

Mesozoic basin inversion in Central Alborz, evidence from the evolution of Taleqan-Gajereh-Lar paleograben

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Abstract

This paper presents evidence on Mesozoic inversion of basin bounding faults within the Taleqan-Gajereh-Lar Paleograben (TGLP) in Central Alborz Range. For this purpose, well documented stratigraphy data across the TGLP together with the new acquired structural data on the geometry and kinematics of the paleograben basin bounding faults are utilized. The TGLP has evolved through the Early and Middle Cimmerian and the Late Cretaceous tectonic events. The Early Cimmerian north verging folds of Paleozoic rocks with development of axial foliation is proposed to be related to inversion of the basin bounding Mosha and Hasanakdar faults. During the Middle Cimmerian (Bajocian), synchronous to opening of the Caspian basin, the TGLP was extended through the growth of the Gajereh half-graben on the hanging wall of the Mosha Fault. This half-graben that accommodated the thickest portion of the Jurassic rocks in the south Central Alborz is considered as the depocenter of Jurassic basin in this region. The Late Cretaceous-Early Paleocene event associated with folding, and thrust faulting of Jurassic and Cretaceous rocks, causes inversion of the TGLP along its north bounding Taleqan Fault. Development of an angular unconformity between the Eocene Karaj Formation and Mesozoic deposits is the result of this inversion. This event that made the TGLP as upland causes deposition of a thick succession of Paleocene Fajan conglomerate outside the TGLP. The presented interpretation of the Mesozoic evolution of the TGLP in the Central Alborz Range is a key finding, applicable to similar paleograben along the range and the neighboring Caucasus region.

Keywords: Basin inversion, Cimmerian orogeny, Central Alborz, Taleqan-Gajereh-Lar paleograben

Introduction

Inversion of originally normal faults is a known process in the mountain belts. These faults are inherited structures that their geometry affects on the evolution of orogenic belts and intracontinental deformation (e.g. Coward, 1994; Ranalli, 2000; Toussaint *et al.*, 2004; Butler *et al.*, 2006). The Alborz range extends throughout the northern Iran, along the Talesh in west and Binalood to the east (Fig. 1), dominated by lithological and structural heterogeneities, inherited from several tectonic events since Paleozoic (e.g. Alavi, 1996). The range, with more than 2000 km length, highlights the collision zone of Gondwana lands of Iranian plateau with the Eurasia Plate (Alavi, 1991, 1992). Although, the evidence of inversion tectonics in the Central Alborz was reported earlier (Gansser & Huber, 1962), it was only during last decade that structural investigation revealed insights into the inversion tectonics of the range (Yassaghi, 2001; Zanchi *et al.*, 2006; Yassaghi & Madanipour, 2008). These studies focused on the Tertiary inversion of the belt and in response to the compressional regime resulted from collision of

Arabian Plate with Eurasia Plate. Nevertheless, major basin-bounding faults in the Central Alborz such as the Mosha Fault are deep-seated and their activity started before Tertiary (Ehteshami-Moinabadi & Yassaghi, 2007). The aim of this paper is to investigate Mesozoic basins inversion in the Central Alborz using stratigraphic and structural evidence. For this purpose an inlier, contains the Upper Precambrian to Mesozoic rocks and surrounded by Tertiary rocks, in the south Central Alborz is selected and herein after named as Taleqan-Gajereh-Lar paleograben (TGLP) (Fig. 2).

The paper is established mainly based on the new structural data from the area. The stratigraphic requirements are mostly taken from well documented data in the literature. The TGLP that is bounded by the Mosha Fault to the south and by the Taleqan Fault to the north. The paleograben has 150 Km length and up to 15 Km width and includes the Shahrestanak and Hasanakdar grabens as well as Gajereh half-graben (Fig 2). These sub-basins are differentiated upon stratigraphic evidence and the presence of subsidiary faults.

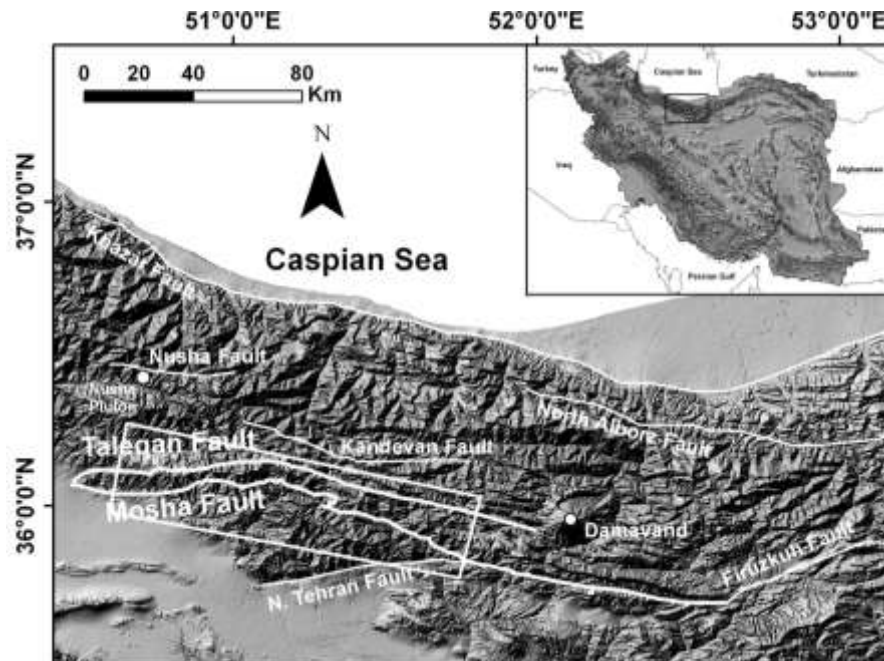


Figure 1: Shaded relief map of the Central Alborz Mountains in northern Iran, showing Moshha and Taleqan faults with major active faults. The quadrangle shows the location of Fig 2.

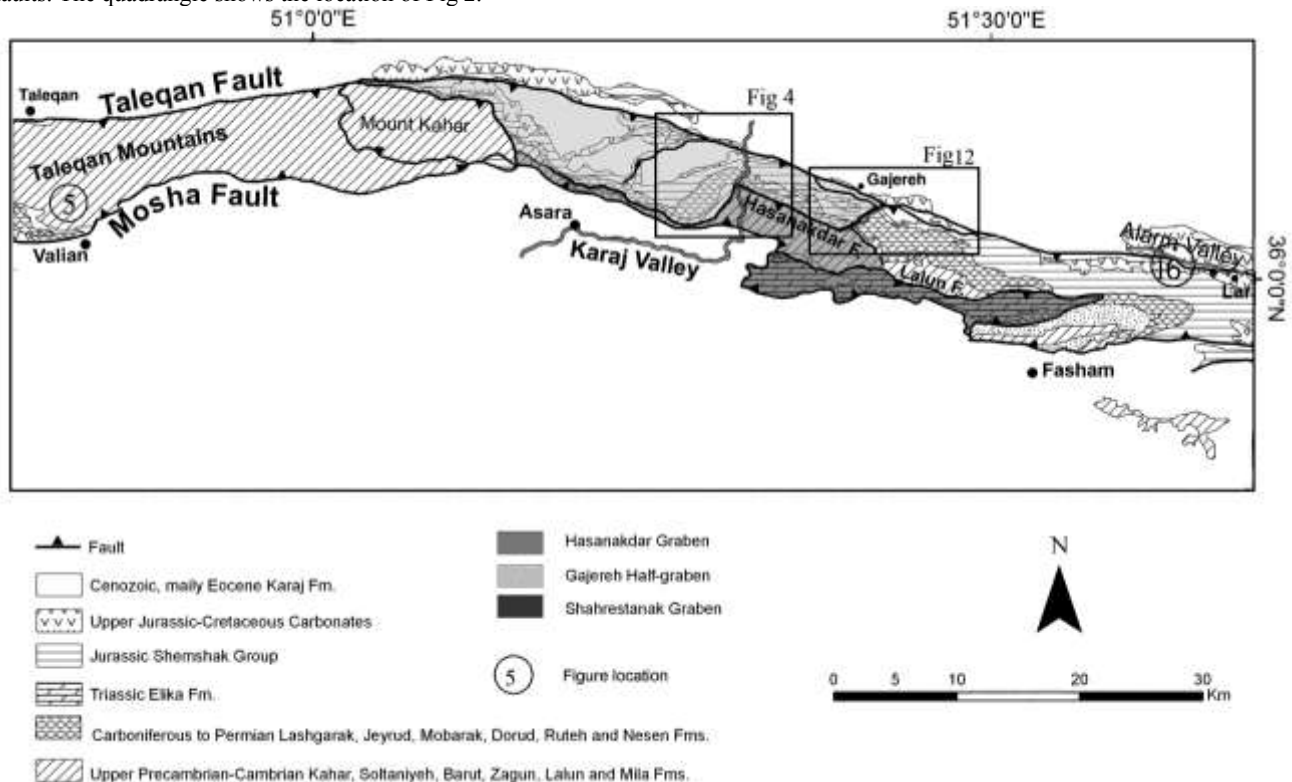


Figure 2: Generalized geology map of the west and central portions of TGLP based on compilation of Vahdati-Daneshmand (1991), Haghypour et al. (1986) and Annells et al. (1985). The rectangles indicate the location of Figs 4 and 12.

Geological setting

Mesozoic Tectonic Setting

The Central Alborz is a polyorogenic folded belt evolved during Cimmerian and Alpine orogenies (Alavi, 1996). Stampfli et al., (1991) suggested that the Alborz block was separated from

Gondwanaland in the Ordovician and Silurian and then collided with the Eurasia Plate in the Late Triassic during Early Cimmerian Orogeny (Zanchi et al., 2009). Metamorphic relics of this collision are only detected in discontinuous outcrops along the northeastern margin of the range (Allen et al.,

2003). In the Middle Jurassic, an extensional regime equivalent to the Middle Cimmerian event caused deposition of the deltaic Shemshak Group (Fürsich *et al.*, 2009a). This deposition followed by changes of sedimentary facies from deltaic (upper Shemshak Group) to marine limestones (Dalichai and Lar formations) (Fürsich *et al.*, 2009a, 2009b) (Fig. 3). Unlike the south Central Alborz where marine condition has continued in the Cretaceous (Brunet *et al.*, 2003), epeirogenic activities in Jurassic-Cretaceous boundary has occurred in some parts of the Alborz (Aghanabati, 2004). The Late Cretaceous (Aptian-Albian) volcanic rocks, which are abundant in the northern Central Alborz (Vahdati-Daneshmand, 1991), have been attributed to the opening of a back-arc basin, related to subduction of the Neo-Tethys (Golonka, 2004; Berra *et al.*, 2007). At the Late-Cretaceous-Early Paleocene an exhumation and cooling pulse with folding has occurred in the south Central Alborz (Guest *et al.*, 2006a) that closed the limited Cretaceous basins in the area (Fig. 3).

Stratigraphy evolution

Regarding the significant use of sedimentary units (strata) and their stratal (stratic) surfaces in the analysis of the paleo-geological events, stratigraphic column of the south Central Alborz (SCA) is prepared (Fig. 3). Generally, the stratigraphy of the grabens and half-graben within the TGLP are reviewed and compared with that of the SCA (Fig. 3). The stratigraphy of Shahrestanak and Hasanakdar grabens are found almost similar, so they are presented here as a single section (Fig. 3).

The Upper Proterozoic Kahar Formation (dolomite, sandstone, and tuffaceous shale) is the oldest sedimentary unit in the SCA (Stocklin, 1972; Vahdati-Daneshmand, 2001; Lasemi, 2001). This Formation is disconformably overlain by the Early Paleozoic deposits of Soltaniyeh (shale and dolomite), Barut (limestone and siltstone), Zagan and Lalun (sandstone and mudstone) formations (Fig. 3). The trilobite-bearing limestones of Mila and brachiopod bearing siltstone and shales of Lashkarak formations characterize the Early to Middle Ordovician deposits in the region, where are bounded by disconformities above and below (Assereto, 1966; Stocklin, 1972; Stampfli, 1978; Hamdi *et al.*, 1989; Alavi, 1996).

The Late Ordovician to Middle Devonian is recorded as a distinct unconformity in the SCA (Annells *et al.*, 1977; Vahdati-Daneshmand, 2001), although the middle Ordovician to Devonian rifting-related igneous rocks are reported in eastern and western parts of the Alborz range (Stampfli, 1978; Berberian & King, 1981; Boulin, 1991; Alavi, 1996). The Late Devonian Jeyrud Formation (phosphatic sandstone, mudstone with lava intercalations) unconformably sits on the Lashkarak Formation and is overlain by a thick succession of Carboniferous carbonates (Mobarak Formation) (Assereto, 1963). The Permian in the SCA is characterized by mixed siliciclastic-carbonates (contain terrigenous clasts) of Dorud, silica-rich limestones (chert-bearing limestone) of Ruteh and carbonates of Nesen formations (Fig. 3). These sediments are related to shallow marine depositional environments on the passive margin of Paleo-Tethys basin (e.g. Alavi, 1996; Allen *et al.*, 2003).

The Triassic age Elika Formation (laminar marly limestone and thick dolostone) overlies the Late Permian Nesen Formation in the SCA unconformably (Glaus, 1964; Seyed-Emami, 2003). This regional unconformity is observed at the base of Mesozoic deposits through the Alborz range. This formation is related to carbonate shelves on the passive continental margin of the Paleo-Tethys basin continuing throughout Paleozoic-Triassic (Zaninetti *et al.*, 1972; Stampfli *et al.*, 1976; Alavi, 1996).

The Elika Formation in the SCA is unconformably overlain by a thick succession of fluvial deltaic to marine deposits known as Shemshak Group is comprised of Shahmirzad, Alasht, Shirindasht, Filzamin and Dansirit formations (Aghanabati, 2004; Fürsich *et al.*, 2009a, 2009b) (Fig. 3). The Norian-Rhaetian age Shahmirzad Formation, and the Sinemurian to lower Bajocian Shirindasht and Fillzamin formations are dominated by marine sediments, whereas the early Liassic strata of Alasht Formation are mostly non-marine (Fürsich *et al.*, 2009a). Such a trend indicates a gradual deepening of the Shemshak basin during Middle Toarcian to Early Alenian (Fürsich *et al.*, 2005). The Bajocian Dansirit Formation with near-shore delta plain

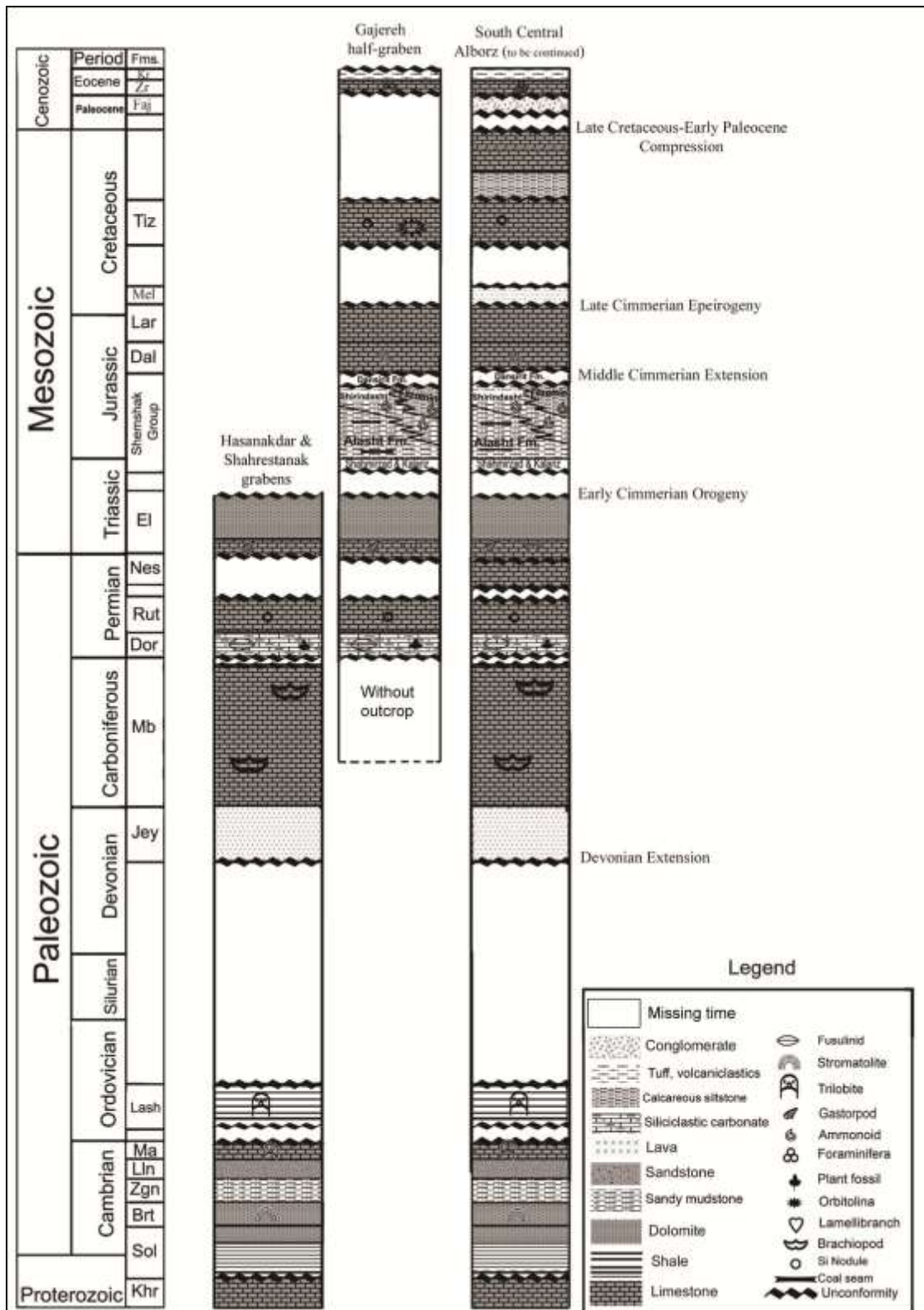


Figure 3: stratigraphic columns of the Shahrestanak and Hasanakdar grabens and Gajereh half-graben, TGLP in the Lar area and Alborz Mountains at south of the TGLP. Mesozoic and Cenozoic tectonic events are simplified. The columns are established based on data from Aghanabati and Rezaie (2009), Ghavidel-Syooki (1995), Vahdati-Daneshmand (1991, 2000 and 2001), Fursich *et al.*, (2009b), Sadeghi and Shemirani (2001a, 2001b) and Shemirani and Sadeghi (2001) and data from field observations of this study. Abbreviations for formations: Khr: Kahar, Sol: Soltaniyeh, Brt: Barut, Zgn: Zagun, Lln: Lalun, Ma: Mila, Lash: Lashkarak, Jey: Jeyroud, Mb: Mobarak, Dor: Dorud, Rut: Ruteh, Nes: Nesan, El: Elika, Dal: Dalichay, Mel: Melaphyre, Tiz: Tizkuh, Faj: Fajan, Zr: Ziarat, Kr: Karaj.

facies, is situated between two local disconformities. The disconformities are related to the local structural deformations (uplift and subsidence) related to the basin floor movements during the Middle Cimmerian (Fürsich *et al.*, 2009a, 2009b). The Middle Cimmerian event initiated a young rift basin (Brunet *et al.*, 2003; Wilmsen *et al.*, 2009), in which deposition of the marls and marly limestones of Dalichai Formation and limestones of Lar Formation took place (Fürsich *et al.*, 2009a) (Fig. 3).

The Jurassic-Cretaceous boundary is unconformable in the SCA, and is related to the Late Cimmerian activities (Aghanabati, 1998) that seems to be responsible for change of deep marine setting of Dalichai and Lar formations to shallow marine environment (Aghanabati, 2004).

The Lower Cretaceous rocks are well exposed in the east (Damavand), where include evaporates and melaphyre that placed upon the Lar Formation, followed by Aptian aged Tizkuh limestone (Emami *et al.*, 1997). Sadeghi & Shemirani (2002) introduced a tectonic movement before Aptian in the Alborz that caused the sea regression and erosion of Baremian and also Neocommian rocks in the most part of the Alborz. The Late Cretaceous rocks in the SCA include more than 800 m limestone, conglomerate, shale and sandstone that disconformably overlie the Tizkuh Formation (Emami *et al.*, 1997).

Cenozoic rocks of the SCA are commenced with a matrix supported polymictic conglomerate known as Fajan Formation (Dellenbach, 1964; Stocklin, 1972). This formation (Paleocene in age) is emplaced over the Cretaceous rocks with a distinct angular unconformity (Emami *et al.*, 1997). The Lower Eocene, nummulite-bearing limestone of Ziarat Formation are locally observed, below the Middle Eocene Karaj Formation (volcaniclastics, sandstone, shale, and interbedded andesitic lava) (Emami, 2000; Khatibimehr & Moalemi, 2009).

Comparison of stratigraphic columns of the Shahrestanak and Hasanakdar grabens with that of the SCA shows similar rock records from Cambrian to Middle Permian (Ghavidel-Syooki, 1995; Vahdati-Daneshmand, 1991, 2001). The upper Permian Nesen Formation however is not deposited in these grabens (Fig 3). Accordingly, the Elika Formation that is the youngest sedimentary unit in the Hasanakdar graben is laid unconformably upon the Ruteh Formation and is topped by Quaternary

deposits. Similarly, in the Shahrestanak graben, the Elika Formation is the youngest deposit crops out, except at its western end, where portion of its southern bounding fault is sealed by the Paleocene Fajan Formation. This association clearly proves a Pre-Paleocene age of the Shahrestanak graben (Zanchi *et al.*, 2006).

Similarities in rock records of the Gajereh half-graben with that of SCA from Permian to Early Cretaceous is understood from the comparison of their stratigraphic columns (Fig. 3), although no exposure of the pre-Permian rocks in the Gajereh half graben, is observed. The Cretaceous deposits in the Gajereh half-graben are limited to the Tizkuh Formation that is locally deposited in the half-graben (Sadeghi & Shemirani, 2001b). An angular unconformity between Ziarat Formation and Mesozoic rocks separates the Eocene deposits (Ziarat or Karaj formations) from the Mesozoic rocks in the Gajereh half-graben. This missing time in the SCA seems too smaller, where a thick succession of Late Cretaceous clastic and carbonate rocks are observed (Emami *et al.*, 1997) (Fig. 3).

Structures

The TGLP has comprises of the Upper Precambrian to Paleogene rocks and bounded by north-dipping Mosha to the south and by south-dipping Taleqan Faults to the north (Fig. 2). The western termination of the TGLP is marked by the intersection of these faults (Fig. 1), while to the east, it extends to southwest of the Mount Damavand (Fig. 1). The paleogaben bounding faults, the Hasanakdar Fault as well as the pre-Tertiary mesoscopic folds and faults are the main structures of the TGLP that are presented in details in this section.

Mosha Fault

The north dipping Mosha Fault along which the Precambrian to Cenozoic rocks emplaced over the Eocene Karaj Formation was mapped by Dellenbach *et al.*, (1964) for the first time. The fault that is bounding the southern margin of the TGLP, extends for more than 200 Km length in Central Alborz. (Fig 1). The fault is an active fault with several recorded devastating historical earthquakes along its segments (e.g. Berberian & Yeats, 1999). The geometry of the basement-involved Mosha Fault varies along strike more likely due to its kinematic variations since

Paleozoic (Ehteshami-Moinabadi & Yassaghi, 2007; Yassaghi & Madanipour, 2008).

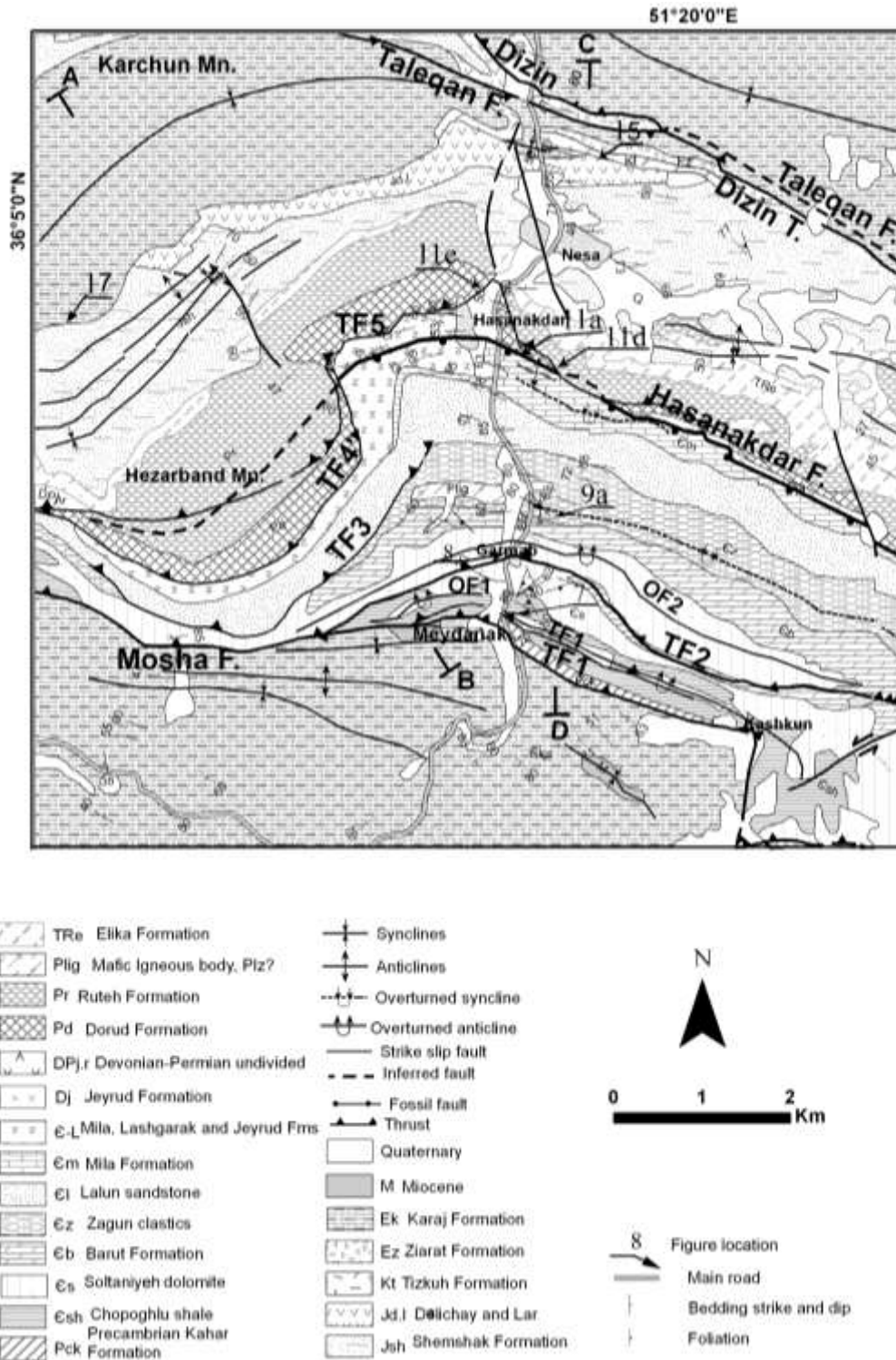


Figure 4: Geological map of the Karaj Valley, based on Vahdati-Daneshmand (2001a). For the location of the area within the TGLP see Figure 2.

The Moshā Fault kinematics during Paleozoic and Mesozoic was not previously studied in details. However, two extensional events have been suggested to occur in the Early Devonian-

Carboniferous (Berberian & King, 1981) and Middle Jurassic equivalent to the Middle Cimmerian event (Wilmsen *et al.*, 2006; Fursich *et al.*, 2009a) in the Central Alborz. The early

Devonian-Carboniferous extension is characterized by basaltic volcanism within the Jeyrud Formation (Berberian & King, 1981; Alavi, 1996) exposed in the hanging wall of the Moshfa Fault (Fig. 4). This may suggest a normal kinematics for the Moshfa Fault during Devonian-Carboniferous. However, because of the dominant influence of Cenozoic compressional events in the Central Alborz, such

earlier structural data is obscured. Therefore, no structural evidence of the fault activity during Paleozoic has been mapped in the study area. Nevertheless, in the Taleqan Mountains (Fig. 2), several north-verging overturned to recumbent tight folds cored Precambrian to Paleozoic rocks is mapped (Fig 5).

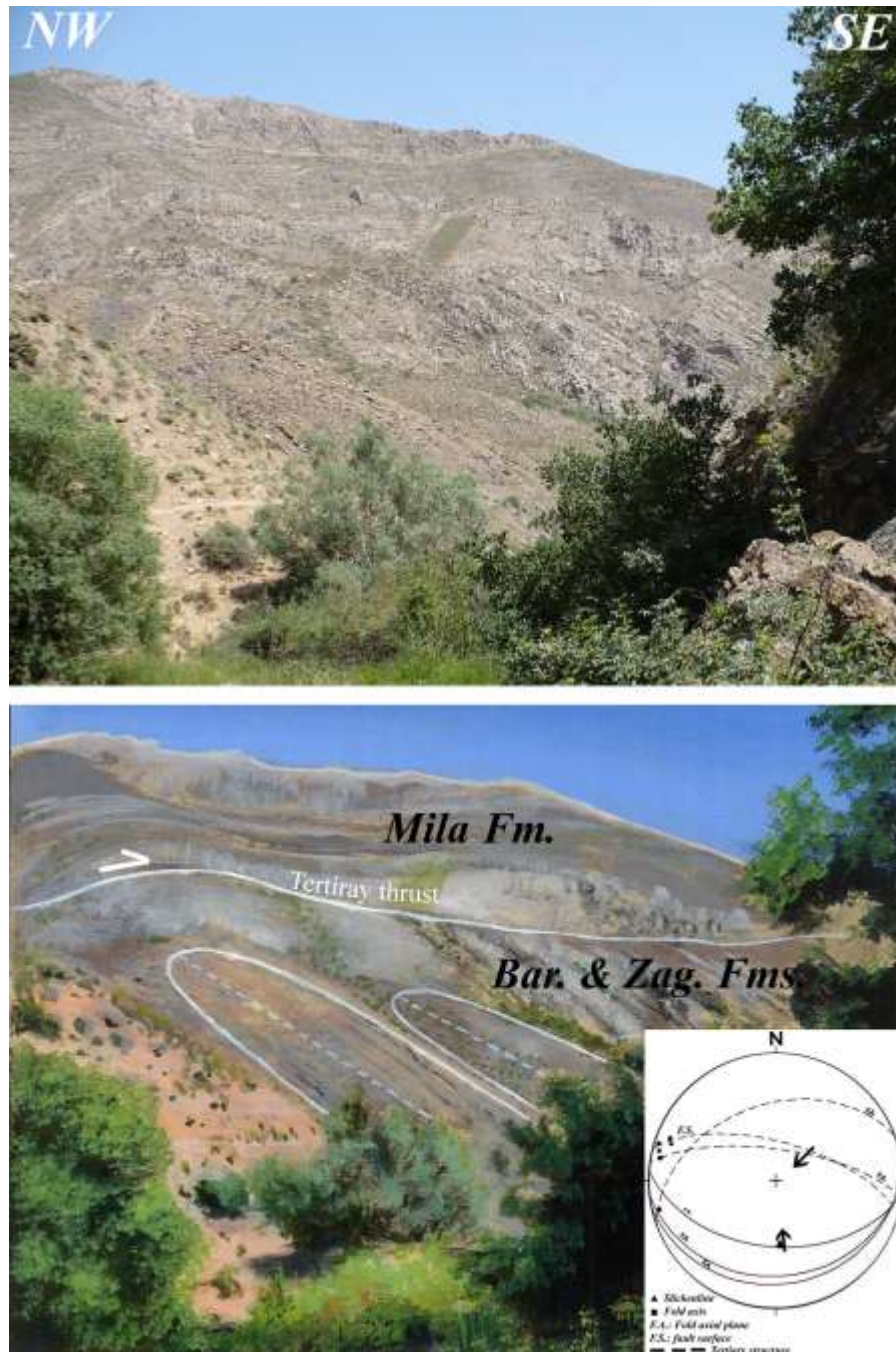


Figure 5: Overturned to recumbent folds with their sketch in the Valian valley, Taleqan Mountains. Bar. and Zag. refer to Barut and Zagun Formations respectively. As shown in the stereogram these north verging folds have different attitude with respect to the post-Eocene south-verging thrust-related folds plotted by dashed lines. Locations of the photographs are shown in Fig. 2.

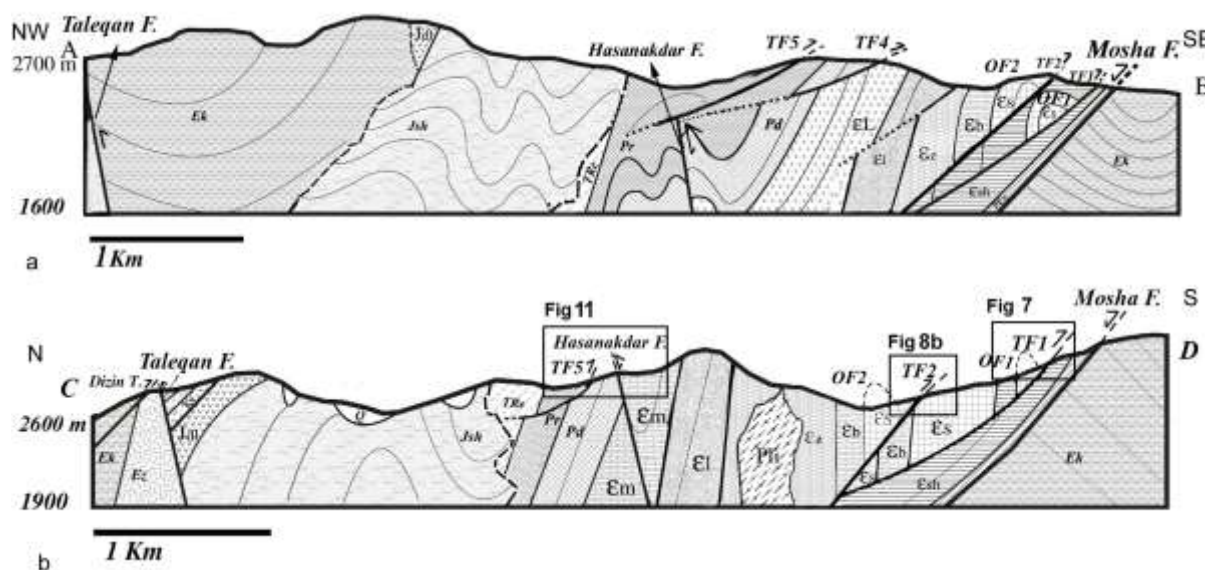


Figure 6: Interpretative geological cross sections across the study area. For location of the sections and their legend see Fig. 4. The dashed lines between rock units are the major angular unconformities. Abbreviations are similar to the legend of Fig 4. They refer to PCk: Kahar, Csh: Chopoqlu shale member of Soltaniyeh, Cs: Soltaniyeh, Eb: Barut, Cz: Zagun, El: Lalun, Cm: Mila, Pd: Dorud, Pr: Ruteh, TRe: Elika, Jsh: Shemshak, Jdl: Dalichay and Lar, Kt: Tizkuh, Ez: Ziarat, Ek: Karaj, Q: Quaternary.

These folds that are laid beneath the south verging Cenozoic thrust (TF2 of Yassaghi & Madanipour, 2008) developed on the hanging wall of the Moshha Fault (Fig. 5). As shown in the stereogram of Fig 5, the attitudes and vergence direction of these folds are different from that of the Tertiary thrust related folds.

Similarly, along the Karaj Valley (Fig. 4), tight to isoclinal slightly overturned folds (OF1 and OF2) cored the Precambrian Soltaniyeh Formation were mapped in which the folds are cut by the TF1 and TF2 Tertiary thrusts (Fig. 6). The OF1 is a NW-plunging, SW-dipping fold that is cut and displaced by the TF1 (solid line) (Fig 7a). The bedding has different attitude with respect to the TF1 attitude in both the fault hanging wall and footwall (Fig. 7b). This verifies that the bedding was folded before cut by the TF1. The OF2 fold cored the Soltaniyeh and Barut formations and cut by the TF2 Tertiary thrust (Figs 4, 6 and 8a), was also mapped in the Moshha fault hanging wall along the Karaj Valley. The S-C structure mapped in the TF2 fault zone near the Garmab village along the valley shows the SSE movement direction for the TF2 (Fig. 8b). The synoptic stereogram that is drawn for both the TF2 and the OF2 fabrics and structures shows variation in their proposed movement direction (Fig. 8c). This means that the OF1 and OF2 folds developed in Paleozoic rocks on the hanging wall of the

Moshha Fault have formed during Mesozoic but were cut later by the TF1 and TF2 Tertiary thrusts. In addition, foliated Cambrian layers are also mapped on the hanging wall of the Moshha Fault along the Karaj Valley. These NW-trending foliations have dip angle generally less than that of bedding (Fig. 9) and hence constrains the overturned geometry of the folded Paleozoic rocks. The synoptic stereogram drawn for the fabrics and structures on the hanging wall of the Moshha Fault in the Hasanakdar graben shows that the movement direction proposed based on the attitude of foliations as well as the axial plane attitude of the OF1 and OF2 folds are roughly similar but different with that of the Tertiary thrusts (Fig. 10). This relationship constrains that the NW-trending foliations together with the OF1 and OF2 axial planes in the Paleozoic rocks have formed by a Pre-Tertiary deformational event.

Hasanakdar Fault

The Hasanakdar Fault mapped by Assereto (1966) is a high-angle south dipping fault that constitutes the northern boundary of the Hasanakdar graben within the TGLP (Figs. 2 and 4). This fault which is well-exposed along the Karaj Valley (Fig 4) is obscured under the Tertiary TF5 thrust in the northern flank of the Hezarband Mountain to the west of the valley (Fig. 4). Along the Karaj Valley,

the Cambrian Mila and Devonian Jeyrud formations are located over the Permian Dorud formations (Figs 6a and 11a). The deformed Dorud Formation in the fault footwall (Fig. 11a) includes small to mesoscopic folds (Fig. 11b), and minor south-dipping faults (Fig. 11c). These structures were used to document the north-northwestward

reverse kinematics of the Hasanakdar Fault (the stereogram in Fig. 11a). Similarly, thrusting of the Triassic Elika Formation over the folded Permian Ruteh Formation observed on the footwall block of the Hasanakdar Fault in the southwest of Nesa Village also provide support for the pre-Tertiary stage of folding (Figs 4, 11f).

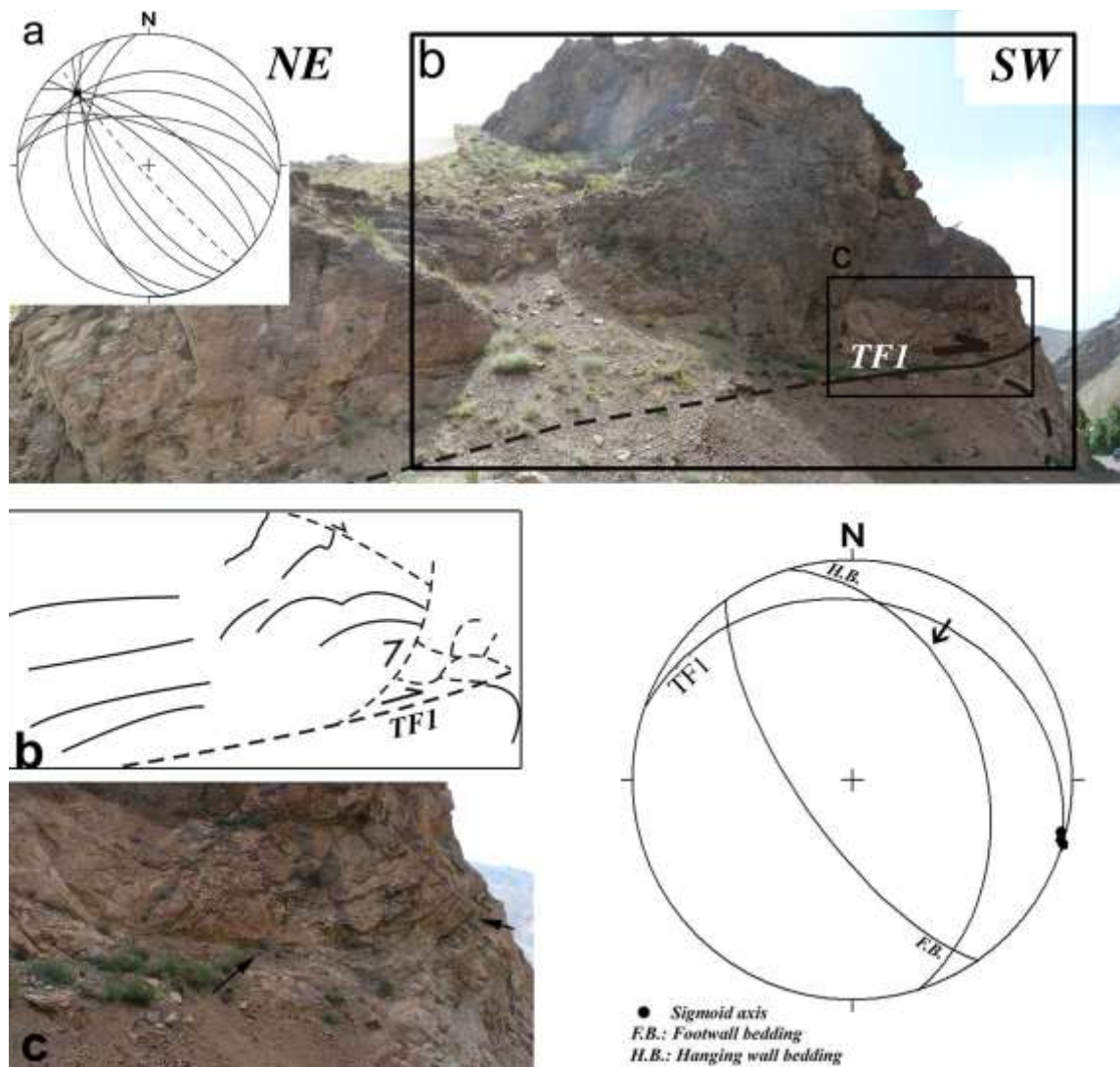


Figure 7: (a) The eroded hinge zone of the OF1 fold, composed of the Infracambrian Soltaniyeh Formation in the hanging wall of the Moshafault that is cut by the TF1 Tertiary Fault, Meydanak area, Karaj Valley. The attitude of fold axial plane (the dashed great circle) and axis (black point) are presented in the stereogram. (b) The sketch of the area in (a), dashed lines are fault surfaces and solid lines are bedding. (c) The TF1 fault zone. (d) Stereogram showing the TF1 fault movement direction to SW, note to differences on the bedding attitude in both hanging wall block (H.B) and footwall block (F.B) in relation to the fault attitude. For the location of photographs see Figs 4 and 6.

Nevertheless, the TF5 Tertiary Fault that puts the younger Permian Ruteh Formation over the older Dorud Formation is a southwestward verging thrust based on the hanging wall drag folds in both the Hezarband Mountain and Karaj Valley (Figs. 11a, d, e).

Taleqan Fault

The E-trending Taleqan Fault is a south dipping high-angle fault, bounding the northern margin of the TGLP (Figs 2, 4). This fault is divided into two eastern and western portions by an N-trending

hidden basement fault along the Karaj Valley (Yousefi, 1994; Yassaghi & Naeimi, 2011).

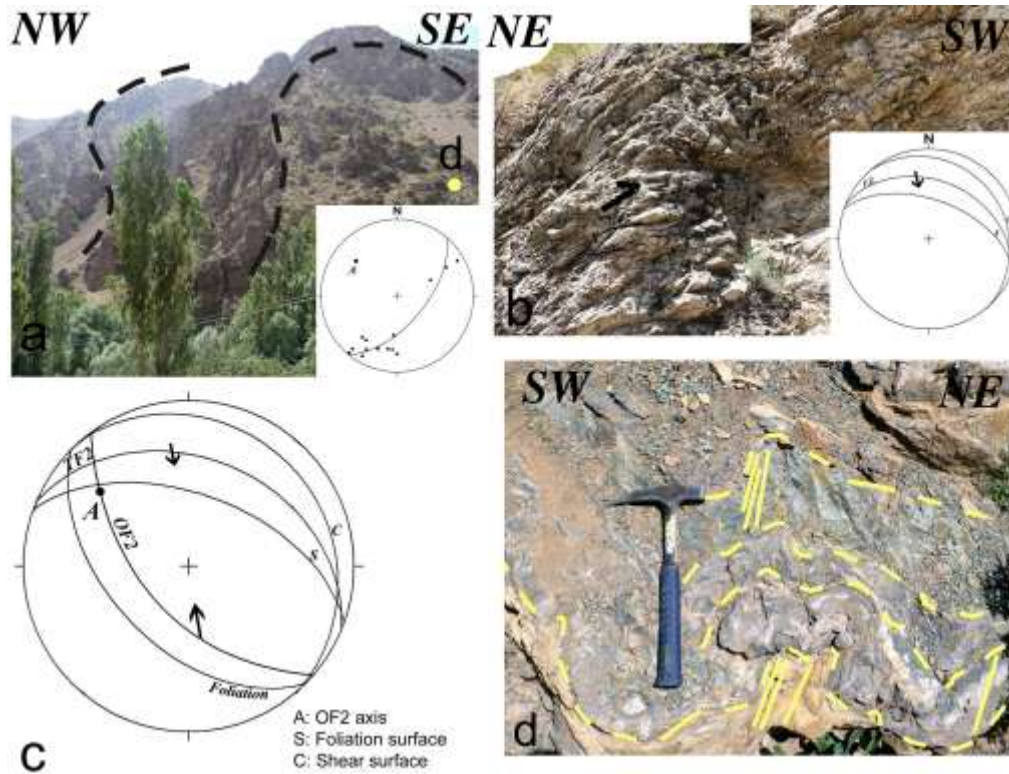


Figure 8: (a) Folded Barut Formation (OF2) in the hanging wall of the Moshafault. Letter A in the stereogram shows the location of fold axis. (b) The S-C structure developed in the TF2 fault zone that cuts the southern limb of the OF2. The stereogram shows the movement direction of the fault toward SSE. (c) Synoptic stereogram on the attitudes of the OF2 and TF2 and their associated structures. Note to difference of the proposed movement directions for the TF2 and OF2. (d) Folding of the Barut Formation and development of axial plane foliation (solid lines) in the OF2. Location of the photo is shown by yellow point on a. For location of photos see Figs 4 and 6.

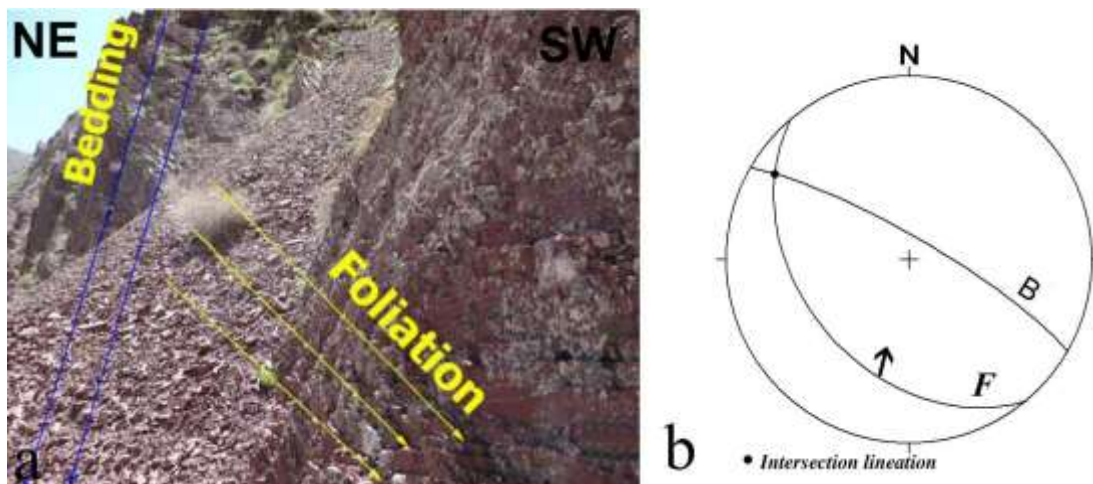


Figure 9: (a) Well-developed and dominant attitude of foliation in the Cambrian Zagun Formation on the hanging wall of the Moshafault in the Sorkhdar valley. (b) The stereogram shows the lesser dip angle of foliation (F) with respect to bedding (B) that implies the overturned layers. Note to the proposed movement direction of the fault based on the location of bedding-foliation intersection lineation. The location of photograph in the study area is shown on Fig 4.

To the east of the Karaj Valley, the Taleqan Fault is partly obscured by recent deposits or covered by a north dipping Tertiary thrust named herein after as

the Dizin Thrust (Fig. 12). Here, the observed minor folds (Fig. 13a) and faults (Fig. 13b) in the Taleqan fault zone within the Shemshak Group

(Figs 13a and b) were used to propose the fault movement direction toward NNE (Fig. 13c).

In the Gajereh area (Fig. 12), along the Taleqan Fault, the Permian Ruteh Formation thrusts over the Jurassic Shemshak Group, to the north and south, to form a pop-up structure (Figs 14a and b). Though the fault zone is eroded or covered by recent deposits, but the footwall structures can be used to determine the movement direction of both the Taleqan Fault and its hanging wall back thrust (Fig. 14c, d and e). The presented evidence indicates that the Permian Ruteh Formation and the Jurassic Shemshak Group are deformed along the Taleqan Fault in the eastern part of the Karaj Valley (Fig. 14d). The presence of an angular unconformity between the folded Permian as well as Jurassic rocks the Tertiary rocks in the Dizin area (Fig. 14f) supports this indication and provides further hint for the Mesozoic deformation of the Taleqan Fault.

Furthermore, evidence of Mesozoic deformation in the Gajereh-half-graben was also mapped along the Karaj Valley (Fig. 4), where a Tertiary thrust puts the Cretaceous Tizkuh Formation over the folded Jurassic rocks (Fig. 15).

Similarly, the Maastrichtian limestone at the Alarm Valley in the Lar area (Fig. 2) is unconformably overlaid by the Eocene Ziarat Formation (Fig. 16). Evidence of this angular unconformity was previously reported by Emami *et al.*, (1997) from Damavand region to the east of the Lar.

Unlike the eastern portion, the western portion of the Taleqan Fault in the Taleqan Mountains is not exposed and a known distinct surficial trace of the Tertiary Taleqan Fault equal to the Dizin Thrust, along which the Mesozoic rocks thrust over the Eocene Karaj Formation (Annells *et al.*, 1977; Guest *et al.*, 2006b; Yassaghi & Madanipour, 2008) (Fig. 6), is present. However, evidence on the presence of an angular unconformity between the Eocene Karaj Formation and Jurassic Shemshak Group mapped in the west of the Karaj Valley, in the Karchun Mountain (Fig. 4), where the folded Shemshak Group have different attitude with respect to that of the Eocene Karaj Formation (Fig. 17) indicate Mesozoic deformation of the Taleqan fault hanging wall rocks.

Discussion

The effect of Early Cimmerian Orogeny on the TGLP

Structural evidence for the influence of the Early Cimmerian Orogeny has been reported mainly from the Eastern Alborz, in the Neka Valley and Binaloud Mountains (Alavi, 1991, 1992; Zanchi *et al.*, 2009). A narrow long belt of metamorphosed chert, ultramafic and mafic rocks in the Binaloud Mountains (Alavi, 1991) as well as the low metamorphosed early Paleozoic rocks of the Gorgan schists are also proposed to represent the Paleo-Tethys margin and encompass the orogenic structures of the Early Cimmerian event (Zanchi *et al.*, 2009).

The change in deposition of shallow marine carbonates of the Elika Formation to siliciclastic rock units of the Early-to-Middle Jurassic Shahmirzad and Alasht formations (lower Shemshak Group) (Fürsich *et al.*, 2009b) in the Alborz in general (Seyed-Emami, 2003) is proposed to occur in an event equal to the Early Cimmerian collisional orogeny. However, in the study area, the Paleozoic to early Triassic rocks in the Shahrestanak and Hasanakdar grabens are folded and evolved to present form during this event. Therefore, the early Triassic Elika Formation is the youngest deposition in the grabens (Fig. 3) developed on the hangingwall of the initial Mosha and Hasanakdar normal faults (Fig. 18a)

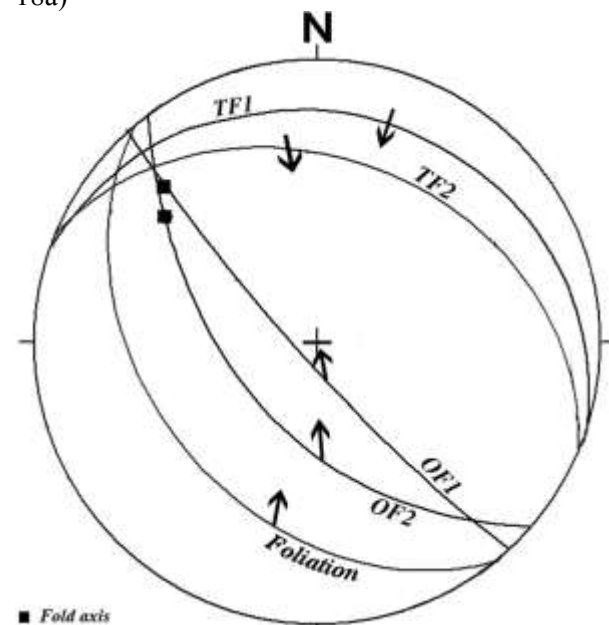


Figure 10: synoptic stereogram of the OF1, OF2, TF1, TF2 and foliation attitudes mapped in the hanging wall of the Mosha Fault (Hasanakdar graben). Note to difference of the proposed movement directions for the OF1 and OF2 kinematics in relation to the TF1 and TF2.

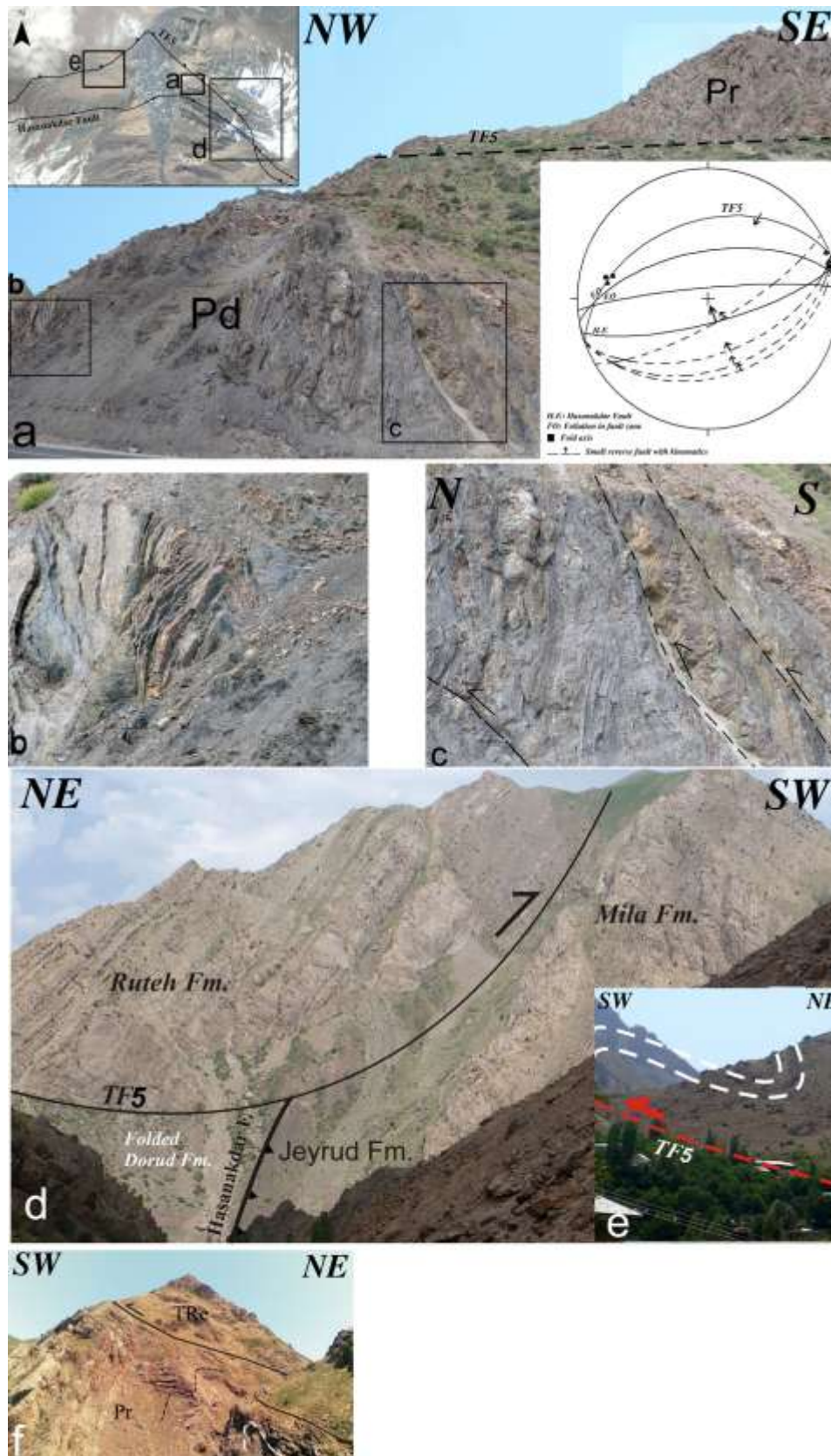


Figure 11: (a) The TF5 Tertiary Fault puts the younger Permian Ruteh Formation over the older and deformed Dorud Formation in the Hasanakdar footwall, Karaj Valley. The stereogram shows the proposed movement directions of the TF5 and that of the Hasanakdar Fault based on the minor faults and folds developed in the deformed Dorud Permian rocks. Insets show the location of b, c and d. (b)

and (c) minor folds and reverse faults in the Hasanakdar fault zone. (d) Regional view of relation between the Hasanakdar Fault and the TF5 Fault in the Karaj Valley. The Hasanakdar Fault places the Devonian Jeyrud Formation over the Permian Dorud Formation. Note that the Tertiary TF5 Fault crosses the Hasanakdar Fault and puts the younger Permian Ruteh Formation over the Older Mila, Jeyrud and Dorud formations. (e) Drag folding in the TF5 fault zone used to document its SW-verging thrust. (f) Thrusting of Triassic Elika Formation over the folded Permian Ruteh Formation. For location of all photographs refer to Fig. 4.

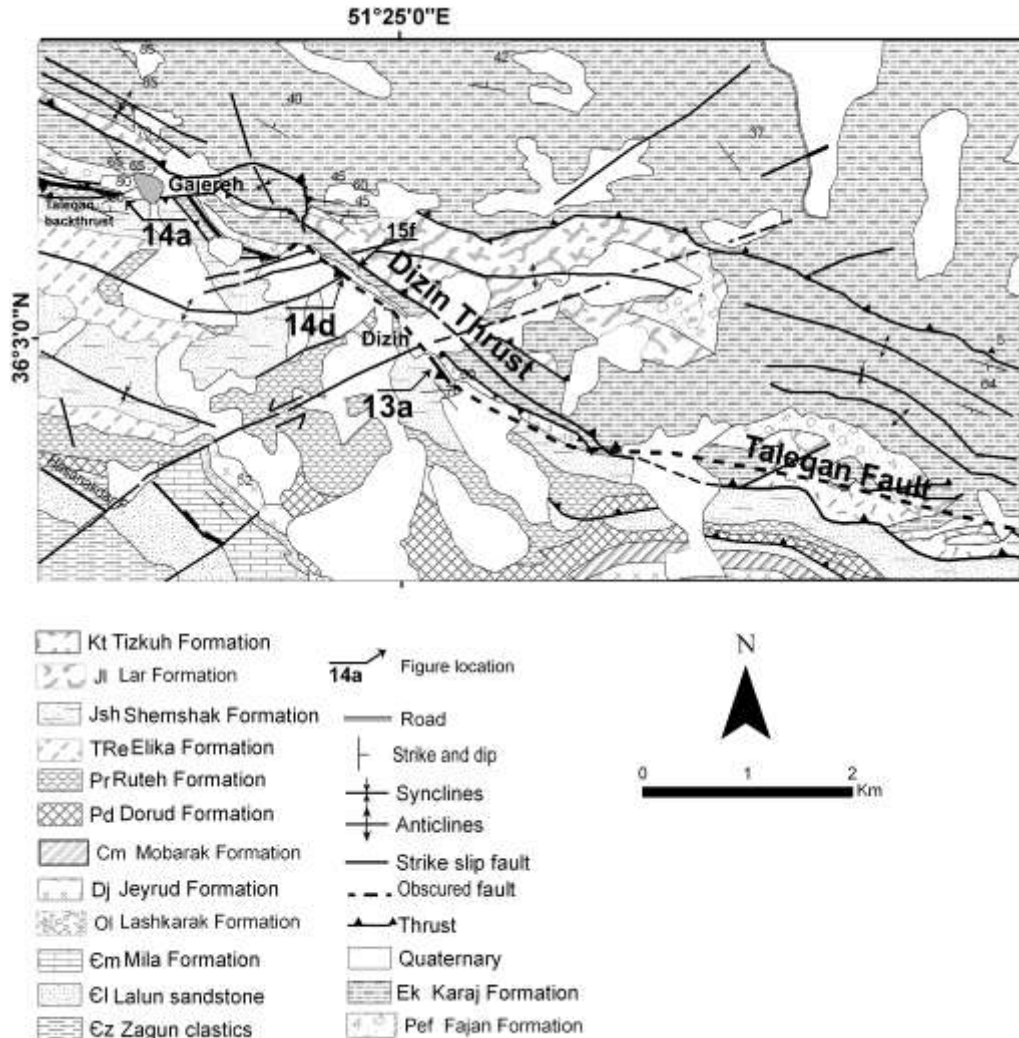


Figure 12: Geological map of the eastern portion of Gajereh half-graben. For the map location in the study area refer to Fig. 2.

The Lalun Fault that composes the northern boundary of the Shahrestanak graben (Fig. 2) separates the Triassic carbonates of the Elika Formation in the fault hanging wall from the Cambrian to Upper Paleozoic sequences in the fault footwall. The fault though has normal stratigraphic throw, but indicate evidence of reverse movement due to fault inversion before Paleocene (Zanchi *et al.*, 2006). In the eastern part of the fault where the Elika Formation is located over the Shemshak Formation, the fault reactivation to reverse movement is significant (Fig 2). The southern

boundary of the graben, in which the Permo-Triassic Ruteh and Elika formations is separated from Precambrian to Lower Palaeozoic successions, is marked by a high angle normal fault that is partially inverted but sealed by Palaeocene Fajan Formation (Zanchi *et al.*, 2006). This evidence is taken into account for Mesozoic inversion of the graben. It should be noted that the Shahrestanak graben also lack the Jurassic and Cretaceous deposits (Zanchi *et al.*, 2006), that means its evolvement to present form might predates the Jurassic Period.

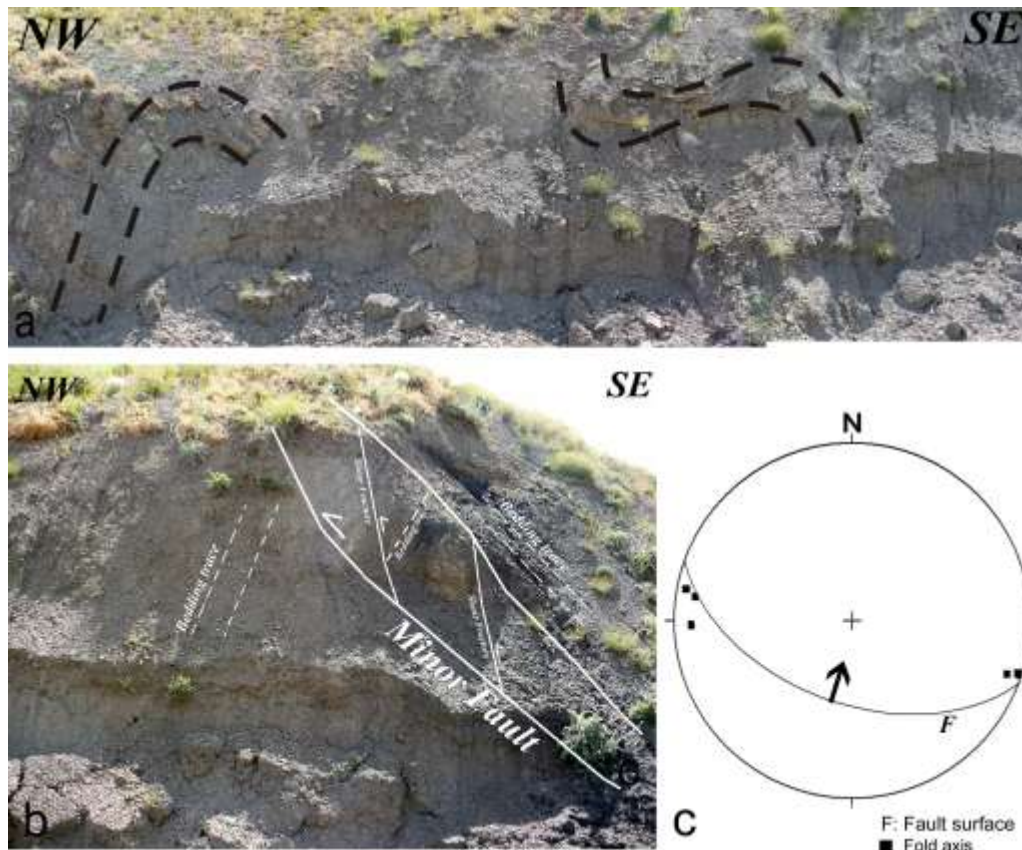


Figure 13: The Taleqan fault zones in the Dizin area. (a) Minor folds within the Jurassic Shemshak Group in the fault footwall. (b) Minor faults in the Jurassic Shemshak Group. Note to the changes of bedding attitude in the other sides of the fault. (c) Stereogram on the attitude of minor folds and faults in the Taleqan fault zone from which the fault movement direction is proposed. For location of photographs see Fig 12.

In the Hasanakdar graben, the presence of north-verging tight to isoclinal overturned folds cored with Paleozoic rocks and cut by Tertiary thrusts (Figs. 5, 7, 8) as well as the NW-trending foliations (Figs 8d, 9, 10) are considered as the structural evidence for the effect of the Early Cimmerian orogeny (Fig. 18b). These evidence provide document to propose that the graben bounding faults, i.e. the Mosha and Hasanakdar faults, were initially basin bounding faults (Fig. 18a) but inverted during the Early Cimmerian event (Fig. 18b).

The effect of the Middle Cimmerian event on the TGLP

Based on stratigraphic evidence, the Middle Cimmerian extensional event during Bajocian stage has acted in Central Alborz (Fürsich *et al.*, 2005, 2006, 2009a, 2009b; Wilmsen *et al.*, 2006, 2009). The upper Shemshak Group that is considered as syn-rift deposits (Brunet *et al.*, 2003; Fürsich *et al.*, 2005; Fürsich *et al.*, 2006; Wilmsen *et al.*, 2009) is

deposited in Mid-Mesozoic in the Gajereh half-graben (Fig. 3). Therefore, the half-graben is proposed to develop during the Middle Cimmerian extension event by initiation of a basin bounding normal fault, i.e. the Taleqan Fault (Fig. 18c). Moores and Fairbridge (1998) have proposed that the thickness of Jurassic Shemshak Group increases to about 3000 m in Central Alborz. By applying this proposition in the Gajereh half-graben, deposition of the Middle Jurassic-Cretaceous sediments are greater in comparison with other portions of south Central Alborz (Fig 3). Thus, the Gajereh half-graben can be considered as a depocenter of the TGLP, at least during Middle Cimmerian.

The rest of the TGLP, i.e. the Shahrestanak and Hasanakdar grabens, however were not active during this event (Fig. 18c). Evidence for the Middle Cimmerian extensional event during Bajocian is also reported by Saintot *et al.*, (2006) in the Caucasus Mountains that show to the north of Alborz range.

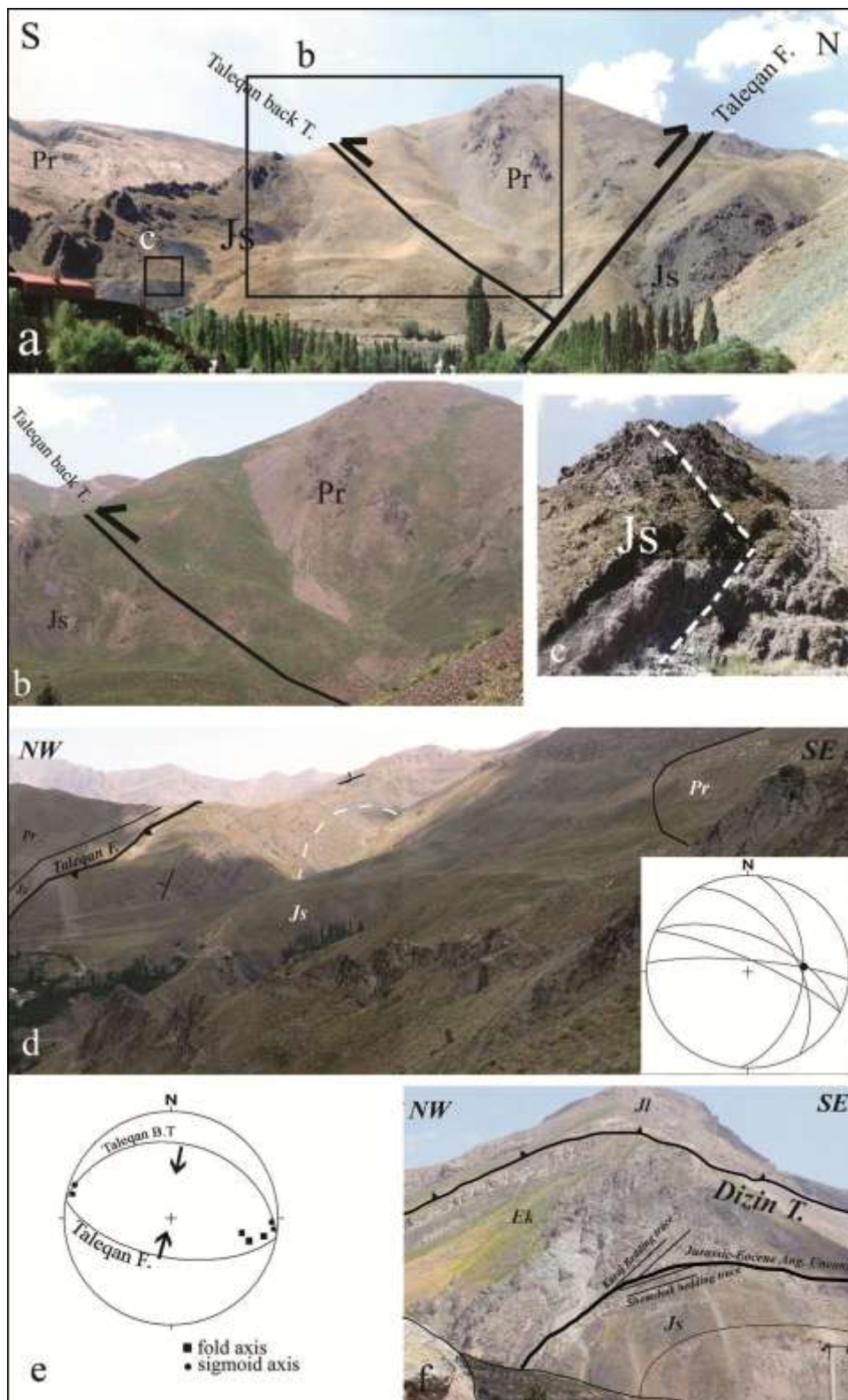


Figure 14: (a) A pop-up structure along the Taleqan Fault and its back thrusts in the Gajereh area that exposes the Permian rocks, Pr: Permian Ruteh Formation, Js: Jurassic Shemshak Group. (b) A close up of the Taleqan back thrust (c) overturned synform in the Jurassic (Shemshak) rocks in the footwall of Taleqan back thrust. (d) Folded Jurassic Shemshak Group (Js) and Permian Ruteh Formation (Pr) on the hanging wall of the Taleqan Fault. (e) Stereogram showing the kinematics of the Taleqan Fault and its back thrust in the Gajereh area. (f) Photograph shows the relation between the Taleqan Fault and the Tertiary Dizin Thrust. Note that folded Jurassic Shemshak Group is unconformably overlaid by the Eocene Karaj Formation. Jl: Lar Formation, Js: Shemshak Group, Ek: Karaj Formation. For location of photographs refer to Fig. 12.

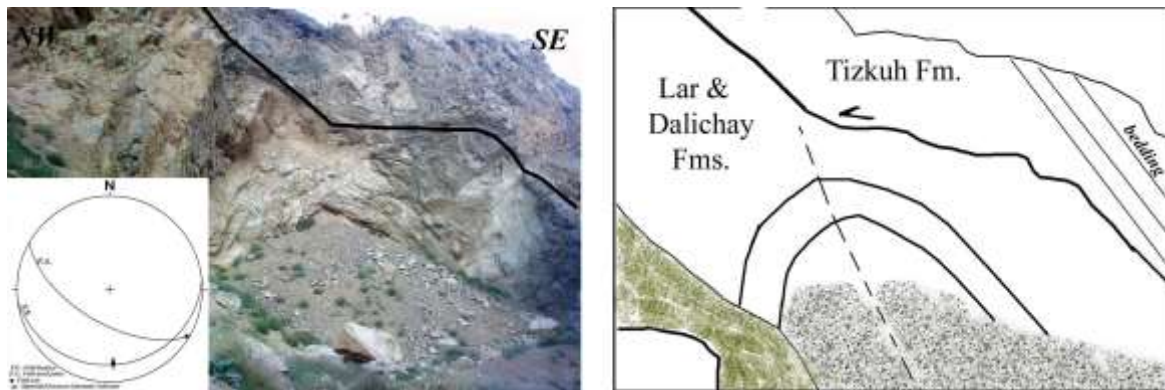


Figure 15: Thrusting of the Cretaceous Tizkuh limestones over the folded Jurassic rocks (undivided Lar and Dalichai) in the Karaj Valley. For the location of photograph, see to Fig. 4.

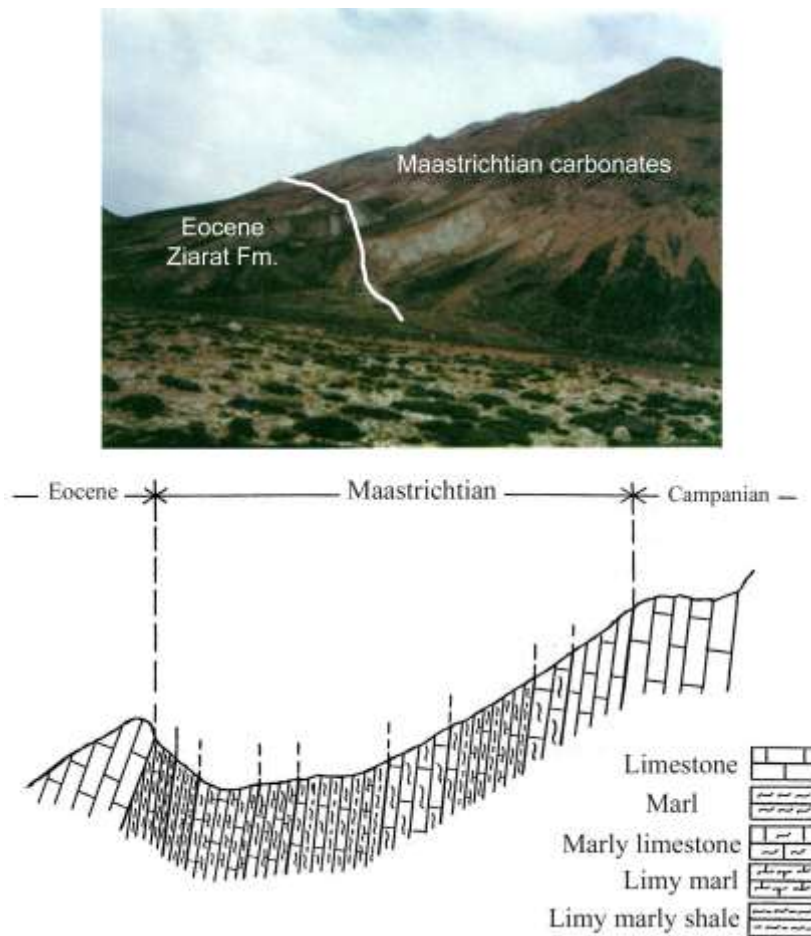


Figure 16: Angular unconformity between the Maastrichtian limestones and Eocene nummulitic limestone of Ziarat Formation in the Lar area, TGLP. As shown in cross section, the Eocene layers dip 60 degrees, while the Cretaceous rocks dipping 80 degrees. Section redrawn from Shemirani and Sadeghi (2001). photograph courtesy of Sadeghi (2010). For the location of the photograph see Fig 2.

Effects of the Late Cretaceous-Early Paleocene orogenic event on the TGLP

The Middle Jurassic-Cretaceous marine basin in the Alborz Range that have been developed during Middle Cimmerian event is thought to be inverted

in the Late Cretaceous-Early Paleocene, probably with exceptions of the South Caspian and Black Sea basins (e.g. Berberian, 1983; Brunet *et al.*, 2003; Golonka, 2004).

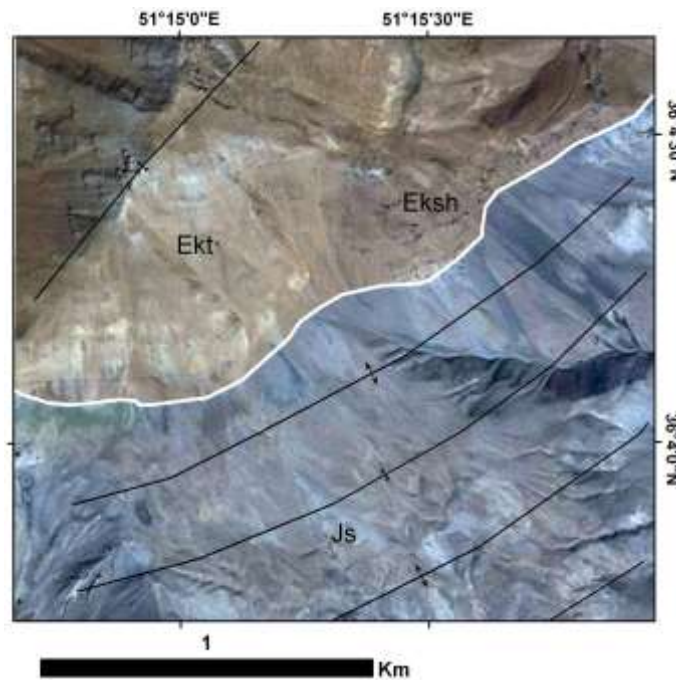


Figure 17: Angular unconformity between the Jurassic Shemshak Group and the Eocene Karaj Formation (white line trace) in the Karchun Mountain. For location of the image see to Fig. 4.

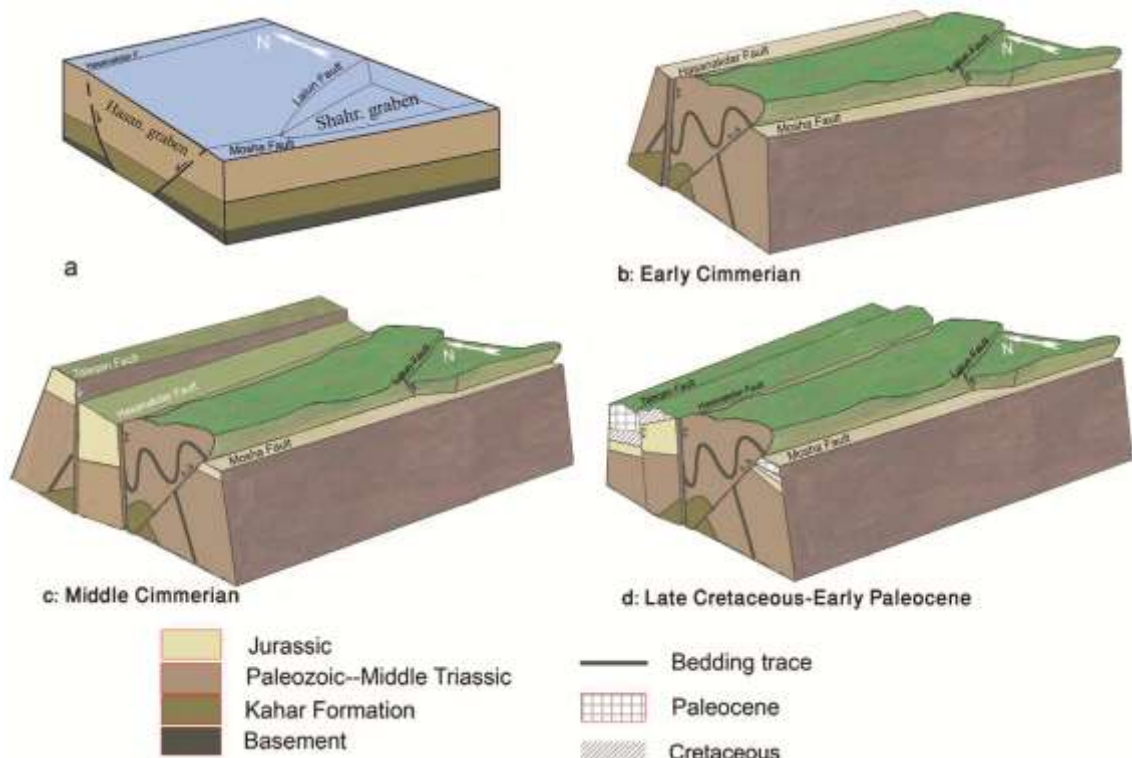


Figure 18: Schematic 3-D models showing development of the TGLP along the Karaj Valley. (a) The TGLP was a part of a passive continental margin that is bounded by normal basement faults extend from the Late Paleozoic to Middle Triassic. (b) Evolution of the Hasanakdar graben through inversion of its bounding faults, i.e. the Moshā and Hasanakdar faults during Early Cimmerian Orogeny. (c) Initiation of the Gajereh half-graben by initiation of the Taleqan normal fault during the Middle Cimmerian extensional event. (d) Evolution of the Gajereh half-graben and inversion of its bounding faults during the Late Cretaceous-Early Paleocene compressional event.

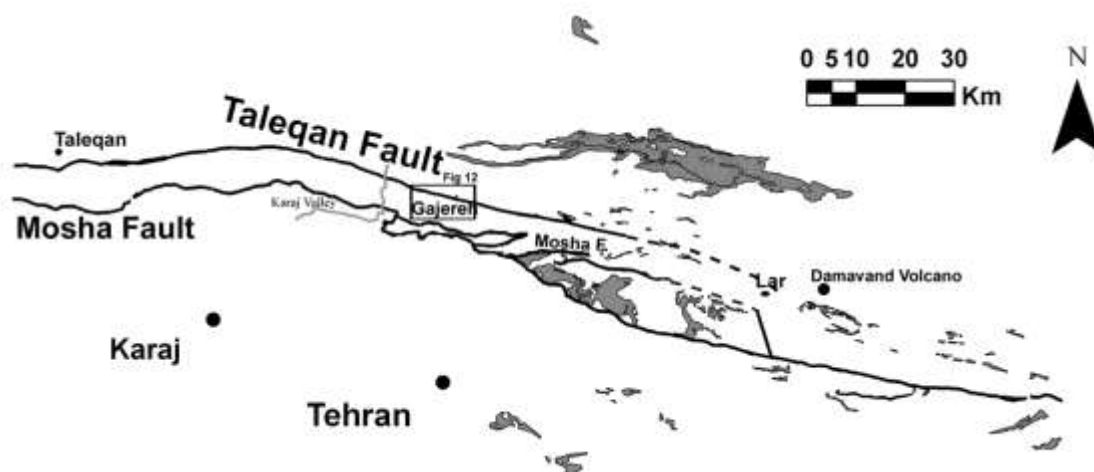


Figure 19: Distribution of Paleocene Fajan Formation (dark grey areas) at north and south parts of the TGLP based on Vahdati-Daneshmand (1999, 2000, 2001) and Annells *et al.*, (1977). For eastern portion of TGLP, the northern branch of the Masha Fault is considered as the southern boundary of TGLP.

Similarly, the thermal history of the Nusha poluton in the western part of the TGLP (Fig. 1) demonstrated an exhumation and cooling pulse with folding from the Late Cretaceous to Early Paleocene (Guest *et al.*, 2006a). The pop-up structure along which the Permian rocks thrust over the Jurassic rocks on both sides of the Taleqan Fault (Figs 14a and d) is considered to show the influence of this exhumation and folding in the Gajereh-half-graben. In addition, the angular unconformity between the Eocene Karaj Formation overlaid the Jurassic Shemshak Group (Figs 14f, and 17) is also justifies the Late Cretaceous to Early Paleocene folding (Fig. 15). Similarly, considerable deposition of Fajan Formation in the footwalls of the TGLP bounding faults, i.e., the Masha and Taleqan faults (Fig. 19) indicates that the paleograben was a highland at Early Paleocene, during which the Paleocene Fajan conglomerate (Fig 3) has deposited. In fact the TGLP was the major source for detrital materials of the alluvial fans composes of the Fajan Formation.

Furthermore, the angular unconformity between the Jurassic or Late Cretaceous rocks and the Eocene rocks in the Karchun and Lar areas (Figs 14f, 16 and 17) are also considered as evidence for the Late Cretaceous-Early Paleocene event in the TGLP.

Conclusions

The TGLP composes of the Shahrestanak and Hasanakdar grabens as well as Gajereh half-graben is an example of an inverted basin that has undergone, at least, two inversion events and basin development during Mesozoic. The first event

occurred in the Early Cimmerian causes inversion of Hasanakdar graben and resulted in the development of north-verging overturned folds and south-dipping axial cleavages. The Middle Cimmerian associated with extensional regime resulted in formation of the basin bounding Taleqan Fault and initiation of newly formed Gajereh half-graben within which Jurassic sediments were deposited. The rate of deposition was not consistent along the TGLP and considerable thickness of Jurassic sediments has been deposited in the Gajereh half-graben, which is proposed to act as the depocenter for the TGLP basin in this period. This evolution history for the TGLP during the Middle Cimmerian in the Alborz range accords with similar cases of the Caucasus region.

By the Late Cretaceous-Early Paleocene time, the second basin inversion event caused inversion of the Gajereh half-graben bounding Taleqan Fault and emergent of the TGLP to higher structural level. Formation of an angular unconformity between Eocene and Mesozoic rocks in the region and deposition of a thick succession of Paleocene Fajan conglomerate outside the TGLP constrain the event.

This study shows that integration of structural and stratigraphic data provides accounts for basin inversion of regions with no subsurface data. The presented model and interpretation on inversion of the TGLP is a key finding applicable to similar structural domains in the Alborz range. It also provides constrains for the neighboring region such as the Caucasus range, though the inversion of such basin occurred in Early Tertiary that is later time

than that of the TGLP.

References

- Aghanabati, A., Rezaie, A., 2009. Stratigraphic chart of Iran. Geological Survey of Iran.
- Aghanabati, A., 2004. Geology of Iran. Geological Survey of Iran. 583p.
- Aghanabati, A., 1998. Jurassic stratigraphy of Iran. Geological Survey of Iran Report No. 65. Geological Survey of Iran, Tehran. 746 p.
- Alavi, M., 1996. Tectonostratigraphic synthesis and structural style of the Alborz mountain system in northern Iran. *Journal of Geodynamics*. 21: 1–33.
- Alavi, M., 1992. Thrust tectonics of the Binalood region, NE Iran. *Tectonics*. 11 (2): 360–370.
- Alavi, M., 1991. Sedimentary and structural characteristics of the Paleo-Tethys remnants in Northeastern Iran. *Geological Society of America Bulletin*. 103: 983–992.
- Allen, M.B., Ghassemi, M.R., Shahrabi, M., Qorashi, M., 2003. Accommodation of Late Cenozoic oblique shortening in the Alborz Range, Northern Iran. *Journal of Structural Geology*. 25 (5): 659–672.
- Annells, R.S., Arthurton, R.S., Bazley, R.A.B., Davies, R.G., Hamed, M.A.R., Rahimzadeh, F., 1985. Geological quadrangle map of Qazvin-Rasht (1:250000) Geological Survey of Iran.
- Annells, R.S., Arthurton, R.S., Bazley, R.A.B., Davies, R.G., Hamed, M.A.R., Rahimzadeh, F., 1977. Geological map of Iran, Shakran sheet 6162: Tehran, Geological Survey of Iran, scale 1:100,000.
- Assereto, R., 1966. Geological Map of upper Djadjerud and Lar Valleys (Central Elburz, Iran) with explanatory notes. Institute of Geology. University of Milan, 86pp.
- Assereto, R., 1963. The Paleozoic Formation in Central Elborz (Iran), (Preliminary Note), *Riv. Paleontology and Stratigraphy*. 69: 503- 545.
- Berberian, M., 1983. The southern Caspian: a compressional depression floored by a trapped, modified oceanic crust. *Canadian Journal of Earth Sciences*. 20: 163–183.
- Berberian, M., Yeats, R.S., 1999. Patterns of historical earthquake rupture in the Iranian plateau. *Bulletin of the Seismological Society of America*. 89: 120–139.
- Berberian, M., King, G.C.P., 1981. Towards a paleogeography and tectonic evolution of Iran. *Canadian Journal of Earth Sciences*. 18: 210 – 265.
- Berra, F., Zanchi, A., Mattei, M., Nawab, A., 2007. Late Cretaceous transgression on a Cimmerian high (Neka Valley, Eastern Alborz, Iran): A geodynamic event recorded by glauconitic sands. *Sedimentary Geology*. 199: 189-204.
- Boulin, J., 1991. Structures in southwest Asia and evolution of the eastern Tethys. *Tectonophysics*. 196: 211-268.
- Brunet, M.F., Korotaev, M.V., Ershov, A.V., Nikishin, A.M., 2003. The South Caspian Basin: a review of its evolution from subsidence modelling. *Sedimentary Geology*. 156: 119–148.
- Butler, R.W.H., Tavarnelli, E., Grasso, M., 2006. Structural inheritance in mountain belts: an Alpine-Appennine perspective. *Journal of Structural Geology*. 28: 1893-1908.
- Coward, M.P., 1994. Inversion Tectonics. In: Hancock, P.L. (Ed.), *Continental Deformation*. Pergamon. Oxford. pp. 289-304.
- Dellenbach, J., 1964. Contribution à l'étude géologique de la région située à l'est de Téhéran (Iran). Faculty of Science. University of Strasbourg (France), 117 p.
- Ehteshami-Moinabadi, M., Yassaghi, A., 2007. Geometry and kinematics of the Mosha Fault, south central Alborz Range, Iran: An example of basement involved thrusting. *Journal of Asian Earth Sciences*. 29: 928-938.
- Emami M.H., 2000. Magmatism in Iran. n. 71; Geological Survey of Iran, Tehran, 608p.
- Emami, M.H., Babakhani, A., (compiler) 1997. Geological map of Damavand scale 1:100,000. Geological Survey of Iran.
- Fürsich, F.T., Wilmsen, M., Seyed-Emami, K., Majidifard, M.R., 2009a. The Mid-Cimmerian tectonic event (Bajocian) in the Alborz Mountains, Northern Iran: evidence of the break-up unconformity of the South Caspian Basin. In: BRUNET, M.-F., WILMSEN, M. and GRANATH, J. W. (eds) *South Caspian to Central Iran Basins*. Geological Society, London, Special Publications. 312: 189–203.
- Fürsich, F.T., Wilmsen, M., Seyed-Emami, K., Majidifard, M.R., 2009b. Lithostratigraphy of the Upper Triassic–Middle Jurassic Shemshak Group of Northern Iran. In: BRUNET, M.-F., WILMSEN, M. and GRANATH, J. W. (eds) *South Caspian to Central Iran Basins*. Geological Society, London, Special Publications. 312: 129–160.
- Fürsich, F.T., Wilmsen, M., Seyed-Emami, K., Majidifard, M.R., 2006. The Upper Triassic – Middle Jurassic Shemshak Group of Iran: foreland basin or rift basin? 7th International Congress on the Jurassic System, Abstract Volume, session 1, p. 41.
- Fürsich, F.T., Wilmsen, M., Seyed-Emami, K., Cecca, F., Majidifard, M.R., 2005. The upper Shemshak Formation (Toarcian-Aalenian) of the Eastern Alborz (Iran): biota and palaeoenvironments during a transgressive-regressive cycle. *Facies*. 51: 365–384.

- Gansser, A., Huber, H., 1962. Geological observations in the central Elburz, Iran. *Schweizerische Mineralogische und Petrographische Mitteilungen*. 42: 583-630.
- Ghavidel-Syooki, M., 1995. Palynostratigraphy and palaeogeography of a Paleozoic sequence in Hasanakdar area, Central Alborz Range, northern Iran. *Review of Palaeobotany and Palynology*. 86: 91-109.
- Glaus, M., 1964. Trias und Oberperm in Zentralen Elburz (persian). *Eclogae Geologicae Helveticae*. 57 (2): 491-508.
- Golonka, J., 2004. Plate tectonic evolution of the southern margin of Eurasia in the Mesozoic and Cenozoic. *Tectonophysics*. 381: 235-273.
- Guest, B., Stockli, D.F., Grove, M., Axen, G.J., Lam, P.S., Hassanzadeh, J., 2006a. Thermal histories from the central Alborz Mountains, northern Iran: Implications for the spatial and temporal distribution of deformation in northern Iran. *Geological Society of America Bulletin*. 118: 1507 – 1521.
- Guest, B., Axen, G.J., Lam, P.S., Hassanzadeh, J., 2006b. Late Cenozoic shortening in the west-central Alborz Mountain, northern Iran, by combined conjugate strike slip and thin-skinned deformation. *Geosphere*. 2: 35-52.
- Haghipour, A., Taraz, H., Vahdati-Daneshmand, F., 1986. Geological quadrangle map of Tehran (1:250000). Geological Survey of Iran.
- Hamdi, B., Brasier, M.D., Jiang, Zh., 1989. Earliest skeletal fossils from Precambrian-Cambrian boundary strata, Elburz Mountains, Iran. *Geological Magazine*. 126: 283-289.
- Khatibimehr, M., Moalemi, S.A., 2009. Depositional history of Jahrum (Zagros) and Ziarat (Alborz) formations, based on distribution of benthic foraminifera. *Iranian Journal of Geology*. 3(9): 87-102.
- Lasemi, Y., 2001. Facies analysis, depositional environments and sequences stratigraphy of the Upper Precambrian and Paleozoic rocks of Iran. Geological Survey of Iran. 180 p.
- Moore, E.M., Fairbridge, R.W., 1998. *Encyclopedia of European and Asian, Regional Geology*. Springer, 825p.
- Ranalli, G., 2000. Rheology of the crust and its role in tectonic reactivation. *Journal of Geodynamics*. 30: 3-15.
- Sadeghi, A., Shemirani, A., 2002. The tectonic movements before Aptian. *Journal of Geosciences, Shahid Beheshti University*. 8-9: 22-28.
- Sadeghi, A., Shemirani, A., 2001a. Marine Neocommian-Barremian deposits of Sepayeh mountains. *Journal of Geosciences, Shahid Beheshti University*. 4-5: 52-64.
- Sadeghi, A., Shemirani, A., 2001b. Albian of Alborz. *Journal of Geosciences, Shahid Beheshti University*. 6-7: 142-156.
- Saintot, A., Brunet, M.F., Yakovlev, F., Sébrier, M., Stephenson, R., Ershov, A., Chalot-Prat, F., Mccann, T., 2006. The Mesozoic-Cenozoic tectonic evolution of the Greater Caucasus. In Gee, D.G., Stephenson, R.A. (eds). *European Lithosphere Dynamics*. Geological Society, London, *Memoirs*. 32: 277-289.
- Seyed-Emami, K., 2003. Triassic in Iran. *Facies*. 48: 91-106.
- Shemirani, A., Sadeghi, A., 2001. Maastrichtian in Alarm Valley (West of Lar Dam). *Journal of Geosciences, Shahid Beheshti University*. 4-5: 14-22.
- Stampfli, G.M., Marcoux, J., Baud, A., 1991. Tethyan margins in space and time. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 87: 373-409.
- Stampfli, G., 1978. Etude geologique generale de l, Elburz oriental au S de Gonbad-e-Qabus (Iran, N-E): These de Docteur des Sciences, no. 1868. Universite de Geneve. pp.328.
- Stampfli, G., Zaninetti, L., Brönnimann, P., Jenny-Deshusses, C. Stampfli-Vuille, B., 1976. Trias de l'Elbourz oriental, Iran. *Stratigraphie, Sedimentologie, Micropaleontologie. Rivista italiana di paleontologia e stratigrafia*. 82(03), 1976, pp. 467-500.
- Stöcklin J., 1972. Iran, in *Lexique stratigraphique international*. 3: Paris, Centre National de la Recherche Scientifique (18), Technical report. Paris. 177p.
- Toussaint, G., Burov, E., Avouac, J.-P., 2004. Tectonic evolution of a continental collision zone: A thermomechanical numerical model. *Tectonics*, 23, doi:10.1029/2003TC001604.
- Vahdati-Daneshmand, F., (compiler) 2001a. Geological map of Marzan Abad scale 1:100,000. Geological Survey of Iran.
- Vahdati-Daneshmand, F., (compiler) 2000. Geological map of Fasham scale 1:100,000. Geological Survey of Iran.
- Vahdati-Daneshmand, F., (compiler) 1991. Geological Quadrangle of Amol scale 1:250,000. Geological Survey of Iran.
- Wilmsen, M., Fürsich, F.T., Taheri, J., 2009. The Shemshak Group (Lower-Middle Jurassic) of the Binalud Mountains, NE Iran: stratigraphy, depositional environments and geodynamic implications. In: BRUNET, M.-F., WILMSEN, M. and GRANATH, J. W. (eds) *South Caspian to Central Iran Basins*. Geological Society, London, *Special Publications*, 312: 175-188.
- Wilmsen, M., Fürsich, F.T., Taheri, J., Brunet, M.R., Seyed-Emami, K., Majidifard, M.R., 2006. The Kashafud Basin (NE Iran): a key for understanding the Jurassic geodynamic evolution of the Iran Plate? 7th International Congress on the Jurassic System, Abstract Volume, session 1, p. 69.
- Yassaghi, A., 2001. Inversion tectonics in the Central Alborz Range. *European Union of Geosciences (EUG XI)*, 335. Abstract. Symposium LS05, pp 335.

- Yassaghi, A., Naeimi, A., 2011. Structural analysis of the Gachsar sub-zone in central Alborz range; constrain for inversion tectonics followed by the range transverse faulting. *International journal of earth sciences*, 100, 6: 1237-1249.
- Yassaghi, A., Madanipour, S., 2008. Influence of a transverse basement fault on along-strike variations in the geometry of an inverted normal fault: Case study of the Mosha Fault, Central Alborz Range, Iran. *Journal of Structural Geology*, 30 (12): 1507-1519.
- Yousefi, E., 1994. Magnetic lineament map of Iran (1:2500000). Geological Survey of Iran.
- Zanchi, A., Zanchetta, S., Berra, F., Mattei, M., Garzanti, E., Molyneux, S., Nawab, A., Sabouri, J., 2009. The Eo-Cimmerian (Late? Triassic) orogeny in North Iran. In: Brunet, M.F., Wilmsen, M. and Granath, J. W. (eds) *South Caspian to Central Iran Basins*. The Geological Society, London, Special Publications. 312: 31–55.
- Zanchi, A., Berra, F., Mattei, M., Ghassemi, M.R., Sabouri, J., 2006. Inversion tectonics in central Alborz, Iran. *Journal of Structural Geology*. 28: 2023 – 2037.
- Zaninetti, L., Brönimann, P., Bozorgnia, F., Huber, H., 1972. Étude lithologique et micropaléontologique de la formation d'Elika dans la coupée' Aruh, Alborz Central, Iran septentrional. *Arch. Sci. Geneve*, 25(2): 215-249.