Variations in the Style of Thrusting Geometry of Shahroud main thrust in the South-east of Alborz Mountains (North of Iran)

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Abstract: Based on the synthesis of information on maps, profiles, three-dimensional diagrams, and on the structural analyses carried out on Shahroud main thrust in the South-east of Alborz Mountains, it has been specified that some fundamental variation in the geometric form of faults have occurred along this thrust zone. These severe lateral variations from west toward east of the zone under study involve changing positive flower structure into cylinder-shaped structure and ultimately forming antiformal stack along Shahroud main thrust. This intricate geometric form indicates that along with transformation of fault trend and the entrance of thrust zone into rock units with variable plasticity, principal variations have taken place in the geometry of faults, and a positive flower structure can turn into classic thrust systems such as imbricate or duplexes. Furthermore, such geometric diversity in structural styles has led to the complexity of tectonic features of the region.

Keywords: Alborz Mountains, Cylinder-shaped structure, Shahroud main thrust

تغییرات سبک هندسه تراست شدگی در طول راندگی اصلی شاهرود

(جنوب شرق رشته کوه البرز)

عباس کنگی
استادیار گروه زمین شناسی دانشگاه آزاد اسلامی واحد شاهرود.

چکیده: بر اساس ترکیب اطلاعات حاصل از نقشه ها، پروفیل ها، دیاگرام های سه بعدی و آنالیز ساختاری انجام شده بر روی راندگی اصلی شاهرود واقع در جنوب شرق رشته کوه البرز، مشخص گردیده که در طول این زون تراستی تغییرات بنیادی در فرم هندسی گسلها صورت گرفته است. این تغییرات جانبی شدید به گونه ای است که از غرب به شرق منطقه مورد مطالعه شاهد تبدیل شدن ساختمان گل مانند مثبت به ساختمانهای سیلندری شکل و در نهایت شکل گیری دوپلکس های تاقدیس گون در طول تراست اصلی شاهرود می باشیم. این فرم هندسی پیچیده حکایت از آن دارد که با تغییر راستای گسل و ورود زون تراستی به داخل واحدهای سنگی با میزان شکل پذیری متفاوت، تغییرات بنیادی در هندسه گسلها ایجاد می شود و یک ساختمان گل مانند مثبت می تواند به سیستم های تراستی کلاسیک از جمله ایمبریکیت و دوپلکس تبدیل شود. بعلاوه چنین تنوع هندسی در سبکهای ساختمانی، سبب پیچیدگی چهره تکتونیکی منطقه گردیده است.

واژه های کلیدی: ساختمانهای سیلندری شکل، راندگی اصلی شاهرود، رشته کوه البرز

1- Introduction

The Alborz Mountains in the north of Iran stretch around 2000 km from Lesser Caucasus in the west to the north of Afghanistan in the east. This range of mountains with a complex tectonic history displays an amazing perspective of thrust systems evolution. In this mountain range, the activity of thrust faults has resulted in disorganization of stratigraphic units as well as formation of various geometric structures. However, due to inadequacy of our information in the domain of tectonic transitions of Alborz, the geology of this mountain range has so far been vague, and different authors have already presented diverse and often controversial tectonic models related to the tectonic evolution of this mountain range. The first serious attempts to find out stratigraphy and structural features of the Alborz Mountains system are limited to studies done by Stocklin (1960, 1968, 1974 a & b) and Stampfli

(1978). After these studies, in terms of information as well as geological views, most of the research carried out by Berberian & King (1981), Davoudzade et al. (1986), Sengor (1990) was typically dependent on original work done by Stampfli and Stocklin. Besides, in this series of research, some interpretations were done on older data as well. Finally, detailed structural analyses and lithostratigraphy in some particular parts of Alborz, which were mostly carried out by Seed-Emami et al. (1971), Bozorgnia (1973), Seger (1977), Hamdi & Janvier (1981) gave a superior insight into the stratigraphy and geometry of Alborz Mountains structures. Of course, most of this scattered research has been systematic palaeontological studies in some given stratigraphic sections.

In this article, a region located in the south-east of the Alborz Mountains has been studied. It has been attempted to present a comprehensive geometric analysis of Shahroud main thrust by employing the combination of profile and map criterion in three-dimensional diagrams. This evidence accompanied by the performed structural analyses present a new pattern of lateral variations it thrust fault geometry.

2- Lithostratigraphy

Based on stratigraphic analyses, several formation may be distinguished in this area (Fig. 1). Each formation is formed in a tectonically controlled environment and in the following paragraphs I present a brief and general description of these formations, ranging from the oldest to the youngest. The Lower Cambrian consists of thick-bedded quartz sandstone and massive cherty dolomite. The most characteristic constituents of the upper Cambrian Mila formation are nodular limestones, in part strongly glauconitic and containing abundant trilobites, brachiopods, and hyolithids. These limestones are associated with dolomitic, marly, shaly and sandy beds. These units are considered to represent deposits of an epicontinental platform sedimentary basin that was influenced by the initial stages of extensional tectonics (Alavi, 1996). The upper Devonian Carboniferous Geirud formation consists of sandstones, shales, fossiliferous sandy limestones and several phosphatic layers, followed by sandstones, shales and fossiliferous limestones. The Lower Triassic to middle Triassic Elikah formation consists of an association of limestone, partly marly, rarely dolomitic, yellow to pinkish. Many beds are crowded with worm-tracks calcaires vermicules (Stocklin, 1977).

The Lower Jurassic Shemshak formation consists of an association of sandstones, siltstones, shales and claystones, that has coal seams up to 1.5 m thick as a characteristic feature (Assereto, 1966). The lower part of the Shemshak formation is characterized by cross-bedding and ripple marks are numerous and indicate a very shallow water to lagoonal environment of sedimentation. The upper parts contain features characteristic of deltaic environment. Regional structural considerations coupled with the sedimentary characteristics of this unit, with distinctive lateral variations, strongly suggest that these rocks may have formed in a foreland basin in front of the tectonically active, south-verging, blocks uplifted during the Cimmeride orogeny, which later became covered by marine transgression strata (Alavi, 1996). The upper Jurassic Lar formation is composed of light gray, compact and thin-bedded to massive, partly-reef limestone 250 to 350 meters thick and contains characteristic nodules and bands of white or violet chert. The limestone overlies conformably the Shemshak formation. The upper Cretaceous consists of an alternation of light grey limestone and green marl at the base and grey, thick bedded to massive cliff forming limestone.

3- Structural Geology

The Alborz is a stack of thrust sheets, produced by late Cenozoic compressional deformation (Alavi, 1996). Thrusts on the northern side of the range are principally directed northwards, those in the south towards the south (National Iranian Oil Company, 1977; Stocklin, 1974).The Alborz range is also an excellent example of coeval strike-slip and compressional deformation, and as such can be an analogue for inactive fold and thrust belts thought to involve a component of oblique shortening (transpressional deformation) (e.g. Harland, 1971; Vauchez & Nicolas, 1991; Dewey et al., 1998).

In the area under study, Shahroud main thrust, as the leading tectonic structure, has played a prominent role in the formation of structural features of the area (Fig.1). This thrust zone with an eastern-western trend and a variable slope has affected all rock units of the area. Mostly, Shahroud main thrust has cut the axis of all folds in the area and led to the formation of en-echelon pattern in the arrangement of folds on the map. These map patterns and the formation of positive flower structure in the western part of the area under study are compatible with laboratory models presented by Harding (1985). According to Harding s model, it appears that this area is influenced by wrench faults. However, in this area, severe lateral variations in the geometry of thrust zone have caused positive flower structures to change into cylinder-shaped structure and eventually into antiformal stack in a short term (Fig 1).

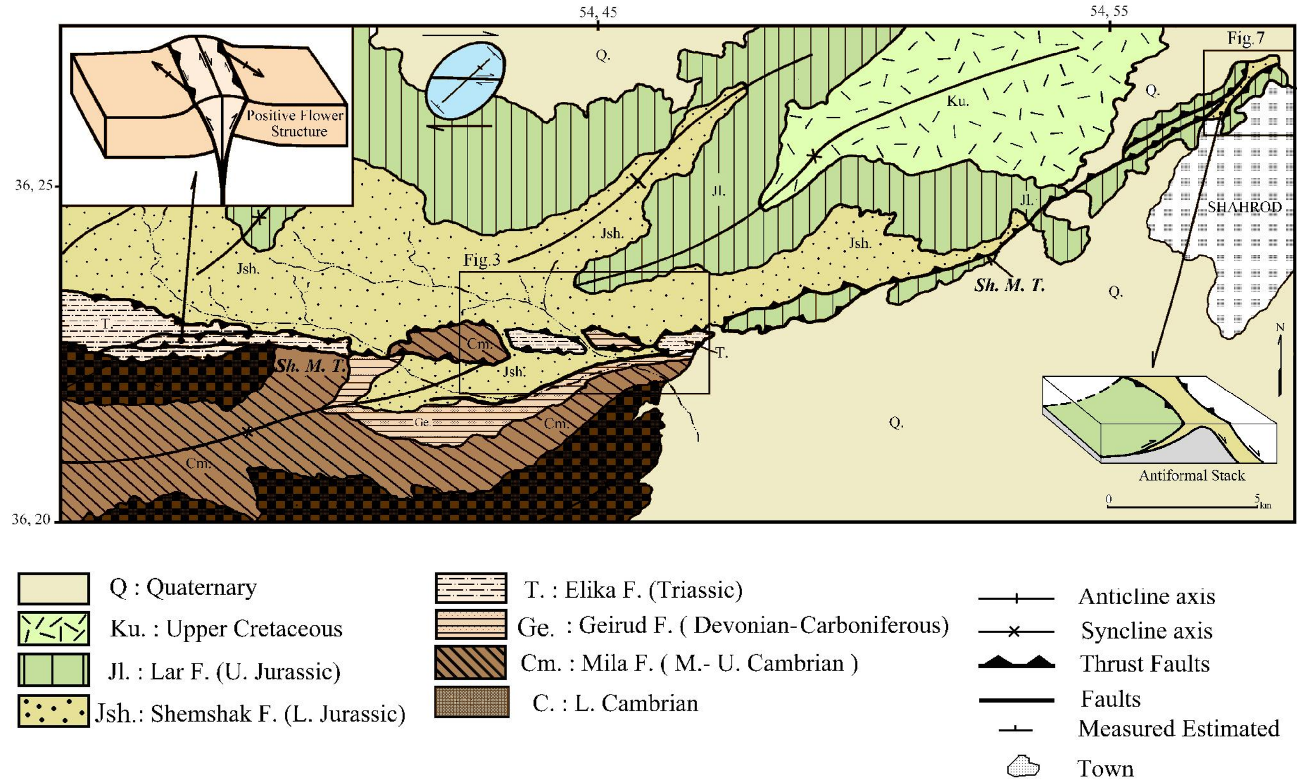

Fig. 1- Tectonic map of Shahroud main thrust and main structural features.

In order to specify the lateral variations in the geometry of thrust system, three geometric forms existing along Shahroud main thrust are described in the following section.

3.1. Positive Flower Structures

In the western part of the area, Shahroud main thrust has passed through ductile rock units (a recurrence of coal-carrying shale, marl, and sandstones in Shemshak formation) and has created an astonishing positive flower structures (Fig. 2). In

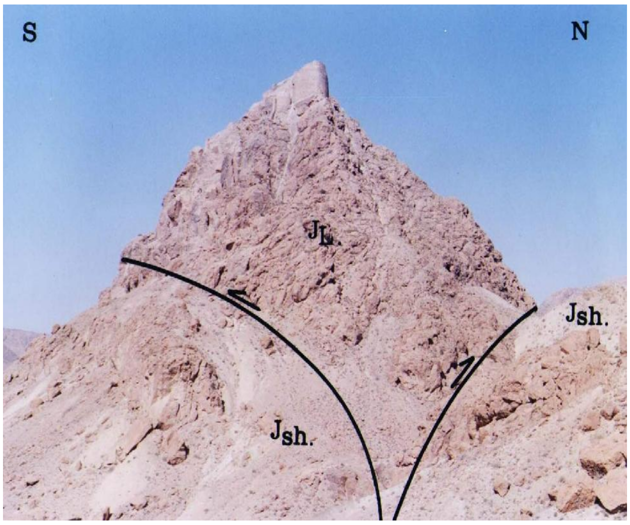

Fig. 2- Interpreted profile across convergent wrench faults in western part of Shahroud main thrust. The reverse motion of fault has been recognized by striations and steps on fault surface. Jsh. Lower Jurassic (Shemshak formation) Jl. Upper Jurassic (Lar formation)

this long, narrow and deformed zone, the association of northern faults has a southbound slope and the set of southern faults has a northbound slope. Measurments on these faults inside coal-extracting tunnels indicate that there is often a positive correlation between depth and slope of the faults. Therefore, the geometric pattern of these positive flower structures can be recognized by surface and subsurface evidence. Harding (1985, 1990) asserts that by making use of positive flower structures and the pattern of neighbouring structures, one can detect structural systems which have created this style. According to Harding, when parallel folded structures with en-echelon pattern have a slanted position on the major fault system, the kinetic relationship prevailing in the area is a combination of shear displacement and thrusting. Such circumstances are indicative of the prevalence of a wrench faults system in the geology of the area. Moreover, based on laboratory modeling on brittle-ductile systems, Krantz (1991) have attributed the formation of such structures to the situations in which most pressure on the zone of deformation is not perpendicular. Thus, considering the fact that in the western part of the area under study, the axis of folds (with en-echelon style) has mostly been cut by main thrust system, and regarding the geometry of faults in profile, it can be concluded that the western part of the area is full of with wrench faults.

3.2. Cylinder-shaped Structures

In the middle section of the area under study, Shahroud main thrust changes and appears as an association of thrust faults with parallel slope. This association of faults with northbound slope follows Imbricate pattern (Boyer & Elliott 1982). The geometric position of secondary fault inside each thrust sheet has created cylinder-shaped structures (Kangi 2003). Each of these cylinder-shaped structures which are surrounded by a association of faults has placed one hard rock unit in soft sediments of Shemshak formation. Therefore, an association of rock units of different ages (Cambrian, Devonian, Triassic) is situated along Shahroud main thrust with a cylinder-shaped pattern (Fig. 3). In appearance a mass of cylinder-shaped rock is surrounded with a group of thrusts in all direction. Moreover, the existing lineations with a radial design on these thrusts can be observed in different parts of the cylindrical structure. The most appropriate place for the observation of such a structure is where there are two cylinder-shaped connections. Here, the geometrical form of cylinder-shaped thrusts are easily observable. Based on desert measurements and observations, attempts are made to display the three-dimensional geometry of such structures in (Figure 4) In order to describe the three-dimensions geometry of cylinder-shaped structures, structural parameters such as faults and fractures found in the region under study have been extensively measured. These measured data have been the main foundation of detailed interpretation on the structural model of the region. Statistical analyses carried out on the conjugate faults indicate that the direction of maximum principal stress generally has an N10E orientation. The measurements conducted on the surrounding faults of a cylinder-shaped structure indicate that every section of this structure follows a particular geometrical pattern. In Figure 8, the geometrical situation of faults in various parts of a cylinder-shaped structure has been illustrated by the stereonet (Fig. 5). This set of measured faults shows this structure in a three-dimensional pattern.

Striations on the surface of faults covering a cylinder-shaped structure have a radial pattern. Therefore, by approaching the end of this structure, the angle of striation pitch will be smaller. Additionally, studies on mylonites (C-Type shear bounds) formed on the surface of these faults indicate that the thrust sheets have transferred from north to south (Fig. 6).

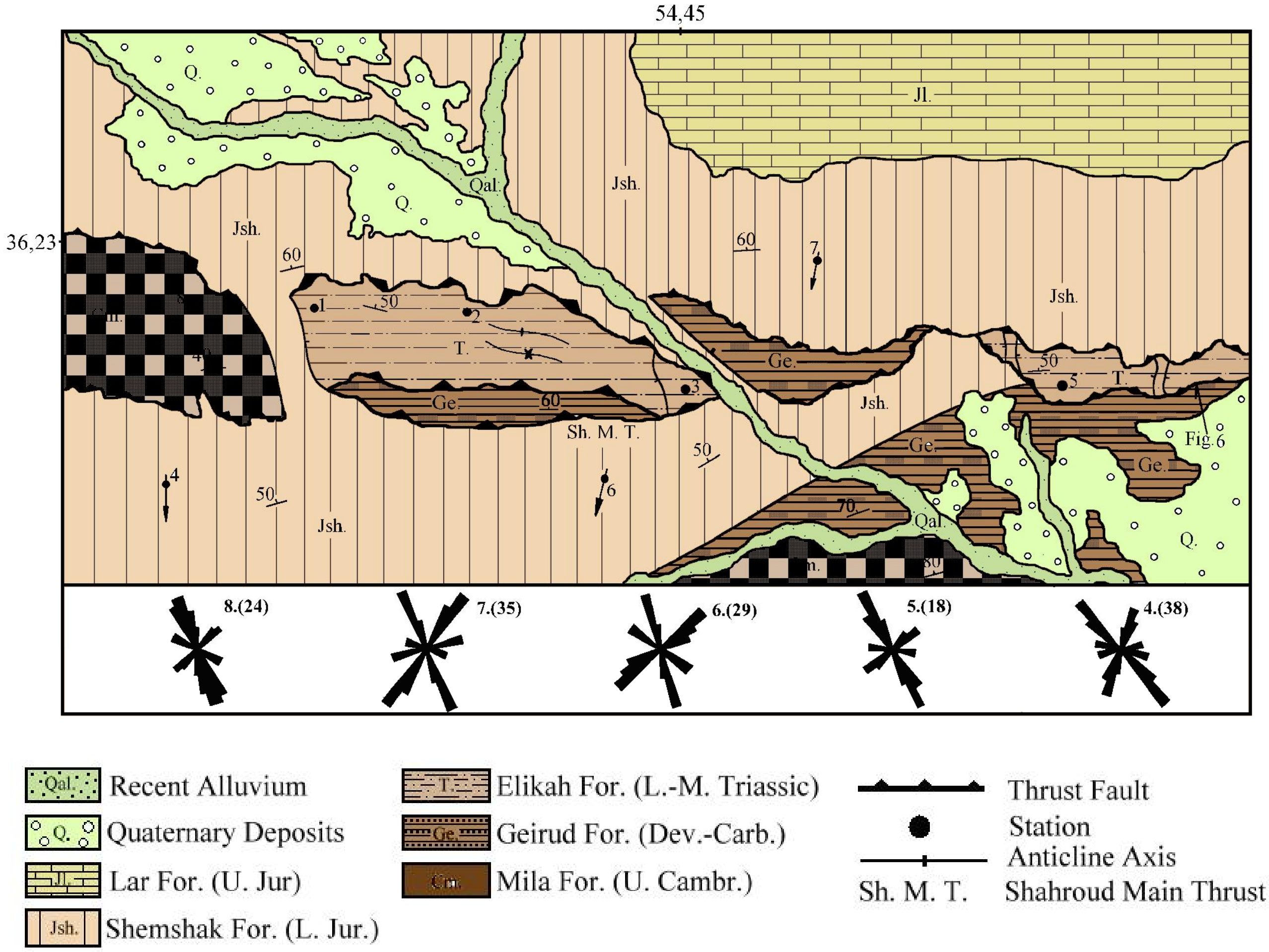

Fig. 3- Tectonic map of central part of Shahroud main thrust (Kangi 2003).

3.3. Antiformal Stack

In northern Shahroud there are extensive outcrops of massive lime of Lar formation the existence of which dates back to upper Jurassic. In this mass of lime, a limited outcrop of sandstones and coal-carrying shales of Shemshak formation (Lower

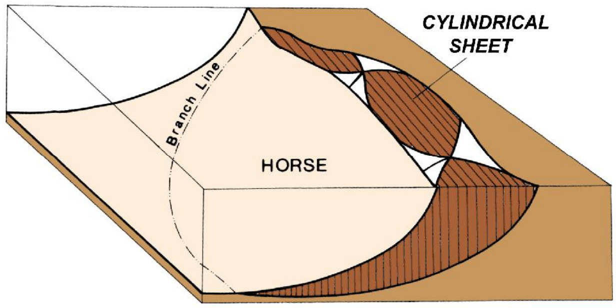

Fig. 4- Block diagram showing horse in a volume of rock surrounded by fault surfaces, formed three cylindrical sheets.

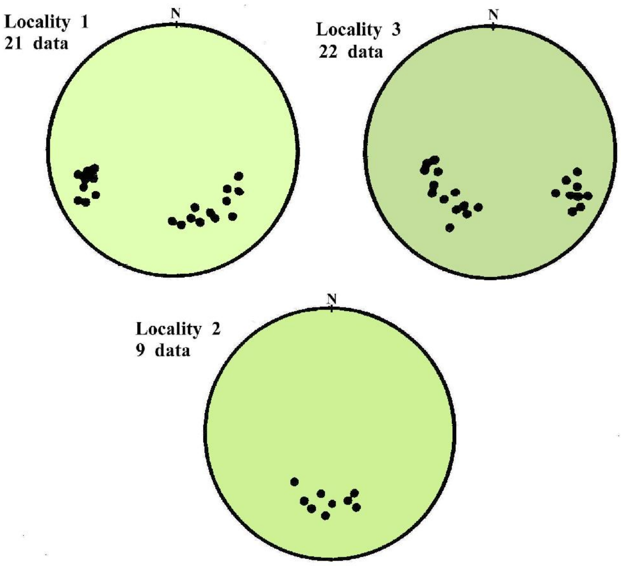

Fig. 5- The measurements conducted on the surrounding faults of a cylinder-shaped structure. Localities shown in Figure 3.

Fig.6- C-Type shear band cleavage in surface Shahroud main thrust. Localities shown in Figure 3.

Jurassic) can exceptionally be observed. Considering low resistance of Shemshak formation caused by erosion, this formation appears as a saddle in the morphology of the area. This coal-carrying unit with a linear outcrop is placed in Lar formation limes by an association of thrust faults (Fig. 7). The faults in the northern contact of Shemshak formation have an approximate northbound slope of 25 degree, and the ones in the southern contact have an approximate southbound slope of 55 degree. Furthermore, considering the intensity of tectonic activities, this association of thrust faults has created a crushed unit of fault-breccia three meters thick. The geometric pattern of this set of faults can obviously be reconstructed by profile characteristics because this association of thrust faults with antiformal stack pattern has caused outcrop of sandstone and coal-carrying shales of Shemshak formation in massive lime of Lar formation (Fig. 8). Therefore, we can observe that Shahroud main thrust in the eastern part of the area under study has changed its nature and created antiformal stack structures.

3.4. The Geometrical Form of Folds

A set of large-scale and polyharmonic folds has formed in northern and southern Shahroud main thrust. Having an en-echelon pattern, these folds are cut by thrust faults. This folding pattern is induced under the influence of thrust fault activities with a transpression mechanism (Harding, 1985). Based on Harding's model, the right-lateral motion of Shahroud main thrust has resulted in the formation of en-echelon pattern of folds (Fig. 1).

Results from 57 assessments of geometrical condition of strata in fold limbs and applying them on the streonet indicate that the general pattern of the folds is conical with a 15 to 20 degree plunge.

3.5. Structural Analysis

Characteristic steps and striations on the surface of Shahrod main thrust confirm the right-lateral motion of this fault. Further, along this thrust system, the angle of striations pitch gradually increases toward east in a way that on the west side of the region, this angle is around 30 degree, while on the eastern section, it is around 80 degree. By the analysis of striations as well as the geometrical condition of fault surface in 12 stations, the maximum principal stress proves to have a N20W to N30W trend.

The bend in Shahroud main thrust in northern Shahroud has transformed the trend of this fault from EW to N70E (Fig. 1). Assuming the direction of maximum principal stress remains constant, this transformation has led to a significant incompatibility in fault motion mechanism in various sections. Put another way, the east side of

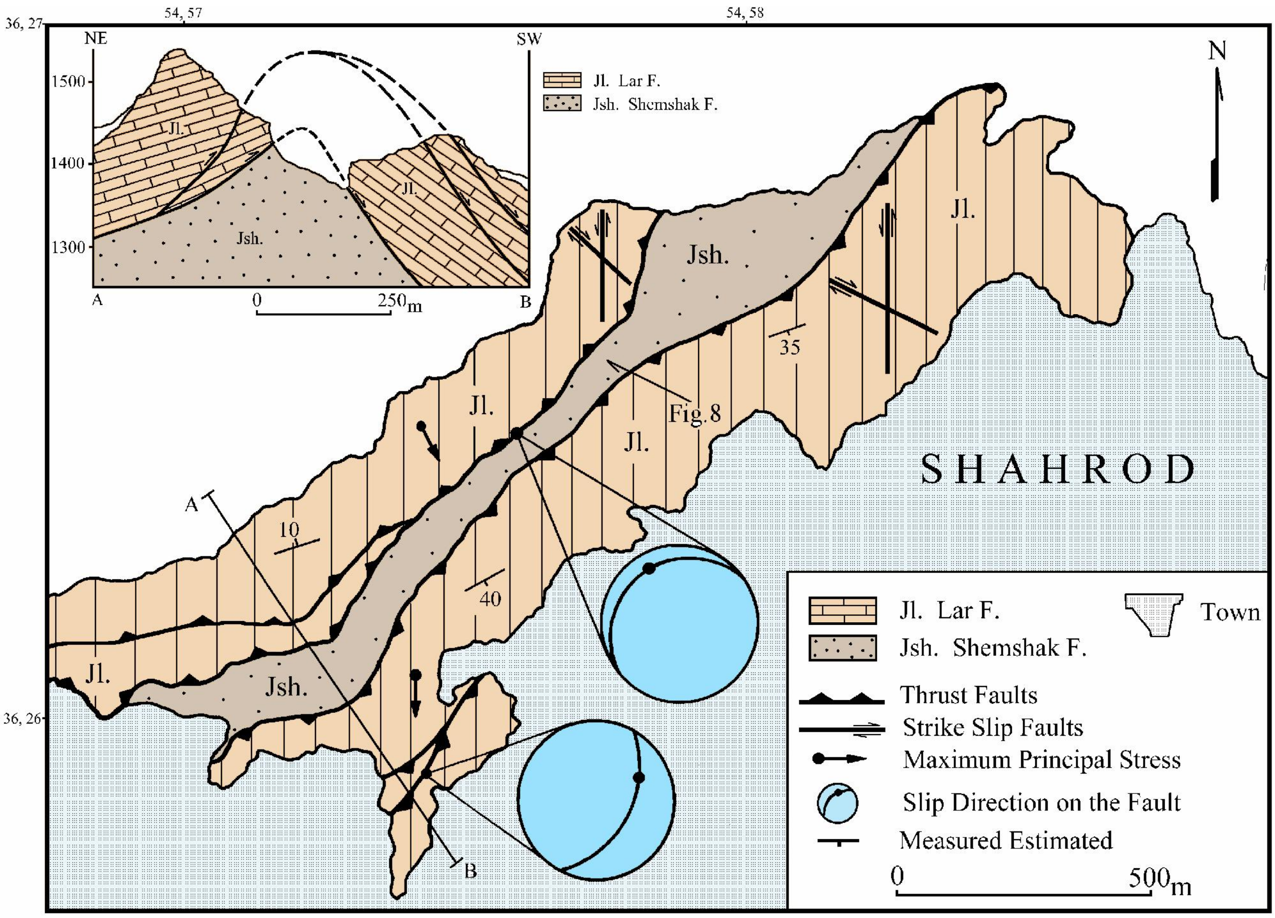

Fig. 7- Tectonic map of eastern part of Shahroud main thrust.

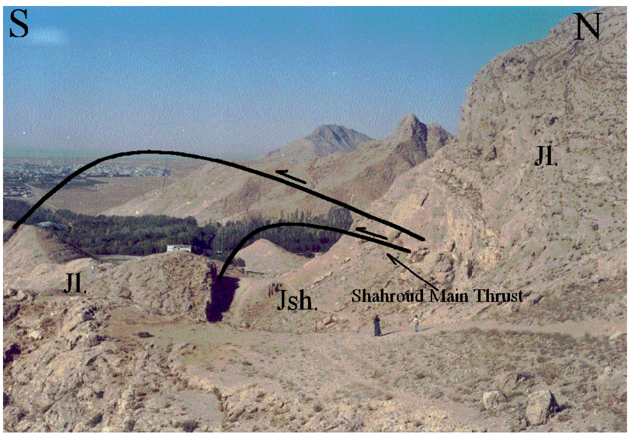

Fig. 8- Interpreted profile across Antiformal Stack in eastern part of Shahroud main thrust. This image is compatible with section AB in Figure 7. Jsh. Lower Jurassic (Shemshak formation) Jl. Upper Jurassic (Lar formation)

the fault is being affected by thrust mechanism, whereas the west side enjoys a strike-slip characteristic. Accordingly, there exists a direct relationship between striation pitch angle changes along the fault and fault orientation as well as the direction of maximum principal stress. The condition of striation on the surface of the fault demonstrates a combined strain of dip slip and strike-slip in addition to the right-lateral motion.

Therefore, the oblique compression, being influenced by transpressional deformation has brought on both right-lateral motions and compression along Shahroud main thrust.

Even though during Pliocene era, due to southern Caspian motions, the left-lateral faulting in western Alborz have been confirmed, tectonic changes of Alborz during Late Cenozoic have induced right-lateral faulting (Allen et al. 2001 & 2002). Approving such cinematic model, it can be asserted that the formation of en-echelon folds and the right-lateral fault motion in the region under study are related to the primary stages of Alborz evolution during Late Cenozoic. Nevertheless, no conversion in mechanism due to Pliocene changes from right-lateral behavior to left-lateral mechanism in this region is witnessed.

4. Conclusion

Regarding en-echelon pattern of folds and other map criteria, the area under study can be considered to be dominated by wrench fault system. However, studies on fault geometry along Shahroud main thrust indicate that with transformation of fault trend and the entrance of thrust faults into rock units with variable plasticity, fundamental variations in the form of fault geometry have arisen.

So from west towards east, a change from positive flower structure into cylinder-shaped structure and ultimately the formation of antiformal stack in eastern Shahroud main thrust can be observed. These intense variations in thrust system geometry indicate that the degree of plasticity in surrounding rocks of thrust system, elastic quality of thrust sheets and the position of fault in relation to maximum principal stress, altogether, play crucial roles in the formation of thrust fault geometry. Thus, due to pressures exerted on rock units, various tectonic deformations in several different structural styles in the area dominated by wrench faults might come into existence.

It should be noted that, based on surface geology, Harding (1985 & 1990) has attempted to make identification of wrench faults plausible. He has tried to present reliable methods to improve the ways for identifying wrench faults and simplify their recognition by standardizing surface appearance of wrench faults. Nevertheless, the prerequisite to standardization of such intricate structures is taking into account all the parameters which play a role in the formation of these structures in different circumstances. Ignoring certain parameters will undoubtedly make the presented patterns deficient and complicate its utilization around the world

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