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Mineral Composition and the Provenance of the Sediments of Thar Coal Basin

R. M. ABDALLAH[1], M. A. A. BAIG[2], A. R. ABRO[2], AHMAD SAGHIR[3], M. A. PATHAN[2] & M. R. AHMED[2]

[1]Ministry of Municipal Affairs & Agriculture Govt. Sand Processing Plant, Civil Engineering Department, Doha, Qatar.

[2]Department of Geology, University of Sindh, Jamshoro, Pakistan.

[3]Pakistan Council of Scientific and Industrial Research Labs. Complex, Karachi, Pakistan.

ABSTRACT: *Ten core samples of two bore-holes from the Tharparker coal basin were investigated for their mineral composition, depositional environments, origin of the mineral phases and the provenance of the studied sediments. X-ray diffraction of the whole-rock and the clay fraction (<2μ) indicated that the samples are composed of detrital components dominated by quartz and Total clays. However, feldspar, biotite and siderite, have shown their presence by very weak XRD peaks in restricted samples.*

The X-ray diffraction of the clay fraction indicated that well crystalline kaolinite is present in samples of both the boreholes. Appreciable amount of Illite and Mixed-layer clays are present in STP-13 samples, whereas, chlorite has shown its presence only in one sample of STP-13. All the samples of STP-11 borehole indicated the presence of appreciable amount of chlorite and negligible amount of mixed-layer clays.

The clay mineral species appear to be detrital in origin, they might have been produced by the weathering of the source rock, having abundant amounts of minerals e.g. quartz, feldspar and Mg-rich silicates.

The presence of well crystalline kaolinite and chlorite in STP-11 borehole samples suggest that the provenance of these sediments was in igneous/metamorphic rocks. The abundance of illite and Mixed-layer clays in STP-13 sediments, strongly suggest contribution of meta-sediments from the source area, a separate provenance, located most probably to the east of the site of this borehole.

The dominant abundance of the detrital components i.e. quartz, kaolinite and total clays, suggest a near-shore deposition of these sediments, under reducing conditions which is indicated by the presence of mineral siderite and the deposits of coal.

INTRODUCTION

The discovery of huge deposits of good quality coal in the thick sequence of fine-grained sediments, composed of clays and other minor lithological units in the Tharparkar coal basin, motivated the present authors to investigate these sediments for their mineral composition in the whole-rock as well as in clay fraction (< 2μ), to gain some insight into the environments of deposition, origin of the minerals and the provenance of the investigated sediments.

The present study can be claimed as the first of its nature. No reference regarding the mineralogy of the sediments of Tharparkar area was available to authors.

GENERAL INFORMATION

A brief account of the geology and stratigraphy of the Thar coal basin, is summarized here.

The Tharparkar area is covered by thick sand dunes. Outcrops are absent, particularly in the area, of present investigation. The only exposed outcrop is that of the "Red Granite", which is exposed in the Nagar Parker area.

Available information regarding the geology of the area, was very limited as already mentioned. The only available published information was those by Ahmed and Zaigham (1993), and Fassette and Durrani (1994). According to these authors, there exists a thick sequence of (4000 meters) sedimentary rocks, ranging in age from Triassic to Post Eocene periods. The stratigraphic sequence in both the boreholes is essentially the same which is illustrated by Fig.1.

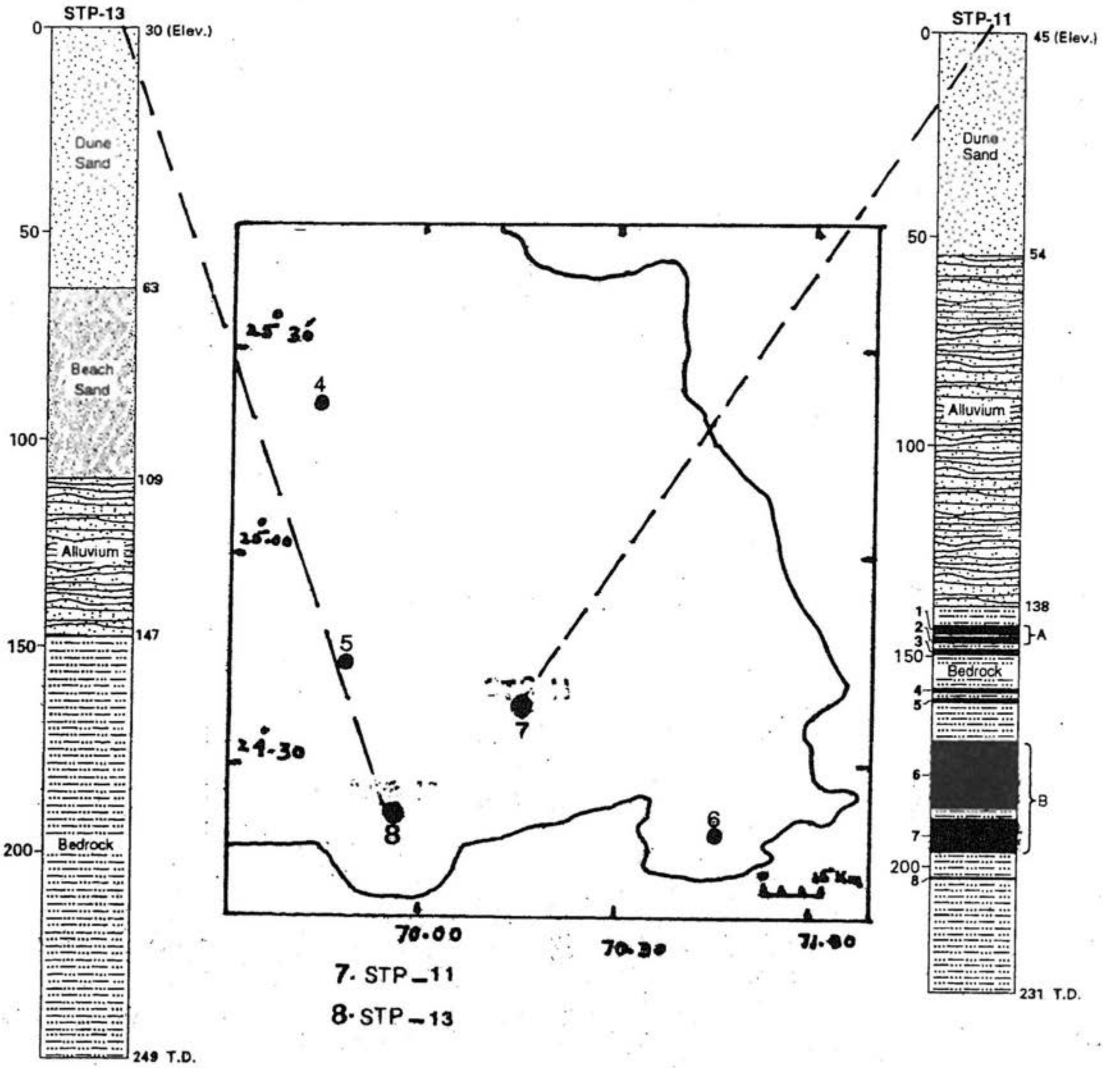

Fig. 1. Location and the stratigraphic columns of the STP-II and STP-13, boreholes, in the Thar Coal basin, Tharparker, Sindh, Pakistan. (After Fassett and Durrani, 1994).
4- Umer Kot; 5- Mithi; 6- Nagar Parker

MATERIAL AND METHODS

Ten core samples, five from each borehole i.e. STP-11 (latitude: 24.73°-91 N and longitude: 15.4° E) and STP-13 (latitude: 4.23°-31 N and longitude: 69° - 55 - 59 E) representing the complete succession in both boreholes, were selected from the core samples obtained from the Core Museum of the Geological Survey of Pakistan. The depth of both boreholes and the position on of each sample is shown in Table 1.

TABLE 1. TOTAL DEPTH OF CORE SAMPLES OF THE STP-11 AND STP-13, BOREHOLES, THARPARKAR COAL BASIN

STP-11 Core samples (Meters)	STP-13 Core samples (Meters)
145.50	156.27
164.00	165.81
186.05	174.96
200.25	194.80
220.00	210.09

Drying and Crushing of Samples

Selected core samples were left for over-night in an oven at 110 °C temperature to remove the moisture content. A representative portion of each sample was ground by hand in an agate mortar and pestle for about 15 minutes, since mechanical grinding destroys the lattices of clay minerals, therefore, it was avoided. This powder was used for the analysis of non-clay minerals in the whole-rock as well as the separation of clay fraction (<2μ), for determining clay mineral species present in the studied sediments. X-ray diffraction technique, described by Klug and Allexander (1974), was used for the identification of clay and non-clay minerals.

Sample Preparation For X-Ray Diffraction

Samples of the whole-rock and clay fraction were prepared according to the method described by Brindley and Brown (1980), Klug and Allexander (1974), Cosgrove (1972), Baig (1982) and Baqri (1979-80).

X-Ray Diffractometry

Klug and Allexander (1974), have described that X-ray diffraction technique for fine-grained sedimentary rocks. Siemens D-5000 X-ray diffractometer, operating at 40 kV and 20 mA using Ni-filtered CuK radiation, was used for analye.

Following XRD settings were used:

XRD Settings:	Random Powder:	Clay fraction:
Scanning range:	2° - 65° (2q)	2°- 36° (2q)
Time constant:	1 second	4 seconds
Step size:	0.050 degrees	0.050 degrees

Random Powder Mineral Analysis

The whole-rock powder of each sample, randomly loaded, in a specially prepared powder holder was scanned from 2°, 2θ65°, 2θ, on the X-ray diffractometer, according to the settings shown above. Klug and Allexander (1974), have mentioned that all minerals which are present in sediments in appreciable amounts, indicate their strong peaks on the X-ray diffractogram within the above mentioned range. Minerals, in the whole-rock and in clay fraction were identified on the basis of the recognition of diagnostic d-spacings, mentioned by Brindley and Brown (1980), Cosgrove (1974) and Baig (1984). The whole-rock samples on X-ray diffraction, indicated the presence of quartz and kaolinite, total clays and siderite, as the main minerals. Description of each mineral is given below. Diagnostic d-spacing used for the identification of non-clay minerals are shown in Table 2.

TABLE 2. DIAGNOSTIC DIFFRACTION LINES OF NON-CLAY MINERALS, IDENTIFIED IN THE SAMPLES OF STP-11 AND STP-13 BOREHOLES, THARPARKAR COAL BASIN

Minerals	Peak Position in degrees (2θ) Angle	D-space Values (A^0)
Quartz:	26.66, 2θ	3.34 A^0
	20.85, 2θ	4.26 A^0
	50.20, 2θ	1.82 A^0
Siderite:	24.90, 2θ	3.59 A^0
	38.40, 2θ	3.35 A^0
Feldspar:	30.3, 2θ	2.95 A^0
	30.6, 2θ	2.92 A^0
Biotite:	33.69, 2θ	2.66 A^0
	33.95, 2θ	2.64 A^0
Kaolinite:	12.41, 2θ	·7.14 A^0
	20.36, 2θ	4.36 A^0
Total Clays:	19.90, 2θ	4.45 A^0

a) Quartz: Mineral quartz, showed its occurrence in the samples of both boreholes, by its diagnostic d-spacings at 3.34 A° (26.6°, 2θ) and 4.26 A° (20.85°, 2θ). Microscopic examination of the coarser fraction of the studied sediments indicated that quartz occurs as fine grains which are well rounded, suggesting that it has experienced many cycles of erosion and deposition and have travelled over a long distance. The abundant amount of quartz in these sediments indicates either a near shore type of deposition (Ronov, et.al, 1956), or abundant supply of quartz from the provenance during the deposition of these sediments.

b) Feldspar: Feldspar, indicated its presence by its diagnostic d-spacings at 2.95 A° (30.3°, 2θ) and 2.29 A° (30.6°, 2θ). Peaks on the X-ray diffractograms, were not strong, indicating a small amount of feldspar in the studied sediments.

c) Biotite: Biotite was recognized by its d-spacing at 2.66 A° (33.69°, 2θ) and 2.64 A° (33.95° ,2θ). Very weak XRD peaks for Biotite suggest that Bioite in the studied samples is present in very small amount.

d) Kaolinite: Kaolinite, though a clay mineral, but being coarser in size compared to other clay minerals, it indicates its peaks in the whole-rock samples on the X-ray diffractograms, especially when present in sufficient amount. Kaolinite was identified by its characteristic d-spacing at 7.14 A° (12.41°, 2θ) on the X-ray diffractogram.

e) Total Clays: Total Clays (Kaolinite + Illite + Chlorite + Mixed-layers) were identified by its peak at 4.45 A° (19.90°, 2θ) on the X-ray diffractograms. Baig (1984), and Cosgrove (1972), identified Total clays at this d-spacing. Considerable amount of clay fraction in the sediments of both the boreholes indicated the fluctuating condition of the depositional environments of the Thar coal basin.

f) Siderite: Siderite, a non-detrital mineral, showed its presence by its d-spacing at 3.59 A° (24.9°, 2θ) and 3.35 A° (38.4°, 2θ) on the X-ray diffractograms. Siderite, was found only in STP-11 borehole samples. This can be justified by considering the higher amount of Fe_2O_3 (2.55%) reported by the authors in these sediments in another publication.

Clay Fraction Mineral Analysis

Clay fraction (<2μ grain size) of each sample was separated from the whole-rock powder, following the conventional methods of sedimentation. Four, oriented slides were prepared as described by Brindly and Brown (1980), Moore (1985), Baig (1984), and Baqri(1979-80). One oriented slide marked (G) was given glycolation treatment for one hour at 60° C., the second slide marked (H) was given heat treatment for two hours in a Muffle furnace at 550° C, the third slide marked (N) is untreated. Because Kaolinite and Chlorite both occur in the studied sediments, therefore, a fourth slide marked (AD) was prepared from the clay fraction slury, boiled in 1:1 HCl for about 15 minutes. Acid digestion treatment removes Chlorite from the sample and thus clear identification of Kaolinite becomes possible. All the four slides, of each sample, mentioned above, were scanned on the Siemens X-ray diffractometer D-5000, from 2°- 36°, 2θ, keeping the XRD settings as mentioned in Table 3.

TABLE 3. MINERAL OMPOSITION OF THE WHOLE-ROCK AND CLAY FRACTION SAMPLES OF THE STP-11 & STP-13 BOREHOLES, THARPARKAR COAL BASIN

Minerals in Whole-rock samples		Minerals in clay fraction samples	
STP-11 samples	STP-13 samples	STP-11 samples	STP-13 samples
Quartz	Quartz	Kaolinite	Kaolinite
Feldspar	Feldspar	Chlorite	Chlorite (Only one sample)
Siderite	Nil	Mixed-layers (M-C)	Mixed-layers (I-C) & (M-C)
Biotite	Biotite	Nil	
Kaolinite	Kaolinite		
Total Clays*	Total Clays		

* Total Clays= Kaolinite + Chlorite + Illite + Mixed-layers clays

The clay mineral species, present in the studied sediments, were identified on the recognition of their basal (001) reflections mentioned by Starkey et al (1984) and Brindley and Brown (1980). The X-ray diffractograms of both the borehole samples, indicated the presence of the following clay minerals. Figs. 2 and 3 show the diffractograms of the Clay fraction of STP-11 and STP-13 samples.

i) Kaolinite: Kaolinite was identified on the acid digested (AD) slide by its d-spacings at 7.14 A° (12.4°, 2θ) and 4.36 A° (20.36°, 2θ). Glycolated slide also showed the same reflections, but the heated slide (H), did not show any reflection for kaolinite at the d-spacings mentioned above, confirming the presence of Kaolinite. The sharp and strong peaks shown by the kaolinite, not only indicated that it is well crystalline, but also suggested that it occurs as a major constituent in the clay fraction. The well crystalline nature of kaolinite, according to Baqri (1978), may be the result of leaching. Table 4 shows the higher abundances of kaolinite in STP-11 samples. Abundant amount of kaolinite in the sediments of coal fields, has been reported by many workers. Baqri (1978), mentioned higher amount of kaolinite in the roof-shale samples from the Lakhra and Jhimpir coal fields in Sindh. Grim and Allen (1938) reported abundant amount of kaolinite in the under-clays of Illinois coal basin.

ii) Illite: Illite is totally absent in the samples of STP-11 borehole. Its presence in STP-13, samples, was indicated by its poor reflections at 9.99 A° (4.84°, 2θ). Poor reflection indicates degraded nature of Illite.

iii) Chlorite: Chlorite showed its presence in all the samples of STP-11 borehole, by its d-spacing at 14.24 A° (6.2°, 2θ) and 13.80 A° (6.4° ,2θ), on the heated (H) slide. Only one sample of STP-13 borehole indicated the presence of Chlorite. It is a well known fact that chlorite occurs in the igneous/ metamorphic rocks and when these rocks are weathered mechanically, mineral chlorite is released from the parent rock and is added to the detritus in the weathering profile. Chlorite, presently under discussion might have been added in the sediments according to the process mentioned above.

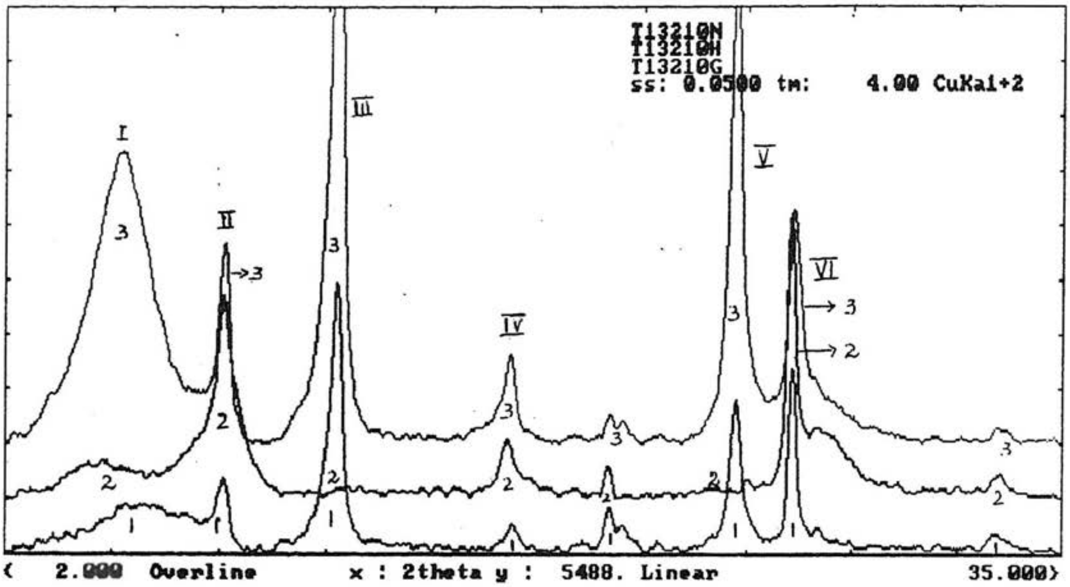

Fig. 2. X-ray Diffractogramme trace of the Clay fraction sample of STP-13 borehole, indicating the d-spacings after glycolation and heat treatments.

STP-13 (210)

I.	(1)	15.4A	(N)	M/L (Mont/Illite:)	IV	(1)	4.99A	(N)	Illite	Vi	(1)	3.35A	(N)	Illite
II.	(1)	10.0A	(N)	Illite		(2)	4.99A	(H)	"		(2)	3.35A	(H)	"
	(2)	10.0A	(H)	"		(3)	4.9A	(G)	"		(3)	3.35A	(G)	"
	(3)	10.0A	(G)	"	V.	(1)	3.5A	(N)	Kaolinite					
III	(1)	7.1A	(N)	Kaolinite		(2)	Nil	(H)	"					
	(2)	Nil	(H)	"		(3)	3.5A	(G)	"					
	(3)	7.1A	(G)	"										

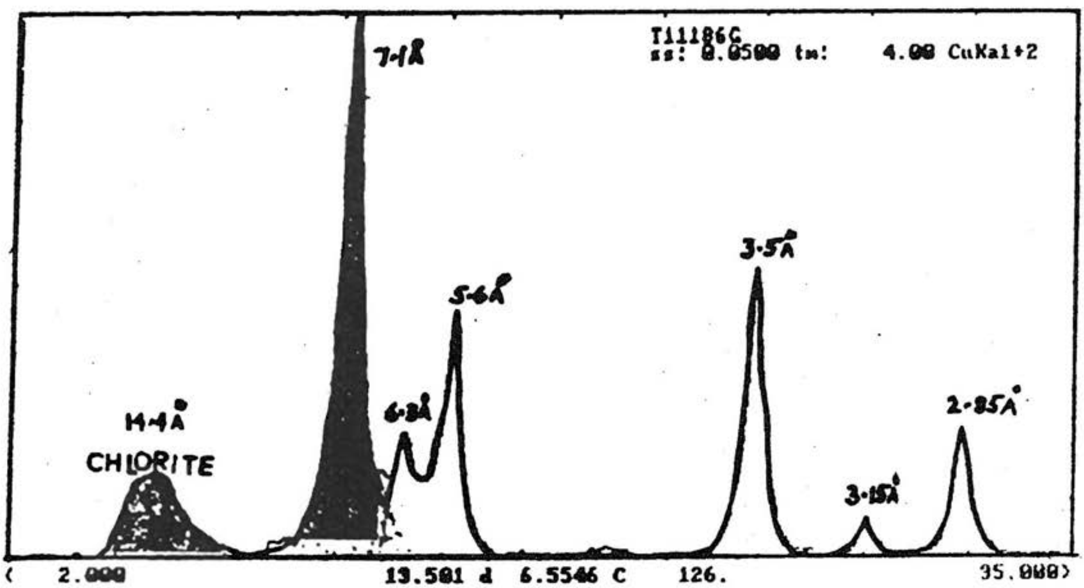

Fig. 3. X-ray Diffractogramme on Glycolated Slide of Sample 186 of STP-11. Borehole indicating the area covered by Kaolinite and Chlorite Peaks which is used for estimation of clay minerals.

iv) Mixed-Layers Clay Minerals: Mixed-layer clay minerals are composed of inter-stratified layers of two or more than two clay minerals. Mixed-layer clay minerals may be the mixture of Illite-Montmorillonite (I.M), Illite-Chlorite (I-C), and Montmorillonite-Chlorite (M-C). Mixed-layers Clay minerals are derived from the degradation of existing Clay minerals. Samples of both the boreholes indicated the presence of Mixed-layer clays on the glycolated (G) slides at 15.5 A° (5.7°, 2θ) and 13.59 A° (6.5°, 2θ) d-spacings. These d-spacings suggest that Mixed-layer Clay minerals belong to (I-M) and (M-C) inter-stratification. Glass (1958), mentioned more amount of Mixed-layer.

Clay minerals than Illite and Chlorite in the under-clays in coal basin. The samples of STP-13 in Table 4, indicated higher abundance of Mixed-layer clay minerals over Illite and Chlorite. Gradual decrease of Montmorillonite and increase of Mixed-layer clay minerals, with the increase of depth, has been reported by many workers. In the present study the abundant amount of Mixed-layers Clays in STP-13 borehole samples may be due to the reason mentioned above. It appears that Illite, Chlorite and Montmorillonite minerals, on their degradation, either in the Thar coal basin or elsewhere, produced the Mixed-layer Clays, present in the studied samples.

TABLE 4. CALCULATED ABUNDANCE OF CLAY MINERALS IDENTIFIED IN THE STP-11 AND STP-13 BOREHOLES SAMPLES FROM THARPARKAR COAL BASIN

STP-11 samples					STP-13 samples				
Sample No.	Kaolinite	Chlorite	Illite	Mixed - layers	Sample No.	Kaolinite	Chlorite	Illite	Mixed - layers
145	88%	07%	Nil	05%	156	63%	37%	Nil	Nil
165	90%	10%	Nil	Nil	165	26%	Nil	26%	48%
186	82%	10%	Nil	08%	174	45%	Nil	20%	35%
200	64%	30%	Nil	06%	194	44%	Nil	28%	28%
220	83%	12%	Nil	05%	210	48%	Nil	06%	46%

Semi-Quantitative Estimation of Clay Minerals

The abundance of clay minerals, was calculated following the method described by Matter (1974). Baig (1982), found this method satisfactory for the estimation of abundances of clay minerals in his study. In this method the peak areas of Smectite, Mixed-layer Clays, Chlorite, Illite and Kaolinite, were divided by 4,2,2,1 and 1 factors, respectively for knowing the abundances of these minerals. Table 4, shows the relative abundances of clay minerals estimated for the samples of both boreholes.

RESULTS AND DISCUSSION

It is clear from the Table 3 that whole-rock samples are composed mainly of detrital minerals including quartz, feldspar, biotite, kaolinite and total clays. Siderite is the only non-detrital mineral which showed its restricted presence only in the samples of STP-11 borehole. Absence of Siderite in the STP-13 borehole samples, may be either due to the absence, of iron-rich minerals in the provenance, which provide iron or the physico-chemical conditions of the depositional environments, Krauskopf (1979) explained the formation of iron carbonate minerals in the sedimentary basins. Salter (1964), reported the presence of abundant amount of siderite in the dirt-band of the British coals. Therefore, the presence of siderite in the STP-11 samples is not unusual. Abundant amount of quartz in association with kaolinite both coarse grained and detrial minerals, suggest that these sediments were deposited under shallow water condition.

The clay mineral composition of the two boreholes, shown in Table 4 clearly indicates that the detritus was supplied from two different provenances. Samples of STP-11, are mainly composed of well crystalline kaolinite and chlorite, indicating an igneous/metamorphic provenance, having abundant amount of feldspar, Mg-rich silicates and chlorite. It is well known that kaolinite is produced by the weathering of above mentioned rocks under acidic environments. The abundant amount of well crystalline kaolinite in the studied samples can be justified if the amounts of Kaolinite reported by Glass (1958) and Grim and Allen (1938), respectively, in the sediments and under-clays of the Illinois coal basin are taken into account. Baqri (1978) reported dominant amount of Kaolinite in the roof-shales of the Lakhra and Jhimpir coal fields in Sindh. The abundant amount of Kaolinite and complete absence of Illite in STP-11, samples may be due to the antipathetic relationship of the two minerals, observed and reported by other Clay Mineralogists. The abundant amount of Kaolinite also indicates the near-shore type of deposition of STP-11, sediments.

The samples of STP-13, showed higher amount of Mixed-layers Clays (M-C) and (I-C) over the amount of Illite. Increasing salinity in the depositional environments causes a gradual loss of Montmorillonite and encourages the formation of poorly crystalline Illite and Mixed-layers Clays. Glass (1958) also noticed higher amount of Mixed-layers Clays than the amount of Illite and Chlorite in the under-clays in contact with coal.

Chlorite, showed its presence as the second subordinate clay mineral with Kaolinite in STP-11, borehole samples. Chlorite bearing igneous/metamorphic rocks, on mechanical weathering, release Chlorite from the source rock and introduces it to the detritus. Also Mg-rich silicates on chemical weathering contributes Chlorite to the detritus. Presence of Chlorite in the samples of STP-11 borehole indicates that detritus was contributed mainly by the weathering of igneous/metamorphic rocks.

The variations shown by the detrital and non-detrital non-clay minerals and also the variation shown by the clay mineral species, strongly suggests that the detritus for STP-11 sediments was supplied by the igneous/metamorphic provenance, most probably the Granite complex exposed in the Nagar Parker area. The detritus for STP-13 borehole sediments, was contributed by the weathering of sedimentary or mete-sedimentary rocks, probably situated to the east of the STP-13 borehole site.

CONCLUSIONS

The above study may be concluded as under:

1. The whole-rock samples of both the boreholes are mainly composed of detrital components e.g. quartz, kaolinite, feldspar, and total clays.

2. Quartz grains are fine and well rounded indicating that it has experienced many cycles of sedimentation and erosion.

3. Siderite, is the only non-detrital mineral, it showed its restricted presence only in STP-11 samples.

4. The presence of Siderite, suggests that micro environments alternating to reducing and oxidizing conditions (Dunoyer- de-segonzac: 1969), were created in the sedimentary basin, as a result of the rapid rate of the deposition of detritus, abundantly

composed of coarser grains of components, such as quartz and kaolinite etc.

5. The clay fraction of STP-11 is mainly composed of Kaolinite and Chlorite, having a negligible amount of Mixed-layer Clays. This composition of clay minerals indicated an igneous/metamorphic provenance.

6. The clay fraction of STP-13 is dominantly composed of Kaolinite and Mixed-layer Clays and degraded Illite. This combination of minerals suggested a different provenance-a sedimentary/metasedimentary rocks for the sediments of this area.

7. Well crystalline Kaolinite in STP-11 borehole samples seems to have been produced by the weathering of Orthoclase feldspar, which was abundantly present in the 'Red granite', exposed in the Nagar Parker area.

8. Mixed-layers Clays are composed of Montmorillonite-Chlorite (M-C) and (I-C) interstratification.

9. The concentration of detrital minerals such as quartz, kaolinite, total clays etc. and siderite, a non-detrital mineral, strongly suggest that these sediments were deposited under shallow water and reducing condition.

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