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## Paleocurrent analysis of Upper Cretaceous Zagros Foreland Basin: A Case Study for Tanjero Formation in Sulaimaniya Area NE-Iraq

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### ABSTRACT

Tanjero Formation is an Upper Cretaceous (Campanian-Maastrichtian) unit, which crops out within the Imbricated and High Folded Zones in Northeastern Iraq. Its outcrop stretches as narrow northwest-southeast belt near and parallel to the Iranian border. The formation mainly consists of alternation of clastic rocks of sandstone, marl and calcareous shale with occurrence of very thick conglomerate and biogenic limestones.

In this study many sedimentary structures are found in the Tanjero Formation, which have paleocurrent importance. These structures are cross bedding, interference ripple marks, imbricated pebbles, plant debris, sole marks, elongate fossil skeleton, valleys and channels. Most of these structures are found in the lower part. The paleocurrent analyses, as revealed by these structures, are presented in rose and stereonet diagrams, which show south and southwest directions.

تحليل التيارات القديمة لحوض الفورلاند للعصر الكريتاسي الاعلى : دراسية حالة لتكوين تانجرو في محافظة السليمانية ، شمال شرق العراق

### المخلص

ان تكوين تانجرو عبارة عن وحدة صخرية تعود إلى الكريتاسي الأعلى (كامبانيان-ماستريختيان) و تقع مكاشفه ضمن نطاق التراكب والطيات العالية في شمال شرق العراق . تمتد مكاشفه كنطاق ضيق باتجاه شمال الغرب -جنوب الشرق على امتداد الحدود الايرانية. يتكون التكوين بصورة رئيسية من تعاقب الصخور الفتاتية الرملية ولغرينية و المارل (أو الطفل الجيري ) ويتغير إلى سمك كبير من المدملكات و الحجر الجيري الحياتي في المنطقة القريبة من المصدر.

تم إيجاد كثير من التراكيب الرسوبية في الجزء السفلي للتكوين و هذه التراكيب ذات اهمية كبيرة في تحديد اتجاه التيار القديم و من بينها و الطبقات المتقاطعة و علامات النيم العرضية و المتداخلة و الحصوات المتراكبة و تراكيب السطوح السفلية و الركام النباتي و الوديان و القنوات القديمة. استخدمت هذه التراكيب ( خاصة

التراكيب احادية الاتجاه) لإيجاد اتجاه التيار القديم بواسطة مخطط الـروز و الستريوننت حيث اظهرت الاتجاه جنوب و جنوب غربي .

## INTRODUCTION

Tanjero Formation, as an Upper Cretaceous (Campanian-Maastrichtian) unit, is exposed within both Imbricated and High Folded Zones in Northeastern Iraq (Buday, 1980) and Buday and Jassim, 1987). It elongates along Iran-Iraq border as narrow and northwest-southeast belt (Fig. 1). The formation mainly consists of clastic sediments which includes sandstone, marl and calcareous shale with occurrence of very thick conglomerate and biogenic limestones (Bellen *et al* 1959). Jaza (1992) studied the sedimentology and environment of the formation and found several facies of turbidite.

On the basis of main lithological attributes, Karim (2004) has divided the formation into three parts (lower, middle and upper parts). The lower part consists of thick succession of conglomerate and sandstone (100-400m) at near shore area and basin respectively. The middle part (middle transgressive part) is composed of 100-300m of bluish white marl and calcareous shale. The upper part (60-200m) consists of alternation of biogenic limestone and calcareous shale with minor amount of sandstone and conglomerate. He concluded that lower and upper parts have been deposited in relatively shallow water while the middle part is deposited in the deep one.

## PALEOCURRENT ANALYSIS

As for paleocurrent analysis, most of the sedimentary structures, discussed by Karim (2004), are exploited in addition to the types of the sedimentary rocks. According to these variables, the paleocurrent direction is indicated accurately to be mainly toward south and southwest directions. The variables used for indication of the paleocurrent direction are as follows:

### Type of sedimentary rocks

From the facies distribution map of Upper Cretaceous can be realizes that the reefal limestones (Aqra-Bekhme Formation) are mainly located at northwest of the main basin of Tanjero and Shiranish Formations. The occurrence of these limestones at west and northwest of the basin is an indirect indication that paleocurrent direction didn't not toward northwest or west as mentioned before. This is because the reefs could not survived turbidity of water moving along this paleocurrent direction. The contrasts of direction with previous studies are possibly due to the fact that all of them were conducted on the distal part of the basin are the paleocurrent direction is not much clear or may have dispersed directions. (Al-Rawi, 1981, Saadalla and Hassan, 1987 and Jaza 1992).

### Grain size and facies change

The change of the grain size from coarse (conglomerate) to fine (sandstone and shale) is generally toward southwest; this is also compatible with facies change. The coastal



and shallow facies changing to deeper ones in the same direction of grain size change. The paleoslope dictated directions of grain size and facies changes. This in turn parallels the incised valleys and associated submarine channels, in addition to the southwest elongation of the conglomerate (see Karim 2004). In one cases the conglomerate (inside and incised valleys and associated submarine fan) extend and thin out from Chuarta area to Sharazoor plain in nearly southwestern and southern direction, toward basin direction (Fig.2).

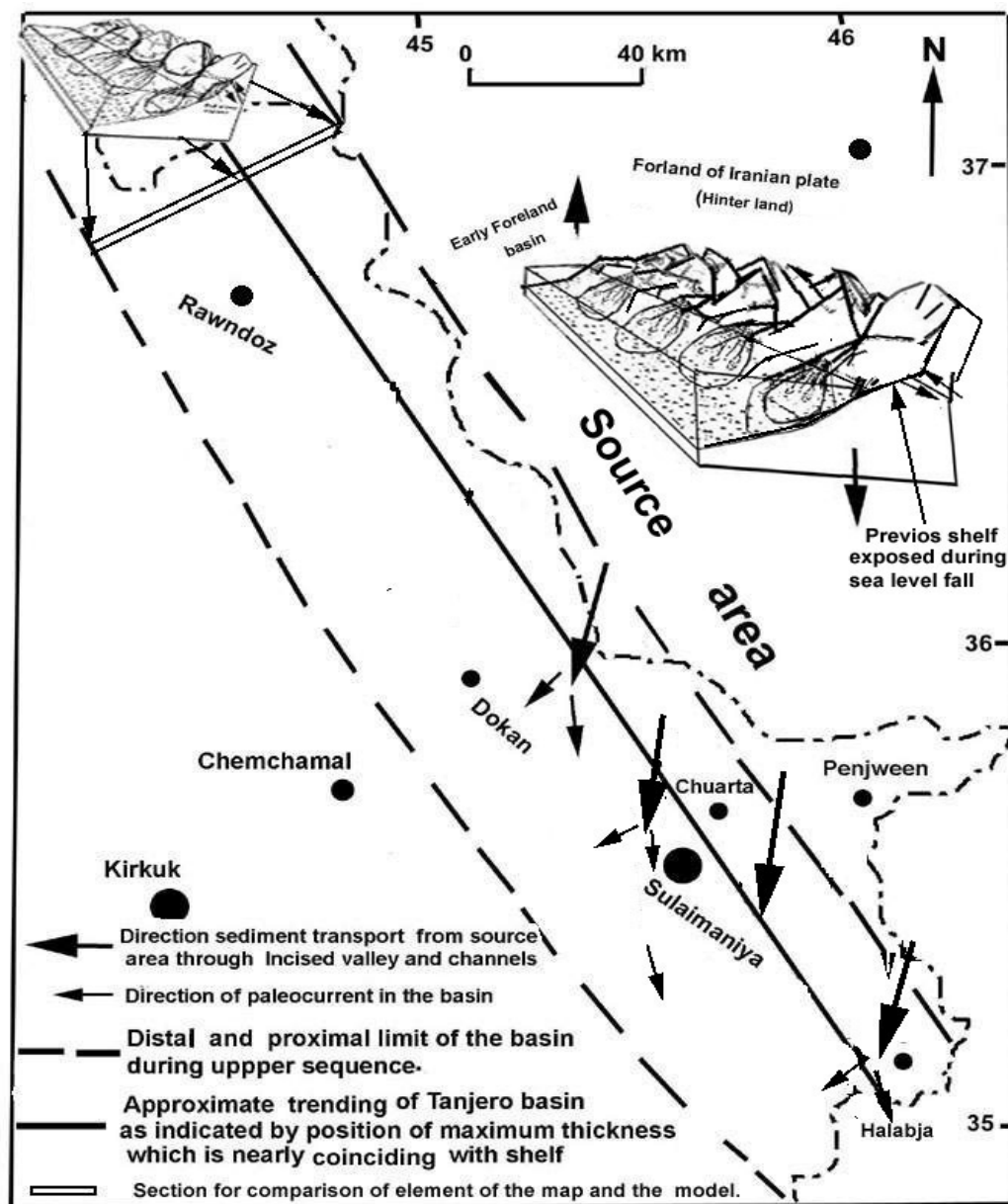


Fig. (2) General basin trend and paleocurrent direction of Tanjero Formation during Upper Sequence.

### Thickness of the sediments

The maximum thickness (2000m) of the formation is recorded in the type section in Sirwan valley (Fig.2). In Chuarta area it reaches 1500m while in Dokan area is only 630m and thins northwestward to about 50m. This general increase of thickness toward southeast (Sirwan section) is indirect evidence that the paleocurrent direction is toward south and southwest. In other sides the isopach and accommodation maps of Upper Cretaceous, as drawn by Minas (1997, p.89 and 92) show the thickest sediments and the deepest basin is located in the area south of the studied area especially, the east and northeast of Baghdad City

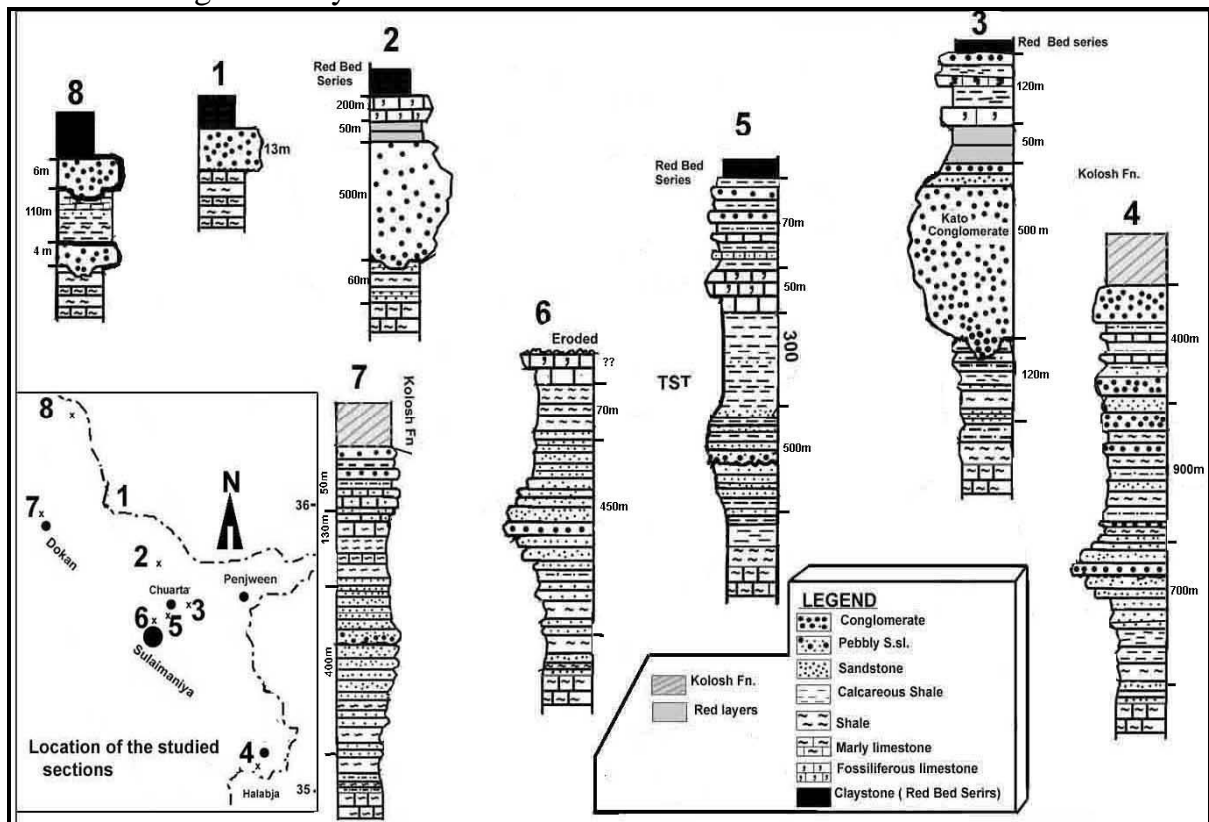


Fig. (3) Location and columns of the studied sections, 1- Iran section, 2-Qashan section, 3-Kato section, 4-Sirwan section, 5-Tagaran section, 6-Malkandi section, 7-Dokan section , 8-Kometan village section( Qandil mountain toe). (After Karim, 2004)

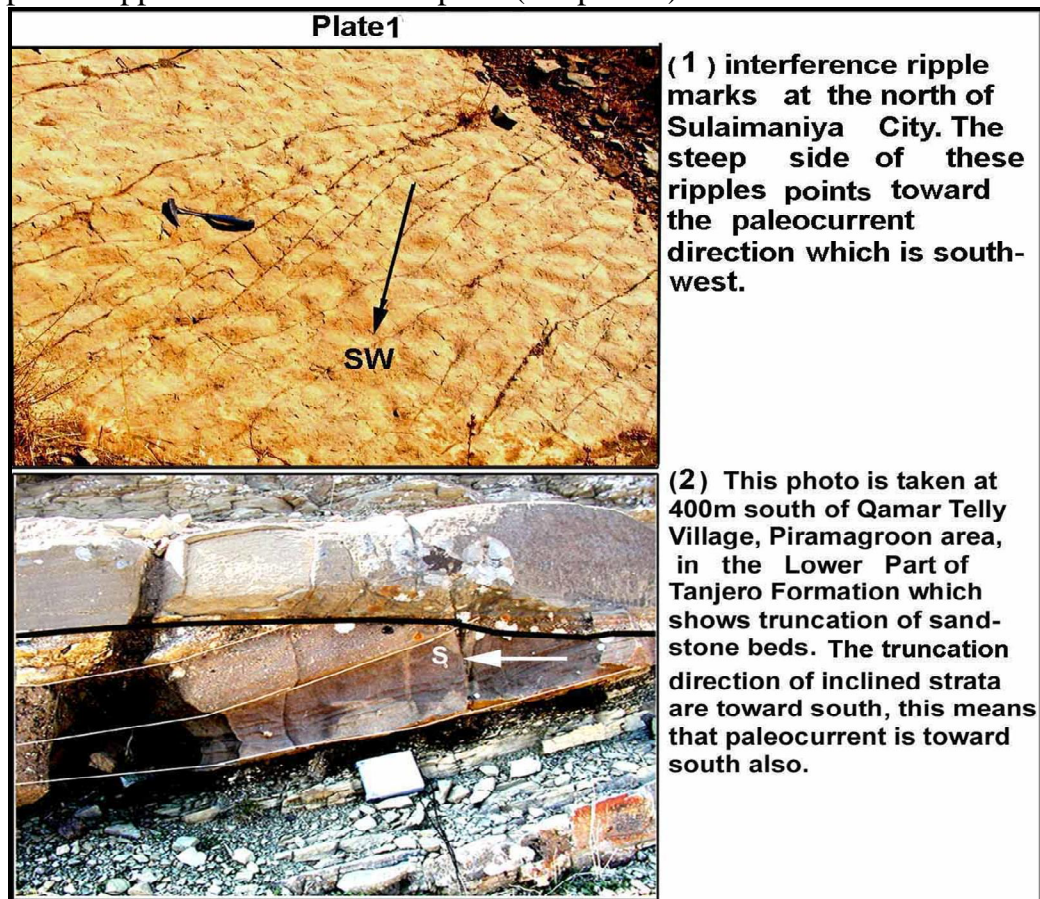
### Unidirectional Sedimentary Structures

They are those structures, which indicate one direction of flow (vectorial direction), and have unique direction and take one value of 0 to 360 degrees. The most important unidirectional sedimentary structures, in Tanjero Formation, are imbricate pebbles, cross bedding, asymmetrical ripple marks and flute casts.



## Ripple Marks

The interference ripples marks are very common in the north and northwest of Sulaimaniya city, in the lower part of the formation, where one can see tens of them at different horizons (Plate 1.1). These ripple marks occur in the lower part of the formation. The peak of these structures is mainly pointing toward S65W (Fig.4B). Similar ripples exist in the upper part of the formation in Dokan area, on the right bank of the Qashqully stream and north of Qulka village. These ripples are more or less resembling linguoidal ripples. Pettijohn and Potter (1964) termed these ripples interference ripples. The interference ripple marks recorded by Ainsworth and Crowley (1994), they attributed these types of ripple marks to storm deposit (tempestite).



## Imbricated pebbles

The most important and abundant unidirectional structures in the Tanjero Formation are imbricated pebbles. They exist in the conglomerate of the lower part of the formation in the proximal area at Chuarta-Mawat and Qandil mountain areas. Nearly more than 60% of the imbricate pebbles in the conglomerate succession are directed toward south (Plate 1). The other ones may have any direction but mostly bearing toward southwest. These structures can be seen as preferred orientation of elongate fragments (pebbles) at angle to the underling bedding.

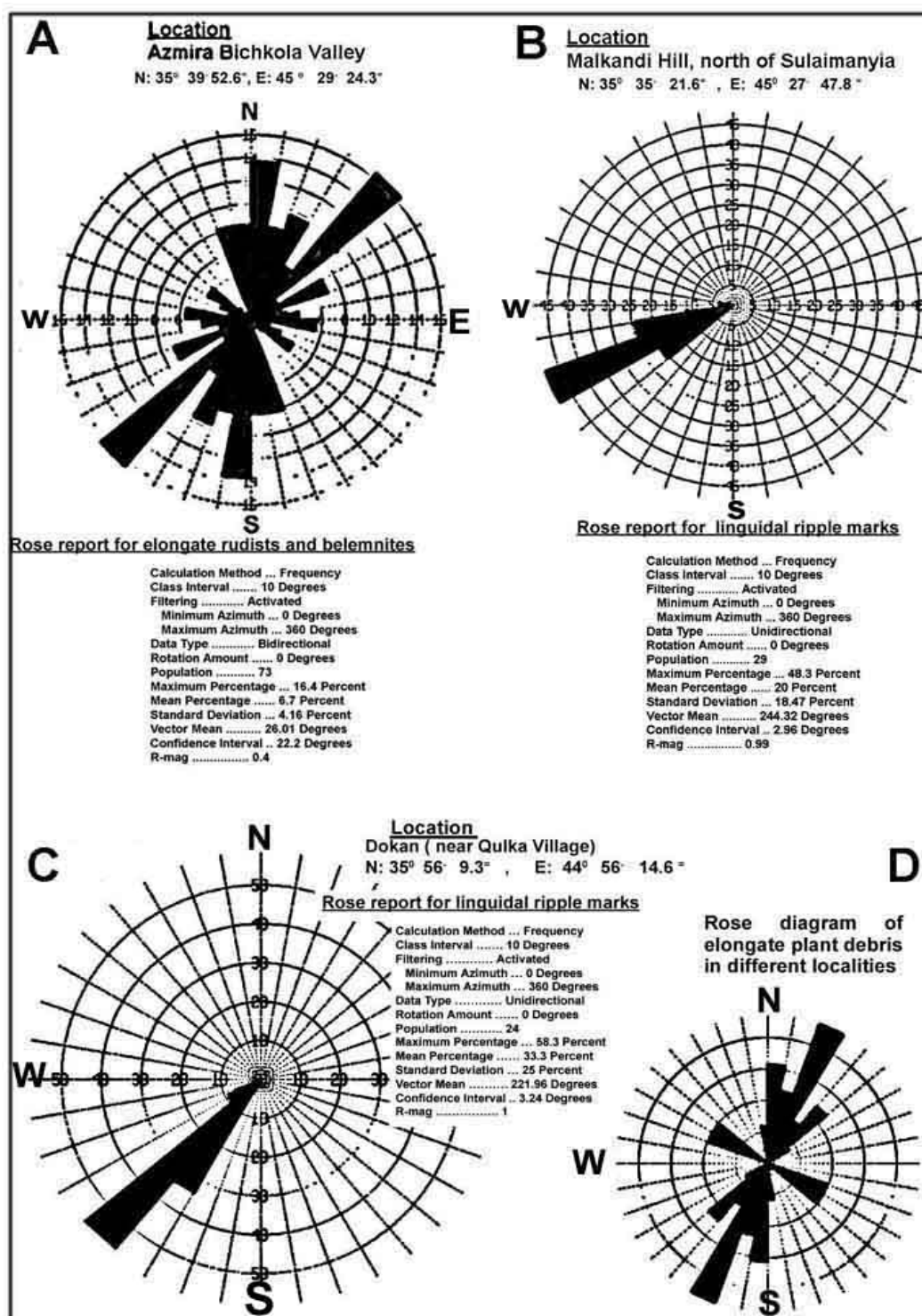
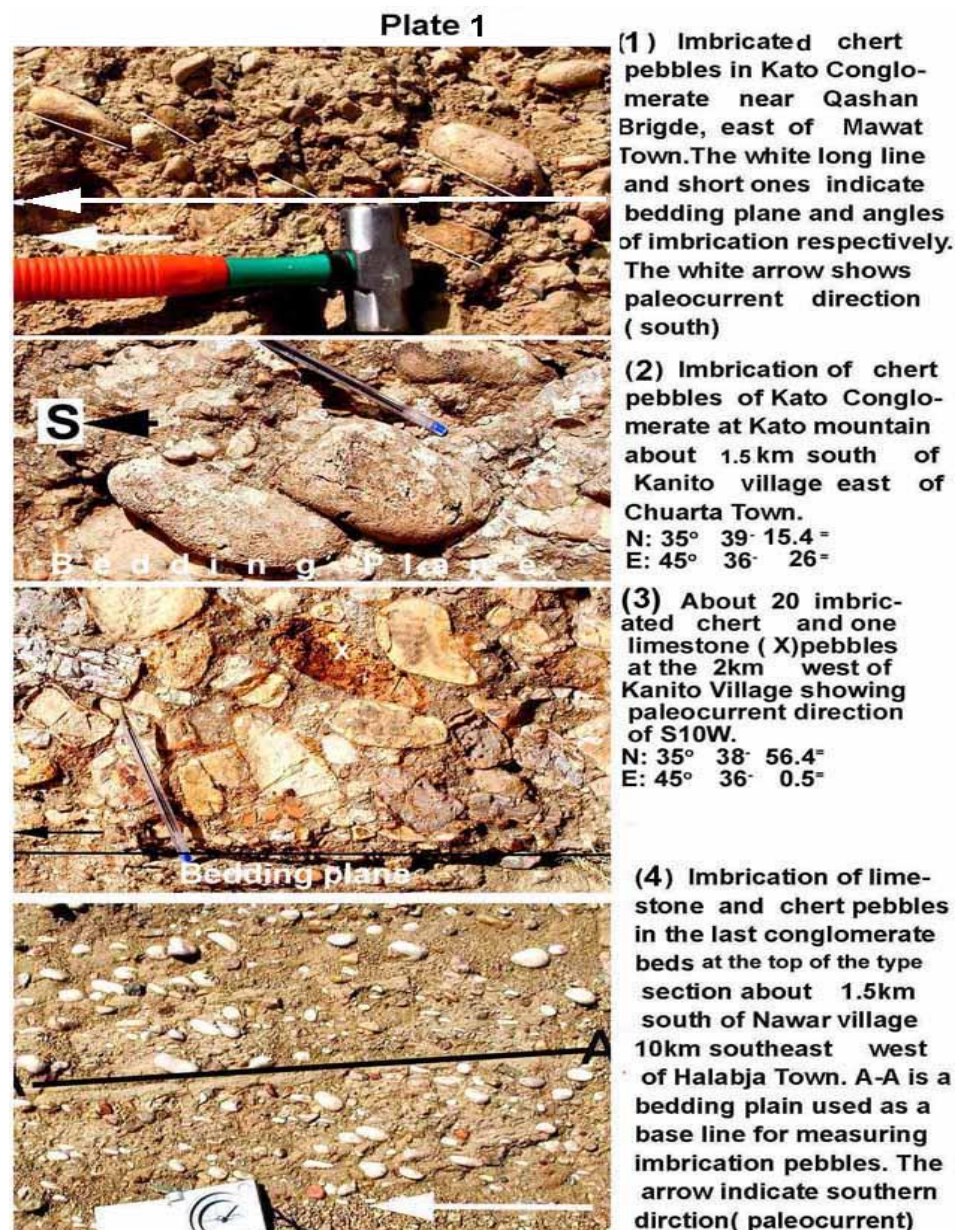


Fig.(4) Rose diagram drawn by PC when the data in the table ( 1 and 2) are entered .  
The general direction of paleocurrent is southwest





This structure is common on streambeds where flowing water tilts the pebbles under the effect of upper flow regime near the bottom of the stream. The flat surfaces of these pebbles dip upstream. In these areas, the attitudes of tens of these pebbles are measured by compass (plunge angles and directions) and arranged (Table 3).

### Bi-directional sedimentary structures

The bi-directional sedimentary structures are those, which have two opposite directions indicating only line (or sense) of movement not unique direction. Each of these structures has direction ranging from zero to 180 degrees. The observed structures are as follows:

Table (1) Azimuth of elongate plant debris measured in different localities such as Mokaba, Chaqchaq valley, Qamartelly Village (foot hill of Pirmagroon), Dokan area and Makandi Hill. All five columns are entered into the PC as one continuous column when RockWare Program is used.

90	210	110	180	186
135	214	110	180	190
140	220	126	187	198
130	190	117	186	200
139	195	120	180	205
151	185	112	177	206
154	200	115	176	200
167	200	112	185	209
167	200	112	190	210
163	90	123	170	211
170	93	124	196	207
178	90	220	184	208
183	230	220	222	211
181	240	226	122	217
178	230	230	209	200
167	234	233	206	205
189		228	199	208
210		226	196	

Table (2) 1. Athimuthal compass reading of 72 elongate rudist and belemnite body fossils at Azmira Bechkola Valley (N:  $35^{\circ} 39' 52.6''$ , E:  $45^{\circ} 29' 24.3''$ ) Fossils. 2. Azimuth of 29 linguinal ripple marks at Malkandi Hill (N:  $35^{\circ} 35' 21.6''$ , E:  $45^{\circ} 27' 47.8''$ ), 3. 2. Azimuth of 24 linguinal ripple marks at Dokan area (N:  $35^{\circ} 56' 9.3''$ , E:  $44^{\circ} 56' 14.6''$ ).

1. Elongate body fossil					2. Linguinal ripple mark (Malkandi)		3. Linguinal ripple Mark (Dokan)	
50	360	61	3	308	240	234	220	220
42	5	33	8	348	240	233	221	216
316	73	5	296	345	260	243	217	224
90	5	65	42	25	250	247	230	223
60	340	20	25	5	270	244	218	215
20	39	55	45	89	240	240	226	228
70	18	352	10	4	240	245	219	224
11	65	10	12	345	235	250	227	217
12	48	355	5	350	250	252	221	225
90	45	88	31	90	255	230	217	215
29	44	45	45	300	240	235	224	222
8	66	49	29	295	245	250	225	230
360	45	5	38	348	240	252		
90	355	355	20	80	235	246		
		360	354	345		245		
		45	360	45				
		308						

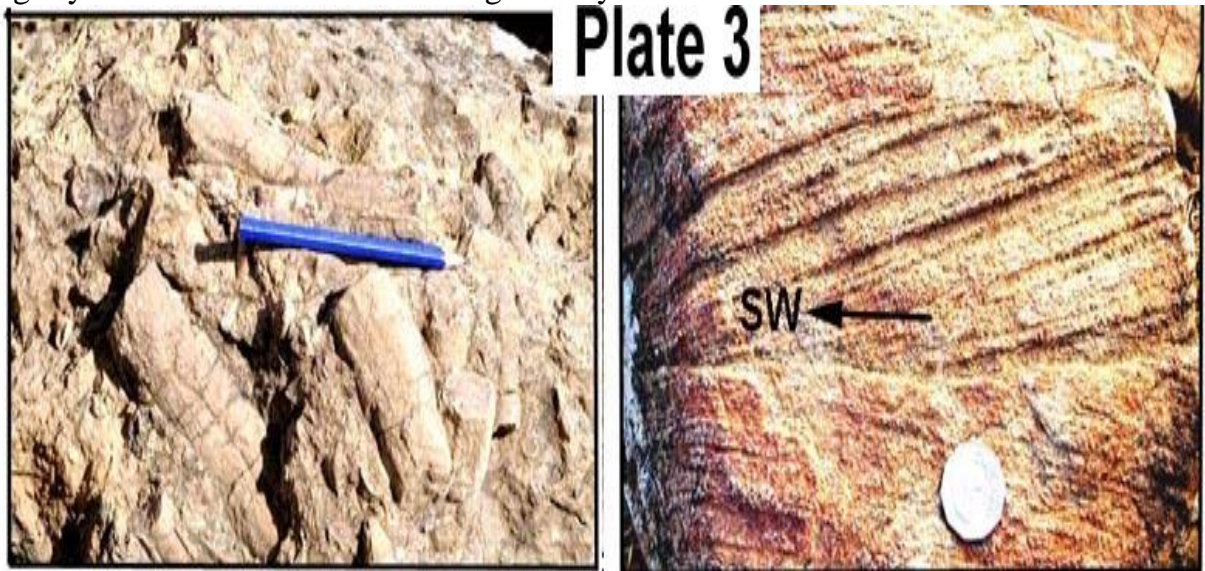
Table (3) Compass reading of plunge azimuth (Left column) and angle of Plunge (right column) of imbricated pebbles of conglomerate at: 1.Malkandi Hill (N:  $35^{\circ} 35'$   $21.6^{\circ}$  E:  $45^{\circ} 27' 47.8''$ ), 2.Damerkan, Arbat (N:  $35^{\circ} 27' 22.4''$  E:  $45^{\circ} 29' 57.1''$ ), 3. Qashan Bridge, Mawat (N:  $35^{\circ} 51' 24''$  E:  $45^{\circ} 24' 29.3''$ ). These data are given as entered into the PC to draw rose diagram (see fig. 3).

1		2		3	
Azimuth	Plunge angle	Azimuth	Plunge angle	Azimuth	Plunge angle
20	63	40	43	9	40
10	52	40	32	8	60
5	32	25	22	352	31
240	51	357	41	348	48
45	22	45	22	355	60
225	35	335	25	358	55
345	45	355	35	4	56
350	33	150	23	11	49
310	55	340	45	10	38
314	43	344	33	11	32
5	30	75	20	360	35
5	35	145	35	351	41
280	54	330	44	347	52
20	34	131	30	14	30
90	64	160	44	15	35
270	43	356	33	9	30
280	70	333	40	5	29
280	60	344	40	355	33
280	46	355	36	357	39
10	60	30	40	360	20
12	34	82	24	4	27
14	52	44	42	20	30
350	33	350	33	15	43
50	75	150	55	10	34
12	43	42	43	50	31
260	66	340	44	340	25
290	60	330	30	3	37
50	51	55	41	7	31
14	44	24	44	310	49
330	55	342	45	330	28
280	67	351	37	5	18
280	44	320	34	351	39
10	34	30	34	349	70
325	63	335	53	9	65
352	53	352	43	10	22
330	34	339	24	350	35
325	66	325	51	20	18
280	54	320	45	7	40
170	47	21	37	353	34
150	56	21	36	150	33
				180	22
				88	29



### Elongate rudist and Belemnite fossils

Elongate Rudist and Belemnite fossils are found together in the same bed in the upper part of the formation at Chuarta area. In this area the mixed carbonate-siliciclastic succession (see Karim 2004) is well developed. The lowest limestone bed, at some locality, composed entirely of a stack of elongate rudist and belemnites body fossils. Their length range between 10-25cm (Plate 3.1) and they have straight shell or slightly curved. Their directions are generally toward southwest.



(1) Elongate rudist, parallelly arranged as response to effect of paleocurrent, at Upper part of Tanjero Formation, Chuarta area.

(2) Cross bedding in the lower part of the formation at 2km north of Sulaimaniya City. Indicates southwest paleocurrent direction.

### Plant Debris

Their paleocurrent significance is less important than above-mentioned directional structures, because:

- 1- They are transported into the basin during the river flooding. But most of the debris are deposited at the end of the storm when the energy is too weak that they take no certain directions.
- 2- As they are normally elongate so they indicate two opposite direction (i.e. not one direction of movement) of the paleocurrent. Potter and Pettijohn (1977) mentioned that plant fragments indicate only line movement of paleocurrent. However, at many localities compass reading of plant debris are taken and their direction are plotted on the rose diagram (Fig. 4D).

### Channel and valleys

The channels and valleys in the coastal area of the formation are anisotropic in structures, as they have imbricated pebbles in the upcurrent direction and their length is directed toward paleoslope. These erosional structures have least width in the direction of the paleocurrent. These two characteristics can be used for indication of paleocurrent

and paleoslope. Several small channels and valleys are found; their imbricated pebbles and length show southwest paleocurrent direction (Plate 2).

### **Stereonet- and rose-diagram plotting**

For the plotting data of the unidirectional and bi-directional sedimentary structures (terminology cited by Sinclair, 1994), a Windows based RockWare program is used as follows:

**1-** The trends (strikes) of bi-directional structures are measured as compass quadrant readings. The trend must be measured by using both ends of the compass needle in the two northern or southern quadrants. Lorenz et al. (2002, p. 509) also used this method for same purpose. Then they changed to their equivalent azimuthal readings for entering the PC to draw rose diagram (Fig.3).

**2-** The effect of tectonic tilt is corrected, by using stereonet where the tilt is more than 30 degrees. Potter and Pettijohn (1977, p.374 and Tucker 1988, p.41) gave this limit for tilt correction and they mentioned that tilt, below 30 degrees needs no correction. Most localities of the studied area have dip amount less than 30 degrees such as, lowland of Chuarta–Mawat area, Sharazoor-Piramagroon plains, Dokan area and Chaqchaq valley, while Kato Mountain and Sirwan Valley have more than 30 degrees of tilting.

**3-** The attitude (plunge angle and direction) of unidirectional (imbricated pebbles) (Plate 1.1 and 1.2) are measured in the field using compass method. Then, they are plotted on the Schmidt stereonet (Fig.4) by carefully treating for the options given by the Streofile of the RockWare program. The data must be formatted either according to *Dip Direction* or according to *Right Hand Rule*. In the present study, the compass readings are arranged (or converted) to azimuthal data by using Dip Direction Format.

**4-** The flute cast and cross bedding have fewer occurrences than imbricate pebbles. So that they are used in field to support and confirm the direction shown on the stereonet (Fig.4). Cross bedding and laminations have more dispersed direction but the more obvious ones give southwest and south direction.

**5-** Ripple marks, elongate fossil shell, plant debris are numerous in the lower part and upper part of the formation. So measurement is made on these directional structures. The azimuths of these structures are plotted on the rose diagram using Rose files of RockWare program (Fig.3). The option of “full rose” and “bi-directional” are given to the program when the bi-directional sedimentary structures are entered while for unidirectional ones “half rose” and “unidirectional” option is activated (Fig.3).

**6-** The over all paleocurrent directions, inferred in this study, are plotted on the map of the studied area (Fig.5).

**7-** Many structures are photographed in their original position with indication of their azimuth. These photos gave a powerful evidence for the direction of paleocurrent (Plate 1). The clearest photos are taken at the Sirwan valley for imbricated pebbles at the near boundary with Kolosh Formation. At this place the plunging (dipping) of the platy pebbles are so clear that one cannot find similar ones in gravels of recent rivers and alluvial fans (Plate 1.4) which show south direction. Another place, which show clear



eyewitness paleocurrent direction, is a very good developed channel filled with conglomerate at the Kato Mountain. There, visual inspection of imbricated pebbles inside the channel without any calculation can easily prove the southern direction of paleocurrent at this location (Plate1.2). But it is possible that the so-called” Qulqula Conglomerate Formation” may have close relation with conglomerate of lower sequence, which deposited at least 10 km far from the upper one. The study of this conglomerate may reveal farther and better paleocurrent study during lower sequence.

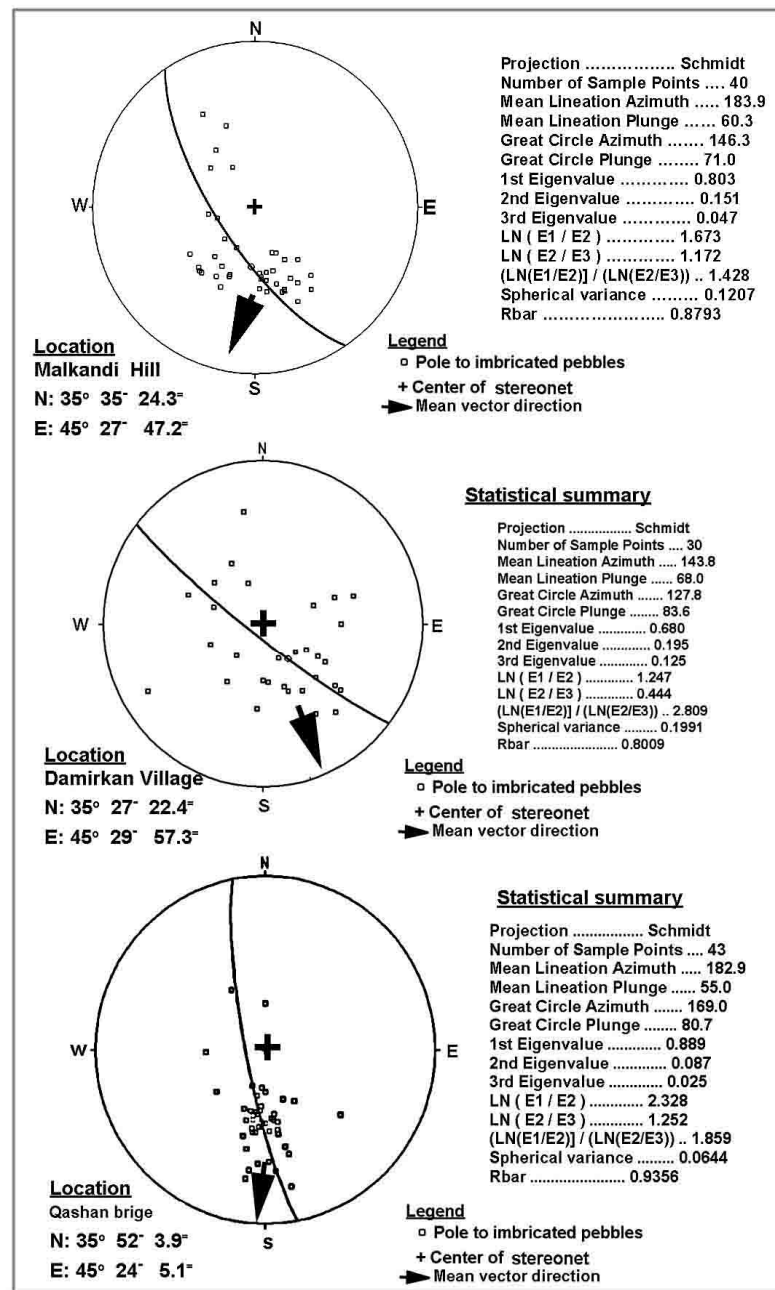


Fig.(4) Stereonet diagram showing paleocurrent direction of the imbricated pebbles of three localities on the outcrops of Tanjero Formation.

## CONCLUSIONS

The paper has the following results:

- 1-In this study many sedimentary structures are found, which are not recorded in the Tanjero formation in previous studies such as cross bedding, interference ripple marks, imbricated pebbles, plant debris, sole marks and channels.
- 2-The direction of these structures are studied and recorded in the field to be used for paleocurrent indication for basin of Tanjero Formation. The data are processed by PC using Rockware program.
- 3-The paleocurrent is inferred to be toward south and southwest.
- 3-The result is shown by rose stereonet diagram in addition to the field photos.

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