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Collapse structures in Dowgonbadan region, Zagros fold- thrust belt

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Abstract
Allochthonous masses are common structures in Zagros fold-thrust belt. They are generally considered as collapse structures formed by the influence of gravity and in rock units with competency contrast. However, large allochthonous masses mapped in Dowgonbadan area in Dezful Embayment near the Mountain Front Fault (MFF) of Zagros show characteristics different from the belt common collapse structures. In this paper, the influences of both gravity and thrusting on development of these masses are presented. Evidences such as the volume of the masses, the greater spacing between the masses and their origin, and the occurrence of crushed zone on the base of the masses are considered as criteria to separate these masses from common collapse structures and are classified as thrust related collapse structures. Thus, thrust faults as well as gravity are proposed as the main features controling the development of these types of collapse structures in the Zagros.

Key words: *Gravity collapse structure, Allochthonous masses, Dowgonbadan region, Zagros Mountain Front Fault*

Introduction

Collapse structures in Zagros fold-thrust belt (ZFTB) (Fig. 1) occur as a landslide, such as the Symareh landslide in Northwest limb of the Kabirkuh anticline in Lurestan province, or as Cascade fold shape (collapse folds). Collapse folds in the most cases occur where the limestone rocks of the Asmari Formation sliding over the shale and marl units of the Pabdeh-Gurpi formations (Figure 2). Harrison and Falcon (1934, 1936) have introduced this type of structures as collapse structures for the first time. They believed that these structures developed by bending or breaking of Tertiary or middle Cretaceous limestone rocks overlaying incompetent shale and marl rocks due to folds amplification during folding and erosion of top structures. Based on their geometries, they classified these structures as slip sheet and cascade (j and p in Figure3), roof and wall (g and m in Fig. 3), flap (h, i, l, n and o in Fig. 3) and complex structures (k and q in Fig. 3).

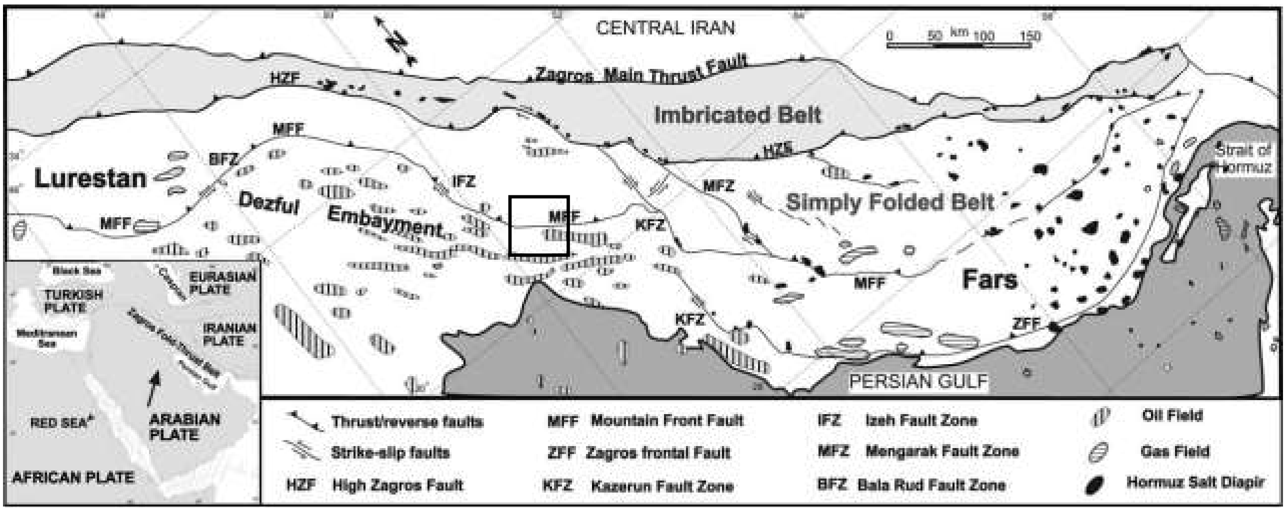

Figure 1: Structural setting of the Zagros Fold–Thrust-Belt showing the major belt subzones and fault zones, distribution of oil and gas fields and the Hormuz salt diapirs. The location of study area is shown by a box.

Collapse structures have reported on various anticlines in Zagros such as Mongasht-Kuh (Talebian & Pourkermani, 2000), Chenareh (Hasan-Goodarzi, 2007) and Soltan (Aflatonian *et al.,*

2003) anticlines. All of these collapse structures somehow are autochthon and their final locations are not far from their origin as described by by Harrison and falcon (1934, 1936). However, in the Dowgonbadan region, situated in central part of Zagros fold-thrust belt, in North of the Dezful Embayment (Fig. 1), there are two large allochthonous masses in which their distance from their origin rocks are greater than the common collapse structures described by Harrison and Falcon (1934 and 1936).

In this paper based on detailed field work and study of terrain elevation models, these two large allochthonous masses as the NW and SE masses (Fig. 4) and in front of the Mountain Front Fault (MFF) have studied in detail and the influence of the fault in formation of the masses is analyzed.

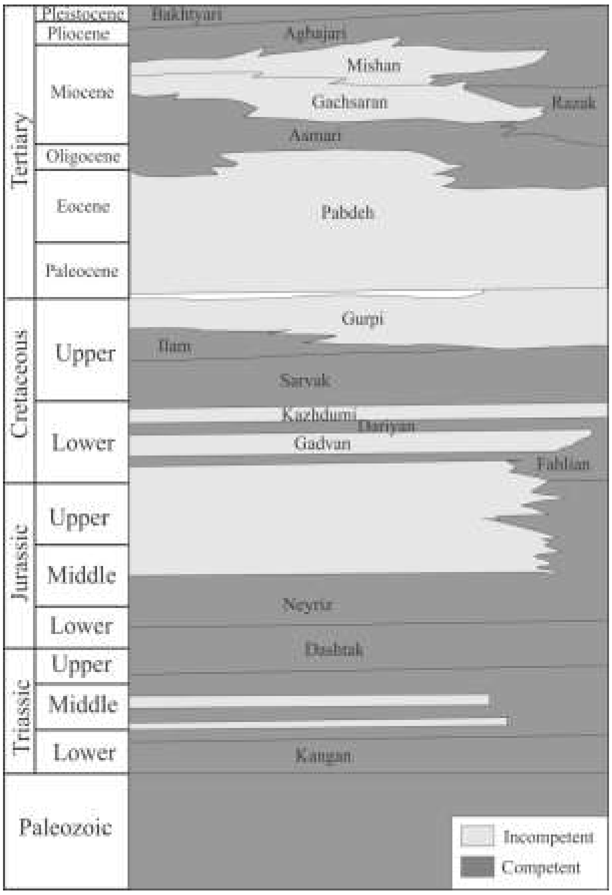

Figure 2: Stratigraphic charts of the Zagros Belt in Dezful Embayment showing major horizontal and vertical variations in the cover rock stratigraphy. The successions are composed of competent and incompetent units, which impart a mechanical anisotropy to the rock mass which controls the scale and style of the folds that develop

Geological setting

The study area is situated in the central part of ZFTB. The belt is a ~1800 km long zone of deformed crustal rocks, formed in the foreland of the collision zone between the Arabian Plate and the Eurasian Plate (Fig. 1). It is host to one of the world's largest petroleum provinces, containing about 49% of the established hydrocarbon reserves in fold and thrust belts and about 7% of all reserves globally (Cooper, 2007).

The ZFTB is divided into several zones that are the High Zagros, the folded belt, the coastal plain and Persian Gulf lowland from northeast to southwest (Fig. 1). On the basis of lateral facies variations, the folded belt zone is divided into different tectonostratigraphic domains bounded by the belt major faults. These domains are the Lurestan, Dezful Embayment, Izeh and Fars from the northwest to southeast (Figure 1). The mechanical stratigraphy of the cover successions in Zagros is represented by a sequence of competent units (such as the Tertiary Asmari, Cretaceous Ilam-Sarvak and Jurassic Darian and Surmeh formations) and incompetent units (such as Tertiary Pabdeh-Gurpi, Cretaceous Kazhdumi and Garau, Triassic Dashtak formations) (Fig. 2).

The Dowgonbadan area is located in a transition zone from south of the Izeh zone to north of the Dezful Embayment, at the north Gachsaran oil field (Fig. 4). Mish, Pahn and Dil anticlines as well as the MFF are the main structures of the study area (Fig. 4). The Mish anticline with higher height in relation to its front zones is situated in hanging wall of the MFF. The anticline forelimb comprises of the Asmari limestone rocks and is overturned through which thrust fault is propagated. The allochthonous masses (NW and SE masses in Fig. 4) under investigations in this study also comprises of the Asmari limestone rocks and are located to the footwall of the MFF, in more than 6 km distance (Table 1) from the overturned limb of Mish anticline (Fig. 4).

Table 1: Characteristics of allochthonous masses

Allochthonous masses	Length (Km)	Width (Km)	Area of the masses (Km^2)	Distance from the MFF (Km)
Southeast Mass	9.5	4.2	26	6.7
Northwest Mass	5	3.5	11	9.5

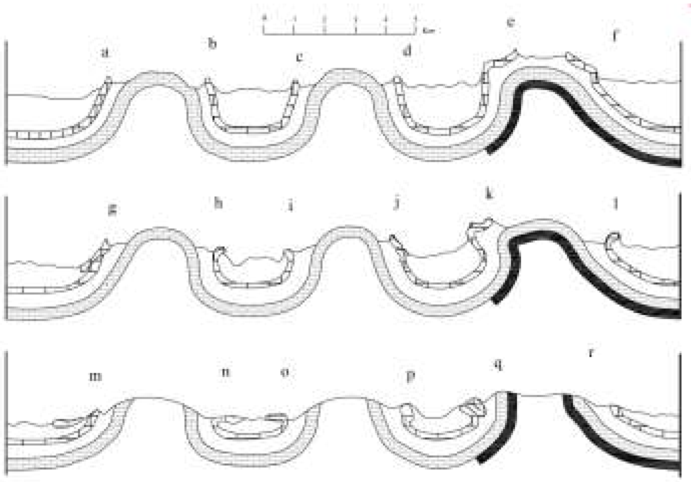

Figure 3: Collapse structures proposed by Harrison & Falcon (1934, 1936) for Zagros fold thrust belt (For more information refer to text).

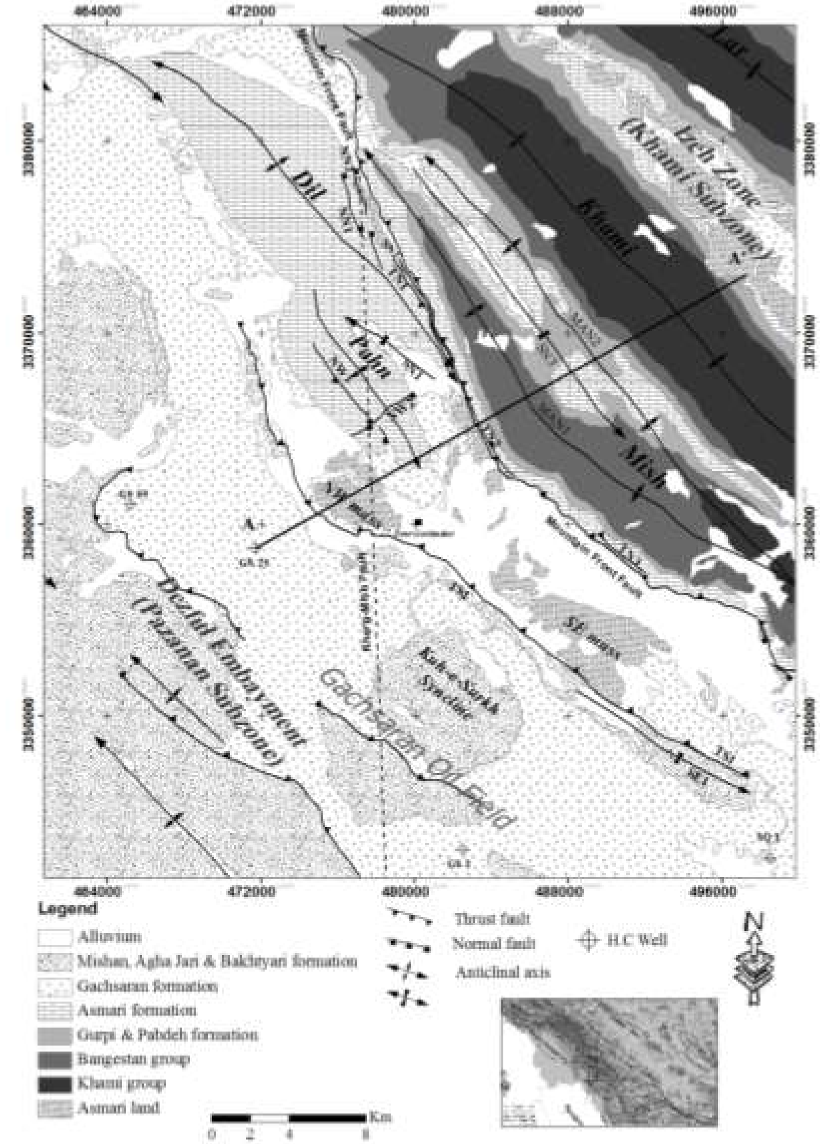

Figure 4: Structural map of Dowgonbadan area. The Mish, Khami and Lar anticlines are located in the MFF hanging wall whereas the Pahn and Dil anticlines, and the NW and SE allochthonous masses are located in the MFF footwall.

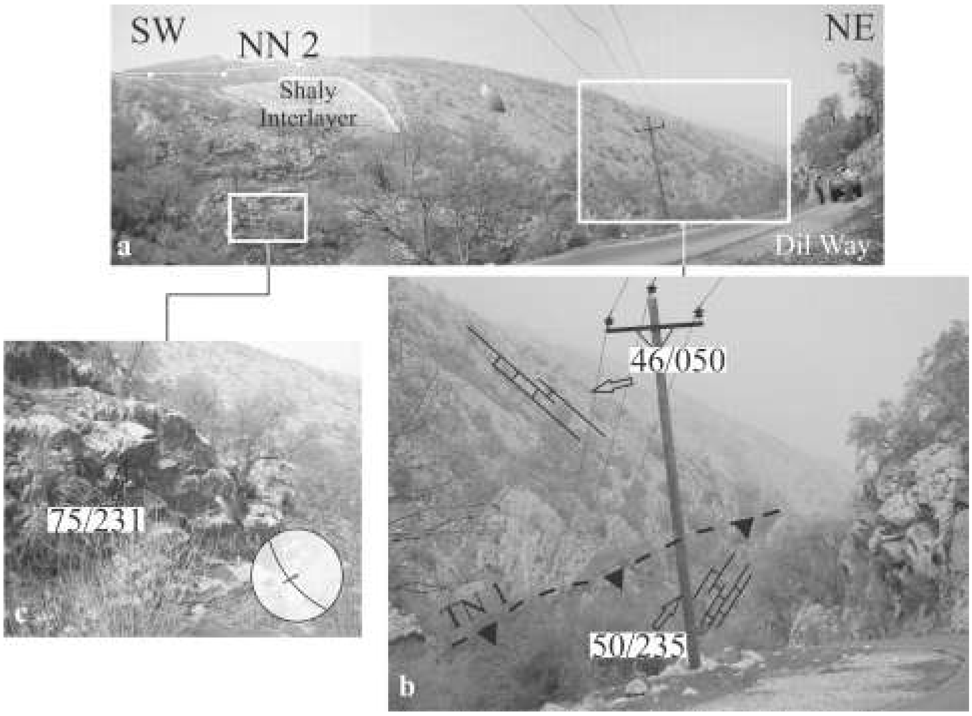

Figure 5: a) Shale interlayers in Asmari Formation in the Dil anticline backlimb, b) breaking knee-shape structure in Asmari Formation along the TN1 thrust, c) crushed zone along the TN1 thrust in the Asmari layers

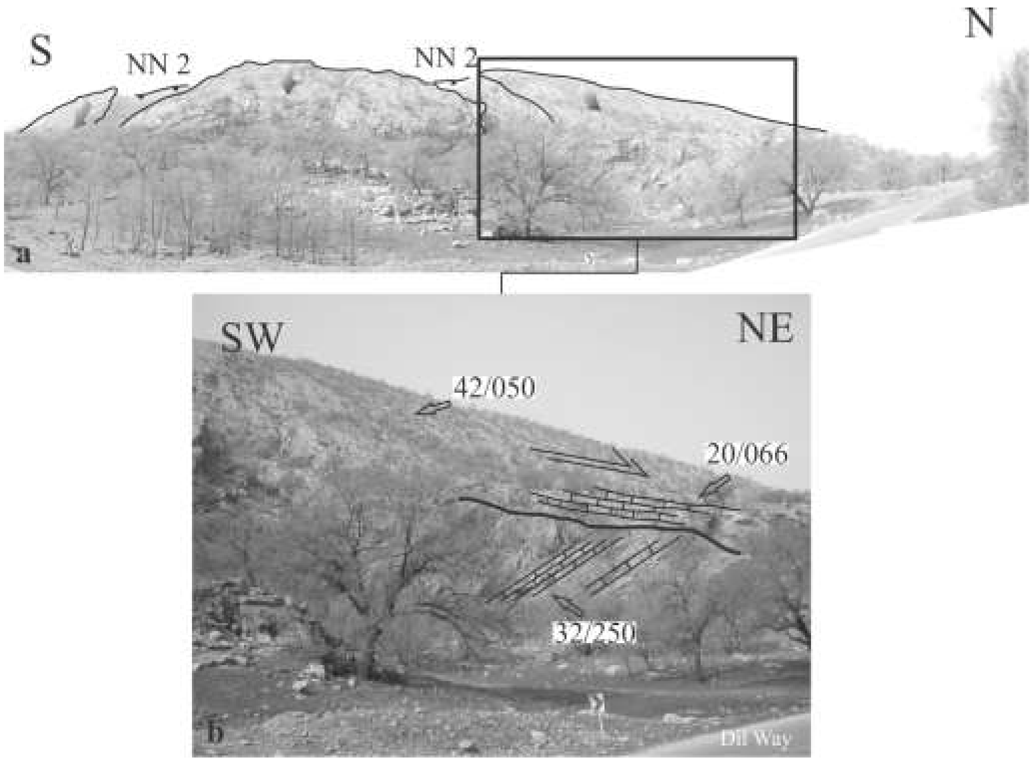

Figure 6:a) Discrete rock blocks of Asmari Formation on Dil anticline backlim. Note to development of the gravity sliding surfaces (NN2 structures) at the crestal zone of the anticline, b) Knee-shape structure on the Dil anticline backlim.

Collapse Structures in the study area

The Dil anticline that has a gentle-to-open geometry in its central part but asymmetric geometry in its southeast termination is located in footwall of the MFF. The anticline back limb is overturned where a back thrust (TN1) is also present (Fig. 4 and 5). In the Dil anticline back limb, along the Dowgonbadan-Dil road, (at a

location E3372543, N479659) (Fig. 4) the attitude of the Asmari limestone rocks changes from 46/050 to 50/235 (Figures 5a and b) and form a collapse rock mass. In first view, the change in the attitude of the limestone layers looks similar to Harrison and Falcon's roof and wall collapse structure (g and m in Figure 3). However, precise investigation show that this change in the attitude has taken place where the TN1 thrust is located and cause thrusting of the limestone layers (Figure 5b). Evidence on presences of slickenside surface along the TNI fault plane shows the NE (N060) movement direction for the fault that is parallel to movement trend of the collapsed rock mass (Fig. 5b and c).
In the central part of the Dil anticline, at a location (E3376026, N477855), the Asmari limestone layers with 20/066 in attitude overlay the overturned Asmari layers with 32/250 in attitude (Figure 6a, b). The knee-shape geometry of the Asmari layers as well as the emplacement of the low dip angle of the limestone rocks over its overturned layers is similar to Harrison and Falcon's roof and wall structure (g and m in Fig. 3). It seems that the NN2 structure on the Dil anticline crest is the main factor on breaking of the Asmari limestone rocks into discrete blocks. These discrete rock blocks then have moved down the fold limb by gravity to form common collapse structure addressed by Harrison and Falcon (1936). Similarly, in the Southeast part of the Mish anticline there is also a collapse structures (Fig.7) similar to Harrison and Falcon's slip-sheet structure (j in Fig. 3).
However, in the footwall of the MFF, two large allochthonous masses (NW and SE masses in Figure 4) are present that have been mapped as landslides by Setudehnia and O'B perry (1966). These masses oriented parallel to Zagros fold trends are located along the road connecting Basht to Dowgonbadan and then to Behbahan cities (Figures 4 and 8a). The allochthonous masses geometry and their distance from the MFF are presented in Table 1. They comprises of limestone and dolomitic limestone similar to the Asmari Formation and emplaced on outcrops of anhydrite, salt and limestone of Gachsaran Formation (Fig. 9). Average height of both masses is about 800 meters (from sea level). In some areas, erosion of Gachsaran Formation resulted in formation of long scarps in the competent limestone masses. Crushed zones with about 2 meters in thickness make up the base of the both masses. The SE mass is located in front of the Mish anticline whereas the NW mass is located in front of the Pahn anticline (Figure 4, 8a). The similar funa (Fig. 10), thickness and rock units are parameters that support similar source (i.e., Asmari limestone rocks) for both masses. Variation on the attitude of allochthonous masses and their underlying Gachsaran Formation layers imply that the limestone rocks of the masses are not interlayer of limestone rocks within the Gachsaran Formation. In addition, at the eastern part of the area, (location: E3355602, N486531), horizontal sheets of Asmari limestone rocks overlaying dipping Gachsaran layers where a crush zone make the base of the limestone sheets (Fig. 9).

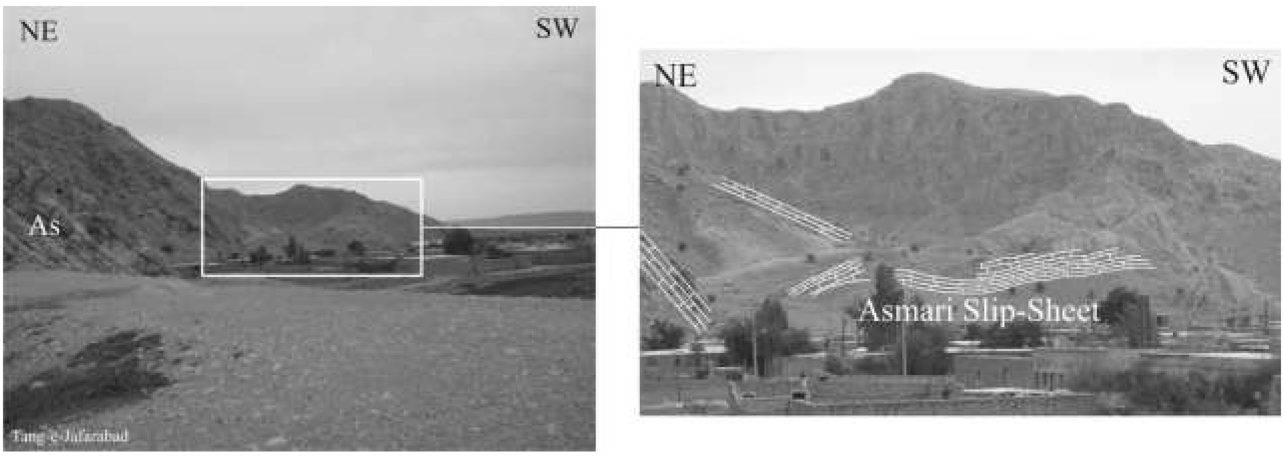

Figure 7: Sliding sheet that have separated from the Mish anticline high dip-angle limb and moved down the hill.

Discussion and Conclusion

Applying Harisson and Falcon's (1934, 1936) criteria, two sorts of collapse structures in form of roof and wall structures are mapped in the Dowgonbadan region. The down movements of the Asmari limestone rocks in the northern limb of the

Dil anticline (Fig. 6) and in the southeastern limb of the Mish anticline (Fig. 7) are proposed to occur mainly by gravity and during fold amplification and thus they classified as common collapse structures in this paper. However, further to southeast on the northern limb of the Dil anticline where the TN1 back thrust exists, sliding masses are mapped that have moved by the influence of the TN1 (Fig. 5). These structures, which have formed by the action of both gravity and thrusting, are proposed as thrust related collapse structures. Similarly, the NW and SE allochthonous masses (Fig. 4 and 8) that are originated from the Asmari limestone rocks (Fig. 9 and 10 ; Table 1) of the Mish anticline formed on the MFF hanging wall are also of thrust related collapse structures type.

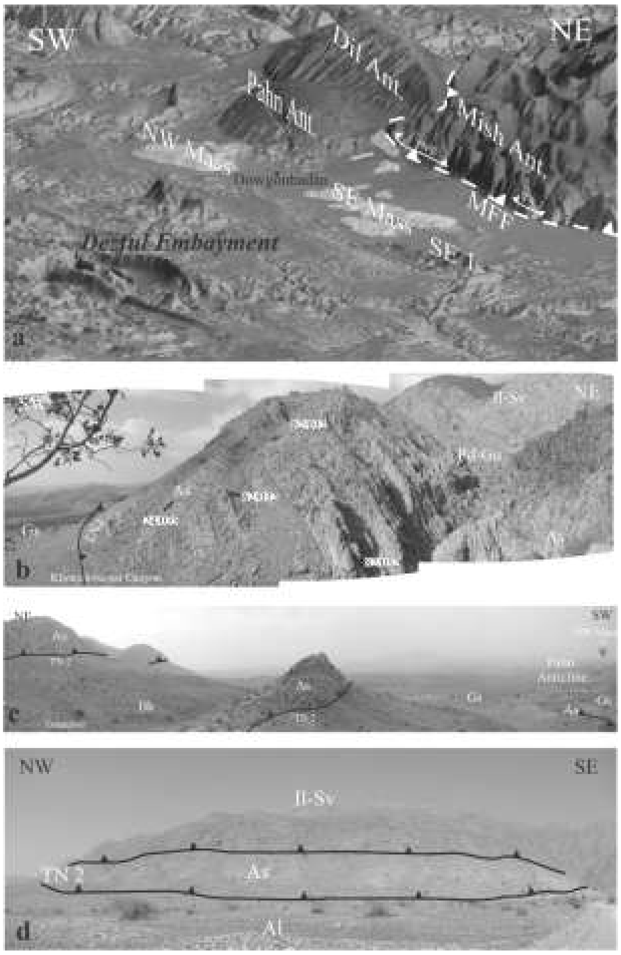

Figure 8: a) The Digital Elevation Model (DEM) of the study area show the location of Mish, Dil and Pahn anticlines as well as the NW and SE allochthonous masses (light colors), b) Overturned Asmari Formation over Gachsaran Formation along the TN2 fault, c) Thrusting of Asmari Formation over Gachsaran and Bakhtiayri formations. Note to location of the NW mass, d) The TN2 Fault along which the Older Sarvak Formation is thrust on Asmari Formation in the Mish anticline forelimb

The location of NW allochthonous mass near the Pahn anticline, composed Asmari Formation, might imply that the mass has originated from the anticline (Fig. 4, 8a). However, the Pahn anticline fold layers neither show any sign of sliding layers or discrete rock blocks similar to that on the Dil anticline northern limb (Fig. 6) nor its front limb is overturned (Fig. 11). Thus, the source for the NW allochthonous mass is not the Pahn anticline and therefore, should have originated from the next Asmari limestone outcrop, that is, overturned forelimb of the Mish anticline (Fig. 8a and b) in which several thrust faults put Asmari Formation over Gachsaran and Bakhtyri formations (Fig. 8c and d, and 11). The presence of such thrusts can be seen not only on the overturned front limb of the Mish anticline but as crushed zone at the base of masses overlaying Bakhtyari and Gachsaran formations located far from the anticline to the south (Fig. 9) and also further to the south of the mass (Fig. 4).

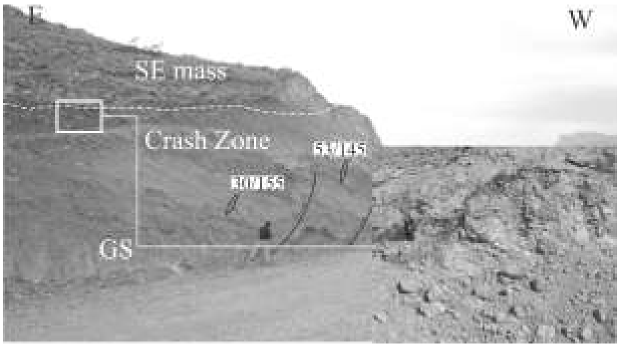

Figure 9: Show thrusting of horizontally eastern allochthonous mass (SE mass in Figure 4 over the Gachsaran Formation. Note to development of crushed zone at the base of the mass

In the overturned forelimb of the Mish anticline splays of the MFF puts the Asmari Formation along high dip angle thrusts over the Bakhtyari and Gachsaran formations (Figure 8b) whereas far from the anticline to the southwest, the Asmari Formation overlay the rock formations along a low dip angle or almost horizontal thrust (Figure 8c). The un-deformed fold surface of the Pahn anticline that should have acts as an obstacle for the sliding of the NW mass imply that the mass is not a common collapse structure related to the anticline amplification but show that its source most likely far to the northeast of the anticline where the splays of the MFF are present (Fig. 11). The development of crushed zones at the base of both the NW and SE masses not only constrains the allochthonous nature of the masses but also imply that they have moved from their source that are far from the masses to the northeast.

The MFF is the only regional structure in the study area that can have such a large displacement (Fig. 4 and 11). Development of thick crushed zones at the base of these allochthonous masses confirms their relocation through such large displacement. Therefore, it is proposed that these allochthonous masses are mainly formed by thrust faulting and moved toward south on hanging wall of low angel thrusts or nappes by the action of gravity. The combination of thrusting and gravity cause the masses to move in distance greater than 6 km which is also greater than the reverse displacement of the MFF (Fig. 11). Thrusting of the masses over the Pliocene-plictocene Bakhtyari Formation (Fig. 2) imply that they have emplaced at least since Pleistocene when the younger Zagros orogeny phase has occurred (Hessami *et al.,* 2006).

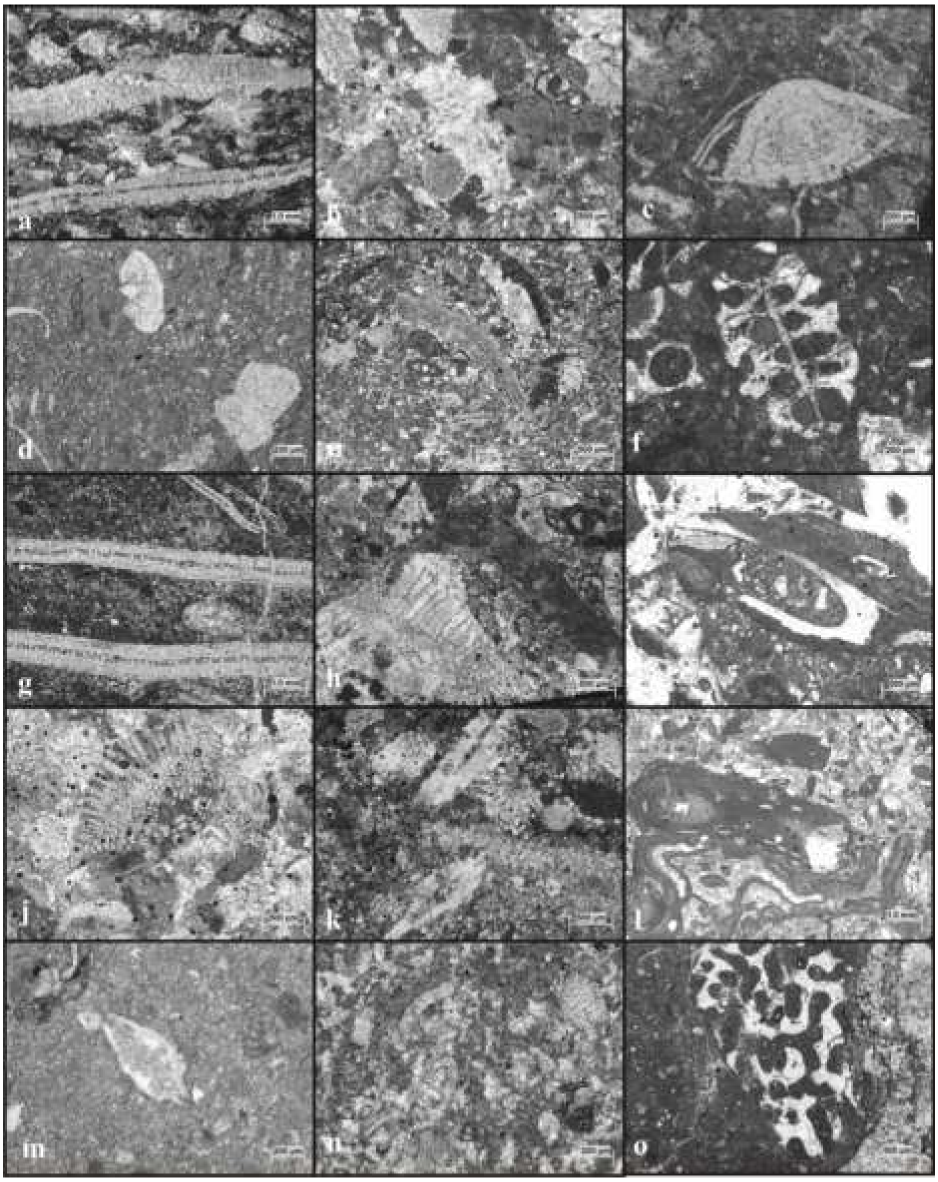

Figure10: Thin sections on samples collected from the NW and SE masses and Mish anticline forelimb, a) Euolepidina dilata, b) Sphaerogypsinaglobulus, c) Astrogerina rotula, d) Ammonia sp, e) Ecinoid and Discorbis sp, f) Bryozoa-tubucellaria sp, g) Eulepidina dilatata, h) Lepidosiclina sp, i) Lithophylum sp, j) Nepherolepidina tournoeri, k) Operculina sp, l) Lithotamitaminium sp, m) Ostracod, n) Rotalia vienotti, o) Coral.All of the funa are located on Miocene until Oligocene and are index funa for Asmari Formation

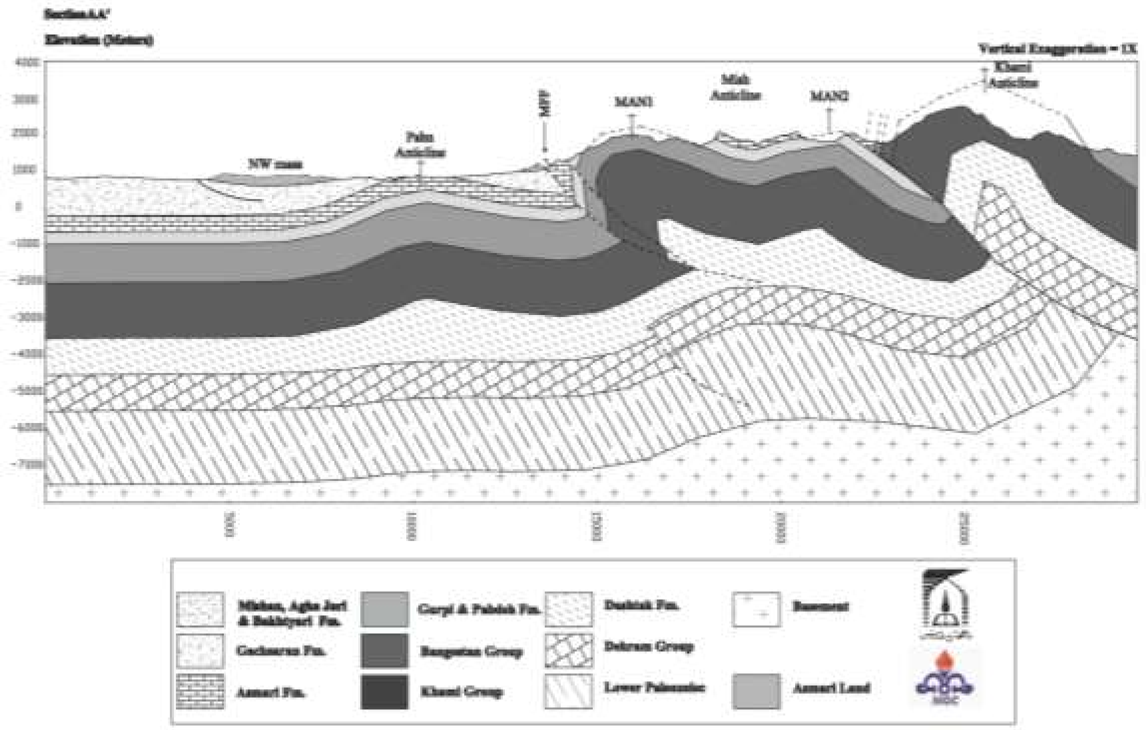

Figure 11: AA' cross section across the study area. Note to location of the NW mass. For the section line refer to Figure 4.

Evidence on source and location of the allochthonous masses presented in this study demonstrate the effect of thrust faulting in formation of collapse structures in ZFTB. These structures are different from common collapse structures, introduced by Harisson and Falcon (1934, 1936), in their large volume, thick basal crushed zone, and amount of emplacement from their origin bed rock. This analysis is compatible with DeSitter (1956) and Sherkati *et al.,* (2005) proposals' that pure gravity forces cannot only be the main source for collapse structures in the ZFTB. Similar collapse structures in Atlas Mountains are proposed to form by action of both tectonics and gravity by Saint Bezare *et al.,* (1998).

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