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Major Tectonic Lineaments Influencing the Oilfields of the Zagros Fold-Thrust Belt, SW Iran: Insights from Integration of Surface and Subsurface Data

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ABSTRACT: The Zagros fold-thrust belt (ZFTB) formed from the progressive collision between the African-Arabian and Eurasian plates. This study focuses on the major tectonic lineaments concerned with the distribution of oilfields in the southern Dezful Embayment as an extremely rich hydrocarbon province in the ZFTB, SW Iran. Integration of surface, near-surface and sub-surface data (e.g., remote sensing, overburden rocks, reservoir and aeromagnetic data) were used for locating major tectonic lineaments in the study area. The results show that the southern Dezful Embayment area was influenced by tectonic lineaments oriented in the NW-SE, NE-SW, E-W and N-S trends, which are possible fault indicators corresponding to surface, shallow subsurface and basement faults. The dominant N-S and E-W tectonic lineaments possibly highlight the stress regime inherited from old structures in the Arabian Shield basement while the NE-SW, NW-SE trends are interpreted as effects of the Zagros orogeny. Generally, these tectonic lineaments influenced both the basement and sedimentary rocks and are used here to divide the belt into several faulted blocks with different structural frameworks. A clear picture of the tectonic trends influencing the Zagros fold-thrust belt oilfields as well as guidance for delineating hydrocarbon reservoirs in the future are presented.
KEY WORDS: aeromagnetic data, remote sensing, tectonic trend, hydrocarbon, Zagros, Iran.

0 INTRODUCTION

Tectonic lineaments indicating structural discontinuities can be detected in the form of geological features such as faults and joints (Richards, 2000). Based on the first introduction of lineaments (e.g., O'Leary et al., 1978; Lattman and Parizek, 1964; Hobbs, 1904), they have rectilinear and curvilinear features, which can be categorized into several groups based on their origin and nature, such as structurally controlled, geomorphological and anthropogenic. The structurally controlled lineaments are created due to forces that originate from tectonic activity (Dasgupta and Mukherjee, 2019, 2017; Kaplay et al., 2019, 2017; Babar et al., 2017; Misra et al., 2014; Rahiman and Pettinga, 2008). These linear features represent weak regions with weakness and structural displacement and can be ground checked at local and regional scales (Jordan et al., 2005). The accurate mapping of tectonic lineaments can be considered as a critical task to solve issues of hydrocarbon and groundwater exploration, and also environmental disasters (e.g., earthquake and landslides) (Vatandoust and Farzipoursaein, 2019; Wang et al., 2019; Zhao et al., 2019; Aluko and Igwe, 2018; Xu et al., 2018; Rahnama and Gloaguen, 2014; Kusky et al., 2005; Sankar, 2002; Sabins, 1996). These issues can be solved through integration of surface and subsurface data such as remote sensing, seismic sections and geophysical data. The tectonic lineaments are considered as expression of underlying geological structures and can highlight an overview of the tectonic events. Therefore, the geometry, scale and nature of tectonic lineaments are critical factors in understanding the influence of these structures during development and evolution of sedimentary basins (Smith and Mosley, 1993). For example, in the petroleum-bearing basins, the characterization and delineation of these lineaments and the relationship between their architecture and hydrocarbon target can strongly enhance the productive capability of the basin and lead to new discoveries (Xu et al., 2004 and references therein).

The southern Dezful Embayment is the most important fertile hydrocarbon province of the Zagros fold-thrust belt, SW Iran (Fig. 1) and hosts several fractured-controlled carbonate hydrocarbon reserves (Asadi Mehmandosti et al., 2015). This study aims to precisely extract and investigate the main trends of tectonic lineaments in the southern Dezful Embayment oilfields within the Zagros fold-thrust belt. This can be used to characterize the relationship between deep structures (magnetic

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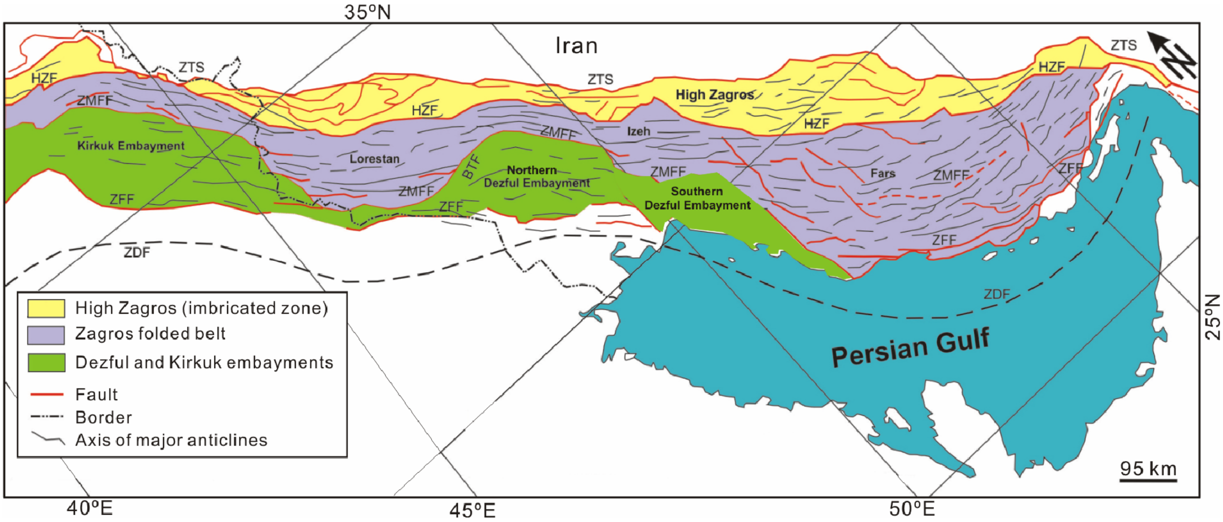

Figure 1. Structural setting and tectonic subdivisions of the Zagros fold-thrust belt, SW Iran and NE Iraq. The position of several major faults and axes of major anticlines in foreland basin of the Zagros Mountain belt is also observed (modified after Pirouz et al., 2011). HZF. High Zagros fault; BTF. Balarud transfer fault; ZMFF. Zagros Mountain frontal fault; ZTS. Zagros thrust system; ZFF. Zagros foredeep fault; ZDF. Zagros deformation fault; KTF. Kazerun transfer fault.

lineaments) and surface structures (lineaments obtained using satellite remote sensing data), and generally, their influence on the formation, distribution and development of different structural traps resulted from tectonic activity in the southern Dezful Embayment oilfields.

1 GEOLOGICAL AND TECTONIC SETTINGS

The Zagros Orogen consisting of three structural belts from SW towards NE, i.e., Zagros fold-thrust belt, Sanandaj-Sirjan metamorphic belt and Urumieh-Dokhtar volcanic belt, highlights the occurrence of a young Tertiary collision and earlier subduction/obduction processes within the Alpine-Himalayan orogenic system started since Late Cretaceous and ongoing to the present (Barjasteh, 2018; Partabian et al., 2018; Alavi, 1994; Berberian and King, 1981) (Fig. 1). This orogen resulted from multiple successive tectonic events in different tectonic settings including continental rifting (Permian–Triassic), seafloor spreading (Jurassic–Early Cretaceous), northeastward subduction and ophiolite obduction (Late Cretaceous), and finally oblique collision between the Arabian and Eurasia plates (Neogene) (Agard et al., 2005). The Dezful and Kirkuk embayments are two regional syntaxes in Iran and Iraq, respectively (Talbot and Alavi, 1996; Berberian, 1995) (Fig. 1). The subsidence due to the development of foredeep of the Zagros fold-thrust belt resulted in sedimentary basins and depocenters of Mid-Miocene to recent age. These basins are characterized by molasses-type deposits (Kazemi et al., 2009). The Dezful Embayment with a trapezoid shape is surrounded by several important faults including mountain front fault (MFF) to the north, the Zagros foredeep fault (ZFF) to the south, the Balarud fault (BF) to the west, and Kazerun fault (KF) located in the east (Ghanadian et al., 2017a, b, c; Fard et al., 2006). The N-S trending Hendijan fault crosses the embayment and has been subdivided into the northern Dezful Embayment and the southern Dezful Embayment, respectively (Fig. 1). The study area is located in the southern Dezful Embayment and hosts several large oilfields including Gachsaran, Bibihakimeh, Aghajari, Rag-e-Safid, Pazanan, Karanj, Parsi, Chilingar-Garangan, Chahrbisheh, Rudak, Milatun, Nargesi, Gulkhari, Shahpour, Siahmakan, Kilurkarim, Khairabad, Mansurabad, Binak and Sarburi oilfields (Rabbani et al., 2010) (Fig. 2). The Gadvan, Kazhdumi, Gurpi and Pabdeh formations as major source rocks and Asmari Formation (Oligocene–Early Miocene) and Bangestan Group (Santonian–Cenomanian) as most important carbonate reservoirs are important constituents of the Cretaceous–Tertiary petroleum system in the southern Dezful Embayment (Alizadeh et al., 2012) (Fig. 3).

2 DATA AND METHODS

The methodologies applied in this study for the extraction of lineaments with possible tectonic origin have been divided into phases based on the decomposing the geological column into several layers and specific technique applied to each of them.

2.1 Surface Techniques

The surface lineaments were extracted using remote sensing techniques. The remote sensing techniques as a source of surface data have become more and more useful for delineating lineament and geological structures (Wang et al., 2019; Lyu et al., 2017; Zhang et al., 2013; Batayneh et al., 2012; Kusky et al., 2011; Farina et al., 2005). Using multi-spectral and high-resolution data with capabilities of digital image enhancements such as image processing, band rationing, colour composites and image fusion made geologists powerful to discriminate geological structures in a given region (Gupta, 2013; Chen and Campagna, 2009; Prost, 2001). In this study, Landsat ETM+ and digital elevation model (DEM), extracted from Shuttle Radar Topography Mission (SRTM) were used. In order to increase the sharpness of the satellite images and enhancement of the geological features we enhanced the data about tectonic lineaments through fusion of panchromatic band with the multispectral bands of LANDSAT ETM+ image, the creation of hill-shading and application of directional filtering via application of different azimuth directions and sun angles.

2.2 Near-Surface Techniques

For the near surface, we utilized underground contour (UGC) data, overburden and reservoir parameters of the Asmari Reservoir throughout the Dezful Embayment oilfields. The static and dynamic parameters of reservoirs include subsurface structural contour map, formation thickness, and mud loss. In addition, several geochemical properties such as total organic carbon (TOC), thermal gradient and Ni/Va index are evaluated in order to highlight their relation to the origin of tectonic lineaments (Emujakporue and Ekine, 2014; Ogiesoba and Hammes, 2014; Huvaz et al., 2007).

2.3 Deep Techniques

Aeromagnetic data are extensively used to recognize subsurface geologic structures (e.g., faults) at different scales especially where the trace of these structures is concealed by younger sedimentary deposits (Emujakporue et al., 2018; Essa and Elhussein, 2017; Muthamilselvan et al., 2017; Fnais et al., 2016; Selim et al., 2016; Biswas, 2015; Okiwelu et al., 2014; Feumoe et al., 2012; Ndougsa-Mbarga et al., 2012). Application of aeromagnetic data is based on the fact which these data result from the magnetic properties of the underlying rocks and structures corresponding to depth of 8–12 km in the study area (Koop, 1977). The derivative maps extracted from aeromagnetic data are important data, which enhance the subsurface lineaments. Among these maps the first horizontal derivative map (FHDM), X derivative maps (XDM) and Y derivative maps (YDM) are most applicable maps, which are used to highlight the evidence of subsurface lineament.

3 RESULTS

3.1 Surface Techniques

The regional map of tectonic lineaments in the southern Dezful Embayment was achieved from interpretation of Landsat images and DEMs. The obtained results show the presence of dominant E-W, NW-SE, NE-SW and N-S trending lineaments in the study area (Fig. 4).

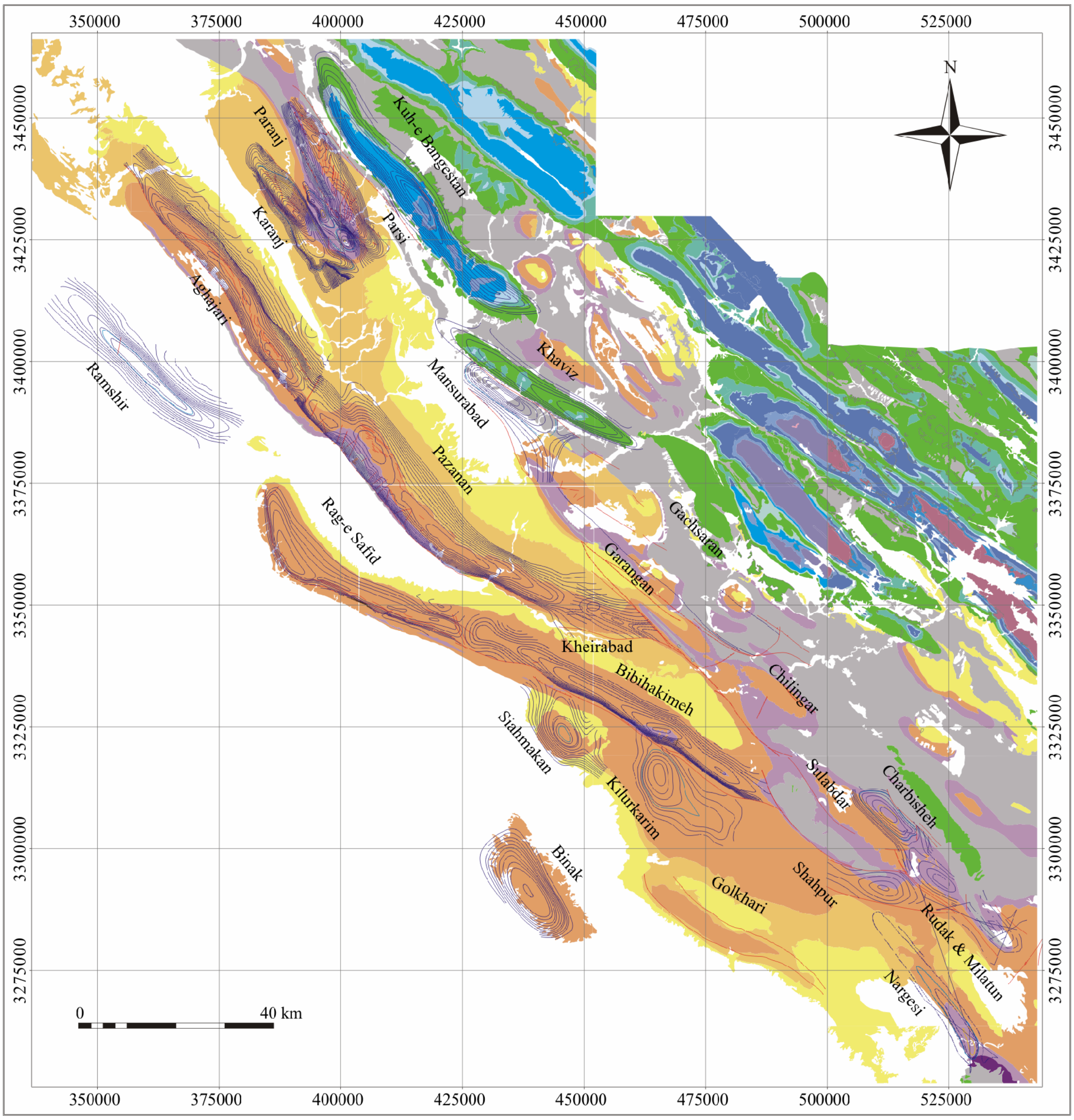

Figure 2. Distribution of major oilfields in the southern Dezful Embayment, SW Iran.

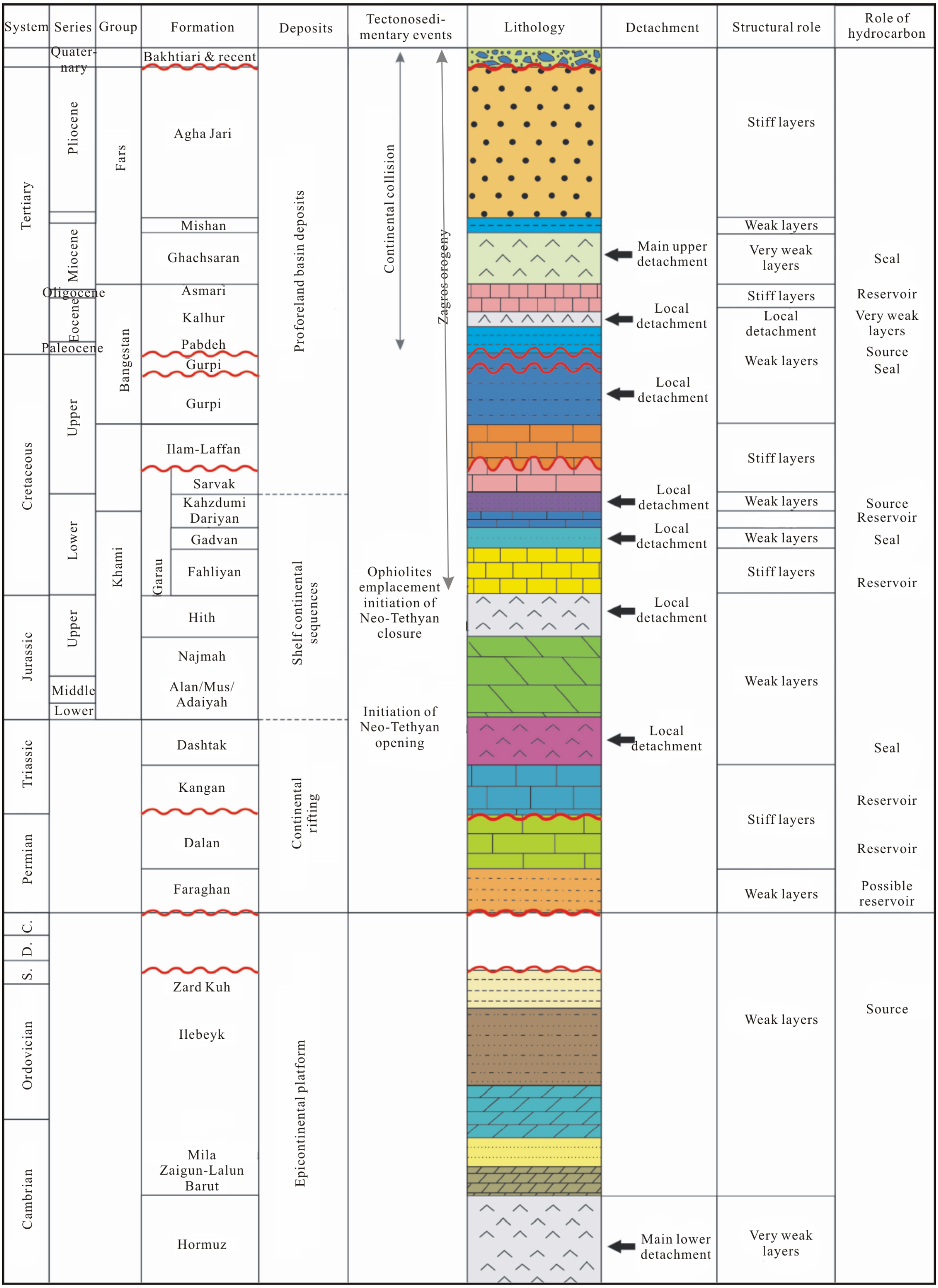

Figure 3. Simplified stratigraphy of the area depicting the major lithological successions and main tectonic events in the Dezful Embayment. The stratigraphic column is modified after Fard et al. (2006) and Alavi (2007).

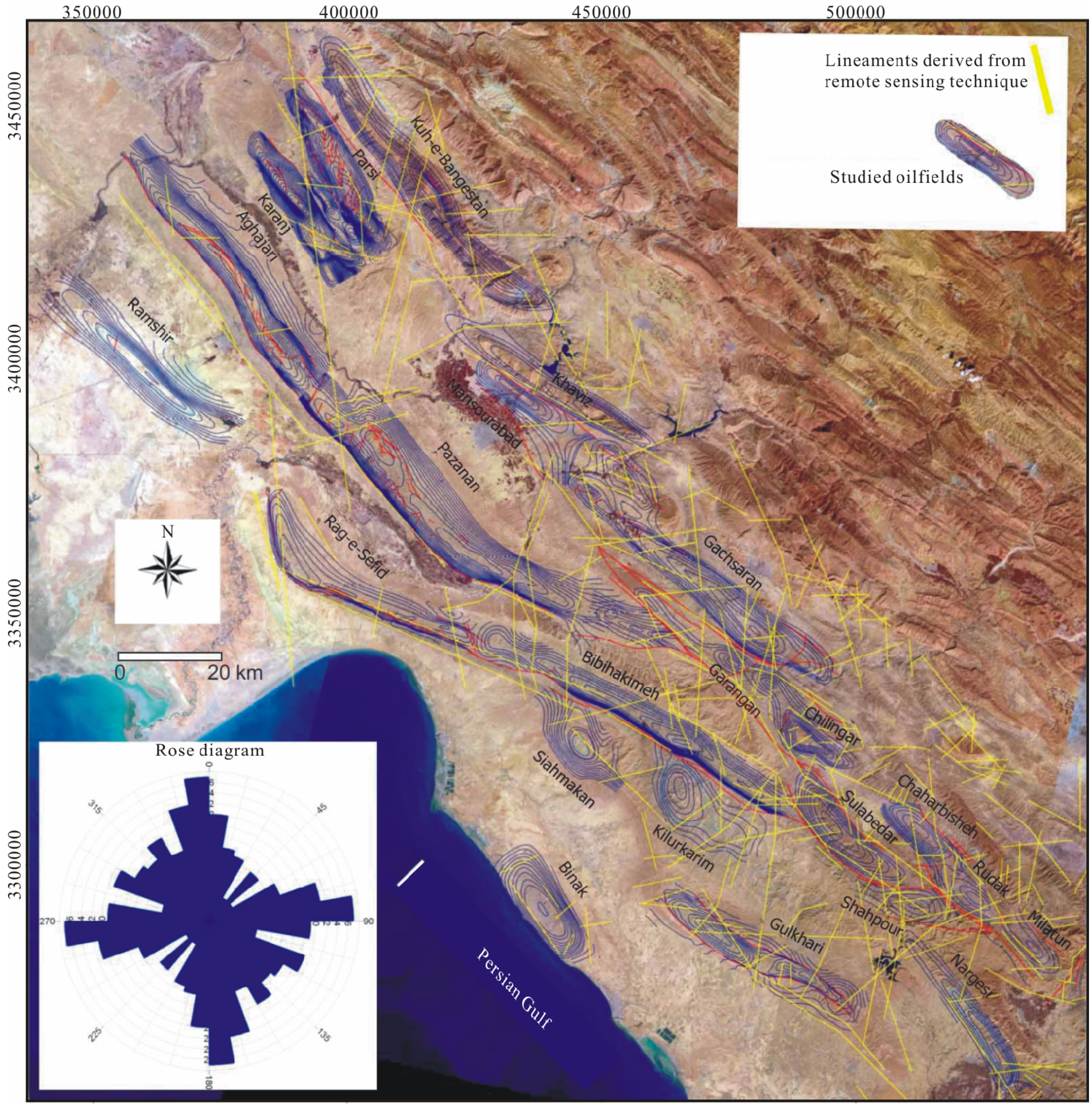

Figure 4. Rose diagram and corresponding lineaments which were extracted through remote sensing techniques in the study area.

3.2 Near-Surface Techniques

3.2.1 Overburden parameters

Several authors (e.g., Jahani et al., 2009; Sepehr and Cosgrove, 2004; Sherkati and Letouzey, 2004; Bahroudi, 2003) have mentioned the presence of deep-seated basement faults and their influences on the folding style and diapirism in the Zagros (also see Misra and Mukherjee, 2015). However, the role of basement faults and their possible effect on paleogeography and the morphology of the Zagros are not so clear. In addition, the behavior of these faults during the sedimentation of Phanerozoic strata is not well understood. It has long been recognized that the deposition of the Phanerozoic sedimentary cover in the Zagros Basin was strongly influenced by the reactivation of old basement structures (Bahroudi, 2003). Therefore, isopach and lithofacies maps of different geologic time periods provided by Ashrafzadeh (1999) and Motiei (1993) were used to interpret the depocenters and syndepositional highs, and to reconstruct the activity of faults during the evolution of the Zagros fold thrust belt.

Considering previous studies conducted by Player (1969), Kent (1979), Barzegar (1994) and Berberian (1995) about the enhancement of the Kazerun fault (KF), the Kharg-Mish fault (KMF) and the Hendijan-Bahregansar fault (HBF) (Table 1, Fig. 1) based on the thickness variation of the sediments, we used isopach maps of the Asmari Formation (Oligo–Miocene) to recognize the subsurface tectonic lineament. The occurrence of the anomaly of Asmari thickness variations in the NW plunge of the Pazanan, Siahmakan, Binak, Parsi, Aghajari and Chahrbisheh oilfields reveals the presence of prevailing lineament's trend as E-W (Figs. 2 and 5). These thickness variations anomalies show that the dominant trend in the southeast parts of the Mansurabad, Gachsaran, Chilingar, Aghajari, Nargesi and Binak oilfields, is N-S (Figs. 2 and 5). The prevailing lineament's in the central parts of the Parsi, Karanj, Gachsaran and Aghajari oilields revealed as 020 based on the occurrence of the anomaly of Asmari thickness variations (Figs. 2 and 5).

3.2.2 Structural pattern of UGC maps

The deflection of fold axial trace in UGC maps is attributed to the presence of certain subsurface structures which are more likely deep-seated or concealed faults (Wheeler, 1939). In addition, the presence of structural patterns including saddle and

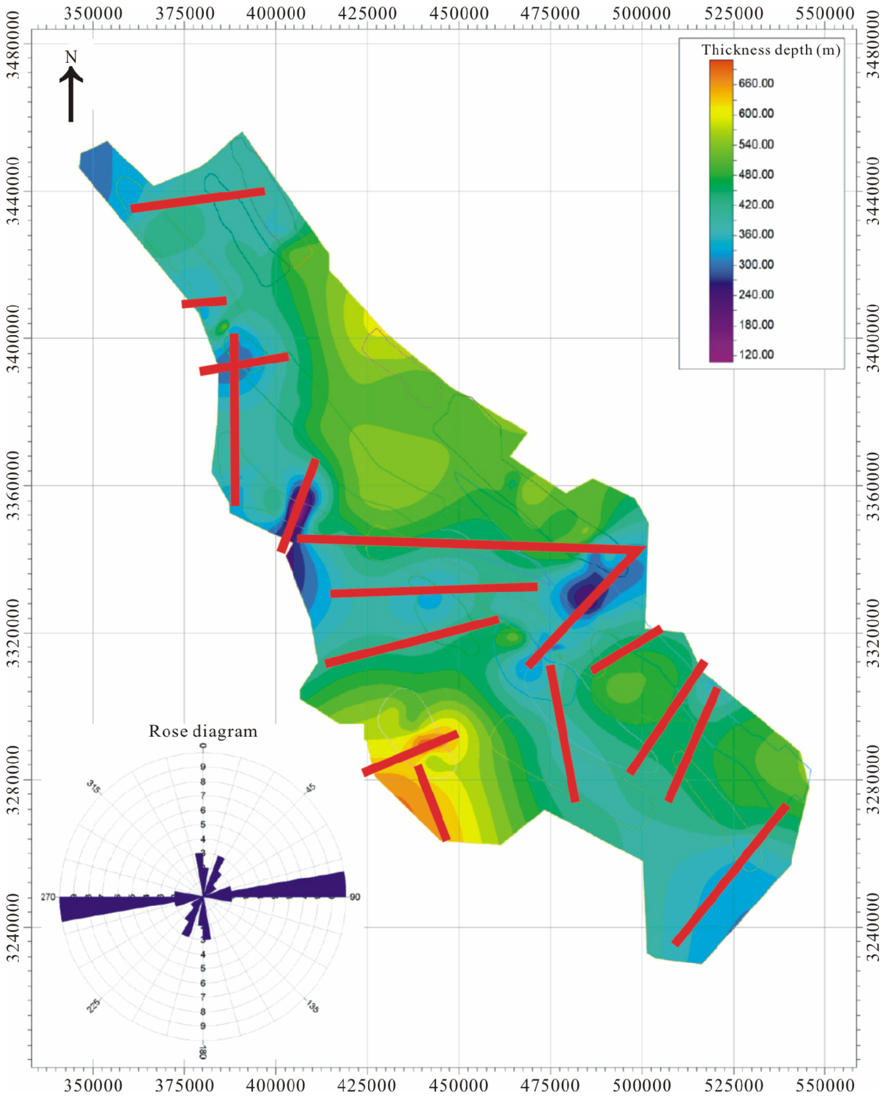

Figure 5. Contoured thickness map showing thickness variations of the Asmari Formation in the study area. The rose diagram shows the direction of lineaments which was extracted based on the thickness variations attributed to tectonic activity.

Table 1 The identified basement faults in the Zagros Mountains and their probable activity as indicated by different data (modified after Bahroudi and Talbot, 2003)

Fault name		Kazeroun lineament	Kharg-Mish lineament	Hendijan-Baregansar lineament
Length in the study area (km)		~50	~80	~80
Seismic activity		Active	Inactive	Inactive
Magnetic indication		Yes	Yes	Yes
Nature		Oblique slip-normal sense/reactivated as reverse with dextral component		
Cuts formation		Basement to Quaternary formations		
Activity inferred from isopach maps (Motiei, 1993; Koop and Stoneley, 1982; Murris, 1980)	Permian	Active	Inactive	Inactive
	Triassic	Active	Active	Active
	Early–Middle Jurrassic	Active	Active	Active
	Late Jurassic	Active	Active	Active
	Early Cretaceous	Active	Inactive	Inactive
	Middle Cretaceous	Active	Active	Active
	Late Cretaceous	Active	Active	Active
	Paleocene–Eocene	Active	Active	Active
	Oligocene–Miocene	Active	Active	Active
	Miocene–Recent	Active	Inactive	Inactive

curving features, transverse faults and en-echelon array of folds in the UGC maps highlight the effects of subsurface lineaments on the sedimentary sequences of the oilfields. The deflection in the fold's axes in the UGC maps (Fig. 2) manifesting the curvilinear fold patterns reveal the occurrence of different tectonic trends (e.g., E-W and N-S trends) which are traceable for ~2–5 km in the South Dezful Embayment. The UGC maps of the Asmari horizon in the Gachsaran, Bibihakimeh, Aghajari, Binak, Pazanan and Gulkhari oilfields have curvilinear shapes and reveal deflection in the axial trace of the folds. Rage-Sefid, Sulabedar, Chilingar, Siahmakan, Kilurkarim, Shur, Bangestan oilfields have boomerang shaped geometries. The Bibihakimeh, Gulkhari, Gachsaran and Nargesi have saddle feature showing the effect of subsurface lineaments. The Bangestan, Khaviz and Gachsaran with en-echelon array manifest the effect of subsurface lineaments. The presence of transverse faults in the Pazanan, Aghajari, Bibihakimeh, Rage-Sefid, Roudak, Milatoun, Garangan oilfields reveal the occurrence of subsurface lineaments in the study area. Based on these geometric features, several tectonic trends have extracted mainly E-W and approximately N-S trends (Fig. 6).

3.3 Deep Techniques

3.3.1 Aeromagnetic data

The interpretation of FHDM data shows the presence of several trend of subsurface lineaments with depth range of 8–12 km and length of 20–80 km in the study area. The concentration of these trends can be divided into two SE and NW sub-areas. The SE sub-area includes NE-SW lineament trends and the NW sub-area is characterized with E-W and N-S trends. The interpretation of XDM data shows the concentration of lineaments is different in the SE, NW and central parts of the study area. The SE and NW parts of the study area mainly include NE-SW and N-S trends, respectively. The central part of the study area is characterized with N-S, NE-SW and E-W trends. The interpretation of YDM data shows the occurrence of several lineament trends in study area. The trend concentration can be divided into two SE and NW regions. The SE and NW parts are characterized lineaments with NE-SW and E-W trends, respectively (Fig. 7).

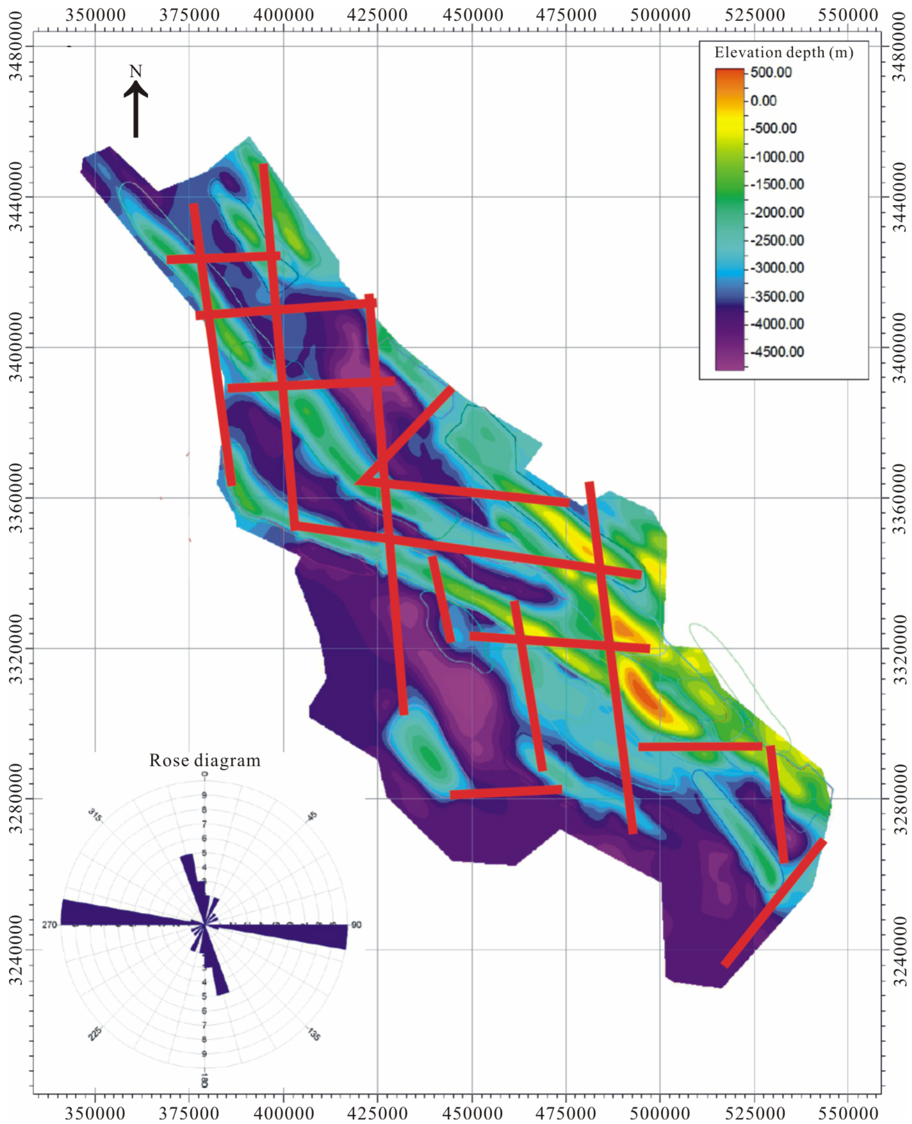

Figure 6. Contoured underground elevation map of the study area and rose diagram showing the major directions of lineaments which were extracted based on the shape of the underground contours influenced by tectonic movements.

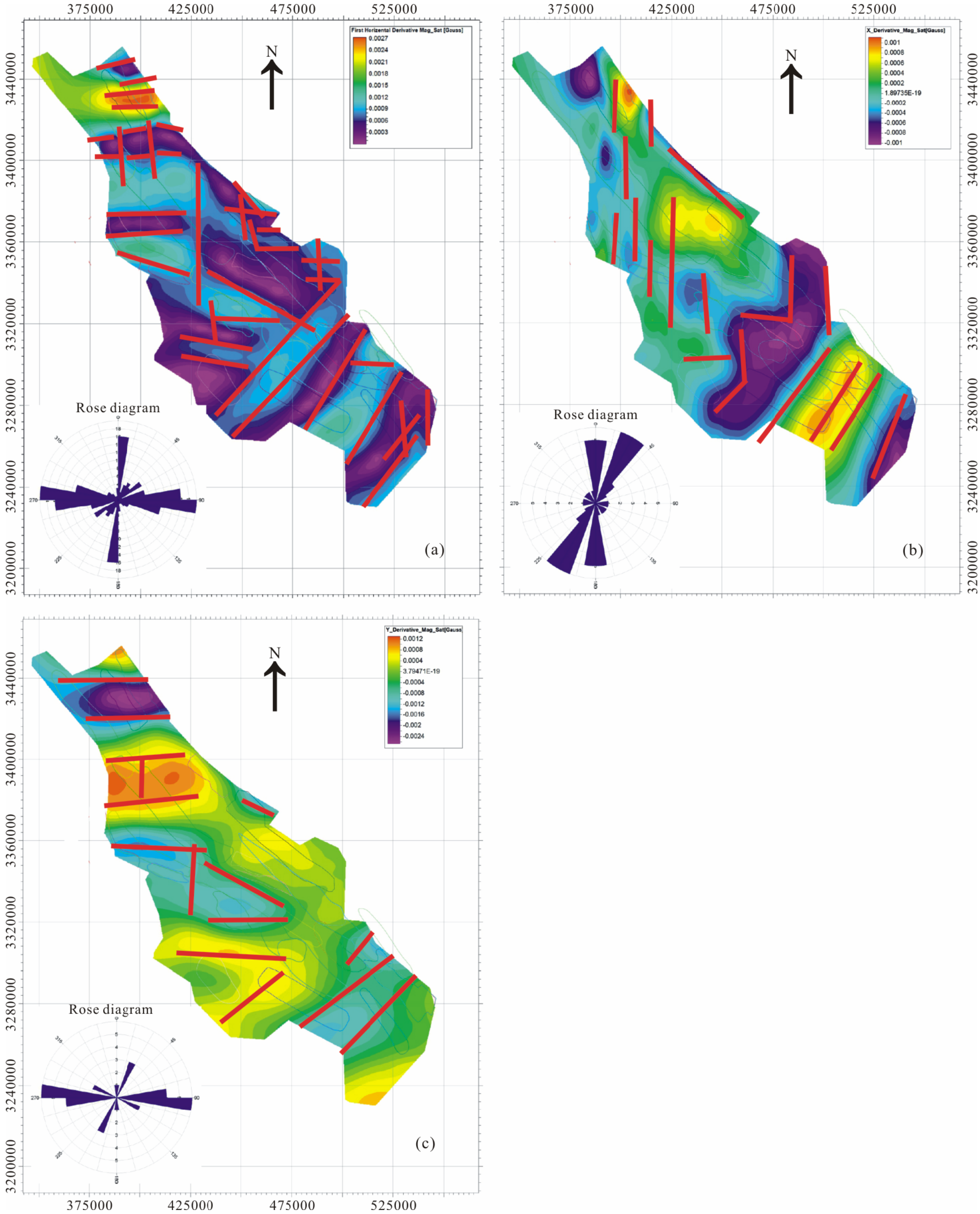

Figure 7. (a) The FHDM and rose diagram showing the major direction of lineaments extracted based on the anomalies; (b) XDM and rose diagram showing the major direction of lineaments extracted based on the anomalies; and (c) YDM and rose diagram showing the major direction of lineaments extracted based on the anomalies.

4 DISCUSSION

4.1 General Comparison of Static Data (UGC, Asmari Thickness, Magnetic and Surface Data)

The probability of correlation between the lineaments derived from analysis of static data was investigated (Fig. 8). A comparison of the trends obtained from magnetic maps (e.g., XDM, YDM, FHDM) and UGC maps reveals a good overall correlation. As the approximate trends of N-S, E-W in the FHDM and UGC maps, the N020, E-W trends in the YDM and the N-S, N020 trends in the XDM map show good agreement with those trends which were derived from UGC map. Deep tectonic trends derived from the magnetic data, in particular the FHDM parameter, with anomalous trends confirm the thickness variations of the Asmari Formation (from 120 to 600 m) in the same way, i.e., N-S, E-W, N020. The similarity can be considered as the result of the active deep processes during the sedimentation of the Asmari Formation. Correlation of UGC-derived trends with deep data-derived trends can be observed clearly in the center and northwest than in the southeast of the study area.

4.2 Comparison of Static and Dynamic Data in the Studied Oilfields

In order to highlight the effect of tectonic trends on the dynamic characteristics of the oilfields in the study area, several maps representing dynamic data such as iso-thermal gradient, iso-mud loss, iso-TOC and iso-Ni/V ratio maps were investigated to extract possible tectonic trends influencing the oilfields. These extracted trends were compared by those which extracted from the analysis of magnetic, subsurface contour and satellite imagery-derived maps. Then, the final lineament map was prepared showing distribution of major tectonic trends (45 trends numbered as L_1 to L_{45}) influencing the oilfields in the study area (Fig. 9). To investigate, in detail, the effect of these lineaments on the static and dynamic characteristics of the oilfields, the affected characteristics of the several oilfields of the study area are discussed.

The Agha Jari Oilfield has two thermal gradient anomalies, one distinct in the northwest and one weaker anomaly in the southeast of the field, which corresponds to the mud loss anomalies in the northwest of the field (Figs. 10a, 10b). There is also an anomaly of increasing TOC in the southeast and northwest of the oilfield (Fig. 10c). Thermal gradient, mud loss and TOC anomalies in the southeast of the Agha Jari Oilfield are correlated with the E-W and N-S trends on the XDM, YDM and FHDM maps, respectively, and E-W trends on the Asmari iso-thickness map (Fig. 10d) and N-S and E-W in the surface fractures. Anomaly on the mud loss map in the middle parts of the oilfield is also correlated with the N-S and E-W trends in the magnetic map. This anomaly is also consistent with the E-W trends on the UGC map, but not correlated with the surface data-derived trends. This may be due to lateral variations in the thickness of Gachsaran Formation as a detachment horizon (Ghanadian et al., 2017b) along the oilfield which can be observed in the seismic sections, possibly due to differential compaction of sediments (e.g., Mukherjee and Kumar, 2018) (Fig. 11). Increasing (~300 m) formation thickness in the middle part of the oilfield relative to the northwest and southeast, led to discrepancies of linear features at the same locations between the maps generated by static and dynamic data. Therefore, the lineaments derived from the remote sensing data for this part of the oilfield removed from the final lineament map (Fig. 11). Finally, mud loss, thermal gradient and TOC anomalies in the northwest of the oilfield coincide with the E-W trends on the UGC and surface maps. Figure 11 shows the effect of the lineaments on the oilfield and their location on the seismic section. These evidence can be observed in the other oilfields of the study area, too. For example, in the Parsi Oilfield (Fig. 2), thermal gradient anomalies (14–34 °C/km) are observed in the southeast, center and northwest of the oilfield. There is a mud loss anomaly (~1 000–45 000 bbl; this is a cumulative range for total thickness of the Asmari Formation during drilling) in the center of the oilfield. Overlying isoparametric maps reveal that east-west trending deep magnetic anomalies shown in FHDM, XDM and YDM in the southeast to center of the oilfield and north-south trending ones in the southeast of the oilfield are correlated spatially with the thermal gradient and mud loss anomalies (Figs. 10a, 10b). Also, surface trends in the southeast, center and northwest of the oilfield are correlated with the thermal gradient and mud loss anomalies (Fig. 8). The north-south trending of magnetic anomalies in the southeast of the oilfield, which is correlated with the thermal gradient, confirm the structural trends of UGC in the Asmari horizon. These tectonic trends on the seismic sections are almost correlated with the position of the

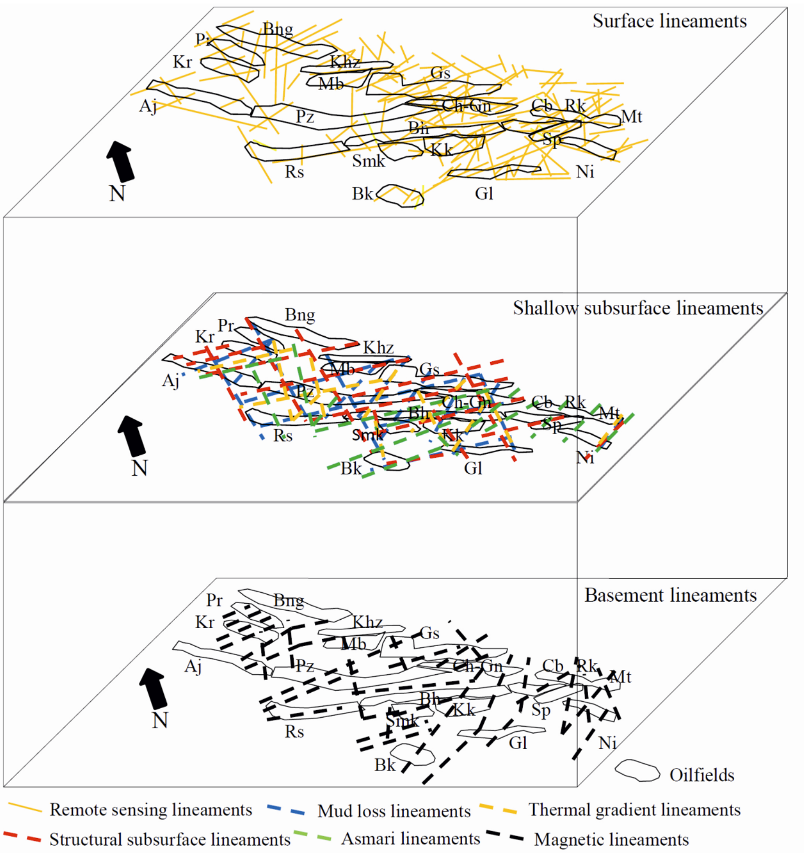

Figure 8. Combined map showing distribution of lineaments extracted from static data using different methods in this study.

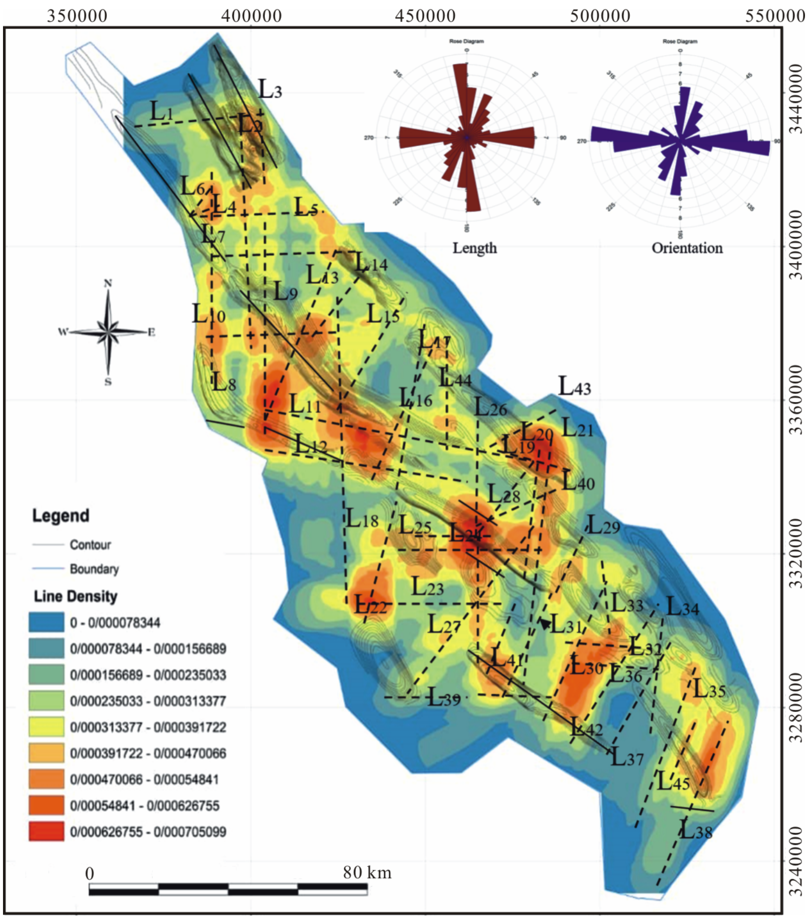

Figure 9. Final lineament map after correlation of results obtained through analysis of statistic and dynamic data in the study area.

dynamic anomalies. In the Karanj Oilfield (Fig. 2), thermal gradient anomalies are observed in the southeast and the center and mud loss anomalies are observed in the center and the northwest of the oilfield. Overlying isoparametric maps reveal that north-south and east-west trending surface fractures are correlated with mud loss and thermal gradient anomalies in this oilfield. East-west and north-south magnetic trends observed in the FHDM, XDM and YDM maps in the center and southeast of the oilfield coincide with the trends observed in the UGC and surface maps. Thermal gradient and mud anomalies are largely consistent with these static data in these parts of the oilfield. But there is a mud loss anomaly in the northwest of the oilfield, which is likely to be affected by local fold-related fractures. These tectonic trends on the seismic sections are almost correlated with the position of the dynamic anomalies. In the Pazanan Oilfield (Fig. 2), the thermal gradient anomalies are observed in the southeast and center of the oilfield. Mud loss anomalies are observed in the southeast, center and northwest of the oilfield. Based on the surface fractures map in the Pazanan Oilfield, two fracture anomalies in the central region of the oilfield with the NE-SW trend and the northwest of the field with the E-W trend are evident. These trends are evident on the Asmari structural map (UGC) and are correlated with thermal and mud loss anomalies. The east-west and north-south magnetic trends in the northwest and southeast of the oilfield observed in the FHDM, XDM and YDM maps are correlated with the structural trends in the UGC maps which cause to rotate the fold axis. Several dynamic data such as mud loss and TOC confirm east-west trends in the northwest of the field. Also, thermal gradient and mud loss data confirm northeast-southwest trends in the center of the oilfield. These tectonic trends on the seismic sections are almost correlated with the position of the dynamic anomalies.

The thermal gradient and mud loss anomalies are observed in the southeast, center and northwest of the Rag-e-Safid Oilfield (Fig. 2), respectively. There are several north-south trending anomalies in the surface maps which are correlated with those structural trends observed in the UGC map. The north-south trending magnetic trends observed in the FHDM, XDM and YDM maps in the center and northwest parts of the oilfield are correlated with tectonic trends in the UGC and surface maps. Thermal gradient and mud loss anomalies coincide with trends. Noteworthy, these tectonic trends on the seismic sections are almost correlated with the position of the dynamic anomalies.

The thermal gradient and mud loss anomalies are observed in the northwest of the Golkhari Oilfield. The north-south trend anomalies observed in the surface map are correlated with those trends in the UGC maps in the southeast and northwest of the oilfield. The NE-SW and E-W magnetic trends observed in FHDM, XDM and YDM maps are correlated with those trends in the surface and UGC maps. Dynamic data such as mud loss and thermal gradient are correlated with these trends. Noteworthy, these tectonic trends on the seismic sections are almost correlated with the position of the dynamic anomalies.

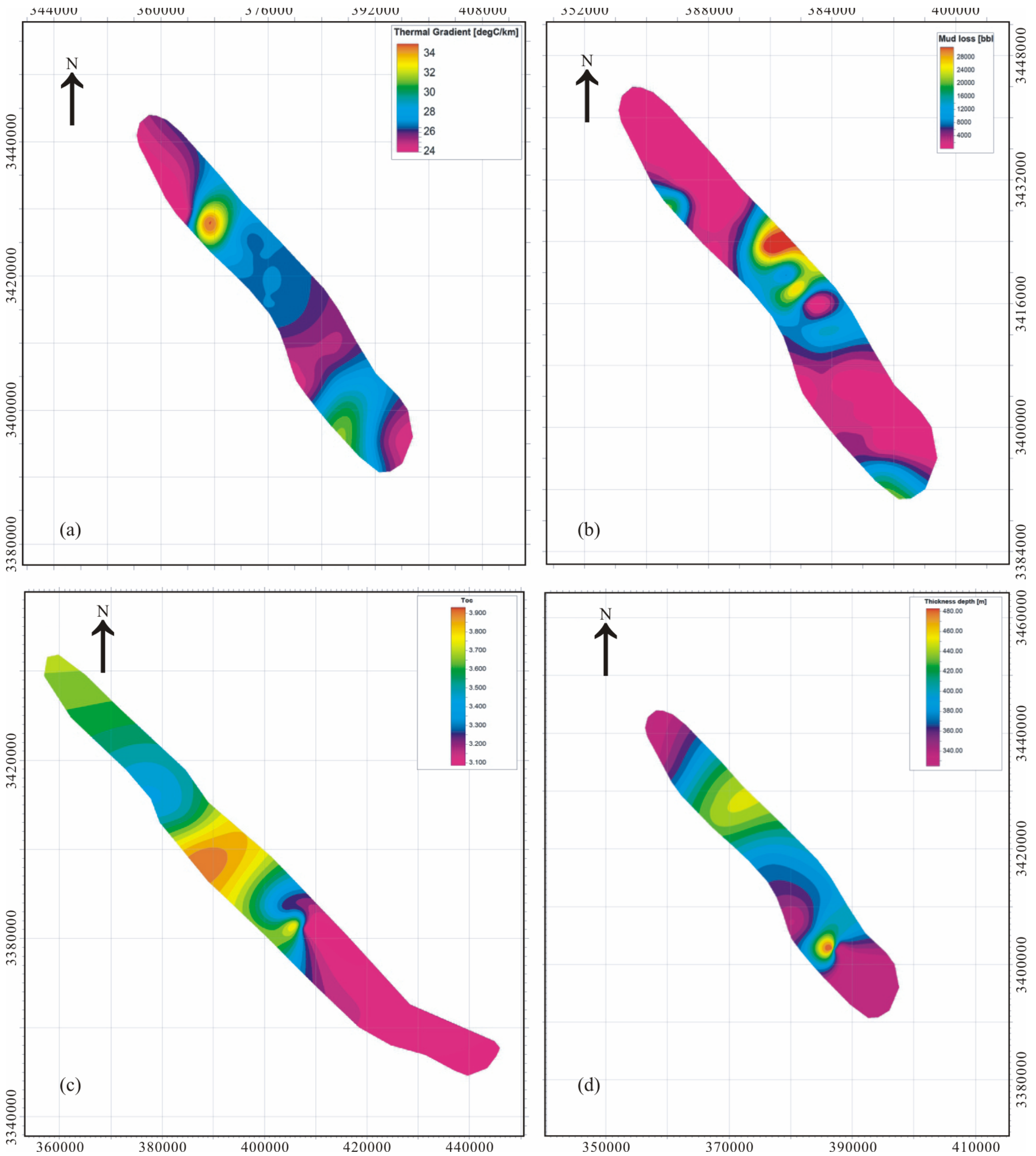

Figure 10. Comparing static and dynamic data in order to investigate the effect of lineaments on the Agha Jari Oilfield in the study area.

4.3 Origin of Extracted Tectonic Trends

Integration of surface and subsurface data reveals the presence of four dominant tectonic trends of N-S, E-W, NW-SE and NE-SW in the southern Dezful Embayment, SW Iran (Fig. 9). Based on the results of this study, it is possible to categorize the extracted lineaments into exclusively surface, shallow subsurface and subsurface lineaments which have been enhanced through interpretation of satellite images, reservoir parameters and magnetic data, respectively. Nogol-Sadat et al. (1993) and Tabatabaei (1997) mentioned and referred the origin of the magnetic-driven lineaments in the ZFTB to the deep-seated basement faults. Most of these lineaments are correlated with those that were derived through surface and near-surface data. The connectivity of basement lineaments to the surface and shallow subsurface lineaments may be due to reactivation and upward propagation of unnamed basement faults and finally their merging at surface. But, some of deep tectonic trends with basement affinity are not correlated with surface and near-surface trends. It can be due to presence of several detachment horizons (Hormuz, Dashtak and Ghachsaran formations) (Motamedi and Gharabeigli, 2019; Mukherjee, 2011; Mukherjee et al., 2010) in the stratigraphic column of the ZFTB (Ghanadian et al., 2017a, b, c). These horizons do not allow basement lineaments to propagate upwards.

The N-S and E-W trends are well-known tectonic trends and also important in forming oil-field structures in the Arabian Peninsula (Bushara, 1995; Henson, 1951). The most prominent are, N-S Arabian trend, as well as the NE Aualitic trend and the NW Erythraean trend in offshore diapiric fields and finally, least conspicuous is the E-W Tethyan trend. The N-S and E-W trends are derived from deep information (i.e., from basement). Since the Zagros basement is northeast continuation of the Arabian basement (Alsharhan and Nairn, 1997; Ameen, 1992; McQuillan, 1991; Al Laboun, 1986; Berberian and King, 1981;

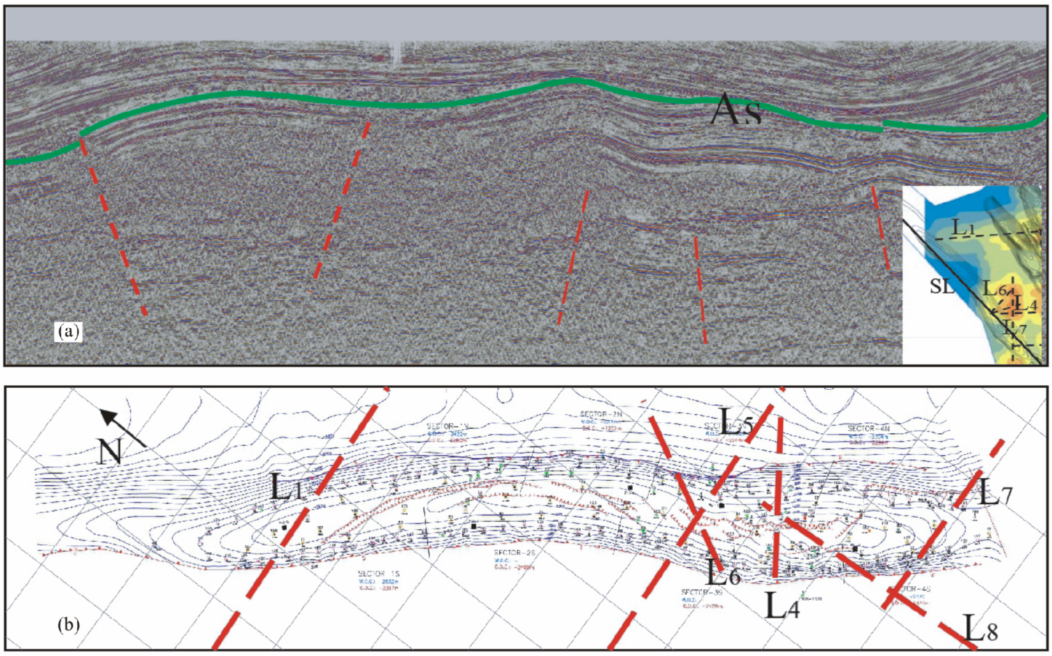

Figure 11. Seismic section (a) and underground contour map (b) showing the location and effect area of extracted lineaments in the Aghajari Oilfield.

Falcon, 1969, 1967), it seems that these trends are inherited from the Arabian basement that have reactivated during the convergence between the Arabian and Iranian lithospheric plates. But the NE-SW, NW-SE trends are derived from surface and near-surface data, and it seems these trends are younger and could be formed during the ongoing Zagros orogeny. According to Edgell (1992), similarities in the basement of Arabia and southern Iran, the recognized lineaments in this study can be categorized chronologically into two groups, namely, N-S and E-W trending lineaments generated in the Late Proterozoic and reactivated in the Late Cretaceous due to the convergence between the Arabian and Iranian plates and NE-SW and NW-SE trending lineaments generated in the Oligocene due to the separation of the Arabian Plate from Africa along the Red Sea. Except for a limited number of Iranian oilfields (e.g., Tango, Siahmakan, kiloorkarim and Hendijan oilfields) that follow the N-S trend of the Arabian grain, other Iranian oilfields have been influenced by the NW-SE's Zagros trends. The re-activation of the Arabian trends in the Zagros has led to changes in the Zagros sedimentary basin (changes in thickness and sedimentary facies; for example ~200 m for the Asmari Formation) and even on the dynamic characteristics of oilfields.

5 CONCLUSIONS

The integration of surface and subsurface data consisting of satellite images, overburden and geomagnetic data in this study provides a framework for delineation of major tectonic concerns to hydrocarbon reservoirs distribution in the southern Dezful Embayment, Zagros fold-thrust belt, SW Iran. This multidisciplinary study led to extraction of some lineaments which can be interpreted as surface, shallow subsurface and basement lineaments. The surface lineaments can be categorized into three groups as (i) exclusively surface lineaments, (ii) surface lineaments with connection to shallow subsurface lineaments, and (iii) surface lineaments with connection to both shallow subsurface and basement lineaments. The presence of several detachment layers in a given sedimentary sequence controls the reactivation and propagation of basement lineaments upward and their merging at surface. The presence of Hormuz, Dashtak, Gachsaran formations in the sedimentary sequences of the ZFTB does not allow the lineaments to merge at surface. However, the results of this study reveal that some satellite image-driven lineaments are surficial manifestations of regional deep-seated concealed faults. The correlation of trends of surface and shallow subsurface lineaments with the magnetic-driven lineaments confirms their basement origin. The basement lineaments were reactivated and propagated upwards and acted as conduits for hydrocarbon migration and entrapment in the shallower rocks where the Gachsaran Formation has less thickness.

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