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The intraplate Euphrates fault system-Palmyrides mountain belt junction and relationship to Arabian plate boundary tectonics

Douglas Alsdorf(1), **Muawia Barazangi**(1), **Robert Litak**(1), **Dogan Seber**(1), **Tarif Sawaf**(2) and **Damen Al-Saad**(2)

(1) *Institute for the Study of the Continents and Department of Geological Sciences, Cornell University, Ithaca, NY 14853, U.S.A.*

(2) *Syrian Petroleum Company, Ministry of Petroleum and Mineral Resources, Damascus, Syria*

Abstract

We interpret seismic data and well logs to indicate that the Euphrates graben, intersecting orthogonally with the Palmyride mountains, is an intraplate transtensional feature that probably developed in response to plate boundary stress created by a latest Cretaceous convergence event along the present-day northern boundary of the Arabian plate. The principal stress direction is proposed to lie generally parallel to the graben; hence, it may have formed as a tear in the Arabian crust while, as previously documented, the Palmyride region underwent shortening and uplift. Arabian plate boundary tectonism as well as shortening in the Palmyrides were periodically active during the entire Cenozoic, especially in Neogene and Quaternary time. However, the normal fault motions that formed the Euphrates graben were not active within the study area after the end of the Cretaceous, and were most active during the Campanian-Maastrichtian. A broad, Cenozoic depression overlying the Euphrates graben and most of Eastern Syria is possibly related to the Mesopotamian foredeep that developed in response to the nearby Zagros continental collision zone during Neogene and Quaternary time. Cenozoic strike-slip faults lie between the Euphrates graben and the Palmyrides belt and may kinematically separate the Palmyrides from the Euphrates system.

Key words *Euphrates graben – seismic data – intraplate deformation – Central Syria – Arabian plate*

1. Introduction and regional geologic setting

In this paper we map the subsurface structure of the intersection of the Palmyride mountains with the Euphrates graben and depression and relate the development of these intraplate features to nearby Arabian plate boundary tectonic events. Syria is located in a primarily intraplate setting within the Northern Arabian platform, but is virtually surrounded by nearby plate boundaries (*e.g.* Barazangi *et al.*, 1993). The Zagros fold belt lies to the northeast and east, to the north are the Bitlis suture zone and East Anatolian fault, and the Dead Sea fault system is located to the west (fig. 1). The structural style of the broad Euphrates depression contrasts sharply with the surface folding and faulting in the adjacent Palmyride mountain belt. The orientation and intraplate setting of these features do not suggest a mountain belt-foreland basin model for their formation. Therefore, we investigate the intersection of

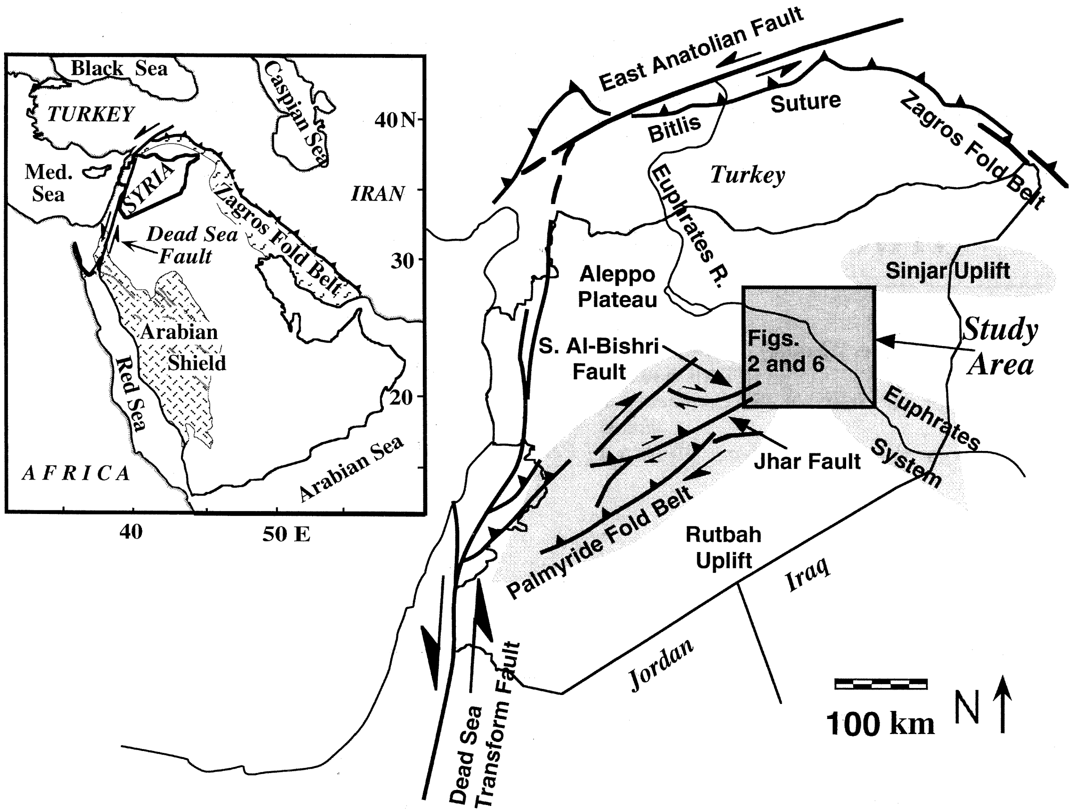


Fig. 1. Left side: map showing bounding faults and folds of the Arabian platform. Right side: location map of the intersection of the Euphrates depression with the Palmyride mountains.

the Euphrates depression and Palmyride mountains for the first-order geologic and tectonic history.

In order to clarify nomenclature, we will use the terminology «Euphrates graben» to refer to a latest Cretaceous graben within the study area, which, as we find, is part of the more well known Euphrates graben system described by Lovelock (1984) that extends southeastward through Syria into Iraq. We use «Euphrates depression» to denote a broad, Cenozoic basin which overlies the graben and adjacent areas. Where appropriate, both features will be called the «Euphrates system».

A number of recent studies within our research group have improved our overall understanding of the geologic history and tectonic evolution of the intracontinental Palmyride mountain belt (Best *et al.*, 1990, 1993; Chaimov *et al.*, 1990, 1992, 1993; McBride *et al.*, 1990; Al-Saad *et al.*, 1992; Barazangi *et al.*, 1993; Sawaf *et al.*, 1993; Seber *et al.*, 1993), whereas previous efforts have elaborated upon the general Arabian plate setting (*e.g.*, Coleman-Saad, 1978; Lovelock, 1984; Quennell, 1984). The following briefly summarizes these previous findings. The Arabian plate boundary tectonism features convergence which emplaced ophiolites along the northern and eastern margins during the latest Cretaceous and, since the Miocene, the main phase of collision of the Arabian and Eurasian plates, the opening of the Red Sea, and left-lateral motion along the Dead Sea fault system. There is a disagreement amongst researchers concerning the exact tectonic setting of ophiolite obduction along the Northern Arabian plate; the ophiolites may represent the closure of the Neo-Tethys (*e.g.* Karig and Kozlu, 1990) or collision of the Arabian plate with an island-arc (*e.g.* Moores *et al.*, 1984). Furthermore, Yilmaz (1993) suggests that the ophiolitic slab in Northwestern Syria is detached oceanic lithosphere which was obducted onto the Northern Arabian plate during the late Campanian to early Maastrichtian and that the emplacement was not a result of continental collision. Given the disagreements, we will refer to this stress regime as a Late Cretaceous «collision event».

In general, the Palmyride mountain belt is a result of Late Mesozoic and Cenozoic shortening and uplift of an Early Mesozoic trough (*e.g.*, McBride *et al.*, 1990; Chaimov *et al.*, 1992; Best *et al.*, 1993). The accelerated convergence of the Arabian and Eurasian plates during the Miocene is coincident with the timing of major deformation in the Palmyride mountains (Chaimov *et al.*, 1992). Construction of balanced cross-sections from seismic lines throughout the Palmyride fold belt show a minimum of 20 km of shortening in the Southwestern Palmyrides as a result of this convergence (Chaimov *et al.*, 1990). The amount of shortening diminishes along the Palmyrides and reaches only a few kilometers in the northeast end of the Palmyrides where the mountain belt intersects the Euphrates system. Ongoing deformation within the Palmyrides mainly results from stresses originating at the plate boundary and transmitted across the Aleppo plateau in the north (fig. 1) (Chaimov *et al.*, 1993). The Palmyrides developed over a pre-existing rift environment, and as we find, the northwest trending Euphrates graben contemporaneously developed orthogonal to the Palmyrides.

We address several basic questions concerning intraplate deformation in Central Syria. Farther southeast, the Euphrates system is marked by typical graben characteristics (*e.g.*, Sawaf *et al.*, 1993); are similar features, hence a similar stress regime, present in the study region? In what manner does the Palmyride fold-thrust belt terminate? What is the first-order kinematic relationship of the Euphrates system with the Palmyrides and with surrounding plate boundaries? To answer these questions, we do not attempt detailed stratigraphic analyses of the cyclic transgressions and regressions; rather, we present the first-order timing and tectonic relationships of the intraplate Euphrates system with the Palmyride mountains and nearby Arabian plate boundaries.

2. Data, interpretation and geologic history

Over 700 km of seismic reflection profiles (4.0 s two-way travel time) collected during the late 1970s and 1980s were recently made available for this study (fig. 2). Figure 3 shows the correspondence between formation names, lithologies, and ages based on the well tops and seismic data supplied by the Syrian Petroleum Company. Formation tops and some sonic and lithology logs from 18 hydrocarbon exploration wells (see figs. 2 and 4a-c) were tied to the seismic data (see fig. 5a,b) using sonic and stacking velocities for depth-to-time conversions. The contacts, faults, and formation thicknesses of fig. 4a-c follow the structures as interpreted from the seismic lines (*e.g.*, fig. 5a,b). For clarity, only the major unconformities are shown in fig. 4a-c. Isopachs of sedimentary formations based on about 200 wells encompassing most of Syria (Sawaf *et al.*, 1988; Best *et al.*, 1993) are also used to guide interpretations of the seismic sections. The 1:200000 scale geologic maps of Ponikarov (1966), combined with digital elevation data and satellite imagery (fig. 6), help to tie the seismic lines to surface geology and to detail the shallow structure. This study is tied into an extensive database of over 13000 km of seismic lines which have been used in previous and on-going tectonic studies of Syria within our research group (*e.g.*, McBride *et al.*, 1990; Chaimov *et al.*, 1992; Sawaf *et al.*, 1993; Litak *et al.*, 1994).

During most of the Mesozoic era, the sediments that make up the present-day Palmyride

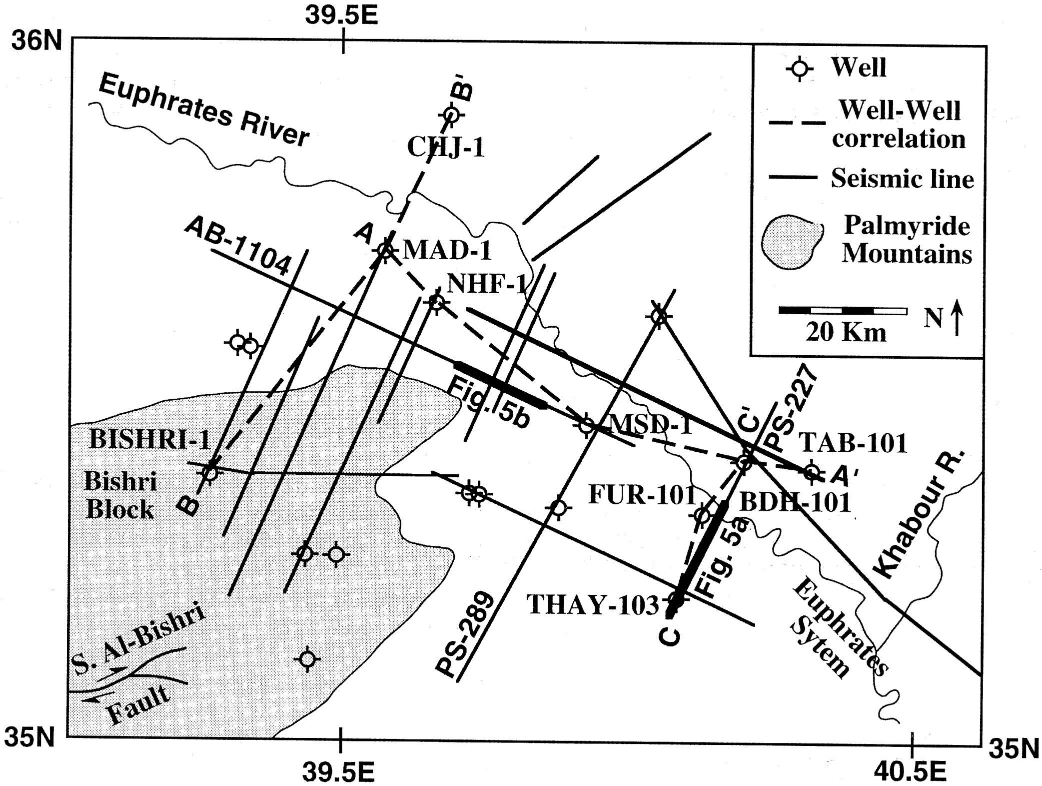


Fig. 2. Map of the study area showing seismic lines and well locations. Figure 1 shows the regional location of this map.

mountains were deposited in a rifted basin (Best *et al.*, 1993). In this study, these same depositional sequences are found in the immediately adjacent Euphrates region (fig. 7a,b); however, the formations rapidly thin away from the Palmyride trough (fig. 4b). We attribute the thinning of the upper Triassic and the entire Jurassic to an unconformity (fig. 4b), indicating a regional paleo-high or relative uplift and erosion of the immediate Euphrates region during the end of the Jurassic (fig. 7a). Note that the Jurassic is encountered in only 5 of the 18 wells within the study area (figs. 2 and 4a-c). This unconformity is not unique to the Euphrates-Palmyrides intersection; others (*e.g.*, McBride *et al.*, 1990; May, 1991; Best *et al.*, 1993) have shown that the unconformity is extensive outside of the study area. Deposition continued through the Jurassic and the Early Cretaceous in the Bishri region of the Palmyride mountains and started again during the Early Cretaceous in the Euphrates area. The lower Cretaceous formations are somewhat constant in thickness throughout the study area and mark the end of the Jurassic unconformity. The Lower Judea formation (see figs. 3 and 4a-c) is missing from the wells in the Euphrates system, marking an unconformity during the Late Cretaceous. In well-to-well correlations (*e.g.*, fig. 4a-c), this unconformity follows the Jurassic unconformity; therefore, it may represent another erosional (regression) event or paleo-high.

We find that the Late Cretaceous marked

the beginning of major change within the Palmyride and Euphrates systems. The upper Cretaceous (Cenomanian through Campanian) rocks are over 1200 m thick in the Bishri block and thin to about 150 m (well MSD-1) in the local Euphrates system (fig. 4b and 4a, respectively). Throughout the Late Cretaceous, the boundary between the Euphrates and the northeast Palmyride trough was denoted by normal faulting with the down-dropped block in the Bishri area (figs. 4b and 7b), probably representing a bounding fault of the trough. During most of the Late Cretaceous (Cenomanian-Campanian), the Palmyride region remained a basin relative to the Euphrates area. However, the overlying uppermost Cretaceous (Campanian-Maastrichtian) rocks are about 550 m thick in the immediate Palmyride region and thicken to over 1200 m in the adjoining Euphrates system (fig. 4b and 4c, respectively). The area just northeast of the Palmyride belt has a constant thickness uppermost Cretaceous

ERA	PERIOD	EPOCH STAGE	FORMATION	GENERAL LITHOLOGY
CENOZOIC	NEOGENE	PLEISTOCENE PLIOCENE	BAKHTIARY	CONGL. & BRECCIA W/SST AND SH
CENOZOIC	NEOGENE	PLEISTOCENE PLIOCENE	UP. FARS	SST & SH W/ANHYDRITE AT BASE
CENOZOIC	NEOGENE	MIOCENE UPPER	LOW. FARS	ANHYDRITE, HALITE W/ SH AND DOLOMITE
CENOZOIC	NEOGENE	MIOCENE UPPER	T. ZONE	TRANSITION FROM L. FARS TO JERIBE
CENOZOIC	NEOGENE	MIOCENE MIDDLE	JERIBE	DOLOMITIC LST W/ MINOR ANHYDRITE
CENOZOIC	NEOGENE	MIOCENE LOWER	MID-YAT: DIBBANE	ANHYDRITE & DOLOMITE W/ HALITE AT BASE
CENOZOIC	NEOGENE	MIOCENE LOWER	MID-YAT: EUPH	LIMESTONE
CENOZOIC	PALEO-GENE	OLIGOCENE	MID-YAT: CHILOU	LST AT TOP BECOMING MARLY
CENOZOIC	PALEO-GENE	EOCENE	JADDALA	MARL & CHERTY, ARGILLACEOUS LST
CENOZOIC	PALEO-GENE	PALEOCENE	KERMAV	MARLY LST & SHALE
MESOZOIC	CRETACEOUS UPPER	MAASTRIC.	SHIRANISH	MARLY SH AND ARGILLACEOUS LST
MESOZOIC	CRETACEOUS UPPER	CAMPANIAN SANTONIAN	SOUK.: A. MARI	MARL, CHERTY LST & SH
MESOZOIC	CRETACEOUS UPPER	CAMPANIAN SANTONIAN	MASS. A: RMAH	CHERTY LST & SH
MESOZOIC	CRETACEOUS UPPER	CONIACIAN	DERRO REDBED	RED SST
MESOZOIC	CRETACEOUS UPPER	TURONIAN CENOMANIAN	JUDEA: UPPER MASS. B.	DOLOMITES & LIMESTONES
MESOZOIC	CRETACEOUS UPPER	TURONIAN CENOMANIAN	JUDEA: LOWER HAY. (MC)	ANHYDRITE, DOLOMITE & LST
MESOZOIC	CRETACEOUS LOWER		GHOUNA / RUTBA	SST W/ CALC. BANDS / FLUVIAL-DELTAIC SST VOLCANIC CLASTICS
MESOZOIC	JURASSIC		HARAMOUN	LIMESTONE, DOLOMITIC LST, & SHALE
MESOZOIC	TRIASSIC UPPER	RHAETIAN	SARJELU	LST, DOLOMITE, SH & ANHYDRITE
MESOZOIC	TRIASSIC UPPER	RHAETIAN	ALLAN	DOLOMITE & SHALE
MESOZOIC	TRIASSIC UPPER	NORIAN	MUSS	DOLOMITE
MESOZOIC	TRIASSIC UPPER	CARNIAN	ADAYA	DOLOMITE, SH & ANHYDRITE
MESOZOIC	TRIASSIC UPPER	CARNIAN	BUTMA	LST, SHALY LST, & DOLOMITE
MESOZOIC	TRIASSIC MIDDLE	LADINIAN	K. ANHYDRITE	MASSIVE ANHYDRITE AND SHALE
MESOZOIC	TRIASSIC MIDDLE	LADINIAN	KURRACHIN DOLOMITE	MASSIVE DOLOMITE W/ THIN SHALE, LST AND ANHYDRITE
MESOZOIC	TRIASSIC MIDDLE	ANISIAN	QARYATAIN	SST W/ SHALY CARBONATIC SST
MESOZOIC	TRIASSIC LOW.	SCYTHIAN	AMANOUS SHALE	DARK GREY, PYRITIC SHALE
PZ.	PERMIAN		AMANOUS	RED SST, RED-GREY SHALE

Fig. 3. Chart showing formation names, ages and general lithologies for Syria. Abbreviations: congl. = conglomerate; sst = sandstone; sh = shale; lst = limestone; calc. = calcareous.

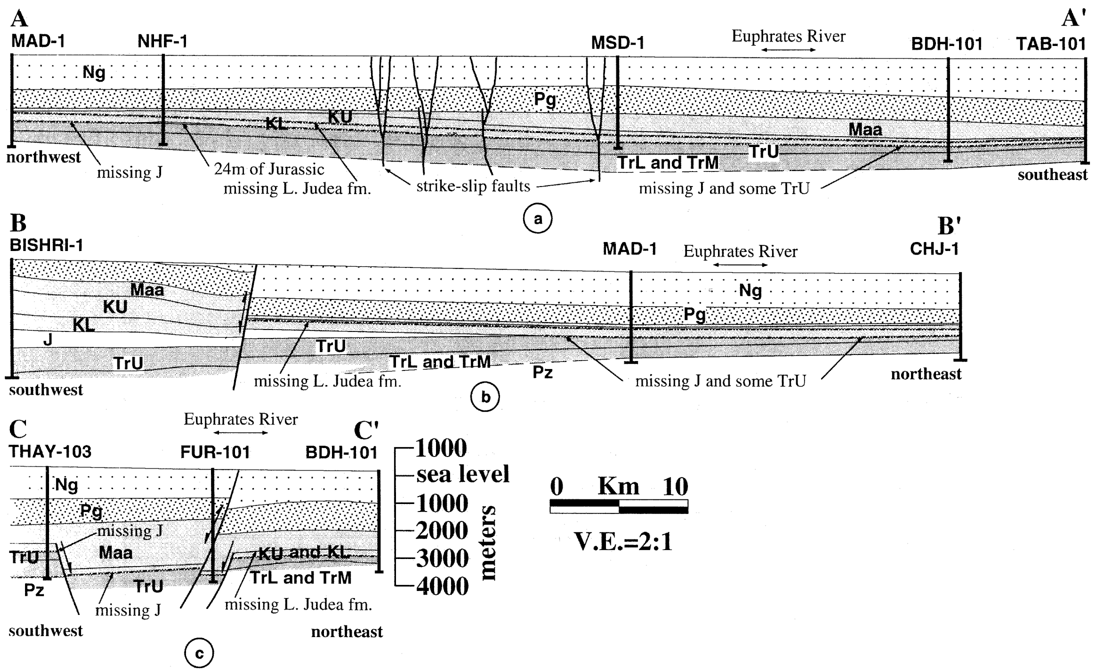
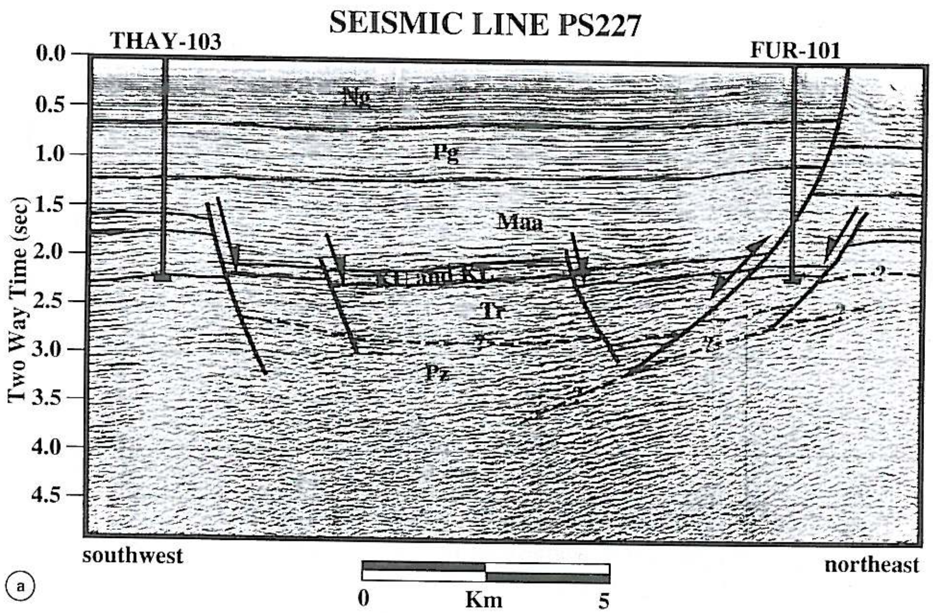


Fig. 4a-c. Well-to-well correlations in which the contacts, faults, and formation thicknesses are drawn following the structures interpreted from the seismic lines. Figure 2 shows map views of well locations and seismic lines. Ng are the Neogene formations of the Lower Fars through the Euphrates A; Pg are the Paleogene formations of the Chilou B through the Kermav; Maa is the Maastrichtian Shiranish formation which slightly overlaps part of the Campanian; KU are the Upper Cretaceous formations of the Soukhneh through the Judea; KL is the Lower Cretaceous Rutba formation; J is the Haramoun formation; TrU are the Upper Triassic formations of the Sarjelu through the Butma; TrM and TrL are the Middle and Lower Triassic formations of the Kurrachin Anhydrite through the Amanous Shale; Pz is the Paleozoic (Permian) Amanous formation. Not all formations from fig. 3 are present in all wells, and only the major unconformities are drawn in fig. 4a-c.

section, around 150 m (fig. 4b). Note that normal faulting along the northeastern Palmyride trough contributed to the ~400 m difference in Maastrichtian sediments between the Bishri block (*e.g.* Bishri well) and immediate Euphrates system (*e.g.* MAD well). Seismic lines PS-227 (figs. 2 and 5a) and PS-289 (fig. 2, section not shown) detail the structural character of the Euphrates region to the southeast of the Palmyrides and mark the morphology of an upper Cretaceous, northwest-southeast trending graben with a southwest-dipping floor. In the south, the graben is narrow and deep with fairly well-defined bounding faults; however, toward the north, it shallows and widens with the bounding faults becoming less distinct as they splay into several smaller normal faults (fig. 7c). Disruption along its flanks and the lack of typical fan-shaped reflections suggest that this feature is not a simple graben; strike-slip faulting may have also been involved in its development. As interpreted from isopach maps of the Cretaceous formations, the first marine sediments deposited in the graben were carbonate sequences of a transgressive sea that was probably advancing from the Palmyra region. Faulting generally ceased near the end of the Cretaceous such that Paleogene formations above the graben are mostly horizontal and continuous. de Ruiter *et al.* (1995) argue that



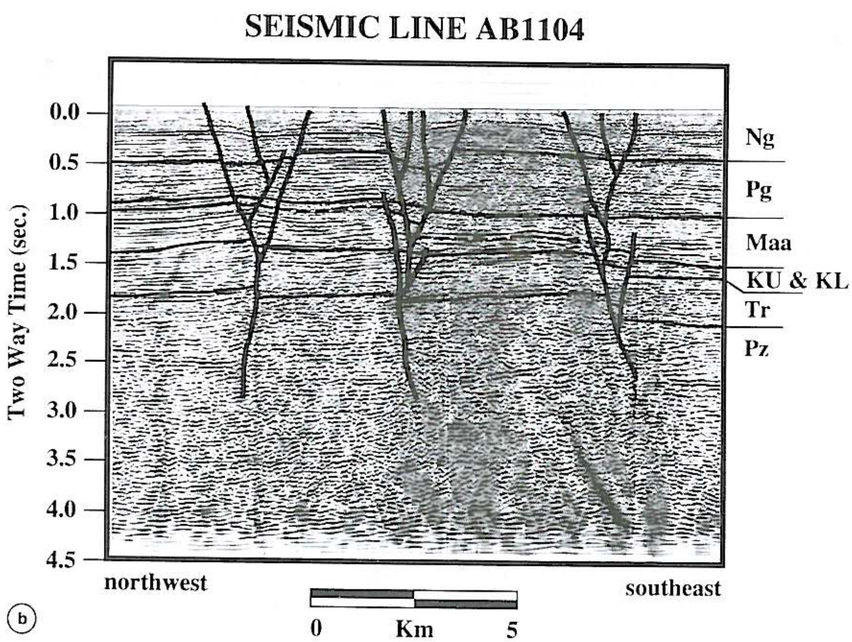


Fig. 5a,b. Example of seismic data and interpretations. Formations picked from well logs are tied to the lines using stacking velocities. See fig. 2 for line locations and figs. 3 and 4a-c for formation names which correspond to the given ages. The lines were collected using Vibroseis CDP profiling with a nominal 60 fold. Data processing includes statics and NMO corrections. Line AB1104 is migrated, whereas PS227 is not migrated.

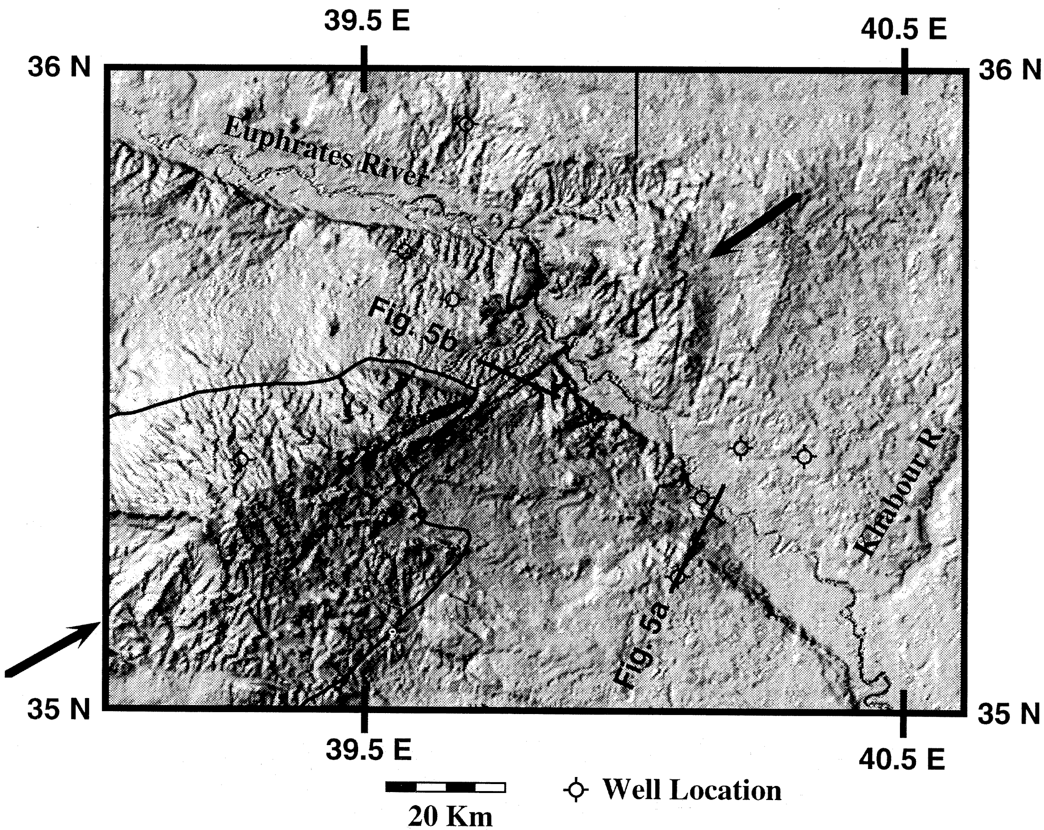


Fig. 6. Shaded relief topographic image of the study region. The image was created using high-resolution (90 m) digital topography with an artificial sun angle at an azimuth of about 290° and an elevation of about 50°. Surface lineaments (arrows) coincide with strike-slip faults mapped from the seismic lines (*e.g.*, fig. 5b). The Palmyride mountains are outlined in the southwestern portion of the figure. Figure 1 shows the regional location. Well locations and seismic lines follow from fig. 2.

the mid-Cretaceous unconformity marks the onset of Euphrates rifting. However, thickening relationships suggest that the main phase of extension within the study area occurred during the late Campanian-Maastrichtian. Therefore, this «Euphrates graben» was active within the study area only during the late Campanian and especially the Maastrichtian and appears to be a northwestern extension of the more well known Euphrates-Anah graben in Southeastern Syria and Iraq (see Lovelock, 1984; Sawaf *et al.*, 1993).

Paleogene formations are relatively constant in thickness (about 900 m) marking even, continuous deposition throughout the Palmyride and Euphrates study area. Thick Late Neogene sediments in the Euphrates area have been eroded in the Bishri block where the Cretaceous basin-bounding normal fault (fig. 7b) appears to have been reactivated as a reverse or transpressional strike-slip fault during Late Neogene (figs. 4b and 7d). This fault marks an abrupt transition from the thick, undeformed sediments of the Euphrates depression to folding and faulting at the northeastern edge of the Bishri block.

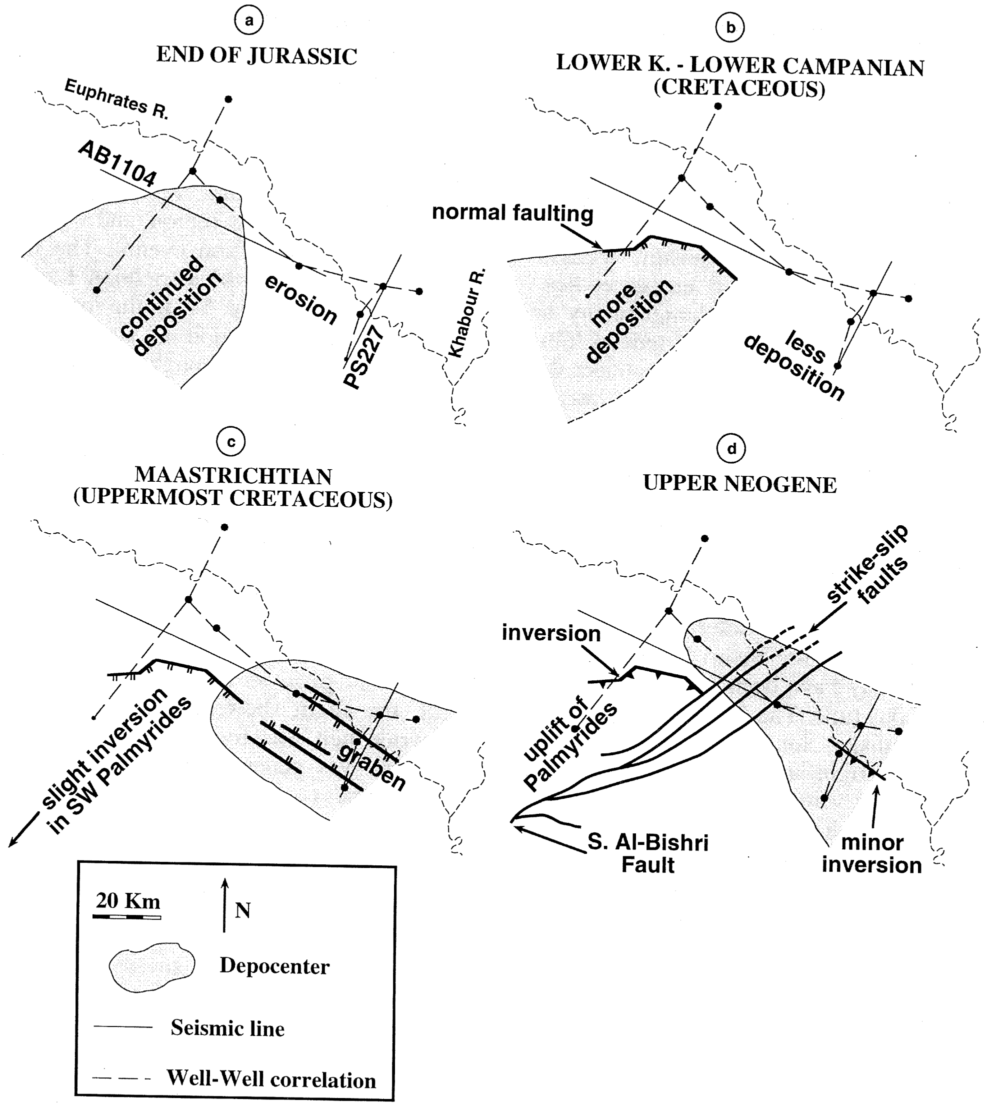


Fig. 7a-d. Maps showing time snapshots from Jurassic through Neogene of the intersection of the Palmyrides and Euphrates systems. See figs. 2 and 4a-c for well-to-well correlation (dashed lines) and fig. 5a,b for seismic lines (solid lines). a) At the end of the Jurassic, erosion marked the Euphrates region while deposition was uninterrupted in the Bishri block of the Palmyrides. b) Deposition began again in the Euphrates during the Early Cretaceous and generally continued throughout the Cretaceous, however, an unconformity occurred at the beginning of the Late Cretaceous. The formations thicken toward the Palmyrides (more deposition) from the Euphrates (less deposition). Normal faulting began during the Cretaceous. c) A minor episode of shortening and uplift in the southwest Palmyrides and a deep graben in the Euphrates developed simultaneously in the Maastrichtian of the latest Cretaceous. Normal faulting, from panel C, along the northeastern Palmyrides also probably continued. d) The Late Neogene marked uplift of the Palmyrides with Mesozoic normal faults reactivated as reverse faults; a broad depression developed in the Euphrates. Northeast-trending strike-slip faults generally separate the two areas.

Several previously unmapped faults bound the southeastern edge of the Bishri block (fig. 7d). On the seismic lines, these near-vertical faults exhibit flower structures typical of strike-slip faults (*e.g.*, fig. 5b). At the surface, the faults coincide with several small stream valleys and are apparent as lineaments on digital elevation (fig. 6) and Landsat imagery. The faults are found on all of the seismic sections which cross the lineaments and are perpendicular to the Euphrates river. Although many of the seismic lines are spaced a few tens of kilometers apart, it seems plausible to connect the faults along the lineaments with right-lateral, strike-slip faults (the South Al-Bishri fault and its subsidiary branches, Best, 1991; Al-Saad *et al.*, 1992) within the Palmyrides. This would indicate that the Palmyride faults extend at least 80 km farther northeastward than previously recognized. At depth, the faults appear to truncate both the Euphrates graben and the Neogene compressional deformation at the southeastern edge of the Bishri block, suggesting that they may have been active as early as Late Cretaceous time. The focal mechanism for a 1970 earthquake along the South Al-Bishri fault indicates right-lateral motion (Chaimov *et al.*, 1990). The vertical sense of displacement along the faults indicates a relative uplift of the northern block, agreeing with the previous findings of Chaimov *et al.* (1990). This narrow band of strike-slip faults cuts Late Miocene units; therefore, the latest deformation postdates these formations. Southeast of these faults, a gentle, northwest-trending anticline is accompanied by minor reverse, and perhaps strike-slip, faulting in the Euphrates area (fig. 7d). This deformation, which rapidly diminishes away from the Palmyrides, signals only minor inversion to the southeast of the South Al-Bishri and associated strike-slip faults.

3. Euphrates, Palmyrides, and regional tectonic relationships

The first phase of shortening and uplift within the intraplate Palmyrides occurred during the Maastrichtian of the latest Cretaceous, penecontemporaneous with ophiolite emplacement along the northern margin of the Arabian plate (Chaimov *et al.*, 1992). As noted previously, there are several tectonic settings which seem possible for this collision event. In our analysis, we only propose to use the stress which developed under any of these scenarios as a possible explanation for intraplate deformation within the study region, and we refer to this stress as a «collision event». The formation of the intraplate Maastrichtian Euphrates graben (figs. 4c and fig. 5a) in the immediately adjacent Euphrates region is also coincident with this collision. Although the depocenter shifted to the Euphrates region from the immediate Palmyrides, deposition of latest Cretaceous sediments continued in the Bishri area of the northeastern Palmyrides. Normal faulting along the northeastern edge of the Bishri block was also active during the latest Cretaceous (fig. 4b and 7c).

A possible tectonic scenario that encompasses the temporal relationships of these three events is: as stress was transmitted across the Arabian plate as a result of the collision event, the slight shortening and uplift in the Palmyride belt was formed in a weak crustal zone that was generally perpendicular to the principal stress axis. The crust northeast of the Euphrates graben, however, may have been relatively stronger than the crust southwest of the graben (*e.g.* Palmyride mountains) such that the stress was transmitted without significant deformation to the northeast. To accommodate the change in stress between the Palmyrides and the crust of northeastern and Central Syria, the Euphrates graben then formed as a tear in the crust somewhat parallel to the maximum principal stress direction.

The major episode of shortening and folding in the Palmyride belt started in the early Miocene and has continued into the Quaternary (*e.g.*, Chaimov *et al.*, 1992, 1993; Best, 1991; Al-Saad *et al.*, 1992). The folding has occurred simultaneously with the continued convergence and collision of the Arabian and Eurasian plates in Southern Turkey and along the Zagros in Iran and Iraq, and the initiation of left-lateral motion along the Dead Sea fault system (Chaimov *et al.*, 1992). Uplift of the Bishri block occurred during the Neogene (Best, 1991), causing folding in the transition area between it and the immediate Euphrates region (figs. 3b and 6d). Accompanying the folding, normal faults of the Late Cretaceous were reactivated as reverse faults (Al-Saad *et al.*, 1992) (figs. 4b and 7d). Several of the normal faults of the latest Cretaceous Euphrates graben were also reactivated as reverse faults during the Neogene resulting in a repeated Maastrichtian section in the FUR-101 well and slight upwarping of the local Cenozoic formations (fig. 5a). However, strike-slip faults perpendicular to the Euphrates depression essentially bound the Palmyride shortening. The stress field of this phase may have been similar to the Late Cretaceous; *i.e.* the collision of the Arabian and Eurasian plates and left-lateral motion along the Dead Sea fault formed a generally northwest-southeast principle stress direction. The Palmyrides again accommodated some of the stress by folding with reverse and strike-slip faulting. Instead of a narrow graben, however, the Euphrates formed a broader depression in most of Eastern Syria, possibly related to the development of the Zagros collision zone to the east and possibly also related to strike-slip motion along the northeast-trending strike-slip faults. That is, this Neogene and Quaternary broad depression may be related to the foreland Mesopotamian basin, formed in response to the Zagros continental collision. Further study (Litak *et al.*, 1994) along the length of the Euphrates, including ties with the Al-Furat graben fault system to the southeast and the Sinjar Trough to the northeast, will help to test the validity of this scenario by better defining the regional kinematic relationships.

Previous work (*e.g.*, Best *et al.*, 1990; McBride *et al.*, 1990; Al-Saad *et al.*, 1992; Chaimov *et al.*, 1992, 1993; Barazangi *et al.*, 1993) has indicated that the strike-slip Jhar and South Al-Bishri faults mark the boundary between two different styles of deformation. The Bishri block, which lies to the north of the faults, marks a region of long-wavelength folding with possible rotation occurring in reaction to plate boundary tectonism (Best, 1991). To the south of the faults and within the southwestern Palmyrides, the deformation is denoted by en echelon conjugate short-wavelength folds (*e.g.*, Chaimov *et al.*, 1993). The strike-slip faults of the transition area (fig. 7d) between the Palmyrides and the Euphrates merge into the South Al-Bishri fault. The Maastrichtian Euphrates graben first appears in the study region just south of these strike-slip faults. Likewise, to the north of these faults, moderate, post-Miocene folds occur within the transitional zone, but are not present south of the strike-slip faults. Therefore, it appears that over time this narrow band of faulting, like the South Al-Bishri and Jhar faults, also marks the division between two regions within the study area which react differently to tectonic forces.

The characteristic folds of the Palmyrides are not present at the surface within the study region, although several authors (*e.g.*, Lovelock, 1984) speculate that these features might be present in the subsurface, cropping out again at the Sinjar folds (fig. 1). Therefore, the east-west oriented Sinjar folds, a localized, uplifted, intraplate region in Northeastern Syria, would be an extension of the Palmyride mountains. However, within the framework of this study, we could find no clear evidence that the folds continue within and/or below the sedimentary sequences of the Euphrates system, suggesting that the Sinjar folds may not be a northeast extension of the Palmyrides. Further regional studies of the Euphrates system and the Sinjar area will help clarify these relationships.

4. Conclusions

Using seismic reflection, well log, and other data from Central Syria, we find that:

1) the Palmyride region was a local depocenter from the Early Triassic through almost all of the Late Cretaceous, and in the adjacent Euphrates an unconformity marking possible erosion is noted at the end of the Jurassic;

2) the depocenter shifted to the immediately adjacent Euphrates region during the latest Cretaceous and remained there throughout the Cenozoic;

3) the Euphrates depression is underlain by the latest Cretaceous, northwest-oriented Eu-

phrates graben which deepens away from the Palmyrides with fairly well-defined bounding faults;

4) northeast trending strike-slip faults, previously unmapped, separate the Euphrates from the Palmyrides;

5) episodes of intraplate deformation in the Euphrates are coincident with Arabian plate margin tectonic events.

This graben appears to be the northwestern extension of the Euphrates graben and the Al-Furat fault system in Southeastern Syria. Previous efforts indicate that the intraplate, transpressional Palmyrides formed due to Arabian plate boundary collision events. We suggest that these same compressional episodes, a latest Cretaceous collision event and the Neogene and Quaternary continued convergence of the Arabian and Eurasian plates, also resulted in the formation of the transtensional Euphrates graben and depression, respectively. The Palmyride mountains may be kinematically separated from the Euphrates fault system by northeast-trending strike-slip faults.

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