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Occurrence of structural features induced by compressional tectonics in the so-called "stable" region of western and southern Iraq: Implications for hydrocarbon potential of the under-explored Paleozoic succession of the region

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Summary

The Zagros Mountain range is the result of the compressional tectonics that caused collision of the Arabian Plate with the Euroasian plate. This convergent tectonics has generated a series of NW-SE-oriented anticline-syncline system with associated faults. Previous work document that the amplitudes of the anticlines decrease southwestward and disappear (with the exception of the Anah anticline) south of the NW-SE-trending Abu Jir – Euphrates Active Fault Zone (AJ-EAFZ). The latter has been commonly considered as a prominent tectonic boundary that divides the country into two tectonically-separated sectors: (i) NW to NE unstable region defined by uplifted, folded and faulted terrain (the Zagros Mountain range and its foothills) and (ii) southern sector underlain by presumably undisturbed (stable) domain. Almost all oil and gas fields in north and southeast Iraq are located within the unstable sector that occurs along the Zagros Foreland Basin and north of the presumed boundary of AJ-EAFZ. Because of this bipartite view of the country, hydrocarbon exploration in the region south of the AJ-EAFZ has been scanty and overlooked. This study demonstrates that this western and southern sectors of the country also has high hydrocarbon potential supported by existence of structural features (anticlines and faults) that could act as structural traps (similar to the northern anticlines), as well as thick sedimentary succession of sandstone, shale and carbonate formations of Paleozoic age. Ordovician to Permian sandstones (Khabour, Suffi, Pirispiki, Kaista and Ga'ara formations) and carbonates (Devonian Harur and Permian Chia Zairi formations) along with hot shales with high TOC content (Ordovician Khabour, Silurian Akkas and Devonian Ora). The TOC of these shales ranges between 0.9% and 16.6%. These organic-rich shales are mature with high hydrocarbon generation potential. Juxtaposition of the mature shales and clastic and carbonate reservoirs, along with the above-mentioned structural elements, underscores the importance of the region south of the AJ-EAFZ sector of Iraq.

Introduction

Hydrocarbon production of Iraq is concentrated in the roughly the upper half (NW to SE) of the country. The northward tectonic shift of the Arabian Peninsula resulted in collision between the Arabian and Eurasian plates (e.g., Beydoun, 1991; Alavi, 2004; Burberry, 2015; Fouad, 2015). This has consequently produced a highly-deformed and elevated region of the Zagros Foreland Basin which transects from Turkey through Iraq to Iran. The compressional tectonics has

generated a series of anticline-syncline features with associated faults. Such anticline-syncline structures are commonly oriented to NW-SE direction being more or less perpendicular to the convergent paleo-stress direction. It is widely documented that the amplitudes of the anticlines decrease southwestward and totally disappear (with the exception of the Anah anticline) south of the Abu Jir – Euphrates Active Fault Zone (AJ-EAFZ). The latter has been commonly considered as prominent tectonic boundary that divides the country into two sectors: an unstable zone of northwest to northeastern region of the country where tectonic deformations (uplifting, faults and folds) are well-developed and southern sector underlain by presumably undisturbed (stable) domain (Buday and Jassim, 1987; Numan, 2000; Aqrawi et al., 2010; Sissakian, 2013, among others). Almost all oil and gas fields in north and southeast Iraq are located within the unstable sector that occurs along the Zagros Foreland Basin and north of the presumed boundary of AJ-EAFZ (Fig. 1). The understanding that the region south of this tectonic boundary lacks structural features that could potentially trap hydrocarbons has down-played hydrocarbon potential in the western and southern regions of the country. Consequently, hydrocarbon exploration in this presumed "stable" sector has been overlooked.

This study intends to demonstrate that the region lying west and south of the AJ-EAFZ does also contain structural features that can potentially function as hydrocarbon traps. We also document existence of other elements essential for functioning petroleum system (e.g., source rocks and reservoirs) within the Paleozoic succession that underlies such structural traps in the western and southern sectors of the country.

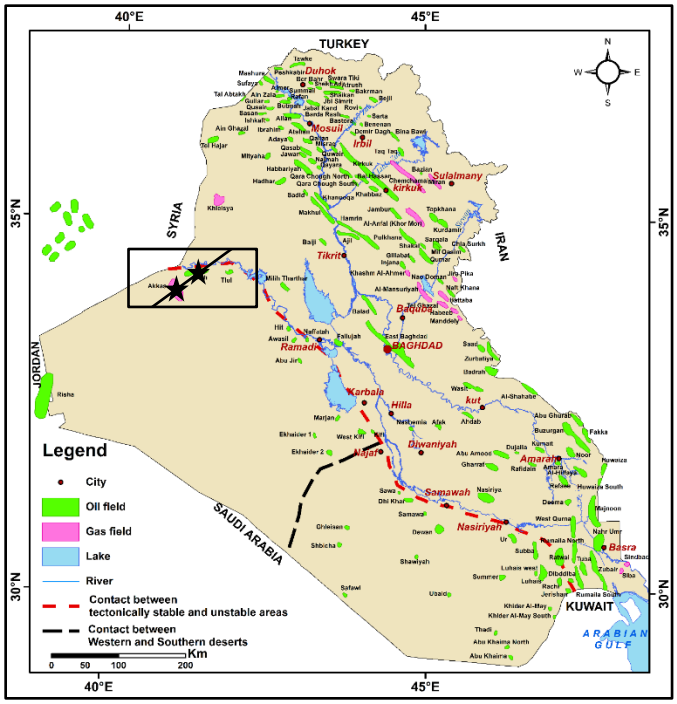

Fig. 1 Map of Iraq with locations of oil fields. Trends of the oil fields are NW-SE and perpendicular to the convergent paleostress direction (NE-SW). Previous work divided the country into two sectors separated by AJ-EAFZ (the NW-SE red dash line). The region south of the line is supposed to be tectonically stable with no significant anticlinal features. However, this study considers that this region has been tectonically active and both anticlines and faults are present. The region is also underlain by Paleozoic strata with complete petroleum system. These parameters underscore the importance of this region for hydrocarbon exploration. The rectangle on the map shows location of Fig. 2A whereas the stars and the line within the rectangle are the locations of Akkas-1 (lower star) and Anah-2 (upper star) wells. See more details in Fig. 2A & 2B.

Structural features

There are several features that indicate evidence of tectonic activities in the western and southern sectors of the country. These include surface anticlinal features (such as, Anah and Akash – Al-Ratgah anticlines, Fig. 2) (Sissakian and Fouad, 2015; Fouad, 2015) and subsurface anticlines inferred from geological cross-sections (e.g., Akaz, Al-Samawa, Diwan, Salman and Abu Khaima anticlines, Fig. 1). Other features that indicate relatively young active tectonic activities in the western and southern sectors of Iraq include dissected/faulted Quaternary deposits (e.g., dislocation of the Al-Batin alluvial fan) and tectonically-controlled and dissected valleys and rock cliffs with walls parallel to the main NW-SE structural lineaments recognized in the southern and western deserts area of the country (Sissakian et al., 2014).

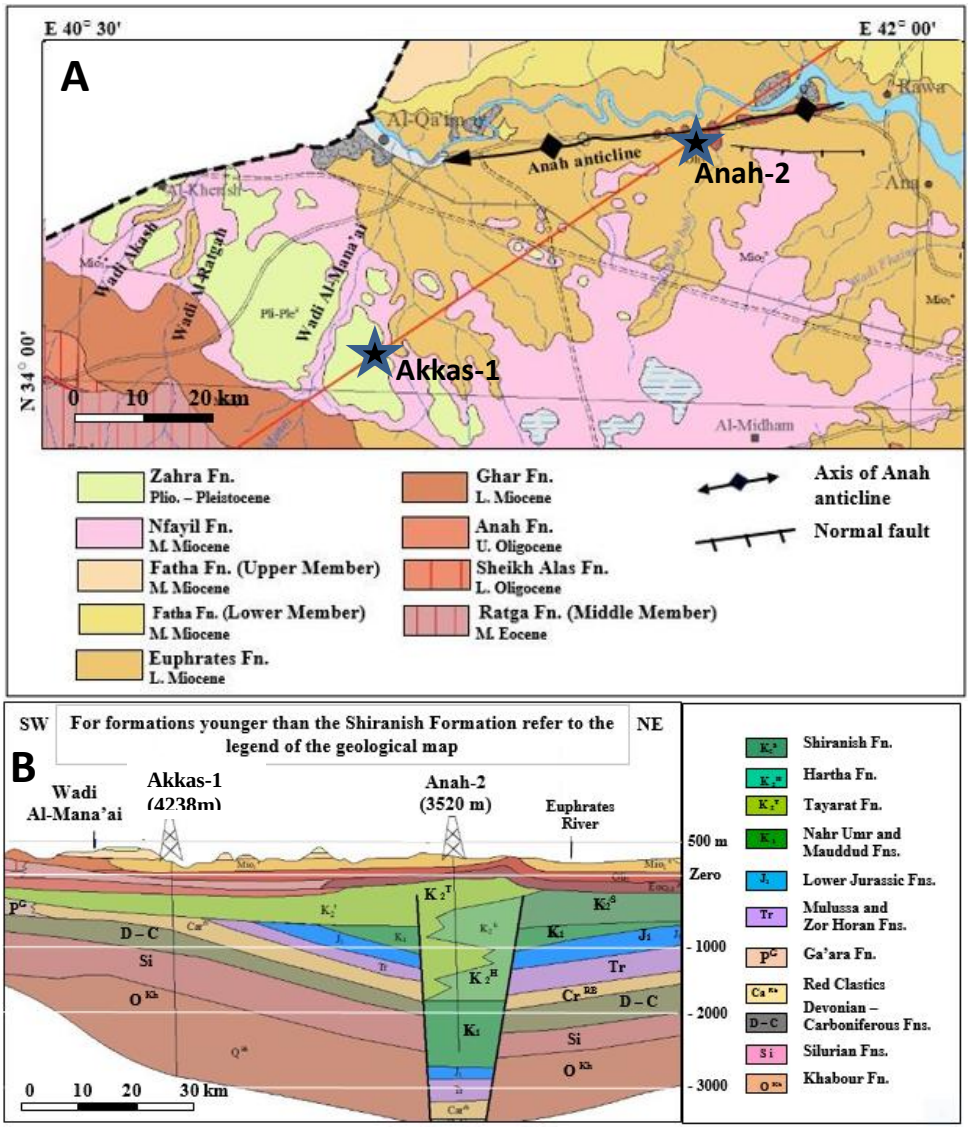

Fig. 2 A) Geological map of Anah anticline and surrounding area. The SW-NE red line shows the location of the cross section in B. Note the double closure of the Euphrate Formation in Wadi Akash and Wadi Al-Ratgah in the extreme western part of the map and compare their trend with that of Anah anticline (Sissakian & Fouad, 2015).

Paleozoic succession

The Paleozoic sedimentary succession of western and southern Iraq includes Ordovician to Permian series punctuated by unconformities (Aqrawi, 1998). The succession can be divided in to three allostratigraphic units separated by prominent stratigraphic hiatuses: (I) Ordovician-Silurian, (II) Devonian-lower Carboniferous and (III) Carboniferous-Permian units (Fig. 3). The Ordovician-Silurian unit is exclusively formed by alternating sandstone and shale lithologies that include Ordovician Khabour Formation. The latter comprises lower Caradocian basal sandstone, upper Caradocian shale and uppermost Caradocian to Ashgilian sandstone. The Silurian succession consists of Llandoverian to Wenlockian Shale of Akkas and overlying Ludlovian sandstone of the Suffi Formation. The second allostratigraphic unit consists of lower Devonian Kaista and Pirispiki formations followed by upper Devonian shales of the Ora Formation and Lower Carboniferous (Mississippian) carbonates of the Harur Formation. The third Paleozoic unit encompasses Upper Carboniferous (Pennsylvanian) to lower Permian sandstone of the Ga'ara Formation and overlying upper Permian carbonates of the Chia Zairi Fm.

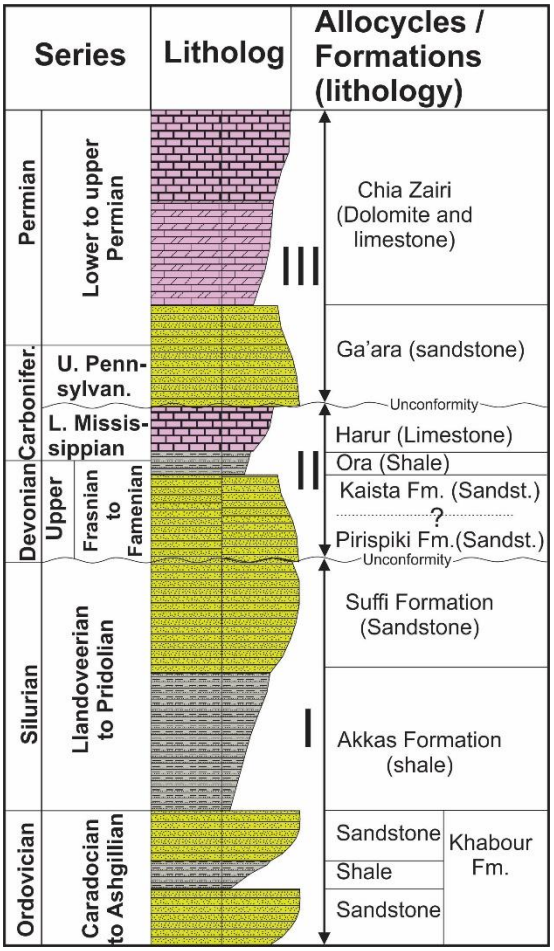

Fig. 3 Paleozoic stratigraphic succession of southern Iraq. Prominent stratigraphic gaps separate the succession into three allostratigraphic units (I, II and III). The sandstone and carbonate units are envisaged to be potentially good reservoirs whereas the shale units contain fair to excellent TOC content with high hydrocarbon generation potential. The stratigraphic log is compiled from Aqrawi (1998) and Aqrawi et al., (2014).

Potential source and reservoir rocks

The shale units within the Paleozoic succession, shales of the Khabour, Akkas and Ora formations constitute high organic content with Total Organic Carbone (TOC) ranging between 0.9 - 5%, 0.96 - 16.62%, and 1 - 9.94%, respectively (Al-Haba et al., 1994; Aqrawi, 1998; Aqrawi et al., 2010). The organic-rich shales are mature and have high hydrocarbon generation potential. The Paleozoic sandstone units that occur within the three allostratigraphic units mentioned above (i.e., Khabour, Suffi, Kaista, Pirispiki and Ga'ara formations) are envisaged to constitute thick and promising reservoirs (Jassim and Goff, 2006; Al-Hadidy, 2007). These sandstones are proven reservoirs in certain oil fields, such as, Risha (straddles across Iraq-Jordan border) and Akkas (western desert of Iraq). Previous work also demonstrates that the

carbonates of the Chia Zairi Formation (equivalent to the highly productive Khuff Formation of the Arabian Gulf countries) are potentially good reservoirs (Aqrawi et al., 2014). Further study on the reservoir qualities of the Paleozoic sandstones and carbonates of western and southern Iraq is required. Shale lithologies that separate the Paleozoic succession of the study area are deemed to be potential cap rocks; they may also generate stratigraphic traps.

Conclusion

The western and southern Iraqi deserts preserve tectonic features and sedimentary successions that have promising hydrocarbon potential. Structural features of anticlines and faults occur in the region. Besides that, the Paleozoic succession contains mature shales with high organic content. These shales are deemed to be capable of generating hydrocarbon. Potential reservoir rocks are interbedded with the Paleozoic hot shales and both structural and stratigraphic traps are likely present in the region. These structural and stratigraphic parameters, along with the existence of few oil fields in the region (e.g., Akkas and Risha) underscore presence of complete and mature petroleum system. It is highly recommended that hydrocarbon exploration companies reconsider their views on this “not-so-stable” region of the country.

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