



## Fold trends and age of folding in NW Persian Gulf

B. SOLEIMANY<sup>1,2\*</sup> AND F. SÀBAT<sup>2</sup>

<sup>1</sup>*National Iranian Oil Company, Exploration Directorate, Seoul Ave., Tehran, 1994814695, Iran.*

<sup>2</sup>*Universitat de Barcelona. Facultat de Geologia. Dpto. de Geodinàmica i Geofísica. 08028, Barcelona, Spain.*

\**e-mail: b\_soleimany@ub.edu*

---

**Abstract:** The study area is located in the foreland of Zagros (Persian Gulf) where important oil and gas fields exist. Data consist of two orthogonal sets of 2D seismic sections. Both NNE-SSW folds (Arabian trend) and NW-SE folds (Zagros trend) are documented. These folds formed during two folding stages: the older one, Late Cretaceous in age and the younger one, Plio-Quaternary. Older folds formed according to the Arabian trend. During the younger folding stage, older folds were reactivated and tightened, and some of the new folds, also with Arabian trend, formed on top of them. This occurred in front of the advancing Zagros trend fold front.

**Keywords:** Arabian plate, Zagros foreland, Persian Gulf, Arabian trend, Zagros trend, folding stages, Late Cretaceous folds, recent folds.

---

The study area is located in the NW part of the Persian Gulf (Iran) in the Zagros foreland basin (Fig. 1). Both the Zagros Range and its foreland are part of the Arabian plate. The Zagros Range is the result of the collision between the Arabian plate and the Iranian block (Eurasian plate). Most of the folds in the Zagros trend NW-SE as the Zagros Range itself does, whereas the main structures (faults and folds) in the Arabian plate south of the Zagros Range trend N-S or NNE-SSW (Alavi, 1994; Abdollahi Fard, 2006).

The Iranian part of the Zagros Range and Persian Gulf accounts for, respectively, 8.6% and 15% of the world's proven oil and gas reserves (Ghazban and Motiei, 2007).

### Method

This study is based on the interpretation of a net of seismic sections of good quality arranged in two orthogonal sets. The study area is covered by 51 sections of 2D seismic lines that are combined to form 27 seismic sections totalling 2760 km. The interpre-

tation has been performed by computer using the KINGDOM Suite software. The tops determined from the seismic and well logs by the National Iranian Oil Company (NIOC) have been used (NIOC internal report, 2008).

### Results

The following features are observed in the seismic sections of the study area:

In all S-N seismic sections each horizon is relatively shallow in the south and changes to a deeper position northward (Fig. 2). In W-E seismic sections, horizons become deeper eastward (Fig. 3).

The main stratigraphic feature in the study area is the unconformity (or set of unconformities) around and below the Maastrichtian horizon (Fig. 3).

The folds observed beneath this unconformity and above it show contrasting styles (Figs. 2 and 3).

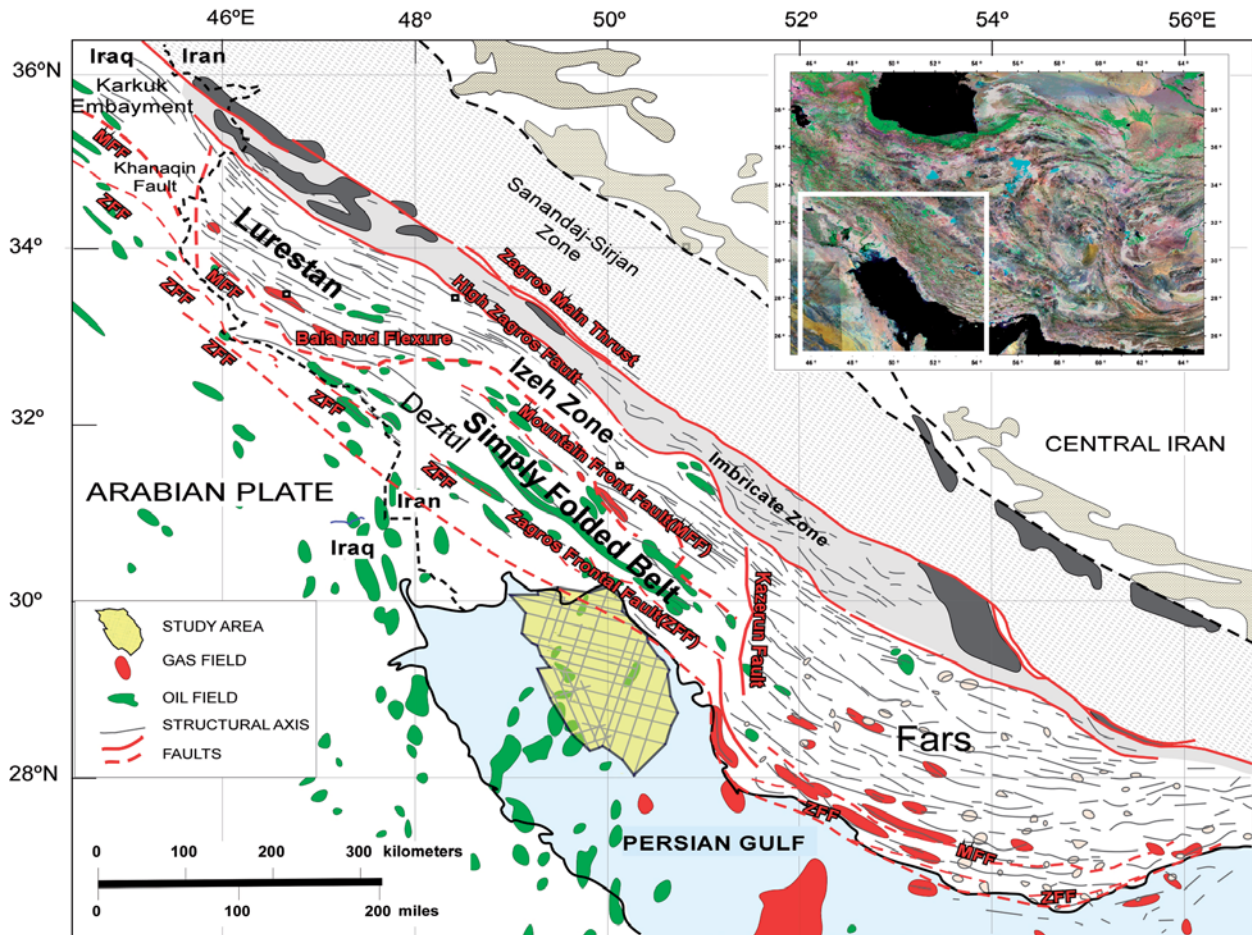


Figure 1. Structural units of the Zagros Range and location of the study area.

In general, folds beneath the unconformity are tighter than those above it, but the number of folds increases above the unconformity (twelve antiforms) compared to beneath it (eight antiforms).

Time Grid Maps with contour lines of the eleven horizons picked in the seismic sections have been prepared. Two of them have been selected to illustrate the trend of the folds: one corresponds to the second horizon of the Fars group (Fgp-2). This horizon is located above the unconformities and is probably Middle Miocene in age (NIOC internal report, 2008) (Fig. 4). The other selected Grid Map corresponds to the Albian horizon. This horizon is located beneath the unconformities (NIOC internal report) (Fig. 5).

#### *Fold trends*

In the contour maps (Figs. 4 and 5) two different main fold trends can be distinguished: NNE-SSW (Arabian trend) and NW-SE (Zagros trend).

These two trends are present at both levels, but sometimes there is a shifting of the axis of the antiforms corresponding to the same structure.

In some places, folds above and beneath the unconformity have different trends. The right place for this observation is the eastern part of the study area where three or four antiforms with NW-SE trend are present above the unconformity but only one antiform and two NNE-SSW trending undulations exist below it (Figs. 4 and 5). This feature should be explained by the effect of an internal detachment in the Albian horizon which is situated below the unconformity and also by a detachment at the base of the Fars group Tertiary sediments (Fgp) (Fig. 2).

#### *Age of folding*

The age of folding is determined according to the observed growth strata. Growth strata are located at two different levels: one beneath the unconformity and the other, above it.

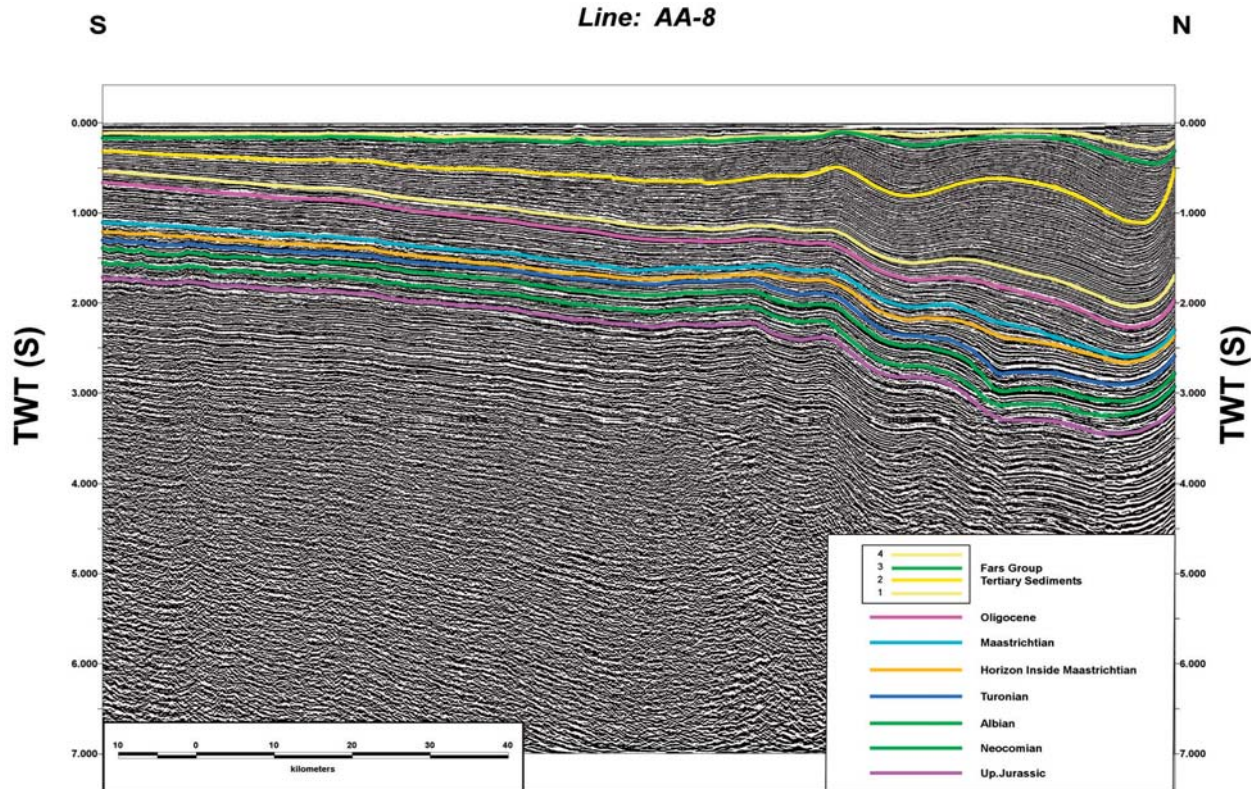


Figure 2. S-N seismic section AA-8 (location in figures 4 and 5).

*Growth strata beneath the unconformity:* on the wide NNE-SSW trending antiform visible at the western side of the W-E seismic section (Fig. 3) the following features are observable: 1) from the Albian horizon downwards, horizons are parallel to each other all along the antiform, 2) from the Maastrichtian horizon upwards, horizons are parallel to each other over the antiform, and 3) between the Albian horizon and the Maastrichtian horizon there is a thickness variation. The reflections between the Albian horizon and the horizon inside the Maastrichtian are folded and are truncated below the horizon inside the Maastrichtian, forming an angular unconformity, whereas the reflections between the horizon inside the Maastrichtian and the Maastrichtian horizon are in a flat laying position and onlap the upper part of the antiform. Both the angular unconformity and the onlap indicate growth of the structure with a different uplift/sedimentation rate.

On the NNE-SSW trending anticline visible on the eastern side of the seismic section the following features are observable: 1) between the Turonian horizon and the horizon inside Maastrichtian there is a dramatic thickness variation, 2) there is a moderate

thickness variation between the horizon inside the Maastrichtian and the Maastrichtian horizon. In the western limb of the antiform the thickness variation (updip thinning of strata) is resolved by several internal onlaps together with few offlaps, whereas in the eastern limb it is mainly resolved by a general onlap disposition and a slight truncation by the overlying horizon inside the Maastrichtian.

This anticline, together with the two flanking synclines, shows an overall geometry that is very typical of growth folds. The clear upward fold attenuation appears because part of the folding had already occurred before the sedimentation of each folded bed considered.

*Growth strata above the unconformity:* NNE-SSW folds above the wide antiform seen in the W-E seismic section (Fig. 3) show growth strata younger than Fars group 2 (Fgp-2) horizon and perhaps older than Fars group 3 (Fgp-3) horizon.

NW-SE folds seen in the northern part of the S-N seismic section (Fig. 2) and the NNE-SSW anticline seen in the eastern part of the W-E seismic section

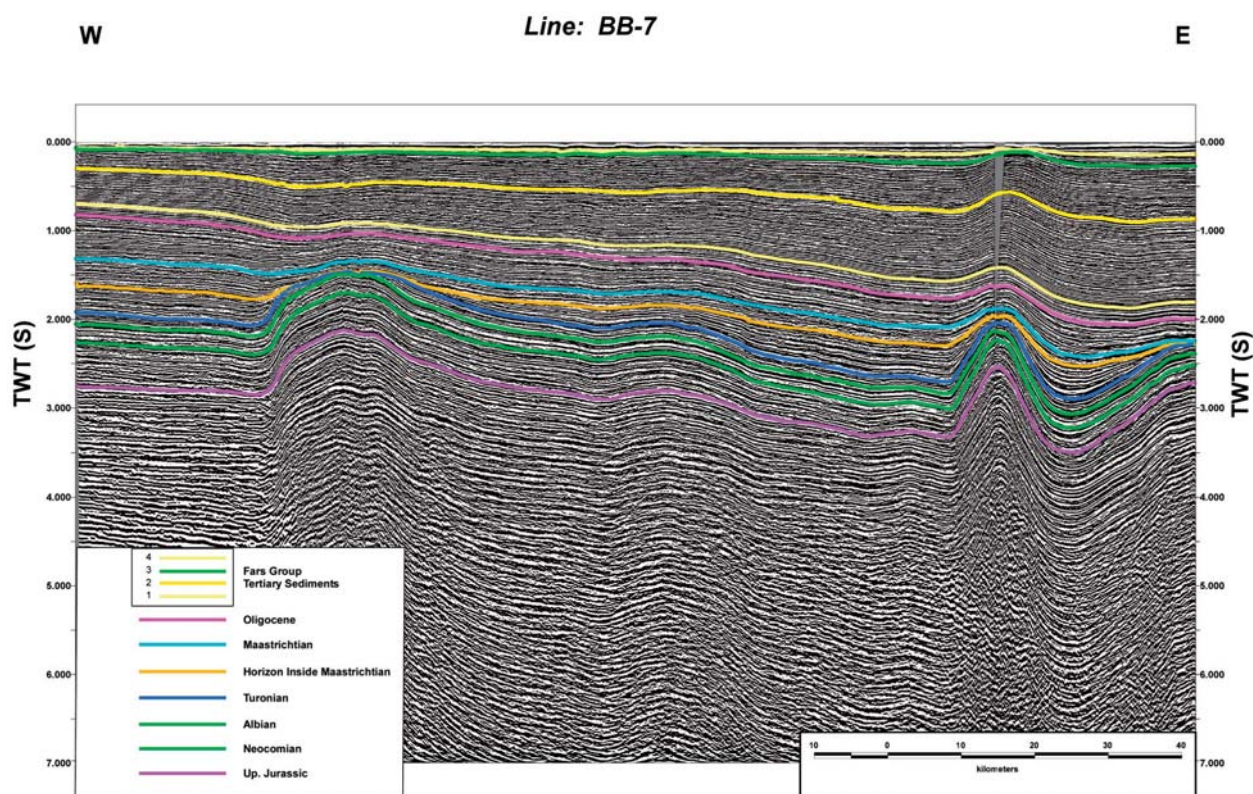


Figure 3. W-E seismic section BB-7 (location in figures 4 and 5).

(Fig. 3) show the following features: 1) from the Fars group 1 (Fgp-1) horizon downward, horizons are parallel, 2) the Fars group 2 (Fgp-2) horizon and the Fars group 1 (Fgp-1) horizon are not parallel because there is a detachment above the latter, and 3) from some horizon in between the Fars group 2 (Fgp-2) and the Fars group 3 (Fgp-3) horizons upwards, horizons are not parallel because growth strata are involved.

From the above observations two folding stages can be deduced: the older one embraces the period between sedimentation of the Turonian and the Maastrichtian horizons and thus is Coniacian, Santonian, Campanian and Maastrichtian (23 Ma), and the younger one developed after sedimentation of the Fars group 2 (Fgp-2), thus it has occurred since Pliocene (?). This second folding stage corresponds to the Zagros Orogeny.

### Discussion

The wide Arabian trending antiform seen in the W-E seismic section beneath the unconformity formed during the older folding stage. The Arabian trending folds above the unconformity located directly on top of the above mentioned antiform formed during the

second stage. The geometric relationships between all these located folds suggest that the folds beneath the unconformity were reactivated and tightened during the second stage of folding.

The NW-SE folds present in the northeastern part of the study area formed late during the second stage of folding.

### Conclusions

Firstly, two stages of folding are documented in the study area: the older one could embrace part of the Late Cretaceous (Coniacian, Santonian, Campanian and Maastrichtian). The younger one is recent and could embrace part of the Pliocene and the Quaternary and, secondly, Late Cretaceous Arabian folds have been reactivated and tightened during Pliocene and Quaternary in front of the advancing Zagros deformation.

### Acknowledgements

All required data for this study were provided by the National Iranian Oil Company (NIOC). We wish to thank the Exploration Directorate of NIOC and, in particular, M. Mohaddes, M.

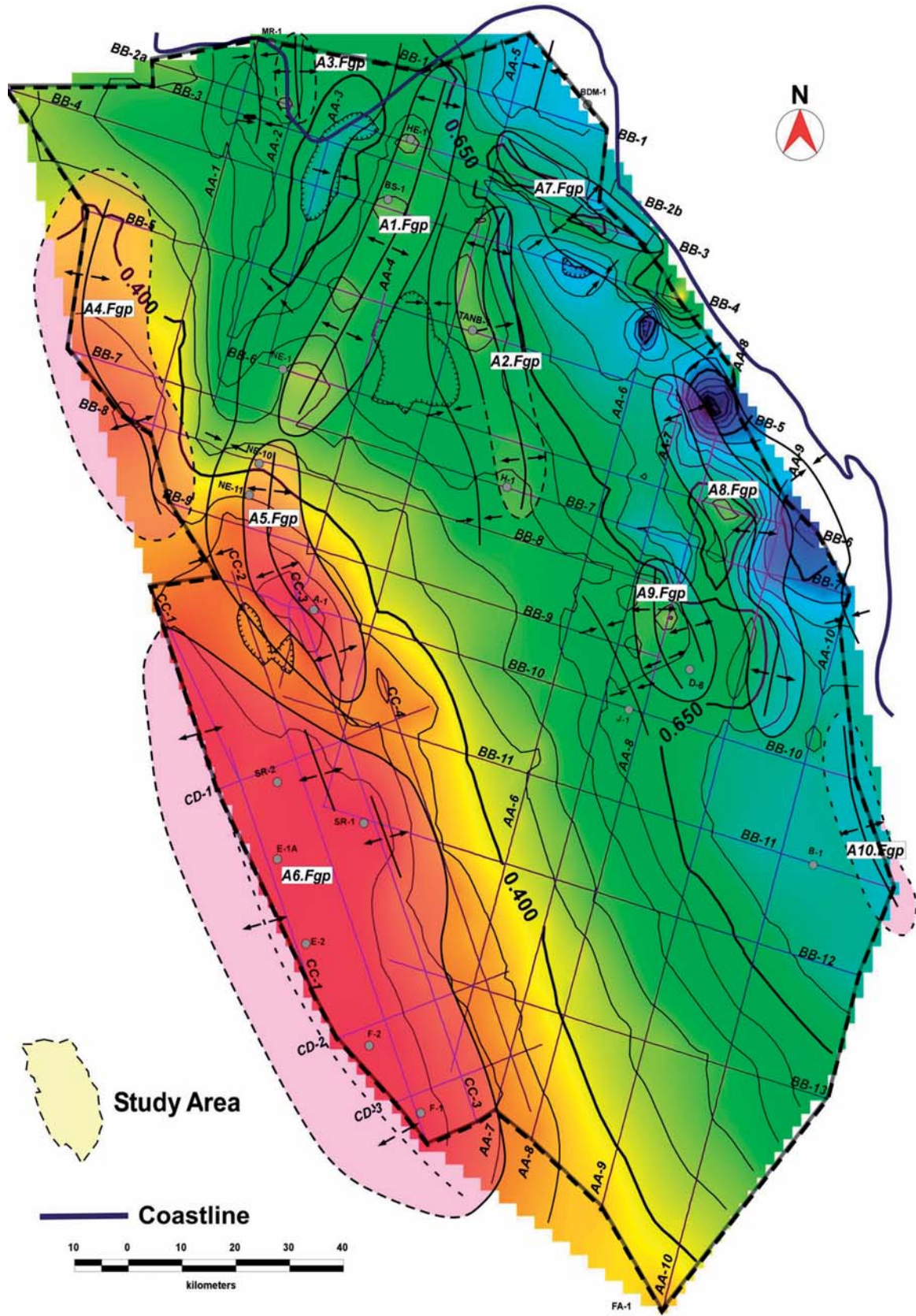


Figure 4. Time Grid Map of Fars group 2 horizon.

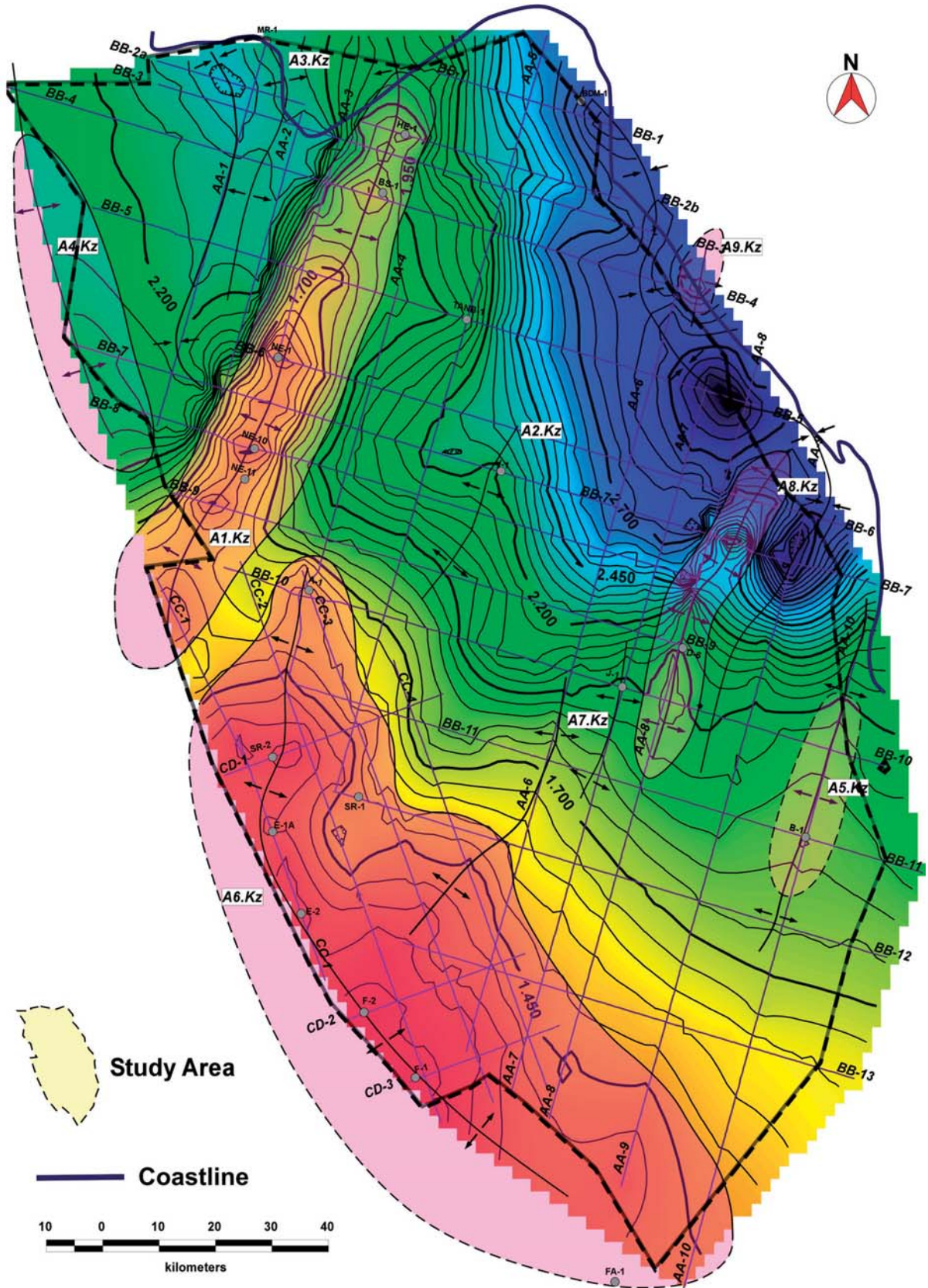


Figure 5. Time Grid Map of Albian horizon.

Zadehmohammadi, S. Javadian, R. Nematollahi, D. Baghbani, M. M. Khorasani, M. A. Naini, I. Abdollahie Fard, G. A. Fakoori, M. G. H. Goodarzi, S. Sherkati, M. Hajian, N. Pasdar, F. Beik, M. A. Parham, M. Aliee, M. Rahimi, H. Ramesh, F. Gholami and

M. Allahyari. Thanks are also due to D. Bello, J. O. Ferrer, J. Mencos, J. A. Muñoz, E. Roca and P. Arbués for their help and advice. The first author has been supported by a Repsol-YPF grant and wishes to thank them opportunely.

## References

ABDOLLAHIE FARD, I. (2006): Interaction of the Zagros Fold-Thrust Belt and the Arabian-type, deep-seated folds in the Abadan Plain and the Dezful Embayment, SW Iran. *Petrol. Geosci.*, 12: 347-362.

ALAVI, M. (1994): Tectonics of the Zagros orogenic belt of Iran: new data and interpretations. *Tectonophysics*, 229: 211-238.

GHAZBAN, F. and MOTIEI, H. (2007): *Petroleum Geology of the Persian Gulf*. Tehran University and National Iranian Oil Company, ISBN 964-03-9420-3, 707 pp.

NATIONAL IRANIAN OIL COMPANY (2008): Geological Reports, Well Final Reports, Reservoir Geology Reports and Geophysical Reports. *National Iranian Oil Company, internal unpublished reports*.