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Studying structural characteristics of Saqez–Takab Region (NW of Sanandaj–Sirjan Zone) using GiT (Geoinformation Techniques)

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Abstract

Saqez–Takab Region, as the northwestern part of Sanandaj–Sirjan deformed and metamorphosed Zone (NW part of Zagros Fold and Thrust belt, NW of Iran) has been studied in this research for detection of structural characteristics and tectonic evolution. Based on the prepared lineament map, all faults (lineaments) can be classified to 3 different sets by their length values: the Major, Main and Minor Faults. Eastern part of the study region is the least populated area by both the number and the length values of measured faults. The faults with E-W strike trends are formed in the east and central east, NW-SE trending faults are situated in the north-west and central west, and NE-SW trending faults can be seen in the south-western part of the region. By analyzing the faults kinematics, containing fault planes and P-Axis values there are at least 3 main structural generations. Based on comparison of the strike values of outcropped faults, fault plane orientations, P-Axes values (directions), observed lateral displacement relationships and the other evidences the oldest fault set is oriented N135 (ductile condition /shear zone) and is dextral. The younger set is N70 (brittle – ductile condition) with both sinistral and reverse slipping; and the youngest one has a mean direction of N15 (brittle condition) with a sinistral movement. These last movements of the 3 old fault systems are related to the final deformation phases of Saqez – Takab Region.

Introduction

A. About Saqez-Takab Region

Sanandaj–Sirjan Zone (SSZ) as a metamorphosed and deformed belt has been studied by many researchers. Southern SSZ is mostly covered with middle to Upper Triassic rock units, but Northern SSZ is composed of Upper Cretaceous rocks (Ghasemi & Talbot, 2006) especially arc-related volcano-sedimentary rocks.

In this research some part of north–western SSZ - *Saqez–Takab* - located in Kurdistan (mostly) and Azerbaijan Provinces was studied to find out the structural characterizations.

Saqez–Takab Region is situated from 45˚ 52΄ 13″ to 47˚ 53΄ 28″ E and 35˚ 53΄ 2″ to 36˚ 24΄ 36″ N by WGS 84 coordination system (about 6000 km^2). Saqez in the central west part is the most important city. The main access road to the area is Divandarreh–Saqez–Bukan .The other roads attach or cross this road (Figure: 1).

To study the morphology, digital elevation model or DEM (SRTM) image of the region virtually *sun-shaded* from northeast. It is obvious that the least elevated area is located at the eastern part, a result of the youngest lithological units and the least deformed area (Figure: 2).

B.Geological Settings

The SSZ belt is localized along the western margin of Eurasian plate and east of *Zagros Main Thr*ust (ZMT). Zagros collisional zone has been divided into a few various subzones by Mohajjel & Sahandi, 1999. The study area is mostly located in a subzone named "*complicated deformed subzone*". This area has been affected by regional metamorphism, subduction, magmatism and finally the collision of Eurasian and Arabian plates in Tertiary. Then, shear zone with regional uplift occurred (Mohajjel & Sahandi, 1999).

Based on the 1/100000 geological map of Saqez–Takab region, the oldest lithological units - the Precambrian metamorphic rocks - are situated mostly in the west and south. It is clear that the Mesozoic units (both metasedimentary and volcanic rocks), especially the Cretaceous members are dominantly spread over the central and central eastern parts of the region. The Oligo-Miocene to the Recent units are formed in the east. Some intruded granites to granodiorites have been formed in the Precambrian (now metamorphosed) and Cretaceous. The 3 main outcrops of these intrusions are located in the northeast, central south and northwestern corner (Figure: 3).

C.Research Methodology

In this research, GIS and RS methods were used for detection of the big brittle structures. These outputs then were modified for preparation of information layers to draw the structural lineaments map.

In the next step some station points were determined for the field study based on the foregoing map. Then data were collected from the stations in the field trip.

Structural analysis was the final stage containing geometric and kinematic interpretation.

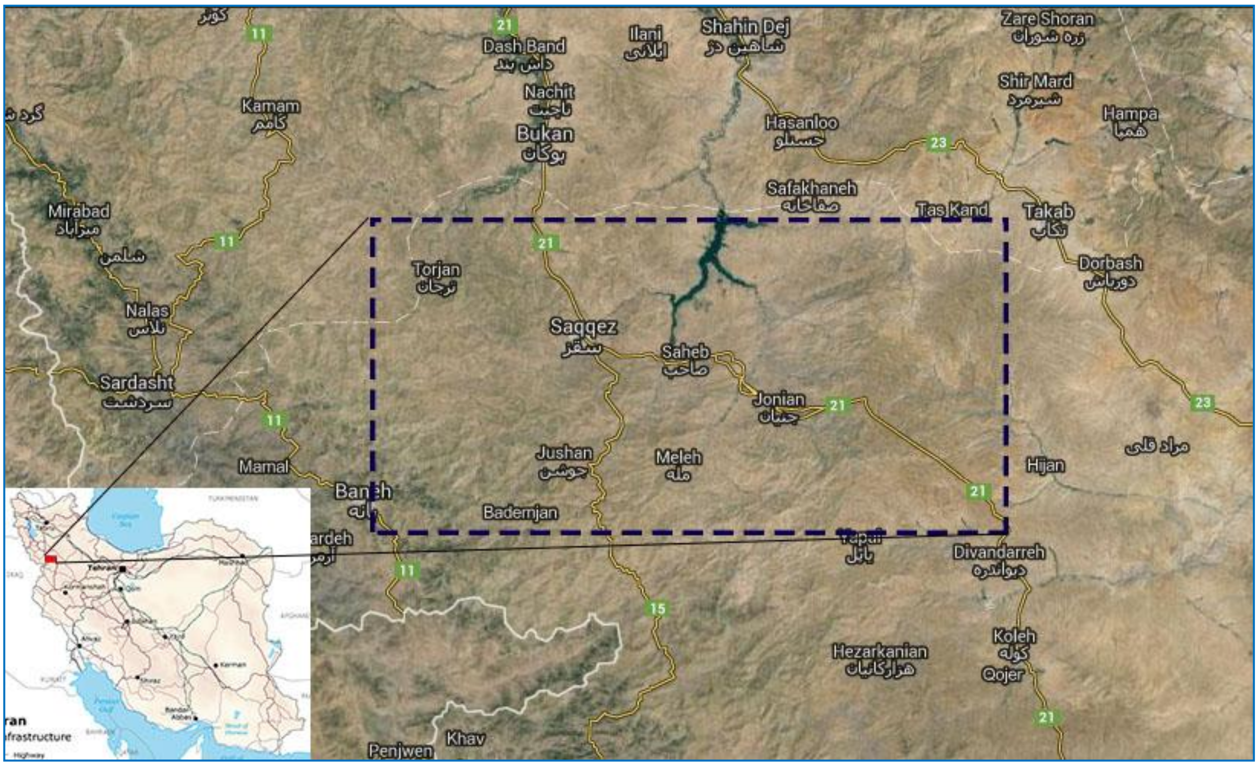


Figure-1: Main Access roads map to Saqez-Takab Region. The longest main road is Divandarreh – Saqez – Bukan trending SE - NW of the study region.

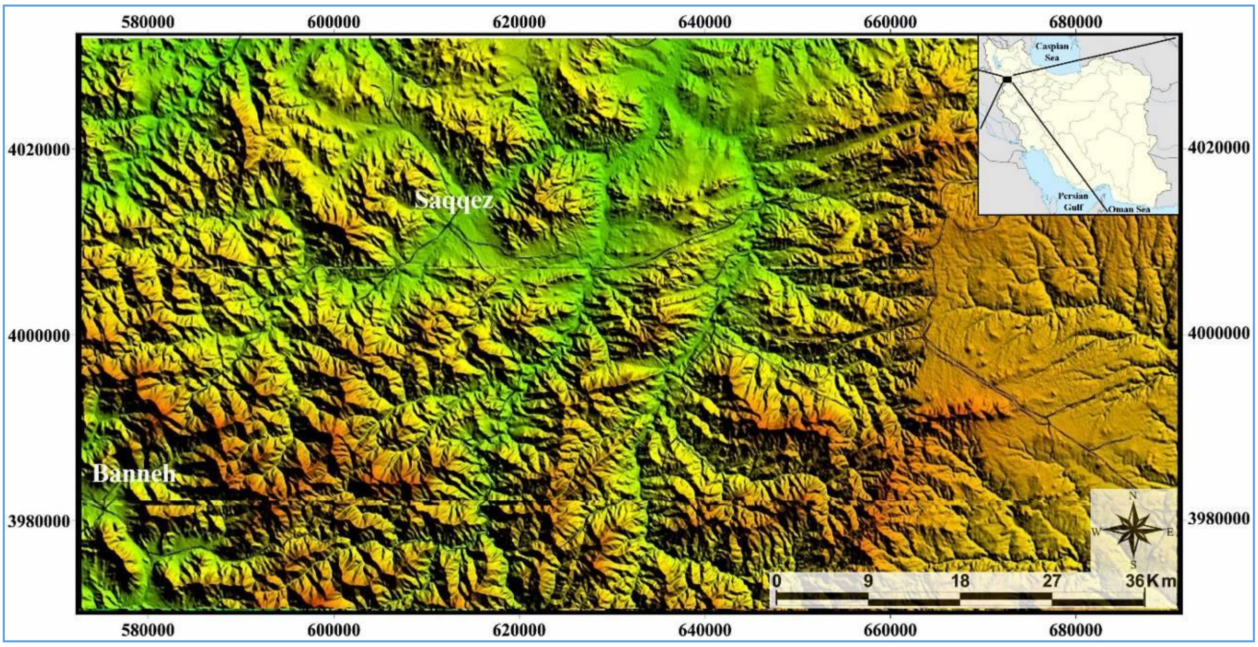


Figure-2: Sunshaded Digital Elevation Model (DEM) image of the region; the eastern part of the region is the least elevated (lowest) area.

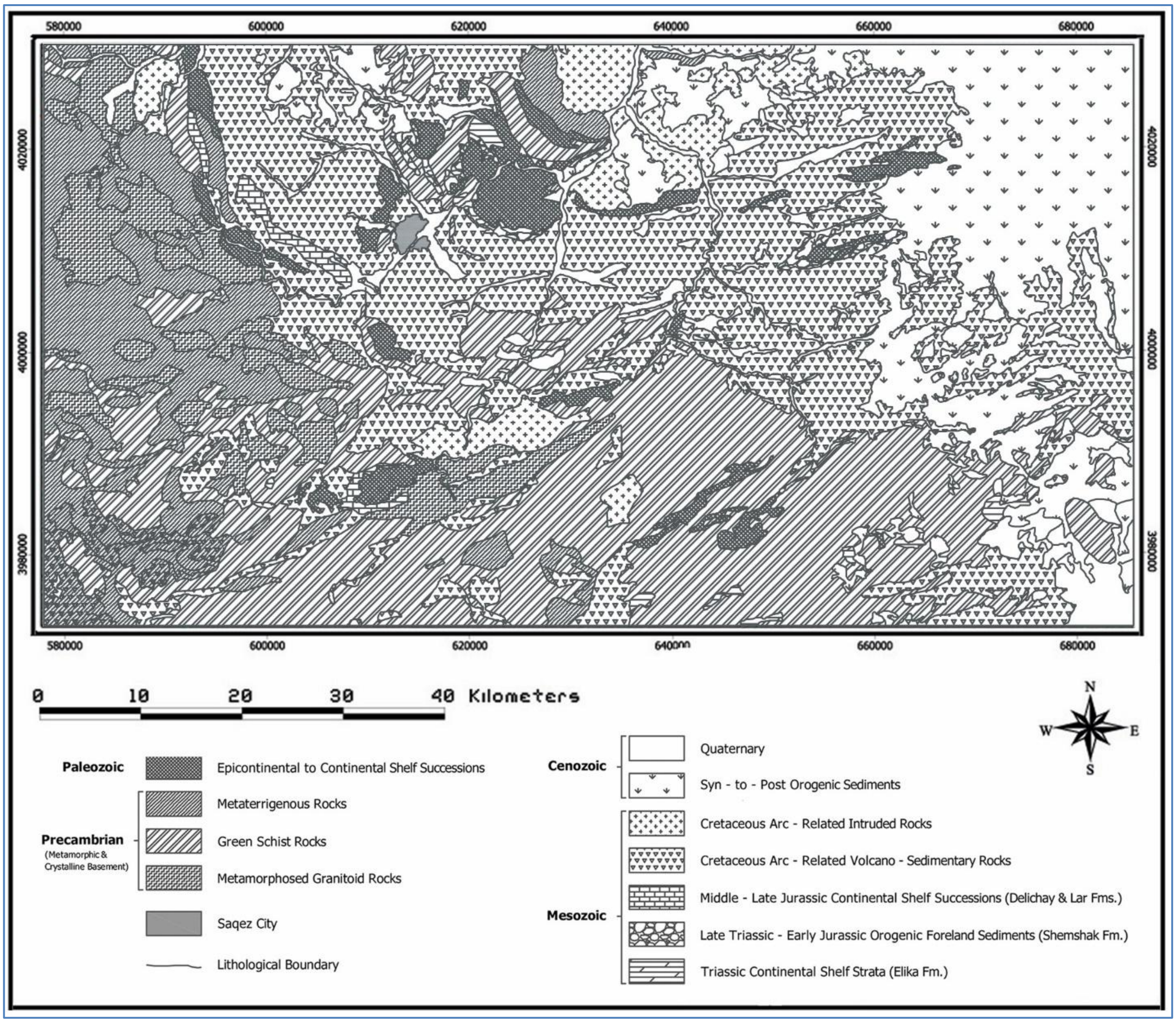


Figure-3: Adapted 1/100000 geological map of Saqez–Takab region (by: Kholghi Khasraghi 1999, Fonoudi & Sadeghi 2000, Fonoudi & Hariri 2000, Omrani & Khabbaz Nia 2001, Hariri & Farjandi 2003, Ghalamghash & Khezri 2005).

Structural Lineaments Map

A. RS Based Methods

The lineaments (probable structural fractures) map was drawn based on a few RS (Remote Sensing) techniques on LANDSAT ETM+ satellite data. The first method was composing 3 visual bands in an RGB output image to distinguish the probable strike-slip movements (sudden color displacements) of the faults. The RGB=741 composition was made and used. Then all the sharp lines and boundaries were checked for being (or not being) fault by directional filtering (sunangle filter) in the 8 main geographical directions. The other technique for detection of fault scarps, narrow and straight valleys and linear uplifts was to use DEM (SRTM) data by flashing virtual sunshine from a moderate angle for the 8 main directions (sunshading tool). Final technique was using the PCA method by performing it just to PC1 for decreasing the image probable visual noises. For drawing the structural lineaments map, 1/250000 and 1/100000 geological maps were used as subsidiary sources, too.

In the prepared structural lineaments map (Figure: 4) the lineaments have been grouped to 3 sets by their importance (in the other words by their length values) containing Major, Main and Minor. The 2 first types (major and main lineaments) have been shown on the RGB (=741) image of the study area (Figure: 5).

B. Isofracture Map

To find out how the faults (still lineaments) have been distributed all over the region, an *Isofracture Map* can be helpful. For doing this, it is necessary to calculate *I* or Intensity factor for all parts of the study region: first the whole rectangular–shaped region was divided into 53×27=1484 equal–area square–shaped cells (with the side length of 2 km) as a network. Then summation of the length values of all the passing lineaments through each cell (over the unit area; here =1) is *I* value (*I Factor*) of the center of that cell. The next step is to draw intensity variations map, or Isofracture Map, which shows the quality of fractures development through the whole region.

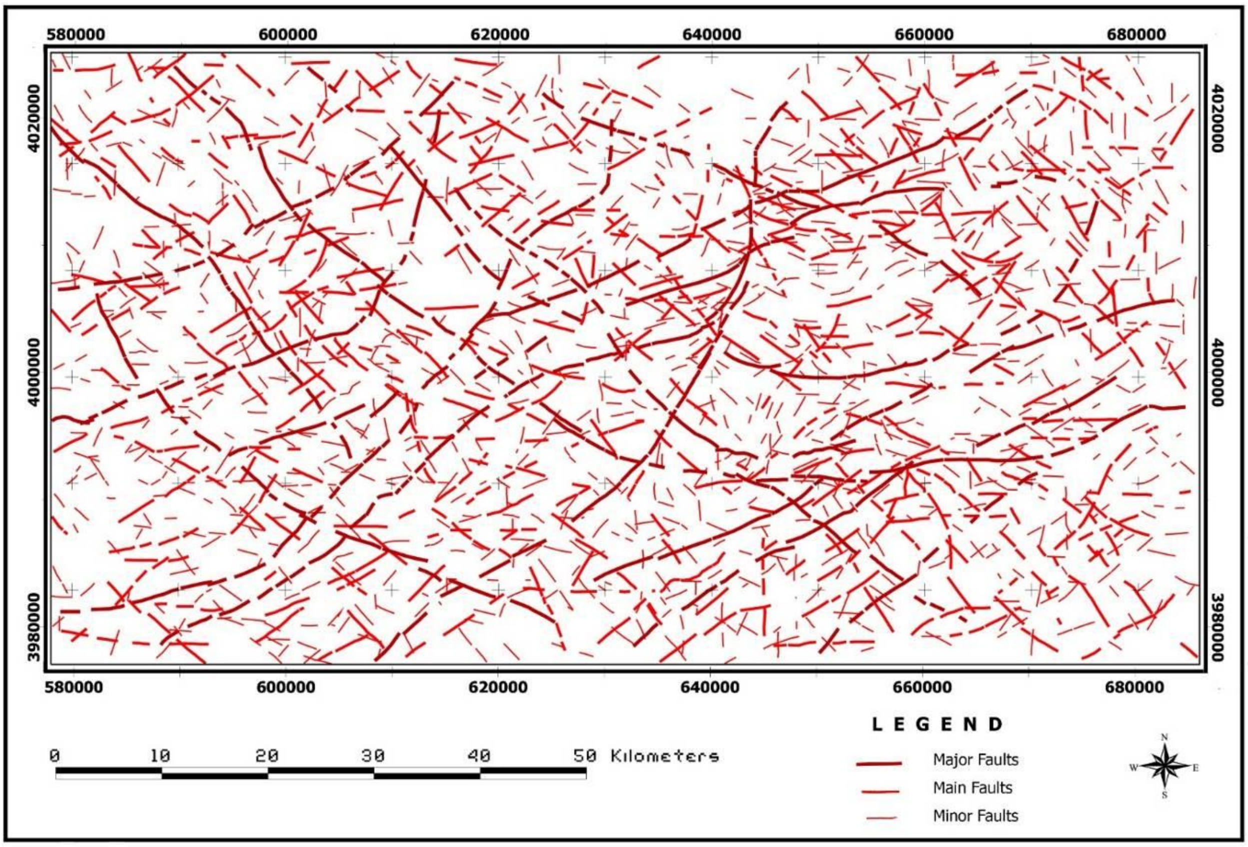


Figure-4: Structural lineaments map of the study region, based on remote sensing methods. The Lineaments (probable faults) have been classified to 3 main classes by their length values.

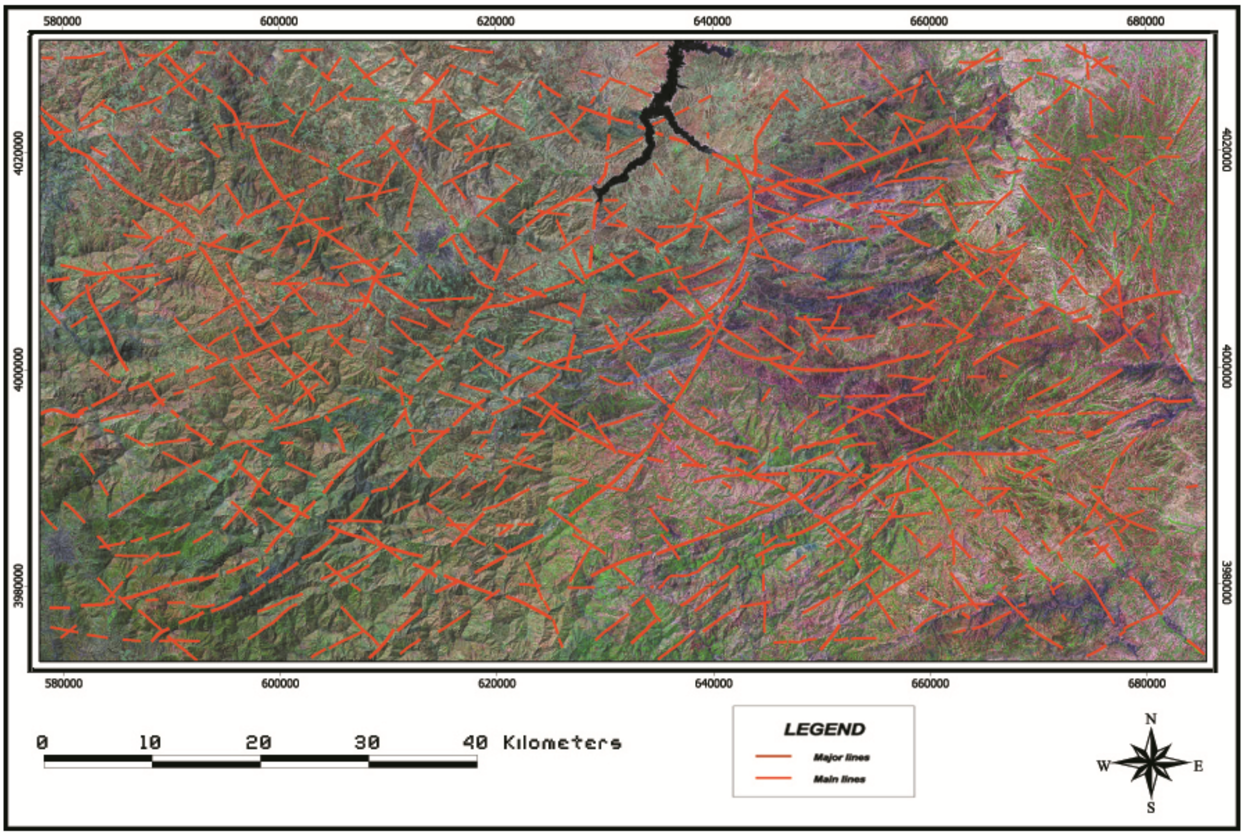


Figure-5: RGB (741) image of the study region with the first 2 lineament classes on it.

Figure: 6 is the prepared map of this type and represents *I* factor variations by a Hot–Cold model of color classification. The map demonstrate that the maximum *I* values are related to the west and the center, and the minimum values appertain to the east. It can be resulted from a few various agents, but probably the simplest and the most important reason is the age effect. In other words, *I* is low in the east because there is lithologically the youngest area and has had the least time to record structural phases.

Field observations

A. Data Collection

In addition to verification of RS based detected faults, field operation was needful for geometric, spatial and kinematic specification measurements of the fractures. Hence, 21 station points were determined in the most fracture-populated places (high *I* values) and /or the locations with the most (fracture) intersections. The station localities with their names (= number) was illustrated on one of the filtered images of Saqez-Takab region, detecting the most common lineament set (N70) to be compared (Figure: 7).

As mentioned, all the lithological units, alterations and the other geological features were observed and noted in the field studies. Also, geometric and kinematic characteristics of the faults in the outcrops and around were measured containing strike, dip, dip direction, rake angle and rake direction. A few other helpful structures, especially some ductile types related to the shear zone were noted, too. For example folds, kink bands, tension gashes, pressure shadows and so on were considered.

Comparing the field observed faults with the lineaments map is remarkable. There is an applicable correspondence between them, especially for the major and main faults. The most measured strike direction values in each checkpoint (station) correlates with the major fault(s), and the second degree value frequencies predominantly correlates with the main fault(s) of the same point on the map. This fact demonstrates that the detected faults are sufficiently valuable.

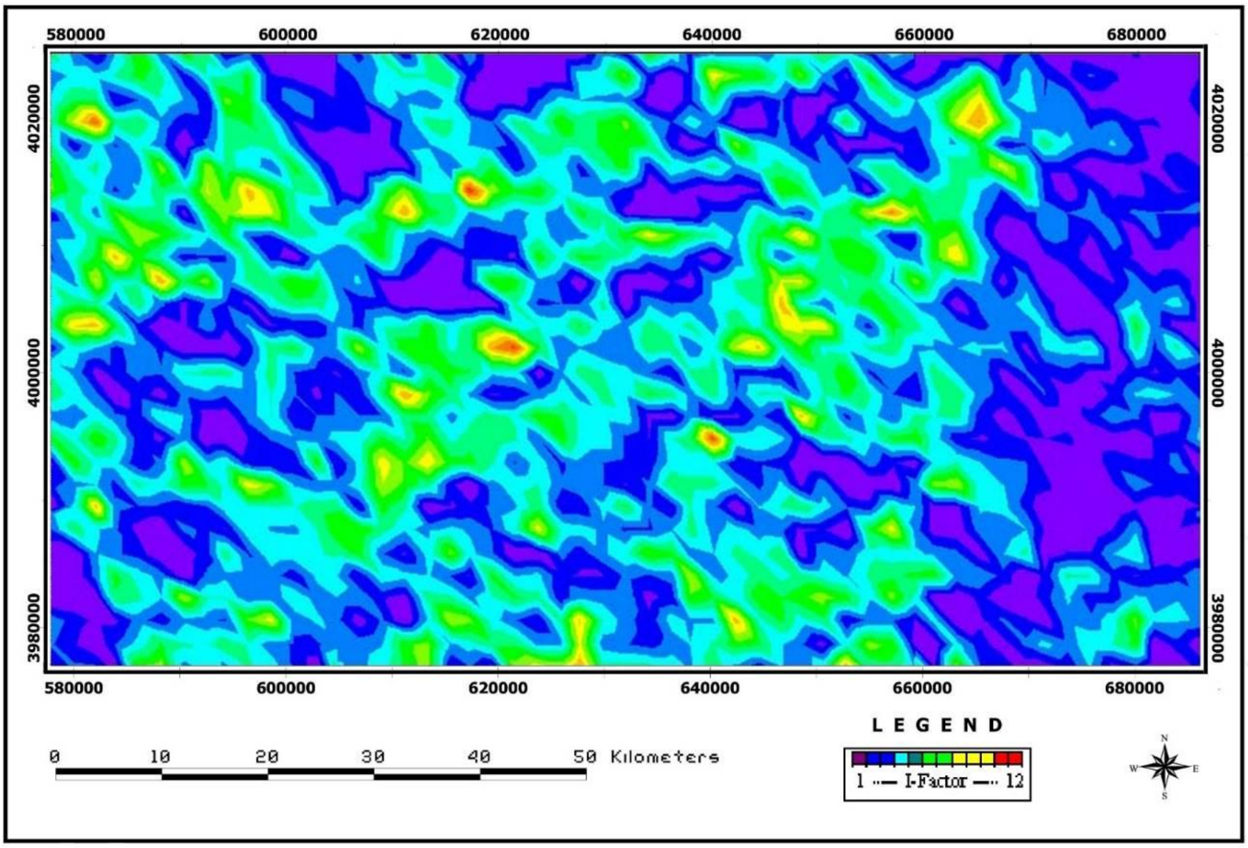


Figure-6: Isofracture (Intensity variations) Map of the region; the eastern part is the least populated area with faults.

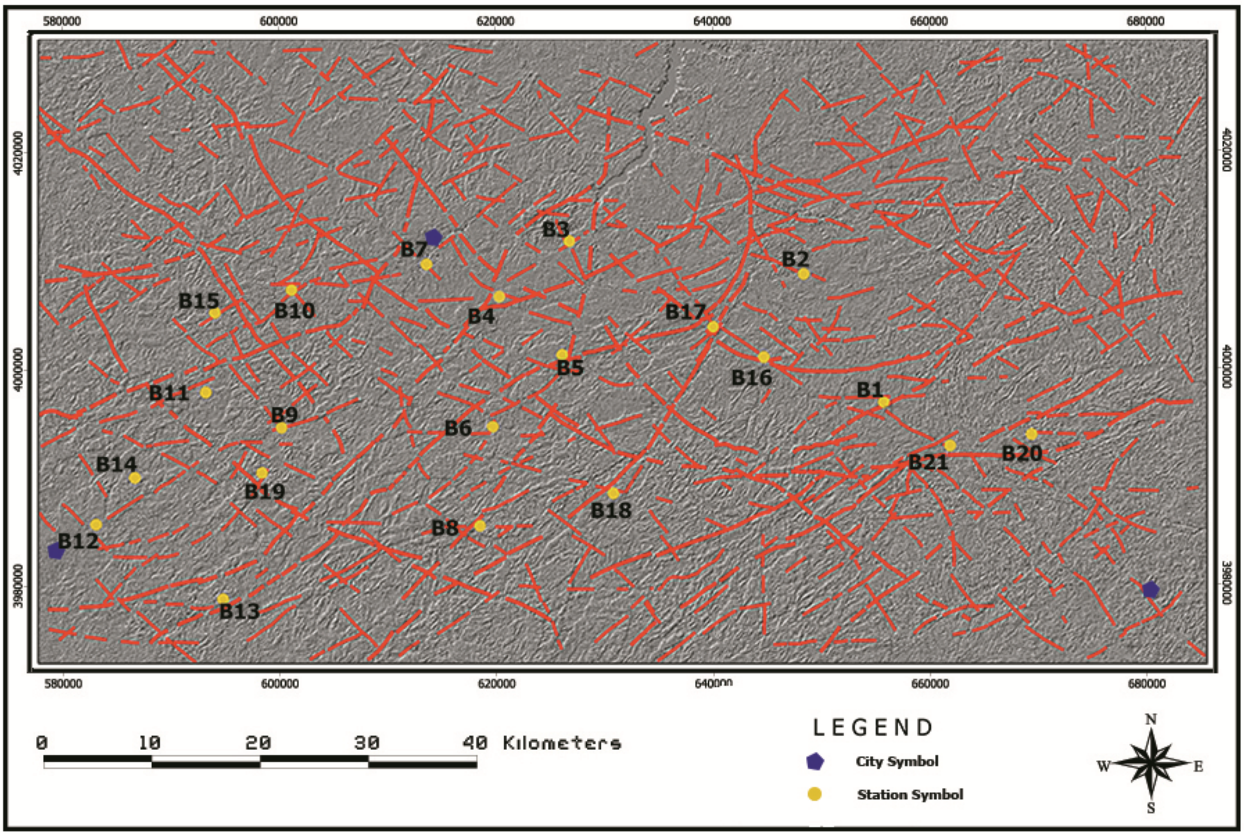


Figure-7: Station names and localities with the major and main faults on the NW-SE directed (Sunangle) filtered image of the region (this filter sharpens all the NE-SW lineaments - normal to the direction mentioned in the name of the filter); The stations are close to the more intersected areas by the major faults.

B. Strike Value Variations

To study the distribution of measured fault strike values, the rose diagram of each station data set was drawn. For an easy comparison, all these diagrams have been plotted on their own station points on the lineaments map (Figure: 8). It is clear from this map that the big petals follow the orientations of the major and main fault zones. This map indicates that the faults with E-W strike trends have been formed mainly in the east and central east. NW-SE trending faults are situated mostly in the north-west and finally, central west and south-western part of the region host the majority of NE-SW trending faults.

C. Fault Kinematics

To find out the kinematic specification variations of the faults, the main fault plane(s) diagram of each station was drawn using rake angle data. The first conclusion of comparing these diagrams is the diversity difference matter: the most various fault planes appertain to the west; the area with the oldest rock units which have recorded the most generations of deformation. Another calculated and drawn parameter was the compression (or tension) orientation vector, the P-Axis trend based on the rake angles. Similarly, this vector was plotted on the fault map for every station, too.

Obviously it could be a single vector or more for each station (Figure: 9). All the P-Axes vectors (Figure: 10-a.) have been classified by their orientations. Each group of parallel or sub-parallel vectors, regardless of having similar or opposed directions was separated and shown in a single map, representing one structural generation. According to this map the Saqez–Takab region has had at least 3 generations of deformation, or 3 phases of **P** axes trends: Northern West–Southern East (Figure: 10-b.), South-North (Figure: 10-c.) and East Northern East–West Southern West (Figure: 10-d.).

D. Introducing the Major Faults

The structural characteristics of the major faults can be mapped now. Figure: 11 is the final and completed

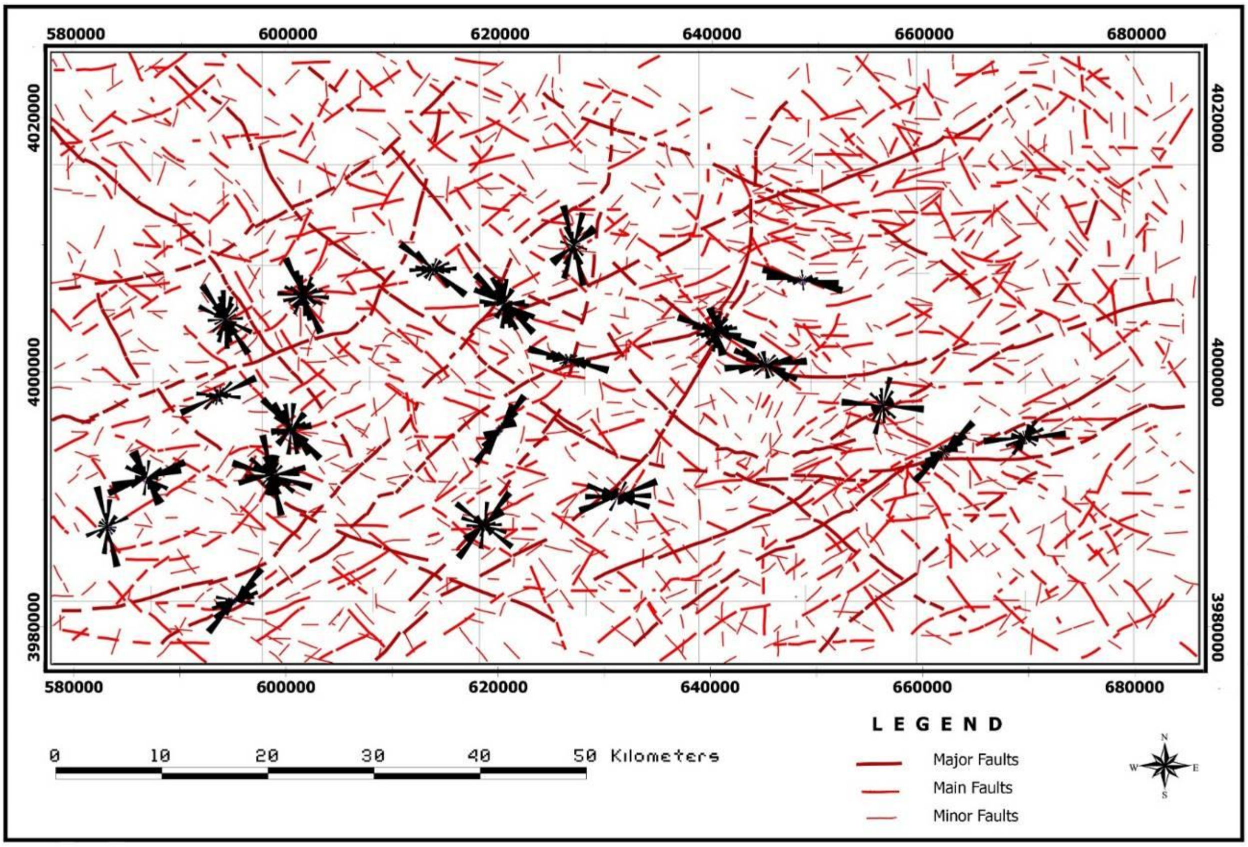


Figure-8: Fault strikes distribution shown by comparison of all the station rose diagrams; the long (main) petals follow the trends of major and main faults.

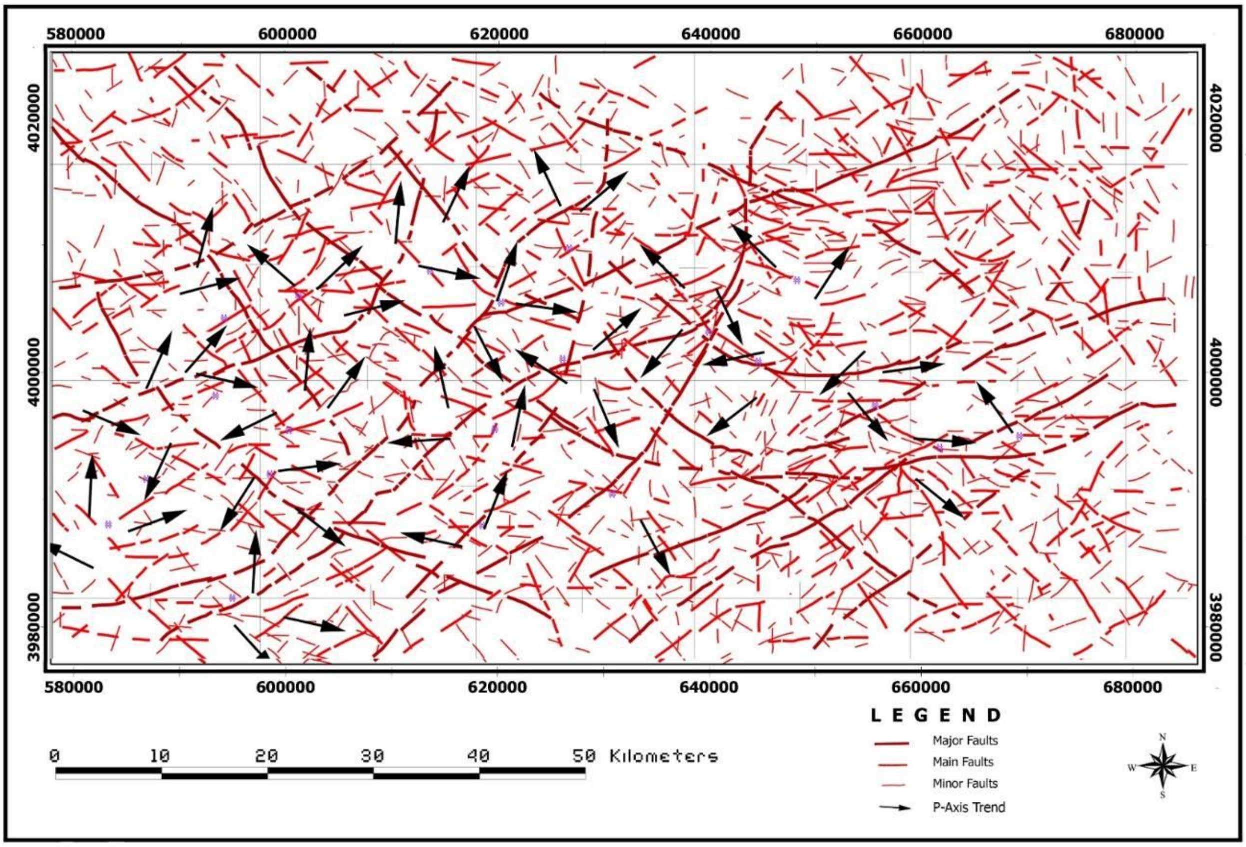


Figure-9: Localities and directions of all the faults P-Axis vectors; Blue points are the station places.

structural fractures map which some major faults have got names (according to the nearest important or famous residential points) and their senses of movements have been illustrated based on this research.

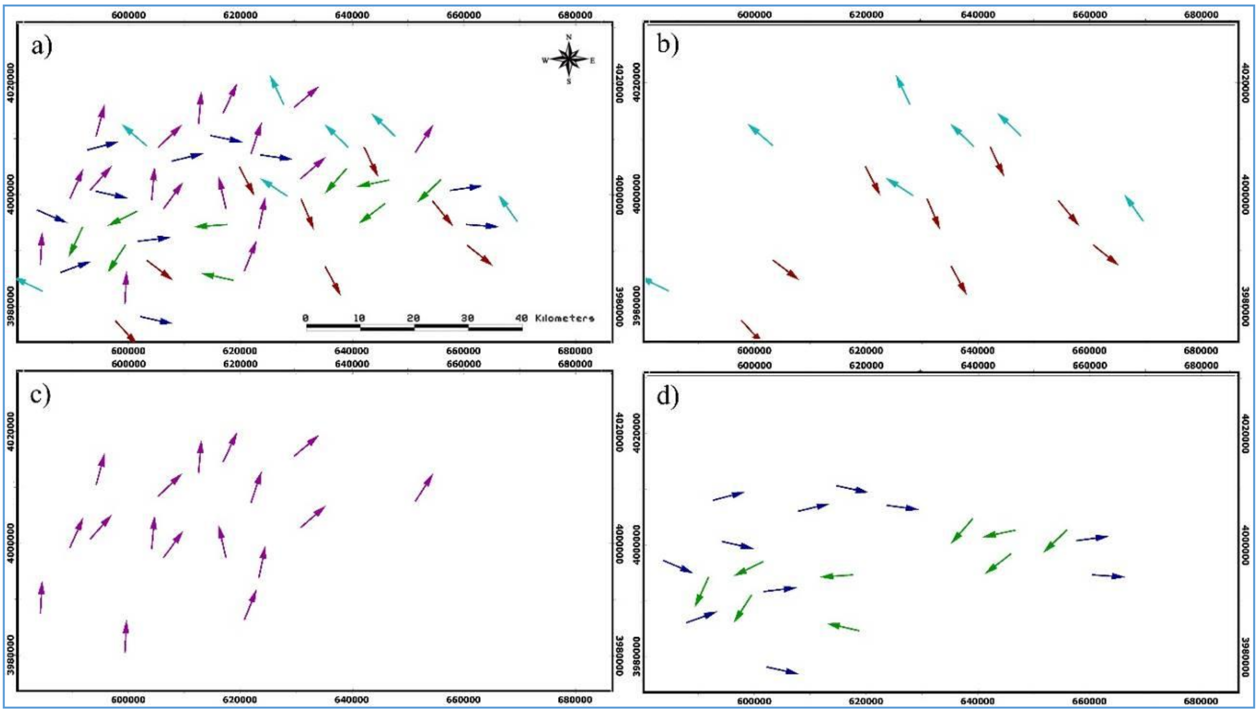


Figure-10: (a) P-Axes vectors map with color classification of them by orientation attitudes. (b), (c) & (d): The 3 orientation groups of the P-Axes vectors on separated maps; (b) NW-SE oriented P-Axis vectors. (c) N-S oriented P-Axis vectors. (d) ENE-WSW oriented P-Axis vectors.

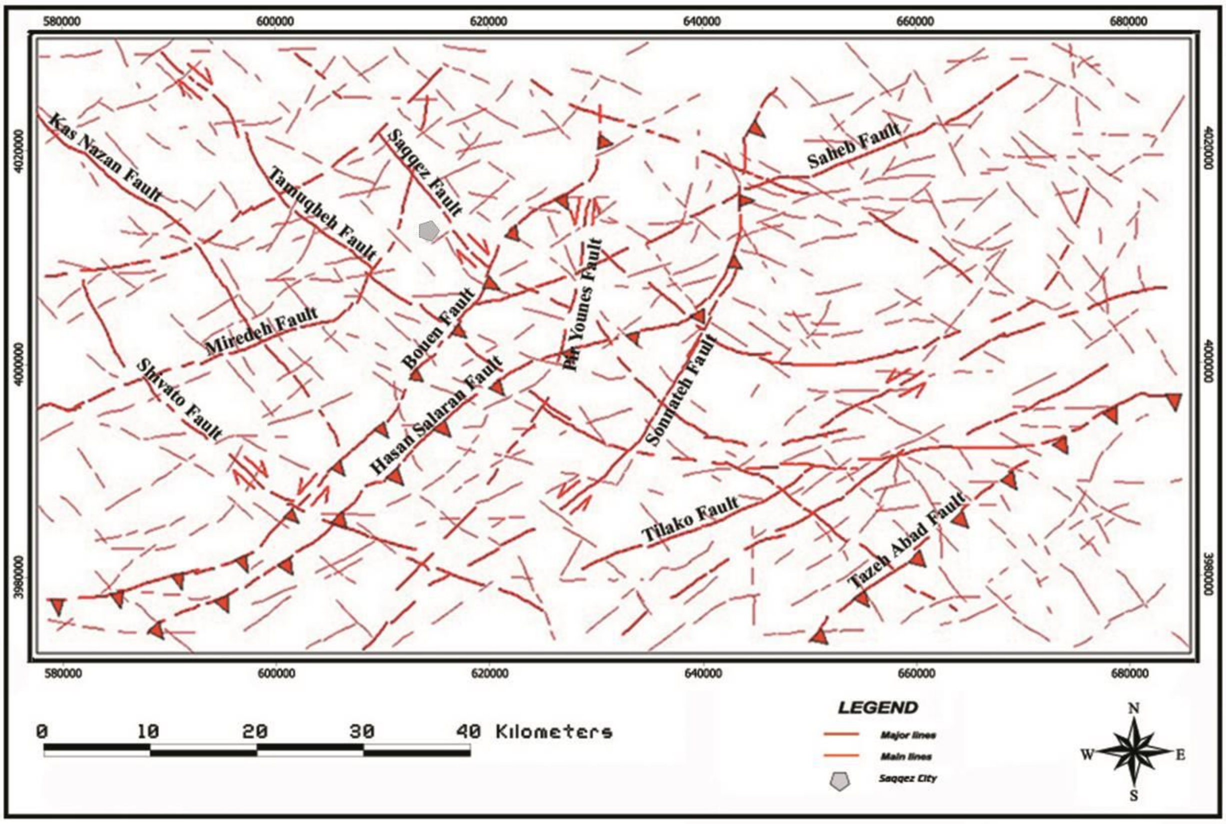


Figure-11: The final structural fracture map of Saqez–Takab Region; major faults have been named and their senses of movements are defined with the standard symbols. N15 Strike-slip faults have displaced older N70 reverse faults, and reverse faults have displaced the oldest N135 strike-slip faults.

Here is a classification of the illustrated major faults by their strike trends and movement senses:

A) The NW-SE trending faults which most of them have had dextral displacement, containing Saqez Fault, Tamuqheh Fault, Kas Nazan Fault and Shivato Fault. In some intersections this group has been displaced sinistrally by groups B & C.

B) The NE-SW trending faults which often have had both sinistral and reverse movements, including Bouen Fault, Saheb Fault, Hasan Salaran Fault, Tilako Fault and Tazeh Abad Fault. This fault group has displaced group A in some junctions. Beside, in some other cases the faults of group C have displaced this fault set with a sinistral movement.

C) The NNE-SSW trending faults with sinistral movements, containing Pir Younes Fault and Sonnateh Fault. These faults have displaced both groups A and B sinistrally.

Some outcrop pictures of the major faults have been shown in the next Figures (Figures: 12-21).

Division of the Region

To better interpret the results, first it is necessary to divide the region to 3 equal areas. This job has been done and represented (Figure: 22). Based on this division, 3 new subareas have been named from east to west as Divandarreh-Takab, Saheb–Sonnateh and Baneh–Saqez. Comparison of the structural characteristics of these subareas will be notable.

Table: 1 displays the rose diagrams of faults for all the stations and a representative rose diagram for each subarea. In a glance, the differences between 3 mean diagrams are clear: Divandarreh–Takab subarea has been affected mostly by E-W and NE-SW trending faults. Saheb–Sonnateh subarea has 2 main trending faults, NE-SW and NW-SE. But fault trends for Baneh–Saqez subarea are NNW–SSE and ENE–WSW.

Figure-12: Saqez Fault, view direction to SE.

Figure-13: Tamugheh Fault, view direction to NW.

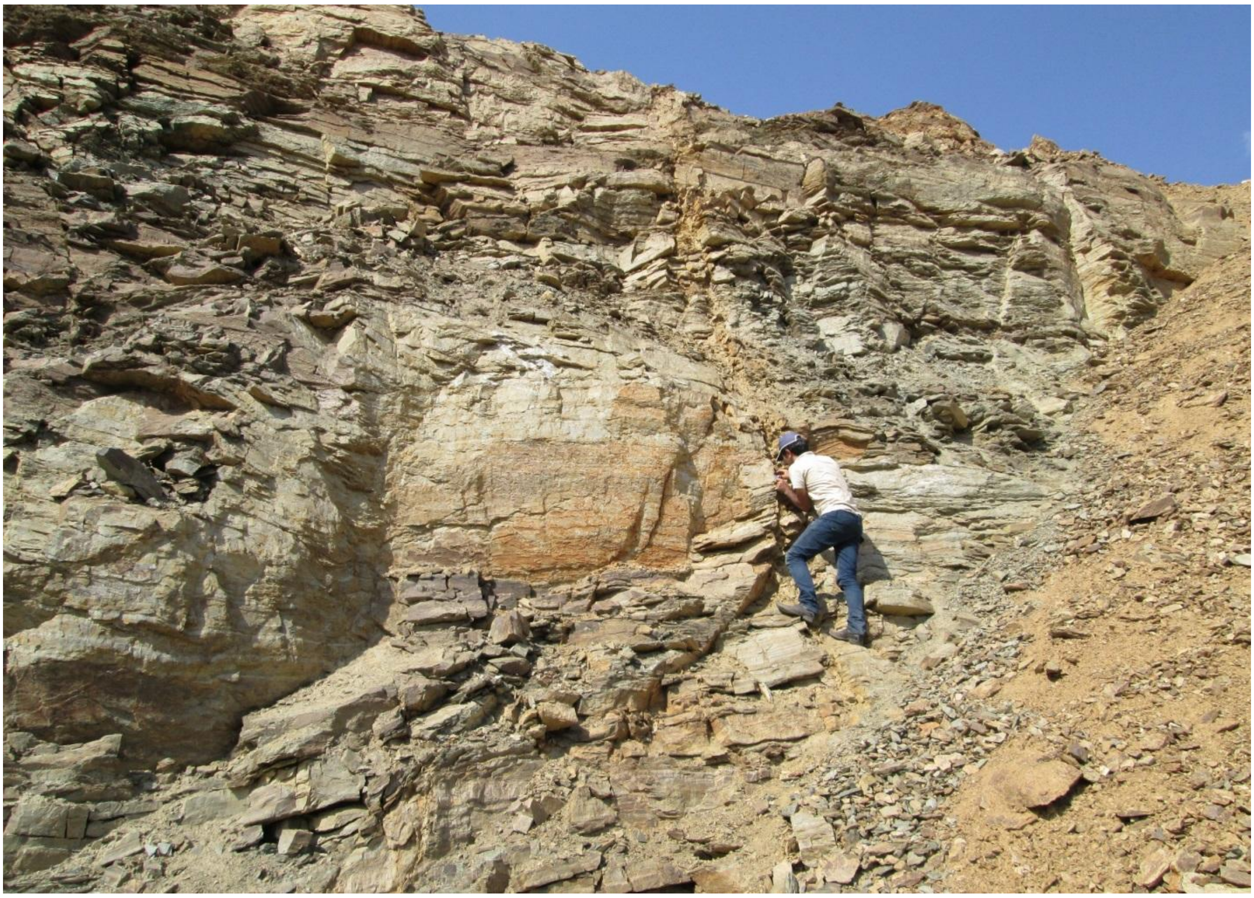


Figure-14: Kas Nazan Fault, view direction to NE.

Figure-15: Shivato Fault, view direction to NW.

Figure-16: Hasan Salaran Fault, view direction to NW.

Figure-17: Bouen Fault, view direction to NE.

Figure-18: Miredeh Fault, view direction to N.

Figure-19: Tilako Fault.

Figure-20:Sonnateh Fault, view direction to SW.

Figure-21: Pir Younes Fault, view direction to SW.

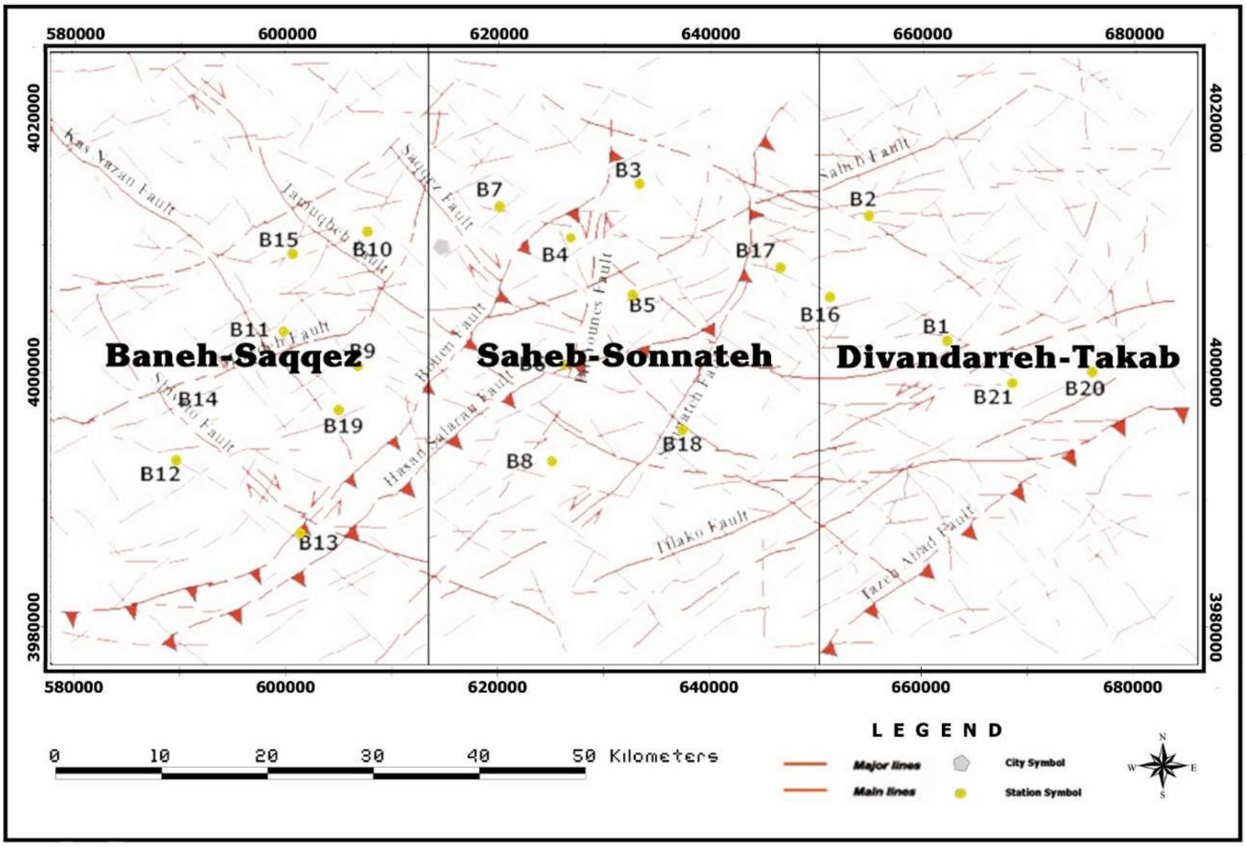


Figure-22: Divided Saqez–Takab Region map into 3 subareas with the station localities.

In Table: 2, which is the classification of the P-axis values for each subarea in a similar way as Table: 1, differences of the P-Axes vectors are obvious. In Divandarreh–Takab subarea the mean vector values are N123 and N225; in Saheb–Sonnateh subarea the 2 values are N235 and N335 and Baneh–Saqez subarea has 3 mean values (more phases of deformation are due to the oldest rocks) by the amounts of N20, N98 and N222.

Finally, Table: 3 is the classification of fault plane orientations for each subarea. The spatial settings for the 2 mean planes of Divandarreh–Takab subarea are 30/55W and 35/71E. The 2 fault planes of Saheb–Sonnateh subarea have spatial attitudes as 24/76W and 68/82E, and Baneh–Saqez subarea has 2 planes with the attitudes by 76/52E and 153/12W.

Conclusions

To have a correct viewpoint and analyzing the structural settings and relationships, it is important to note all the collected, measured and concluded data. Figure: 23 is the suggested structural evolution model for Saqez–Takab Region, the best-fit case which can explain all results acceptably: the oldest generation of the faults (fractures) is the one with the strike of N135 in Baneh–Saqez subarea (N153 by Table: 3), which is composed of Precambrian rocks. By the mean rose diagram of this subarea (Table: 1), this system is the NNW-SSE oriented fault set. This fault system is the group which was named A in the field studies, and has been displaced sinistrally by group B. As mentioned in the field observations chapter, these faults have had a dextral movement and are related to the trend of N20 of P-Axis vectors by the subarea mean diagram (Table: 2). The map in Figure: 10-c is the group of vectors which is related to this phase. As it is labeled as A in Figure: 14, the vectors have been concentrated dominantly in the west.

The second fault group by the time order is the group with the strike of N70 in Saheb–Sonnateh subarea (68 by Table: 3). By referring to the mean diagram of this subarea in Table: 1, the fault set with NE-SW trend is the best correlated group with that. According to field data this set was named B, which has displaced the

Table-1: Classified rose diagrams for all divided subareas both for the individual stations and as a representative (mean) diagram for each subarea.

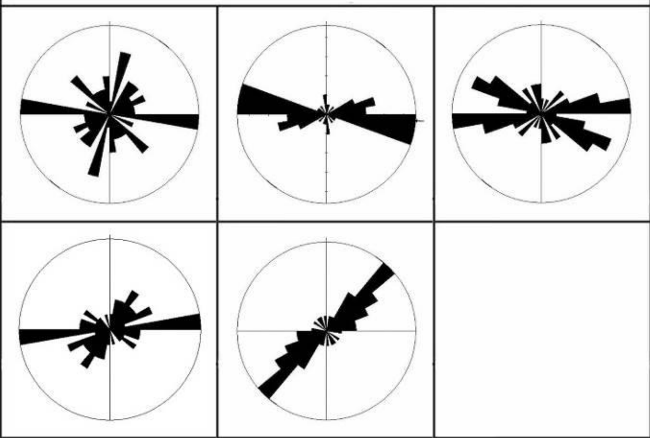
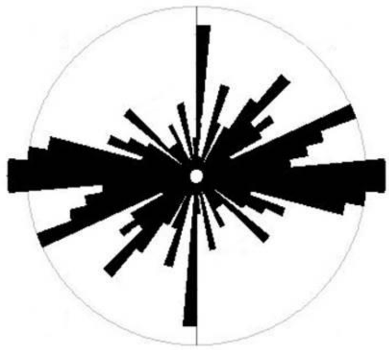
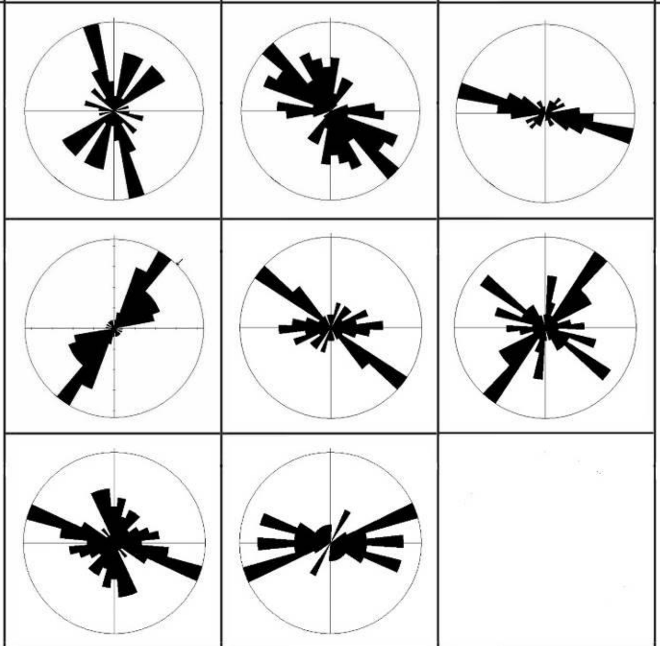
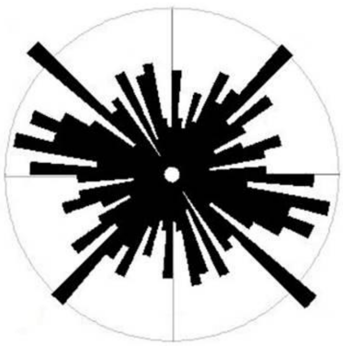
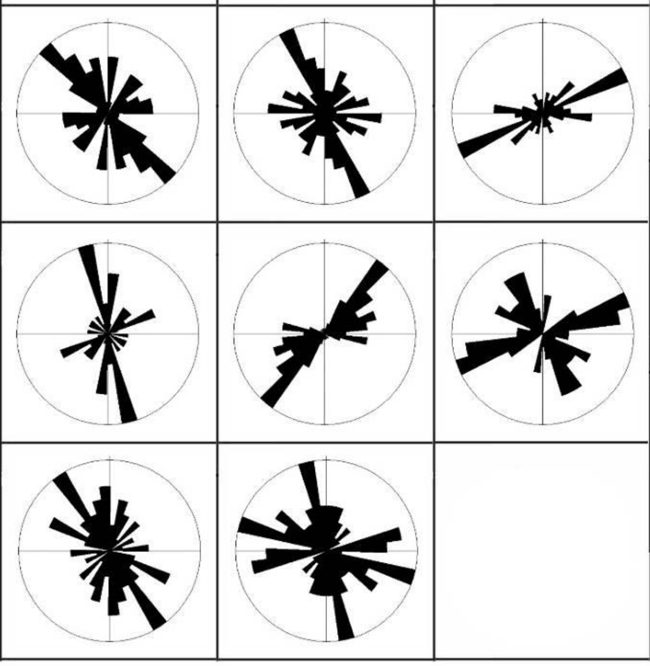
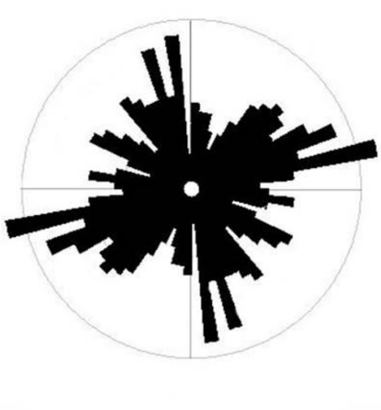
Divided Areas	Rose Diagrams of each Station	Rose Diagram of the whole Area
Eastern Area (Divandarreh – Takab)		
Central Area (Saheb – Sonnateh)		
Western Area (Baneh - Saqqez)		

Table-2: Classified P-Axis diagrams for all divided subareas both for the individual stations and as a representative (mean) diagram for each subarea.

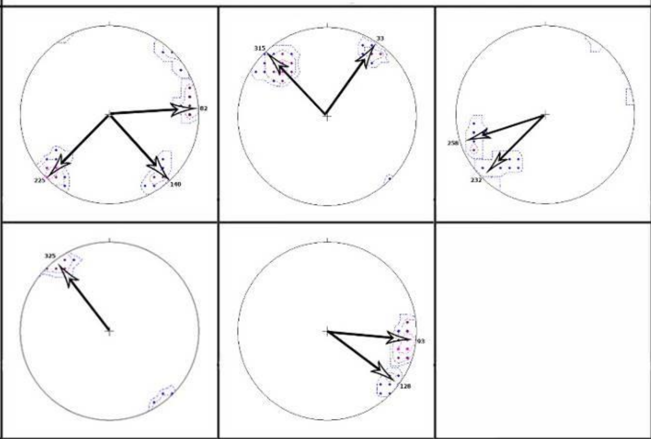
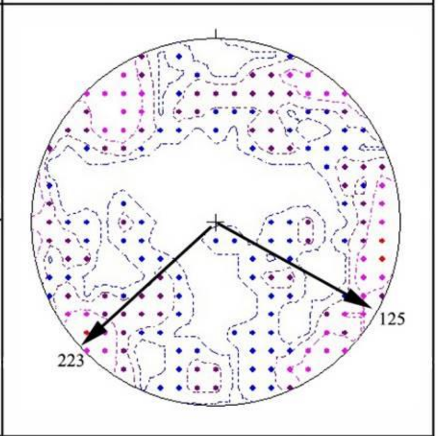
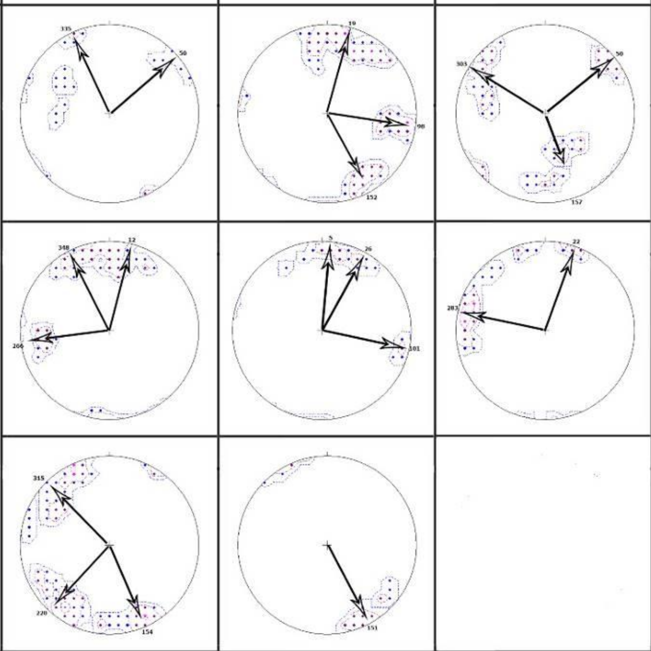
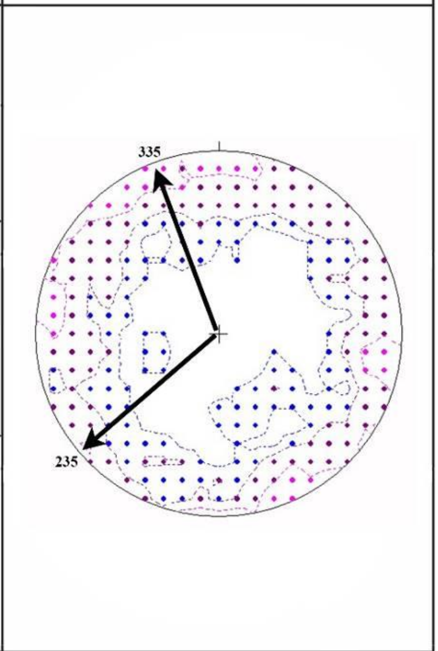
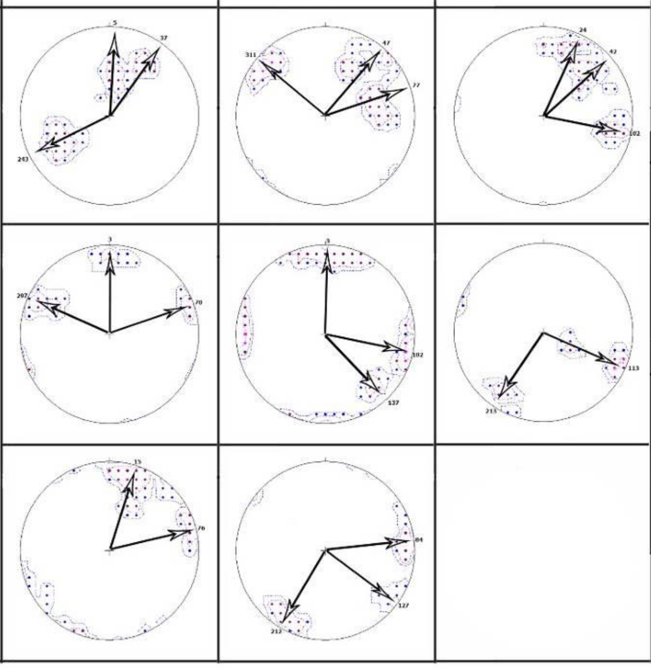
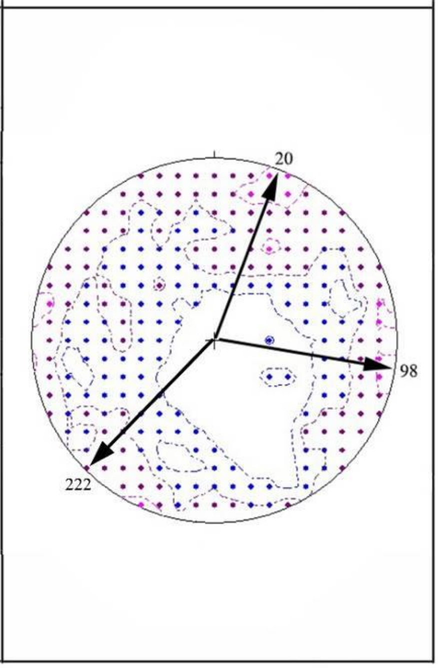
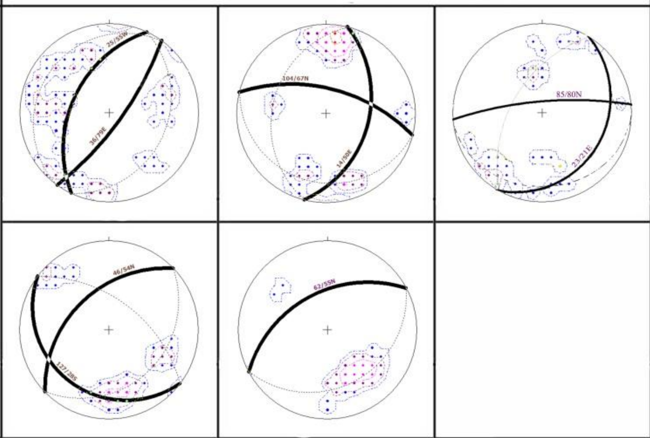
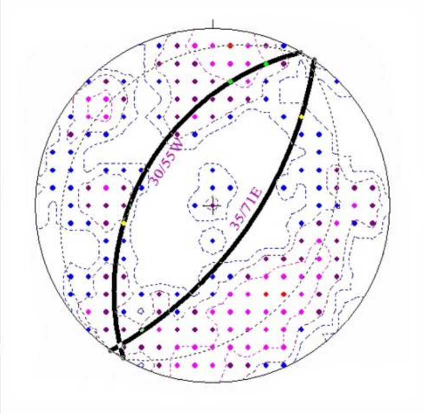
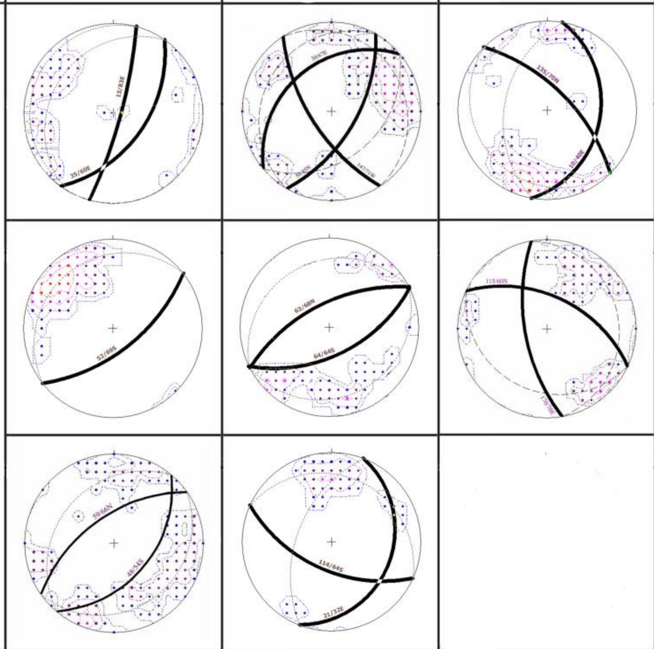
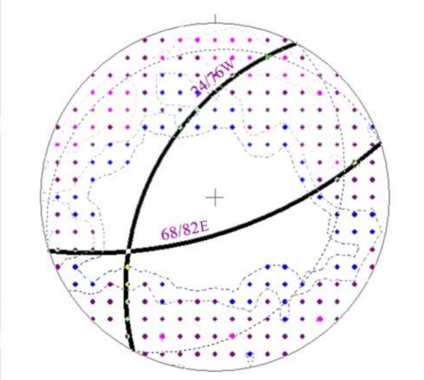
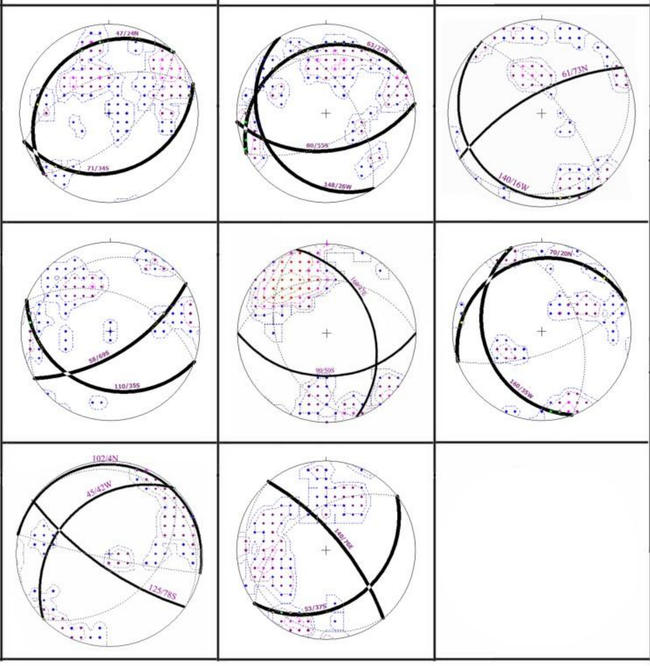
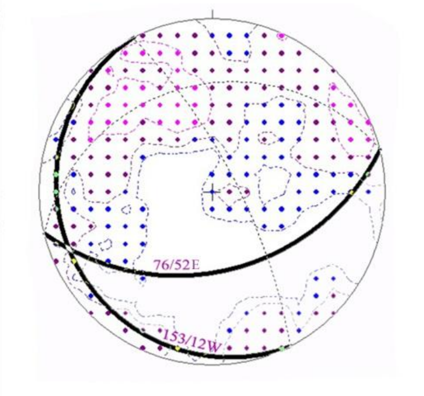
Divided Areas	P-Axes Vectors of each Station	Mean P-Axes Vector(s) of the whole Area
Eastern Area (Divandarreh – Takab)		
Central Area (Saheb – Sonnateh)		
Western Area (Baneh - Saqqez)		

Table-3: Classified fault plane diagrams for all divided subareas both for the individual stations and as a representative (mean) diagram for each subarea.

Divided Areas	Fault Plane Directions of each station	Mean Fault Plane Direction of the whole Area
Eastern Area (Divandarreh – Takab)		
Central Area (Saheb – Sonnateh)		
Western Area (Baneh - Saqqez)		

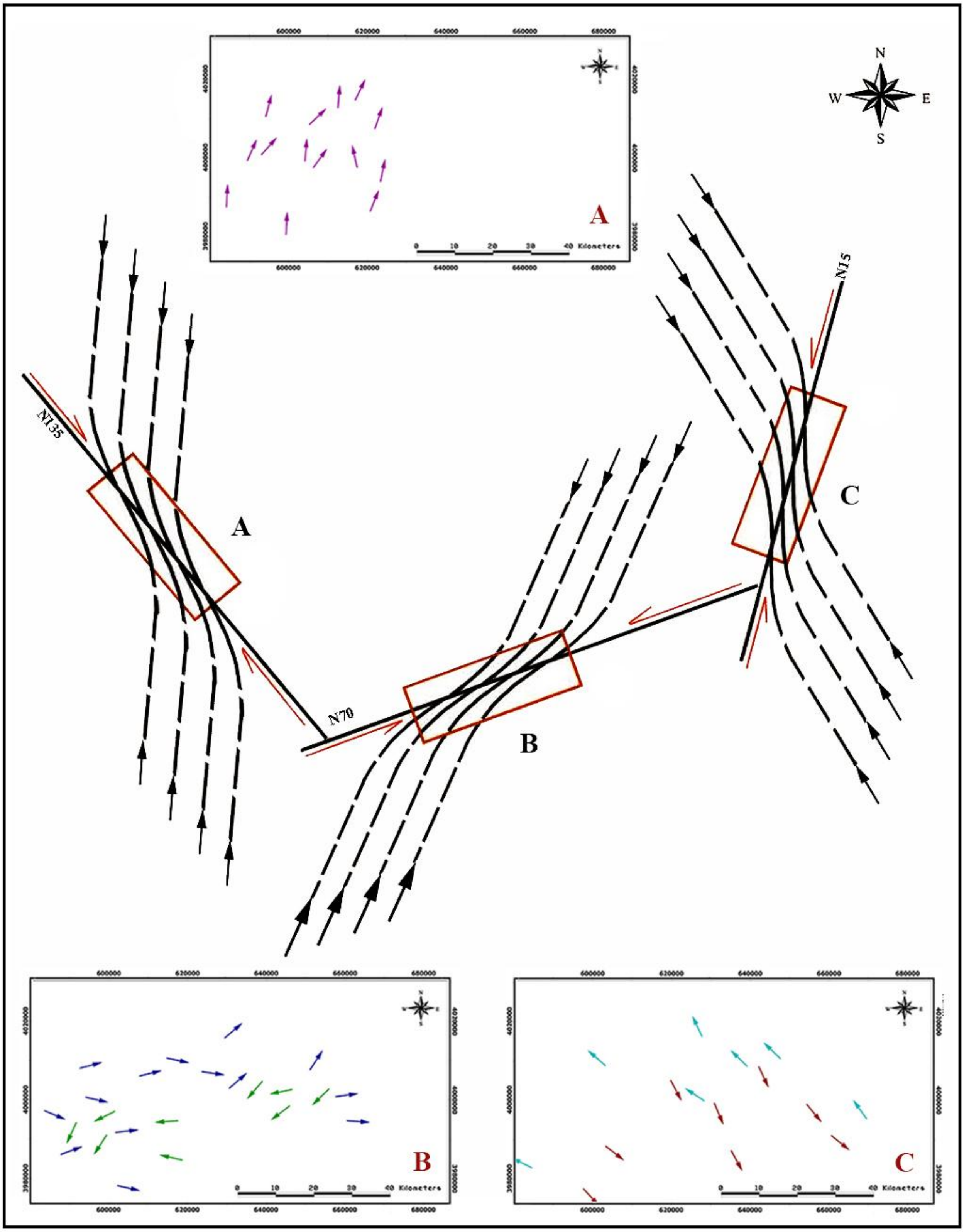


Figure-23: Suggested model for structural generations order, analyzed based on all data.

group A sinistrally, and then both of them have been displaced sinistrally by group C. Mean P-Axis value of this fracture set, as it is shown in Table: 2 for the subarea is oriented toward the azimuth of N235. Figure: 10-d represents the P-Axes set related with these faults, and that Figure has been shown again in Figure: 14 as B label to compare the related trajectories.

The third and final phase of deformation - which still is evoluting - has developed the N15 trending faults in Divandarreh–Takab subarea, mentioned in subarea mean fault plane as N30 (Table: 3). This fault set has a NNE-SSW direction by the mean diagram in Table: 1. This group was named C in the field studies, the youngest fault set which has displaced both the fracture groups A and B sinistrally. The azimuth value of the mean P-Axis diagram is equal to N125. In Figure: 10-b all the *P* vectors of this group have been mapped. Similarly as the two older phases, the P-Axes vectors map has been shown in Figure: 23. It has got C label.

The first deformation generation has been developed in a mostly ductile zone (shear zone). But the other younger phases have affected the Saqez–Takab region in a brittle–ductile condition (Figure: 24). All the structural phases have influenced almost all over the region, unlike the first phase which has been limited to the western part. So they have overprinted the first generation's deformation on the western old rocks (Figure: 25).

The main tectonic regime is the scenario which was explained above, but there are some local fractures or small variations in tension trajectory lines as it can be derived from the diagrams. For example there are some bending along the fault trends around the big granodiorite intrusions, especially in the north–east of Saqez City.

The second fault set is economically important for being the structural controller zone of mineralization of gold and some other valuable ore indexes. These mineralization occurrences have been formed first during the regional metamorphism (ductile phase). Then they have been enriched and concentrated in the fractures and veins by hydrothermal mechanism (Yarmohammadi et al, 2006).

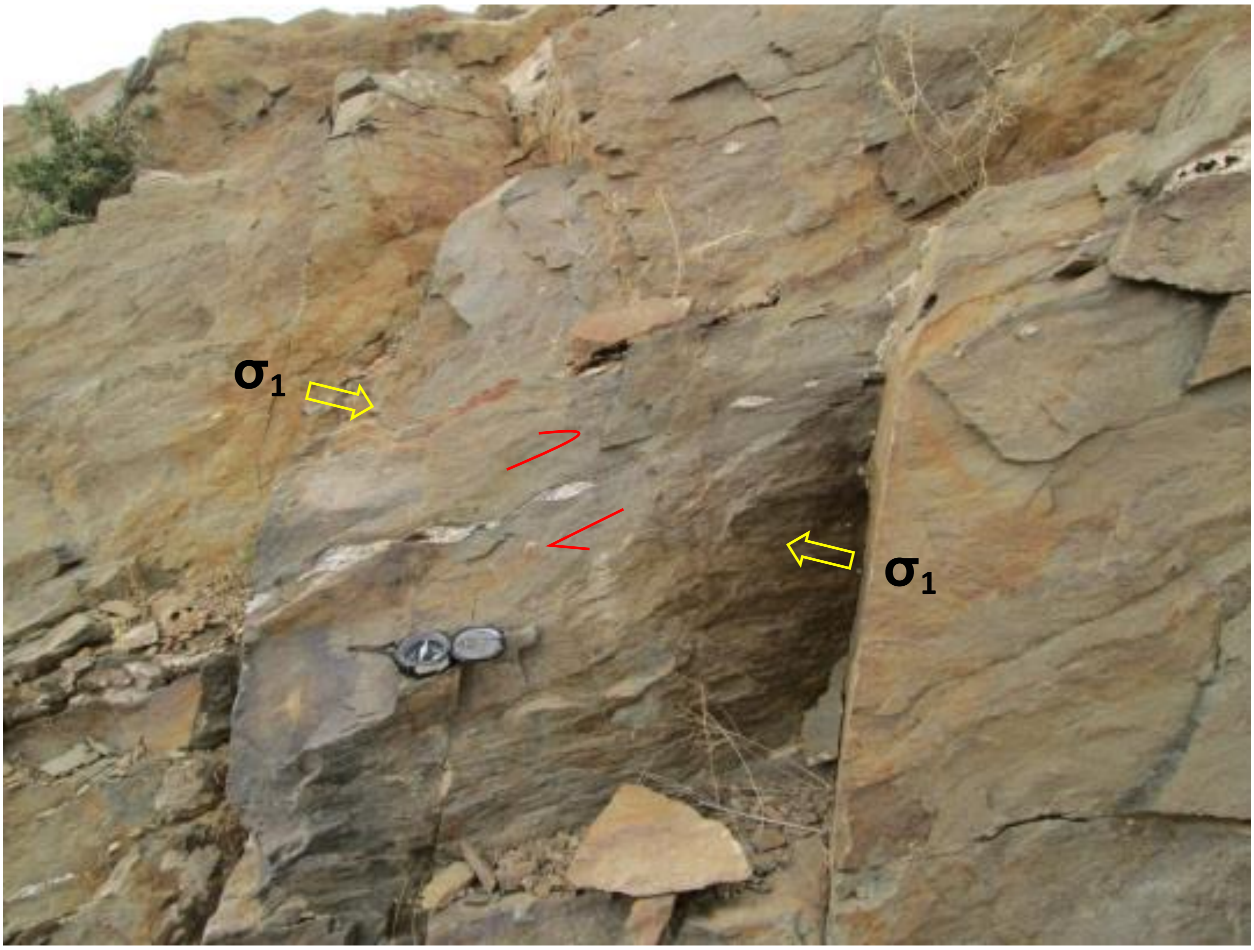


Figure-24: A fault zone with Z structures in the west, an indicator of dextral – reverse movement of the 2 blocks in brittle - ductile condition related to the first phase of deformation (shear zone); view direction to N.

Figure-25: The younger deformations have overprinted the older ones; (a) & (b) one fault plane with 2 different striations. (c) sinistral displacement of quartz layer by the younger fault sets (brittle phase).

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