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# RECONSIDERATION OF THE BOUNDARY OF THE SOUTHERN PART OF THE MESOPOTAMIA FOREDEEP OF IRAQ

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## ABSTRACT

The tectonic setting of the southern part of Iraq is reconsidered on the light of the foreland concept. The nature of the regional gravity field, regional magnetic field and the Megaseismic Line 7 reflectors are inspected and integrated. The central gravity –magnetic high of Iraq (CGMHI), behaves tectonically, as a crustal flexing zone. The eastward continual tilting of post Gotniya (U. Jurassic) depositional basins resulted in gradual increase of time thickness (across Abu Jir Fault Zone) and begining at the flexural axis. The uniform continuity of the depositional cycles across Abu Jir Fault Zone denies the tectonic role of Abu Jir Fault Zone as a main boundary fault zone. During the Cretaceous and later history, the eastern part of Salman region behaves as a part of the Mesopotamia Foredeep. The study shows also that the boundary of the (CGMHI) with the Western Desert Gravity Low is associated with more profound fault zone. During the deposition of Chia Zairi and Kora China formations, slight syndepositional uplift at the western side of (CGMHI) could be detected. The (CGMHI) marks the crustal flexural zone; it is in congruence with the Foreland Basin Concept. The results of this study could help in a better comprehension of the tectonic framework of Iraq.


# مراجعة الحدود الجنوبية لحوض وادي الرافدين في العراق

**جاسم محمد البديوي**


## المستخلص

تمت مراجعة النظام الحركي لجنوب العراق على ضوء نظرية الأحواض الرسوبية المتقدمة. تم تدقيق هيأة الحقل الجذبي الإقليمي، الحقل المغناطيسي الإقليمي والمقطع الزلزالي الإقليمي رقم 7. إن نطاق المرتفع الجذبي – المغناطيسي الممتد وسط العراق (نطاق المرتفع الجذبي – المغناطيسي المتوسط) حركياً تصرف كنطاق انحناء للقشرة الأرضية يبدأ الى الغرب من نطاق فوالق أبو جير، ميل مستمر لما بعد ترسيب تكوين القطنية تسبب بزيادة سمك الترسبات اللاحقة (عبر نطاق فوالق أبو جير). إن التناسق المستمر للدورات الترسيبية عبر نطاق فوالق أبو جير تنفي أي تأثير فعال لهذا النطاق كحد حركي لحوض وادي الرافدين، إن الجزء الشرقي لمنطقة نطاق السلمان خلال الحقبة الطباشيرية وما بعدها تصرف كجزء من حوض وادي الرافدين. إن الدراسة أظهرت أيضا أن حدود المرتفع الجذبي المتوسط مع المنخفض الجذبي للصحراء الغربية يرتبط مع نطاق فوالق أساسية. خلال ترسب تكويني الجيازيري والكورا جاينا، من الممكن ملاحظة نهوض للجانب الغربي لمنطقة المرتفع الجذبي المتوسط متزامن مع ترسب هذه التكوينات. نأمل أن تساهم هذه الدراسة في فهم أفضل للنظام الحركي في العراق.


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## INTRODUCTION

In the light of the Foreland Basin Concept, Fouad (2010) considered the Jazira Subzone and the northern part of (Salman Zone) to be a part of the Mesopotamia Foredeep. Fouad, (2010), based his supposition on the characteristic wedge shape profile of the foreland basin and the major tectono – stratigraphic assemblages. The new Foredeep Boundary raises serious problem of inconsistency with the Gravity – Magnetic Fields characteristics of the region which should be taken in consideration in discriminating the real tectono – stratigraphic nature of the different zones. In contrast to the southern part of the Mesopotamia Foredeep, its northern part is characterized by the northern part of the Central Gravity High of Iraq (CGHI); the southern part occurs to the east of the CGHI. This serious inconsistency is a reasonable cause to review the situation using the available geological and geophysical data.

The Megaseismic Line No.7, which crosses the major tectonic zones of Iraq, Mohammed (2006) specified the location of the Palaeozoic Platform Edge along the eastern flank of Maania Depression and considered it as the start of the Mesozoic near – platform flank of the Mesopotamia Foredeep. He defines the migration during the Mesozoic and Cenozoic times of the hinge line separating the Arabian Platform from the Mesopotamia Basin as corresponding to the Lower Cretaceous progradational pattern seen as clinoforms in the Megaseismic Section. Mohammed (2006) simply concludes that a good correlation exists between the Bouguer gravity anomaly profile with the position of the Maaniya Depression, with the main Paleozoic anticline and with the greater thickness of the Cenozoic succession. The main aim of this work is to discuss in detail the tectonic nature of the Central Gravity – Magnetic High region and its western boundary with the Maaniya Depression as well as its response to the actual structural setting of the distal part of the Mesopotamia Foredeep. The paper also defines the nature of the Western Gravity Low of Iraq. The work could contribute in developing a better understanding of the tectonic framework of Iraq.

Two main studies concerning the tectonic framework of Iraq are based on gravity, magnetic and seismic data. They are the works of Jassim, *et al.* (2006) and Fouad (2010). Jassim and Goff (2006), prepared the structural map of Iraq and depth of the basement and interpreted the longitudinal and transversal fault systems from the horizontal derivative of gravity and magnetic data. They also defined major tectonic zones. In their new subdivision of the tectonic zones of Iraq, they modified the Stable Shelf to include the Mesopotamia Zone and proposed that the Stable Shelf is divided into Rutba – Jazira, Salman and Mesopotamia Zones. On the other hand, Fouad (2010) supposed that the Jazira Subzone and the northern part of Salman Zone belong to the Mesopotamia Foredeep (the Unstable Shelf). He introduced the term (Mesopotamia Foredeep) to be used instead of Mesopotamia Zone. The Mesopotamia Foredeep is a part of the Zagros Foreland Basin which is formed as a result of the down flexing of the continental lithosphere in response to the collision in the east.

## ASPECTS OF THE GEOPHYSICAL SECTIONS

A discussion of the Bouguer gravity map of Iraq and the gravity trend map of the Middle East (Fig.1) could be helpful as introductory theme in comprehending the nature of the configuration of the gravity field of Iraq. The majority of the Western Desert is characterized by major gravity low extending along the boundary with Saudi Arabia (Western Gravity Low of Iraq, WGLI), limited from the east by a major gravity high (the Central Gravity High of Iraq, CGHI, which is associated with expressive magnetic anomaly zone, the Central Magnetic High of Iraq, CMHI Fig.2). The Western Gravity Low of Iraq is interpreted as a northern extension of the huge gravity trough (– 120 Mgal at the Arabian Shield**)** that spreads

around the Shield; the author calls it the Arabian Gravity Low Province. This gravity province reflects the old least deformed Arabian Platform. In bulk, it expresses crustal composition and thickness relative to lithosphere/ upper mantle transition total thickness, it also represents the crystalline basement (thickness of the Phanerozoic Sequence). A major gravity gradient zone, of relatively shallow source, separates the WGLI from the CGHI indicating that a more basic nature of basement (CGHI) bounding the western acidic crust (WGLI). Within the Western Desert, it is believed that major faults accommodating basic intrusions separate the Western Gravity Low into three minor gravity lows: Rutba Gravity Low (anomaly A) in the west, Maania Gravity Low (anomaly B) in the east and North Nukhaib Gravity Low (anomaly C). The basic intrusions are very well defined by both magnetic and gravity elongated positive anomalies (Al-Bdaiwi, 2011). From the east, the CGHI is bordered by the eastern great gravity low of Iraq which mainly relates to the western flank of the Zagros Gravity Trough (– 220 Mgal) and depth of the crystalline basement (thickness of the Phanerozoic sequence).

A megaseismic section, starting from the eastern end of Khalija gravity–magnetic anomalies throughout the whole aforementioned gravity zones is performed (Mohammed, 2006, Figs.3, 4 and 5). In order to express only the time thickness anomalies in each of the depositional cycles (regardless of the actual time thickness of the cycles) all reflectors in Fig.3 are shifted to bring the reflectors closer to each other **(**Fig.4). The configuration of the reflectors in this figure expresses:

**1-** Lower Mesozoic syndepositional uplift, could be indicated by the reduction of the total time thickness of the Chia Zairi and Kora China formations over the eastern flank of Maaniya Depression (western flank of the CGHI). Good correlation with the magnetic marker 2a and 2b and gravity marker 2; basement fault zone (Fig.5).
**2-** Slight increase in total time thickness of Alan and Gotnia formations at the CGHI region, indicating slight syndepositional subsidence during the deposition of these formations in this region.
**3-** Clear northeast gradual increase in time thickness (slight initial tilt increase) from top Gotnia to top Saadi (or top Hartha) formations started from the western part of the CGHI region; flexing of the crust. Otherwise, uplift at the western side of Salman area could be inferred.
**4-** Interruption in the Flexural growth during the deposition of the Late Cretaceous Hartha (reflector not clear) and the Late Eocene Jaddala formations (uniform thickness); intermediate stable period.
**5-** Great growth in total time thickness due northeast started with the deposition of the Middle Miocene (Fatha Formation) indicating accelerated growth of the previously mentioned initial tilting of the crust. This tilting reached maximum rate during the deposition of the Mukdadiya Formation in the east. The overall configuration of the Seismic Transect shows that this tilting is not restricted to the Mesopotamia area; it prevails over the whole area of the Transect (including the Western Desert), though it is much greater to the east of the Flexure Axis. This regional tilt is mainly attributed to the sub lithosphere driving agent that started with the opening of the Gulf of Aden and the Red Sea in the west and to the opposing mechanical loading in the northeast due to the subduction and collision.
**6-** Chia Zairi and later Reflectors, to the west of the Flexural Axis shows harmonic (same) regional northeast dip around faults (B, C and D zone) but with shifted levels; differential vertical displacement can be seen between the Western and the Eastern Blocks around the area of Maaniya of about 0.25 second magnitude.
**7-** Across Abu Jir Fault Zone no tectono – stratigraphic sign could be seen.

**8-** Fault G (far to the east of Abu Jir Fault Zone) could be introduced as a significant fault, since it coincides with a great Gravity – Magnetic boundary lineament (the suspected major boundary fault zone) (Figs.1 and 2).

**9-** Figure (3) (colored area) shows the relative transposition of the greater time thickness sections of tentatively gathered sedimentation periods oscillate between east and west, starting from the Hercynian Unconformity up to the top of Saadi Formation within the area of the CGHI, indicating higher mobility of the Salman area.

**DISCUSSION**

Within the tectonic framework of Iraq, Fouad (2010) defined the boundary of the Mesopotamia Foredeep with the Stable Interior of the Arabian Plate to run with Abu Jir Fault Zone to the east of the CGHI area and Anah Fault Zone to the south of Khlasiya Gravity High which is a part of the CGHI. The present reconsideration of the boundary is based on the distribution of the Late Cretaceous Formations (post Hartha) – present Foreland Basin Assemblage. Following Fouad (2010) definition, the detailed analysis of the Megaseismic Line 7 shows that the actual boundary of the Foreland Basin does not agree with the position of Abu Jir Fault Zone; it agrees with the central part of the CGHI. In fact, the area of the CGHI shows clear sign of Crustal Flexing, which caused the formation of broad depositional basin initiated with the deposition of Ratawi Formation (Early Cretaceous), and started from the central part of the CGHI; clear shift of the local depositional centre from the area of the flexural axis (area with one white asterisk) due east (area with two white asterisks) (Fig.4).

From Fig. (3), it could be concluded that the wedges of the post Jeribe formations (Middle Miocene – Pliocene) do not start from the position of Abu Jir Fault Zone, but from west of it (see the thicknesses of the formations). In addition to the conclusive fact that across Abu Jir Fault Zone no tectono – stratigraphic sign could be seen, the central part of the CGHI could be more actual boundary for the Mesopotamia Foreland (to the west, far from the position of Abu Jir Fault Zone). This new proposition makes the distal part of the Mesopotamia Foredeep to be included within the eastern side of the CGHI. This tectonic setting runs in accordance with the gravity – magnetic configuration of Iraq.

The CGMHI belt, which extends far through Saudi Arabia, surely reflects a zone of lithosphere characterized fundamentally by different mechanical characters; less thickness (higher heat transformation from the Upper Mantle) and heterogeneous composition thus more liable to bend. This belt consumed the stress by bending leading the initiation of crustal tilting along its eastern flank. The previous boundary of the Mesopotamia Foredeep as suggested by Fouad (2010) is discordant with the extensions of the CGHI, which is essential in delineating the tectonic setting of the region. In fact, the fluxture axis of the crust in the south as that in the north (Khlasiya area) is the actual boundary of the Foredeep (not Abu Jir Fault Zone) (Fig.4).

Two phases (of northeast tilting) could be recognized. The first, pre tectonic collision, is very slight and limited between top Gotnia and top Saadi depositional period. This phase is of extensional nature; many normal faults ended within the Cretaceous formations (Fig.3). The most extensive tilting (the second) started with the deposition of the Fatha Formation onward (the Foredeep proper). These two phases were separated by stable period; uniform time thickness during the deposition of Late Cretaceous and Late Eocene.

It should be pointed out that Fault G (Fig.5) may have more significant tectono – stratigraphic action than Abu Jir Fault Zone especially because it is located at a main Gravity – Magnetic Discontinuity (Figs.1 and 2, Al-Bdaiwi, 1995). This great discontinuity longitudinally transects the Mesopotamia Foredeep from north Haditha to west Kuwait (Haditha – Ramadi – West Amara – West Kuwait Lineament (Al-Bdaiwi, 2010). It is noted further that a graben – like feature (green bar, Fig.5) located to the south of Baghdad can well be recognized. This feature is located between East Baghdad structure in the north and Aziziya structure in the south. Baghdad and Aziziya structures have foundations within the basement (magnetic signature) and show en echelon arrangement. Nevertheless, the seismic transect, here, crosses a complex structural area.

The regional gravity picture (to the east of Maania Depression) is worth of consideration as a net resultant of the latest constructive great driving agent that generates the Alpine Orogeny; the western gravity picture is related to a much older tectonism. The great process of basic magmatization that characterizes the CGHI, in fact, is much older and could be related to the first stage of the rifting period that took place along the northeastern part of the Arabian Plate; it could represent an aborted rift zone. The overall configuration of the Central Magnetic High of Iraq (CMHI) anomalies with the transversal anomalies of (Wadi Ghadaf and Wadi Al-Ubayidh and many others, Figs.1 and 2) could refer to an aborted rift zone model extending from Syria through Iraq. The basement at and about the zone of the Crustal Flexure naturally suffers a greater stress action causing the original (old) configuration of the basic intrusions of the supposed rift to be slightly distorted during the Neogene tectonic processes and resulted in propagation of the old basement weakness zones throughout the sedimentary cover. Generally, the area of Khlesiya Gravity High is with a low magnetic field; the only expressive magnetic anomaly present within Khlesiya Gravity High is in about E – W direction, located within the area of ENE – WSW trending well known Khlaisya graben, which could confirm reactivation of basement weakness zone along the intensive magnetic anomaly (see also the good alignment of the major valleys of the Western Desert with the major magnetic anomaly belts, for example, Wadi Ghadaf and Wadi Al-Ubayidh (Al-Bdaiwi, 1997).

The good correlation between the Early Mesozoic syndepositional uplift and the northwesterly trending magnetic marker 2a and 2b and gravity marker 2 (Fig.5) could indicate basement structural control of the development of Maaniya Depression (western boundary of the CGHI).

In a more regional scale (Gondwana scale) the CGHI, which extends to the south through Arabia, could be a part of a more extended crustal feature as a similar feature present in India; two prominent strips of positive gravity residual anomalies bounded the Himalaya Foredeep (the magnetic anomaly map of India is not available for the author). Within Iraq, the magnetic anomaly map expresses two magnetic strips as well (Fig.2).

The suitable position of the CGHI relative to the hydrocarbon rich Mesopotamia Basin, makes the local structures, the stratigraphic and facies boundaries of the CGHI region more profitable as a catchment area (traps area) for the expected up dip migrating hydrocarbons from Mesopotamia, the hydrocarbon showing along Abu Jir Fault Zone is a conclusive phenomenon for this migration. High resolution gravity survey for the CGHI region could give unpredictable results in this context; three local gravity surveys (Al-Bdaiwi, 2011) at the extreme west of the Western Desert have indicated that the available Bouguer gravity map of the measured areas, which are parts of the Western Desert are poor with respect to

prospecting for local structures such as that of hydrocarbon importance. The gravity and magnetic maps are of first order aid in guiding hydrocarbon seismic exploration and drilling if statistically integrated with the seismic anomalies. In contrast to the gravity survey of the western desert, it is noticeable that most of the structures marked by the Seismic Transect within the Mesopotamia Zone and Maaniya Depression are well marked by the gravity and magnetic maps (for correlation see Fig.5, especially for Baghdad – Aziziya, Ghazal, Kilo 160 and Al-Sahan structures and the seismic faults). For instance, Jassim and Goff (2006, p.62) mentioned that Kilo 160 and Al-Sahan anticlines (one black star, Fig.5) are associated with prominent gravity lows and thus probably located above the Infracambrian salt graben, in fact, they are associated with positive residual superimposed on regional gravity low, Al-Bassam *et al.* (1995).

Getech and Jassim (2002) in Jassim and Goff (2006), (Fig.6), and based on 3d inversion of the gravity field of Iraq, gave a depth of more than 11 Km for the basement at Maaniya Area (a great sedimentary basin). We believe that Maania gravity trough, in majority, is related to granitic basement rather than basement deep. The structural configuration of Al-Breet – Maaniya area is exceptionally reflected by the constructive configuration of the magnetic – gravity fields (magnetic basement – gravity sedimentary column) consistent structural configuration, a situation which should be considered in the evaluation of the thickness and nature of the sedimentary cover of the area; relatively low sedimentary cover thickness and absence of detachment surfaces especially at deeper horizons, permit propagation of the basement differential movements throughout the sedimentary cover with noticeable consistency (Al-Bdaiwi, 2012).

The author agrees with the postulation of Mohammed (2006) that the eastern flank of Maaniya Depression is a major tectonic boundary zone about which the attitude of its eastern strata experienced appreciable local change beside the differential vertical movements of about 0.25 Sec. but neither as a location of the Palaeozoic platform edge marks the Mesozoic near – platform flank of the Mesopotamia Foredeep nor as a start hinge line separating the Arabian Platform from the Mesopotamia Basin during the Mesozoic (see the similar dip of the tops of the formations and nearly similar total thickness) around Ma'ania Depression, which deny presence of hinge line at this location (Fig.4).

The structural configuration, explained above, is a normal consequence of the interactive effects expected to be connected with the driving complex stress field for the Arabian Plate and minor tectonic processes and plate kinematics and subsequent development of the region. This deep seated complex driving action is mainly attributed to the sub lithosphere driving agent that started with the opening of the Gulf of Aden and Red Sea in the west and to the opposing mechanical loading in the northeast due to the subduction and collision. This major action is continually active from Late Cretaceous, especially during Neogene, reactivating old weakness zones even within the least deformed part of the Plate; far from the major tectonic zones (collision zones).

## CONCLUSIONS

In the light of the geophysical and geological information related to the tectonic situation of central and southern Iraq and the discussion in this paper, the author finds that there is a necessity to revise the idea which states that Abu Jir Fault Zone forms the western boundary of the Mesopotamia Foredeep whereas the real boundary from the present study lies far to the west along the axis of the flexure of the crust, in accordance with the extension of the gravity – magnetic high of central Iraq.

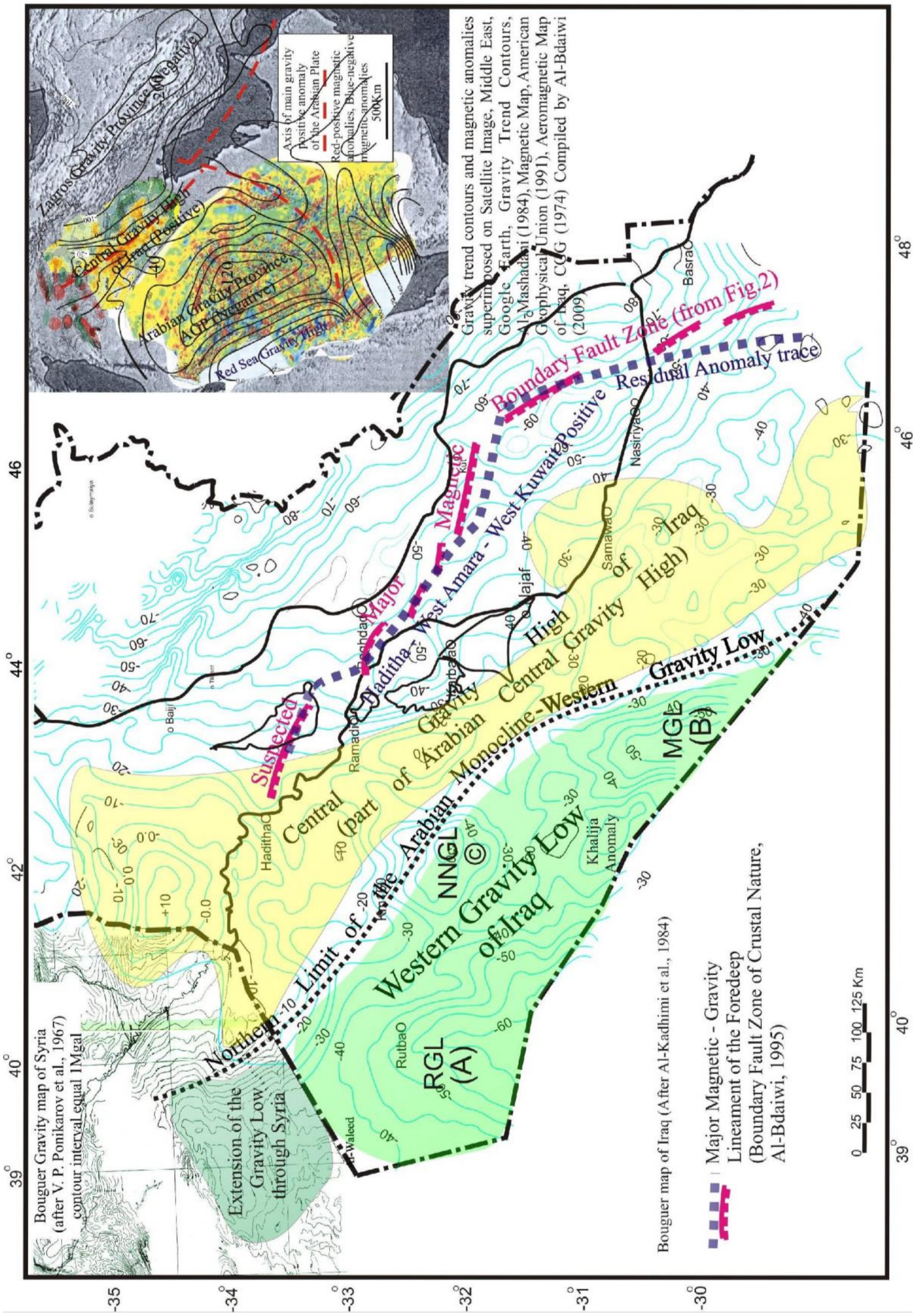



Fig.1: Bouguer gravity map of Iraq and Syria

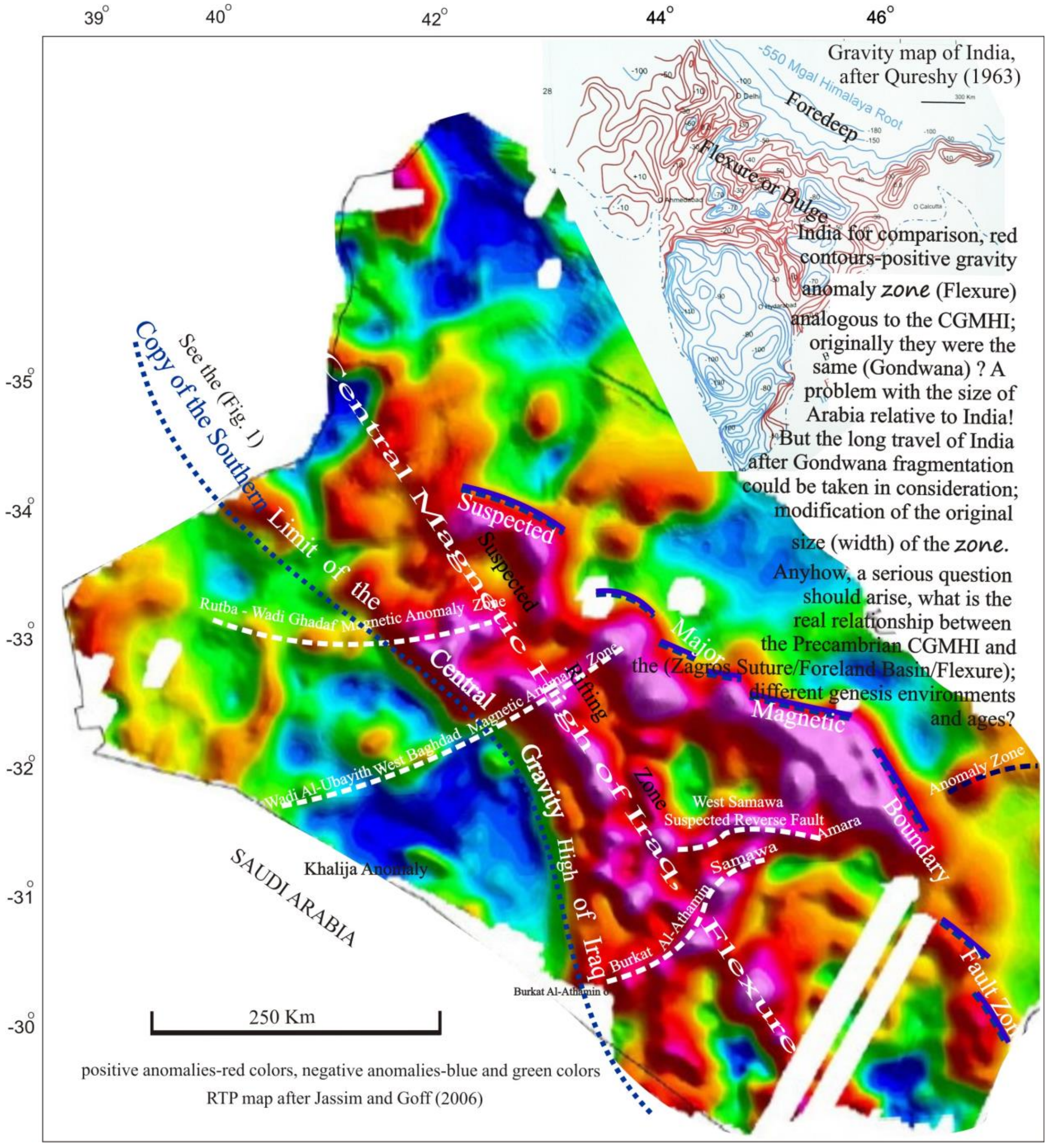



Fig.2: RTP map of Iraq with axes of major features, (interpretation after, Al-Bdaiwi 2011)

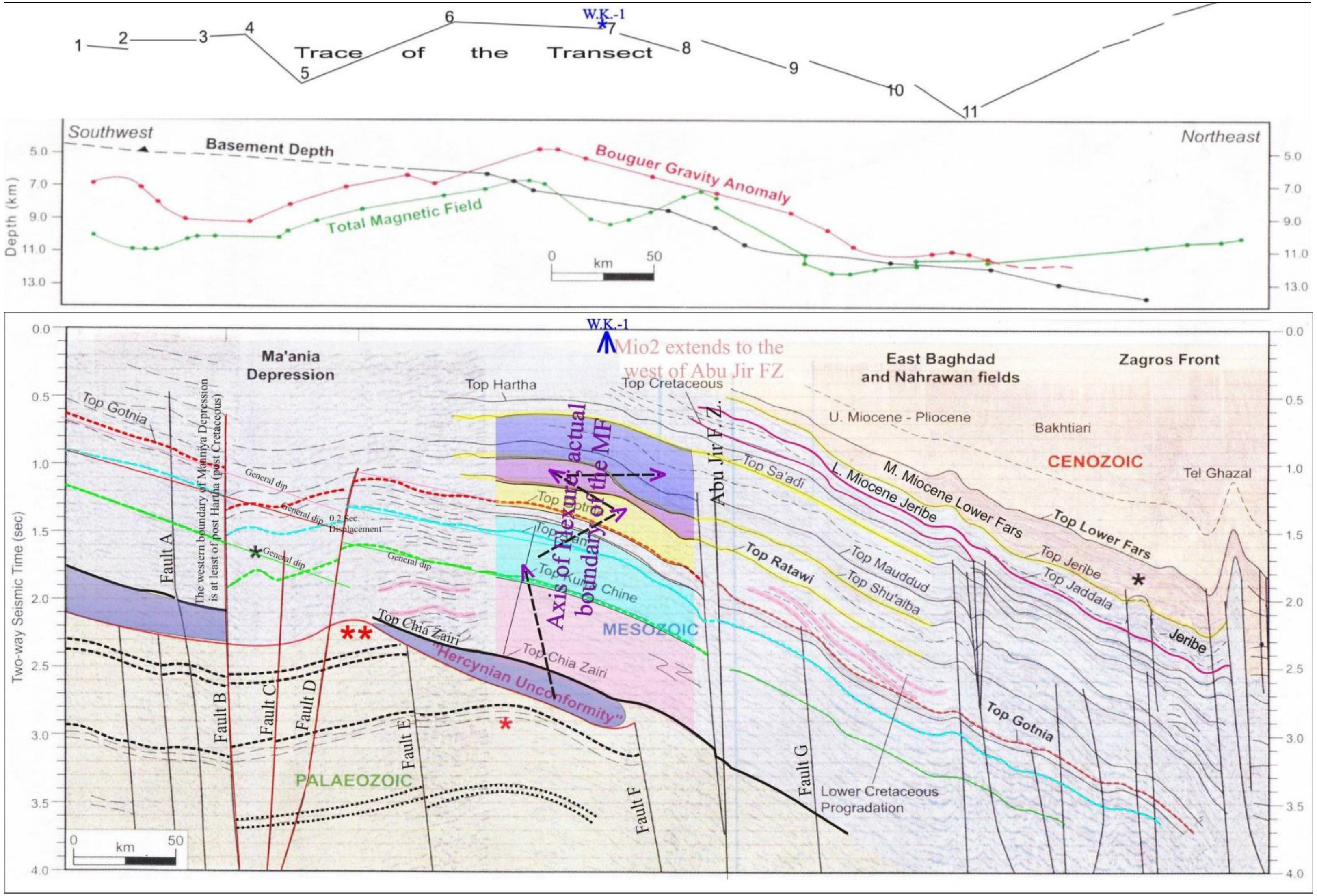



Fig.3: Megaseismic section a cross the northeastern slope of the Arabian Plate (after Mohammed, 2006). Colored block within the area of the High Gravity-High Magnetic Zone shows in detail the local fluctuation in time thickness relative increase within the zone, implying a zone of higher mobility, arrow pointing to higher thickness.

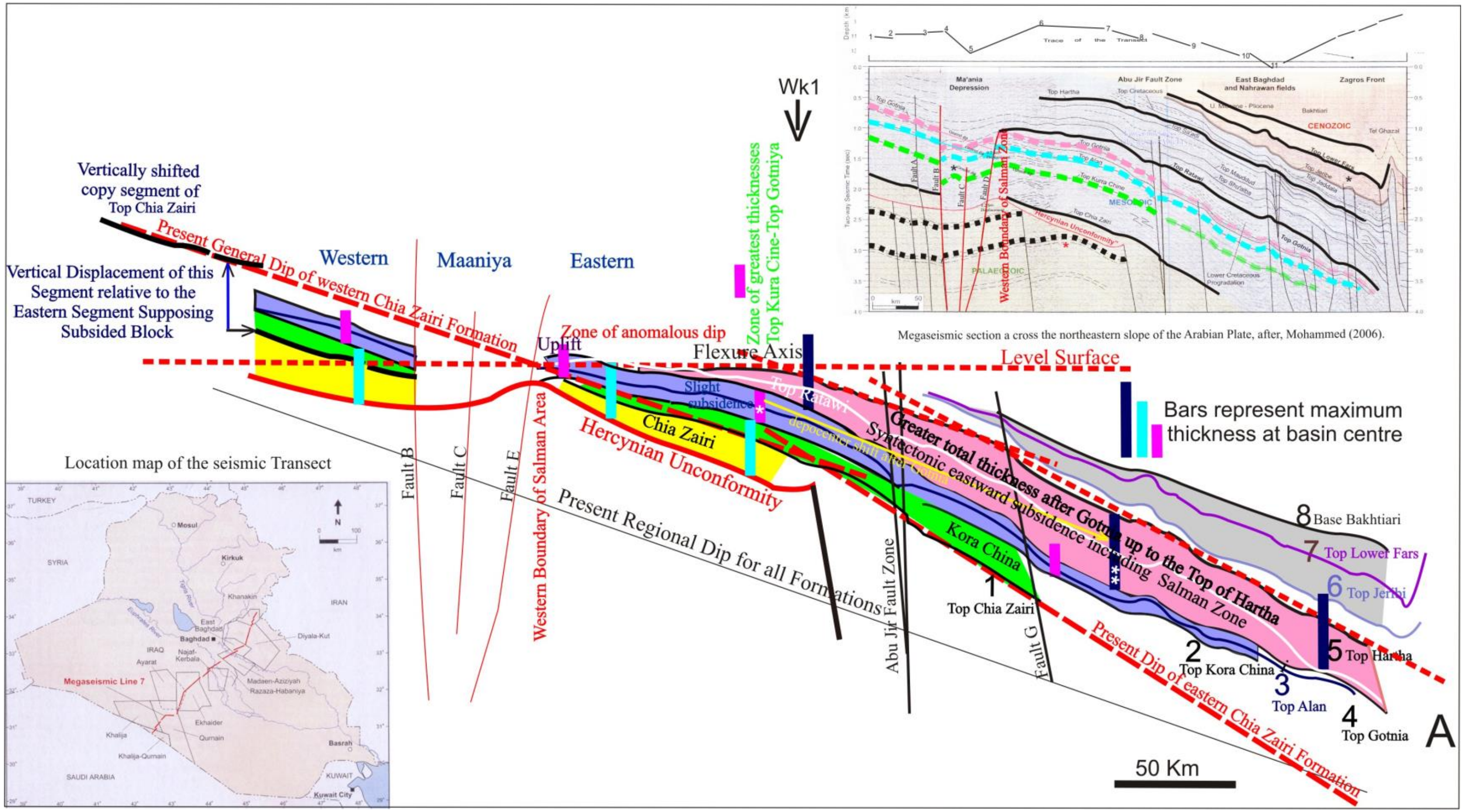
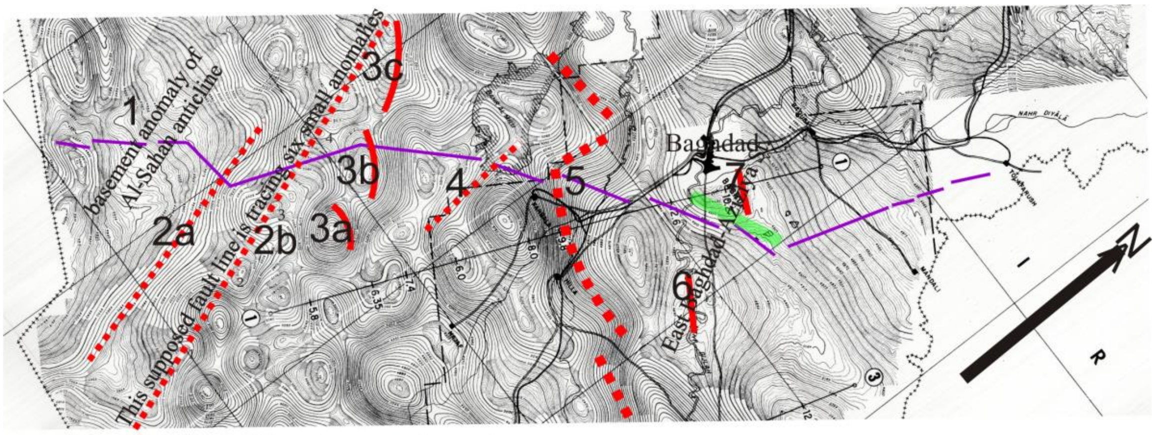
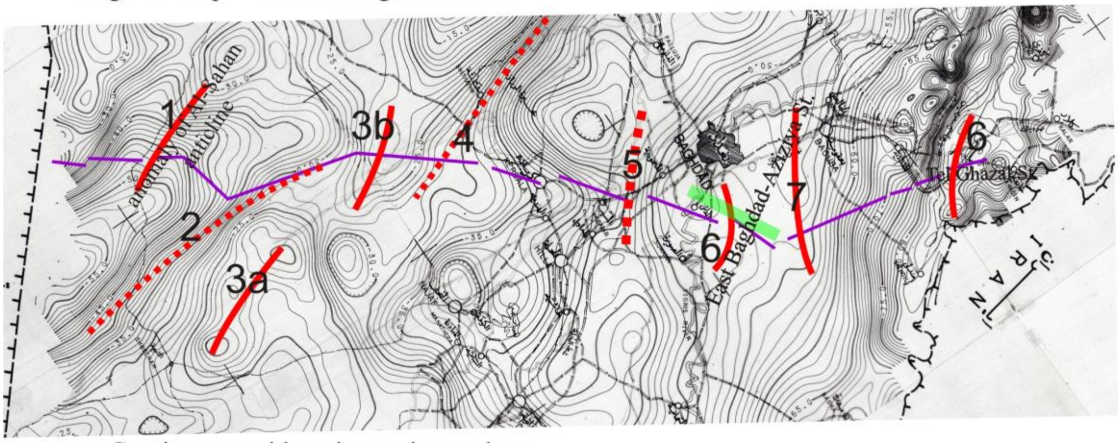



Fig.4: Reduced time thicknesses of formations to express thickness anomalies, Note that only during the deposition of Chia Zairi and Kora China, the western side of Salman Area could experience slight syndepositional uplift; during the deposition of Alan and Gotniya slight syndepositional subsidence at Salman Area could be noted; only after the deposition of Gotniya, the Mesozoic at Salman Area behaves as a part of the Mesopotamian Foredeep. After the stable deposition of the Late Eocene Jaddala Formation and the Early Miocene Jeribe Formation, the deposition of Middle Miocene – Recent,experienced the most expressive tilting of the crust due northeast starting from the axis of the flexure. Note that Abu Jir Fault Zone shows no tectonic role in all the above mentioned scenario.




Magnetic map with main magnetic markers




Gravity map with main gravity markers

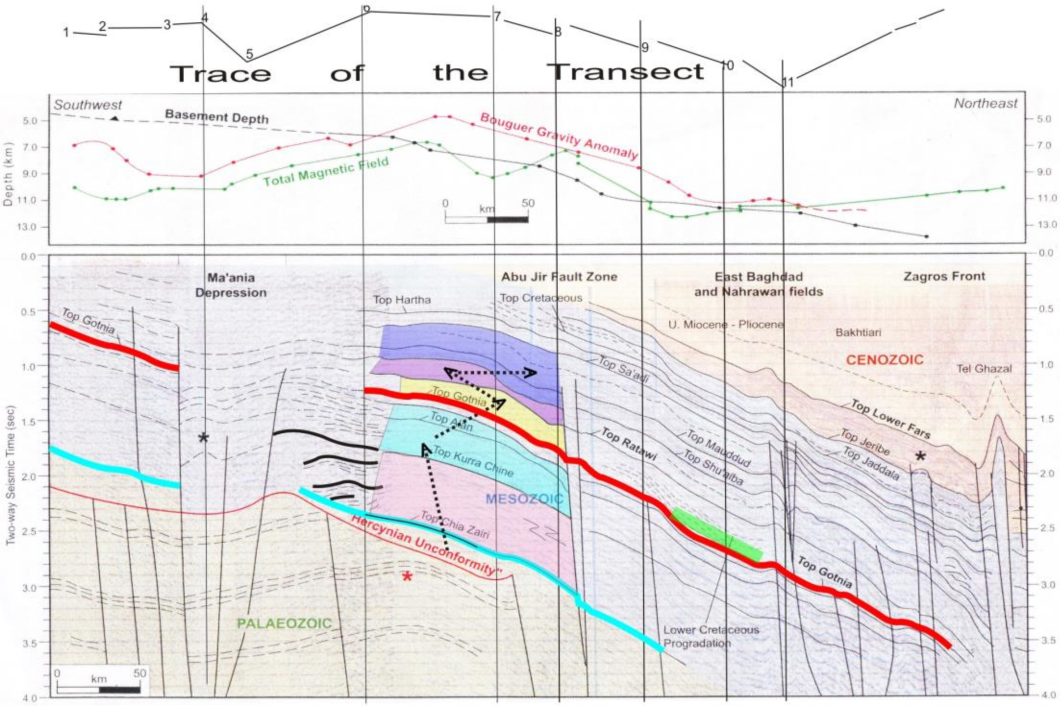



Fig.5: Megaseismic section a cross the northeastern slope of the Arabian Plate, (after Mohammed, 2006) in correlation with gravity and magnetic fields anomalies. Arrows show the relative position change of the greater time thickness within the area of High Gravity Zone, implying a zone of higher mobility

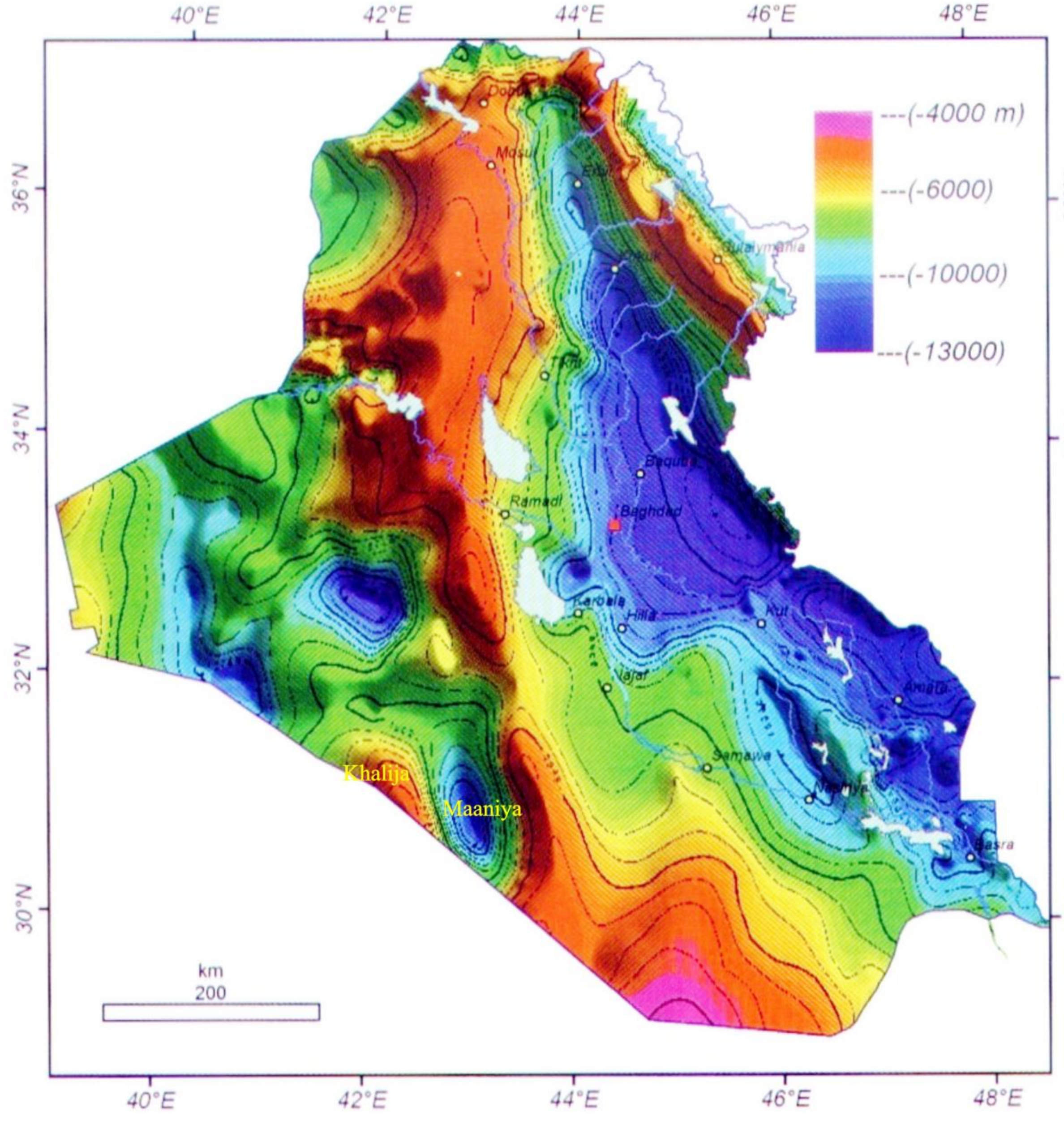



Fig.6: Depth to the crystalline Precambrian Basement (in meters relative to sea level) derived from 3D inversion of gravity
(after Getech and Jassim, 2002, in Jassim and Goff, 2006)

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