Strain Analysis of Injana Formation at Durbendbazian Anticline /Northern Iraq

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Abstract
Durbendbazian Anticline locates at the Southwestern city of Sulaymania about 50 Km. north of Iraq. The objective of the study is to identify the strain state in Injana Formation, which locates on southwestern limb of Durbendbazian Anticline, by using Fry method technique.

The results of the study showed that the orientations of the shortest axis **E3** is in NE -SW direction, while the orientations of the intermediate **E2** and the longest **E1** of strain ellipsoid axes are in parallel and inclined directions with the fold axis. The Results of Flinn diagram represented from strain ratios indicate that the strain ellipsoids have oblate shapes with (**K- value)** less than one. From this study, we can conclude that the studied area subjected after sedimentation of Injana Formation to biaxial negative strain by effect of two stress components. The first was in northeast-southwest direction caused by compression stress resulted from the oblique collision of Arabia and Eurasia as a major stress component affected perpendicular to the fold axis of Durbendbazian Anticline. Whereas the second one acted along the fold axis and resulted by stress component parallel with plate margin due to oblique collision of Arabian and Eurasian plates. The effect of the second stress component is evident in curving manner of the fold axis.

Introduction
The Durbendbazian Anticline locates between Chamchamal and Sulaymania regions. It lies within high folded zone in northern Iraq. Tectonically, it is located in the high folded zone of Iraqi Tectonic division **Fig. 1.**

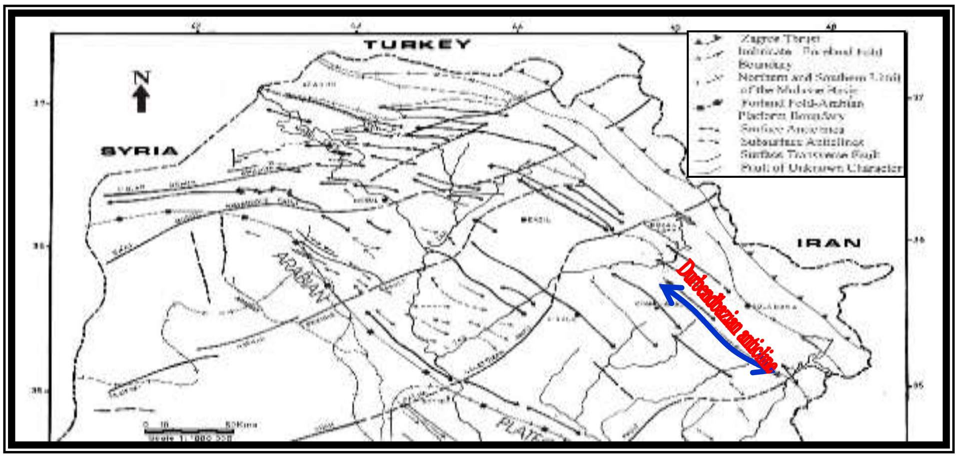

Fig.(1) : Tectonic framework of Northern Iraq. After (Adeeb, 2006**)**

Structurally; Durbendbazian Anticline is the longest anticline in the high folded zone in Iraq, it is asymmetrical double plunge anticline extends **107** kilometers in southeast - northwest direction with southwestern vergency (Al - Azzawi, 2003), **Fig.(2)**.

Fig. 2: Location Image of Durbendbazian Anticline

Stratigraphicaly including Pila Spi Formation (Upper to Middle Eocene) in the core of the anticline, Fatha Formation (Middle Miocene), Injana (Upper Miocene), Muqdadiya (Pliocene) and Bai- Hassan (Pliocene) Formations respectively **Fig. 3, Fig. 4**.

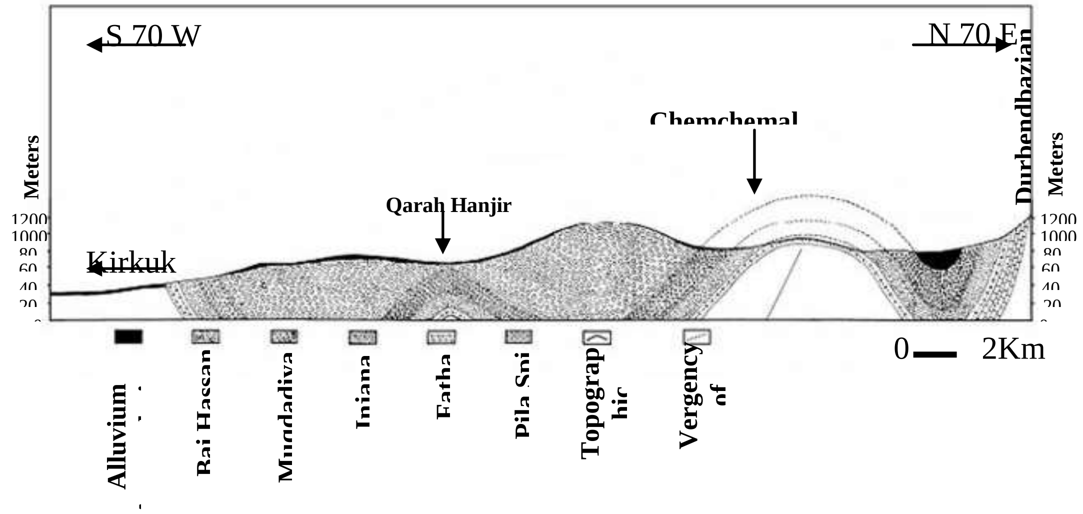

Fig. 3: Geological cross section between Durbendbazian and Kirkuk-Anticlines, After (Adeeb, 2006**).**

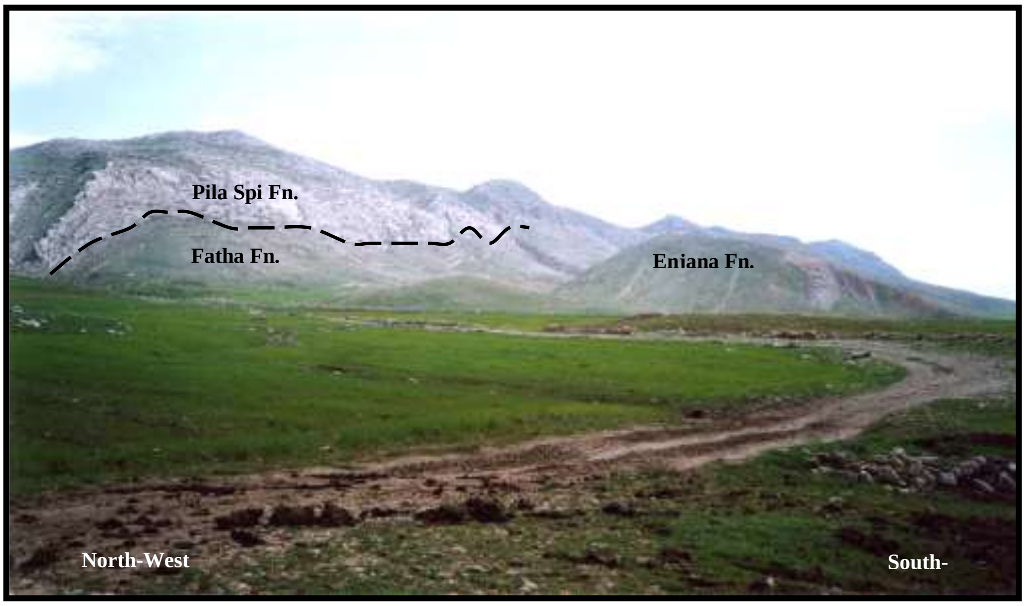

Fig. 4 : Geological photograph of Durbandbazian and Anticlines.

Materials and Methods

Seven oriented samples of sandstone were taken from Injana formation on the southwestern limb of Durbendbazian Anticline. Brunton compass used to determine the attitude of the beds at the sample locations. Each sample is cut along three perpendicular sections **ab, ac, bc.**

Thin sections were done for each of the mentioned sections, then photographed with an electronic camera. Fry method that depends on centre to centre concept of Ramsay et al. (1983) was applied on three sections of each sample. The resulted data were converted to digital form by representing the coordinates of the points in the space relative to the three Cartesian axes **x, y, z**.

A statistical Matlab7 programme was applied to create the matrix of Eigenvalues and Eigenvectors of strain ellipsoid for each sample as (Melton, 1980) equation matrix. Specified equations were applied for determining the length and directions of the strain ellipsoid axes of the seven samples, these equations are:

$$xyz\begin{pmatrix} a & b & e \\ b & d & f \\ e & f & c \end{pmatrix}\begin{pmatrix} x \\ y \\ z \end{pmatrix} = 1 \quad \ldots\ldots \text{(Milton, 1980)}$$

E1= $\sqrt{\text{Maximum Eigenvalue}}$ = Longe axis of strain ellipsoid

E2 = $\sqrt{\text{Intermediate Eigenvalue}}$ = Intermediate axis of strain ellipsoid

E1= $\sqrt{\text{Maximum Eigenvalue}}$ = Short axis of strain ellipsoid

D = Sin^{-1} (**Z**) -------------- (1)

H= Cos (**D**)

d = Cos^{-1}(**X** / **H**) --------- (2)

Where **D** is a dip amount of strain ellipsoid axes, **H** is a horizontal projection of strain ellipsoid axis and **d** is a direction of strain ellipsoid axis. The strain ellipsoid axes that obtained by equation **1** and **2**, were changed in their orientations equals to turn the beds to horizontal state by using the Schmidt net stereographic projection..

Results and discussion

The results of strain analysis included Eigenvectors and Eigenvalues matrix of the principal strain axes, which contained the square values of the length of these axes, which programmed in Table **1**.

Table1: Matrix of Eigenvector and Eigenvalue of strain ellipsoids.

Sample No.	Eigenvectors			Eigenvalues		
1	0.6705	-0.4715	0.5728	3.5458	0	0
	0.7047	0.1633	-0.6905	0	11.3500	0
	0.2320	0.8666	0.4417	0	0	13.8353
2	0.7423	-0.6269	-0.2364	3.8065	0	0
	0.6092	0.4847	0.6276	0	13.9189	0
	0.2789	0.6099	-0.7418	0	0	15.6715
3	-0.6482	-0.4681	0.6007	5.3593	0	0
	-0.7260	0.6178	-0.3020	0	15.6429	0
	-0.2298	-0.6318	-0.7403	0	0	15.8615
4	0.7395	-0.4997	-0.4511	3.8476	0	0
	0.6136	0.2247	0.7570	0	12.4378	0
	0.2769	0.8366	-0.4727	0	0	13.5196
5	0.6904	0.5129	0.5102	3.1022	0	0
	0.6659	-0.1750	-0.7252	0	10.9321	0
	0.2827	-0.8404	0.4624	0	0	13.2120
6	0.8136	-0.5441	0.2048	3.3520	0	0
	0.5192	0.5215	-0.6771	0	11.8469	0
	0.2616	0.6572	0.7068	0	0	12.3011
7	0.7891	0.1881	0.5848	3.9077	0	0
	0.5559	-0.6237	-0.5495	0	11.6218	0
	0.2613	0.7587	-0.5967	0	0	15.8019

Attitude of the three main strain ellipsoid axes are determined from Eigenvector and Eigenvalue matrix in Table**1** by means of equations **1** and **2** that are mentioned in Materials and research methods section, **Table 2**.

Table 2: Results of strain ellipsoid analysis

Sample No.	attitude of the bed		Strain ellipsoid axes orientation			Strain ratios of strain ellipsoid		
	Dip direction	Dip Amount	E1	E2	E3	Maximum Strain ratio	Intermediate Strain ratio	Minimum Strain ratio
1	234	60	320/26	109/60	226/13	2	1.8	1.1
2	238	40	339/48	142/38	231/16	2	1.91	1.06
3	234	38	117/48	323/39	222/13	1.73	1.72	1.01
4	230	38	329/29	114/57	230/16	1.88	1.8	1.04
5	214	20	325/27	109/57	226/16	2.06	1.88	1.1
6	260	06	343/45	134/41	238/15	1.92	1.88	1.02
7	230	08	133/37	343/49	235/15	2	1.72	1.16

The results of strain analysis revealed in **Table 1** and **2**, showed that the study area subjected after Upper Miocene (after deposition of Injana formation) to a major sub-horizontal to horizontal stresses in NE-SW direction. The main direction of short axis **E3** of the strain ellipsoid in all samples represents generally the trend of maximum compression stress axis which status is almost perpendicular to fold axis of

Durbendbazian Anticline. The orientation of the longest strain ellipsoid axis **E1** is parallel with the fold axis, while that of the intermediate strain ellipsoid axis **E2** is sub-vertical. The strain ratios and K- values in **Table 3** showed that the strain ellipsoids have Oblate shapes with **K<1** in Flinn diagram, **Fig.5**.

Table3: Parameters of Flinn diagram and shape of strain ellipsoids.

Sample No.	Value of strain ellipsoid axes			Strain ellipsoid ratios			a-Factor	b-Factor	k-value	Strain ellipsoid shape
	E1	E2	E3	Max.	Medium	Minim.				
1	3.72	3.37	1.88	2	1.8	1.1	1.06	1.64	0.64	Oblate
2	3.96	3.73	1.95	2	1.91	1.06	1.05	1.8	0.58	Oblate
3	3.98	3.95	2.3	1.73	1.72	1.01	1.01	1.7	0.59	Oblate
4	3.68	3.53	1.96	1.88	1.8	1.04	1.04	1.73	0.60	Oblate
5	3.63	3.31	1.76	2.06	1.88	1.1	1.09	1.7	0.64	Oblate
6	3.51	3.44	1.83	1.92	1.88	1.02	1.02	1.84	0.55	Oblate
7	3.97	3.41	1.98	2	1.72	1.16	1.16	1.48	0.78	Oblate

However, same results obtained by strain analysis of Injana Formation (Upper Miocene) at Sheikh Ibrahim Anticline and in Shiranish formation (Upper Cretaceous) at Sinjar anticline (Fanoosh, 1998). Further, analog strain analysis done in the Sinjar Formation (Paleocene to Lower Eocene) at Sinjar Anticline, gave Oblate strain ellipsoids also, (Fanoosh, 2001). Although the later folds are located in the low folded zone of Iraq.

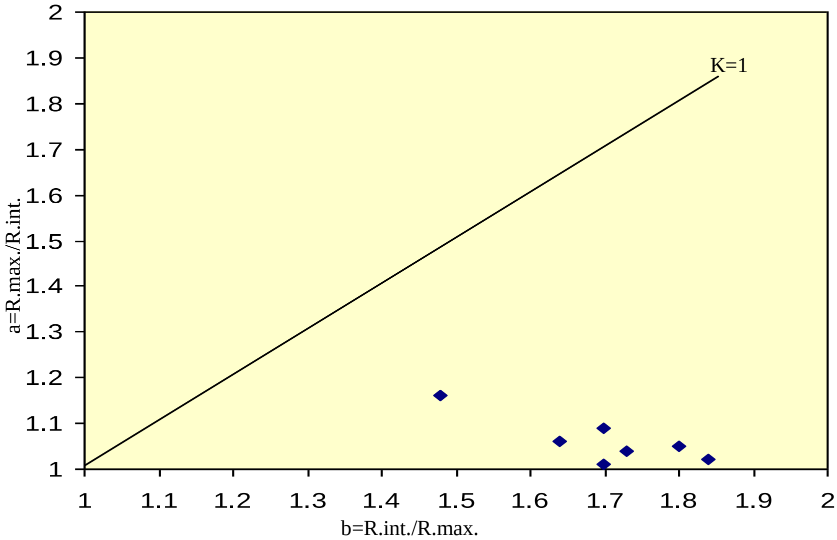

Fig. 5 : Flinn diagram of the strain ellipsoids of the studied samples

The results revealed in **Table1, 2** and **3**, appeared that Durbendbazian Anticline had been subjected to biaxial negative strain as diagram of (Lisle& Salih, 1988). The first was in northeast-southwest direction caused by direct stress resulted from the oblique collision of Arabia and Eurasia as a major component of stress perpendicular to the fold axis of Durbendbazian Anticline. Whereas the second one acted along the fold axis and resulted by stress component parallel with plate margin due to oblique collision of Arabian and Eurasian plates, which is The effect of the second stress component is evident in curving manner of the fold axis.

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تحليل الاجهادات التي تعرض لها تكزين انجانه في طية دربندبازيان / شمال العراق

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الملخص

تقع طية دربندبازيان المحدبة جنوب غرب مدينة السليمانية بحوالي 50 كيلومتر شمال العراق. يهدف البحث إلى تحديد حالة الإجهاد في النماذج الصخرية المأخوذة من تكوين انجانة على الجناح الجنوب الغربي لطية دربندبازيان المحدبة، باستخدام طريقة فراي.

أظهرت نتائج تحليل الانفعال، أن اتجاه محور أهليج الانفعال القصير(E3) هو شمال شرق . جنوب غرب. أما وضعية محوري أهليج الانفعال المتوسط (E2) فهو شبه شاقولي، والطويل (E1) فانه موازي لمحور الطية. أظهر مخطط فلن، أن شكل أهليج الانفعال كان مفلطحا لجميع النماذج، حيث كان مقدار(**K-value**) أقل من واحد. تشير نتائج تحليل الانفعال في النماذج، إلى تعرض المنطقة بعد ترسيب تكوين انجانة لتأثير إجهادات ضاغطة ثنائية المحور حسب مواقع النماذج في مخطط فلن. الأولى باتجاه شمال شرق . جنوب غرب ناتجة من تأثير إجهاد ضاغط عمودي على محور طية دربندبازيان، وهي تمثل إجهادات رئيسية نتجت من التصادم المائل للصفيحة العربية بالصفيحة اليوراسية، والثانية باتجاه موازي لمحور الطية موازية لحافة التصادم المذكورة، وكان له دور في إحداث انحناء لمحور الطية.