devonian reservoirs).

Palinspastic Restorations

Figures 6-9 attempt to match up isopach and facies patterns on opposite sides of the Main Zagros Fault, eliminating the effects of strike slip displacements indicated on Figures 2-5, respectively. Similar palinspastic reconstructions for Triassic, Jurassic and Lower Cretaceous isopachs and lithofacies are in preparation as part of an ongoing research into the history of the strike slip component of offsets along the Main Zagros Fault Zone.

Acknowledgements

Some of the best published Paleozoic stratigraphic data and local isopach/ facies maps may be found in Al-Laboun (1986, 1987, 1989, 1990 1993), Al- Marjebi and Nash (1986), Ali and Silwadi (1989), Alsharhan et al (1991, 1994), Barazangi et al (1993), Bender (1967, 1968) Beydoun (1964, 1966, 1988, 1989), Bishlawi, (1985), Bishop (1994), Boote et al (1990), Bozdogan et al (1987, 1990), Bratsch (1975, 1978), Davoudzadeh et al (1981, 1982, 1984, 1986), Dean et al (1980, 1990), Demidov (1981), Dyer and Husseini (1991), Edgell (1977, 1989, 1991, 1992), Eschet (1990), Frieslander et al (1990), Gaetani (1967), Gorin (1967), Grantham et al (1987), Guven et al (1982), Husseini et al (1988, 1990, 1991), Koop et al (1982), Le Nindre et al (1990), Levell et al (1988), Leven (1971), Loutfi and Bishlawi (1989), Mahmoud et al (1992), Marganou et al (1972), Mattes and Conway Morris (1990), May (1991), McBride et al (1990), Momenzadeh and Heidari (1995), Montenat et al (1976), Picard et al (1986), Ponikarov et al (1967), Powers et al (1966), Rigassi (1971), Ruttner (1984), Sadek (1971), Sallomy and Al-Khatab (1986), Seber et al (1993), Sengor (1990), Stauffer (1967),

Stocklin et al (1964), Styeranov, (1969), Szabo and Kheradpir (1978), Tardu et al (1987), Vaslet (1990), Vaziri (1993), Violetich (1994), Weddige (1984), Weissbrod (1976), Wensink (1991), Wolfart (1965, 1967, 1981), and Zharkov (1981, 1984). Without these and the other references cited text this study would not have been possible.

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