STRUCTURAL AND GEOTECTONIC INTERPRETATION OF VERGENCE DIRECTIONS OF ANTICLINES IN THE FORELAND FOLDS OF IRAQ

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Abstract

One of the intriguing geometrical characteristics of the Foreland Folds Belt in Iraq is the opposing vergence directions of the different asymmetrical anticlines towards either the north and northeast or the south and southwest. Folds with similar vergence alternate with other zones of opposing vergence both transversely and longitudinally with respect to the regional trend of the Foreland Folds. At least in a well documented case (The Ain Zalah Anticline), opposing vergences are noticed along the axis of the same anticline. This work is based on protracted field observation and compilation from previous local studies. The extensional and wrench tectonics model proposed in previous work for the Foreland Folds of Iraq is adopted and interpretation is given for the mechanism of folding and the opposing vergences.

Introduction

The Foreland Folds in Iraq (commonly called the folded Zone of Iraq) represent the area between the Arabian Craton and the Alpine Orogen Proper (Fig.1). Mesozoic and Tertiary successions are thrown into anticlinal and synclinal structures that are mostly well exposed. Paleozoic successions that are subsurface in the Foreland Folds are exposed towards the axial zone of the Alpine Orogen in the extreme northern parts of Iraq. Table (1) shows the generalized stratigraphic column of Northern Iraq after Bellen et al. (1959).
In the allocations of the classical terminology of geosynclines into the geology of Iraq, Bady and Jassim (1987) described the Folded Zone of Iraq as being a part of an unstable shelf and a miogeosyncline, whereas earlier workers; e.g. Naqib (1967), Kukal and Saadallah (1970), etc. allocated the whole region of the Folded Zone as a part of a miogeosyncline called the Mesopotamian Geosyncline. Indeed a perplexing plethora of archaic geosynclinal terms describing the geology of Iraq in the Literature still awaits to be filtered through the modern understanding and advances in the application of the plate tectonic paradigm into continental geology (work in progress).

The problem of vergence of anticlines in the studied region has been dealt with passively in previous work from a purely descriptive geometrical point of view in individual structures; e.g. Zwain (1976), Nadir (1983), Ahmad (1980), Al-Azzawi (1982), Al-Alawe (1980), Al-Naqib (1980), Ameen (1979) and Fouad (1983). However, no coherent genetic interpretation has hitherto been put forward for the whole region. In the present work the configuration put forward by Numan (1984, 1991) and Numan et al. (1991) for the Foreland Folds in Iraq is adopted and relevant parts are reviewed here for the purpose of interpretation. This configuration involves the formation of thinned continental crust basins and accumulation of stratigraphic successions on a passive plate margin formed originally by stretching with eventual oblique plate collision. In view of this, an interpretation is given for the mechanism of folding and the resulting opposing vergences.

**Structural Characteristics of the Foreland Folds**

The Foreland Folds of Iraq follow two major trends, the first is a NW-SE (Zagros trend) in the northeastern part of Iraq. The second is an E-W (Taurus trend) in the northern parts. Some anticlines and synclines however exhibit both trends with curvilinear or swinging axes (e.g. the Beka Air Anticline). The Zagros and Taurus trends are situated in two distinct geographical districts. Numan (1984) related the two trends to two major basement blocks on structural and stratigraphical grounds and named them, the Mosul block for the Taurus trend and the Kirkuk block for the Zagros trend. An echelon arrangement of anticlines, with or without overlap of plunge areas is quite common. Several of the swings of the anticlinal axes as well as noses of anticlines are located on transverse lineaments. This could be depicted easily from satellite imagery (SPOT and LANDSAT). Depending on these large scale shifts of the anticlinal axes along the lineaments, Numan (op.cit) postulated large scale strike-slip movements in the basement, i.e wrench tectonics. This together with the
intermittent vertical basement blocks movements or interplay determined the stratigraphic and tectonic framework of the Foreland Folds. The intensity of folding of the Foreland Folds of Iraq increases generally towards the north and northeast where each anticline is followed academically by a syncline. In the southern and southwestern areas of the region however, successive anticlines are separated by very wide flat areas (Fig.1). Numan (1984) proposed that the strata under these flat areas are nearly horizontal.

The style of folding in the Foreland folds is flexural slip which is persistent vertically. There is no regional disharmonic folding noticed in the field. The folds fall within class 1B of Ramsay (1967). The profile section of any folded surface in the Foreland Folds shows non-periodic mostly asymmetrical waves. Some anticlines show a close similarity to the unilateral box fold style described from the Colorado Plateau by Hodgson (1963). Anticlines are open with wide or rounded hinge zones. Most of the fold limbs are normal, a few are overturned. The overturning is mostly local and due to torsional flexuring or rotational faulting that is transverse to the strike in the steep limbs (Fig.2a).

As for the vergence of the asymmetrical anticlines, two opposite vergences are noticed. These are either towards the north and northeast or the south and southwest. Belts of folds with similar vergence alternate with other belts of opposing vergence both transversely and longitudinally with respect to the regional trend of the Foreland Folds (Fig.3). A well documented case is The Ain Zalah Anticline which shows opposing vergences along the axis of the same anticline. These fluctuations are described and deciphered below in terms of the geometrical characteristics of anticlines and the proposed mechanism of folding.

The Geotectonic Set-Up of the Foreland Folds

The simple stretching model proposed by Mckenzie (1978) for the Aegean Sea and surrounding areas of the Alpine system could be extended with a fair degree of certainty into the Foreland Folds Belt of Iraq. Field data from our area agree very well with the mathematical model produced by Le Pichon and Sibuet (1981). The model is based on Mckenzie's original stretching model and the profiles of Montadert et al. (1979 a,b) on the Armorican continental margin. Accordingly, Numan (1991) proposed an extensional and wrench tectonics model for the Foreland Fold Belt of Iraq. The thinned continental crust had basins formed by listric normal faults on the
passive continental margin. The total width of the Foreland Folds Belt of Iraq (165-225 km), and the distance between successive listric faults (4-35 km) fit well with the observed and mathematically predicted models of the Armorican continental margin and the Aegean Sea of the Alpine system mentioned above. This proposed geotectonic setup helps decipher many of the characteristic features of the Foreland Folds geometry including the vergence behaviour (see discussion).

**The Vergence Behaviour of Anticlines in the Foreland Folds**

Figure (3) shows the vergence directions of major anticlines in the Foreland Folds Belt. Since the Vergence direction is related to the asymmetry of the anticlines, it follows that understanding the mechanism of folding and asymmetry would explain the vergence direction. It is now well established by various authors (Jassim, et al. 1975; Maala, 1977 and Barwary, 1983) that many of the major anticlines exhibit major longitudinal high angle normal faults along the steeper limbs of the anticlines. Numan (1984), (Figs.3 and 4) gave sections in such anticlines.

The asymmetry of the anticlines and the unilateral box fold style of folding is attributed to the basement faulting. The limb of the anticline which happens to be directly over the basement fault is going to be the steeper one (Fig.2). In some cases as is noticed clearly in Sinjar and Bashiqa, the basement fault ruptures the limb, whereas in other cases the basement fault remains buried in the subsurface (Figs.5 and 6c).

**Discussion**

In trying to relate the above described geotectonic model for the Foreland Folds Belt of Iraq to the local geometry of the individual folds, Numan (1991) envisaged the following tectonic and sedimentational events which are listed in the time sequence as follows:-

1. A protracted phase of crustal stretching accompanied by extensional tectonics which started with the opening of the Neo-Tethys in the Early Jurassic (lias) and continued throughout the Mesozoic and well into the Tertiary.
2. The development of listric normal faults dipping away from the craton with tilted blocks.
3. The occurrence of the sedimentary basins on subsided tilted blocks. These basins have different domains in terms of time and space distribution depending upon timing, duration and spatial extent of the above mentioned listric faults.
4. Minor oscillations in the extentional regime through time might close some basins, starve other basins or open new basins. These changes are expressed in the field by changes in the sedimentary environments and facies.

5. The transition from continental stretching to oceanic accretion and Himalaya type continental collision reversed the extentional tectonic environment to a compressional environment. This lead to the reversal of the movement on the originally normal listric faults causing the initiation of anticlinal structures by basin inversion and the accentuation of the folding by the ensuing compressional stress (Fig. 5 and 6).

6. The continuous development of folds in the foreland by the regional primary horizontal compression and the secondary vertical movement, also the development of large scale strike slip movements along some of the previous listric faults and other shear zones caused the formation of drag and/or drape folds on a large scale (Fig. 7). The strike-slip movements are adumbrate of the oblique collision of the Arabian Plate.

The kinematics and dynamics described in stage 5 above initiated folds which were accentuated in the stage 6. Two main cases are put forward here for the situation before stage 5, they are:

A- A listric normal fault is transmitted through the sedimentary cover with a normal sense of displacement.

B- The upper part of the sedimentary cover is not affected by an underlying listric fault.

As the transition from continental stretching to oceanic accretion (stage 5 above) sets in, figures (5) and (6) describe the varieties of response of the sedimentary cover in the cases of A and B above.

In addition to the reversal of displacement along the originally normal listric faults described above, wrenching sets in along some of the listric faults or along geofractures or shear zones in the basement rocks. Strike-slip movements between basement blocks develop drag folds (in the sedimentary cover) along wrench corridors in the manner shown in Figure (7). The axes of these folds are oblique to the strike of the wrench faults. However very narrow wrench corridors or longitudinal basement slabs might be uplifted during regional wrenching in an oblique-slip fashion thus
forming drape folds (Fig.7). The axes of these drape folds are parallel to the strike of the wrench faults.

The discrepancy of the axes directions of the drag and drape folds explains the local changes in the directions of adjacent or successive fold axes in the southern part of the Foreland Folds of Iraq, e.g. the difference between Atshan and Alan Anticlines or between Zimbar-Shaikh Ibrahim and Sasan West with Ishkaft Anticline, Fig.(3). The amount and direction of dip of the longitudinal basement slabs under the drape folds would decide the direction of vergence of these folds. Purely vertically uplifted basement slabs would lead to symmetrical folds in the sedimentary cover. In figure (7), it could be imagined that the change of the dip direction of the narrow basement slab along its strike, i.e. change in the vergence of the fault plane or the so called scissor fault, would lead to opposing vergences in the drape folds on top. This is the most likely explanation for opposing vergences in the Ain Zalah anticline (Fig.3).

Conclusion

The vergence of anticlines in the Foreland Folds Belt is either to the north and northeast, or to the south and southwest. Adopting the geotectonic model envisaged by Numan (1991), a geometric and genetic explanation is given for the genesis of folds, the first is related to purely vertical reverse movements along listric faults (Fig.5 and 6), the second is related to strike-slip movements along listric faults or shear zones in the basement (Fig.7) both these modes could theoretically be coeval (i.e. oblique-slip on the listric faults). Circumstantial field evidence, i.e. detailed stratigraphical and structural mapping should answer the question as to which of the modes is prevailing in each particular anticline.
Captions For Figures

Table (1): The generalized stratigraphic column of North Iraq after Bellen, et al. (1959).

Figure (2): (a) Block Diagram in a typical anticline in the Foreland Folds of Iraq showing a traverse, rotational and longitudinal faulting (i.e. Bashiq Anticline, southward vergence).
(b) Schematic cross-section in the Sinjar Anticline with northward vergence from Numan (1984).


Figure (4): The Arabian passive continental margin, north and northern Iraq, a model for the time span between Liasic and Middle Tertiary, from Numan (1991).

Figure (5): The formation of anticlines with buried subsurface basement faults, (a) listric normal fault in the basement with undisturbed sedimentary cover. Reactivation of the fault in (a) as a low angle fault in (b), and a high angle fault in (c) result in opposing vergences of the anticlines, in (b) and (c).

Figure (6): The formation of anticlines with surface expressions of the subsurface basement faults. (a) listric normal fault in the basement with disrupted sedimentary cover, (b) and (c) reactivation of the fault in (a) with different amounts of reverse movement on the normal fault, (d) is a case where cylindrical faulting (Sanford, 1959) develops as a further stage from figure 5c.

Figure (7): Wrenching in the basement rocks resulting in drag and drape folds.
Table 1

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<tr>
<th>Formations Names</th>
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<td>Khabour</td>
<td>L.Ordov.-Camb.</td>
<td>Fine grained sandstones, quatzites, greywackes.</td>
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Fig. 1
Fig. 3: Verge directions of the foreland folds in northern Iraq.

LEGEND:
- Anticline with a north or northwest vergence
- Synclinal with a north or northwest vergence
- Anticline with no obvious vergence
- Synclinal with no obvious vergence

Fig. 3
Fig. 4
Fig. 5
References


Numan, N.M.S., Extensional and Wrench Tectonics in the Foreland Folds of Iraq with Geotectonic Implications, *First Inter. Conf. on the Geol. of Arab world, Cairo, Egypt*, 1991.


