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PETROGRAPHIC AND CHEMICAL CHARACTERISTICS OF GLAUCONITIC AND PHOSPHATIC SEDIMENTS OF THE KUSSAK FORMATION, KHEWRA GORGE, SALT RANGE, PAKISTAN**

S.R.H. Baqri*, Viqar Husain, Rubina Bilqees, Nazir Jan and Nisar Ahmad
PCSIR Laboratories, Jamrud Road, Peshawar 25120, Pakistan

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The Kussak formation is a sequence of glauconitic sandstone, shales and dolomite. Quartz, feldspar, dolomite, glauconite, apatite, illite, calcite, goethite, chlorite and montmorillonite were identified by XRD and microscopy. Quartz, feldspar and dolomite are predominant. Glauconite occurs as medium to coarse rounded pellets. Goethite occurs mostly as stain around grains. Apatite occurs as small pellets or as matrix. The green and rounded nature of the glauconitic pellets with approx. 6% K_2O and high percentage of major elements like Si, Al and Fe in most of the samples from Khewra Gorge suggest marine authigenic origin for the glauconite. Field and laboratory data suggest that glauconitic sandstones were deposited in deep and semiconfined conditions followed at the top by shallow sea conditions. The phosphatization may succeed glauconitization in a normal evaluation of an epicontinental basin but low concentration of P_2O_5 in the Kussak sediments was perhaps due to lack of organic compounds.

Key words: Glauconitic and phosphatic sediments, Kussak fomation, Khewra Gorge salt range.

Introduction

The association of apatite and glauconite in sediments has frequently been reported but comprehensive studies of the two minerals have been few. These sediments are widely distributed in the geological column, particularly, in the strata of Cambrian, Cretaceous, Lower Tertiary and in the case of phosphatic sediments, Permian and Miocene-Pliocene ages [1]. Glauconitic and phosphatic sediments have been reported from the Kussak formation exposed at Khewra Gorge in salt range, but no integral studies of the two minerals have been made so far (Fig. 1).

Earlier workers on the salt range have carried out mostly regional stratigraphic and palaeontological studies [2-3]. The Kussak formation was studied in detail by Wynne [4] and Noetling [5] who described it as consisting of greenish grey, glauconitic, micaceous sandstone and siltstone beds. Schindewolf and Seilacher [6] studied the fossils of the Kussak formation and assigned it an early middle Cambrian age. Khan [7] studied the Kussak formation exposed at Khewra Gorge and identified the presence of phosphatic shells of brachiopods in the formation. Detailed petrographic and mineralogical studies of salt range sediments in general and Kussak formation in particular are still lacking. The present paper describes the geological, petrographic and chemical characteristics of Kussak sediments. A discussion on the palaeogeographic environment of the glauconitic and phosphatic sediments of Kussak formation has also been included.

* Pakistan Museum of Natural History, PSF, Islamabad.

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Materials and Methods

Geologic setting. The oldest sediments of the salt range represent an Eocambrian to Cambrian rock sequence of non-marine and marine origin, which are overlain by a thick sedimentary sequence, ranging in age from Permian to Pleistocene [3]. The distribution of various formations within the salt range is governed by four major unconformities [3]. The Kussak formation is one of the members of the Jhelum group (Table 1). This group is composed, predominantly, of sedimentary rocks comprising sandstone, shale and dolomite.

According to Shah [3] the Kussak formation unconformably overlies the Khewra sandstone and consists of grey to dark grey shale with alternate sandstone and shale containing fossils. The sequence of the formation started with pebble bed at base, through marine environment depositing glauconitic sandstone and shale, followed at the top by shallow sea conditions.

The Kussak formation exposed at Khewra Gorge is about 62 metres thick and consists of silty sandstone to siltstone, sandy dolomitic limestone and dark grey to bluish grey shales. The formation can be divided into 4 distinct units on the basis of lithology and bedding characters. These units may be labelled A,B,C and D from bottom to top.

Unit A. The lower unit or unit A of the Kussak formation is about 37 metres thick. Unit A overlies the Khewra sandstone disconformably. This unit contains thinly bedded siltstones, shales, sandstone, silty shales, glauconitic sandstones, siltstones and dolomitic sandstones to sandy dolomites.

The lower part of unit A is about 13.80 metres thick and consists of well bedded sandstones, siltstones, shales, dolomitic sandstones and sandy dolomites. This sub unit displays bioturbation and lenticular glauconitic - silty beds. The unit also shows muscovite at the bedding surfaces and also randomly distributed in shaly-silty bands. The bioturbation is due to annelids type of animals, generally, observed at bedding surfaces as fossilcasts. The sandstones are silty, clayey, dark coloured and carbonaceous.

The middle subunit of unit A is about 17.5 metres thick. This unit consists of mainly silty shales to shaly siltstones and fine grained calcareous sandstones. The silty shales are poorly bedded and bedding is most likely destroyed due to bioturbation in the argillaceous beds. The sandy silty beds are well bedded. The shales are greenish grey to brownish grey, silty micaceous and bioturbated. The siltstone to fine sandstones are greenish grey to whitish grey, friable, lenticular bedded, cross bedded, and display an alternation of glauconitic and silty dolomitic beds.

The upper subunit of unit A is about 6.3 metres thick consisting of intercalated shales, siltstones and sandstones. These sediments are glauconitic and micaceous. The sandstones are also calcareous, dolomitic and medium to fine grained.

Unit B. Unit B is about 12.5 metres in thickness. This unit contains mainly shales intercalated with thin siltstones and sandstones. The shales are greenish grey to grey, medium hard to soft, fine grained and poorly bedded, bedding destroyed by the burrowing animals. The sandstones and siltstones are calcareous, dolomitic, greenish grey to grey, showing typical differential weathering.

TABLE 1. STRATIGRAPHIC SEQUENCE IN SALT RANGE AFTER GEE [15].

		Unconformity	
		Baghanwala formation (Salt pseudomorph beds)	– Blood red shales and flaggy sandstones with salt pseudomorphs.
Middle and Early Cambrian	Jehlum Group	Jutana formation (Dolomitic sandstone)	– Massive light coloured dolomite and dolomitic sandstone, subordinate shales.
		Kussak formation (Neobolus shales)	– Grey and purplish shales glauconitic sandstone; pebble bed at base.
		Khewra sandstone (Purple sandstone)	– Massive maroon fine textured sandstone, maroon shales.
Eocambrian		Salt range formation (Punjab saline series)	– Red gypseous marl with rock salt gypsum-dolomite above, occasional oil shale Khewra trap in the east.

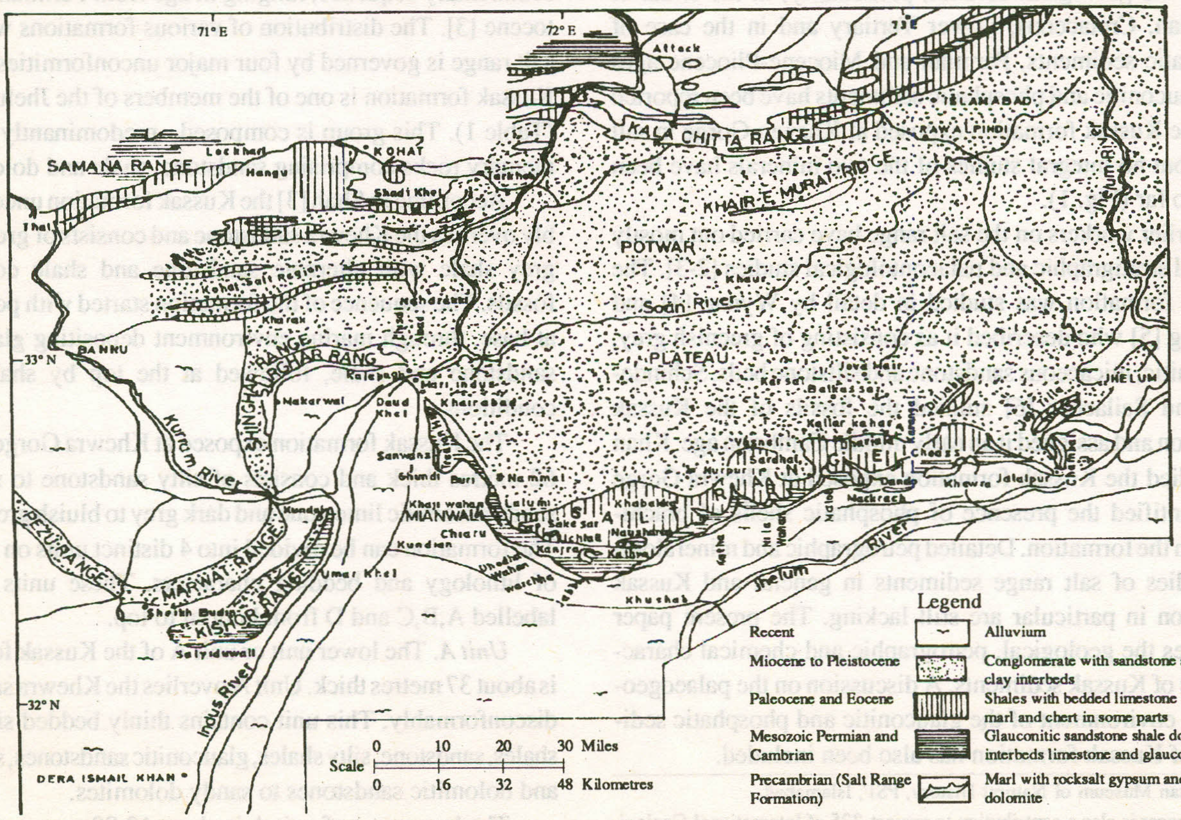

Fig. 1. Location map of the salt range and related areas. After Gee (1983).

Unit C. The Unit C is about 13.1 metres in thickness. Unit C is easily distinguished from Unit B due to sudden increase of carbonates, sandy fractions and also due to the appearance of glauconitic beds. This unit includes mainly calcareous, dolomitic sandstones to sandy dolomites with argillaceous siltstones and sandstones. The glauconitic sandstones with rounded glauconites are very prominent in this unit and can be easily used as marker beds to differentiate this unit at other places in the Kussak formation. The argillaceous calc-silty sandy beds display abundant body and trace fossil impressions in Unit C.

Unit D. The upper unit or unit D is about 2.3 metres in thickness. This unit contains shales intercalated with thin siltstones and sandstones, separating the Kussak formation from the Jutana formation. The shale is light grey, thinly bedded and micaceous at bedding surfaces.

Experimental Work. The field characteristics of the Kussak formation were studied in detail and the thickness of individual beds exposed at Khewra Gorge section was measured. About 25 representative samples were collected from this section and some of these were studied for their petrographic, mineralogical and chemical characteristics. One hundred grams of each sample was ground to a fine powder (-100 to -150 mesh) and the chemical analysis was carried out using standard analytical methods [8-11]. The constituents determined were SiO_2, Al_2O_3, Fe_2O_3, P_2O_5, MgO, CaO, Na_2O, K_2O and loss on ignition. These samples were crushed to 200-250 mesh for whole rock mineralogy of each sample using X-ray powder diffraction (XRD). Samples were irradiated with CuK radiation for 6 hrs. at 35 Kv and 20 mA.

TABLE 2. X-RAY DIFFRACTION ANALYSES OF THE SAMPLES FROM THE KUSSAK FORMATION, KHEWRA GORGE, SALT RANGE.

Sample No.	Minerals in major quantity	Minerals and clays in minor quantity	Minerals and clays in very small quantity
HKU			
1	Quartz	Calcite, illite	
2A	Quartz	Feldspar	
4	Quartz, feldspar		Calcite & kaolinite
6	Quartz	Feldspar	Dolomite & apatite
7	Quartz	Feldspar	Calcite
9	Quartz	Feldspar	Calcite
11	Quartz, feldspar, Dolomite		Calcite, apatite
12	Quartz		Chlorite, illite
		Dolomite, glauconite	
13	Quartz	Feldspar, calcite	
15	Quartz	Illite	Apatite
16	Quartz		Illite, mica
17	Dolomite	Quartz	Feldspar
18	Quartz	Illite	Dolomite
20	Quartz	Feldspar	Chlorite, calcite
21	Dolomite	Quartz	Apatite
22	Dolomite	Illite	Kaolinite, glauconite Quartz
23	Quartz, dolomite, Feldspar	Calcite	Apatite
24	Quartz	Feldspar, calcite	Montmorillonite
25	Quartz, dolomite		Illite

Results and Discussion

Mineralogy. All twenty five samples, collected from the Kussak formation, were subjected to X-ray diffraction studies. These rocks consist predominantly of quartz, feldspar and dolomite. Other minerals which occur in minor quantities include calcite, illite, apatite, glauconite, mica, kaolinite, montmorillonite and chlorite (Table 2).

Petrography. Detailed petrographic study of the samples from the Kussak formation reveal that medium to coarse sized subhedral grains of quartz and feldspar with equigranular texture are common (Fig. 4). In some thin sections, coarse and subhedral shaped dolomite grains with well developed cleavages are frequent which show interlocking texture with their

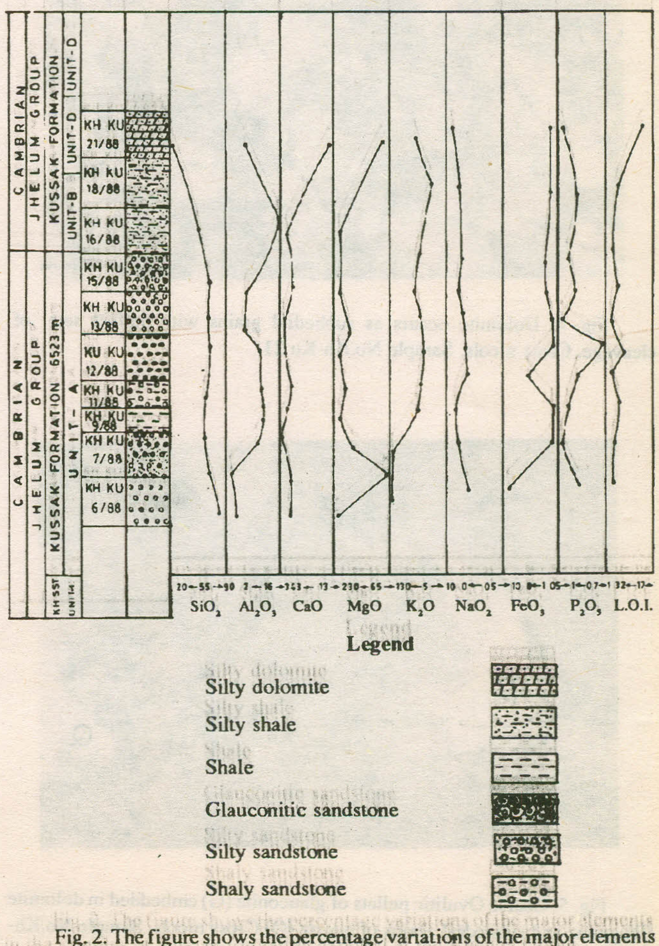

Fig. 2. The figure shows the percentage variations of the major elements in the samples of Kussak formation exposed at the Khewra Gorge.

Fig. 3. Quartz (Q) and Feldspar (F) showing equigranular texture. Cross nicols. Samples No.Kh-Ku-2A.

Fig. 4. Dolomite occurs as subhedral grains with perfect sets of cleavage. Cross nicols. Sample No.Kh-Ku 21.

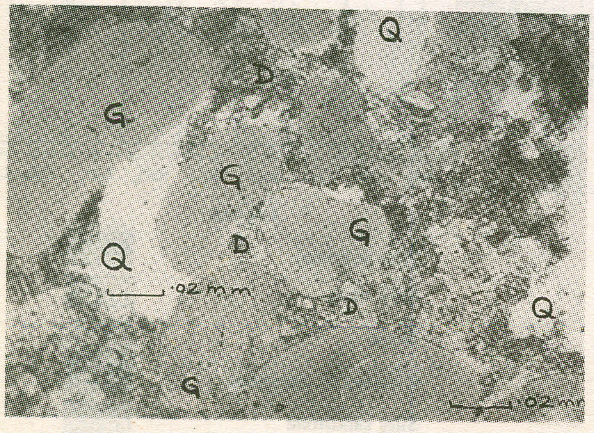

Fig. 5. Coarse Ovulitic pellets of glauconite (G) embedded in dolomite (D) grains and subhedral grains of quartz (Q) Cross nicols. Sample No.Kh-Ku-19.

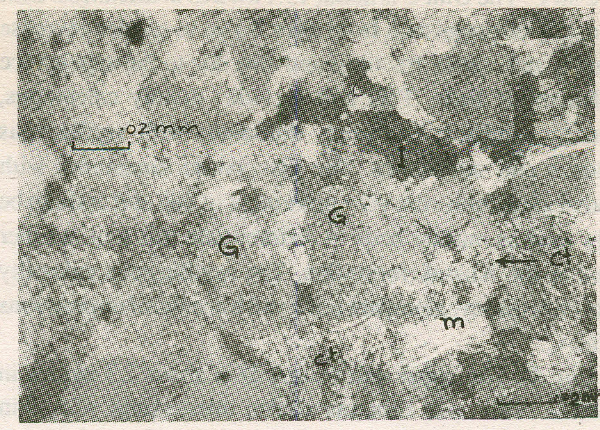

Fig. 6. Some glauconite grains (G) showing alteration within and on the margins of their pellets-muscovite (m) illite (i) and recrystallized calcite (ct). Cross nicols Sample No.Kh-Ku-19.

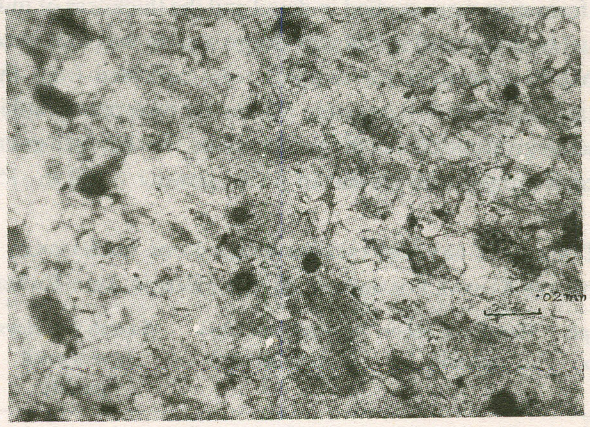

Fig. 7. Apatite (A) occurs in small quantities mostly as matrix in between quartz grains, plane polarized light. Sample No.Kh-Ku-20.

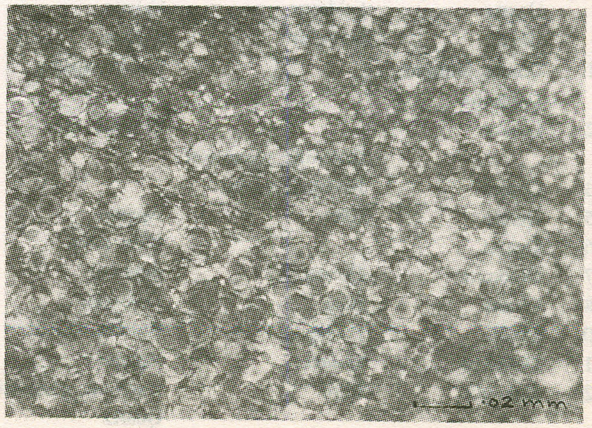

Fig. 8. Small sized phosphatic shells of Brachiopods. Cross nicols. Sample No.Kh-Kh-12.

TABLE 3. CHEMICAL ANALYSIS OF THE SAMPLES FROM THE KUSSAK FORMATION, SALT RANGE.

Weight	Sample number									
% oxide	KH.HK-6/88	7/88	9/88	11/88	12/88	13/88	15/88	16/88	18/88	21/88
SiO_2	82.80	72.22	63.14	65.38	54.94	73.56	68.09	68.26	50.02	20.04
Al_2O_3	6.08	2.29	17.47	18.96	17.99	12.29	12.96	13.96	34.02	12.62
Fe_2O_3	0.88	1.27	1.27	1.00	1.25	1.28	1.20	1.22	1.22	1.28
P_2O_5	0.26	0.10	0.24	0.30	1.30	0.18	0.40	0.30	0.34	0.10
MgO	Traces	12.45	3.27	Traces	2.08	1.02	2.49	0.26	0.35	11.50
CaO	6.33	7.39	3.32	4.42	6.96	3.25	4.62	7.08	3.13	21.17
Na_2O	0.45	0.23	0.19	0.34	0.39	0.30	0.20	0.25	0.20	0.50
K_2O	0.50	0.51	5.50	5.66	5.83	5.65	4.40	5.62	7.05	2.70
L.O.I.	2.50	3.97	5.43	4.27	9.84	3.29	5.98	2.51	4.50	30.68
Total	99.80	100.43	100.23	100.33	100.58	100.82	100.34	100.48	100.83	100.59

common grain boundaries (Fig. 5).

Glauconite occurs as medium to coarse sized, subrounded to spherical shaped pellets. These pellets occur embeded in dolomite, quartz and feldspar grains (Figs. 6-7). Some glauconite grains show inclusions and alteration on their margins (Fig. 7).

Apatite is a small to minor constituent of these samples which occurs as matrix and as phosphatic shells (Fig. 8). Goethite occurs as small oolites and as stains around the grains or as matrix (Figs. 4,6-8).

Other minerals occuring in these samples in very small quantities include chlorite, muscovite, illite chert and recrystallized calcite. (Fig. 7).

Chemical characteristics. Table 3 gives the results in percentages for major elements analysed. Figure 3 provides the stratigraphic positions of the samples selected for analysis and the variations of the major elements from the basal part of the formation to the upper part.

The silica varies from 20 to 83% (Table 3). The silica is mostly present in quartz as free silica and is also present in clay minerals and feldspars. The decrease of SiO_2 content towards the top reflects that transportation of detrital minerals such as quartz, feldspars and clay minerals gradually decreased during the end of the depositional cycle of the Kussak formation (Fig. 3).

Al_2O_3 content decreases in sample Kh-Ku 6/88 but increases in other samples and reaches maximum in sample Kh-Ku 18/88. Fe_2O_3 content varies from base to the top of formation. P_2O_5 content is very low in all the samples except in sample Kh-Ku 12/88 in which relatively higher P_2O_5 content could be due to its local concentration. Oxides of magnesium, calcium, sodium and potassium also show variations in their contents throughout stratigraphic column of the Kussak formation. The loss on ignition is low in all the samples of glauconitic sandstone except in shale sample (Kh-Ku 21/88) in which the loss on ignition is enormous (Table 3, Fig. 3).

Environment of glauconitization. In samples of the Kussak formation, glauconite occurs on diverse mineral phases such as dolomite, quartz and K-feldspar which reveals that glauconitization involves both potassium free and potassium bearing phases [12]. In the Khewra Gorge, well developed grains (pellets) of glauconite often occur in dolomite grains, but they are formed later as the glauconitic minerals appear to replace the dolomite (Fig. 6).

Glauconitization generally occurs at a water depth between 60 and 350 meters but well developed and green coloured glauconite pellets which are commonly observed in the study area suggest that glauconite rich sediments of the Kussak formation were deposited far from zones of active sedimentation at relatively low temperature (7 to 15°) and at the time of deposition of these sediments, conditions of deposition were neither too warm nor too oxidized and the depth was more than 350 metres [13].

There is often an inverse relationship between the kaolinite, an indicator of detrital deposition in this case, and that of glauconite in samples from Khewra Gorge. Kaolinite occurs in small quantity (Table 2) which suggests that detrital deposition was a minor event during the deposition of Kussak formation [13].

Pelletal facies of the glauconitization observed in the Kussak formation is generated in a semi-confined environment which permits crystal growth in protected milieu but slow exchanges remain active [14].

A general glauconitization occurs sometimes at the base of transgressive series [13]. In the salt range area, the events like sub-sidence of the Precambrian basement attended by a widespread shallow marine transgression; led to rapid evaporation resulting in the deposition of the saltiferous deposits of the salt range, followed by mainly clastic sediments of the Jhelum group [15].

Environment of phosphatization. Phosphatization is, in a more or less indirect way, much more closely related to upwelling and concomittant biological development than is glauconitization [13]. Marine phosphates in contrast to glauconite occur on the open sea bottom as well as near estuaries. Agitated beachwater or very shallow waters (less than 50 meters) are suitable for the formation of phosphorites but glauconite grains do not develop under such oxidized conditions [13].

Although glauconitization and phosphatization occur in neighbouring stages in the evaluation of a sedimentary basin, petrographic and chemical data from the samples of Kussak formation indicate that phosphatization which generally succeeds glauconitization in the normal evolution of an epicontinental basin remained a minor event in this area.

Many major phosphate deposits have a close link with marine transgressions. The concomittant and often extensive reworking of sediments and weathering are major factors in concentrating phosphate into large and economic deposits [1]. The mineralogical, petrographic and chemical data from the samples of the Kussak formation show that probably climatic and eustatic changes during Cambrian period were favourable for phosphatization but further sedimentary processes like weathering did not play an effective role in the deposition and accumulation of significant phosphate deposits in the area.

Economic applications. Pakistan's economy is mainly based on agriculture, however, the country is fertilizer deficient. The imported and indigenously manufactured chemical fertilizers are quite costly and a large number of small farmers are not able to purchase such fertilizers. Glauconite rich sediments with about 6% K_2O and small space quantity of P_2O_5 alongwith other important soil nutrients are suitable for use as straight fertilizers and as soil conditioners. The Government of Pakistan has already undertaken the distribution of gypsum among farmers for soil conditioning through its agriculture extension departments throughout the country. Glauconite rich sediments from Khewra Gorge should also be distributed alongwith gypsum as soil conditioner by the agriculture extension departments in the country. Furthermore, glauconite, if separated from green sands of Khewra Gorge, could also be used for the treatment of water.

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