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Strain Analysis of Dana Conglomerates in Ad Dhira Area- Dead Sea

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Abstract

This research is aimed at calculating the strain ellipses to investigate the intensity of deformation in different stations of Dana Conglomerate Formation (DCF). The investigated area lies to the eastern margin of the Dead Sea, in the Ad Dhira area. The outcropping rocks in the investigated area range from the Upper Cretaceous to the Quaternary age. The DCF was deposited in tectonically unstable basins during an extensional tectonic phase. Its deposition is associated with early rift tectonics and also was affected by Neogene movements. The DC is used in this study as a strain indicator using Fry method. The performed strain analysis in 2D showed a high deformation for most of the oriented photographed samples, where the shape of the ellipse is a flattened type, while a few showed a low deformation, where the shape of the ellipse is of the semi-circle type and the R- ratios range from 1.123 to 2.248.

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Keywords: Dead Sea, Ad Dira area, strain analysis, Fry method.

1. Introduction

Strain as a concept in geology is any change in length or shape of the rocks that resultin deformation. Mostly defined for ductile deformation, however, it is also used in areas of faulting (Fossen, 2016). In this study, the state of strain observed in the rocks is known as the finite strain; this results from a succession of very small strain increments over a period of time (Marshak and Mitra, 1988). It is graphically represented by strain ellipsoid that is the result of the strain from a unit sphere.

Strain analysis (SA) is a significant aspect of structural geology (Vollmer, 2019), which deals with the quantification of geological deformation (Lisle, 1985). It is an essential method for a perfect understanding of the finite deformations of the lithosphere (Yamaji, 2008). It offers an opportunity to discover the state of strain in rock and to map out strain variations in a region, an outcrop, or a sample (Fossen, 2016) Moreover, the SA gives insight into both the distribution of strain and the mechanism of development of ductile structures in the earth's crust (Kumar et al., 2014). It is a tool for unraveling tectonic histories (Mulchrone, 2013).

The investigated area lies to the east of the Dead Sea Basin (DSB) which is part of the most conspicuous structural feature in the Middle East that is the Dead Sea Transform Fault (DSTF). The DSTF is an active left-lateral fault zone, with approximately 1100 km of length (Weber et al., 2009). It constitutes the northern part of the Syrian-African rift system, which spans 6000 km from Turkey to Mozambique (Ben-Avraham et al., 2012). It forms the tectonic boundary between the Arabian plate to the East and the Sinai subplate to the West (Lefevre et al., 2018). Moreover, the motion along the DSTF is transferred from the opening of the Red Sea in the south to the Taurus- Zagros collision zone in Turkey and Iran to the north (Ben-Avraham et al., 2005) (Figure1).

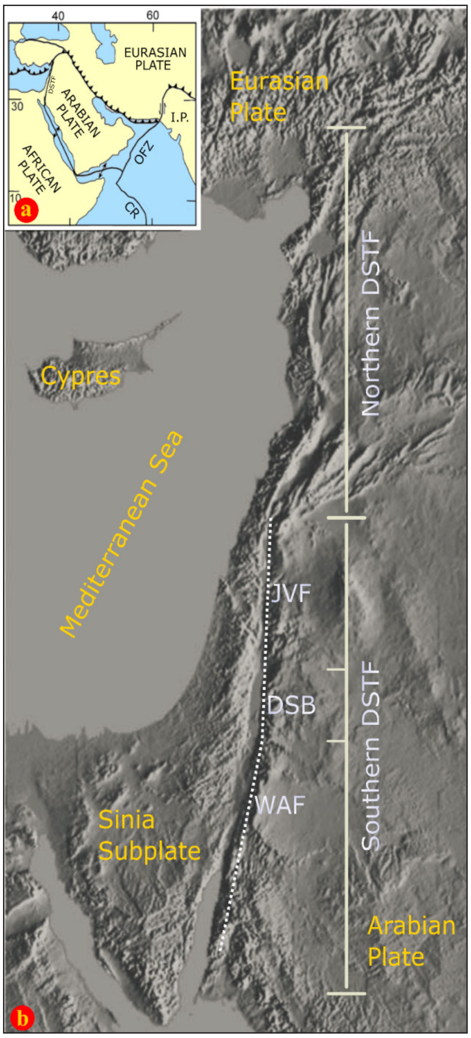

Figure 1. a) Tectonic setting of the area of the DSTF and b) Digital terrain model (DTM) showing the divisions of the DSTF into the northern and southern sections (Modified from Lazar, 2019)

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The area under investigation is located at the eastern margin of the Dead Sea, in the Ad Dhira area (Figure 1). The Dana Conglomerates Formation (DCF) as a unit was deposited in tectonically unstable basins during an extensional tectonic phase. The deposition of the formation was associated with early rift tectonics, and the beds are affected by Neogene movements (Powell, 1988).

Geographically, it extends from (31° 12’ 26.96” to 31° 16’ 19.07”) N and (35° 30’ 58.29” to 35° 35’ 24.24”) E. It covers an area of 35 Km^2 (Figure 2).

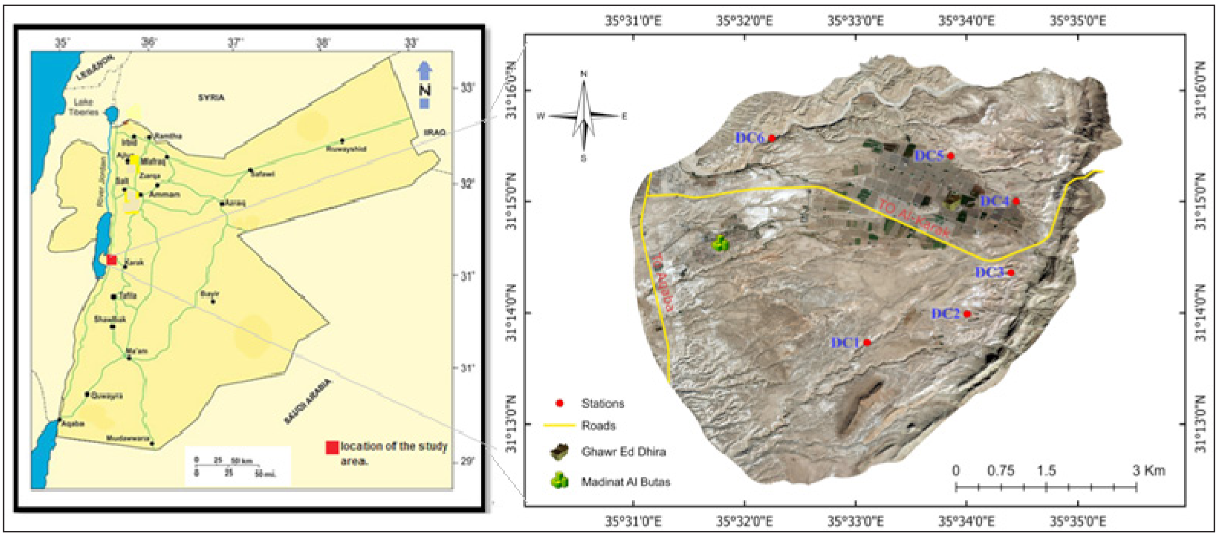

Figure 2. Location map and Satellite image of the investigated area.

The investigated area varies in elevation from 383m below sea level (b.s.l) along the western part to 233 m above sea level (a.s.l) in the eastern part (Figure 3). It is of a low relief adjacent to the Lisan peninsula comprising alluvial fans, lake deposits and lacustrine fans deposited by stream following from the mountains to the Dead Sea depression (Powell, 1988). Moreover, the area is characterized by the presence of valleys and hills.

The main aim of this study has been to apply a suitable method of strain analysis in Dana Conglomerates as there are no such researches except the work of Al- Diabat (1999 and 2002), in which he used quartz in sandstone and oolites in limestone as strain indicators. The achievement of the above objective would contribute to increasing knowledge about the intensity of deformation in six measurement stations of the investigated area (Figure 4).

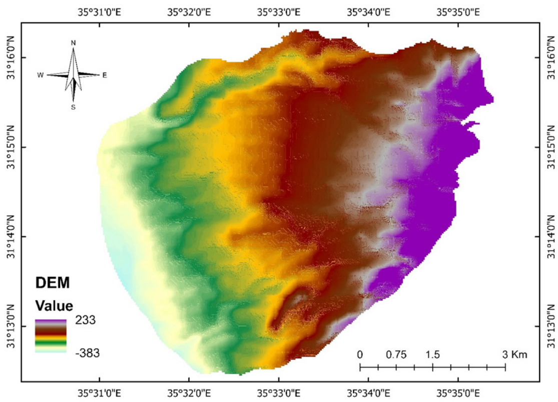

Figure 3. Digital elevation map of the investigated area.

2. Geological Setting

2.1 Stratigraphy

The investigated area presents sediment sequences ranging from the Upper Cretaceous to the Quaternary age (Figure 4).

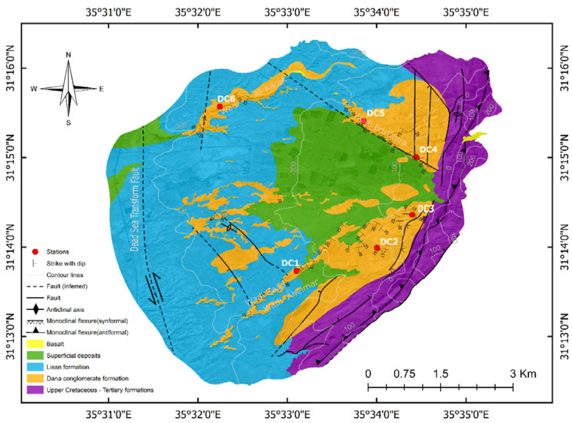

Figure 4. Geological map of the investigated area (Modified after Powell, 1988), with the established field stations.

2.1.1. Dana Conglomerate Formation (DCF)

The deposition of the DCF was associated with early rift tectonics and the beds are also affected by Neogene movements (Powell, 1988). Moreover, this formation has been subdivided by Powell (1988) into informal lower- and upper-members equivalent to the subdivision of Bender (1974) who also referred to this unit as the Syntectonical Conglomerate. These members are described as follows:

The lower member which is comprised of thick beds of pebble to boulder conglomerate composed of well-rounded, poorly graded, clast of chert, chalk and chalky limestone derived from the Umm Rijam Formation. The Texture is mostly clast-supported, but matrix-supported areas are also present. Furthermore, synsedimentary normal faults with centimeter throws are common in some of the thicker conglomerate beds (Powell, 1988; Khalil, 1992).

The upper member is composed of thick beds of clast-supported, well rounded, poorly sorted, pebble-boulder conglomerate with a calcarenite/ siliclastic matrix. It has not yielded any fauna, but it is overlain by Pleistocene basalts and gravel with middle Pleistocene flint implements in the Dana area (Bender, 1974), so the age of this unit cannot be established more accurately than the Miocene to Middle Pleistocene; a major synchronous depositional phase in response to the synchronous tectonic activity along the rift margins (Powell, 1988).

2.2. Tectonic Setting

The DSTF is a prominent shear zone in the region (Maercklin et al., 2005). It has been active since Early Miocene owing to its activity. Along the DSTF, many morphotectonic features were formed such as fault scarps, offset of stream courses, alluvial fans, pressure ridges, linear valleys, and sag ponds (Garfunkel, 1981; Galli, 1999; Al-Taj,2000; Klinger et al., 2000; Niemi et al., 2001; Atallah and Al–Taj, 2004). The Ad Dhira area is situated on the eastern side of the Dead Sea to the East of the Lisan Peninsula. It is bounded by the Ad Dhira monocline and splay fault to the east, to the west by the DSTF and in the northeast by the Siwaqa Fault (Figure 5).

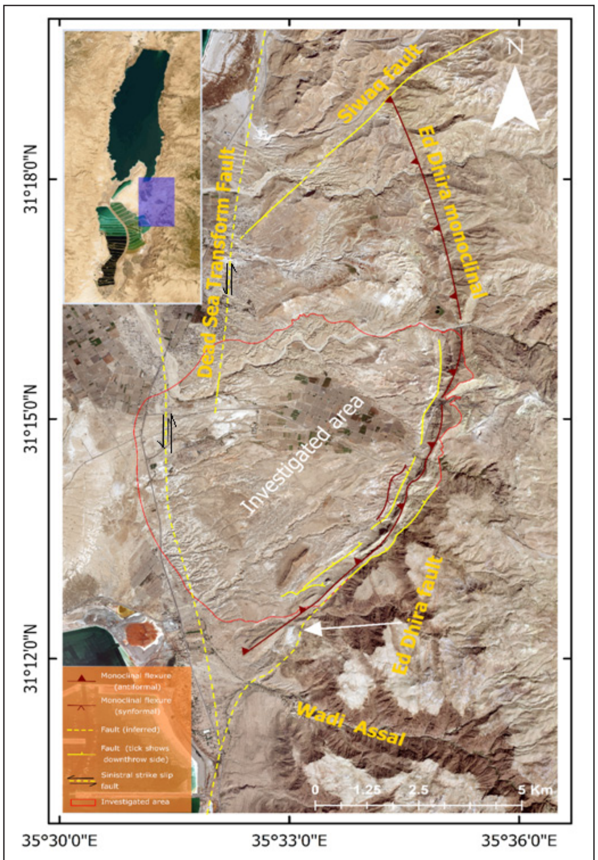

Figure 5. A satellite image showing the tectonic setting of Ad Dhira area and the main geological structures of the investigated area. Inset image shows the Dead Sea region.

The Ad Dhira fault is a major NE-SW trending splay fault that branches off the main Dead Sea structure in the area of Wadi Assal few kilometers south of the study area. The southern part of the Wadi Ad Dhira structure shows an overall displacement of 500 m with a down throw to the NW. Moreover, along the fault trace, the beds are often crushed or shattered by small faults. This Fault disappears and passes into a major monoclinal flexure with minor faults (Powell, 1988). Rhomb- shaped faulted blocks are bounded by N-S and NW-SE trending faults and are well preserved in the strata belonging to the Dana Conglomerate Formation in the Ad Dhira Plain (Khalil, 1992). Most of the folds in the investigated area are directly related to flexuring adjacent to the associated faults; these include the Ad Dhira fault-monocline (Powell, 1988). This major flexure extends from Wadi Assal in the south to the Siwaqa fault in the north. It forms an arc-like structure trending NE in the south, N in the middle, and NNW in the northern part (Figure 5).

3. Methodology

3.1 Strain Markers

The most paramount principle in the strain analysis (SA) is finding the appropriate markers that assist geologists for strain studies. The key to the SA lies in getting objects with known initial packing arrangement or features which enable final angles or lengths to be measured. Strain markers are objects showing the state of strain in a deformed medium, i.e. objects or lines of known undeformed shape, length and/or orientation. They reveal how much the rock has been strained, and give information about the nature of the deformation (Fossen, 2016). Furthermore, some strain markers are comprised of individual objects with a specific shape (e.g., fossils, and sedimentary clast outlines), and other strain markers may contain groups of objects with particular orientation patterns (e.g., preferred orientation patterns of muscovites in a sample of slate) (Lisle, 2010). Conglomerates are usually used for the SA, and their regular occurrence in the geological succession makes them promising strain-marker horizons (Treagus and Treagus, 2002). However, according to Ramsay and Huber (1983); Lisle (2010); and Mulchrone (2013), strain markers can be grouped into three general categories as follows:

a) Geometric: Objects or collections of objects with known pre-strain geometries.
b) Ellipses: Objects whose shapes can be approximated by ellipses.
c) Points: Groups of objects whose special arrangement defines a fabric.

3.2 Fry Method

The Fry method is a quicker and visually more impressive method for finding a two-dimensional strain (Fossen, 2016). It was developed by Norman Fry (Fry, 1979), and it is considerd a significant and widely-used method for analyzing point distribution data (Vollmer, 2019). This technique is based on the hypothesis that an initially uniform anti-clustered distribution of points will change after deformation into a nonuniform distribution. The distance between points become decreased in the contractional field and increased in the extensional field of strain (Marshak and Mitra, 1988). This method depends on a plot of the position of every particle center with respect to a particle put at the origin. The origin is, then, sequentially placed on each center, and the relative position of every other center is plotted (Genier and Epard, 2007). This produces a graphical point distribution; it is called the "Fry plot" that immediately shows the ellipse in form of a characteristic central vacancy and/ or a high point density ring in the vicinity of the central vacancy (Kumar et al., 2014). The practicability and accuracy of measuring strain in this method is greatly dependent on the type and degree of ordering of centers and the number of centers taken into consideration (Fry, 1979).

Owing to its applicability to a wide range of situations and procedural simplicity, this technique is adopted by many contemporary studies around the world (e.g. Genier and Epard 2007; Longet al.; 2011; Eichelberger and McQuarrie, 2014; Kassem and Hamimi, 2018). It is most easily dealt with using one of the numerous available computer programs (Fossen, 2016). In the present research, the Fry method is used through Ellipsfit software because it is more appropriately used compared to other methods for strain markers that are found in the area of investigation.

3.3 Strain Data Analysis

Photographs of oriented sections in an outcrop of Dana Conglomerate Formation were used as strain indicators. In the present research, strain analysis was conducted using the Fry method through EllipseFit software (Vollmer, 2019). The Ellipse Fit software is an integrated program for geological fabric and strain analysis. It is used for determining two- and three-dimensional strain from oriented photographs of outcrop surfaces, hand samples and thin sections using various objects including center points, lines, ellipses polygons, and shapes. The software involves procedures for complete fabric and strain analyses, including digitizing, image processing, calculation of two-dimensional sectional ellipses, and the combination of sections to get three-dimensional ellipsoid (Vollmer, 2019).

4. Results

Within the area of investigation, it was difficult to locate three perpendicular sectional blocks of rock to determine the Ellipsoid in 3D. In order to apply the Fry method in 3D, a cutting technique in the field is required to prepare the oriented samples in three dimensions. This technique was impractical given the financial restraints in support of this research. Therefore, oriented photographs of Dana Conglomerate Formation (DC) outcrops, which have strain markers, were taken in all field stations. These photographs were used for determining the Ellipse in 2D. The results of strain analysis in all stations are arranged in Table (1).

Table 1. Results of strain analysis of all stations

Station		P	X	Z	R	ϕ	RMS
DC1	a	220	71.474	63.643	1.123	17.77°	0.0735
	c	500	43.593	19.391	2.248	175.26°	0.0451
DC2		320	47.894	27.951	1.714	158.00°	0.0468
DC3	a	230	72.118	38.488	1.874	50.76°	0.0409
	c	210	71.355	57.103	1.250	164.59°	0.2054
	e	310	49.242	24.710	1.993	0.74°	0.0963
DC4	a	500	48.597	27.940	1.739	151.85°	0.0321
	c	380	69.334	42.004	1.651	149.63°	0.0840
	e	600	44.045	34.320	1.283	10.11°	0.0857
DC5		218	57.607	36.956	1.559	32.77°	0.0606
DC6	a	565	45.673	20.825	2.193	163.54°	0.0695
	c	260	40.908	18.967	2.157	176.65°	0.0373

(St.: stations, P: points, X:maximum elongation axis, Z:minimum elongation axis, R:ellipse ratio, ϕ:Orientation of ellipse long axis clockwise from X axis, and RMS: root mean square).

Moreover, after the application of the steps in the field of strain analysis, the following are the outcomes of each station:

4.1. Field Station DC1

In this station, two oriented photographs were taken. The result of strain analysis shows that the first photograph, ellipse (E),is characterized by maximum elongation axis (X) = 71.474, minimum elongation axis (Z) = 63.643 and ellipse ratio (R) = 1.123. The shape of the ellipse is semicircular, and that suggests a low degree of deformation, which can be observed by the slight difference between the length of the X and Z (Figure7 a and b). On the other hand, the second photograph E is characterized by the X = 43.593, Z=19.391, and The R = 2.248. The shape of the ellipse is a flattened type, and in this case, it shows a greater degree of deformation and a big difference between the length of the X and Z (Figure 6 c and d).

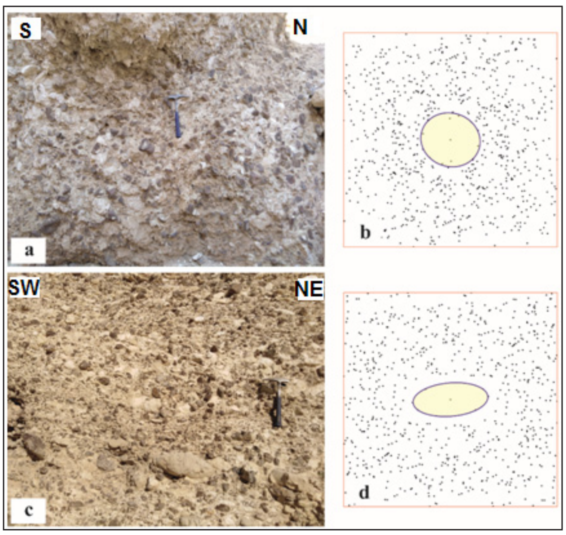

Figure 6. Oriented photographs and their ellipses in DC1

4.2.Field Station DC2

In DC2, only one oriented photograph has been taken. The result of strain analysis shows that photograph E is characterized by the X = 47.894,

Z=27.951, and the R = 1.714. The shape of this ellipse is a flattened type; thus, this shape indicates that a great degree of deformation; also the difference between the X and Z is high as it is observed (Figure 7 a and b).

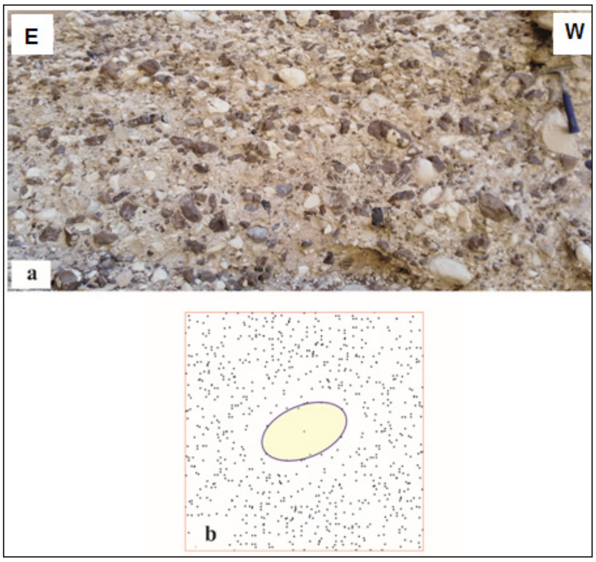

Figure 7. Oriented photograph and its ellipse in DC2.

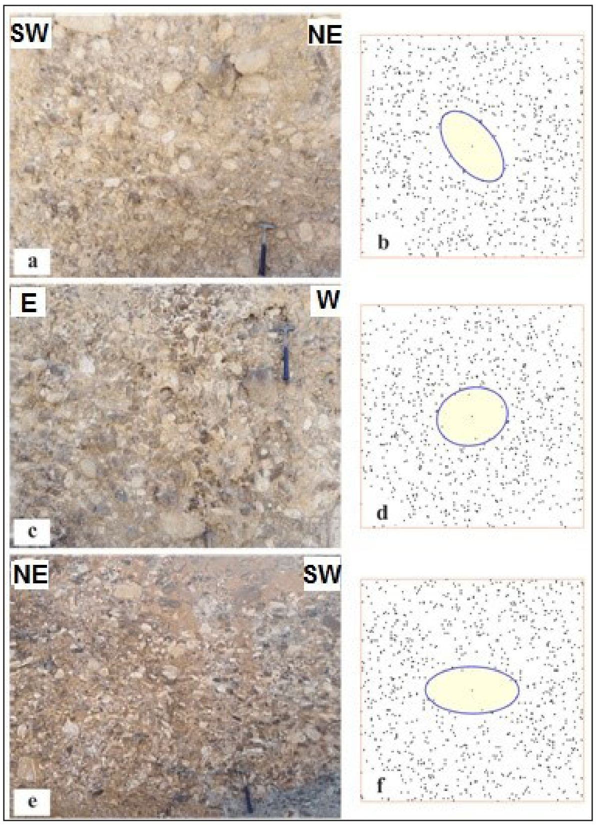

Figure 8. Oriented photographs and their ellipses in DC3.

4.3 Field Station DC3:

Three oriented photographs were taken in this station. The result of strain analysis shows that the first photograph E is characterized by the X= 72.118, Z=38.488, and R= 1.874. The ellipse is a flattened, and it suggests a great degree of deformation (Figure9 a and b). The second photograph E is characterized by the X = 71.355, Z=57.103, and R=1.250. The shape of the ellipse is almost circular, and that shows a low degree of deformation (Figure9c and d), while the third one E is characterized by the X= 49.242. Z= 24.710, and R= 1.993. Ellipse is flattened, and it indicates a great degree of deformation here (Figure 8e and f).

4.4 Field Station DC4

In this station, three oriented photographs were taken. The result of strain analysis shows that the first photograph E is characterized by the X= 48.597, Z= 27.940, and R= 1.739 (Figure 10a and b). The second photograph E is characterized by the X = 69.334, Z= 42.004, and R= 1. 651 (Figure 10c and d). The shape of the ellipses in both of the first and second photographs is a flattened type which suggests a great degree of deformation and an observed difference between the length of the X and Z. The third one E is characterized by the X= 44.045, Z= 34.320, and R= 1.283. The shape of the ellipse is almost circular, and that shows a low degree of deformation, which can be observed by the small difference between the length of the X and Z (Figure 9 e and f).

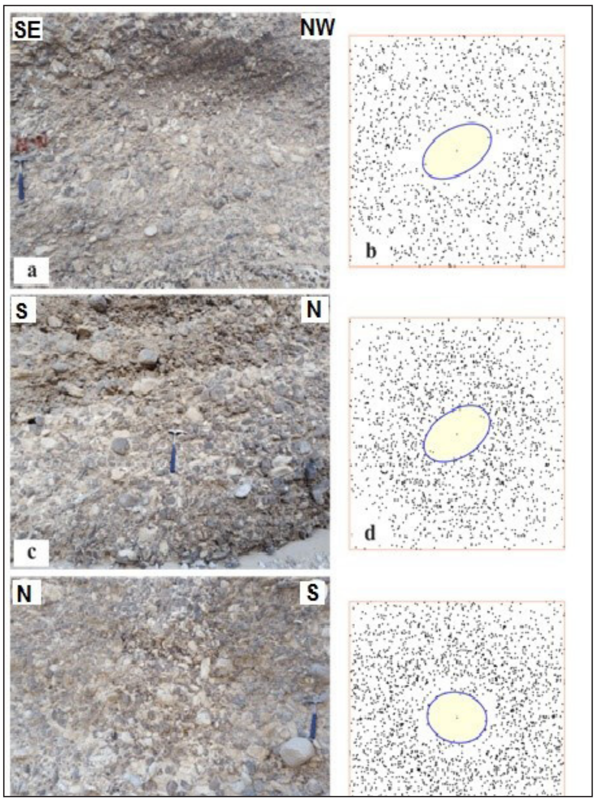

Figure 9. Figure9. Oriented photographs and their ellipses in DC4.

4.5 Field Station DC5

In DC2, only one oriented photograph has been taken. The result of strain analysis shows that the photograph E is characterized by the X =57.607, Z=36.956, and The R =1.559. The shape of this ellipse is a flattened type; thus, this shape indicates that there was a great degree of deformation here (Figure 10 a and b).

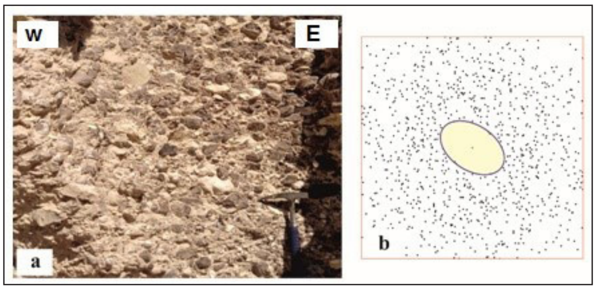

Figure 10. Oriented photograph and its ellipse in DC5.

4.6 Field Station DC6

Two oriented photographs were taken in this station. The result of strain analysis shows that the first photograph E is characterized by the X= 45.673, Z= 20.825, and R= 2.193. The second photograph E is characterized by the X = 40.908, Z= 18.967, and R= 2.157. For both photographs, the ellipses are a flattened type, and this suggests a great degree of deformation (Figure 11).

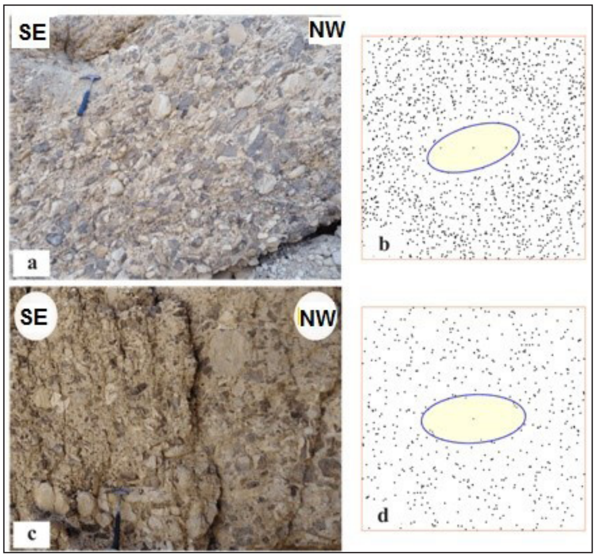

Figure 11. Oriented photographs and their ellipses in DC6.

5. Discussion and Conclusions

The outcropping rocks in the investigated area range from the Upper Cretaceous to the Quaternary. The DC was deposited in tectonically unstable basins during an extensional tectonic phase. Its deposition was associated with early rift tectonics and was also affected by Neogene movements. This is inferred from the observation of meso-scale extensional, transtensional and syndepositional structures in most stations of the study area e.g., faults mainly normal and strike-slip, negative flower structures, grabens and horsts, step- normal faults, sigmoidal en echelon joints, plumose joints, and tension gashes (see Al- Adamat, 2020).

In the current research, Fry method was applied for strain analysis in 2D for oriented photographs that have been taken in the field stations. Results of strain analysis for most oriented photographs showed that there is a high deformation where the shape of the ellipse is a flattened type (Figs. 7 d, 8, 9b and f, 10 b and d, 11, and 12). On the other hand, few oriented photographs showed a low deformation where the shape of the ellipse is of the semi-circle type (Figs. 7 b, 9 d, and 10 f).There are several orientations in flattening axes. This means that there is rotation in the area along major faults between the stations, and even local rotation between the same sampling area of the same station along small structures.

The Fry method was successfully used in Dana conglomerates as strain indicators in 2D strain analysis. The R-ratios in the investigated stations range from 1.123 to 2.248 which can be considered as a relative deformational scale in the study area at least in the investigated stations. This is due to local variations in the strain intensity from one place to another in a small specific area, which is related to the local geological structures that affected the sample sectional area.

The findings of this research have an important impression for future practice i.e. to carry out a study to determine the principal strain axes and the shape of strain ellipsoids in 3D using both Fry method and Rf/φ method, and to compare the relationship between stress and strain in order to accurately understand the dynamics of the investigated area.

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