

Complex Tectonic History of Al-Yutamah Dome Area within Hijaz Terrane, Arabian Shield, South of Al Madinah, Saudi Arabia

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Abstract: This paper documents the Al-Yutamah tectonic dome, located in the northwestern part of the Arabian Shield, Saudi Arabia. A new Infracambrian over-thrust fault zone is mapped, which superpose the Late Proterozoic rocks in the area. Kinematic indicators suggest top-to-the-south movements along this fault, mainly compressional and some extensional in nature. The area experienced several tectonic events that resulted in to a complex dome like structure formation with a surface area of $20 \times 50 \text{ km}^2$. The S_1 cleavages, which have been determined as the oldest structural features in the area, are attributed to (D_1) tectonic event along the Labunah Thrust Fault. This event was followed by another deformational event (D_2) that produced N-S trending F_2 folds in the area. The third deformational event (D_3) observed in the area is the brittle high-angle reverse faults, which generally dip toward north and south, suggesting compressional nature of the event. Fourth deformational event (D_4) in the area resulted in the formation of E-W trending F_4 folding, which occurred subsequent to the development of Najd Strike-slip Faulting and F_2 folding. Superposition of the F_2 and F_4 folds in the area developed a complex structural feature in the shape of Al-Yutamah dome. Overthrusting of the meta-sedimentary rocks as a result of movement along the Al-Yutamah fault is considered as a fifth tectonic event (D_5). The Al-Yutamah over-thrust fault is most likely late Infracambrian in age, which is associated with the Najd Strike-slip Fault zone. The Cenozoic listric faulting that probably exhumed the dome is considered as a sixth deformational event (D_6) in the area. During the Cenozoic, cross-cut faults developed in the dome by high-angle normal faulting that dissected it into different segments.

Keywords: Al-Yutamah Dome, superposed folds, Labunah Thrust Fault, Al Madinah.

1. INTRODUCTION

Although, the Neoproterozoic (900 - 550 Ma) Arabian Shield is considered as a juvenile shield [1], it underwent several phases of subduction, amalgamation and post-amalgamation tectonic events, which resulted in to a reworked complex continental lithosphere of the heterogeneous terranes [2-8]. Amalgamation of these terranes formed the Arabian Shield by accretion and juxtaposition of the oceanic slivers. Slivers are mainly ophiolitic in nature, which occur within the arc-arc suture zone [9]. Post-amalgamation deposition, accompanied by extension, was followed by collision tectonics [2, 8]. All these tectonic events are in one way or another linked to different grades of metamorphism and plutonic emplacement.

The Arabian Shield has been divided into western and eastern parts [1]. The western part (oceanic crust affinity) extends over the Red Sea to African continent, and is made of four terranes. From north to south, they are Midyan, Hijaz, Jeddah and Asir terranes. On the other hand, eastern part of the Arabian Shield is believed to have mainly continental crust affinity, which consists of Khida, Afif, Ar-Rayn, Ad-Dawadimi and Hail terranes.

The Thurwah-Bir Umq Suture (TBUS) zone, which separate Hijaz terrane from Jeddah terrane in the western part, extends up to 300 km towards northeast from Rabigh Town, *via* the Red Sea coast, to Bir Umq area. This suture zone has been named as Labunah Thrust Fault in the 1:250,000 geological maps of Rabigh and Umm Al-Birak [10, 11]. The TBUS zone contains NE-SW trending thrust faults, verging toward south and southeast. This suture zone, which evolved during the 783-764 Ma interval [1], is located at about 100 km south of the study area. Based on other assumptions, formation of the TBUS has been linked to collisions between intra-oceanic island arc and back arc terranes between 800 and 700 Ma [12-15]. In addition, they are considered as E-NE trending arc-arc sutures due to their association with ophiolite slivers (Fig. 1). The deformation occurred in the interval between 783 and 764 Ma is considered as one of the oldest tectonic events that affected the Arabian Shield.

The Najd Fault System (NFS), which is a NW-SE trending left lateral (wrench) strike-slip fault, is one of the structural features in the region that postdate the East African Orogeny (EAO) or the Pan African Orogeny [9, 15]. The EAO took place between 670 and 610 Ma as a result of collision between the east and west Gondwanaland [9, 15 and 16]. However, activities along the NFS occurred between 620 and 540 Ma, which significantly affected a part of the Arabian Shield with a total area of $1200-2000 \times 300 \text{ km}^2$ [17]. Displacements along the NFS vary from 2 to 25

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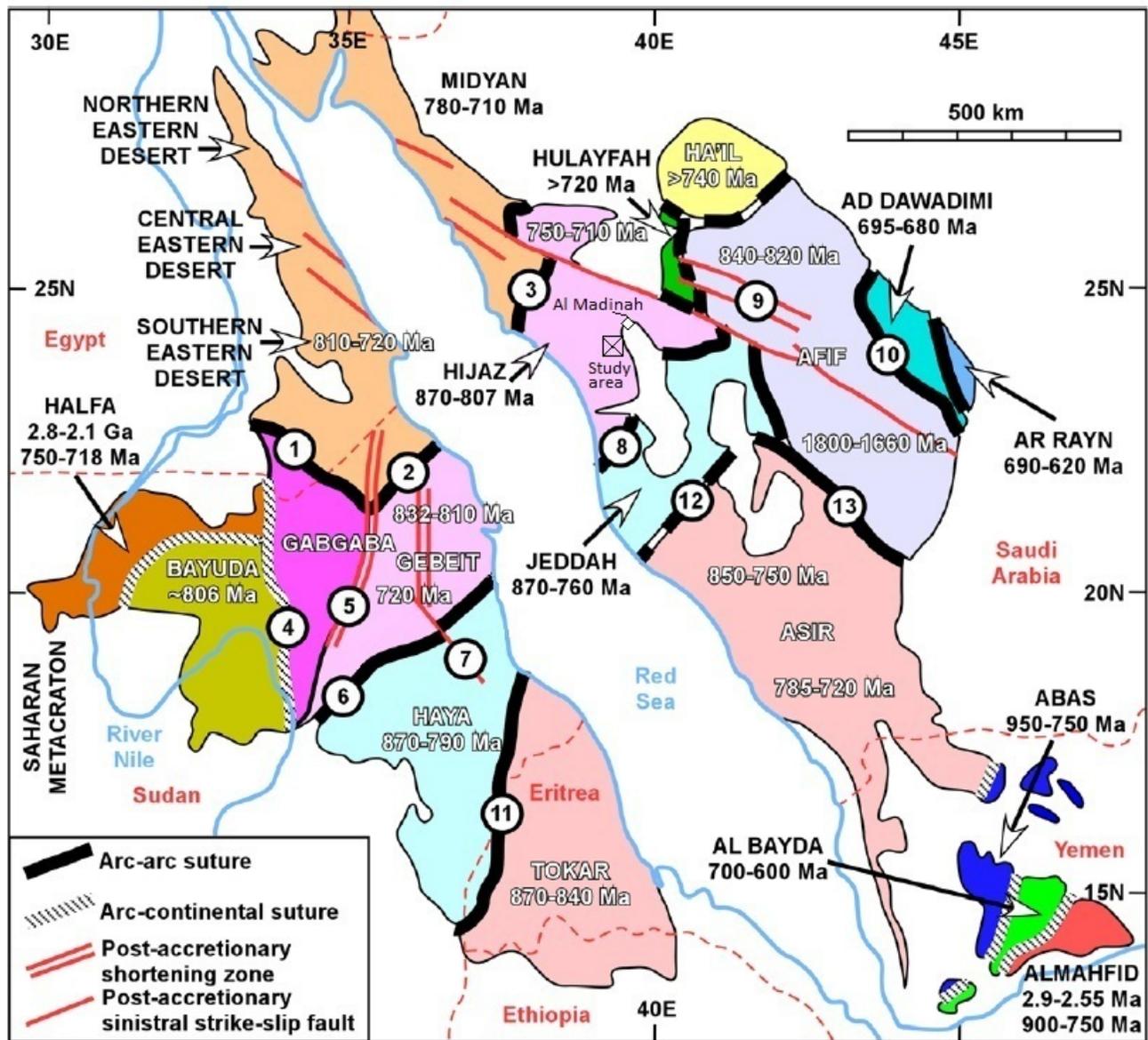


Fig. (1). Tectono-geological map of the Arabian-Nubian Shield terranes [modified after 15]. Location of the study area, south of Al Madinah, is marked on the map. 1 = Allaqi Suture, 2 = Sol Hamed Suture, 3 = Yanbu Suture, 4 = Keraf Suture, 5 = Hamisana Shear Zone, 6 = Nakasib Suture, 7 = Oko Shear Zone, 8 = Thurwah-Bir Umq Suture, 9 = Najd Fault System, 10 = Al Amar Suture, 11 = Baraka Lineament, 12 = Afaf Belt and 13 = Hulayfah-Ad Dalinah-Ruwah Fault Zone.

km and at some places they reach up to 40 km [18]. The NFS is also taken as an instigator for E-W trending folds in the area. Superposition of these folds on N-S trending fold structures caused a dome like structure formation and refolding of the strata in central part of the Arabian Shield [11].

During the Oligocene, western part of the Arabian Shield was affected by continental basaltic eruptions (alkaline) associated with Red Sea opening [19]. The Cenozoic tectonics resulted in to large thermal plume activity below the African Horn [20]. Remanents of this volcanism are mainly present in the Asir Terrane, western part of the Arabian Shield. From mid-Miocene, the western part of the Arabian Shield experienced intermittent intra-plate volcanic eruptions, known as the Harrat Volcanics. These volcanics

cover over 900 km long north-south zone, starting from north Yemen, through Makkah and Madinah to Nafud desert in the north. The northernmost 600 km long part of this zone is known as the Makkah-Madinah-Nafud (MMN) Volcanic Zone, believed to be the surface manifestations of mantle plume system [21, 23].

This study aims to present new mapping of the over-thrust fault zone, which significantly affected the Al-Yutamah structural Dome in the Arabian Shield. The study further aims to examine the origin of over-thrusting, whether it is related to late Proterozoic east-northeast trending TBUS zone or to Infra-Cambrian north-west trending Najd Fault system. The present study also shed lights on structural development in the Al-Yutamah area as a result of subsequent deformational events.

2. GEOLOGY OF THE STUDY AREA

The rock units exposed in the study area belong to Qahah Formation (Birak Group), which consists of mafic to felsic epiclastic rocks, conglomerate and subordinate volcanics [11]. The Birak Group rocks, which are affected by low-grade greenschist metamorphism, are overlain by Furayh Group rocks. The Furayh Group rocks were deposited in post-amalgamation basins [3]. The youngest rock unit of Ar-Rayyan Formation (about 1500 m thick) is exposed in the southernmost part of the study area, which unconformably overlies the Furayh Group. This Formation varies in composition from conglomerate-rich beds in the lower part to siltstone and shale in the upper part, with no traces of volcanic rocks [11]. The study area is geologically a part of southern Hijaz Terrane in western Arabian Shield, Saudi Arabia. Geographically, the study area is located in the vicinity of Al-Yutamah town, about 80 km south of Al-Madinah along the Makkah-Madinah (Hijrah) Highway (Fig. 2).

3. METHODOLOGY AND RESULTS

This study was conducted based on two aspects: field investigations and image interpretations. Field investigations were performed along the Hijrah Highway, which was

chosen as a main transect due to good rocks exposures. Most of the structural trends are oblique or perpendicular to the path of the road. Image interpretations were performed on Landsat ETM+ remote sensing data. The Landsat imagery is a false color composite image of bands 7, 4, 2 in red, green and blue filters (Fig. 2). In order to get reliable results, several image pre-processing techniques (such as geometric correction) and image enhancements methods (such as histogram stretching) were used for this study. The following sections describe and classify the investigated structural features from older to younger, such as pre-EAO, syn-EAO and post-EAO.

3.1. Pre- EAO Structures

3.1.1. Low Angle S_1 Cleavages

In the study area, S_1 cleavages are nearly flat surfaces and can be seen clearly in greenschist grade metamorphic rocks of the Birak Group for more than 20 km along the road. They are bounded by Furayh Group rocks from north and south in the core of Al-Yutamah Dome (Fig. 2). An over-thrusting structural feature together with low-grade greenschist metamorphism is observed in the Birak Group rocks of the area. This deformational event is considered as

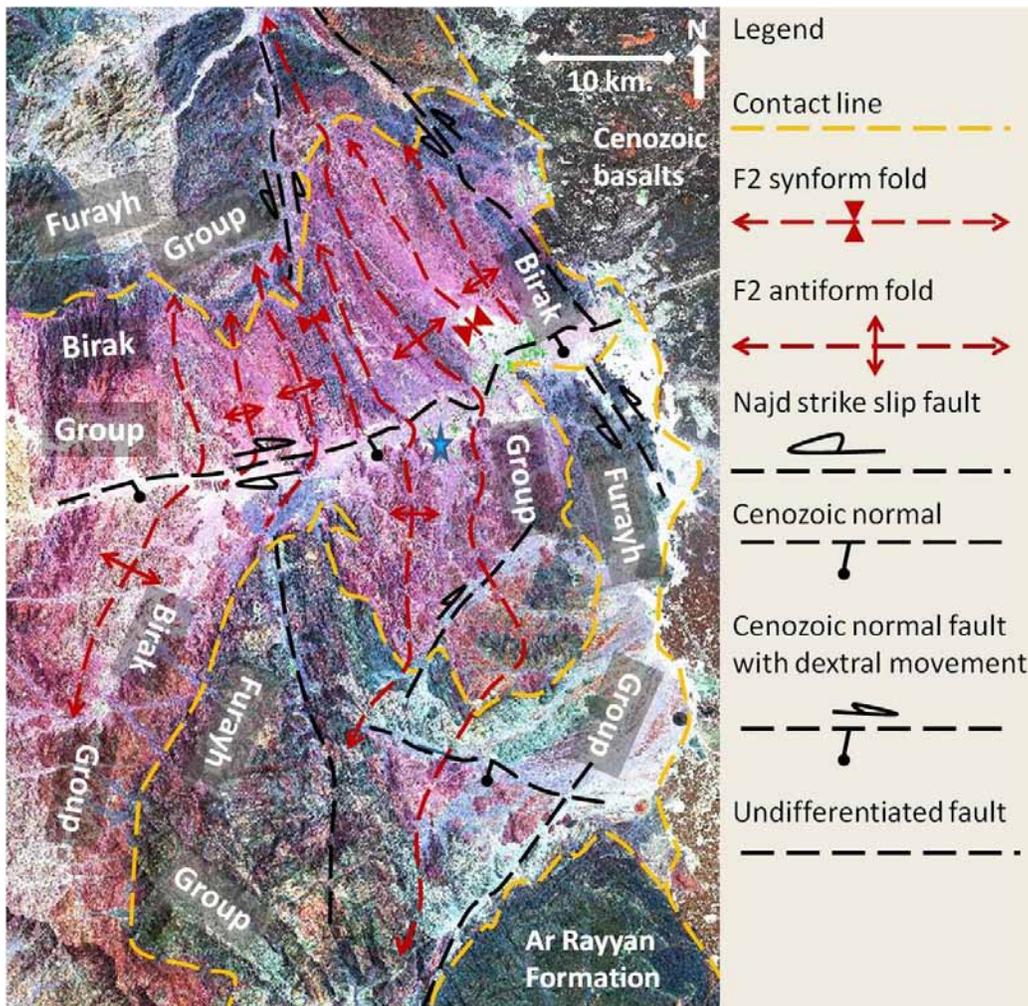


Fig. (2). Geologic map of the study area. This map is drawn using FCC image of 7, 4, and 2 bands in RGB from ETM+ data. Geologic relationships and structural features are taken from [11]. Blue star in the map indicates the Alyutamah town.

D₁, which is probably related to activities along the Labunah Thrust Fault.

3.2. Syn-EAO Structures

3.2.1. Development of F₂ Folding

The second deformational event (D₂) resulted in to F₂ folding and S₂ axial plane cleavages (associated with F₂ folds). This may be an oldest tectonic event occurred after the deposition of Qahah Formation and the development of S₁ cleavages. The structures developed by this event cross-cut the features of F₂ folding. The F₂ folding has generally N-S trending axial planes, suggesting an E-W directed compressional stresses caused by syn-EAO tectonic event.

The Furayh Group rocks consists of rhyolite tuff and marbled carbonates (similar to rocks of Ablah Group), which are affected by F₂ folding [8]. The intersection between S₁ and S₂ surfaces has produced pencil-like linear structures that plunge gently towards north. The lineations produced by S₁/S₂ intersection are only observed in the greenschist rocks of Birak Group, but not in the Furayh Group, suggesting that the Furayh Group of rocks were deposited after the development of S₁ cleavage development.

3.2.2. High-Angle Reverse Faults

Reverse faults in the area mainly trend in E-W direction and dip towards south and north, suggesting two sets of high-angle reverse faults (Fig. 3). These faults have been

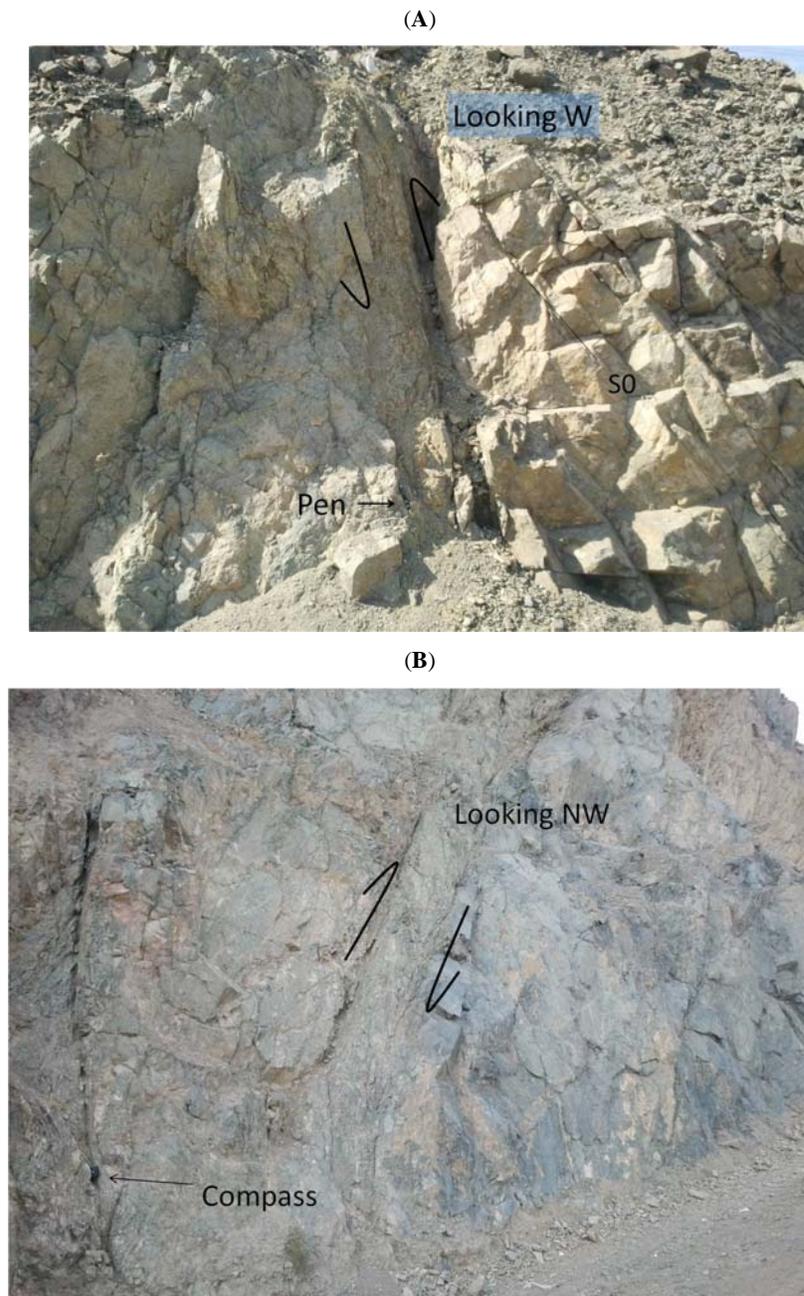


Fig. (3). Images (A, B) showing bedding surfaces (S₀) of the Furayh Group rocks, cut by high-angle reverse faults that dip towards the north, view looking W.

observed in the Furayh Group, which is considered as a post-amalgamation unit. These structural features are probably related to D_3 deformation in the area, which faulted the Furayh Group rocks against the Birak Group and juxtaposed them against each other. Depositional contacts between these two rock units are obscured by high-angle reverse faulting, which caused low-grade metamorphism in the Furayh Group rocks, as evident from the presence of phyllosilicate minerals. According to field observations, high-angle reverse faulting has dissected granitic rocks, which intruded the Furayh Group volcanic rocks, linking their occurrences to syn-EAO activities. The granitic rocks are, therefore, considered as post-tectonic intrusions with respect to the Furayh Group rocks.

3.3. Post-EAO Structures

3.3.1. Najd Strike-Slip Faults

The NW-SE directed left-lateral strike-slip fault is observed in the area, interpreted to be a part of the NFS (Fig. 2). This fault cross-cut the F_2 folding in the north and caused deformation in the Birak Group rocks. In the southeastern part of the study area, this fault is however covered by Cenozoic basalts. This deformational event, which is considered D_4 in order, produced the E-W trending F_4 folding in the area as a result of rotation along the F_2 folding by Najd Faults System [11]. Features related to Najd Fault System can be observed in the study area, which bound the Al-Yutamah Dome in the northeast (Fig. 2). The F_4 folding superposition on F_2 folding developed a large tectonic dome, in which older rocks of the Birak Group occur at the core,

(A)



(B)



Fig. (4). A. (A) Felsic sill cut through the rocks of Birak Group, which itself is then affected by a listric fault. This sill incorporates with over-thrust fault zone in Fig. (5). Dashed lines of 5 m long on the asphalt road are for scale. (B) Microgranite body faulted by high-angle normal fault against rhyolite tuff of the Furayh Group, view looking W.



Fig. (5). (A) Over-thrust fault zone with top-to-the-south kinematics, view looking E. Note that the fault zone is cut by listric faults. (B) Single overthrust fault surface occurs to the north and south.

and the outward dipping younger rocks of Furayh Group surround them.

3.3.2. Overthrusting Event

Overthrusting in the area is considered as fifth deformational event (D_5) that occurred subsequent to intrusions of the felsic dykes and sills (Fig. 4). These intrusive bodies were significantly affected by over-thrusting in the area. Kinematic analysis along the fault zone suggests that the fault is top-to-the-south and strikes generally in E-W direction (Fig. 5). It has reworked felsic and carbonate rocks

of the Furayh Group. The overthrust fault extends for several hundred meters with a single surface plane (Fig. 5b) and is mainly present in the Furayh Group rocks. The successive D_1 to D_5 events have probably increased metamorphism in the Birak Group from greenschist to amphibolites grade [11].

3.4. Red Sea Rifting Structures

3.4.1. Listric Faults Development

The EAO formed structures are found to be generally dissected by E-W trending and southward dipping normal

(A)



(B)

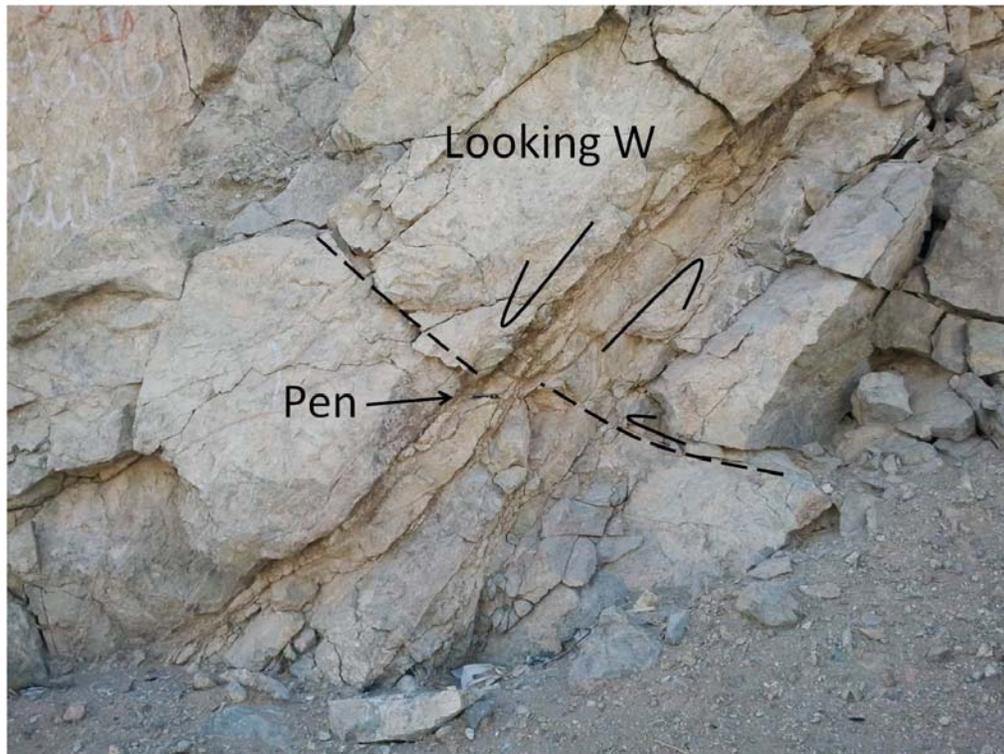


Fig. (6). (A) Listric faults cutting through the bedding of Furayh Group. (B) The listric faults can be observed in the Birak Group rocks, which cut the minor thrust faults. These phenomena are showing clear relationship between the two successive events.

faults (Fig. 6). These listric faults have probably exhumed and exposed low-grade greenschist core of the Al-Yutamah Dome during the EAO in a similar manner as the gneisses core of the Nubian Shield [24].

3.4.2. Cenozoic High-Angle Normal Faults

The Cenozoic extensional faults, both east-west and north-south directed, have broken the structural dome into

several segments (Fig. 2). These faults are parts of the Red Sea rifting, which seem to have strike-slip motion. They were probably reactivated as trans-tensional faults during the final stage of Red Sea rifting.

4. DISCUSSION

Tectonically developed Al-Yutamah Dome, which is located in the southern part of Hijaz Terrane, is mapped by this study. Deformational features produced by folding episodes (F_2 and F_4) and Najd faulting dominate the structural framework of the study area. These structures were developed in central part of the Arabian Shield as a result of post-amalgamation tectonic activities. The mapped F_2 and F_4 folds, located in the extreme southern part of the Hijaz Terrane, can be traced for several kilometers inward. In the study area, these folds are later on dissected by Najd Fault System as well as by Cenozoic faulting. These folding related tectonic events even affected the Ablah Group rocks of Ablah Graben (Asir Terrane) at about 500 km south of the study area. These rocks of Asir Terrane have been correlated with the Furayh Group rocks of the study area. In the Hijaz Terrane F_2 folding are more dominant in the greenschist grade metamorphic rocks. The E-W trending reverse faults have not been observed in the Asir Terrane. However, N-S trending high-angle reverse faults have been traced, which could be related to N-S directed folds in the area.

The Labunah Thrust Fault, exposed in the south of the study area, is associated with ductile structural features, such as nappe folds and mélange style [10]. However, an over-thrust fault in the study area exposed the brittle deformation, which has incorporated the metamorphosed carbonate and felsic rocks of the Furayh Group. The Labunah Thrust Fault was probably developed in a different environment, may be much deeper than the environment of the over-thrust faults in the study area. The Labunah Thrust Fault was probably developed as a result of oceanic crust subduction beneath the continental crust. On the other hand, faults in the study area are younger in age due to their formation at the time of continent-continent collision. It can thus be said that the Alyutamah Over-thrust fault is most likely related to the NFS development due to its cross-cut relationship with the late wrench activities and with the post-tectonic granitic intrusions.

5. CONCLUSION

The Birak Group of rocks in the study area is affected by low-grade greenschist metamorphism during the 783-764 Ma interval, when the Asir Terrane was probably subducting beneath the Hijaz Terrane. The rock units of the Birak Group may have developed S_1 cleavages during the 783-764 Ma interval. Rock units related to Furayh Group were deposited over the Birak Group rocks in post-amalgamation basins, and were not affected by structures related to D_1 deformation (S_1 cleavages). Following their deposition, the Furayh Group rocks were folded and faulted against the Birak Group rocks during the EAO tectonisms (D_2 - D_3). The pre- and syn-EAO (D_1 - D_3) structures development were followed by strike-slip faulting (D_4) that produced F_4 folding and formed a large dome structure. Activities along the NFS produced F_4 folding by rotating F_2 folds in the area. The easterly and westerly dipping limbs of this regional dome can be

observed along the transacted highway. Low greenschist grade metamorphic rocks constitute the core of the dome, forming it as a complex anticlinorium. Minor N-S trending F_2 folds can also be observed in some areas, particularly in central part of the dome. Greenschist grade metamorphism increased into amphibolites grade metamorphism, which may be due to successive tectonic activities. Over-thrust faulting in the study area (related to D_5 deformation) probably occurred subsequent to movement along the NFS.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGMENTS

The author is grateful to anonymous reviewers for their suggestions and comments that improved the text significantly. The author is also grateful to chief editor for his support. The author is also in debt to Prof. Haider Zaman and Prof. Zakaria Hamimi for their help, suggestions and comments that enhanced the manuscript.

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Received: April 22, 2013

Revised: May 29, 2013

Accepted: June 24, 2013

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