Geology and petroleum systems of Akri-Bijeel Block, Kurdistan region of Iraq

László Csontos, Dr. (53)
MOL Ltd. E&P, Middle East, Africa, Caspian Region, Budapest
Advisor
lcsontos@mol.hu

Tamás Pocsai (30)
MOL Ltd. E&P, Middle East, Africa, Caspian Region, Budapest
Expert
tpocsai@mol.hu

Ágoston Sasvári (32)
Fugro Robertson Landundo Wales
Expert
sasvariagoston@yahoo.com

István Koncz (71)
MOL Ltd. Upstream Laboratories, Nagykanizsa Hungary
Independent Expert, retired
ikoncz@mol.hu

Abstract

The studied area in Kurdistan region of Iraq lies across an apparent important topographic/structural boundary between southern lowlands and northern, folded and imbricated mountains. Geological mapping and structural observations both in the mountains (Mesozoic – Paleogene) and in the lowlands (Neogene) led to the following conclusions. The oldest recorded deformation is a layer-parallel shortening, coupled with south-vergent shear that was followed by major folding of ca. 10 km wavelength and ca. 1,000 m amplitude. Even the Upper Miocene – Pliocene Bakhtiari Formation has steep to overturned beds in some parts, and synclines preserve growth strata of Neogene – Pliocene age. En echelon fold relay patterns suggest left-lateral shear along the E-W oriented segment and right lateral shear along the NW-SE oriented segment. The general structural setting of the area is certainly linked to the northeastwards - northwards propagation of the Arabian Margin beneath Eurasia. The ca. 30° curvature of the mountain chain may be explained by the original shape of the Arabian margin, or by pre-existing tectonic zones of E-W orientation in the northern part. The changing shortening directions (first NE-SW shortening, followed by N-S shortening) generated structural combinations of linear and en echelon folds on both the NW-SE and the E-W segments of the arc.

Spectacular bitumen seepage in Upper Cretaceous and Paleocene limestones comes from fractures or geodes. Many of the voids filled by bitumen are clearly linked to the above-described Late Neogene – Recent shortening-folding process; therefore petroleum migration into these voids should be very young, synchronous to, or post-dating major folding. This contradicts earlier ideas about massive Late Cretaceous breaching-bleeding off of hydrocarbons.

Wells drilled by MOL or Partners discovered significant volumes of petroleum in at least 5 different petroleum systems. The most important of these are the Jurassic and Triassic systems, which contain movable oil and gas-condensate. The younger systems contain only unmovable tar, due to under-mature state of the source rock and/or to biodegradation. The good quality petroleum in Triassic corresponds to the late oil-wet gas maturity state of those rocks at present. The quality of the Jurassic oil does not correspond to the oil window maturity state measured on Jurassic source rocks. Regional studies are needed to solve the origin and migration of this oil. Our observations would rather support a local migration due to Tertiary burial, versus a Late

Cretaceous, long range lateral migration due to tectonic loading of the obducted ophiolites.

Összefoglalás

A kurdisztáni (Észak-Irak) Akri-Bijeel blokk földtani felépítése és szénhidrogén-földtana

Észak-iraki, kurdisztáni kutatás során, terepbejáráson szerkezetföldtani és szénhidrogén-földtani megfigyeléseket végeztünk. A kurdisztáni terep hosszú, keskeny, az előterük fölé 800 m-rel magasodó mezozoos anyagú redőkből-hegyekből és deformált tercier előtérből áll. A merev mezozoos karbonátok néhány szurdokban jól feltártak és számos deformációs bélyeget megőriztek. Még a legfiatalabb, pliocén konglomerátumok is erősen deformáltak.

A legidősebb megfigyelt szerkezet rétegzéssel párhuzamos (általában dél felé irányuló) nyírás volt. E rétegzéssel kis szöget bezáró szerkezeteket a későbbi általános redőződés meghajlította. E fő redőződés hullámhossza kb. 10 km, amplitúdója kb. 1000 m és a mezozoos – pliocén rétegsor minden elemét érinti. Vastagságváltozások és belső diszkordanciák miatt e folyamat bizonyíthatóan a kései miocén – pliocénban érte a területet. A folyamatos déli irányú rövidülést lapos, az előző szerkezeteket átmetsző feltolódások és az igen fiatal domborzat jelzik. A feltolódások helyenként a pliocén rétegeket is átbuktatják.

A fő redőződés mellett kései, eltolódáshoz kapcsolható nyírásokat, redőződéseket is észleltünk. Ezek a K-Ny-i szerkezetek csapása menti balos nyírásról tanúskodnak.

A töréses szerkezetek ÉK-DNy-i, É-D-i és ÉNy-DK-i kompresszióra vezethetők vissza. Ugyanilyen deformációk találhatóak az iráni Zagros előterében is.

A terület általános fejlődésmenetét a Zagros kollízió (paleogén) utáni, délnyugati irány felé haladó feltolódási front szabta meg. Az általunk tanulmányozott terepen is ez és az É-D-i rövidülés volt a meghatározó. A Zagros feltehetően követte az Arab-tábla szegélyének lefutását, azaz sosem volt lineáris. Különböző szakaszokon a kombinált szerkezetek a két eltérő feszültség-főirány miatt jöttek létre.

A lemélyített fúrásokban és a felszíni szelvényekben több (legalább 5) szénhidrogén-rendszert lehetett elkülöníteni. Úgy tűnik, hogy a kréta rendszer még éretlen bitument tartalmaz, de az alatta levő kora-kréta és jura, triász rendszerek már érett olajakat, sőt gáz-kondenzátumot eredményeztek.

Felszíni szénhidrogén-földtani megfigyelések szerint a kréta karbonátokat legalább két olaj-átitatás érte. Az első a kristályokat átitató sárszerű anyag, mely biztosan a fő betemetődés (harmadidőszak) előtt került a kőzetbe. A másik olaj-bitumen következetesen ásványi kéreggel bélelt üregek belsejében, vagy a fiatal tektonikai elemek mentén található. Ezek a megfigyelések arra utalnak, hogy a második olajáramlás a mélybetemetődés alatt-után, a szerkezet-alakulással egy időben vagy utána történt. Annak kiderítésére, hogy a mélyszinti olajfelfedezés a korai, vagy a kései migráció terméke további vizsgálatok szükségesek.

Introduction

In 2007 MOL through its subsidiary, Kalegran Ltd. got exploration rights for Akri-Bijeel Block, located in the Kurdistan Region of N Iraq (Fig. 1 and Fig. 2), in the Zagros Mountains. Primary geologic information was gathered during a 3 week long field trip, completed by acquisition of a 440 km 2D seismic network in the Akri-Bijeel Block. The first phase of exploration was terminated by successful drilling of the Bijell-1 exploration well, proved to be a major onshore discovery of 2010. We also drew conclusions from the surface and subsurface observations to arrive at a hydrocarbon system model.

Fig. 1. Structural subdivision of Zagros on Google Earth map (after [1-2]) and position of the study area

Fig. 2. Position of the Akri-Bijeel Block in Kurdistan Region of Iraq

Akri-Bijeel Block has a total area of 889 km^2. From a topographic point of view, the Block is bipartite: in the northern part, there is a mountain range with roughly E-W orientation, and with heights reaching 1,500 m, while the southern half is a gentle hilly, plateau-like area, with an average height of 500 m (Fig. 3). Similar to topography, the vegetation and landscape also differs in northern and southern parts of the Block. The northern mountains are characterised by nice Mediterranean forest, or bush, with barren rock surfaces. The southern lowland is almost totally barren of trees and is covered by grass. While the northern mountain area abounds in water (especially in gorges, but also in form of karstic wells), the southern lowlands have mostly dry wadis with very limited water flow. The Zab River makes a natural boundary in the eastern part of the Block.

Fig. 3. Topography of the Akri-Bijeel Block

General geology of Zagros

The Zagros forms a major mountain system in the Middle East, ranging from Southern Turkey through the Kurdistan region of Iraq to Iran. It has direct links to the Oman Mountains of the Arabian Peninsula and hosts one of the richest petroleum provinces of the world.

The mountain chain consists of a southern foreland (Simply Folded Zone), two parallel ophiolite belts (green and blue on Fig. 1), the Sanandaj-Sirjan zone in between these belts and the Urumqieh-Dokhtar magmatic belt in the north (cross-hatched), on top of various Internal Iranian blocks, forming the northern edge of Zagros.

The southern foreland is the NE edge to the Arabian Platform, with stratigraphy and structures very similar to Iran and Arabia. This is the hub of the major petroleum deposits. The southern, Late Cretaceous ophiolite belt was obducted in the Late Cretaceous and is the direct equivalent of the Oman ophiolite. The Sanandaj-Sirjan zone is a complex of nappes, often composed of metamorphic Mesozoic sediments and volcano sediments, and stands for an internal continent/volcanic arc between the two ophiolite belts/oceanic tracts [3,1]. The northern ophiolite belt was obducted in Paleocene. Collision probably occurred only in Eocene, testified by ample volcanics of a magmatic arc (Urumqieh-Dokhtar), on the margin of the northern continental margins of the northern oceanic tract.

General stratigraphy

The stratigraphy of the area ([4,5] Fig. 4) is characteristic for the whole Iraqi Simply Folded Zagros. The bulk of the succession was deposited on the southern shelf of Tethys Ocean, from the Permian to Eocene.

The whole sedimentary succession is possibly more than 10 km thick and quite probably begins with a ductile Late Precambrian series. This is topped by several thousand metre thick Paleozoic – Lower Mesozoic succession, of which the shallow water carbonates of Chia Zairi (Permian) and Kurra Chine (Triassic) form thicker, more rigid units with locally anhydrites.

Jurassic begins by a several hundred metres thick neritic carbonate. In the Middle Jurassic this dolomitic platform passes laterally to evaporites (Alan, Adaiyah Formations). In the higher Middle Jurassic, Upper Jurassic, there is a widespread, yet thin basin facies, divided into Sargelu and Naokelekan Formations, which are black shales and limestones. In the Late Jurassic this basin passes either to neritic dolomites (Barsarin Fm) or to evaporites (Gotnia Fm).

In the Early Cretaceous yet another basinal black shale, marl, the Chia Gara Formation was deposited. It passes upwards into the Sarmord/Balambo marl and into the Qamchuqa neritic carbonate. After a not really marked unconformity in the mid-Cretaceous, an Upper Cretaceous platform carbonate, the Aqra-Bekhme carbonate was deposited. This platform passes laterally into basinal sediments (Shiranish and Tanjero marls). The upper part of the deep-marine marl may be also Paleocene in age (Kholosh Formation; [6]). The Cretaceous neritic carbonates (Qamchuqa, Bekhme and Aqra) form a stiff, ca. 600 m thick resistant structural level of the area. Most fold cores are formed of the Qamchuqa-Bekhme Formations in the region.

In the Paleogene a carbonate bar (Khurmala/Sinjar Formation) is followed by a characteristic brick-red Eocene clay forming a detachment horizon (Gercus Formation) and by a thin and chalky-dolomitic Eocene carbonate (Pila Spi Formation).

Neogene is represented by the sometimes evaporitic, variegated Lower Fars Formation (Middle Miocene), the mostly sandy, fluviatile Upper Fars (Middle-Upper Miocene) and the conglomeratic Bakhtiari Formation (Upper Miocene-Pliocene). All these formations are rarely and poorly dated [5] and have a cumulative thickness above 1,500 m.

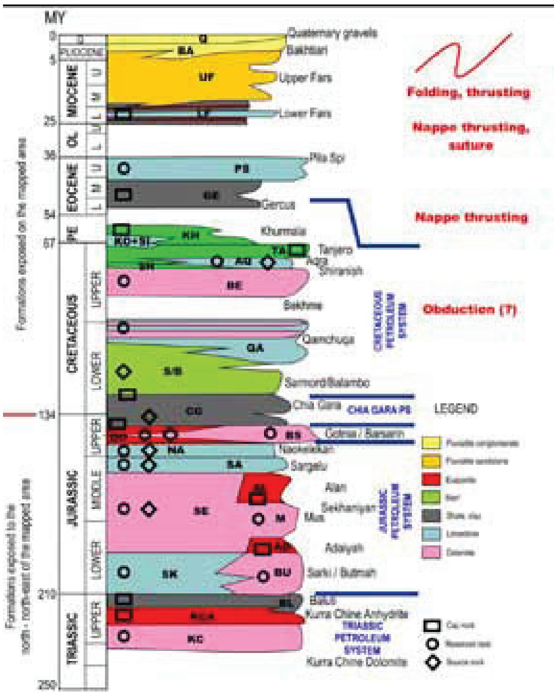

Fig. 4. Stratigraphy of the study area (pre-Triassic formations are omitted). Blue lines separate different petroleum systems. Main tectonic events are marked in red

Summary of structural observations

Geological mapping and structural observations led to the following conclusions:

1, The oldest deformation is due to the Late Cretaceous obduction of ophiolite nappes onto the Arabian margin. It has only created a characteristic, forebulge-linked sedimentary pattern in the region. In our area the shallow water Upper Cretaceous limestones were deposited on the forebulge. This deformation was preserved only in stratigraphy and did not leave observable structures.
2, The oldest observed deformation is a layer-parallel shortening (Fig. 5), coupled with south-vergent shear that was followed by a
3, major folding event of ca. 10 km wavelength and ca. 1,000 m amplitude (Fig. 6). Even the Upper Miocene – Pliocene Bakhtiari Formation has steep to overturned beds in some parts, and synclines preserve growth strata of Neogene – Pliocene age (Fig. 7). On the southern limb of the major folds thrusting of variable offset can be observed. En echelon fold relay patterns suggest left-lateral shear along the E-W oriented parts (Fig. 8) and right lateral shear along the NW-SE oriented parts.

Fig. 5. Layer-parallel thrusts in Eocene carbonate on the southern limb of Bekhme and northern limb of Aqra anticlines. The beds are tilted to sub-vertical or to steep now, due to later major folding

Fig. 6. Major folding in the Aqra anticline

Fig. 7. Successive unconformities in Upper Fars and Bakhtiari Formations in the Dinarta syncline. General view and close-up of gradually changing dips

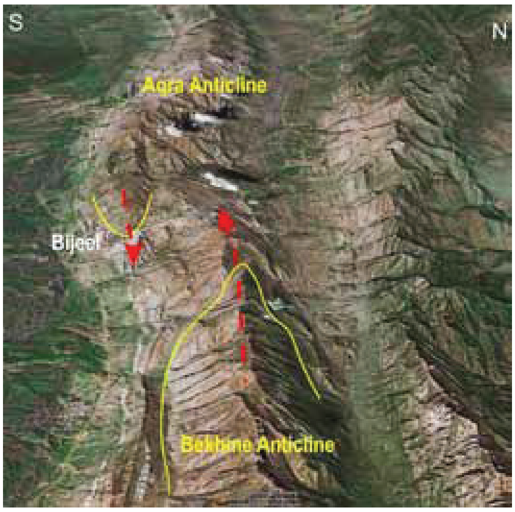

Fig. 8. En echelon pattern of Aqra and Bekhme folds in the Akri-Bijeel region, Google Earth satellite oblique view. Note the left lateral relay pattern

The general structural setting of the area is certainly linked to the north-eastwards-northwards propagation of the Arabian Margin beneath Eurasia. The ca. 30° curvature of the mountain chain (Figs 1,2) may be explained by the original shape of the Arabian margin, or by pre-existing tectonic zones of E-W orientation in the northern part.

In the study area we observed traces of a first NE-SW shortening and a second N-S shortening. These results corroborate with similar results in Iran [7,8]. From GPS measurements we know that the present shortening between Arabia and Eurasia is N-S oriented [9].

The apparently changing shortening directions from NE-SW to N-S generated several structural combinations on both the NW-SE and the E-W segments of the arc, many of which are still preserved (Fig. 9). During NE-SW compression (Fig. 9a), one may find only linear folds on the NW-SE oriented segment, while en echelon folds would be found on the E-W segment. During N-S compression (Fig. 9b), linear folds would be expected on the E-W segment, while right lateral en echelon folds would be found on the NW-SE segment. We believe that we observe superposition of both combinations on both segments.

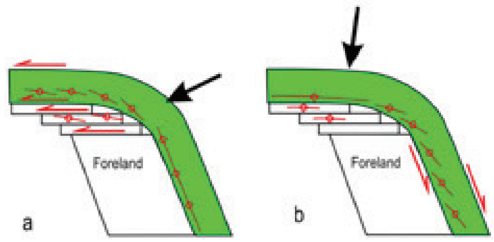

Fig. 9. Explanation of complex shortening and shear related structures on the different segments of Zagros. Note that main shortening direction probably changed from NE-SW to N-S in Pliocene

Petroleum geology

Petroleum fields discovered in Iraq so far are almost exclusively found in the plateau-lowland area, where the targeted structures have generally a good, thick Fars cover. The basal part of this succession (Lower Fars) has very good sealing capacity. Since folding deformation affected even Plio-Quaternary beds, the resulting folds are well seen and measurable in these younger sediments. All these features were already recognized by the first exploration geologists; therefore a common method of exploration was to drill the apex of the anticlines. Kirkuk is a prominent, very long anticline, which was among the first to be drilled [10]. The huge reserves discovered in carbonate reservoirs gave a positive feedback to the aforementioned exploration strategy, and in the following years a great number of topographically well-expressed anticlines were drilled. Although most of these structures contained very big quantities of hydrocarbons, there are some unexplained exceptions (Quwair), or many variations regarding reservoir rocks and their effectiveness. In some fields oil of variable quality, or gas and condensate was discovered in the same reservoirs.

During field work we documented spectacular bitumen seepage in Upper Cretaceous and Paleocene limestones. The bitumen is found 1, in shear related fractures (Fig. 10); 2, fold-related systematic fractures (Fig. 11) or 3, geodes of these formations (Fig. 12). These seeps are found in the heart or on the limbs of exposed anticlines. The shear-related fractures, fold-related fractures and some voids are clearly linked to the described Late Neogene – Recent shortening-folding tectonic process, therefore hydrocarbon migration into these voids should be also very young. This contradicts earlier ideas about massive Late Cretaceous breaching-bleeding-off of hydrocarbons.

Fig. 10. Bitumen in lozenge shaped shear related slip surface. Note that the bitumen infill formed after the movement

Fig. 11. Systematic joints in Shiranish Marl linked to the formation of major folds. Note bitumen injected in the sub-millimetric separations along joints

Fig. 12. Geodes with mineral coating. Note the innermost position of bitumen, suggesting a late infill (post-mineral coating)

Microscopic investigations of Cretaceous carbonates [11,12 (exclusive studies for MOL)] showed that beside the above-mentioned late migration event, an early, pre-diagenetic migration also occurred, that created a mud-like substance in the carbonate crystals. The time of this early migration is not known, but it most probably precedes the major Tertiary burial.

Bijell-1, the first well in MOL-operated area was spud on an anticline hidden beneath thick Tertiary sediments. A similar well (Shaikan-1) operated by our partner, Gulf Keystone International was spud on an exposed Mesozoic anticline. The two wells discovered significant amount of oil, and smaller gas volume.

Based on our surface and subsurface observations five petroleum systems were recognized (see Fig. 4):

Cretaceous system with
- Multiple potential Cretaceous carbonate source rocks,
- Aqra, Bekhme and Qamchuqa fractured carbonates (mostly dolomite) as reservoir,
- Tanjero and Kolosh marl as seal,
- containing 6-10° API unmovable tar;

Chia Gara system with
- Chia Gara shale as source rock,
- Chia Gara carbonate interbeds as reservoir layers,
- Chia Gara shale and overlying Sarmord shale as effective seal;

Gotnia system with
- potential independent source rock layers within Gotnia Fm, or alternatively, Sargelu Fm,
- Carbonate stringers in Gotnia Fm as reservoirs. This system is similar to the Ara Formation hydrocarbon system in Oman,
- Thick anhydrite interlayers of Gotnia Fm are efficient seal,
- Possibly 18° API oil with minor gas is contained in the reservoir beds;

Main Jurassic system with
- Sargelu and Naokelekan black shale and marl as source rocks,
- Naokelekan, Sargelu, Sekhaniyan and Sarki fractured carbonates as reservoir,
- Gotnia anhydrite as seal,
- containing 12-13° API oil in upper, and 6-10° API unmovable tar in lower part;

Triassic system with
- Kurra Chine dolomite as possible source rock,
- Kurra Chine fractured dolomite reservoir,
- Kurra Chine anhydrite and Baluti Shale as seal,
- this system contains good quality oil, gas and condensate.

MOL geochemists performed maturity studies on both the surface and well samples. It turned out that Cretaceous sources are marginally mature. The oil stored in Cretaceous is derived from a Cretaceous source. It is biodegraded in the exposed sections and non-biodegraded in the deep sections; however, even at depth the tar is unmovable.

In consent with other regional studies [13] the Jurassic source rocks are rich and are/were in the oil window. The carbonate source may explain the high sulphur content and relatively high viscosity, but the derived oils should be much better quality than found. It was supposed that a fractionation or gravitational separation occurred. Anyway, more volatile fractions seem to be absent from these oils.

The Triassic system should be late oil to wet gas matured, and the petroleum found there corresponds to the suggested maturity of the source.

Surface seeps and discoveries prove that the mentioned petroleum systems work, charge occurred. There are two possible charge models related to the tectonic evolution of the area (Fig. 13).

1, The first model suggests that the first important burial-maturity event happened in Late Cretaceous, due to the tectonic load of the ophiolite nappes. Jurassic-Cretaceous source rocks depressed by those nappes could be mature at that time. Since that area lies relatively far from the investigated Block, a long lateral migration should be proposed. The generated petroleum should have migrated towards the forebulge, i.e. our study area. This region was still uncovered (shallow water carbonates were being deposited), and the generated petroleum should have massively seeped away (Fig. 13a). We have found massive seeps, but all related to Late Tertiary structural features. However, the generated petroleum could have been preserved in Jurassic and Triassic reservoirs. The early, mud-like migration substance might be the result of this primary, long distance migration.

2, The second model suggests that all local source rocks were matured during the massive Tertiary sedimentary burial, and the generated petroleum should have migrated into the freshly formed structural traps (Fig. 13b). The migration is thus young, synchronous to (or post-dating) folding - thrusting and occurs as a local, possibly short distance process. We do have local, deep kitchens within the block. Since most of our field evidence points to Tertiary migration, we rather think that this model would fit better to our observations. Most maturity data and resultant oil qualities in agreement with their present positions also suggest that they have been generated by the Tertiary burial. However, the high viscosity Jurassic oil needs another explanation. Its relation with the other products is also questionable. It seems that all depends on the sealing ability of the different petroleum systems, which may leak due to lateral facies changes or due to high intensity fracturation during Tertiary structural evolution. Therefore a more regional geochemical correlation work is needed to arrive at conclusive answers in the maturity-migration model.

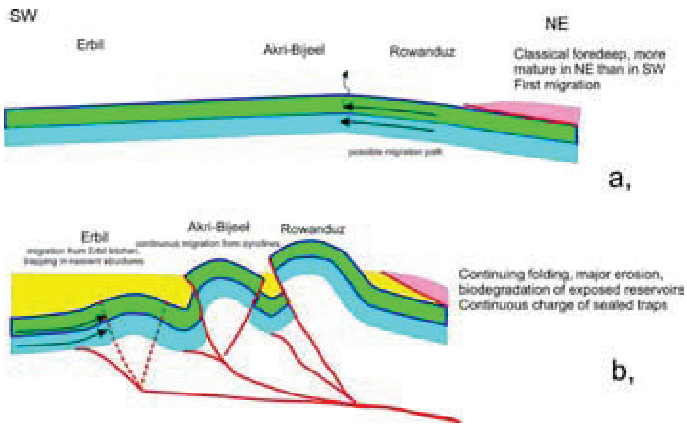

Fig. 13. Migration models of the area. Schematic structural section drawn at Late Cretaceous (a) and Pliocene (b) times. Note the changing direction of charge

Acknowledgement

The authors wish to thank to MOL/Kalegran for support to publish the material. Attila Fogarasi is specially thanked for reviewing the paper.

References

[1] Ghasemi, A. - Talbot, C.J.: A new tectonic scenario for the Sanandaj–Sirjan Zone (Iran) Journal of Asian Earth Sciences 26, 683–693. (2006).

[2] Goncuoglu, M.C. - Turhan, N. - Senturk, K. - Ozcan, A. - Uysal, S. - Yaliniz, M.K.: A geotraverse across northwestern Turkey: tectonic units of the Central Sakarya region and their tectonic In: BOZKURT, B., WINCHESTER, J.A. & PIPER, J.D.A. (eds) Tectonics and Magmatism in Turkey and

the Surrounding Area. Geological Society, London, Special Publications, 173, 139-162. (2000).
[3] Blanc, E. J-P. - Allen, M.B. - Hassani, H.: Structural styles in the Zagros Simple Folded Zone, Iran. Journal of the Geological Society, London, Vol. 160, 401–412. (2003).
[4] van Bellen, R.C. - Dunnington, H.V. - Wetzel, R. - Morton, D.M.: Stratigraphic Lexicon of Iraq. Reprinted by Gulf Petrolink 239. (2005).
[5] Jassim, S.Z. - Goff, J.C.: 2006. Geology of Iraq. Dolin and Moravian Museum Publications, Prague, Brno 341. (2006).
[6] Sarbazheri, K.M. - Ghafor, I.M. - Muhammed, Q.A.: Biostratigraphy of the Cretaceous/Tertiary boundary in the Sirwan Valley (Sulaimani Region, Kurdistan, NE Iraq) Geologica Carpathica, October 2009, 60, 5, 381–396.
[7] Lacombe O. - Mouthereau F. - Kargar S. - Meyer B.: Late Cenozoic and modern stress fields in the western Fars (Iran): Implications for the tectonic and kinematic evolution of central Zagros Tectonics, Vol. 25 (2006).
[8] Navabpour P. - Angelier J. - Barrier E.: Cenozoic post-collisional brittle tectonic history and stress reorientation in the High Zagros Belt (Iran, Fars Province) Tectonophysics 432, 101–131. (2007).
[9] Vernant, Ph. - Nilforoushan, F. - Hatzfeld, D. - Abbassi, M.R. - Vigny, C. - Masson, F. - Nankali, H. - Martinod, J. - Ashtiani, A. - Bayer, R. - Tavakoli F. - Chéry J.: Present-day crustal deformation and plate kinematics in the Middle East constrained by GPS measurements in Iran and northern Oman Geophys. J. Int. 157, 381–398. (2004).
[10] Dunnington H.V.: 1958 Generation, migration, accumulation, and dissipation of oil in Northern Iraq In: "Habitat of Oil" (Ed. L.G. Weeks), AAPG, 1194–1251. (1958).
[11] Benkó, Zs.: Fluid inclusion studies on hydrothermal minerals, Kurdistan, Iraq. Internal study. 59. (2008).
[12] Hips, K.: Diagenetic evaluation of outcrop samples, Kurdistan, Iraq. Internal study. 17. (2008).
[13] Pitman J.K. - Steinshouer D. - Lewan M.D.: 2004 Petroleum generation and migration in the Mesopotamian Basin and Zagros Fold Belt of Iraq: results from a basin-modeling study. GeoArabia, Vol. 9 No. 4, Gulf Petrolink, Bahrain 41-72. (2004).

Keywords: Iraq, structural evolution, petroleum systems

Reviewed by Attila Fogarasi