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THE CLAY MINERAL STUDIES OF THE KHEWRA SANDSTONE EXPOSED AT KHEWRA, EASTERN SALT RANGE

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ABSTRACT

Detailed investigations were conducted to understand clay mineral composition of the Khewra Sandstone exposed at Khewra Gorge, Salt Range. Oriented clay mineral slides were prepared for X-ray analysis for less than 5 μ fraction. X-ray diffraction studies indicate that the dominant clay mineral in the formation is illite, along with subordinate mixed layer clays in the Khewra Sandstone. Experimental studies indicate that mixed layer clay is a random mixture of illite and chlorite of which the latter is the third dominant mineral. These investigations suggest that genetically both illite and chlorite are detrital in nature brought into the depositional basin by erosion of sedimentary and metamorphic source rocks. The origin of the random mixed layer clay mineral has been interpreted as diagenetic. The temperatures and pressures during burial diagenesis were not high enough to create regularity in the random mixture of illite and chlorite.

INTRODUCTION

The Khewra Sandstone exposed in Khewra Gorge, eastern Salt Range (Fig. 1) is about 159 m thick and overlies the Salt Range Formation of Precambrian to early Cambrian age, with some local disturbance. The Kussak Formation disconformably overlies the Khewra Sandstone. The disconformity is represented by a 2m thick bed of conglomerate. The Khewra Sandstone represents the lower most unit of the Cambrian rocks exposed in Salt Range. It can be observed in the eastern and central Salt Range but it is missing in the western Salt Range with the exception at Khan Zaman Nala. The Khewra Sandstone can be divided into three units on the basis of lithology and bedding characters, the lower unit or unit A is about 45 m thick and includes thin to medium bedded fine siltstone and shale with occasional beds of fine sandstone and lenticular carbonate beds. The middle unit or unit B is 95 m thick and is composed of medium to thick bedded fine sandstone, siltstone and minor shale. The upper unit or unit C is 29 m thick and includes massive bedded fine to medium grained sandstone with a conglomerate bed at the top.

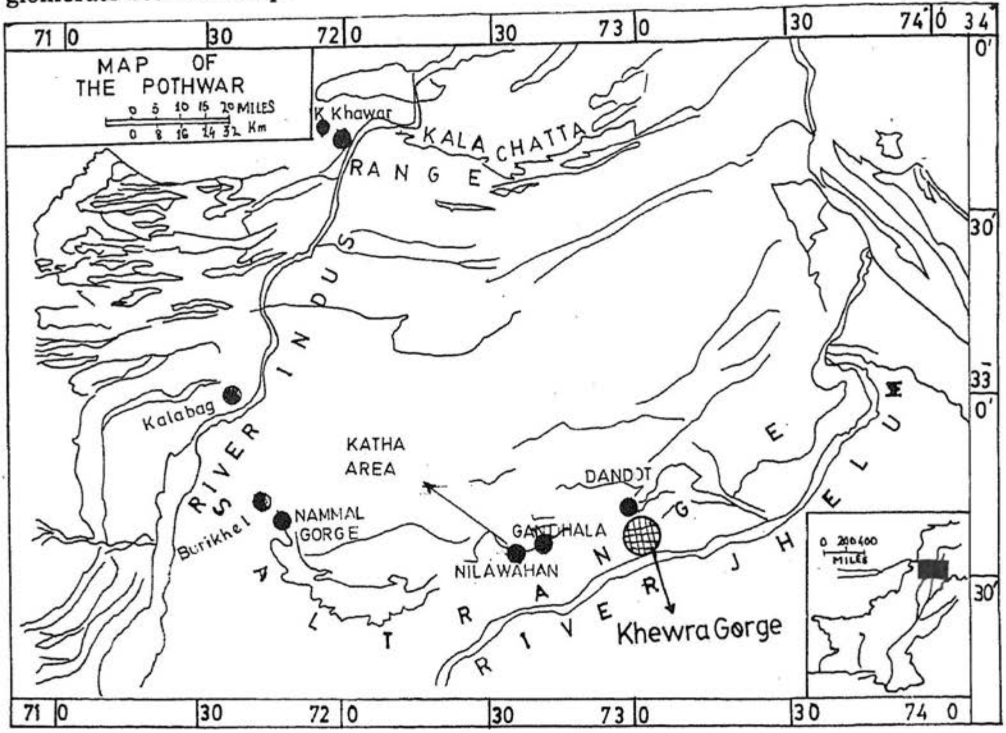

Fig. 1. Location map of the area.

Clay mineral composition of the Khewra Sandstone have not been studied to understand the nature of source rocks responsible for their deposition. Thus clay minerals of the Khewra Sandstone were studied to understand their distribution, mineral composition and genesis. Sixty five samples were collected for analyses from base to top of the formation in order to achieve the above mentioned objectives. These samples represent all lithological variations and lithological units of the formation. Table 1 provides lithological detailes of the samples with their position in the respective unit. Figure 2 gives lithological log and stratigraphic position of the samples.

METHODS OF INVESTIGATION

The samples were gently crushed to prepare a fine powder which was used for taking the random powder X-ray diffractograms of the whole samples. The oriented slides for clay mineral X-ray diffraction analysis were prepared by sedimenting the

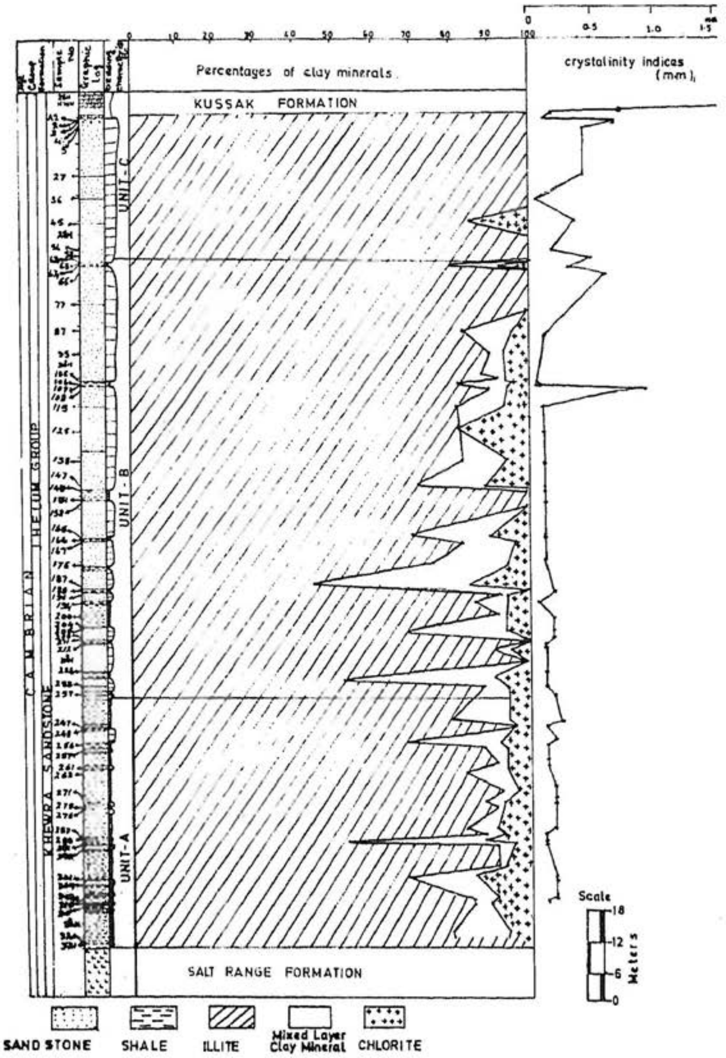

Fig. 2. Percentage of clay minerals in Khewra Sandstone and crystallinity indices of illite.

samples in de-ionized water for 35 minutes and obtained a fraction of less than 5 μ grain size. This fraction was taken on a glass slide and by evaporating the water, a thin clay mineral film was obtained on the glass slide. Four slides were prepared for each sample. The first slide was run for normal clay mineral analysis. The second slide was glycolated at 60° C for about an hour to find any expansion on glycolation. The third slide was heated for an hour at 550° C to know the effect of heat on different clay minerals and the interpretation of the X-ray diffractograms and the 4th was acid digested with dilute hydrochloric acid to understand the effect of acid on original clay minerals. Brown (1961) has given the detailes for preparation of clay mineral samples and the interpretation of the X-ray diffractograms for clay minerals composition. Baqri (1977, 1978) provided details for the semi-quantitative analysis of the clay minerals. The crystallinity index of illite was detected by measuring the width of illite peak at half height in mm observed at 10 A°. The crystallinity index is inversly proportional to the actual crystallinity.

RESULTS

Random powder analyses (general minerals)

Random powder data was obtained by running the fine powder on X- ray with scan range from 2 to 65 2θ. The random powder diffractograms provided the reflections of quartz, feldspar, calcite, dolomite, ankerite, heamatite, apatite, mica and chlorite (Fig. 4). The reflections of quartz and feldspar were observed in all samples, while the reflections of calcite, dolomite and ankerite were noted in a few samples and especially in the samples of carbonate nodules. Weak reflections of gypsum and halite were also observed. The apatite reflections were obtained only in a few samples. The mineral goethite reflections were also observed in the samples from the top of the formation. Figure 4 provides the random powder diffractogram of a representative sample in range from 19 to 34 2θ. The sharp reflections of quartz, feldspar, dolomite and calcite may be noted.

Oriented slide analyses (clay minerals)

The diffractograms of clay minerals were obtained by running the oriented slide to scan the range from 2 to 35 2θ to understand the behaviour of clay mineral reflections in the oriented slides. Figure 2 gives the distribution of clay minerals in the Khewra Sandstone with respect to lithology in unit A, B and C. Figs. 3a-g provide the nature of clay minerals in the Khewra Sandstone from base to the top, respectively.

The clay minerals did not give strong reflections in samples of unit C which could be due to the presence of small quantity of clays in unit C. Fig. 3a gives the nature of clay mineral reflections in the upper unit (Unit C). The mixed layer clay mineral was not observed in the unit with the exception of only one sample. The reflection of illite were noted in most of the samples. Sharp reflections of chlorite were observed in one sample while two samples gave poor reflections at the place of chlorite. This suggests that clay minerals in the upper unit are illitic clays with minor quantity of chlorite and mixed layer clay mineral. Reflections of clay minerals obtained by an oriented slaide of the Unit C from 5 to 32 2θ are given in Fig. 5 which shows prominent reflections of illite and chlorite. In addition to clay minerals the reflections of quartz, feldspar and dolomite may also be observed (Fig. 5). In unit C illite is 95.6%, the mixed layer clay mineral is 1.5% and chlorite is 2.9% (Table 1).

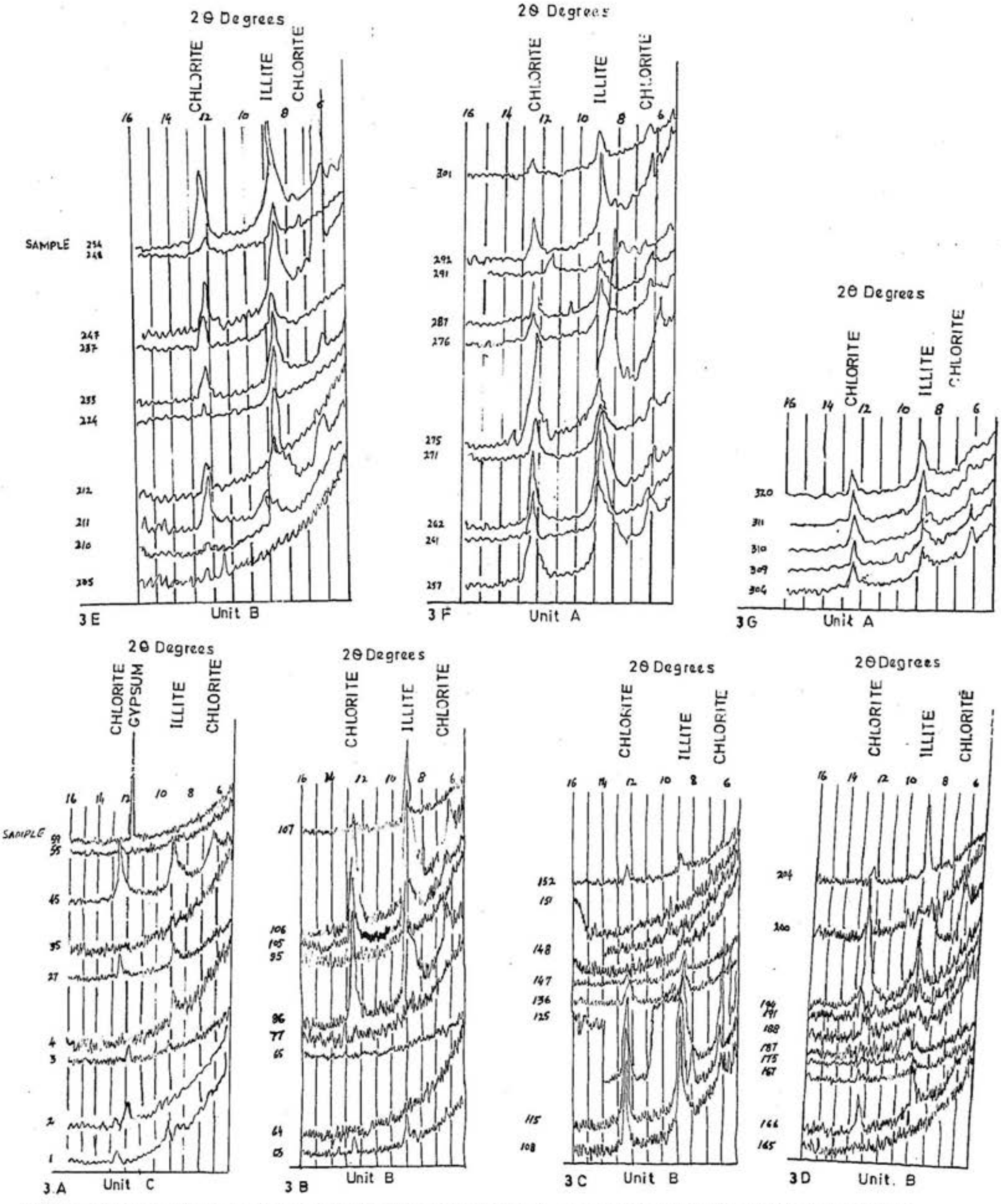

Fig. 3. Nature of clay mineral reflections in units A, B and C of the Khewra Sandstone.

Fig. 3 b-e provide the nature of clay mineral reflections from samples of the middle unit (unit B). The semi-quatitative analysis (Baqri, 1977) indicate that illite is dominant (~85.3%), the mixed layer clay mineral is the second dominant (average 9.6%) and chlorite is the least abundant mineral in middle unit (~5.1%) (Table 1). The mixed layer clay mineral appears to be a random mixture of illite and chlorite and mostly occurs as a long tail of the 10 A^{o} illite reflection towards low angle 2q. It did not show any expansion on glycolation but contracted on heating at 550^{o} C. The chlorite reflections were obtained at 14 A^{o}, which did not show much change on heating but

TABLE 1. THE LITHOLOGY OF SAMPLES, PERCENTAGE OF CLAY MINERALS AND THE CRYSTALLINITY INDICES OF ILLITE IN THE KHEWRA SANDSTONE.

Sample No.	Lithology	1	2	3	4
UNIT -C					
1	Sandstone	100	-	-	0.3
3	Sandstone	100	-	-	0.2
4	Sandstone	100	-	-	1.1
27	Sandstone	100	-	-	0.7
35	Sandstone	100	-	-	0.1
45	Sandstone	84.8	-	15.2	0.5
55	Sandstone	100	-	-	0.3
62	Sandstone	80.0	12.0	8.0	0.8
AVERAGE % OF UNIT-C		95.6	1.5	2.9	0.5
UNIT-B					
63	Shale	100	-	-	0.5
64	Carbonate	Poor diffraction pattern			
65	Sandstone	85.8	9.9	4.3	1
77	Sandstone	86.0	-	14.0	0.5
86	Sandstone	88.4	5.8	5.8	0.2
95	Sandstone	82.0	11.6	6.4	0.1
105	Sandstone	82.1	13.6	4.3	0.3
106	Shale	89.9	4.8	5.3	0.1
107	Shale	82.1	11.8	6.1	1.5
108	Sandstone	81.9	-	18.1	1.1
115	Sandstone	83.4	11.0	5.6	0.2
125	Sandstone	73.6	15.9	10.5	0.2
136	Sandstone	100	-	-	0.2
147	Sandstone	100	-	-	0.2
148	Shale	100	-	-	0.2
151	Shale	100	-	-	0.2
152	Shale	70.0	19.5	10.5	0.2
165	Sandstone/Carbonate		Poor diffraction pattern		
166	Shale	83.2	13.8	3.0	0.2
167	Sandstone	76.7	19.1	4.2	0.2
175	Shale	46.3	38.4	15.3	0.4
187	Sandstone	78.2	21.8	-	0.8

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Sample No.	Lithology	1	2	3	4
188	Shale	95.1	-	4.9	0.1
191	Sandstone	85.8	9.5	4.7	0.3
194	Shale	93.8	2.3	3.9	0.3
204	Shale	68.6	25.5	5.9	0.3
205	Sandstone	100	-	-	0.2
210	Sandstone	100	-	-	0.2
211	Shale	90.8	3.9	5.3	0.2
212	Shale	100	-	-	0.2
224	Sandstone	55.8	35.3	8.9	0.3
233	Sandstone	86.8	6.6	6.6	0.2
237	Shale	80.3	14.4	5.3	0.3
AVERAGE % OF UNIT-B		85.3	9.6	5.1	0.3
UNIT-A					
247	Sandstone	97.3	-	2.7	0.4
248	Shale	68.9	24.2	6.9	0.2
254	Shale	89.6	5.2	5.2	0.3
257	Sandstone	92.8	2.8	4.4	0.2
261	Sandstone	83.6	12.1	4.3	0.2
262	Shale	93.4	3.8	2.8	0.2
271	Shale	87.5	7.1	5.4	0.3
275	Shale	92.4	1.6	6.0	0.3
276	Sandstone	83.4	8.3	8.3	0.3
287	Shale	79.6	12.8	7.6	0.3
291	Shale	63.9	22.8	13.3	0.2
292	Sandstone	92.5	3.8	3.6	0.2
301	Shale	91.9	1.7	6.4	0.2
304	Sandstone	68.5	17.6	13.9	0.3
309	Shale	80.5	12.7	6.8	0.3
310	Sandstone	86.1	6.6	7.3	0.3
311	Shale	85.2	4.9	9.9	0.3
320	Shale	79.9	15.9	4.2	0.2
321	Shale	80.5	14.1	5.4	0.2
AVERAGE % OF UNIT-A		84.0	9.4	6.6	0.2
AVERAGE % OF THE KHEWRA SANDSTONE		88.4	6.8	4.8	0.3

1- Illite, 2- Mixed Layer Clay Mineral, 3- Chlorite, 4- Crystallinity of illite (mm) shifted its place on glycolation. It is likely that chlorite is expandable. It is also probable that illite has been degraded into a mixed layer clay mineral forming a mixture of illite and chlorite.

The lower unit (unit A) consists of mainly illite, chlorite and mixed layer clay mineral. Illite gave a reflection at about 9.98 A° which did not expand on glycolation but contracted on heating. Illite is the most abundant mineral in Unit A and is about 84.0% (Table 1). The mixed layer clay mineral appears as a long tail reflection of 10A° illite peak towards low angle 2θ. The mixed layer clay mineral appears to be random mixture of illite and chlorite and amounts to be about 9.4%. Chlorite gave its reflection at 14A° which did not expand on glycolation and increased in intensity on heating at 550° C. It reflects the contraction of some mixed layer clay mineral with chlorite. It is about 6.6%.

The crystallinity indices of illite peak at half height of the illite 10°A reflections were determined in all the samples. Table 1 gives the crystallinity indices of the representative samples of unit A, B and C and Fig. 2 displays the variations of crystallinity indices from the base to the top of the formation. The average crystallinity index of illite is 0.3 in the Khewra Sandstone. The average crystallinity indices in units A, B and C are 0.2, 0.3 and 0.5, respectively.

DISCUSSION

In Khewra Sandstone illite appears to be detrital in origin (Weaver & Pollard, 1973), transported into the depositional basin by the erosion of older sedimentary or metamorphic rocks. Weaver (1967) stated that much of the Paleozoic and Precambrian illite was formed on land rather than in ocean and it is most likely that illite of the Khewra Sandstone was transported from continents during Cambrian times. Dunoyer de Seganzac (1970) stated that most of the Paleozoic rocks especially shales and siltstones included the illite and chlorite. It is probable that illite in the sandstone has been converted into the mixed layer clay mineral due to addition of sodium and magnesium (Weaver, 1967; Weaver & Pollard, 1973). The presence of the sodium and magnesium ions has been indicated by the presence of salt and chlorite in different samples of the Khewra Sandstone. The salt pseudomorph structures have been observed in the sandstone exposed at Khewra Gorge and Nilawahan. The study for clay mineral in Paleozoic sediments have been conducted by several workers. Grim (1951) investigated the Paleozoic shales in Illinois and stated that illite is the dominant mineral. The same is concluded in present studies. Grim (1958) explained the changes during the diagenesis which vary with nature of the environment and kind of materials in particular environment. It is likely that the diagenesis has partly converted the well crystallized illite into a degraded illite in the presence of sodium ions, released from the associated minerals. It is concluded that illite in Khewra Sandstone is detrital in origin

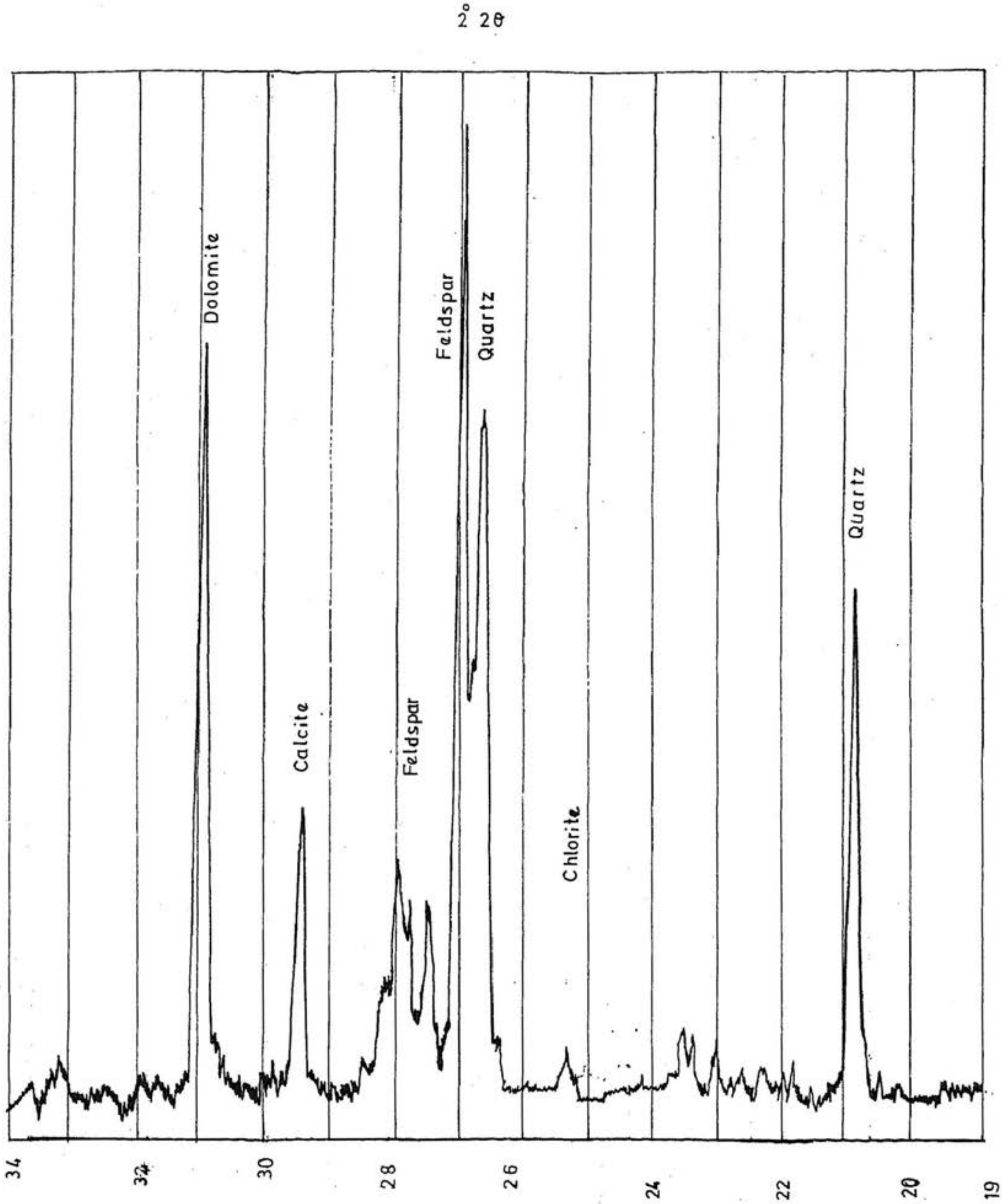

Fig. 4. The reflections of quartz, calcite, dolomite, feldspar and chlorite observed in the random powder of a representative sample (A-64).

and has been partly degraded into a random mixed layer clay mineral forming a mixture of illite and chlorite.

Chlorite was also concluded as a detrital mineral (Weaver & Pollard, 1973) deposited in the Cambrian basin during the deposition of Khewra Sandstone. The chlorite is a well known constituent of igneous rocks as altered product and as essential mineral assemblage of the metamorphic rocks (Deer et al., 1966) and mostly these minerals are transported into the depositional basin as a part of the sedimentary sequences. Mechanical weathering of the above stated chlorite bearing rocks may release chlorite and introduce it into the weathering profile.

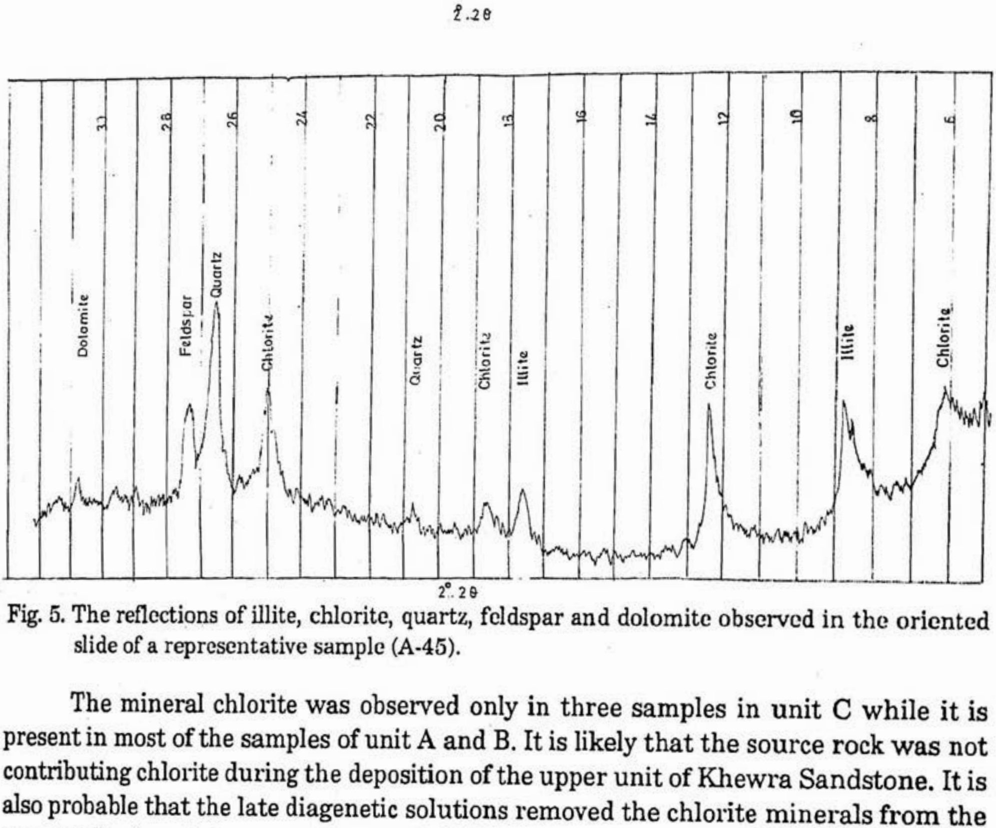

Fig. 5. The reflections of illite, chlorite, quartz, feldspar and dolomite observed in the oriented slide of a representative sample (A-45).

The mineral chlorite was observed only in three samples in unit C while it is present in most of the samples of unit A and B. It is likely that the source rock was not contributing chlorite during the deposition of the upper unit of Khewra Sandstone. It is also probable that the late diagenetic solutions removed the chlorite minerals from the upper unit of sandstone as this is highly porous zone indicating the free movement of fluids.

The mixed layer clay mineral appears to be a random mixture of illite and chlorite. Weaver (1956) stated that mixed layer clay mineral is derived from the degradation or aggradation from the pre-existing clay minerals. Burst (1959, 1969) found evidence of systematic diagenetic changes in clay minerals with depth in the subsurface samples of the Wilcox Formation (Grim, 1958). The mixed layer clay mineral probably originated diagenetically due to the degradation of illite and chlorite in the presence of sodium ions.

But in the absence of sodium ions in the upper unit, the mixed layer clay mineral was not formed from the degradation of illite. The absence of chlorite in most of the samples also indicates that the mixed layer clay mineral was also dependent on the chlorite mineral. It is also concluded that the temperatures were not high enough to create regularity in the mixed layer clay mineral as most of the samples are the random mixtures of illite and chlorite. Economically, the presence of random clay minerals is a valuable information as it indicates the burrial temperatures favourable for the presence of oil (Burst, 1959, 1969).

The crystallinity indices (inversly proportional in the present data) of illite mineral display significant variations from base to the top of the formation. The crystallinity indices of unit C are comparatively lower than the crystallinity of units A and B. This indicates that crystallinity of illite was destroyed due to its transportation from the source area through the rivers. Illite was weathered in a continental weathering profile and potasium ions were lost during the transportation through fresh water. The other reason for poor crystallinity could be the depletion of potasium ions in diagenetic waters. It is also likely that the circulating diagenetic waters in unit C destroyed the crystallinity of illite. This is indicated by the high porosity of unit C as compared to units A and B. It is most likely that unit A was deposited in waters with relatively more potasium ions. The difference in crystallinity indices of the three units indicates that units C and B were deposited in brackish waters with poor potasium ions. Generally brackish waters and fresh waters are poor in potasium ions (Weaver, 1967). It is further concluded that units B and C were deposited in deltaic conditions through fluvio-marine processes by the rosion of pre-existing rocks. It is probable that unit A was deposited in the delta front area where more fine grained clays were transported farther into the ocean. The area subsided due to the collapse of evaporites/carbonate platform and also due to volcanic activity. The evaporites/carbonates and the volcanic rocks are found in the Precambrian rocks just below the Khewra Sandstone.

CONCLUSION

The dominant clay mineral in the Khewra Sandstone is illite which averages to about 85.3%. The second dominant clay mineral is the mixed layer clay mineral and is the random mixture of illite and chlorite. The least abundant clay mineral is the chlorite clay mineral which is about 5.1%.

The random mixed layer clay mineral is a mixture of illite and chlorite and was originated from the illite and chlorite and may be called as a diagenetic clay mineral. The mixed layer clay mineral indicates favourable conditions for the preservation of oil.

The chlorite and illite clay minerals are detrital in nature, transported into the depositional basin due to erosion of the older sedimentary/metamorphic rocks.

It is likely that the Khewra Sandstone was deposited in fluvio- marine conditions.

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REFERENCES

Baqri, S.R.H., 1977. The mineralogy and chemistry of some coals and associated sediments from the South Wales coalfield. Unpub. Ph.D. Thesis, University of Southampton.

Baqri, S.R.H., 1978. The mineralogy and chemistry of refractory clay deposits from Lakhra and Jhampeer in Sind, Pakistan. Pak. Jour. Sci. Ind. Res., 21, 25-28.

Brown, G. (Ed.), 1961. X-ray identification and crystal structures of clay minerals. Min. Soc. London, 427.

Burst, J.F., 1959. Postdiagenetic clay mineral environmental relationship in the Gulf Coast Eocene. Proc. 6th Nat. Conf. Clay and Clay Mins., 327-341.

Burst, J.F., 1969. Diagenesis of Gulf Coast clayey sediments and its possible relation to petroleum migration. Bull. Am. Assoc. Petrol. Geol. 53, 73-93.

Deer, W.A., Howie, R.A. & Zussman, J., 1966. An Introduction to the Rock Forming Minerals. John Wiley & Sons, New York, 335pp.

Dunoyer de Segonzac, G., 1970. The transformation of clay miner als during diagenesis and low grade metamorphism: A review. Sedimentology 15, 281-346.

Grim, R.E., 1951. The depositional environment of red and green shales. J. Sed. Petrol., 21, 226-232.

Grim, R.E., 1958. Concept of diagenesis in argillaceous sedi ments. Bull. Am. Assoc. Petrol. Geol., 42, 246-253.

Weaver, C.E., 1964. The distribution and identification of mixed layer clays in sedimentary rocks. Amer. Mineralogist 41, 202- 221.

Weaver, C.E., 1967. Potassium illite and the ocean. Geochim. et. Cosmochim. Acta 31, 281-296.

Weaver, C.E. & Pollard, L.D., 1973. The chemistry of clay minerals. Elsevier Sci. Pub. Co. Amsterdam, 213p