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Finite strain of the Tertiary rocks and their relation to tectonic deformation at Al-Tib Anticline in Missan governorate, Southeastern part of Iraq

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Abstract

This paper presents the finite strain results from seven oriented samples data on Tertiary sandstone of Muqdadiya Formation and (400) samples of pebbles and conglomerate of Bai –Hassan Formation at the southwestern limb of Al-Tib Anticline in the Southeastern part of Iraq. Measurement and analysis of finite strain are carried out including these rocks at fluvio- lacustrine environment. The present study followed Fry method. The computed strain was, in the form of ellipses, within three prepared perpendicular planes in a single sample and Center to Center method was used to determine the strain ratio of the these samples. The strain in the studied area is low, this is mainly due to the sampled rocks underwent brittle deformation during folding. The calculated axial ratios (Rs), (three dimensional orientations of the strain axes) of strained rocks are shown which is equivalent to the log Flinn diagram normally used for plotting strain ellipsoids and according to the stereographic projection method, the long axes of this ellipsoid are sub parallel to measured Al-Tib Anticline axis and the short axes are approximately perpendicular to the axis of Al- Tib Anticline in the study area. This orientation of these axes is related to the movement of the Arabian plate.

Keywords: Strain analysis, Fry method, Center to center, Al- Tib Anticline, Missan, Iraq

الانفعال الكلي لصخور العصر الثلاثي وعلاقته مع التشوهات التكتونية لطية الطيب في ميسان جنوب شرق العراق

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الخلاصة

يمثل قدم هذا البحث نتائج الانفعال الكلي لبيانات سبعة نماذج موجهة من صخور الحجر الرملي لتكوين المقدادية التي تعود للعصر الثلاثي و اربعمائة نموذج من الحصى و المدملكات لتكوين باي حسن في الجناح الجنوبي الغربي لطية الطيب في الجزء الجنوبي الشرقي من العراق. تم حساب الانفعال الكلي لتلك الصخور ذات البيئة المختزلة. اتبعت الدراسة الحالية طريقة فراي لحساب الانفعال الكلي الممثلة باشكال اهليجية ذات بعدين ضمن ثلاث مستويات متعامدة، واستخدمت طريقة المركز الى المركز لتحديد نسبة التشويه لتلك النملذج. ان الانفعال في منطقة الدراسة يمكن وصفة بالواطئ وذلك يعود الى المستوى التركيبي الواطى و لنوع الصخور التي تتكسر بسرعة. بين حساب النسبة المحورية للصخور المتشوهة على مخطط (فلن) استنادا

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لطريقة الاسقاط الفراغي، المحور الطويل شبه موازي لمحور طية الطيب، والمحور القصير تقريبا عمودي على محور طية الطيب، اتجاه هذه المحاور مرتبط بحركة الصفيحة العربية.

Introduction

Iraq is one of the countries that are exposed to tectonic activity due to its location. Zagros- Taurus belt is located in the collision area between the Arabian and Iranian plates. The principal strain axes have been analyzed and this related to tectonic deformation of beds. Under certain conditions the distribution of particles centers of rock components making up an aggregate (e.g. Conglomerates can be used to determine the state of finite strain. The strain is a relationship between the size and shape of a body before and after deformation [١]. In other words, it describes the direction of a body in response to an applied stress [2]. Finite strain means an accumulation of changes in the shape and internal configuration due to deformation [3]. Finite strain data can provide important information about the structure of a deformed terrain, such as strain intensity gradients or distribution of strain in the low folded zone in the south eastern part of Iraq. Many methods of finite strain determination exist, and are based either on grain-location analysis [4] and [5], or on grain-shape analysis (Rf /ϕ) method of Ramsay [6], [7], [8] and [9], Feret diameters method [10]. Reflectance method [11], [12] and [13]. These methods require different parameters to characterize the shape or location of the quartz grains or other strain markers (coordinates of the centers of mass, lengths of major and minor axes and their orientations, or location of whole boundaries of grains). Al-Tib Anticline lies in the northeast of Missan district, Southeastern of Iraq, is located between latitudes (32° 15′ - 32° 30′ North) and longitudes (46° 55′ - 47° 25′ East), covering about (1191) Km². The boundary of the study area represents the Iraqi-Iranian border Figure -1.

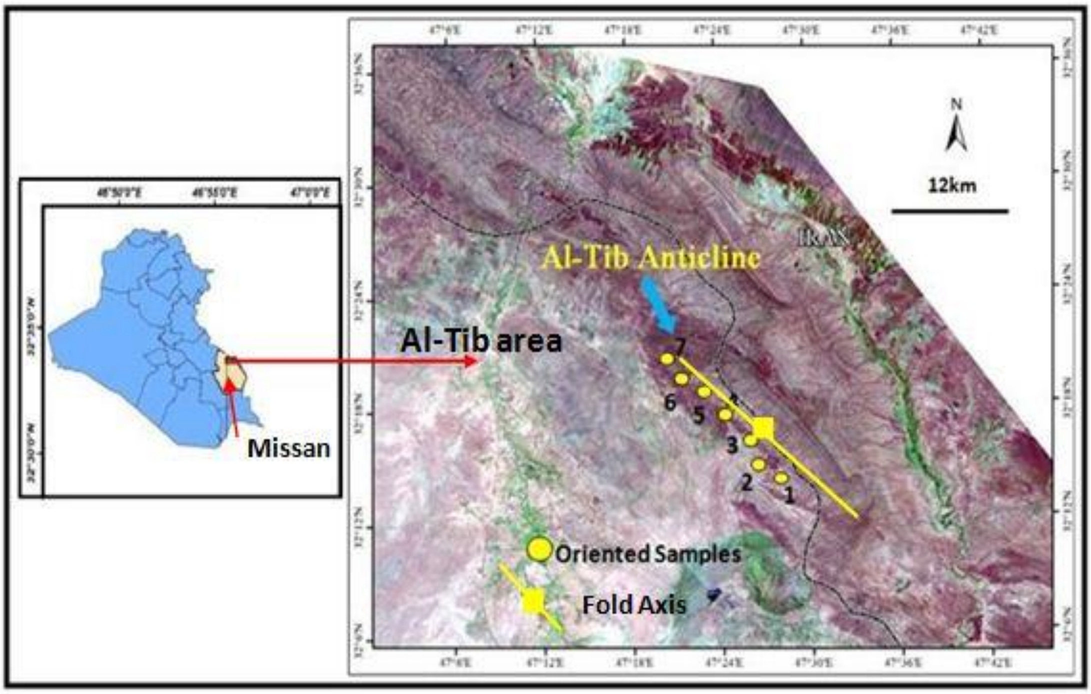


Figure 1-Satellite image shows the oriented sample measurements in the study area (Google earth, 2017).

Aims of Study

1. Determination of the principal strain axes and the shape of strain ellipsoids.

2. To determine the finite strain of the rocks in the study area by using Fry method and Center to Center method.

3. To measure the relationship between stress and strain in order to understand the dynamics of the study area.

4. To analysis the kinematics and the propagation of the collision on the Arabian plate Boundary.

Geological Setting

Tectonically, the study area belongs to the un stable shelf represented by two Zones, Foothills Zones, along the Iraqi-Iranian international boundaries and the Mesopotamian Zone, more precisely, the former is represented by Hemrin Sub zone ,whereas the latter by Tikrit-Amara Sub Zone [14]. The exposed rocks in the study area belong to the late Miocene and Late Pliocene ages. These rocks include **Injana Formation (Late Miocene)** of the southwestern limb at attitude (240°/40°). It comprises of fine grained, molass sediments deposited initially in the coastal environment and later in fluvio- lacustrine environment. The basal unit comprises thin bedded calcareous sandstone, siltstone, marls and reddish brown and brownish grey mudstone. **Muqdadiya Formation (Early Pliocene).** It comprises pebbly sandstone, grey and brownish grey sandstone, red mudstone and marls. Sandstone rocks are often strongly characterized by cross- bedding., and **Bai-Hassan Formation (Late Pliocene).** It is characterized by interbedding of gray conglomerate, brown claystone and lenses of gray sandstone. Bai-Hassan Formation was deposited in fluvio- lacustrine environment. The Upper boundary of Bai-Hassan Formation eroded. The formation is overlain by terrace gravels and/or alluvial deposits and is covered by fine grain sediments of Quaternary age [15] and [16].

Methodology

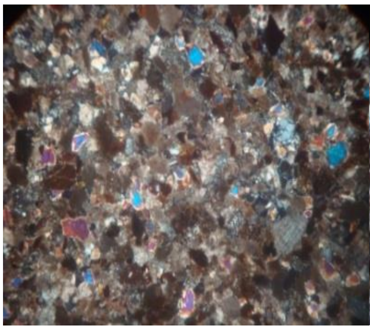
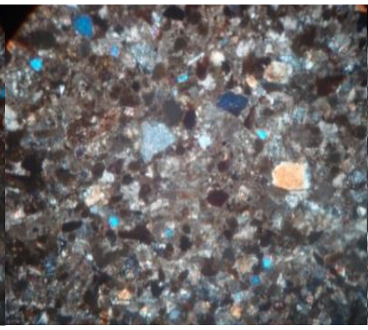
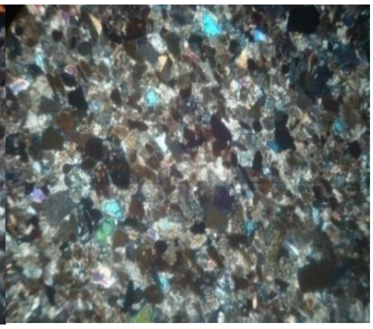
Strain analysis quantifies strain magnitude and/or orientation of distortion in rocks between microscopic to regional scales [4]. The basis of strain-measurement techniques involves measuring strain markers to obtain principal strain axes orientations and axial ratios. In case strain markers are passive, which means they have similar rheological properties as the host rock and deform in the same manner as the whole rock, then the total strain in the sample can be characterized. Non-passive strain markers have rheological properties which are contrast those of the host rock, and thus provide only a minimum estimate of total bulk strain [17].

1: Fry Method

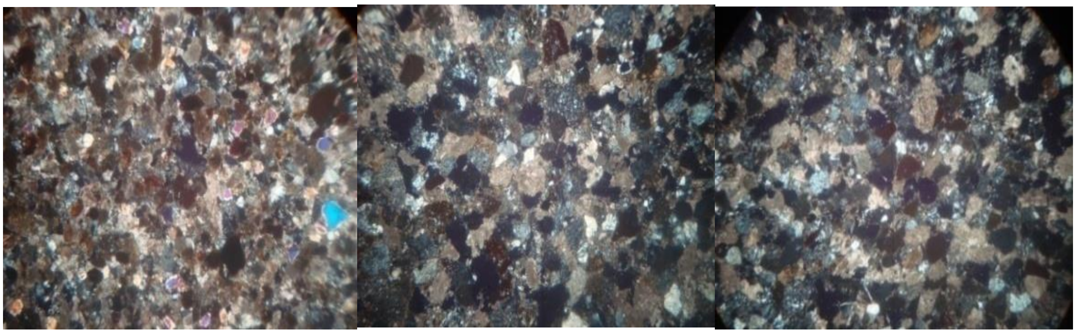
Seven sandstone field oriented samples of Muqdadiya Formation were cut into blocks (about 15 cm on aside), and polished on three mutually perpendicular planer section (PTS, IDP and PTB) in anticipation of a future 3D strain analysis.

1- Parallel to strike (PTS).
2- Parallel to dip plane (PDP).
3- Parallel to bedding (PTB).

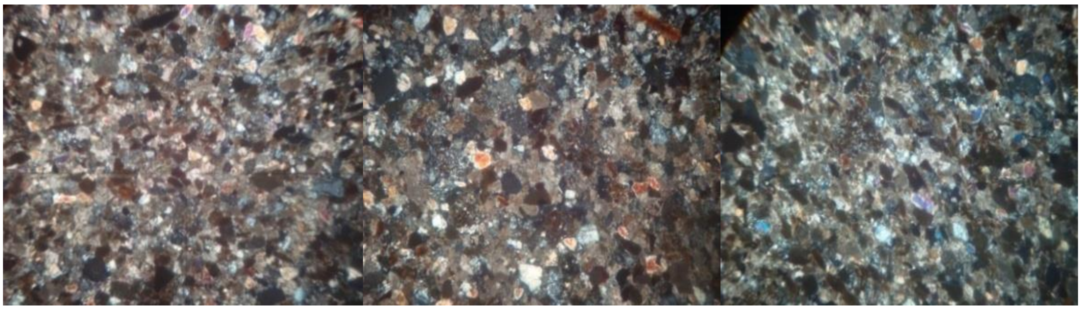
Slabs were notched to preserve the field orientation of the sample during professional thin section preparation. Large-format thin sections were used to provide sample surface area for choosing representative areas for analysis (Plate,-1) - (Figure-2). Strain analysis quantifies strain magnitude and orientation of distortion in the rocks on scales ranging from microscopic to regional. The basis of strain measurement techniques involves measuring strain markers to obtain principle strain axes orientations and axial ratios. If strain markers are passive, meaning they have similar rheological properties as the host rock and deform in the same manner as the whole rock, then the total strain in the sample can be characterized. Non-passive strain markers have rheological properties that contrast those of the host rock, and thus provide only a minimum estimate of total bulk strain [18].

Sample (2) PTS (2.5X) **Sample (2) PTB (2.5X)** **Sample (2) PDP (2.5X)**

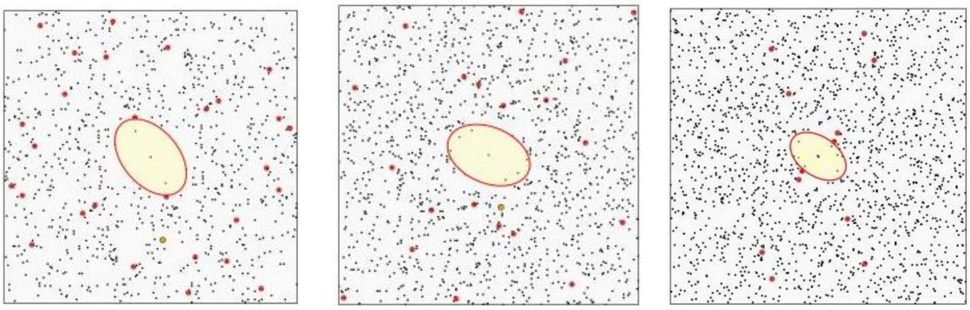


Sample (5) PTS (2.5X) **Sample (5) PTB (2.5X)** **Sample (5) PDP (2.5X)**

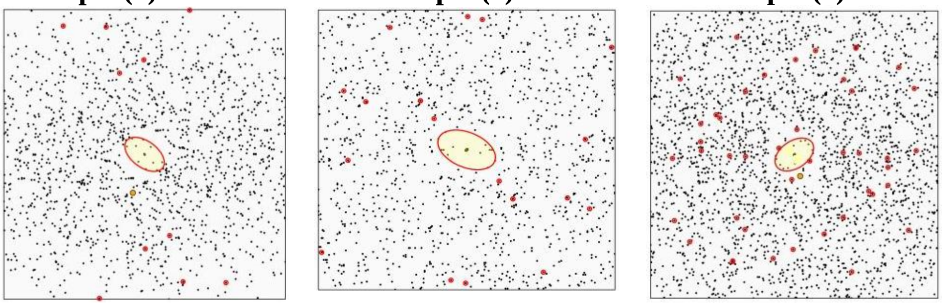


Sample (7) PTS (2.5X) **Sample (7) PTB (2.5X)** **Sample (7) PDP (2.5X)**

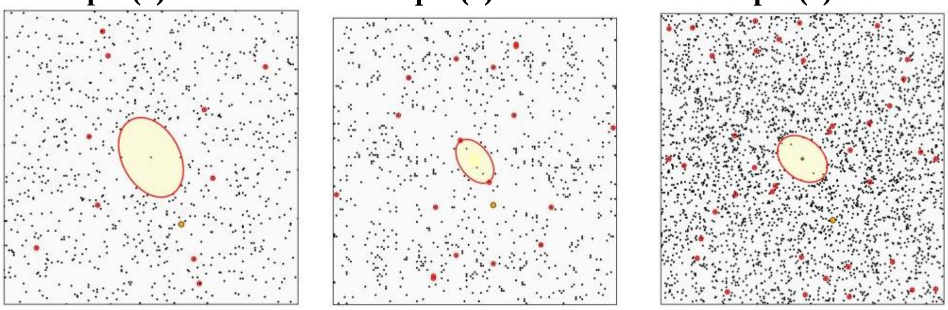
Plate 1-Shows thin sections of Sandstone samples (2 ,5, and 7) in SW limb of Al-TibAnticline.



Sample (2) PTS **Sample (2) PTB** **Sample (2) PDP**



Sample (5) PTS **Sample (5) PTB** **Sample (5) PDP**



Sample (7) PTS **Sample (7) PTB** **Sample (7) PDP**

Figure 2-Fry plots of sandstone samples (2, 5, and 7) in SW limb of Al-Tib Anticline.

2: Center to Center Method.

This method is based on the principle that the distance and angular relationships between particles in an aggregate of objects as sand grains with a statistically uniform initial distribution should help to determine the orientation of the strain ellipse in the deformed aggregate [18]. The method involves measurement of the distances and angles between a reference grain and its nearest neighbors. Application of the technique is rather simple, but it is slow without a computer and digitizer. A transparent overlay is placed on an oriented plate (at convenient magnification) of the objects to be measured. The overlay can also be placed onto a sawed slab of the rock if the objects to be measured (sand grains in well-sorted sandstone) are large enough [19].

3: Three - dimensional strain (Flinn Diagram).

Finite spatial change in shape that is connected with deformation is completely described by the strain ellipsoid. The strain ellipsoid is the deformed shape of an imaginary sphere with unit radius that is deformed along with the rock volume under consideration. The strain ellipsoid has three mutually orthogonal planes of symmetry, the principal planes of strain, which intersect along three orthogonal axes that are referred to as the principal strain axes. Their lengths (values) are called the principal stretches. These axes are commonly designated (X, Y , Z), (S1, S2 , S3) and (e1, e2 ,e3) are used, where (X) represents the longest,(Z) the shortest and (Y) the intermediate axis :(X > Y > Z)When the ellipsoid is fixed in space, the axes may be considered vectors of given lengths and orientations. Knowledge of these vectors thus means knowledge of both the shape and orientation of the ellipsoid [19] and [20]. Any strain ellipsoid contains two surfaces of no finite strain. For constant volume deformations, known as isochoric deformations, these surfaces are found by connecting points along the lines of intersection between the ellipsoid and the unit sphere it was deformed from. In general, when strain is three-dimensional, the surfaces of no finite strain are non-planar. Lines contained in these surfaces have the same length as in the undeformed state for constant volume deformations, or are stretched an equal amount if a volume change is involved. In other words: A plane strain deformation produces two planes in which the rock appears unstrained. The shape of the strain ellipsoid can be visualized by plotting the axial ratios (X/Y) and (Y/Z) as coordinate axes. This widely used diagram is called the Flinn diagram [1] and [21].

4: Strain Analysis in the study area by Flinn diagram.

Two hundred (200) oriented samples of pebble were collected of the study area refer to Muqdadiya Formation and about two hundred (200) oriented samples of conglomerate refer to Bai- Hassan Formation in Al- Tib Anticline. These samples the principal strain axes (X,Y and Z) or (S1, S2 and S3) were measured by vernier scale which have average the attitudes at (060˚/ 80˚), (310˚/20˚), (240˚/ 40˚) respectively. The representation of (a and b) values on Flinn diagram show that the strain ellipsoid , generally its increase away from the origin and show strain ellipsoid lies in the three sets: (**R>1),** prolate geometries or cigar shapes of the upper half of the field (Constriction strain), (**R=1)** (Plane strain), and **(R<1) ,** oblate geometries or pancake shapes of the lower half (Flattening strain) Figures-(3, 4). This indicates that the area has been affected more than one regime of the stress, the first stress, in NE – SW trend, when the maximum principal stress (σ١) was horizontal, when (R>1), the second stress, in NW – SE trend, when the maximum principal stress (σ١) was vertical, when (R<1).

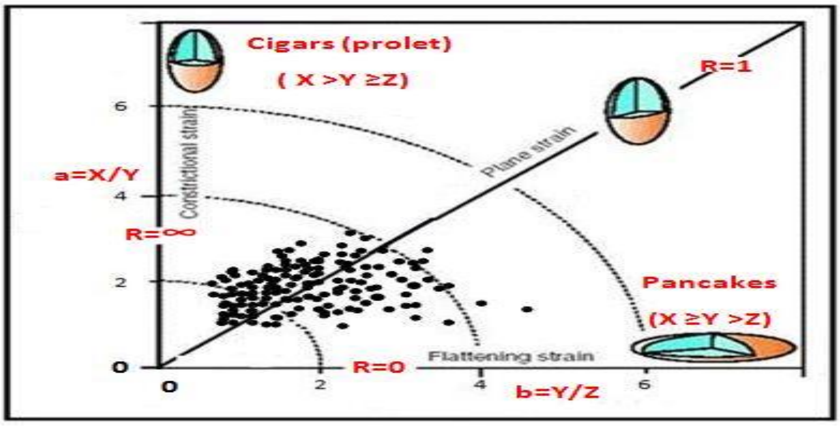


Figure 3-hows Strain ellipsoid of Muqdadiya Formation represented on a log Flinn diagram.

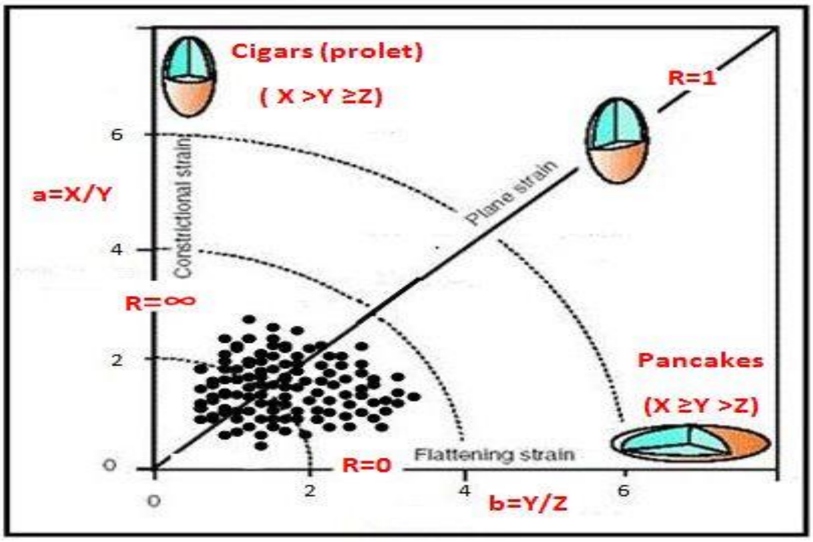


Figure 4-Shows Strain ellipsoid of Bai- Hassan Formation represented on a log Flinn diagram.

Results:

1: Results of Fry Method.

Fry Method used for sandstone (21 thin sections) samples to estimate the strain ellipse for each sample. Strain ellipses were obtained for three mutually perpendicular sections for all twenty one samples from Fry plots, generated by Ellipse Fit. Ellipse orientation (phi), axial ratio (Rs), and calculated percent shortening for each ellipse are summarized in Tables-(1, 2, 3, 4, 5, 6, and 7). Strain magnitudes of surface sandstone samples are ranging from (5 % -24%) shortening, with an average of (14.5%) shortening of PTB section, ranging from (12 % - 20%) shortening, with an average of (16%) shortening of PDP section, and ranging from (18 % - 25%) shortening, with an average of (21.5%) shortening of PTS section. Strain magnitudes of conglomerate samples are ranging from (9 % - 13%) shortening, with an average of (10.5%) shortening of PTB section, ranging from (12 % - 14%) shortening, with an average of (13%) shortening of PDP section, and ranging from (12 % - 23%) shortening, with an average of (17.5%) shortening of PTS section. Strain magnitudes of cores samples of sandstone are ranging from (18 % - 26%) shortening, with an average of (22 %) shortening of PTB section, ranging from (12 % - 28%) shortening, with an average of (20%) shortening of PDP section, and ranging from (20 % - 29%) shortening, with an average of (24.5%) shortening of PTS section.

Table 1-Ellipse orientation (phi), axial ratio (Rs) and percent shortening (es%) for ellipse of sample (1) of Sandstone grains of Muqdadiya Formation in Al-Tib Anticline.

Sample 1	PTB Section	PDP Section	PTS Section
A	١٢٨	86	93.2
B	٨١	54	58.5
ϕ	٤٩.٢	44.6	34.9
Lu	102	68.14	73.8
Rs	١.٥٨	1.59	1.59
es . Eq. 3.1	-0.205	-0.207	-0.207
es .Eq. 3. 2	-0.204	-0.206	-0.206
es %	20 %	20 %	20 %

Table 2-Ellipse orientation (phi), axial ratio (Rs) and percent shortening (es%) for ellipse of sample (2) of Sandstone grains of Muqdadiya Formation in Al-Tib Anticline.

Sample 2	PTB Section	PDP Section	PTS Section
A	152.2	114.7	78.8
B	90.8	74.7	47.16
ϕ	26.14	22.59	12
Lu	117.5	92.56	60.96
Rs	1.67	1.53	1.67
es . Eq. 3.1	-0.227	-0.192	-0.226
es .Eq. 3. 2	-0.226	-0.191	-0.226
es %	22%	19%	22%

Table 3-Ellipse orientation (phi), axial ratio (Rs) and percent shortening (es%) for ellipse of sample (3) of Sandstone grains of Muqdadiya Formation in Al-Tib Anticline.

Sample 3	PTB Section	PDP Section	PTS Section
A	66	98.2	91.7
B	59.4	65.6	57.9
ϕ	48.13	17.83	30.79
Lu	62.6	80.2	72.8
Rs	1.11	1.49	1.58
es . Eq. 3.1	-0.05	-0.182	-0.204
es .Eq. 3. 2	-0.05	-0.18	-0.20
es %	%٥	18%	20%

Table 4-Ellipse orientation (phi), axial ratio (Rs) and percent shortening (es%) for ellipse of sample (4) of Sandstone grains of Muqdadiya Formation in Al-Tib Anticline.

Sample 4	PTB Section	PDP Section	PTS Section
A	١٢١.٩	٦٦.٥	١٢٩
B	٧٧	٤٢.٤٣	٨٢.٥
ϕ	٥١	٣٣.٨٩	١٠.١٢
Lu	٩٦.٨	٥٣	١٠٣.١٦
Rs	١.٥٨	١.٥٦	١.٥٦
es . Eq. 3.1	-0.204	-٠.١٩٩	-0.200
es .Eq. 3. 2	-0.204	-٠.١٩٩	-0.199
es %	20 %	19 %	20 %

Table 5-Ellipse orientation (phi), axial ratio (Rs) and percent shortening (es%) for ellipse of sample (5) of Sandstone grains of Muqdadiya Formation in Al-Tib Anticline.

Sample 5	PTB Section	PDP Section	PTS Section
A	٤٣.٣٥	123.19	79.74
B	٢٩.٨٤	77.5	52.54
ϕ	٣.٧٧	37.55	15.79
Lu	٣٥.٩٦	97.7	64.72
Rs	١.٤٥	1.58	1.52
es . Eq. 3.1	-0.17	-0.206	-0.188
es .Eq. 3. 2	-0.169	-0.20	-0.189
es %	17 %	20%	18 %

Table 6-Ellipse orientation (phi), axial ratio (Rs) and percent shortening (es%) for ellipse of sample (6) of Sandstone grains of Muqdadiya Formation in Al-Tib Anticline.

Sample 6	PTB Section	PDP Section	PTS Section
A	٨٧.٨٤	119.4	١٠٩.٧٤
B	٦٢.٤٢	91	٦٠.٣٨
ϕ	٣٦.٧٦	58.18	٢٠.٥٢
Lu	٧٤.٠٤	104.23	٨١.٤٠
Rs	١.٤	1.31	١.٨١
es . Eq. 3.1	- ٠.١٥٦	- ٠.١٢٦	-٠.٢٥٨
es .Eq. 3. 2	-٠.١٥٦	- ٠.١٢٧	-0.256
es %	15%	12%	25 %

Table 7- Ellipse orientation (phi), axial ratio (Rs) and percent shortening (es%) for ellipse of sample (7) of Sandstone grains of Muqdadiya Formation in Al-Tib Anticline.

Sample 7	PTB Section	PDP Section	PTS Section
A	81.67	138.61	74.8
B	46.71	94.1	46.08
ϕ	50.12	61.78	53.53
Lu	61.76	114.2	58.7
Rs	1.74	1.47	1.62
es . Eq. 3.1	-0.243	-0.176	-0.214
es .Eq. 3. 2	-0.241	-0.175	-0.214
es %	24 %	17 %	21 %

2: Results of center to center method.

Result of strain analysis by center to center method were, Strain magnitudes of sandstone samples are ranging from (17 % - 21%) shortening, with an average of (18%) shortening of PTB section, ranging from (15 % - 20%) shortening, with an average of (18%) shortening of PDP section, and ranging from (19 % - 23%) shortening, with an average of (21%) shortening of PTS section as shown in the Table-8, Figures-(5, 6 , 7).

Table 8-Shows mean of the axial ratio (Rs) and percent shorting (es %) for sandstone samples of Al-Mugdadiya Formation in Al-Tib Anticline .

PTB		PDP		PTS	
Rs	**es %**	**Rs**	**es %**	**Rs**	**es %**
1.5	**18 %**	**1.5**	**18 %**	**1.6**	**21 %**

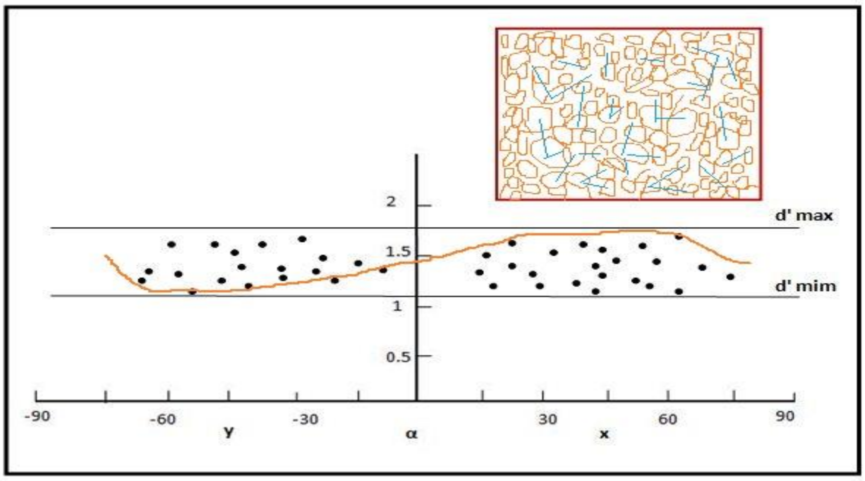


Figure 5-Shows applied Center to center method for Al-Tib Anticline of sandstone samples (mean PTB) slide.

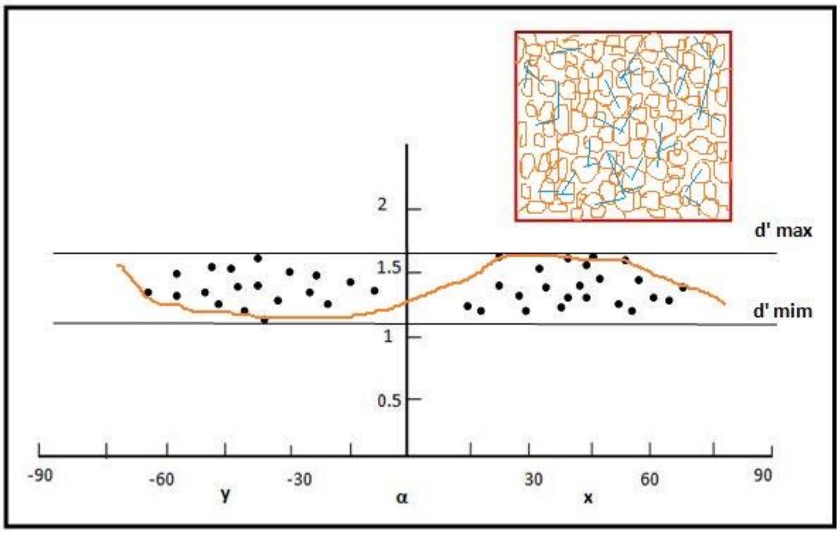


Figure 6-Shows applied Center to center method for Al-Tib Anticline of sandstone samples (mean PDP) slide.

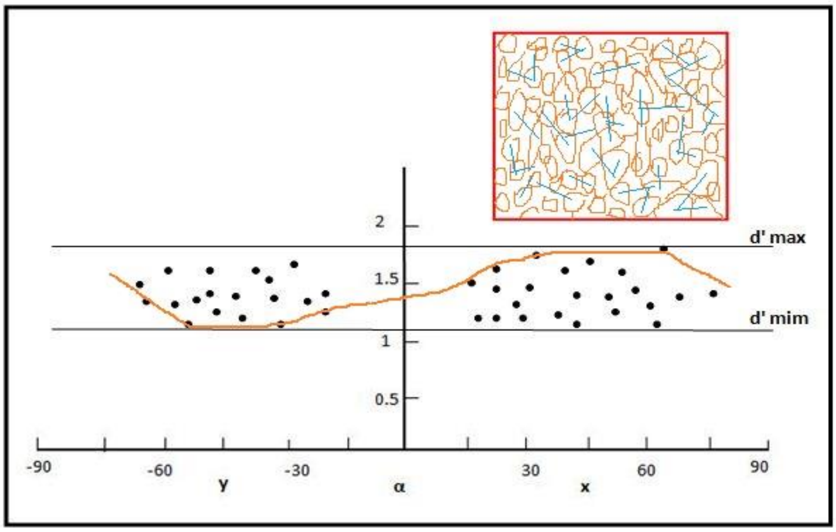


Figure 7- Shows applied Center to center method for Al-Tib Anticline of sandstone samples (mean PTS) slide.

3: Results of Flinn diagram.

Calculation of the axial ratio (R) are shown in Figures-(2, 3), of the log Flinn diagram normally used for plotting strain ellipsoids. All classify as biaxial positive they passes prolates indicators **(∞ < R < 1)**. Strain ellipsoid lies in the three sets: (**R>1),** cigar shapes of the upper half of the field (Constrictional strain), (**R=1)** (Plane strain), and (**R<1),** pancake shapes of the lower half (Flattening strain). The calculated three dimensional orientations of the axes show different relationship with folding (Figure-8). The orientation of long axis is close in orientation of the axis of Al-Tib Anticline from which the samples were taken. The short axis is perpendicular to fold axis. According to these results the elongation is nearly parallel to the anticline axis. These results of strain analysis are shown that the regional finite strain is heterogeneous and generally increases northwards. In general, the final geometry is the end product of complex strain history, but the evolution may be viewed in simplified fashion as potentially consisting of three sequential steps: 1) pre tectonic vertical loading, 2) incipient tectonic compression (prior to folding) strong tectonic compression accompanied by folding and thrust faulting (Figure -9). Strain ellipse was shown on the limb of the Al- Tib Anticline. A proposed model for this superimposition is presented viaFigure-(10) which was inspired by Ramsay (1967) explanation of Pebble fabric in folded conglomerate beds. This model could account equally well for the prolate ″ strain″ estimated from grain fabrics in the Sandstone. These results agree with thrust fault model of

Anderson (1951) [22], where (σ 3) is vertical and (σ 1) is parallel to the bedding plane and perpendicular to the fold axis.

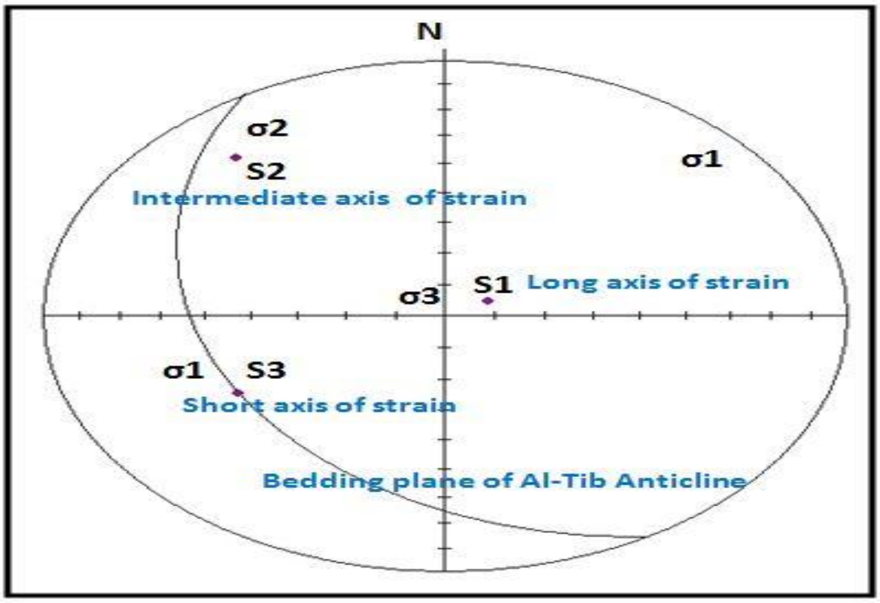


Figure 8-The relation between strike of Al-Tib Anticline and the orientations of the principal axes of the strain (Long, intermediate and short axes).

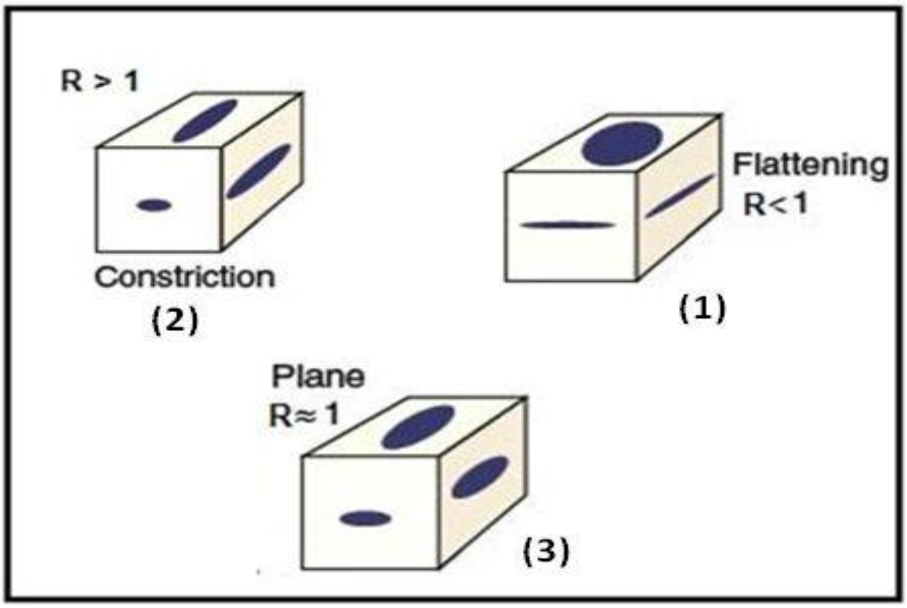


Figure 9-Origin of prolate strain **1:** The initial compaction of Uniaxial negative symmetry with the short axis perpendicular to the bedding plane and the long axis parallel to the bedding plane. **2:** Tectonic strain associated with folding. **3:** Final prolate resulting from the superimposition of initial fabric and tectonic strain.

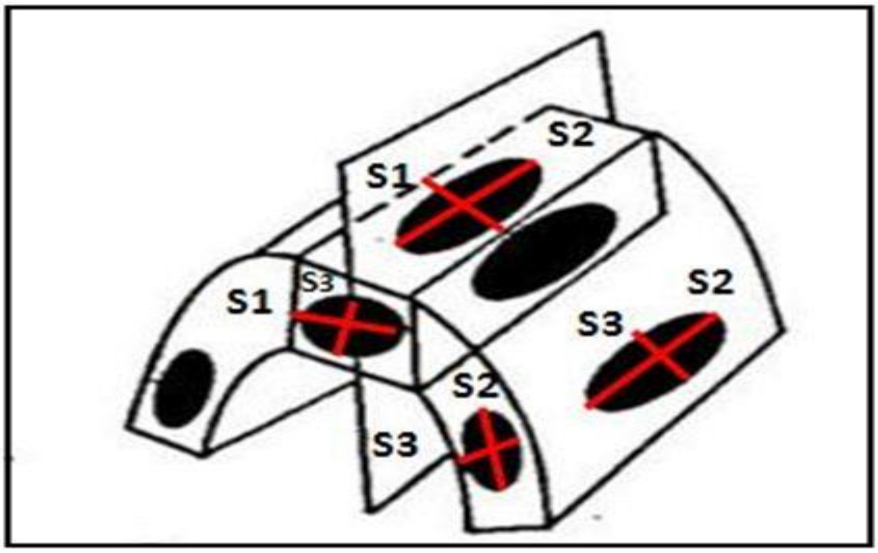


Figure 10-Final prolate fabric resulting from the superimposition of initial tectonic strain [11].

Discussion

Strain analysis results by Fry method and Center to Center method show that are approximately corresponding or similarly that data of axial ratios (Rs) of the strain for sandstone samples in Muqdadiya Formation of Al- Tib Anticline. The ellipses of all samples were combined with each other forming ellipsoids with distinct strain axes orientations, axial ratio (Rs) and (R) values which were plotted on Flinn diagram. The samples lie in the three sets (R<1, R=1, and R>1), therefore the strain must have resulted from triaxial stress effects.

The comparison between the present strain results and other results in Northern Iraq, shows there is high corresponding between them [23], resulted (R=1), this indicates the strain was plane type [24], resulted the studied samples lie within three fields: constriction, flattening and plane strain and [13] resulted (R>1), this indicates the strain was constriction type.

Conclusions

Shape of the created strain ellipsoid and the degree of 3D strain are illustrated on Flinn diagram, the studied samples lie within three sets: flattening strain, constrictional strain and plane strain. As a result, the obtained types of strains are Triaxial strain. This indicates the area is affected by stresses of the different magnitudes.

Orientations of the finite strain ellipsoid are the long principal strain axis (S2) is trending NW- SE which is parallel to bedding plane and parallel to the fold axis, and the short principal strain axis (S3) is perpendicular to the fold axis , which indicate an elongation in these trends. Strain analysis indicated that the study area was subjected to more than one stress condition which continued from Cretaceous to Late Tertiary.

The range of shortening (es) in the study area between (5-25%) that indicates the study area is located within low deformation and affected mostly by thrust faults where (σ1) is parallel to (S3), (σ 2) is parallel to (S2), and (σ3) is parallel to (S1).

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