GEOSPATIAL INVESTIGATION OF A HORSE-TAIL STRUCTURE ALONG ASWA SHEAR ZONE

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Abstract

The study area is in the Central Equatoria State of South Sudan, where a horsetail geological structure exists as part of the Aswa Shear Zone (ASZ) that extends in a SE direction into Uganda and Tanzania. Remote sensing data comprising of Landsat 7 and Digital Elevation Models (DEM) have been utilized to map the architecture of the horsetail structure which constitutes an important source of mineral potentials in the area. The enhancement of the DEM imagery together with Landsat 7 have been achieved by application of spatial filers and principal component analysis (PCA).

Remote sensing and Geographic Information System (GIS) have been utilized to provide rapid geological mapping results wherever accessibility is difficult. The present study is intended to interpret the tectonic evolution of some geologic structures along the Aswa Shear Zone in the Central Equatoria State of South Sudan. The detected structures indicate mineralization zones in areas of intense folding which exhibit some geometrical shapes such as the S-, the N-, the C-, and Lens-shapes as have been deduced from the interpretation of geological structures in the area. The study area is a highly mineralization zone with a variety of mineral resources such as gold, copper, tin, asbestos, aluminum, iron, mica, manganese, lead, and zinc. The mapped structures elucidate the uniqueness of Aswa Shear Zone (ASZ) on the tectonic evolution of Central Equatoria horsetail structure which is considered a geological structure of prime importance in that region of South Sudan.

1. Introduction

The Aswa Shear Zone (ASZ) is a major NW-SE trending intra-cratonic, crustal-scale structure extending for more than 1000 km, from the Indian Ocean in the SE passing through Tanzania, Uganda, South Sudan, into Sudan in the NW. The ASZ is believed to have been caused by continent collision and closure of the Mozambique ocean further to the east, that potentially caused a lateral escape as manifested in this NW-SE striking sinistral shear zones [1]

The activation of ASZ is linked to underthrusting of the Congo Craton and coeval high-grade metamorphism and intense deformation in the orogen interior.

The application of remote sensing together with geographic information system (GIS) techniques are considered to be fast and cost-effective means for detection and extraction of geological structures (e.g., Lineaments) which could be constituting potential sites for mineral deposits in the region.

Remote sensing data comprising of Landsat 7 and Digital Elevation Models (DEM) have been utilized in the study to map the architecture of the horsetail structure in the vicinity of the ASZ in South Sudan. Additional information obtained from field observations in the study area have been utilized as ground truth for a greater and better structural and geological correlation.

The principal component Analysis (PCA) technique was applied for enhancement of both the Landsat and DEM images, thus making it easier to detect and extract geologic structural features and lineaments from the satellite data. PCA is used to reduce redundancy in multispectral data based on a statistical method of data analysis [2].

The applied processing techniques of Band Combination, PCA, and Spatial Filtering have been effective in revealing the dominant lineament features and their directions in addition to elucidating the geodynamic setting in this region of South Sudan.

Figure 1. Location of the study area

2. Geological Settings

A horsetail structure is located between longitude from 31° 19’ 21.33” E to 31° 50’ 29.50” E and latitude from 03° 36’ 44.40” N and 05° 01’ 48.09” N. The structure stretches to the western side of White Nile, the southwestern part is bordering Uganda. The area has been influenced by intensive regional low-grade metamorphism comprising of Charnockite granulite facies to medium Amphibole facies [3]. The rocks in the area are composed of Nile gneiss, mica schist, chlorite schist, quartzite, amphibole, and Para-schist. Also, Pan African young intrusion exists in form of granite, diorite, and gabbro. The basic volcanic rocks are mainly basalt [3] Lower protozoic remobilized esaillic continental basement complex in form of migmatite.

The effect of ASZ at the western side of the Nile is different than it is on the eastern side. Here (western side) the basement complex is in form of Nile gneiss (pink) and undifferentiated igneous rocks (red in color), and basement complex is a floor for highly metamorphosed meta-sediment. There are isolated hills and red laterites in the study area.

3. Tectonic settings

Tectonically, the study area is part of an active region that is characterized by a series of continental rifts, widespread magmatic activity, strong deformation, and frequent earthquake events [4].

The region is structurally dominated by NE-SW lithospheric extension which formed the NW–SE trending Mesozoic rift basins in the Sudanese and South Sudanese regions, such as the "Pull-apart" sedimentary basins of Muglad, Melut, and the Blue Nile.

4. Materials and Method

The geological map of the Republic of South Sudan and the geological map of Central Equatoria State at a scale of 1:2000.000 have been used as reference data for the study area. Landsat 7 and DEM images were used for spatial investigation of the study area by application of the band composite, principal component (PCA) and spatial filtering techniques.

The Landsat image has been calibrated and subjected to quick atmospheric correction to improve and enhance the geological features in the area. A 30 m resolution ASTER Digital Elevation Model (DEM) image has been used for determination of aspect and shaded relief, whereas the azimuth angles with varying exaggerations was utilized to reveal topographic features such as valleys and ridges. Several lineaments have been delineated manually and compared with those identified using DEM and Landsat 7 images of the study area.

A TIN file has been created and then overlain by the Landsat 7. Linear stretching, contrast was performed, and a transparency of the Landsat 7 image was created.

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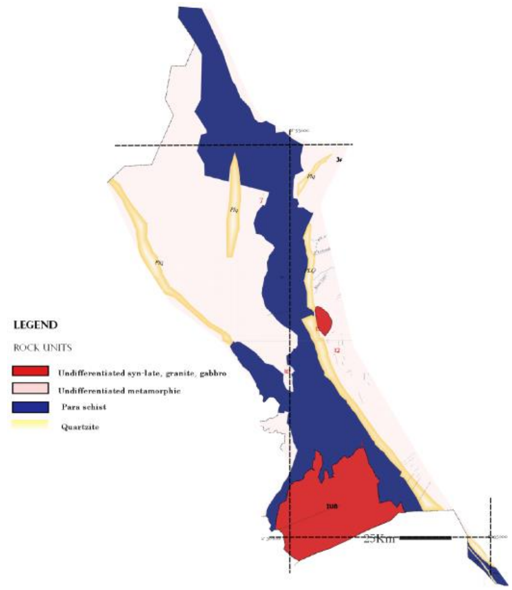


Figure 2. Geological map of the study area

5. Digital image processing

The seven bands of Landsat 7 have been pre-processed by calibration to give accurate analysis, bands were combined into one view as multispectral image, and atmospheric correction was applied to removed some of dust and clouds. It worth mentioning that not all the bands are good for geological purposes, only bands 4 and 7 were processed individually (Fig. 3) by manual stretching, with a better cumulative count cut values of Min7 – Max 97.7%, The load min/max value for mean +/- standard deviation of ×3.

The purpose of digital image processing is to provide scientific and enhance visual interpretation of the data.

I. Band Composite

Band Composition is one of the techniques used to process multispectral images, the sensitivity of human vision can distinguish only red, blue, and green coloured surfaces but by with Band Combination the intermediate mixture of the primary colors like yellow, orange and burble can be distinguished [5] Band Combinations of bands (7,5,3) and (7,3,1) assigned to Red Green and Blue colors, with 2 % linear stretch applied on the above band combinations revealed the importance of Gaussian stretching in exposing some man-made linear features for example highways (Fig. 3).

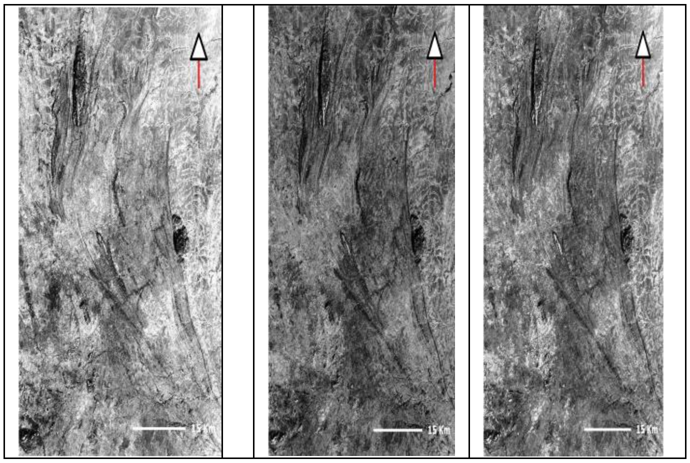


Figure 3. Band 3, Band 5, Band 7 Combination.

II. Principal Component Analysis (PCA)

The PCA is one of the complex transformation techniques used for lineaments extraction statistically, and it is to reduce the dimensionality of a data set which consists of large number of interrelated variables [6]. Components are the new bands resulting from the complex statistical procedures, and the analysis is to reduce the redundancy and correlation in the multispectral data, the first view of the principal components which contain 90% were selected for visual structural interpretation, because they contain informative information than the rest of the components.

Three selected principal components were PCA (4,3,2), PCA (2,3,4) and (5,7,4) on which equalization stretching were applied are shown in Figure 5, with structural trends more clearly visible, in addition to the regionally folding expressions. PCA3 gave a clear view of the surface lineaments of the area (Fig. 5).

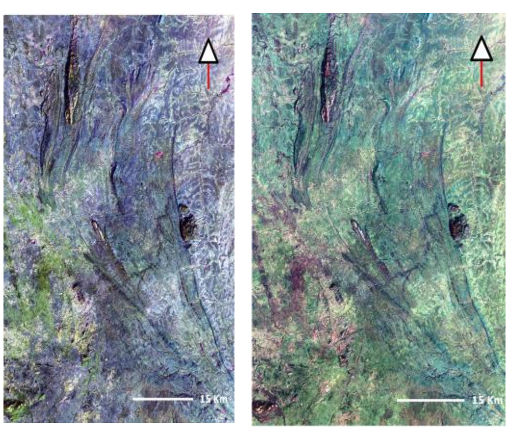


Figure 3. Band combinations (R7, G3, B1) and (R7, G5, B3)

III. Spatial filtering

Spatial filtering is a spatial enhancement technique which highlight specific structural features and enhances linear edges. Band 4 of PCA and version 3 SRTM were used for the spatial filtering, using two moving widows or spatial convolution. The first is a low pass filter to highlight the homogenous regions with similar tones, the second is a high pass filter which has been used to sharpen the fine tone within the band. The second filter has revealed high spatial frequency information in form of geological features. Kernel's filter which is a domain spatial filtering has been used in two steps 3×3 and 5×5 matrices, the purpose is to sharpen the edges (Fig 5).

IV. Geo-structural interpretation

Lineaments are resulting from different dipping, heterogeneous sediments, or metasediments [7] the extraction of geological structures was enabled by applying several techniques on both DEM and Landsat 7, the major lineament features are faults, foliations, and ASZ, all are evidence for Multi dextral shear zone, basement complex evolutions, and young intrusion (granite and gabbro).

The stretched grey color views of band 3 and 7 indicated various faults on the extended quartzite belt. The trend of ASZ is NW-SE and thrust fault is NE-SW. This ASZ is extending to Jebel Mara in western Sudan [3]. The band combination 7,3,1 in R, G, B (Fig 3) shows the drainage pattern which are structurally controlled, with certain pattern indicating the more erosion-resistive rock type being younger intrusion but the lesser is para-schist and quartzite. The white tone inside the drainage is tertiary sand. The applied angle of 315 degrees azimuth and 45 degrees angle aspect on the ASTER DEM (Fig. 6), shows lineaments clearly e.g., transcurrent fault, especially in the northern and southern parts. The spatial transformation of the false color combination (R7, G4, B1) emphasized the S-shape to the north of river kijjo, whose shape compared with a field photo (Fig.9) proofed to be a refolding structure. Other major structural features for mineralization zones include the lens-shape and C-shapes which are revealed in the enhanced Landsat 7. Foliation and developed joints are elements of the regional metamorphism. Joints are demonstrated in the far western part of the map, there is no doubt the horse tail structure on the DEM is observable, and the metamorphosed basement complex is well banded, exhibiting strong mineral orientation [8]. As shown in Figure 6, the foliated Chernokites-granulite is considered as an older basement complex unit in the study area.

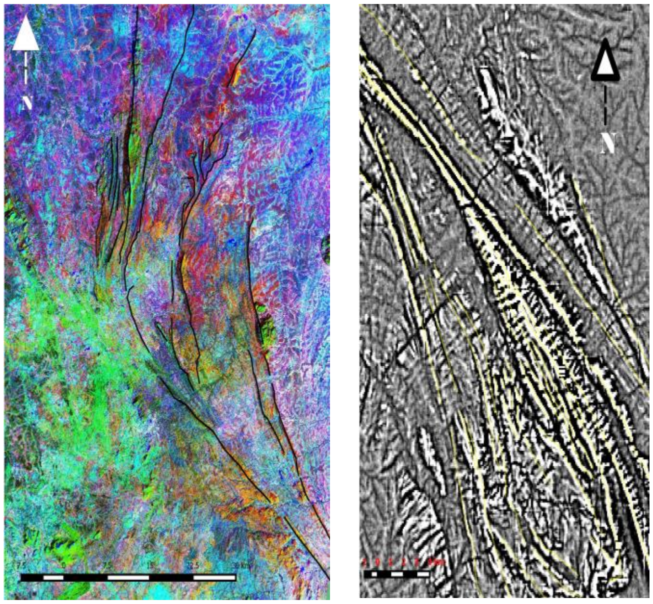


Figure 5. PCA (4, 3, 2) and High pass filter kernel's (5×5) applied on Dem. The black planes are some lineaments that have been extracted manually.

6. Results

After the applied analysis on the satellite images, the prominent geological features became more interpretable. The most effective tools which had demonstrated effectiveness and were able to expose the horse tail structure and other lineaments are: Gaussian contrast, equalization contrast, spatial filtering, and principal components analysis.

Although the resolution difference between DEM and Landsat is approximately 30 meters, the ability of each to detect lineament features is significantly different.

The high pass filter (5×5) on DEM shows the general view of the horse tail structure (Fig. 7). On the other hand, the features which the Landsat 7 was able to reveal better than the DEM include faults, folds, ring structures, foliations, drainage patterns, and fractures.

The lower part of the horse tail structure shows intensive regional metamorphism, especially the southern part (Fig. 7). These delineated geological structures have direct relationship with field reconnaissance maps of the study area, and thus, do possess proofs for some inquiries about earlier studies in the area.

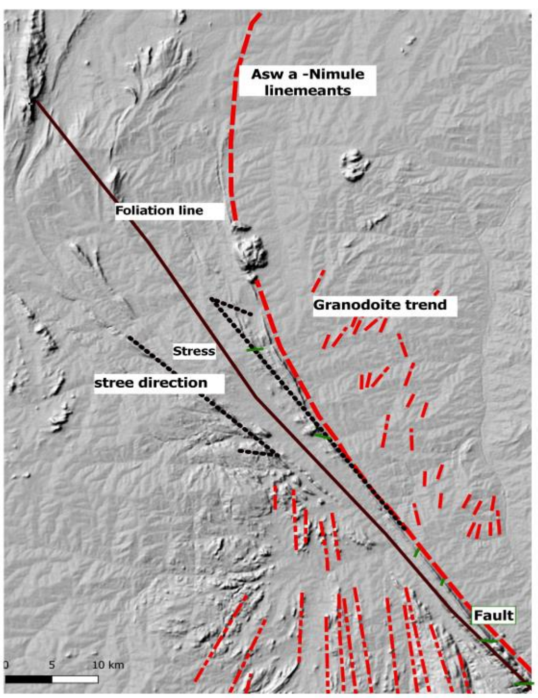


Figure 6. Shows some of the lineaments features within the study area.

The micro lines which are trending NW and then turning to SE are the effect of thrust fault.

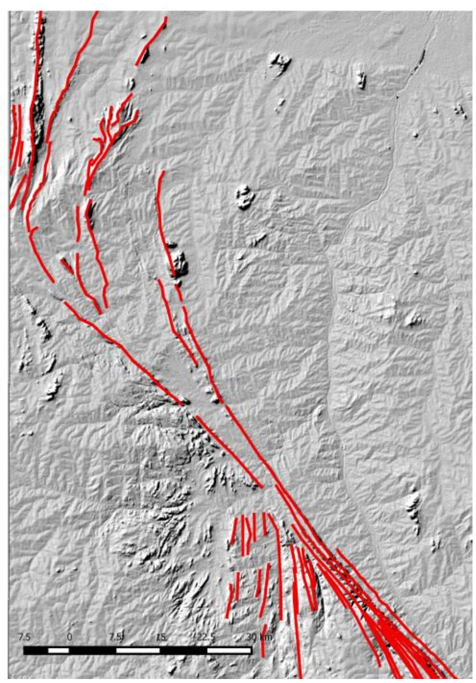


Figure 7. Shows the general view of the Horsetail structure (red lines).

There is a highly metamorphose gneiss of the basement complex in the northern part of the research area which had produced a wide range of deformation on the quartzite belts in the region as is exemplified by the very complex superposition of several generations of strong deformation that produced these isoclinal folded gneiss layers (Fig. 8) and quartz veins [8].

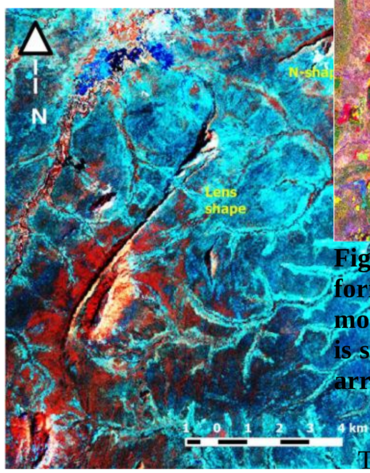
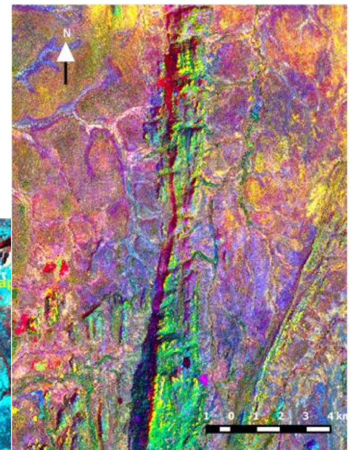


Figure 8 (left). Shows isoclinal fold in quartzite and on the right side is the lens and N-shape structure with the yellow font, the picture has been taken from the midst of the plunging fold at the upper right side of the Landsat imagery.

Figure 8 (right). Showed a very complex superposition of several generations of strong deformation which produced these isoclinal folded gneiss layers and quartz veins [8].

Figure 9. Shows the display of (R7, G2, B1) the S-shape fold is marked by black dot, and on the right side is angular refolding on chlorite-schist, the white spots are quartzite, the two photos reflect regional and micro structural relation



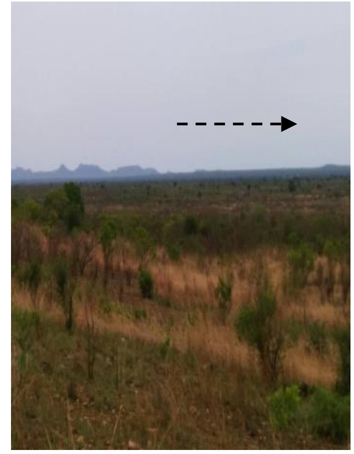
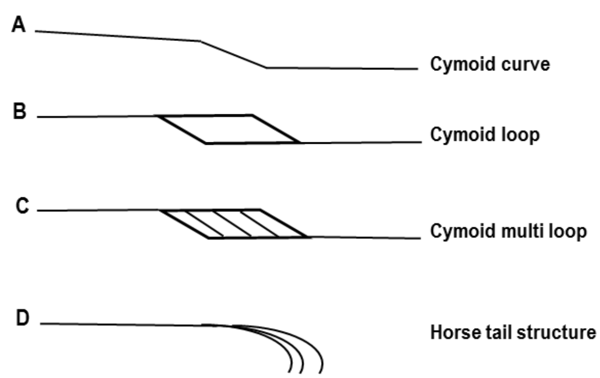


Figure 10 (left). Represents a PCA (2,3,4) showing deformation which generated joint and fracture along the mountain belt, trending east west, while the field picture is showing, regional view of the same mountain belt. The arrow on Figure 10 (right) shows geographic north.

This horsetail structure has passed three stages of development, namely, cymoid curve, cymoid loop and multi cymoid. During this development stages, disfiguring has taken the shape of irregular joints loop and the final stage is the fourth stage shown in Figure 11.

From structural perception the whole horsetail structure is a fold, whose parallel planes show regional foliation. However, the change of the orientation proves two things, deformation or folding during more than one period of metamorphism [9].



Development of a horse tail structure [after Mckinstry.1948]

Figure 11. Shows how the horsetail structure develop in four stages.

7. Discussion

Early orogenic initiation of shear activity along the ASZ could be explained in terms of a crustal ramp activated during the underthrusting of Congo Craton's lower crust. This led to an oblique ramping and concentration of non-coaxial strain along the ramp resulting in sinistral displacements along ASZ via ductile shear at amphibolite facies conditions [1]. The activity along the ASZ can be linked to collision-related escape tectonics. Being located at the northeastern margin of proto–Congo Craton, whose orientation in this region is NW-SE and deviates from the dominant N-S trend in both the Mozambique Belt (MB), as well as the N-S shear zones in the Arabian Nubian Shield (ANS) which marks suture zones between accreted blocks; towards the south, in the vicinity of South Sudan and western Kenya, where they have been curved to a NW-SE trend parallel to ASZ [10]. However, it contains mafic and ultramafic rocks interpreted as ophiolitic cumulates [11] or mantle slivers, which does not corelates with the ASZ.

Each of these major structural environments is typically associated with relatively high density of faults, fractures, and intersections of faults and fractures, which collectively enhances permeability that facilitates convection of geothermal fluids [12]. This is being demonstrated by the existence of the geothermal activity in the vicinity of Wonduruba.

Mapping geological structural lineament is important in revealing the tectonic behavior of the NW-SE trending active ASZ. The identified lineament map in this study (Figs.5 and 6) illustrates fault systems as well as other significant fold structures that have not been mapped previously by any geological expeditions to the area. It is worth noting that the comparison between the extracted lineament map of the study (Fig 7) and the available unpublished geological map of the area shows an update of the location of the new findings that modify the existing unpublished maps of the study area. It is obvious, in structural geology, that extensional horsetail splays may host pull-apart sedimentary basins while compressional horsetail splays may display thrust faults and folds at the tips of major strike-slip faults, such as the ASZ that could host metalliferous deposits and other industrial minerals [13].

The conceptual model (Fig. 11) illustrates ASZ transgression together with the northern end of the horsetail.

The model suggests that both structures are reactivated splays within the area of the restraining bend.

Depending on the direction of curvature to the sense of displacement, thrust components of displacement occur on faults of the horsetail, and these movements are accompanied by folding and uplifting. Extensional structures, such as the NW trending normal faults, and compressional structures, such as NE-trending folds and reverse faults, are believed to have resulted in the association of the major strike-slip system.

8. Conclusion

The results of the present study revealed the behavior of the horsetail splay caused by the major intracontinental NW-SE trending Aswa Shear Zone as it extends from the Indian Ocean in the SE to the Sudan in the NW. The study utilizes remote sensing and GIS techniques to detect and map the horsetail geological structure in Central Equatoria State of South Sudan. Remote sensing data comprising of Landsat 7 and Digital Elevation Models (DEM) have been utilized in the study to map the architecture of the horse tail structure in the vicinity of the ASZ.

Ground-truth for the purpose getting a greater and better structural and geological correlation has been provided by additional data which were collected during previous field surveys conducted in this area. The study area is a highly mineralization zone with a variety of mineral resources such as gold, and associates. It is obvious, in structural geology, that extensional horsetail splays may host pull-apart sedimentary basins while compressional horsetail splays may display thrust faults and folds at the tips of major strike-slip faults, such as the ASZ that could host metalliferous deposits and other industrial minerals as is the case with the area surrounding Gorom village in Central Equatoria where artisanal gold activities are being carried out by the natives in the vicinity of the horsetail splay.

The applied processing techniques of Band Combination, PCA, and Spatial Filtering have been effective in revealing the dominant lineament features and their directions in addition to elucidating the regional fracture pattern and the respective relationship between the major tectonic elements and the geodynamic setting in the broader region of the study area. The identified lineament map in this study illustrates fault systems and several significant fold structures that were not mapped previously by any geological studies which have been carried out in this study area.

Characteristically, these major structural environments are typically associated with relatively high density of faults, fractures, and intersections of faults and fractures, which collectively enhances permeability that facilitates convection of geo-thermal fluids as exhibited by the existence of the geothermal activity in the vicinity of Wonduruba.

The formation of the horsetail structures in this part of Central Equatoria are consistent with the conceptual models for the tectonic features associated with strike-slip restraining bends which are caused by the sinistral NW-SE major ASZ termination by the principal faults bounding the Muglad pull-apart basins. The results show good correlation between the distribution of the extracted lineaments and those lineaments obtained by structural geology work from previously unpublished literature and the digitalized lineaments from the geological maps, which were validated through geological field excursions (ground-truth) conducted in the study area.

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