Geology, Geomorphology and Economic Potentiality of Al Barzah Depression, West Central Arabian Shield, Saudi Arabia

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Abstract: The study area located in the west central part of Saudi Arabia. It is about 150km NE of Jeddah city, and it is reached by highway from Al Haramain Road to the East and then NE. The present study aims to shed light on the geology, geomorphology and economic potentiality of Al Barzah area. The present study is based on the regional and detailed field works and mega-and microscopic investigations. Geomorphologically, the study area represents a closed depression occupied by Quaternary wadi deposits within the Arabian shield rocks. The rock units of the study area include gabbro, diorite and rhyolites of the Kamile suite that intruded by the Hashash Granites. The Hashash granite is highly weathered and is overlained by red clays and oolitic ironstones of Haddat Asham Formation. Tertiary black basalt (harrat) is present in the topmost part of the high scarps of the depression. The area is of characteristic geomorphologic features where it is bounded by scarps from the overall directions and comprises many residual landforms. The Quaternary groundwater aquifer is about 50m thick, and it is composed from gravels, sands. Many cultivated lands are present within the study area. The present study concludes the importance of Al Barzah area where it contains many natural resources. i.e. clay deposits, oolitic iron ores, granitic and basaltic rocks. Also, large areas of cultivated lands and Quaternary groundwater aquifers are present.
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1. Introduction

1.1. Literature Review

Al Barzah, Madrakkah and Haddat Asham depressions form a characteristic triangle in westcentral Arabian shield. These depressions form a characteristic green color areas within the Arabian Shield rocks (Fig. 1). These three depressions are lithologically and structurally controlled in their origin and mechanism of formation by the presence of many wide areas (wadies) raining in two main directions (NW and NE) of faults (Fig. 1). The geology of Makkah area appears in the publications of Larken 1936, Karpoff 1955; 1957a, b; 1958; 1960; Brown et al. 1963; Al Shanti 1966; Hashem 1971; Nebert et al. 1974; Skiba et al. 1977; Tayeb 1983; Moore and Al-Rehaili (1989; Sonbul (1995; Al-Harthi & Amin (1997) and Johnson 2006.

1.2. Aims of the Study

This present study aims to give detailed geology of Al Barzah area. The geomorphological features and description of the different landforms and economic potentiality of Al Barzah area are also achieved. Also, the study deals with the clarification of the different geomorphologic processes that resulted in the formation and evolution of the landforms of the study area.

1.3. Methods of Study

This study is based on detailed field measurements and descriptions of the different landforms. Global mapper and Arc GIS programs are used in the preparation of satellite images and geologic maps as well as the topographic and contour maps. CorelDraw 12 is used for Stratigraphic sections.

1.4. Geologic Setting

Geologically, Makkah district contains four main rock units from older to younger as follows: Arabian Shield rocks, Tertiary sedimentary succession, Tertiary basic volcanics (Harrat) and Quaternary wadi deposits (Fig. 2). The geology of Makkah district is shown in the publications of Moore and Al Rehaili (1989) and Johnson (2006). The Arabian Shield rocks are represented by different rock units. According to Johnson (2006), Makkah suite (Tonian age $\simeq$ 1000 m.y) is recorded in the southern flank of wadi Fatima and it is represented by plutonic basic, intermediate and acidic igneous rocks (Gabbro diorite and granites).

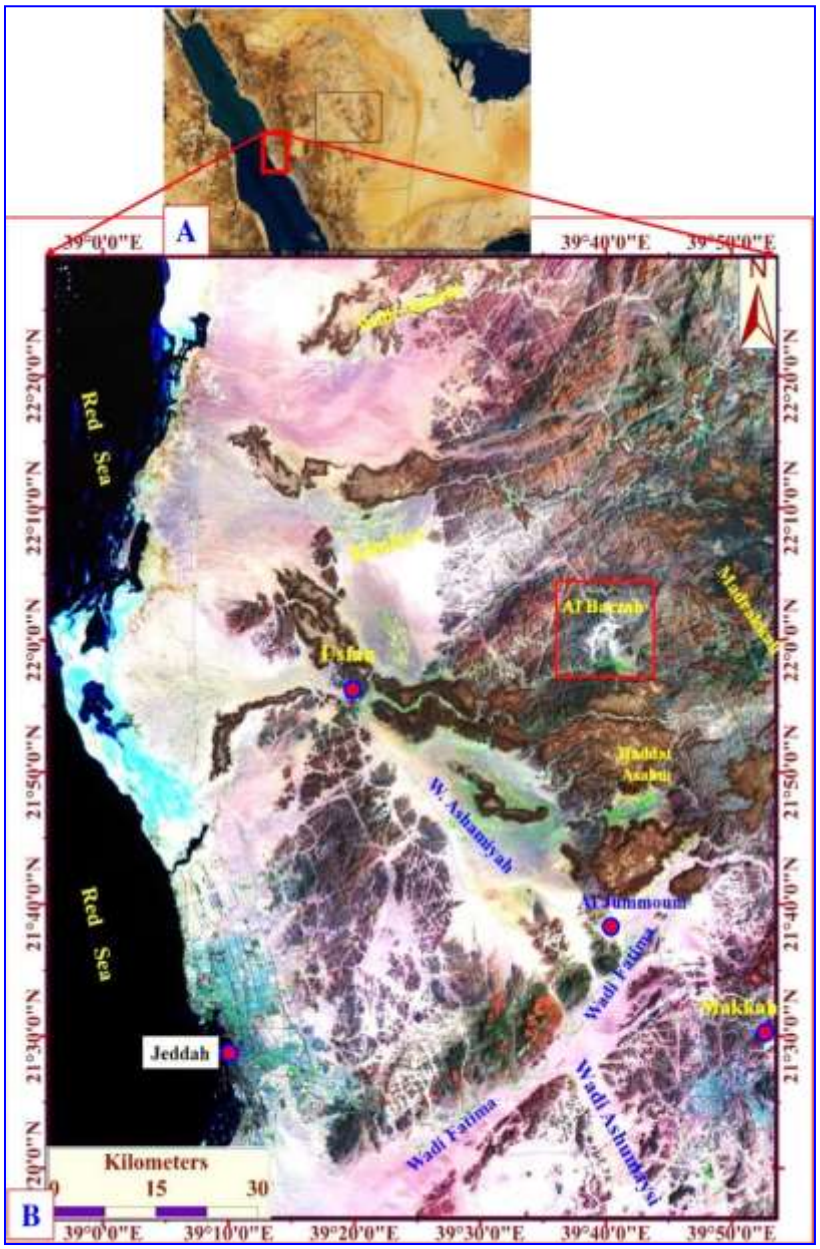

Figure 1: Satellite image of Makkah district showing the location of Al Barzah Depression

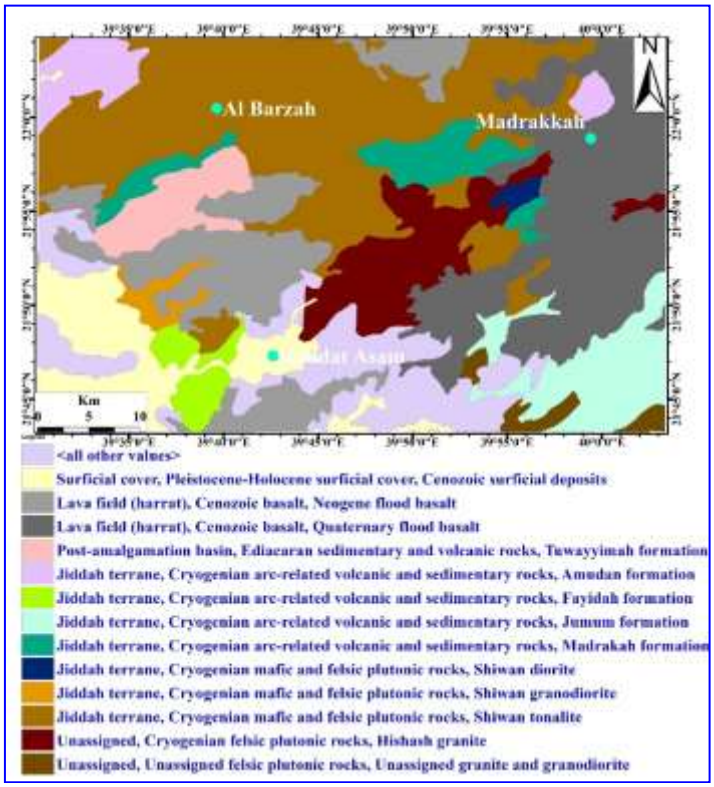

Figure 2: Geologic map of Haddat Ash Sham-Al Barzah and Madrakkah triangle (Johnson, 2006).

The Cryogenian rocks are presented by the layered Cryogenian rocks and the Cryogenian intrusive rocks. The main layered island arc layered rocks are represented along the southern flank of wadi Fatima by the sheared rocks of Jeddah Group (mainly green schist and amphibolite). Along the northern flank of wadi Fatima, post amalgamation basin rocks are represented by the succession of Fatima Group. Toward the north in Usfan area, these rocks are replaced by the succession of Samran Group (Gabal Samran area). The Samran Group are represented to the east of G. Samran area, by non-metamorphosed volcano-sedimentary succession of Madrakkah and Faydah formations (Figs. 3).

The intrusive Arabian Shield rocks are represented by Gabbros, diorite and granites of Kamil and Hishash Suites. In wadi Fatima area, these rocks are represented by pre-Fatima granite diorite and Gabbro. The Tertiary sedimentary succession is represented by thick ironstone-bearing clastic succession of clays, siltstones and sandstones of Ash Shumaysi, Haddat Asham, Usfan, and Khulays formations. Thin yellow dolostone interbeds are present within this succession specially in Haddat Asham and Usfan areas. The Tertiary basalt (Harrat) covered a vast area in the north and east of Usfan (Figs. 3). The Quaternary wadi deposits cover vast areas within the main NW and NE wadies.

According to Moore and Al Rehaili (1989, Fig. 3), the following rock units are described: **a) Samran Group** which consists originally of mafic to felsic lavas and volcaniclastic rocks with subordinate sedimentary rocks. In many places the original volcanic, volcaniclastic, and sedimentary textures are preserved, but elsewhere deformation and metamorphism have caused the development of chlorite, chlorite-sericite, quartz-sericite, and quartz-feldspar schists. The name Samran group was first applied in the Rabigh Khulays area by Skiba and Gilboy (1975) to rocks originally shown as Jeddah greenstone on the 1:2,000,000-scale Arabian Peninsula geologic map (USGS and Aramco, 1963); **b) Madrakah Formation** (sm) which occurs as large keel-like masses, rafts, and screens within and between plutons of the Shiwan and Hafnah batholiths in the north-central and west-central parts of the quadrangle. It consists predominantly of andesitic to basaltic lavas, subordinate andesitic volcaniclastic rocks and dacite, together with felsic pyroclastic rocks and minor metasandstone and marble.

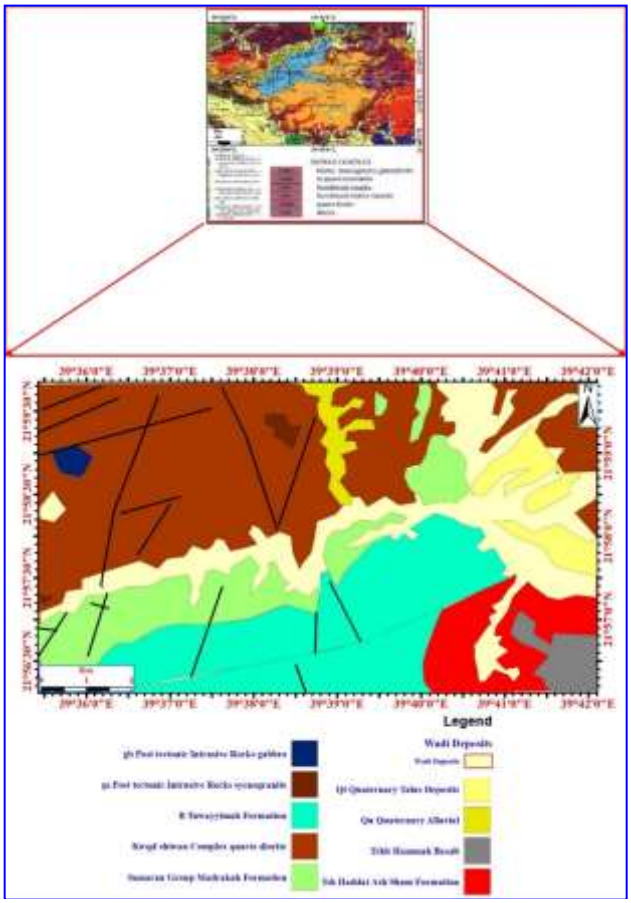

Figure 3: Detailed geologic map of Al Barzah area (modified after Johnson, 2006).

The name is a modification of the Madrakkah sequence of Skiba et. al. (1977) and was introduced by Khallaf et. al. (1980) for volcanic rocks that form rafts within the Hafnah batholith and an envelope around its southwestern flank; **c) Tuwayyimah Formation (ft)** were first assigned to the Fatima group by Skiba et. al. (1977). The Tuwayyimah and Daf formations may be lateral equivalents. It consists mainly of volcaniclastic rocks that are predominantly basaltic to basaltic andesitic, although there are some of felsic composition; mafic lavas are intercalated with the volcaniclastic rocks.; d) **Kamil Suite (Shiwan Complex)**, the Shiwan complex (Ramsay,1983) forms the large Shiwan batholith that occupies much of the south-central part of the Rabigh quadrangle and extends southward into the extreme north-central part of the Makkah quadrangle. The complex consists of hornblende tonalite (kwtn), hornblende-biotite tonalite (kwU), quartz diorite (kwqd), diorite (kwdi), granodiorite to quartz monzonite (kwgq), and biotite monzogranite (kwgm) in order of decreasing abundance; **e) Hishash Complex** (late-tectonic intrusive rocks) the Hishash complex (igm, igd), named after Wadi Hishash, it is composed of monzogranite (igm) but substantial amounts of granodiorite (igd) (tonalite of Skiba et. al.,1977), are present at the periphery of the pluton, especially in the southeast. Granodiorite exposed northwest of the Hadat Ash Sham- Madrakah road and mapped as quartz leucodiorite of the Fayidah pluton by Skiba et. al. (1977), and f**) Unassigned Plutons** these are predominantly granitic- alkali-feldspar granite (gf), syenogranite (gs), granite (gr), monzogranite (gm), and two-mica granite (gmb), a few are granodioritic(gd) and gabbroic (gb), and there are irregular masses of pegmatite (peg). **Hadat Ash Sham Formation** (Tsh) occupies the Sham trough and the age of the formation is not known. Because it occurs in the most easterly, and thus possibly the earliest formed through, the Haddat Ash Sham Formation could be the oldest unit of the Suqah group.**Hammah Basalt which** consists mainly of olivine basalt and minor pyroclastic deposits. It presumably overlies the Shawahit basalt in the northeast of the quadrangle, but elsewhere rests directly on Precambrian or Tertiary rocks. Individual

lava flows are from 3-60 m thick; they have not been mapped separately in this compilation but Smith (1981,1982) and Camp and Roobol (1987) delineated some of the major individual flows from aerial photographs and satellite images. **Quaternary Deposits** cover extensive areas of the quadrangle, principally on the coastal plain, but also in the large inland drainage basins of Wadi as Suqah, and Wadi Fatima, and the 'Uranah, Malakah drainage systems. The deposits have been divided into seven units. The oldest is raised reef limestone (Qc) that crops out along the coast of the Red Sea.

2.Geomorphology of Al Barzah Area

Al Barzah depression is of n shape where it represents an area of intersection of group of wadies from SE, NE, NW and SW (Figs. 4A, B). The floor of this depression is composed from coarse acidic volancilastics (weathered granites?). The core (central part) of the depression is represented by intrusive and layered Arabian Shield rocks. The GDEM of the area shows the presence of relatively higher central part and the eastern and the western scraps. The contour maps of the study area show the lowest elevation (green areas, 30m and the highest elevation red areas, 240m, Fig. 4C).

Geomorphologically, the area is accessible through good networks of highways. The eastern and western scarps and the northern plateau are of high topography. The central part of the depression contains many vast areas containing very small residual landforms. These small residual landforms are structurally controlled. The landforms of the central part of the depression are composed of two main units: lower slope-forming friable coarse acidic volcaniclastics which grades upwards into hard step unit of bedded volcanics and related volcaniclastics. The rosette forms of the northern part of the central rock mass of the depression and is related to the very tight group of antiforms and synforms (Fig. 5A, B). This northern part contains a characteristic very narrow small depression (green color). This is related to the very drastic changes that related to the style of folds and faults (Fig. 6A, B). The landforms of the study area are lithologically controlled where the low- lying residual hills are represented mainly by the acidic coarse volcaniclastics (weathered granite unit) while the steep landforms are represented by the bedded volcanics and related volcaniclastics. Some small, elongated landforms are present in the northern part of the study area (Fig. 7A, B).

Al Barzah area is very important green (cultivated) window within the overall desert character of Saudi Arabia. The area is of characteristic geomorphologic and geologic setting:

1) It represents one of the small empty diagnostic areas nearby the main structural belt of the red sea coastal zone. The area is located within the belt of the Arabian Shield of the western part of Saudi Arabia. The area contain lower coarse crystalline acidic igneous rocks and volcaniclastics that overlaid by layered volcaniclastics and the related volcaniclastics. Tertiary sedimentary succession was recorded and described in the study area for the first time.

2) The satellite images of the study area (Figs. 4A, B, C) revealed that, the area represent major N-S fold that contains small group of folds along their limbs. The area represents a low topography downstream area of many wadies coming from the north and the coast. This water is directly shifted toward the west in a main E-W wadi to the north of wadi Fayda (Fig. 1). The shape of Al Barzah area is related to the presence of major N-S series of alternating anticlines and synclines (Figs. 4A, C). The n shape of the main landmass represents a major syncline bounded from the east and the west by major anticlines (the main eastern and the western wadies). This central syncline contains numerous synforms and antiforms specially in its northern part (Figs. 6 & 7). From the geologic points of view, the southern part of this landmass is occupied by layered succession of green and red volcanics and the intercalated volcaniclastics (green tuffaceous mudstone) unit of the geologic map of (Fig. 8). The central part of this landmass is occupied by layered acidic volcanics, volcanics and
friable granite. Along this area, the main NW trending highway is present (red line of Figs. 8, 9). To the north of this highway, (blue area of Fig. 9), bedded basic volcanics and the associated volcaniclastic is present (Fig. 9).

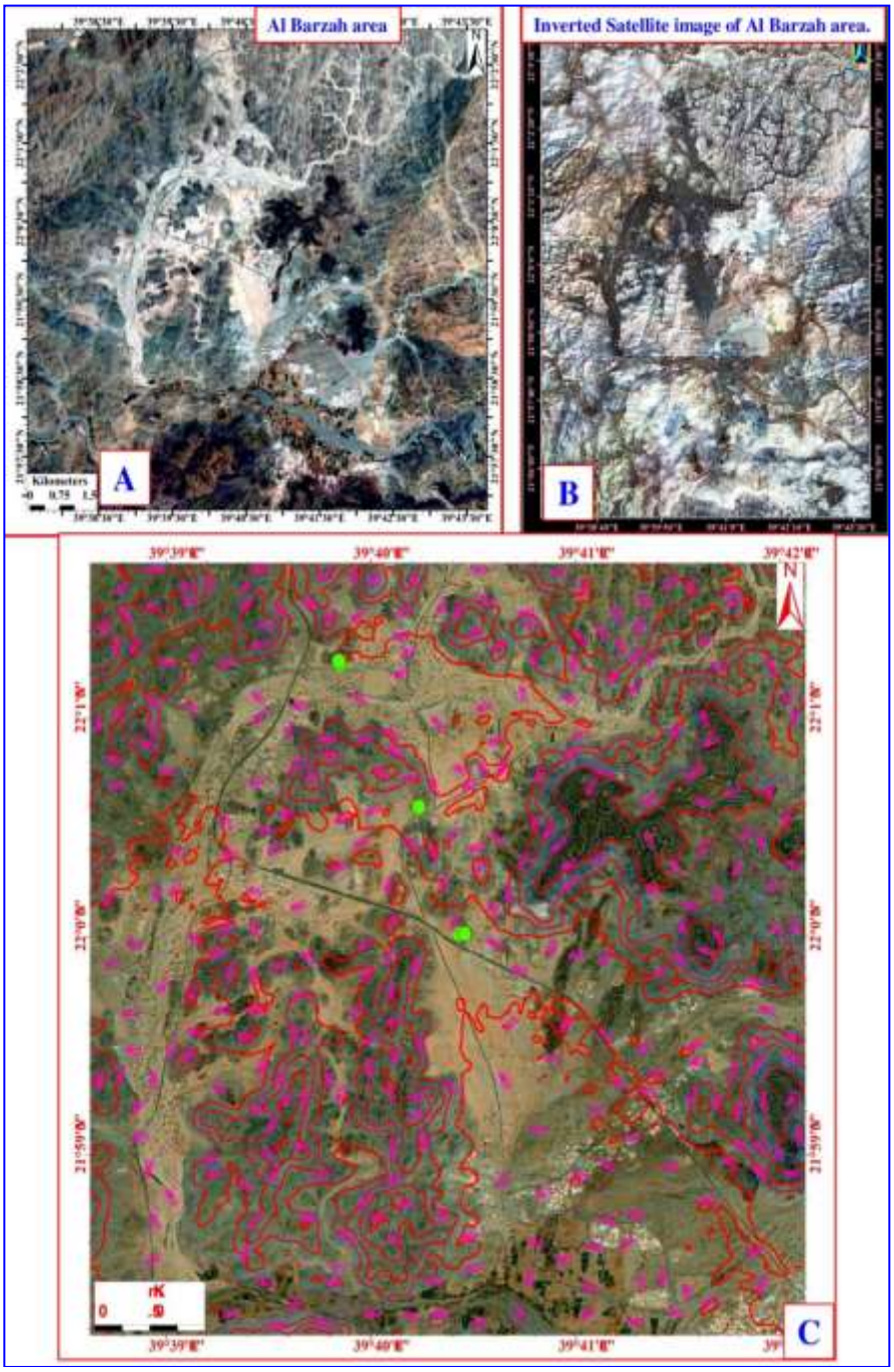

Figure 4: A=Satellite image of al Barzah area showing n shape; B= Inverted satellite image of the study area; C= Contour lines of the satellite of Al Barzah area.

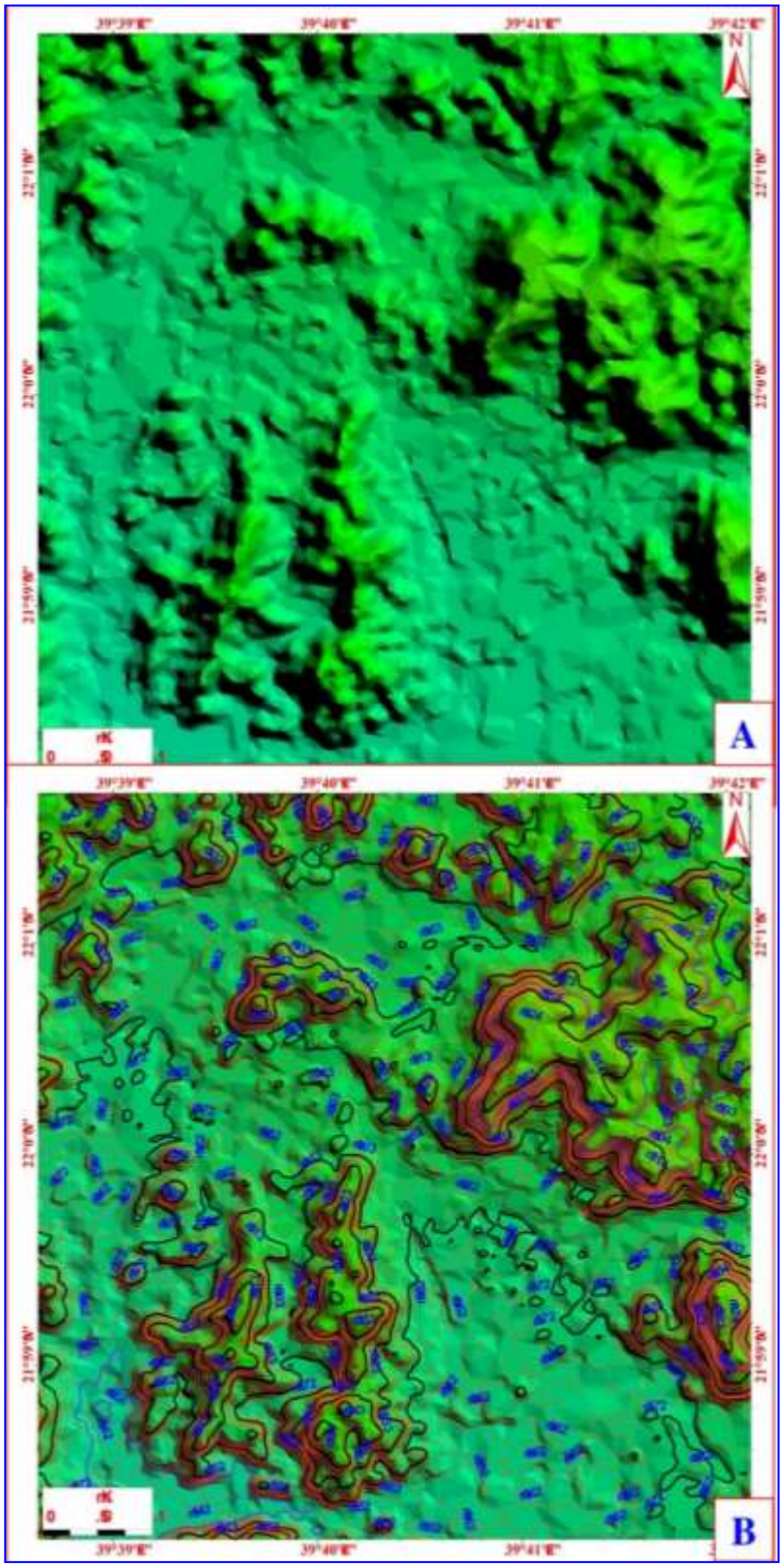

Figure 5: A= 3D Aster GDEM of Al Barzah area, B= contour lines of Al Barzah area.

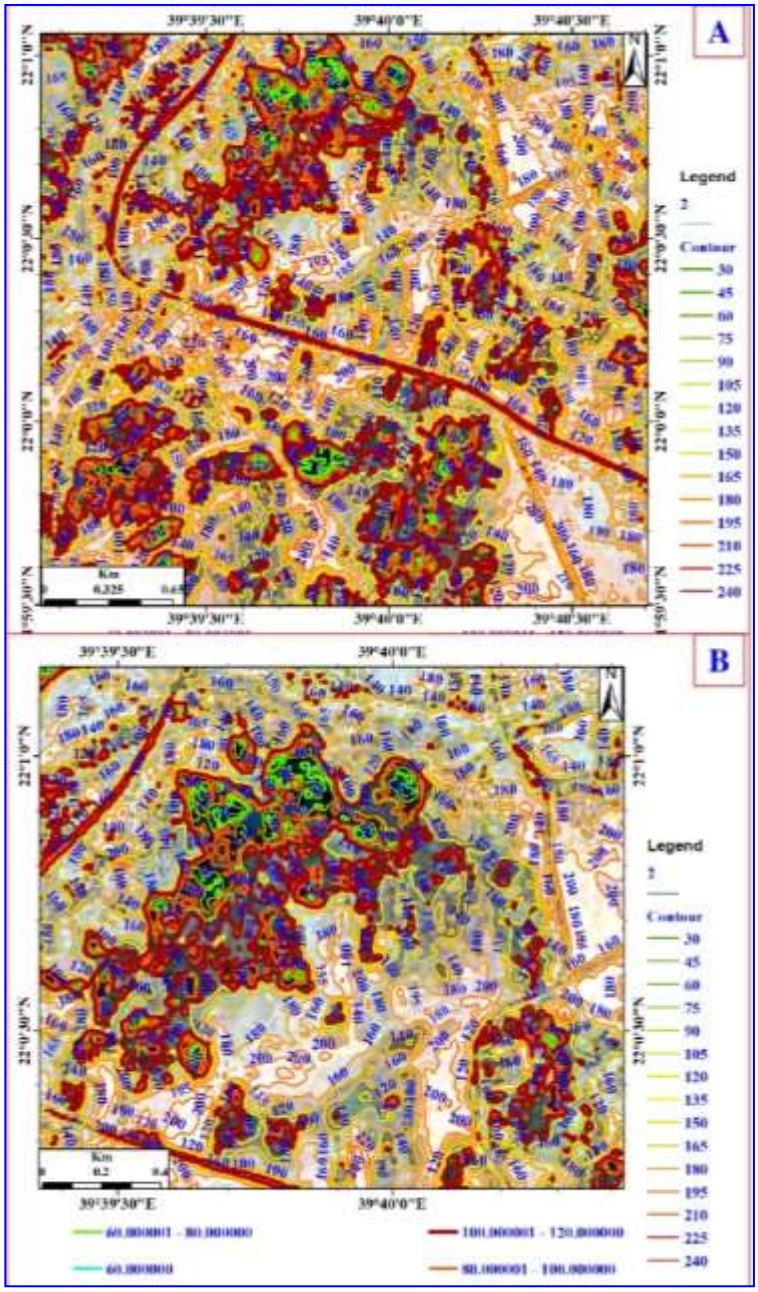

Figure 6: A= Contour maps (topography) of Al Barzah area showing the different landforms, B= Contour maps (topography) of the different landforms of the northern part of Al Barzah depression.

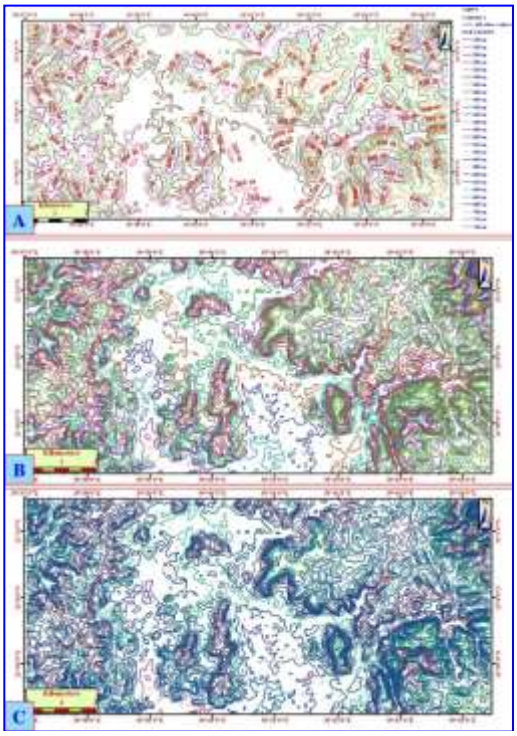

Figure 7: A, B, C= Contour maps (topography) of Al Barzah area showing the different landforms. i.e. embayed scarp, elongated residual landforms and small cone-hills of the southern part of the depression

3.Detailed Geology of Al Barzah Area

Al Barzah area, i.s. of characteristic geologic setting. The area was subdivided into 6 zones from the eastern side to the western side in anti-clock wise direction (Figs. 8, 9). These zones are A, B, C, D, E, F. The area of zone A, B is represented by the high eastern scrap of the study area. The western scarp is represented by zones E, F while the central part is represented by zone C, D. The detailed field works of this area led to the recognition of 5 main rock units which are presented in the geologic map of figure 10 and the stratigraphic sections of figure 12. The detailed description of these units is given below in the next lines.

1. Coarse acidic volcaniclastics granite and rhyolite; This unit is almost recorded in the central part of the depression (Figs. 9, 10). It consists of cyclic friable argillaceous acidic volcaniclastics that terminated with thin Cu-bearing hard pink granitic and rhyolitic zones. These volcaniclastics are thinly laminated and thinly bedded. Thin white quartz veins and /or K-feldspar laminae are observed. These friable zones are spheroidal weathered giving rise to small rounded landmasses in the floor of the depression. Small thin andesitic flows are observed int the lower part of depression. This unit is recorded in the highest landform in the northeastern corner of Al Barzah depression (Fig. 9). In this area, the coarse acidic volcaniclastics is highly weathered giving-rise thick white kaolinitic regoliths resulted from subaerial weathering processes. This unit is overlained by red unit of interbedded ferruginous clays and fine sandstones. This unit terminated with the next bedded grey tuffs and black basalt.

2. Bedded basic volcanics and volcaniclastics. This unit forms a characteristic step ledge- forming unit. It consists of interbedded andesite/ andesitic tuffs and rhyolite. It is dominated in the eastern and southeastern part of the study area. This unit is highly folded and faulted and dominated in the southeastern corner of the depression area (Fig. 12A, B).

3- Green tuffaceous mudstone. This unit forms a characteristic flat- lying zone just underlying the red zone of Haddat Asham Formation and underlying the Black basalt (Harrat). It consists of interbedded green tuffaceous mudstones, tuffaceous basalts and green clays (Fig. 13A). This unit is dominated in the eastern and northeastern scarps of Al Bazah depression. In the eastern scrap of the depression, this unit attains up to 150m thick and it is composed from successive cycles of scoraceous basalt and light calcareous sandstone beds. In this scarp, this unit is terminated with vescicular and amygdaloidal basalt unit (Fig. 13A). Towards the central part of the depression, thin red characteristic red zone of Haddat Asham Formation is present in between this unit and the topmost black basalt (Harrat).

4.Haddat Asham Formation. This red unit is only described in the eastern part of Al Barzah depression (Fig. 13B). It represents a lateral facies change of the above mention unit of the bedded basalt unit. This unit is present in two main areas, the thickest one is present in the southeastern corner of the depression (Fig. 11B, Column 1, 2 and column 5, 6) and the second one about 4 km NE of the first occurrence.

5. Black Basalt (harrat): This unit is present as black horizontal unit in the submit of most of the high mountainous region in both the eastern and western scraps of Al Barzah depression (Fig. 8).

The geologic map of the study area (Fig. 10) revealed the presence of wide empty areas free from any landforms specially in the eastern and southeastern parts of the study area (Fig. 10; Fig. 11A). N-S trending rock mass is present in the western part of the study area. The stratigraphic sections of the study area (Fig. 11B), revealed that:

A. The eastern scarp of the study area (Sectors A, B; Sections 1, 2 of Fig. 9). in this area, there are four main rock unit:

i) Interbedded coarse acidic volcaniclastic-friable weathered granite/ rhyolite. This unit forms characteristic low-lying unit in the floor of the depression.

ii) Interbedded dark green basic and intermediate volcanics and related volcaniclastics: This unit forms a characteristic light green unit in the middle part of the eastern scarp of Al Barzah depression (Figs. 14B & 13A). This unit is highly folded and faulted (Fig. 14A, B). It shows drastic thickness and lithologic changes from the southern to the northern part of the eastern scarp.

iii) interbedded light green tuffaceous mudstones and sandstones: this unit is well represented in the Al Barzah area. It forms a characteristic slope green volcaniclastic unit (Fig. 13A). This unit is related to the volcanisms of the lower part of basic volcanism (Harrat) of the western part of kingdom of Saudi Arabia. It shows lateral and vertical facies changes to the basalt and basic tuffs of many areas in Al Barzah- Haddat Asham.

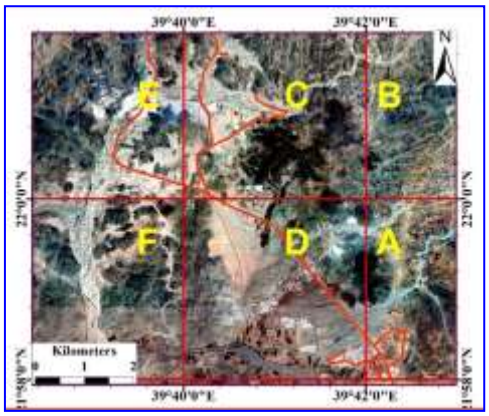

Figure 8: Satellite image of Al Barzah depression showing the location of the studied sectors A, B, C, D, E, F.

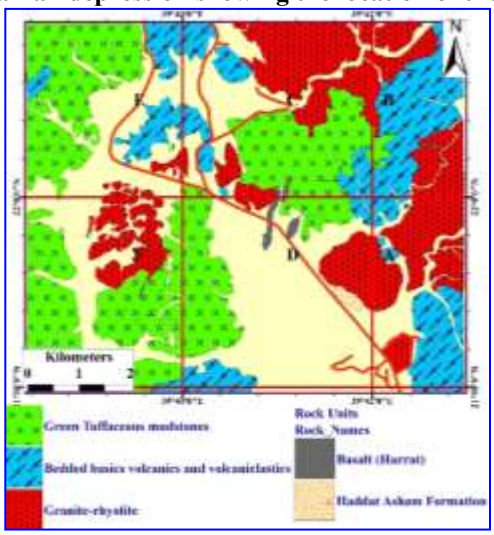

Figure 9: Detailed geologic map of Al Barzah Depression of the studied sectors A, B, C, D, E, F.

Figure 10: Google image showing the different rock units of Al Barzah depression from the southern (Fig. C) to the middle (Fig. B) and the norther (Fig. C).

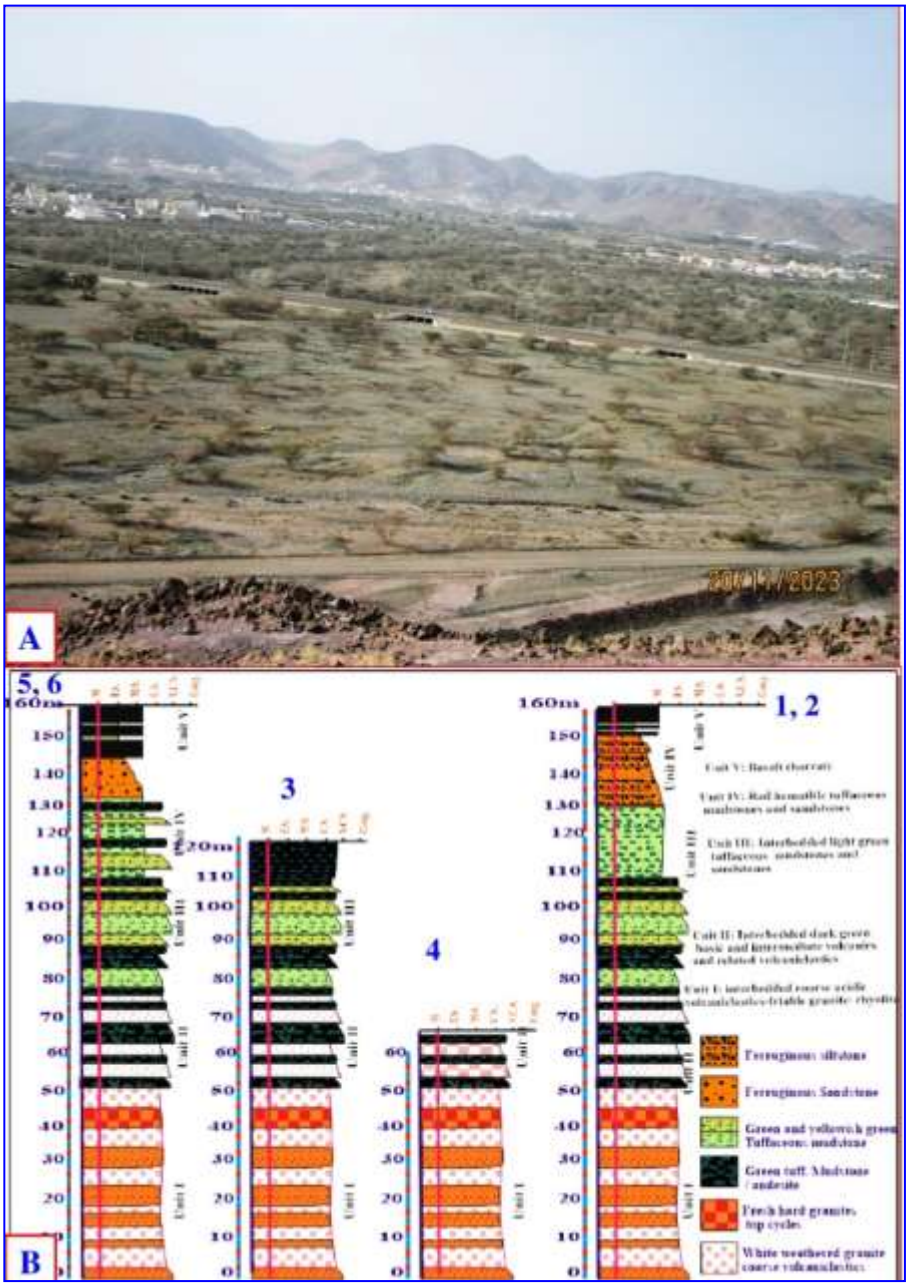

Figure 11: Field photo of Al Barzah depression showing the peniplained vast area and the cultivated lands and human populations; B= Stratigraphic sections of the different sectors of the study area.

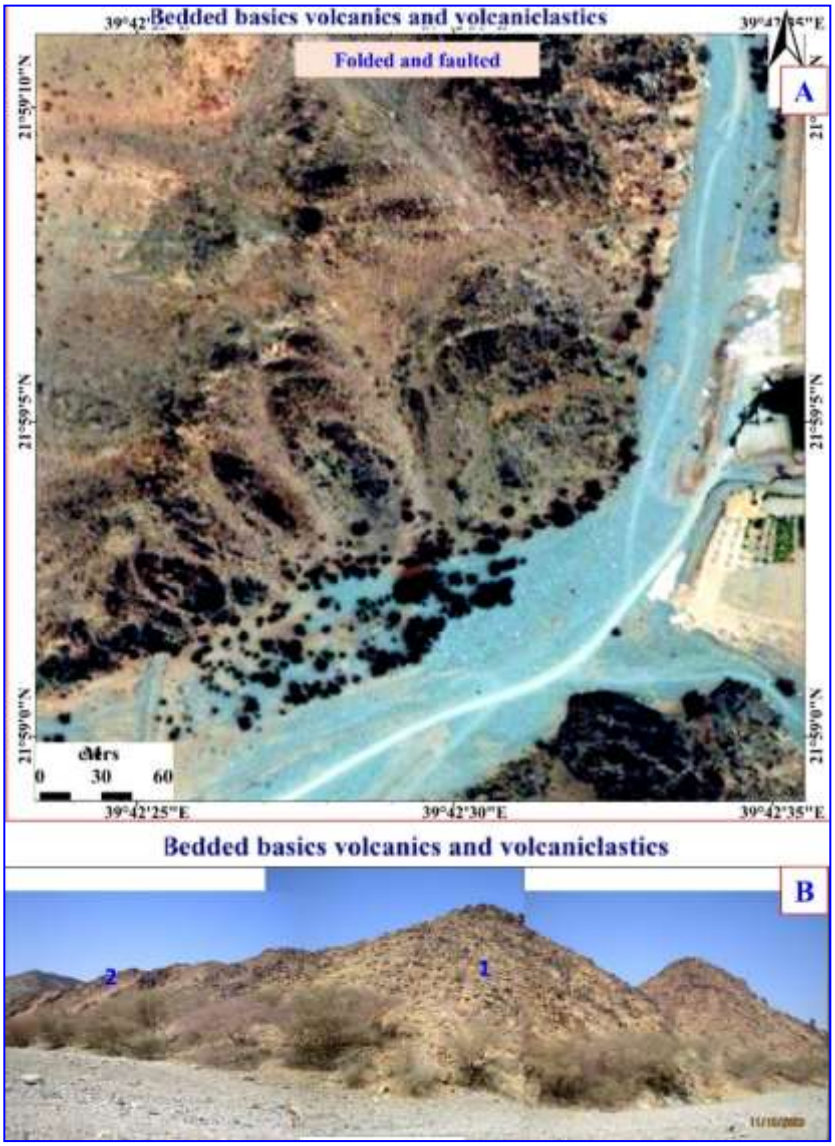

Figure 12: A= Satellite image of the folded and faulted bedded basic volcanics and volcaniclastics of the southeastern corner of the study area; B= Field photo of the folded and faulted bedded basic volcanics and volcaniclastics of Fig. A.

Figure 13: A=The complete succession of the eastern scarp of al Barzah depression of lower green tuff the middle Tertiary sedimentary succession and topmost black basalt (harrat); B= The Tertiary sedimentary section of Haddat Asham Formation in the southeast corner of Al Barzah depression.

Figure 14: A= The acidic volcanics and the associated volcaniclastics of the floor of Al Barzah depression; B= The acidic volcanics and the associated volcaniclastics and the overlying Tertiary sedimentary section of Haddat Asham Formation and the harrat of the eastern and northeastern scarps of Al Barzah depression.

iv) Red hematinic tuffaceous mudstones and sandstones: This unit is newly described in this area. It represents the northern extension of Haddat Asham Formation of Haddat Asham area. This unit is of characteristic red color and have certain stratigraphic position above the Arabian shield rocks and underlying the flat lying basalt of Harrat (Fig. 13A). It is also represented by small red hills of ferruginous sandstones, mudstones and siltstones (Fig. 13B).

A. The central part of the study area (Sector C, D; Fig. 10). These two sectors are present to the west of the eastern scarp. They represent the residual landforms of the central part of Al Barzah depression. Some of these landforms are composed of two units of column 4, Fig. 9), while other landforms comprises the three units of column 3 (Fig. 11B). The landforms of units I & II are of low elevation and are composed mainly from acidic coarse volcaniclastics/ granite and rhyolite (Fig. 15A). The other higher landforms are recorded in the northeastern part of Al Barzah depression and are composed from the three units I, II and III of column (3, Fig. 11B). These landforms are terminated by horizontal flat-lying basalt (Harrat). The lower parts of these landforms are composed from the coarse acidic volcaniclastics/granite unit (Fig. 15A). This unit grades upward into interbedded acidic volcaniclastics- rhyolite (Unit I), and basic and intermediate volcanics and related volcaniclastics (Fig. 15B). In the northern part of the central rockpile

in the depression the light unit I is overlain by thick green unit II (Fig. 15A).
In zones E, F (Fig. 11Fig. 16B), the landforms of the western scrap of Al Barzah depression is composed from relatively thickly bedded acidic volcaniclastics granite of unit I that overlain by green bedded units II, III. With very thin red zone of unit IV and finally Harrat (Unit V).

4.Landforms evolution of Al Barzah Depression

During heavy rainy periods, the uplifted rocks Al Barzah area are subjected to intensive weathering and denudation processes which resulted in the formation of the present-day landforms. Al Barzah, Haddat Ash Sham and Madrakkah areas represent depressions within the Arabian Shield Rocks. Aref et.al.1991 studied the mechanism of formation El Bahariyah depression, western desert, Egypt. The residual landforms within Al Barzah depression are completely similar to those described by El Aref et.al. (op.cit.). Mesaed et al. (2020) described the landforms evolution of W. Qudaid area in the west central part of Saudi Arabia
The incision of rivers with gradual dissection and etching of the coarse acidic volcaniclastics and/weathered granites by slope and scarp retreat. The wide interfluves were formed because of the continuous slope retreat and the gradual consumption of the cap of the formed landforms. The continuation of the retreat of the slope led to the further consumption of the wide interfluves and the development of large inselbergs and ridges. The continuation of these processes led to the formation of vast low-lying areas empty from any residual landforms.
The absence of residual landforms within the floor of some areas within Al Barzah area represents an advanced stage of dissection and stripping of the friable igneous rocks and associated volcaniclastics. This led to the reduction of the wide interfluves into small areas. During this stage, the pediments become wider, and the formed residual landforms are still of the same slope angles and of the same elevations. The denudation processes are fully guided by the main fault lines and week planes. The N-S wadies in the eastern and western scarp of Al Barzah depression are running along previous axes of two main anticlines. The main residual landforms (rock mass in the central part of Al Barzah depression) represent a major syncline between the eastern and western anticlines.
Al Barzah depression is of high economic potentiality, this is related to the following: 1) The geo-tourism nature of the depression because of the presence of vast green cultivated areas within the heart of the Arabian Shield desert nature; 2) The presence of fantastic landforms in the central part of Al Barzah depression gives this area high geo-tourism importance.

5.Summary And Conclusions

The present study revealed that: i- Al Barzah depression has diagnostic geomorphologic and geologic nature. It resulted from the integration of the geologic processes and structural elements in the formation and evolution of the landforms. The depression represents an excellent window that expose the rock units of the western part of the west central Arabian Shield. The structural elements are of prime importance in the formation of this depression. The weathering processes (mainly running water) are mainly guided by the main structural elements. The main faults (especially along the fold axes) of the major synclines and anticlines. Two main weak rock units facilitate the weathering processes, these are: a) the coarse acidic volcaniclastics/ friable granite, b) the clastic succession of Haddat Asham Formation. The residual landforms within the depression reflect the role of the weak planes of the main structural elements as well as the rock units that penetrated by these weak planes.
The landforms of the study area include small semicircle bodies especially in the western and eastern parts of the study area. The elongated landforms are dominated in the central part of the study area. The erosion processes begin with the scrap retreat of the tablelands and formation of very deep galleries. The progress of the erosion processes led to the formation of wide interfluves and formation of wide pediment area.

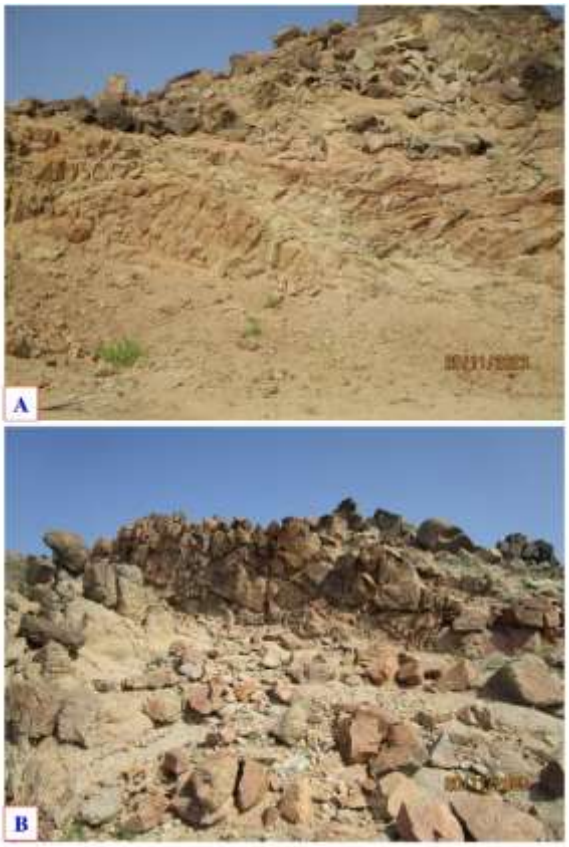

Figure 15: A, B= Close up views of the acidic volcanics and the associated volcaniclastics of the floor of the northern part of Al Barzah depression

Figure 16: The axes of the small tight antiforms and synforms of the north central part of Al Barzah depression.

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