Pak. J. Sci. Ind. Res. 2010 **53**(4) 180-186

Paleocurrent Analysis of the Early Pliocene Nagri Formation, Southern Kohat Plateau, Sub Himalayas, Pakistan

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(received October 29, 2009; revised March 8, 2010; accepted March 14, 2010)

Abstract: The present study is based on the paleocurrent analysis of sandstone of the Early Pliocene Nagri Formation, exposed in the southern limb of Shahbazgarh Syncline, Shahbazgarh area, southern Kohat Plateau, sub Himalayas, Pakistan. The readings of paleocurrents were taken from the cross beds of the sandstone by following a traverse of one and a half kilometer along the strike of formation. The analysis of data and its graphical presentation indicated that the orientation of paleostreams and direction of their paleocurrents was north 30° east at the time of deposition of early pliocene Nagri formation. The paleo position of the Indo-Pakistani plate was in the north-east orientation during the pliocene. Based on the present study, it is concluded that the Himalayan Hinterland was the probable sediment source of the Nagri formation in the study area and the sediments were transported through paleostreams flowing in the north-east south-west orientation.

Keywords: paleocurrent Nagri formation, southern plateau, Pakistan, Kohat plateau, sandstone

Introduction

The study area lies in the southern Kohat Plateau, sub Himalayas, Pakistan. This part of plateau is occupied by a complex assemblage of rocks, sandstones, shales, limestones, gypsum and salt of tertiary system (Meissner *et al.*, 1974).The paleocurrent analysis and paleostream orientation have been carried out to decipher the direction of flow of paleo channels along with gradient by measuring the attributes of cross beds of sandstone of the early pliocene Nagri formation from the Shahbazgarh area, southern Kohat Plateau, Pakistan. The formation is exposed in the southern flank of the Shahbazgarh syncline. The Shahbazgarh structure is doubly plunging syncline; southern flank of the syncline is east-west trending and is gently dipping. Detailed field observation manifested that the Nagri Formation is widely exposed in most of the southern part of this syncline. The study area lies in the Kohat quadrangle and forms a part of the southern Kohat plateau (Fig. 1). The Shahbazgarh area is located at about 25 km NE of Karak town, about 65 km south of Kohat city and lies within the longitudes 71° 11′E to 71° 15′E and Latitudes 33° 12′N to 33° 15′N (Survey of Pakistan Toposheet No. 38 O/4). Indus Highway is the main and easy access to the study area.

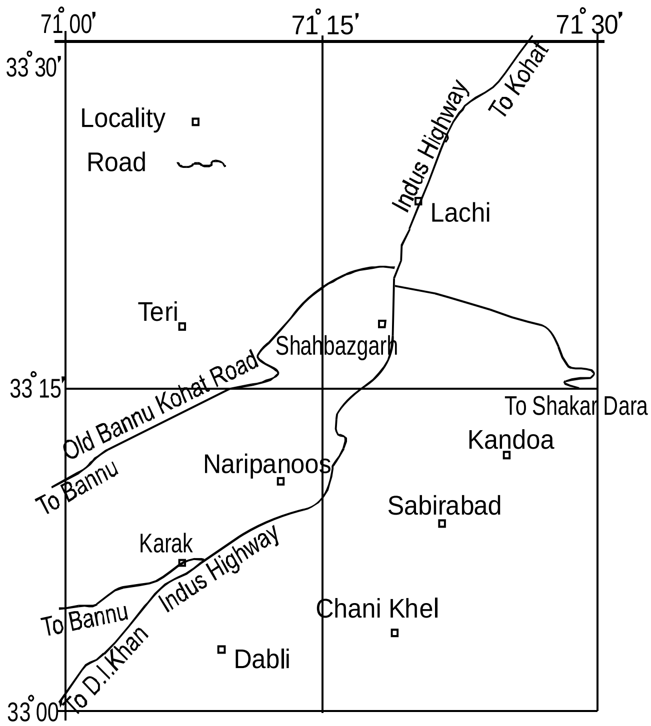

Fig. 1. The location of Shahbazgarh area, southern Kohat Plateau, sub Himalayas, Pakistan.

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Literature survey reveals that no research on the paleocurrent analysis of sandstone of the early Pliocene Nagri formation has been undertaken so far in the study area. The present study is, therefore, first of its kind in this area.

Wynne (1875) investigated the Kohat Plateau and gave its generalized geological account. Davies (1926) worked on the homotaxial position of the salt marl of Bahadur Khel along with notes on the geology of Kohat. Gee (1945) investigated the age of saline series of the Punjab and Kohat (salt range formation from Salt Range, the Punjab and Bahadur Khel salt from Kohat, NWFP, respectively). Eames (1952) worked on the geology of standard sections of Kohat area along with western Punjab. Lithostratigraphy of the Kohat Plateau was narrated by Fatmi (1973) in the description of lithostratigraphy units of Kohat-potwar province. Meissner, *et al.* (1974) investigated the area thoroughly and gave a detailed account of stratigraphy of the Kohat Quadrangle including the southern Kohat plateau, hosting the study area. Rehman *et al.* (1982) worked on the regional geology of the Karak Quadrangle covering its structure and tectonics. A sedimentological research assignment was carried out in the southern Kohat plateau by Wells (1984). Pivnik and Sercombe (1993) studied the deformational features developed due to transpression and compression. Ali *et al.* (2000) studied the imprints of transpressional deformation in the southern Kohat plateau.

The literature survey reveals that no research work has been conducted on the paleostreasm orientation and paleoflow patterns. The present research work was carried out in the study area for the first time on the paleostream orientation and on its paleocurrent to analyze the direction of flow of paleo channel.

Materials and Methods

The paleocurrent analysis is a standard method for the determination of paleoflow direction and paleoflow orientation of paleostreams and paleorivers within an ancient drainage basin (Tucker, 1988). The sediment transport and depositional features like sedimentary structures, are important tools to carry out the paleocurrent analysis. These sedimentary structures are indicators of the direction of flow and/or orientation at any geographic entity in geologic time, for which the populations of sedimentary structures are treated statistically in a systematic way. These newly generated data sets can provide main paleoflow current directions in the geographic region of interest during targeted period of time. The sedimentary structures like asymmetric ripples and through cross-bedding, are important tools to decipher paleo-flow information about the down flow direction while tool marks e.g. skips marks, groves casts, and prod marks, provide information about the paleocurrents (Tucker, 1988).

The first step in the paleocurrent analysis is to execute fieldwork for the collection of field data regarding any suitable sedimentary structure, like cross bedding, from the area of interest. The field data includes the dip and strike measurements of the appropriate sedimentary structure with the use of Brunton compass. The structures, which point out down stream flow, are measured to record the down current direction and those structures, which provide only stream orientation, their bearing (such that, the trend expressed as so many degrees from north towards east or west) is taken for all available structures within the area of investigation. All these data are recorded in field notebooks. This field data is exploited to plot a "rose diagram" (Tucker, 1988). The methodology used in this research work is described in the following:

1. The field data includes the dip and strike measurements of an appropriate sedimentary structure with the use of Brunton compass.
2. As sedimentary structure cross bedding points out downstream flow, therefore, these are measured to record the down current direction.
3. Cross bedding measurements are made in the well-exposed cross bedded sandstones.
4. The down current data on cross bedding is tabulated.
5. Different classes based on appropriate ranges of cross bedding measurements are determined and by counting up, the number of measurements that fall in these classes are put in the frequency table.
6. The sum total of all of these frequencies is put in the total column.
7. Each frequency is divided by the total and the result is entered in the percentage of total column for each class.
8. These data are normalized to 100% for comparison of results of one set of measurements with an other one.
9. A rose diagram is drawn by plotting these dip and strike data of cross bedding.
10. The rose diagram is constructed by dividing a circle of an appropriate radius into 24 petals, while each petal represents 15 degrees of arc.
11. The length of each petal is drawn proportionate to the percentage of total given in the above mentioned table. For example, in the rose diagram of 10 cm radius the length of a petal representing 50% of the total would be 5 cm.
12. Normally in simple cases the direction of paleocurrent for a certain population of measurements is determined by the direction of the longest petal in the rose diagram. It is called the mode of the data set, which means there is only one direction of paleocurrent.
13. In case of more than one current direction the term bimodal current pattern is used, i.e., two directions of paleocurrent, while a polymodal pattern exhibits several

directions of paleocurrent. In this case none of the petals is clearly dominant.

14. The accuracy of paleocurrent determination depends upon two factors:
    i) The skill in measuring the dip and strike values of the cross beds.
    ii) The size of the population of these measurements, such that, the larger is the size of data, the more reliable is the determination of the paleocurrent.

The cross bedding of sandstone of the Nagri formation, which belongs to the Siwalik group of rocks, was studied for present research work. Its lower contact with Chinji formation is conformable and is found in the southern most part of the Shahbazgarh syncline. The sandstone beds are counted from this contact. These sandstone beds range in thickness from 3 to 500 feet (Fatmi, 1973). However, most of these sandstone beds are 50 to 100 feet thick (Shah, 1977). The sandstone bodies are internally composed of plane-bedding, low angle plane bedding, trough cross-bedding, both small and large scale bar macroforms and channel scour features. The sandstone bed chosen for the paleostream orientation and paleoflow patterns is fine to coarse grain and is cross bedded. This cross bedding is of wedge type (Fig. 2). This measured bed lies in the mid of southern part of the studied syncline.

Fig. 2. Field photograph; cross bedding in sandstone of the Pliocene Nagri formation, Shahbazgarh area, southern Kohat plateau, Sub Himalayas, Pakistan (Scale: geologic hammer).

Results and Discussion

A reconnaissance of the outcrop of the Nagri formation was conducted and the outcrop was surveyed using a Brunton compass and tape measure. One hundred dip and strike readings of cross beds were taken from the measured sandstone of the Nagri formation by following a traverse of one and a half kilometer along the strike of this formation in the southern most part of the Shahbazgarh syncline. These data were, also, processed to convert it into trigonometric values. These readings are shown in Table 1 and Table 2, respectively, whereas Table 3 shows frequency distribution of the corrected

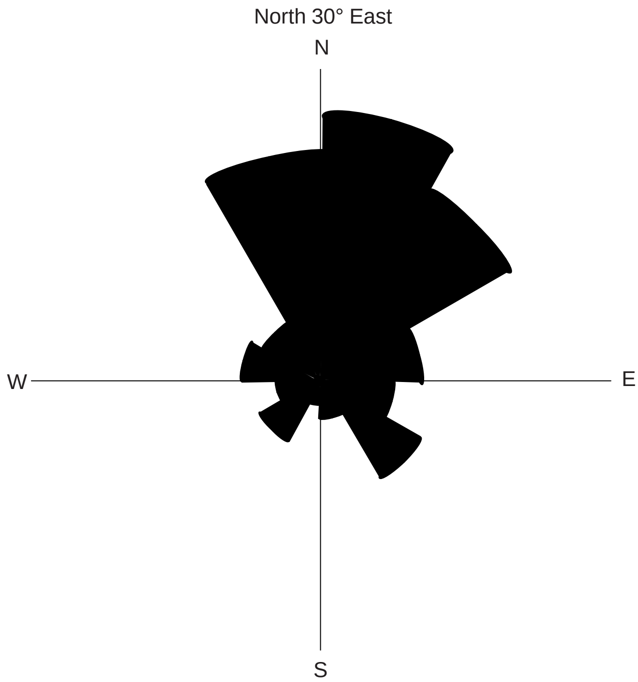

Fig. 3. Rose diagram indicating the mean direction of paleocurrents in the study area.

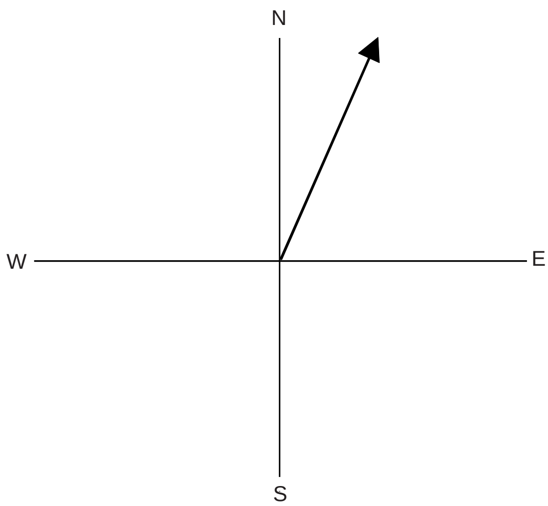

Fig. 4. Vector diagram indicating the mean flow direction of paleocurrents in the study area.

Table 1. Paleocurrent readings collected from the study area
Strike of main bed N70° E, **Dip** of main bed 26°NW

No. of readings	Strike	Dip	Corrected readings Bearing and Dip
01	325°	33° NW	308°/12° NW
02	351°	44° NW	358°/16° NW
03	345°	44° NW	353°/19° NW
04	347°	35° NW	358°/09° NW
05	345°	33° NW	359°/07° NW
06	276°	21° SW	211°/22° SW
07	340°	42° NW	344°/17° NW
08	09°	35° NE	52°/17° NE
09	2°	36° NE	44°/24° NE
10	357°	42° NW	15°/19° NE
11	342°	39° NW	344°/13° NW
12	05°	37° NE	41°/17° NE
13	296°	28° NW	237°/20° SE
14	308°	27° NW	221°/30° SW
15	329°	36° NW	306°/11° NW
16	354°	26° NW	63°/07° NE
17	315°	22° NW	218°/12° SW
18	354°	34° NW	25°/11° NE
19	350°	39° NW	06°/14° NE
20	347°	36° NW	359°/11° NW
21	334°	26° NW	274°/03° NW
22	347°	49° NW	353°/23° NW
23	344°	28° NW	20°/03°NE
24	354°	30° NW	39°/09° NE
25	356°	22° NW	79°/06° NE
26	349°	23° NW	97°/07° NE
27	355°	28° NW	119°/08° SE
28	16°	27° NE	79°/16° NE
29	06°	45° NE	30°/24° NE
30	05°	35° NE	47°/16° NE
31	05°	30° NE	52°/13° NE
32	03°	28° NE	71°/10° NE
33	13°	19° NE	109°/13° SE
34	354°	21° NW	100°/10° SE
35	353°	18° NW	129°/09° SE
36	19°	24° NE	85°/16° NE
37	02°	26° NE	73°/10° NE
38	343°	20° NW	136°/06° SE
39	344°	29° NW	04°/04° NE
40	354°	11° NW	139°/16° SE
41	349°	06° NW	145°/20° SE
42	334°	06° NW	146°/20° SE
43	271°	15° NW	196°/22° SW
44	348°	10° NW	153°/15° SE
45	355°	10° NW	127°/10° SE
46	344°	19° NW	131°/08° SE
47	06°	15° NE	128°/12° SE
48	346°	20° NW	145°/07° SE

(Cont'd .....)

(Table 1 cont'd .....)

No. of readings	Strike	Dip	Corrected readings Bearing and Dip
49	351°	17° NW	149°/10° SE
50	354°	19° NW	132°/09° SE
51	02°	24° NE	95°/10° SE
52	350°	22° NW	113°/06° SE
53	354°	44° NW	10°/19° NE
54	355°	38° NW	22°/14° NE
55	21°	29° NE	87°/18° NE
56	19°	32° NE	70°/20° NE
57	338°	42° NW	331°/13° NW
58	354°	41° NW	13°/17° NE
59	350°	40° NW	06°/15° NE
60	354°	48° NW	03°/23° NE
61	353°	31° NW	33°/09° NE
62	03°	31° NE	56°/12° NE
63	351°	33° NW	28°/09° NE
64	343°	35° NW	345°/10° NW
65	342°	11° NW	156°/14° SE
66	341°	39° NW	344°/13° NW
67	341°	42° NW	343°/16° NW
68	01°	36° NE	33°/16° NE
69	03°	34° NE	46°/16° NE
70	359°	35° NW	35°/12° NE
71	356°	31° NW	25°/14° NE
72	08°	37° NE	48°/19° NE
73	10°	34° NE	56°/18° NE
74	338°	33° NW	335°/09° NW
75	348°	34° NW	13°/10° NE
76	356°	32° NW	44°/09° NE
77	347°	39° NW	01°/14° NE
78	341°	36° NW	269°/18° SW
79	15°	38° NE	52°/22° NE
81	342°	42° NW	347°/16° NW
82	342°	41° NW	344°/15° NW
83	15°	33° NW	62°/19° NE
84	350°	35° NW	12°/10° NE
85	04°	36° NE	36°/17° NE
86	05°	35° NE	46°/18° NE
87	356°	39° NW	22/°15° NE
88	348°	41° NW	358°/15° NW
89	358°	39° NW	24°/17° NE
90	330°	34° NW	311°/09° NW
91	326°	29° NW	271°/07° SW
92	304°	29° NW	244°/16° SW
93	332°	29° NW	292°/05° NW
94	325°	29° NW	277°/07° NW
95	347°	36° NW	01°/11° NW
96	344°	36° NW	351°/10° NW
97	328°	33° NW	399°/09° NW
98	334°	45° NW	326°/19° NW
99	325°	29° NW	277°/07° NW
100	05°	37° NE	41°/17° NE

Table 2. Trigonometric readings used for paleocurrent determination

No.	Sin θ	Cos θ
1	-0.7880	0.6156
2	-0.0340	0.999
3	-0.1218	0.9925
4	-0.0348	0.999
5	-0.0174	0.9998
6	-0.5150	-0.8571
7	-0.2756	0.96126
8	0.7880	0.6156
9	0.6946	0.7193
10	0.2588	0.9659
11	-0.2756	0.96126
12	0.6560	0.7547
13	-0.8386	-0.5446
14	-0.6560	-0.7547
15	-0.8090	0.5877
16	0.8910	0.4539
17	-0.6156	-0.7880
18	0.4226	0.9063
19	0.1045	0.9945
20	-0.0174	0.9998
21	-0.9975	0.0697
22	-0.1218	0.9925
23	0.3420	0.9396
24	0.6293	0.7771
25	0.9816	0.1908
26	0.9925	-0.1218
27	0.8746	-0.4848
28	0.9816	0.1908
29	0.5	0.866
30	0.7313	0.6819
31	0.7880	0.6156
32	0.9455	0.3255
33	0.9455	-0.3255
34	0.9848	-0.1736
35	0.7771	-0.6293
36	0.9961	0.0871
37	0.9563	0.2923
38	0.6946	-0.7193
39	0.0697	0.9975
40	0.6560	-0.7547
41	0.5735	-0.8191
42	0.5591	-0.8290
43	-0.2756	-0.9612
44	0.4539	-0.8910
45	0.7986	-0.6018
46	0.7547	-0.6560
47	0.7880	-0.6156
48	0.5735	-0.8191
49	0.5150	-0.8571
50	0.7431	-0.6691
51	0.9961	-0.0871
52	0.9205	-0.3907
53	0.1736	0.9848
55	0.9986	0.0543
56	0.9396	0.3420
57	-0.4848	0.8746
58	0.2249	0.9743
59	0.1045	0.9945
60	0.0543	0.9986
61	0.5546	0.8386
62	0.8290	0.5591
63	0.4694	0.8829
64	-0.2588	0.9659
65	0.4067	-0.9135
66	-0.2756	0.9612
67	-0.2923	0.9563
68	0.5446	0.8386
69	0.7193	0.6946
70	0.5735	0.8191
71	0.4226	0.9063
72	0.7431	0.6691
73	0.8290	0.5591
75	0.2249	0.9743
76	0.6946	0.7193
77	0.0174	0.9998
78	-0.9998	-0.0174
79	0.7880	0.6156
80	-0.0348	0.9993
81	-0.2249	0.9743
82	-0.2756	0.9612
83	0.8829	0.4694
84	0.2079	0.9781
85	0.5877	0.8090
86	0.7193	0.6946
87	0.3746	0.9271
88	-0.0348	0.9993
89	0.4067	0.9135
90	-0.7547	0.66560
91	-0.9998	0.0174
92	-0.8987	-0.4383
93	-0.9271	0.3746
94	-0.9925	0.1218
95	0.0174	0.9998
96	-0.1564	0.9876
97	-0.8746	0.4848
98	-5591	0.8290

values. Analytical procedures were carried out on the newly generated data on dip and strike. The cross beds measurements were plotted and analyzed using the techniques described by Tucker (1988). These data were exploited to draw the rose and vector diagrams (Fig. 3 and 4) to plot the counts of each observation for understanding general current flow at the time of deposition of this formation in the studied location.

Conversion of data to trigonometric values was made so that the trigonometric method could be applied to it (Table 4). All these techniques contributed to determine the direction of paleocurrents of the paleostreams present in the study area in the Early Pliocene age. All these standard analytical procedures (Tucker, 1988) indicated that at this location and time (10 mya), the paleocurrent of the paleostreams in the investigated area was flowing N 30° E (Table 4).

The Nagri formation in the study area consists of alternative beds of sandstone and clay. The sandstone is predominant in almost 3:1 sand/clay ratio (Shah, 1977). This formation is widely exposed in the southern and southern most part of the Shahbazgarh syncline. The southern flank of this syncline is east-west trending and is gently dipping. The dip and strike readings of cross beds were taken from the sandstone along the strike by following a traverse of one and a half kilometer in the southern most part of the Shahbazgarh syncline.

Table 3. Frequency distribution of corrected values

No.	Classes	Frequency	Values (%)
01	01°-30°	22	22
02	31°-60°	17	17
03	61°-90°	08	08
04	91°-120°	06	06
05	121°-150°	11	11
06	151°-180°	02	02
07	181°-210°	01	01
08	211°-240°	04	04
09	241°-270°	02	02
10	271°-300°	05	05
11	301°-330°	04	04
12	331°-360°	18	18
		$\sum f = 100$	

Table 4. Result of the trigonometric method

$$\sum \text{Sin}\,\theta = 23.337°$$
$$\sum \text{Cos}\,\theta = 38.8188°$$
$$\text{Tan} = \sum \text{Sin} / \sum \text{Cos}\,\theta = 23.337° / 38.8188°$$
$$\text{Tan} = 0.6011°$$
$$\theta = \text{Tan-1}[.06011°]$$
$$\theta = (30.00170°)$$

The result shows the flow of paleocurrents in the direction of N 30° E.

The paleoposition of the Indo-Pakistani Plate during Pliocene age was in NE orientation while at the same time an accelerated uplift of Himalayas, NW Pakistan was taking place (Powell, 1979). The catchment area of the Paleo Nagri river and its contributory streams was lying in the swiftly rising Himalayas at that time. So the probable source of sediments (i.e. sandstones with characteristic cross beds and clay) of the Nagri formation in the study area is thought to be the Himalayan hinterland with its fluviatile sedimentary environment of deposition.

Conclusion

On the bases of analysis of data and its graphical presentation, the following conclusions ensued as the back drop of this research investigation:

The paleocurrent analysis indicates N30^{0}E direction of paleoflow of paleostreams in the investigated area which coincides with the NE paleoposition of Indo-Pakistani plate at the time of deposition of Nagri sediments in early Pliocene age.

The probable source of sediments of the Nagri formation in the study area was the Himalayan hinterland as during the early Pliocene age, an accelerated uplift of Himalayas was taking place. Therefore, water in the paleostreams flowed out of the Himalayan mountains and followed this direction.
The sediments were being transported through paleostreams flowing in the NE-SW orientation in the area, under study.

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