Trabajos de Geología, Universidad de Oviedo, 29 : 146-150 (2009)

Oviedo (Spain) 1-3 July 2008 International Meeting of Young Researchers in Structural Geology and Tectonics
ORSGET

Fold distribution and multilayer properties, a case study from the Lurestan province of Iran

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Abstract: The characteristics of folds of the southern Lurestan province have been studied in terms of wavelength and axial-length distribution. The large variability of these parameters occurs in relation to facies changes within the Cretaceous Bangestan group which acts as the competent carbonate unit that governs bucking in this region. Disharmonic folding of the overlying Asmari formation occurs where the thickness of the interposed incompetent units exceeds a critical thickness that leaves the Asmari limestone outside of the zone of contact strain of the Bangestan buckles.

Keywords: Zagros, folding, wavelength, axial-length, thickness measures.

The Zagros mountain range is a NW-SE trending segment of the Alpine-Himalayan suture originated from the Late Cretaceous-Cenozoic convergence of the Arabian and the Eurasian plates, which led to the closure of the Neotethys Ocean and to plate collision (Golonka, 2004). The southwestern margin of this suture, in Iraq and Iran, is occupied by the Simply Folded Belt, an elongated region extending almost 2000 km with spectacular trains of folds developed in a thick multilayer of Paleozoic to Cenozoic sediments (Fig. 1a). These folds contain a large proportion of the Middle-East oil reserves and have therefore attracted the attention of structural geologists since the beginning of oil exploration. Because of their size, their spatial arrangement and the lack of major thrusts, these anticlines were originally interpreted as detachment folds generated by the buckling of competent units above a weak detachment at the base of the sedimentary cover (Colman-Sadd, 1978; Price and Cosgrove, 1990; Sattarzadeh *et al.*, 2000). However, further studies conducted in the Fars region and in the central Zagros (Sherkati *et al.*, 2005; Carruba *et al.*, 2006; Sepehr *et al.*, 2006) indicate that more than one mechanism is responsible for the growth of these structures, and that their geometry, size and distribution is intimately related to the mechanical properties of the folded multilayer. The characteristics of folds in the Pusht-e Kuh Arc (Fig. 1a) have been analysed in terms of fold shape and amplitude (Vergès *et al. submitted*); in this contribution we analyse fold characteristics in map view and integrate these data with the facies distribution and other relevant stratigraphic parameters to better understand the relation between folding and mechanical stratigraphy.

Fold patterns in the Pusht-e Kuh Arc

To analyse fold patterns along the Simply Folded Belt, the southeastern termination of the Pusht-e Kuh Arc was selected (Fig. 1). This portion of the Simply Folded Belt is particularly interesting since it contains the transition between the Lurestan arc and the

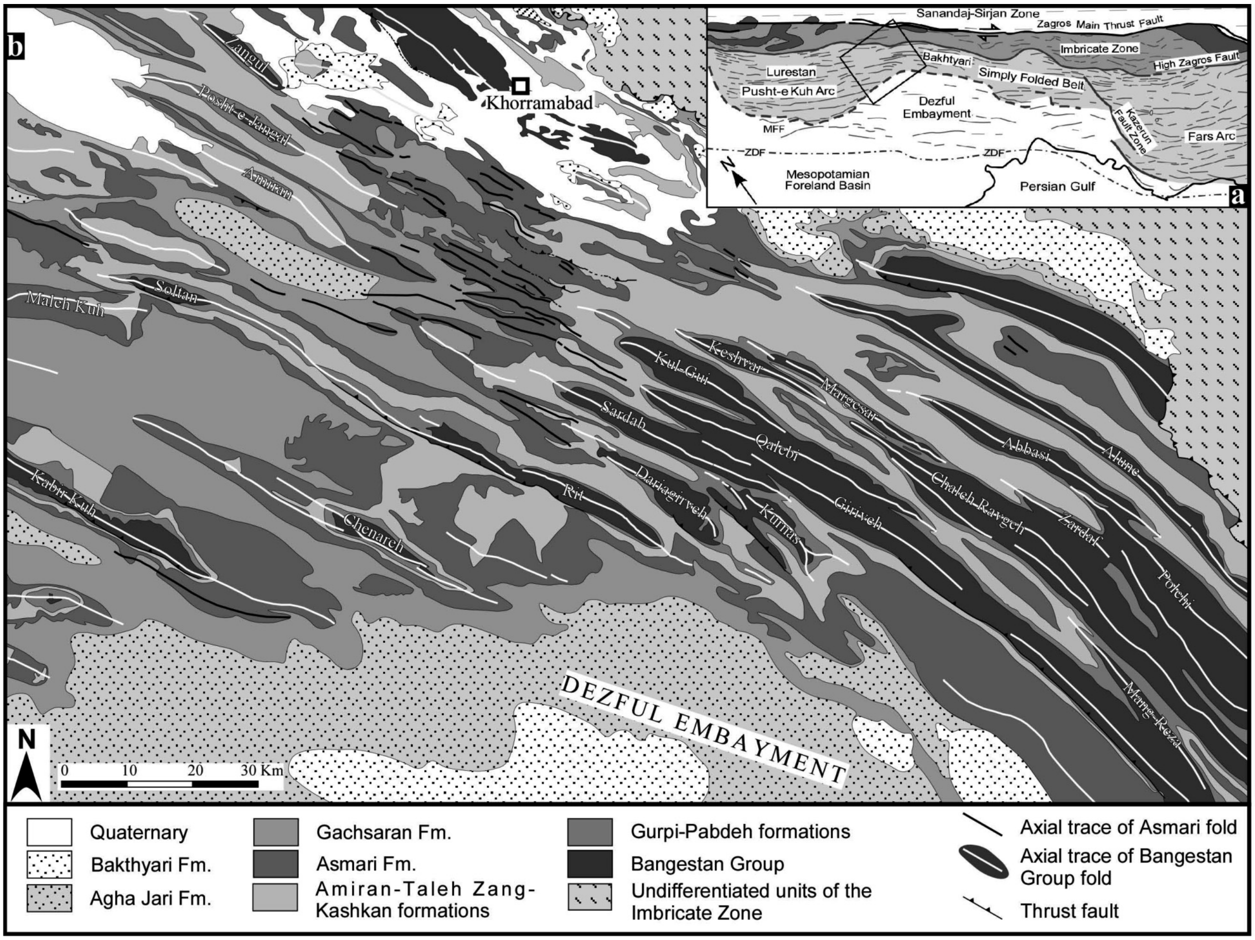

Figure 1. (a) Tectonic sketch of the Zagros range, (b) geological map of the studied area obtained from NIOC geological maps and satellite imagery.

Bakhtyari culmination, marked by a rapid change in the level of exposure along the folds trend. This change in exposure level allows comparing, across a relatively short distance, the characteristics of folds developed within the two carbonate units that form the upper and lower reservoir units throughout the Zagros, i.e. the Bangestan group and the Asmari formation. It must be noted that these two carbonate units represent the major competent units in a stratigraphic succession that is otherwise dominated by clastic deposits, shales, evaporites and subordinate pelagic limestones (Fig. 2). The parameters used to analyse fold distribution are the axial length and the wavelength of anticlines, measured from their axial traces. These were obtained from geological maps published by NIOC (National Iranian Oil Company; 1:100 000 scale) and were successively integrated and modified through the analysis of 3D stereo (Spot5) satellite images and field surveys. Axial traces were then sorted in two groups according to the competent carbonate unit in which the fold developed, i.e. Bangestan group anticlines and Asmari formation anticlines. For each group wavelengths were measured averaging the distance between adjacent axial traces and were then plotted against axial lengths (Fig. 3).

Characteristics of folds in the Bangestan group

Anticlines developed in the Bangestan group display extremely variable axial lengths and wavelengths (Fig. 3). The majority of Bangestan group anticlines present wavelengths between 3.5 and 7.5 km and axial lengths ranging from 20 to 50 km. Outside of this cluster, two anticlines present anomalous axial lengths and other two display larger than average axial length and spacing. Observing the geological map in figure 1 it is evident that this important change in the spacing of Bangestan group anticlines occurs along the northern side of the Soltan-Rit anticline. The region to the NE of this boundary is characterised by tightly packed anticlines separated by extremely narrow, pinched synclines. In this area anticlines can be seen to merge and

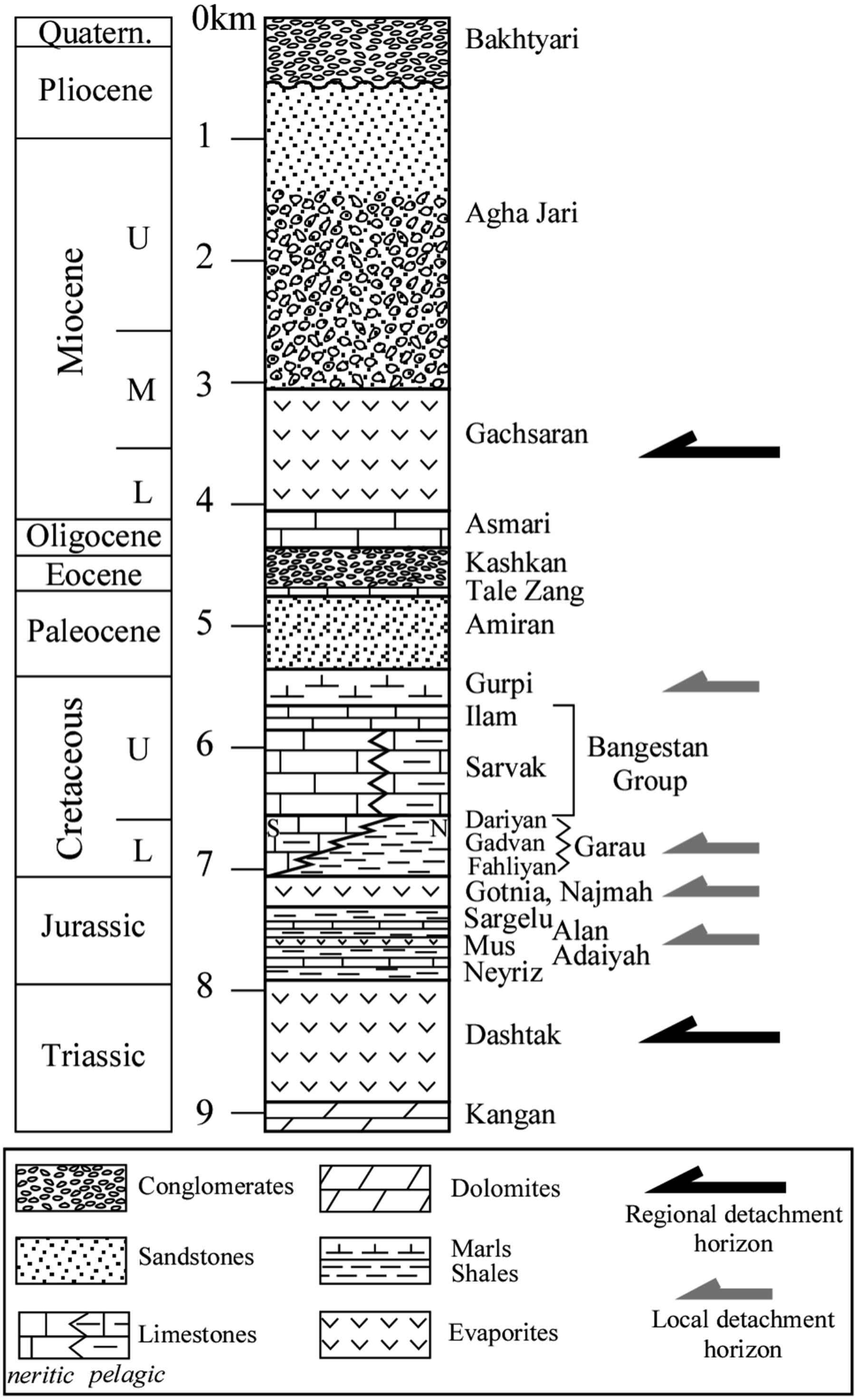

Figure 2. Mesozoic to Recent stratigraphy of the southern Lurestan area, based on data published by Homke *et al.* (2004), Homke *et al.* (*in press*), well data (Samand 2, Kabir Kuh 1) and isopach maps published by Koop and Stoneley (1982).

link together with the modalities described by Sattarzadeh *et al.* (2000), generating twists or saddles in the axial traces. By contrast, the few anticlines located to the SW of the Soltan-Rit anticline, namely the Chenareh and Kabir-Kuh anticlines, appear widely spaced and with an axial length above the average of the main cluster in figure 3. The Soltan-Rit and Kabir-Kuh anticlines also present evidence of thrusting along their forelimbs (Fig. 1), however, field analysis and section construction indicate that the amount of displacement along these faults is very limited, generally inferior to 1 km and not exceeding 2 km (Vergés *et al.*, *submitted*).

Characteristics of folds in the Asmari formation

The Asmari limestone is an erosion resistant unit that forms the outer shell, or carapace, of many of the folds in the selected area (e.g. Chenareh, Maleh Kuh anticlines). In general a good coupling is observed between the Bangestan group level and the Asmari formation, which is to say: the two units fold harmonically with a parallel style. This is documented, for example, by the deep, pinched synclines that bound on each side the Sardab anticline (Fig. 1). Nevertheless, in the area located to the northwest of this latter fold, the Asmari formation is deformed by tight folds with wavelengths as small as 870 m (average: 2 km) and axial lengths shorter than 20 km (Fig. 3), and by few thrust faults. The presence of short wavelength Asmari folds along the prolongation of large Bangestan group anticlines with a wavelength in excess of 5 km indicates that in this specific area the folds of the Asmari level are decoupled from that of the Bangestan group.

Discussion

The large variability of wavelength and axial lengths displayed by the anticlines of the competent Bangestan group (Fig. 3) can be understood by analysing the Cretaceous facies distribution. Field surveys and published paleo-facies maps (Koop and Stoneley, 1982) indicate that the northeastern flank of the Soltan-Rit anticline represents a facies boundary, separating a carbonate platform to the SW from a pelagic area to the NE, with an associated reduction in thickness, of approximately 200 m, from platform to basin. The short wavelength of the anticlines located to the NW of the Rit anticline reflects, therefore, the reduced competence and thickness of this pelagic facies and the higher degree of anisotropy induced by the smaller bed thickness and frequent shale partings. Conversely, the greater thickness and higher competence of the carbonate platform facies are reflected by a higher spacing between anticlines and the development of thrust structures. Furthermore, the higher anisotropy of the pelagic facies influences also the shape of anticlines which frequently display a 'bullet' shape (Sepehr *et al.*, 2006), i.e. subvertical, near-isoclinal fold limbs, with a pointed crest region. This fold shape implies necessarily the existence of a detachment horizon in the Lower Cretaceous Garau shales underlying the Bangestan group (Fig. 2). Regarding the variation in behaviour of the Oligocene Asmari limestone, from perfectly coupled with the Bangestan group to completely decoupled, two hypotheses can be made. One possibility is that a local, shallow detachment exists in the units underlying the area of short wavelength Asmari anticlines; the other is that the two competent units fold disharmonically due to an increase in the thickness of the incompetent units separating them, causing the Asmari formation to exit the zone of contact strain of the Bangestan group (Price and Cosgrove, 1990). To test this second hypothesis over 300 thickness measurements where conducted on the stratigraphic units interposed between the two carbonate units. Thickness measures were carried out using 2.5 m resolution Spot images and a 25 m resolution DEM. Field based control measures indicate that these remotely sensed measures have accuracy in the range of 5-15 %. The stratigraphic unit displaying the largest thickness variations is the Amiran formation, a clastic wedge formed by shales and sandstones derived from the erosion of obducted ophiolite and radiolar-

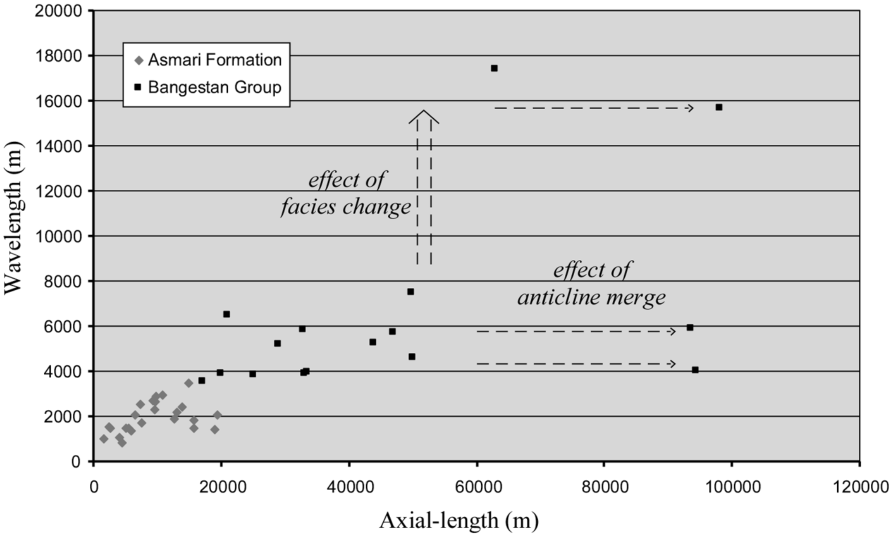

Figure 3. Plot of the wavelength and axial-length of anticlines developed in the Bangestan group and in the Asmari formation.

ite nappes (James and Wynd, 1965; Homke *et al.*, *in press*). The Amiran isopach map constructed with this thickness database indicates that the largest thicknesses, in excess of 1100 m, are reached in the area corresponding to the short wavelength Asmari folds. On the other hand, the hypothesis of a local detachment underlying the area of short wavelength Asmari folds appears unlikely for two reasons. Firstly, for of the lack of suitable lithologies (e.g. shales, evaporites) in the units immediately underlying the Asmari limestone (Fig. 2), and secondly, because the coincidence of the hypothetic detachment with the area of documented increase of the Amiran thickness appears improbable.

Conclusions

Fold patterns of the southern Lurestan region, expressed in terms of axial-length and wavelength distribution, reflect the characteristics of the sedimentary multilayer in which they formed. Within the carbonate deposits of the Bangestan group the transition from pelagic to neritic facies determines a threefold increase in anticline spacing and may be associated with the development of thrust structures in the forelimb of anticlines. The shape of anticlines within the pelagic facies indicates that the underlying Garau shales behave as a detachment horizon. The Oligocene Asmari formation folds harmonically with the Bangestan group, except in the areas where the Paleocene Amiran formation exceeds 1100 m of thickness. In these areas the Asmari limestone displays short wavelength folds indicating a complete decoupling from the folds of the Bangestan group. It is suggested here that this decoupling occurs because the summed thickness of the incompetent units which separate the two competent units exceeds the thickness of the zone of contact strain of the Bangestan group folds.

References

CARRUBA, S., PEROTTI, C. R., BUONAGURO, R., CALABRÒ, R., CARPI, R. and NAINI, M. (2006): Structural pattern of the Zagros fold-and-thrust belt in the Dezful Embayment (SW Iran). *Geol. Soc. Am. Spec. Pap.*, 414: 11-32.

COLMAN-SADD, S. P. (1978): Fold development in Zagros simply folded belt, southwest Iran. *AAPG Bull.*, 62: 984-1003.

GOLONKA, J. (2004): Plate tectonic evolution of the southern margin of Eurasia in the Mesozoic and Cenozoic. *Tectonophysics*, 381: 235-273.

HOMKE, S., VERGÉS, J., GARCÉS, M., EMAMI, H. and KARPUZ, R. (2004): Magnetostratigraphy of Miocene–Pliocene Zagros foreland deposits in the front of the Push-e Kush Arc (Lurestan Province, Iran). *Earth Planet. Sc. Lett.*, 225: 397-410.

HOMKE, S. J., VERGÉS, J., SERRA-KIEL, G., BERNAOLA, M., GARCÉS, R., KARPUZ, I., SHARP, M., GOODARZI, H. and VERDÚ, I. M. (in press): Late Cretaceous-Paleocene formation of the early Zagros foreland basin: biostratigraphy and magnetostratigraphy of the Amiran, Taleh Zang and Kashkan sequence in Lurestan Province, SW Iran. *Geol. Soc. Am. Bull.*

JAMES, G. A. and WYND, J. G. (1965): Stratigraphic Nomenclature of Iranian Oil Consortium Agreement Area. *AAPG Bull.*, 49: 2182-2245.

KOOP, W. J. and STONELEY, R. (1982): Subsidence history of the Middle East Zagros Basin, Permian to Recent. *Philos. T. Roy. Soc. London, Ser. A*, 305: 149-168.

NATIONAL IRANIAN OIL COMPANY (1966): *Geological compilation map; Sheet No. 20825E: Kuh-e Asmari, scale 1:100 000*. Geology and Exploration Division, Tehran, Iran.

PRICE, N. J. and COSGROVE, J. W. (1990): *Analysis of Geological Structures*. Cambridge University Press, 502 pp.

SATTARZADEH, Y., COSGROVE, J. W. and VITA-FINZI, C. (2000): The interplay of faulting and folding during the evolution of the Zagros deformation belt. In: J. W. COSGROVE and M. S. AMEEN (eds): *Forced folds and fractures*, *Geol. Soc. London Spec. Publ.*, 169: 187-196.

SEPEHR, M., COSGROVE, J. W. and MOIENI, M. (2006): The impact of cover rock rheology on the style of folding in the Zagros Fold-Thrust Belt. *Tectonophysics*, 427: 265-281.

SHERKATI, S., MOLINARO, M., FRIZON DE LAMOTTE, D. and LETOUZEY, J. (2005): Detachment folding in the Central and Eastern Zagros fold-belt (Iran): salt mobility, multiple detachments and late basement control. *J. Struct. Geol.*, 27: 1680-1696.

VERGÉS, J., KARPUZ, R., EFSTATHIOU, J., GOODARZI, H., HEMAMI, H. and GILLESPIE, P. (submitted): Multiple detachment folding in the Pusht-e Kuh Arc, Zagros: role of mechanical stratigraphy. In: K. MCCLAY, J. H. SHAW and J. SUPPE (eds): *Thrust fault related folding*, *AAPG Mem.*