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GEOMORPHOLOGY

Geomorphology and Landforms Evolution of Roste Valley, Western Zagros Fold-Thrust Belt, Iraqi Kurdistan Region

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ABSTRACT

This study presents a detailed geomorphological survey and mapping of the main landforms in the Roste Valley, which have resulted from a combination of surficial and tectonic processes. The landforms are classified using the ITC system, which is based on the origin of the landforms and the forces that shape the Earth's surface and is supported by extensive fieldwork. The Roste Valley is located within the Zagros Imbricated and Zagros Suture zones on the unstable shelf of the Arabian Plate, contributing to the formation of a variety of geomorphic features with different genetic origins. Local climatic conditions significantly enhance the rate of surficial processes, while the tectonic setting near the subduction zone adds further complexity to the landscape. The geomorphological survey and mapping reveal that the area is polygenetic in origin, with landforms shaped by both tectonic and surficial forces. These landforms are categorized as tectonic, structural, denudation, mass-wasting, fluvial, and karst in origin.

Keywords: Roste Valley, Landforms, Tectonics, Drainage deflection, Pressure ridge, Klippe and Window thrusting, perched syncline.

Geomorfología y evolución de accidentes geográficos del Roste Valley, cinturón plegado del Zagros occidental, región del Kurdistán iraquí

RESUMEN

Este estudio presenta una investigación geomorfológica y un mapeo de las principales características naturales de la superficie terrestre en el Roste Valley, el cual ha sido el resultado de una combinación de procesos tectónicos con procesos superficiales. Las características de la superficie en la zona de estudio se clasificaron de acuerdo con el sistema ITC, el cual se basa en el origen de los accidentes geográficos y las fuerzas que modelan la superficie terrestre, y se sustentaron en un amplio trabajo de campo. El Roste Valley se ubica en las zonas traslapado y sutura del Zagros, en la inestable placa tectónica árabiga, lo que contribuyó a la formación de una amplia variedad de características geomorfológicas con diferentes orígenes genéticos. Las condiciones climáticas locales acentúan el peso de los procesos superficiales, mientras que la estructura tectónica cerca de la zona de subducción añade complejidad al paisaje geológico. La investigación geomorfológica y el mapeo revelan los orígenes poligenéticos del área, con accidentes geográficos moldeados por fuerzas tectónicas y superficiales. Los orígenes de estas características naturales de la superficie se categorizan como tectónicos, estructurales, de denudación, de remoción de masa, fluviales y kársticos.

Palabras clave: Roste Valley; accidentes geográficos; tectónica; deflexión del drenaje; cresta de presión; cabalgamiento de Klippe y de ventanas; sinclinal encaramado

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1. Introduction

Tectonic and surficial processes are responsible for the development and evolution of landforms, the differences in the genetic origins resulted from the interaction between tectonic, surficial, and climatic conditions. Endogenic forces, specifically tectonic processes driven by the ongoing collision between the Arabian and Eurasian plates following the closure of the Neo-Tethys Ocean in the late Miocene, have caused compressional forces leading to uplift and overthrusting of existing anticlines, while exogenic forces (surficial process) act to flatten the land surface through the geomorphic agents and processes. The study is located in the Kurdistan Region, northeast- Iraq, about 128 km east of Erbil City, within the Imbricated and Suture Zones of the western Zagros Fold-Thrust Belt (ZFTB). It lies between longitudes 44°38' E and 454°50' E and latitudes 36°37' N and 36°44' N, (Figure 1), Bounded by Tanoun anticline in SW, Hasanbag mountain in N, and Halgurd mountain in NE (Figure 2).

The study area is complicated in terms of geomorphology, which was dominated by landforms of different genetic origins and is an area of high relief and steep slopes with rainy and snowy climatic conditions (Zhazhlayi and Surdashy, 2022). Tectonically, the fundamental framework of the stratigraphy and structure of the study area is influenced by the positioning of Iraq within the tectonic units of north Iraq (Bety, 2022). The tectonic settings show that this area is active in terms of neotectonic and reactivation. However, the stratigraphic successions of the study area consist of Jurassic, Cretaceous, and Tertiary (Neogene) rocks and are represented by Sarki, Sehkaniyan, Sargelu, Naokelekan, Barsarin, Chia Gara, Balambo, Sarmord, Qamchuqa, Aqra, Bekhme, Shiranish, Tanjero, Govanda, and Redbed series (Merga I) formations in the Imbricated Zone, and Suture Zone also called nappe zone (Dunnington, 1958), and consisting of Zagros nappes and represented by Cretaceous (Metamorphic Qandil Series) and Tertiary (Paleogene) rocks of (Walash and Naoupurdan Volcano-sedimentary Group (Koshnaw et al, 2021), (Figure 3).

The geomorphological mapping and survey is considered an effective tool for the ability to notice the physical condition of the surface of the earth and gives useful information about landforms (Smith et al, 2011). There are several methods of geomorphological survey, such as the Topographic Position Index (TPI) and different automated landform classifications, but the most comprehensive geomorphological survey among the other systems is the ITC system proposed by (Verstappen et al, 1975), This system gives information about morphogenesis, morphometry, and morpho-chronology of the landforms (Rao, 1974). In this study, the ITC (International Terrain Classification) system of geomorphological mapping and survey is used, and it shows the information about the process, morphometry, genesis, lithology (rock type physical and chemical properties), and age. The geomorphological map based on the field observation and remote sensing data (Figure 4).

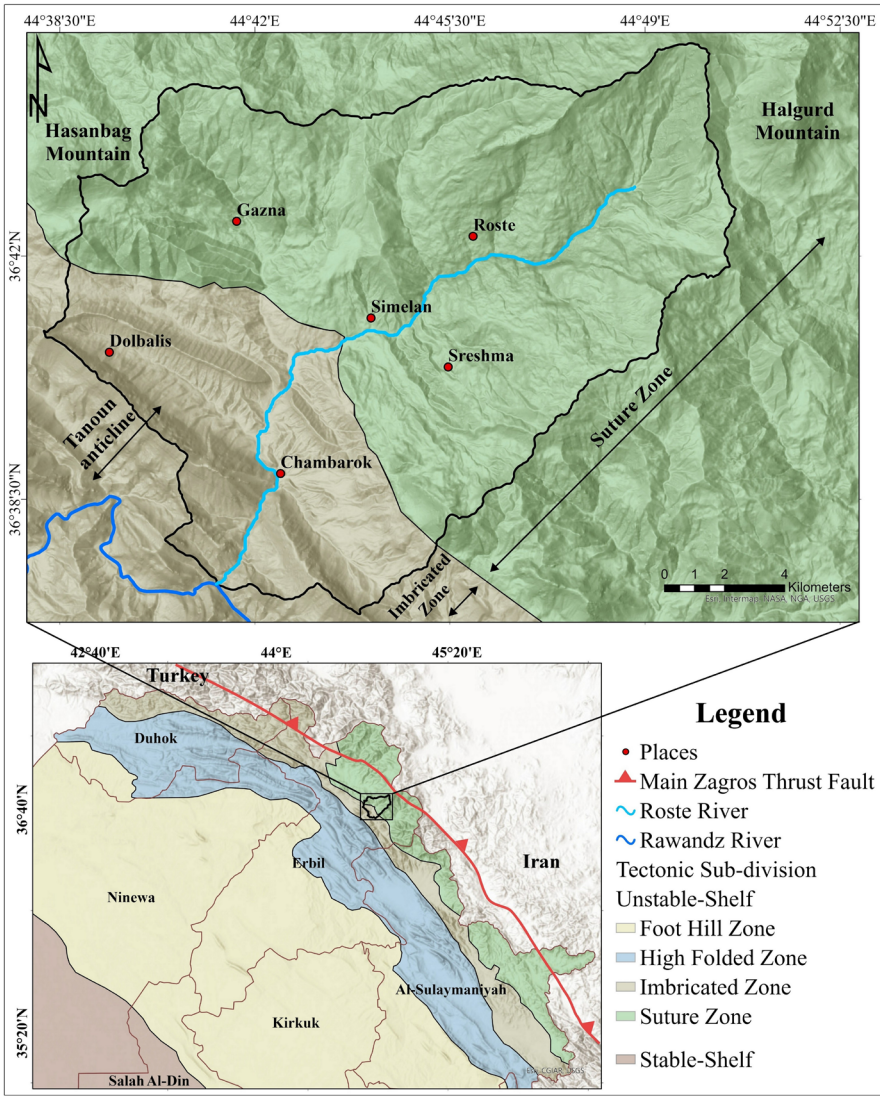

Figure 1. Shows the location of the study area, modified after (Jassim and Goff, 2006).

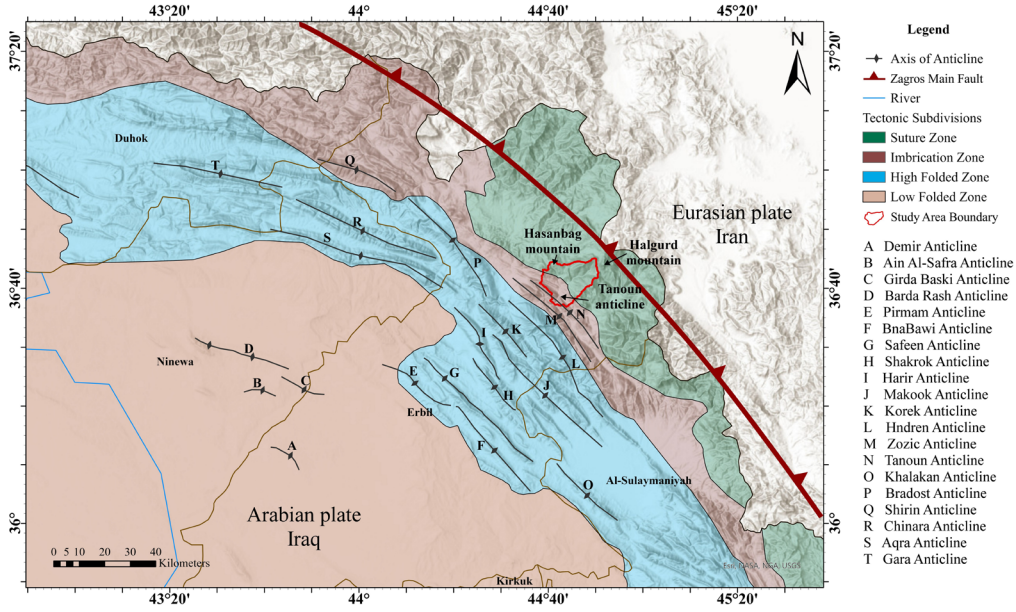

Figure 2. Shows a structural and tectonic map of the study area after (Vera et al, 2009).

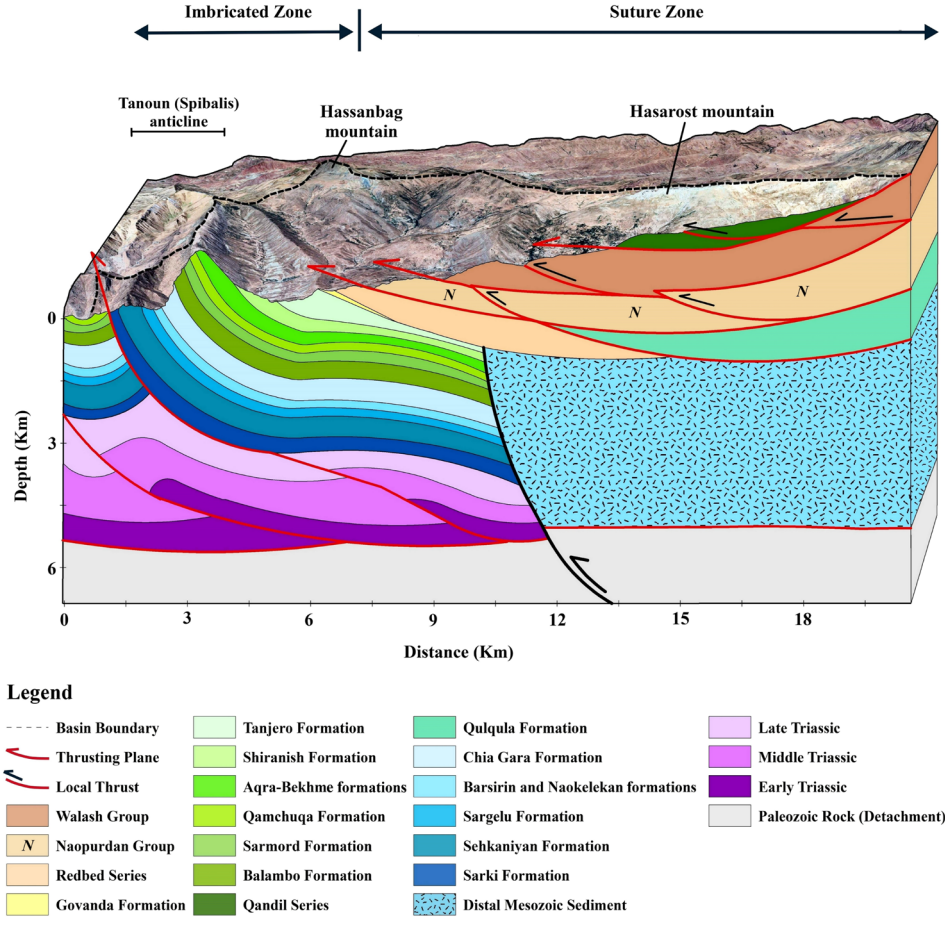

Figure 3. Shows the three dimensional geological cross-section of the study area, after (Zhazhlayi and Surdashy, 2022).

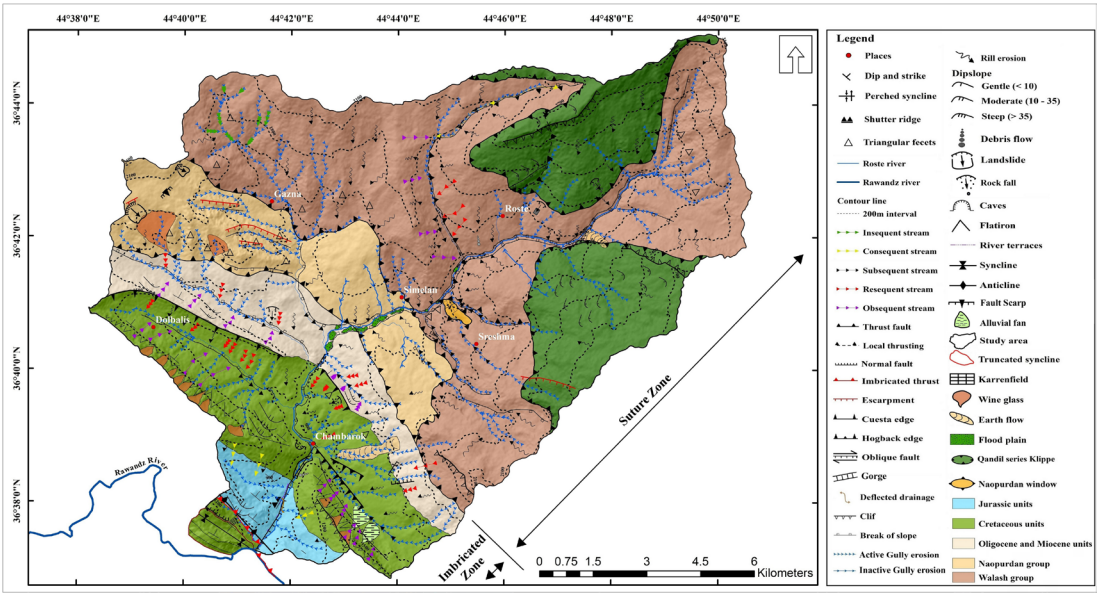

Figure 4. Shows the geomorphological map and landforms distributions within the study area. The mapping based on the field work, satellite image and remote sensing data.

2. Landforms of Tectonic Origin

Klippe and Window

The Klippe are the isolated and separated over-thrusted rock masses, particularly nappes, and can be defined as the nappe's outlier or the remnant portion of over-thrusted rock masses as the erosion isolates masses from the surrounding(Pirasteh et al, 2009). In the study area, the Qandil Series klippe thrusting over the Walash Group which was observed in the Suture Zone (Figure 5.A), as the Qandil Series is surrounded by the Walash Group.

The window landform is formed when the sheets of thrust fault are eroded by surficial processes and expose the underlying rocks. In the study area, the Naopurdan Group was exposed as the window thrusts when the overlaying Walash Group eroded in the Suture Zone (Figure 5.B).

Deflected Drainage

The drainage line changes its path when subjected to the structural and tectonic barrier, this barrier is formed in response to strike-slip movements or the growth of anticlinal folding which results in changes in the path of the drainage (Gutiérrez and Gutiérrez, 2016). In the study area, the deflection of the drainage course was found in the Roste gorge and it was formed by the oblique faults that crossed the Tanoun (Spibalis) anticline (Figure 5.C).

Shutter Ridge

It is the barrier developed across the drainage valley through a tectonic process (Zilberman et al, 2011), this barrier blocks or closes the downstream drainage flow, commonly developed in response to the horizontal and/or vertical displacement by strike-slip and dip-slip faults respectively. In the Roste valley, this ridge was observed on the NE side of the river in the core of the Tanoun (Spibalis) anticline (Figure 5.C).

Pressure Ridge

The pressure ridge landforms are developed in the compressional zone by tectonic pressures found in thrust and strike-slip fault zones, this pressure changes and modifies fault scarps into pressure ridges (Philip et al, 1992). In the study area, this feature was observed in front of Walash Group sheet thrusts near the Kawlan and Neris villages (Figure 5.D).

Fault Facet (Triangular Facets)

The fault facets are the trace of the active faulting generally referring to triangular and trapezoidal-shaped fault-related geomorphic features (Balogun et al, 2011), dissection and erosion are dominant processes in the uplifted part or blocks whereas the subsided or downward moved block commonly defined the low land area (pediment zone) and filled with the weathered rock sediments or aggradation (Gutiérrez and Gutiérrez, 2016). In the study area, the fault facets were observed near Hassanbag Mountain within the Naopurdan Group, in front of Halgurd Mountain, and within the Walash Group and these facets define the thrust surface of the Walash and Naoupurdan Groups (Figure 5.E).

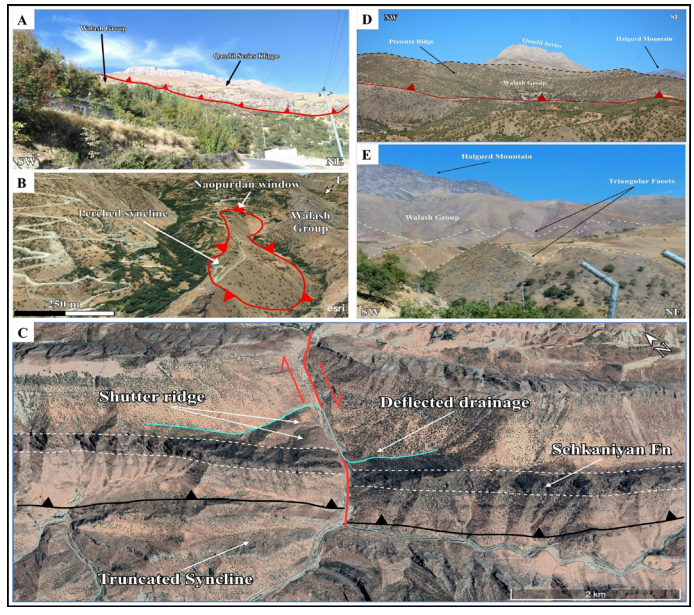

Figure 5. Shows the tectonic generated landforms, A) Field photo shows Klippe thrusting, B) Window thrusting, C) Satellite image shows Deflected drainage and Shutter ridge, and D) Field photo of Pressure ridge, and E) Triangular facets.

3. Landforms of Structural Origins

Structural origin unit represents all landforms that resulted from the impact of structure and/or tectonic processes associated with geomorphology aspects. Those processes play a key role in the emergence of this origin. It is also includes those units that are relate to the regional or local bedrock structures or crustal movement,(Bety, 2013). This group includes:

Perched (Hanging) Syncline

The perched syncline landform formed when the adjacent anticlinal folding eroded and the syncline remained as an elevated area than the surrounding. The morphology of the perched syncline is based upon the interlimb angle, the tight or narrow syncline produces a narrow synclinal ridge and the open and wide syncline produces broad U- shaped tops mesa-like landforms (Sebai et al, 2021). The narrow-perched syncline in the study area was observed near the Sreshma village within the Naoupurdan Shaly Group as exposed by window thrusting in the Suture Zone (Figure 6.A).

Flatiron

The flatiron is the fin-shaped landform produced through differential rates of erosion and weathering in the interfluvial drainage led to the separation of resistant lithology beds, the flatiron is also regarded as the base of triangular facets (Bucci et al, 2013). This type of landform was observed in the NE limb of the Tanoun (Spibalis) anticline, as the Aqra-Bekhme formations bed separated by narrow gullies and wineglasses (Figure 6.B).

Water Gap

The water gap can be defined as the deep passage within the mountain range or anticlinal structure and is the perpendicular cross-cutting through the mountain and ridge or any structural and tectonic barrier (Oard, 2008). In the study area, this landform was found in the Govanda cuesta ridge and Tanoun (Spibalis) anticline as the water course passed through the normal and oblique faults respectively (Figure 6.C).

Breached Anticline (Eroded Core Anticline)

The eroded core anticline or breached anticline was observed in the Tanoun (Spibalis) anticline. The anticline crest highly eroded and formed this type of landform in the core of the anticline (Michard et al, 2011). The core of the Tanoun anticline consists of Jurassic formations, the NE limb consists of Cretaceous formations, and the SW limb is crossed by imbricate thrusting. This imbricate thrusting may be another factor aiding in the formation of this type of landform (Figure 6.D).

Homoclinal Ridge (Cuesta and Hogback)

The homoclinal ridge is the inclined strata with a constant dip, generally with a contrasting resistance of lithology(Sponemann, 1989). The cuesta ridge is defined as an asymmetrical ridge formed of gently dipping (less than 35o) sedimentary strata with hard and soft rock alternation (Ward, 2019), the soft lithology eroded easily and left the hard lithology as cap rock. According to (Bety, 2013), usually this unit presents in an areas of mass wasting on these parts of the study area. The cuesta scarp slope steeply dipping and the dip slope is gently dipping, the dip slope is almost parallel to the dip of the strata. The cuesta ridge was observed in the study area, in the imbricated zone as the resistant limestone of Govanda formation formed the cap of the landform and overlaid less resistant rocks of the Tanjero formation near the Dolbalis village (Figure 6.E).

The hogback landform is the symmetrical ridge developed of steeply dipping strata (more than 35o) with hard and soft rock alternation (Ward, 2019). The hogback scarp slope and dip slope are almost the same amounts, and the dip slope of the hogback landform is also parallel to the bedding plane. In the study area, this landform is found in the imbricated zone within the Tanjero formations near the Sherkawa village (Figure 6.F).

According to (Jain, 2014) the drainage network in the hogback and cuesta landforms are genetically classified into five types and including the following: 1) Consequent: Flows in the topographic slope direction such as the main Roste river, 2) Subsequent: This type of stream flows along the weak zone such as along the fault zone as in the Besha and Dolbalis subbasins, 3) Resequent: this type flow in the direction of the original slope but in the lower levels as in the scarp face of Govanda cuesta ridge, 4) Obsequent: this type flows in the direction opposite to the main slope as in the NE limb of the Tanoun (Spibalis) anticline, and 5) Insequent: this type of streams is characterized by dendritic patterns, the stream network distributed randomly as in the Suture Zone within the Walash Group, (Figure 4).

Figure 6. Shows structural origins landforms, A) Perched syncline, B) Flatiron, C) Water-gap, and D) Breached anticline, E) Cuesta, and F) Hogback.

4. Landform of Denudational Origin

Wine Glass

The wine glass landform developed as the result of intense erosion of triangular facets and flatiron and consists of wide and broad top parts with narrow and small outlets. The wine glass generally appears as a small V-shaped gorge or valley (Bahrami, 2012). This landform developed from the Early Pleistocene to the Late Pliocene (Sissakian et al., 2014). The wine glass is well developed in the NE limb of the Tanoun (Spibalis) anticline and in front of Hassanbag Mountain within the Qamchuqa/Aqra-Bekhme and Naopurdan Group respectively (Figure 7.A and B).

Badland

The badland landform is defined as an intensely eroded landscape with a dense drainage network dissection (Howard, 1994). The badland landform is characterized by relatively high relief, steep gradients, soft erodible lithology, and low vegetation covers. In the study area, the badland is well recognized at the end of the Roste Valley, in front of Halgurd Mountain within the Walash Group (Figure 7.C).

Gorge

The gorge is developed when dissolution and physical erosions in the carbonate rocks incise the fluvial system and produce a narrow and deep valley, with a river or stream running along the bottom of the gorge (Gutiérrez and Gutiérrez, 2016). This landform was found at the entrance of Roste Valley to the NE limb of the Tanoun (Spibalis) anticline (Figure 7.D).

5. Landform of Mass Wasting Origin (Slope Movement)

Block Slide

The rock block sliding is defined as the movement of the single rock masses along the planer surface and moving downslope along the sliding surface. Generally, less common sliding as compared to other types of sliding (Luino and Turconi, 2020). In the study area, this landform was observed in the Imbricated and Suture Zone within the Qamchuqa Formations (NE limb of Tanoun anticline) and Qandil Series rocks near the Grtik villages (Figure 8. A and B) respectively.

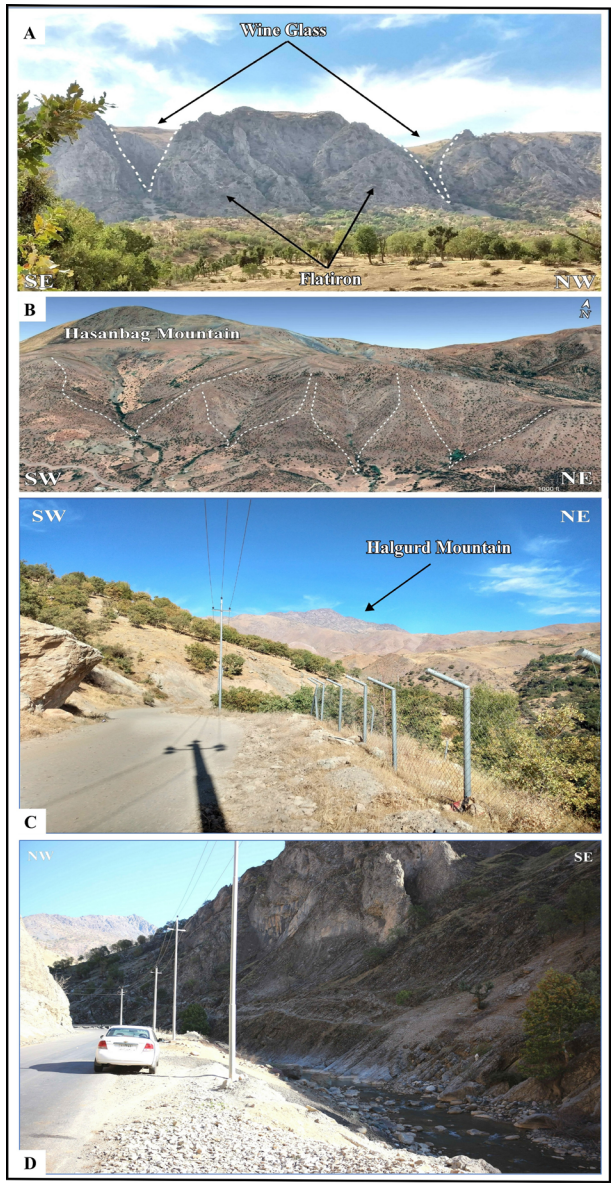

Figure 7. Shows landforms generated through denudation process, A and B) Wine glass in the NE limb of Tanoun anticline and Hasanbag mountain, C) Badlands, and D) Gorge in the core of Tanoun anticline.

Earth Flow

The earthflow generally occurs in the humid area on the hillside and the failure surface, followed by torrential rain or snow melting. The fluvial process of heavy rain and snow melting moving the fine-grained material (silt and clay) in the elongate and narrow transportation zone and depositing them downslope, the earthflow is generally taken the shape of the narrow tongue.

The activity of earth flow is continuous for a long time (Conforti et al, 2020); (Jain, 2014). In the Roste valley the earthflows are well developed within the soil covers above the Qandil Series in the Suture Zone, near the Piromar village (Figure 8.C), the climatic condition (heavy rain and snow) and the topographic form (mountains and hill slopes) in the study area aids the movement of fine-grained soil cover, the material transported downslope and formed the lobate-shaped depositional feature.

Rockfall

Rockfall is defined as the bounding or free movements of loose and fragmented rock downward along the slope surface under the action of gravity (Luckman, 2013). In the study area, the rock fall was found in several parts because of high relief and climatic conditions, the climatic factor aids in rock fragmentation (weathering), and the steep slope and gravitational process moves the fragmented rock downslope (Figure 8.D and H).

In the Imbricated Zone the rock fall was observed near the Besha village within the Redbed series (Merga I) and in the core of Tanoun anticline, in the Suture Zone was found within the Qandil Series and Walash Group near the Roste and Grtik villages.

Transitional slide

A transitional slide is a type of mass wasting developed when the masses of the coherent rock or soil move and displace along the failure surface of the plane or the shear zone. The transitional landslide occurs on the planer surface with the linear displacement whereas the rock mass in the rotational sliding moves along the concave and curved surface.

The failure surfaces are generally caused by preexisting stratigraphic or structural discontinuities such as contact between weak and soft cover with bedrock, bedding, faults, and joints (Morino et al, 2022).

According to (Gomberg et al, 1995), the faulting in landslides is the same and similar to the crustal rock faulting, both including the displacement of masses along the planer failure surface. In the study area, the land-sliding occurred near Hasanbag Mountain within the Naopurdan Group (Figure 8.E and F).

Toppling

The rotation in the forward direction of rock about an axis located below the gravity center of the mass movement is known as Topples. Toppling generally occurs on steep slopes and cliffs and consists of slabs or rock columns separated by steeply dipping vertical discontinuous planes such as bedding planes, joints, and cracks due to the unloading of masses.

The progression of forward rotations results in losing basal supports of rock slabs or blocks and the toppling starts to fall. The toppling is well developed in the NE limb of the Tanoun (Spibalis) anticline within Cretaceous rocks (Figure 8.G).

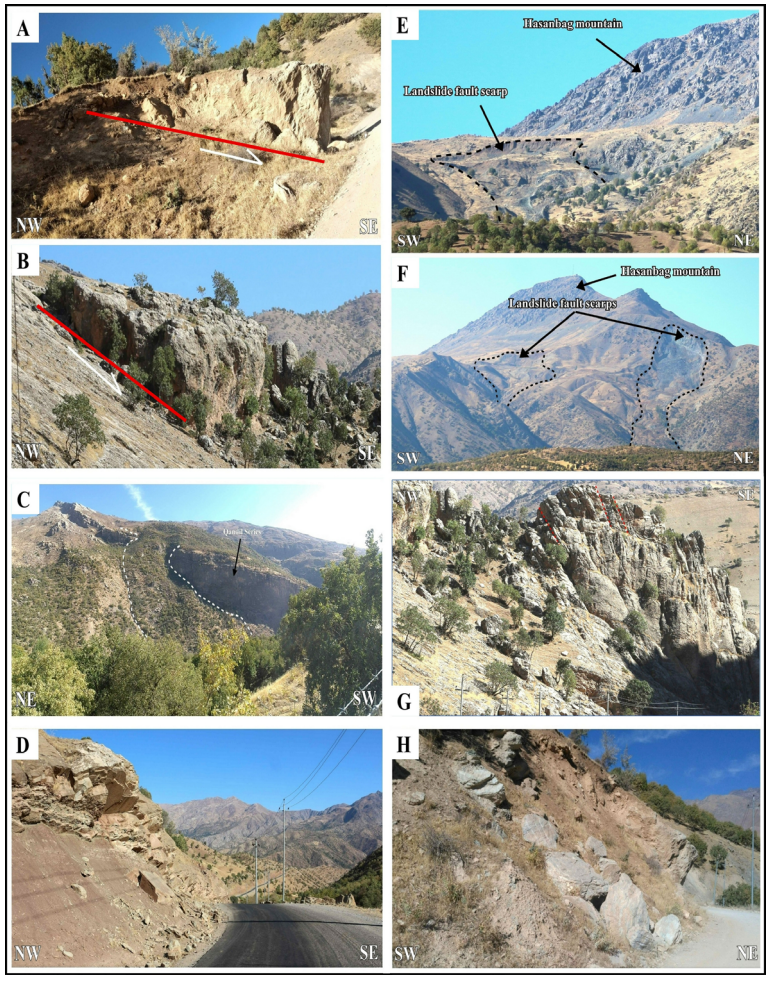

Figure 8. Shows landforms produced by mass wasting process, A and B) Block slide in the suture zone and core of Tanoun anticline respectively, C) Earth flow, D and H) Rock fall, E and F) Transitional slide in the Hasanbag mountain the red line indicate seemingly sliding surface, and G) Toppling in the core of Tanoun anticline.

6. Landforms of Fluvial Origins

River Terraces

The river terraces are commonly developed in response to tectonic and/or climatic controls, in high tectonic settings continuous uplifting can develop river terraces hundreds of meters higher than the present elevation of the channel (Daley and Cohen, 2018). Terraces commonly represent the old channel locations now abandoned by the migration of the channel. In the study area, the river terraces are well developed in the core of the Tanoun (Spibalis) anticline, when the Roste river migrated across the oblique faults leaving behind 7 levels of terraces within the Jurassic rock (Figure 9.A).

Abandoned Alluvial Fan

Alluvial fans are morphologically fan-shaped landforms, developed as the result of the accumulation of sediment and clastic rock materials at the outlets of the river which flows from the mountain range in narrow valleys into the low-land area (Haldar, 2020). The sediment and clastic material from the apex of the fan flows out radially into planes, the size ranges from small to large alluvial fans. In the study area, the abandoned or old alluvial fan was found in the NE limb of the Tanoun (Spibalis) anticline (Figure 9.B).

Floodplain

The flood plain is a flat area adjacent to the drainage stream, mainly consists of alluvium (unconsolidated) deposits, and is periodically subjected to stream flooding. Floodplains are generally developed by point bar deposition and sometimes may be formed by overbank flow deposition during the flooding period (Panizza and Goudie, 2013). The floodplain in the study area is narrow and small located in the middle of Roste Valley near Simelan and Mama Khatybian village (Figure 9.C).

Gully and Rill

The gully erosion is formed as the result of several rainfall events (overland flow) morphologically linear, small, and deeply eroded channels with steep slope sides (divide), and ephemeral gullies may be continuous or discontinuous depending on the climatic conditions (Gao, 2013). The rill erosion is developed as the consequence of repeated and periodic rainfall and the overland flows, and morphologically is small incised channels on slope surfaces. The depth and width are tens of centimeters, formed on a bare surface with little or no vegetation (Berger et al, 2010). In the study area, the gully and rill erosion were recognized in different parts of the valley, particularly within the Naopurdan shaly group in the Suture Zone, near the Gazna village (Figure 9.D).

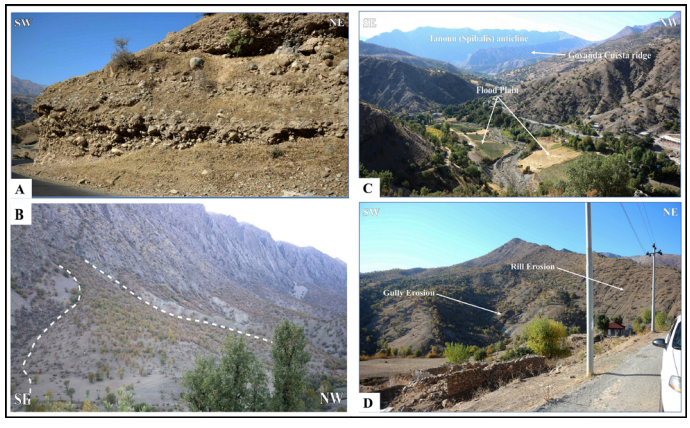

Figure 9. Landforms developed through fluvial process, A) River terraces, B) Abandoned alluvial fan in the NE limb of Tanoun anticline, C) Flood-plain, and D) Gulley and rill erosions.

7. Landform of Solutional Origin

Karstification (Cave)

A cave is defined as a natural ground opening, formed in a variety of lithology, particularly in carbonate rocks (Limestone) and resulting from the dissolution process spatially in limestone rocks. The size ranges from small caves (room-size) to the large interconnecting caves passage that extends to several Km in length (Morgan, 1991). In the study area, a cave landform was found in the NE of Tanoun (Spibalis) anticline within the Aqra-Bekhme formations, near the Chambarok village. The caves in the study area are formed by the dissolution process in the carbonate rocks (Figure 10.A).

Karren field and Solution Pits

The Karren landform is formed by the dissolution process in bare rocks and is typically formed in the areas where the carbonate rocks (Limestone and Dolomite) are dominant and may develop in the evaporitic rocks. The channel depth ranges from millimeters to one meter or more and is several centimeters wide. The solution pits are the type of circular Karren formed as the result of dissolution typically in the carbonate rocks (Figure 10.B). The size of the pit is up to 5 cm and is elliptical or circular in shape (Lundberg, 2019). In the study area, the Karren field and solution pits were developed within the Qamchuqa limestones in the truncated syncline near the imbricate thrusting in the core of the Tanoun (Spibalis) anticline.

Figure 10. Karstic origin landforms, A) Cave, and B) Karren field and solution pits in the NE limb and core of Tanoun anticline respectively.

Conclusion

Finally, the geomorphological survey and mapping of the Roste Valley emphasize the study area's complex polygenetic nature, with a diverse range of landforms formed by various geological processes. These include tectonic landforms generated by the compressional and extensional stresses started from the closure of the Neo-Tethys Ocean in the middle Miocene, and the tectonic movement is still ongoing to the present day. Structural features developed by faulting and folding in combination with the erosion process. Surficial processes and climatic conditions of the study area aid erosion and transportation processes, resulting in the formation of different denudation landforms Fluvial landforms resulted from river action; the Roste River, from the end of the Miocene period, changed in its path, velocity, and intensity, hence shaping different landforms. Furthermore, because of high relief and steep slopes, mass-wasting processes have led to the formation of different landforms. The solution features are especially evident in the Tanoun anticlines in the imbricated zone, as it is composed of limestone and favourable for the dissolution process. Overall, the Roste Valley's different range of landforms provides unique insights into the dynamic interaction of geological processes that shape the landscape throughout time.

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