GEOLOGY AND CLAY MINERALOGY OF PATALA FORMATION IN SALT RANGE & KALACHITTA RANGE WITH REFERENCE TO PALEOENVIRONMENTS

BY

SHAHINA TARIQ

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APPROVED BY

Dr. M. Rafiq
(Research Supervisor)

Dr. S. R. H. Baqri
(Co-Research Suprvisor)

Dr. M. Raees Ahmed
(External Examiner)

Dr. M. Qasim Jan
(Director)

C O N T E N T S

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ABSTRACT

The Patala Formation was studied in Salt Range and Kala Chitta Range. About 99 samples were collected to investigate the clay mineral composition and to understand the paleo-environments and diagenetic/ sedimentological control of the clay minerals. The samples from the Salt Range representing the southern end of the Potwar basin contain mostly kaolinite, illite and mixed-layer clay mineral (a mixture of general illite/ montmorillonite). The chlorite mineral was detected only in five samples from the Nilawahan area (central Salt Range).

The samples from the Kala Chitta Range (Khawri Khawar section) contain mostly illite, chlorite and mixed-layer clay mineral. The kaolinite was found in 12 samples. It was concluded that the illite, chlorite mineral are the detrital clay minerals which were brought into the depositional basin through erosional and sedimentological processes from a source rock exposed in the south.

The kaolinite from both localities, was found to be partly diagenetic and partly of detrital origin. The mixed-layer clay mineral was observed to be of diagenetic origin. The kaolinite in Khawri Khawar section (Kala Chitta Range) was interpreted as detrital mineral. The comparison of clay mineral composition from the Salt Range and Kala Chitta Range (Khawri Khawar section) indicated that kaolinite decreases in the samples of Kala Chitta Range while illite and chlorite show increase. The mixed-layer clay mineral did not show any significant variations. The decrease of kaolinite in Kala Chitta Range samples was interpreted as a sedimentological/ depositional control.

The crystalinity indices of illite and kaolinite show a decrease in crystallinity in the samples from the Kala Chitta Range as compared to the Salt Range samples. It is 0.77 for kaolinite, 0.37 for illite in Kala Chitta Range, and 0.26 for kaolinite and 0.19 (average) for illite in Salt Range. The decrease in crystallinity of illite and kaolinite again verify the transportation of kaolinite and illite from south to north of the depositional basin which was the direction of deepening of the basin.

L I S T O F F I G U R E S

L I S T O F T A B L E S

CHAPTER - I

A. INTRODUCTION

1. LITERATURE REVIEW

Davies and Pinfold (1937) named a series of shales with subordinate limestone as "Patala Shale" after the Patala Nala, Salt Range. Prior to this Wynne (1878) named it Nummulite Formation and described it as a part of the Hill limestone. Cotter (1933) refered to it as the unit of " Nummulite series of Middlemiss" (1896). Stratigraphic committee of Pakistan formalized it as the Patala Formation, and included it in the Tarkhobi Shales and Tarkhobi limestone described by Eames (1952) from Kohat area.

Wadia (1957) described the Patala Formation as the upper unit of Ranikot series, which lithologically comprises shale with interbeds of limestone and sandstone.

Krishnan (1968) described the Patala shales as the upper Ranikot beds consisting of dark grey shales, often carbonaceous with subordinate limestone and sandstone. The shales are alum bearing on accounts of the action of sulphuric acid derived from decomposing pyrite in them. Fatmi (1978) described Patala shales in detail, discussing the lithology, contacts, thickness, age and fossils. Shah (1980) briefly accounted about the Patala shales.

The type locality of the Patala Formation is the Patala Nala (lat 32° 39′ N :long 71° 49′E) located in the western Salt Range, district Mianwali, Punjab (fig. 1.1).

The upper part of the Patala Formation is composed of olive green, grey to brownishgrey shales, light grey siltstones and grey limestone. In the central Salt Range the upper unit can

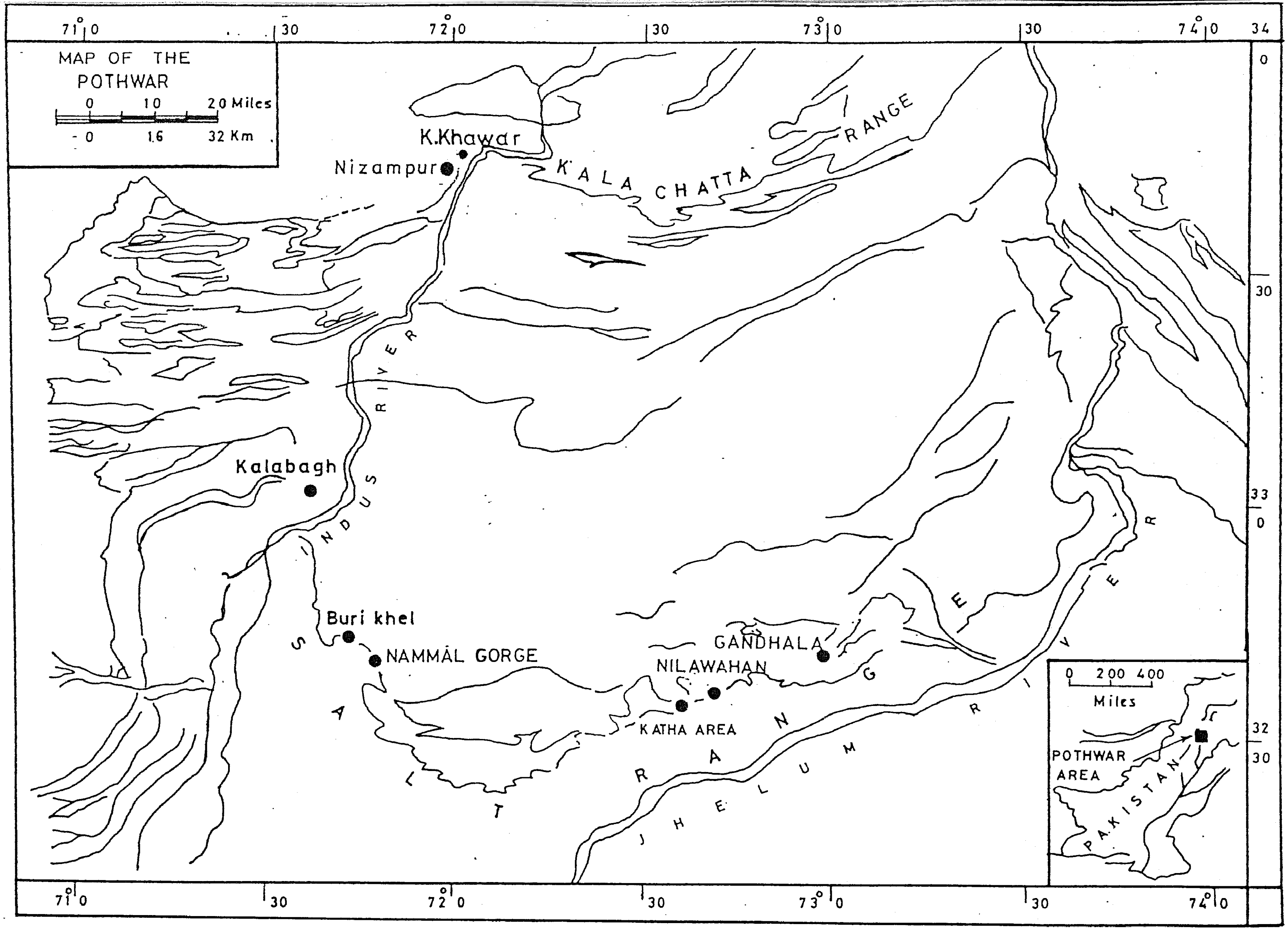


Fig: 1·1. LOCATION MAP OF THE POTHWAR AREA.

be further divided into two parts,the lower part is predominantly shale where as the upper part shows more frequent occurrence of limestone layers. The shale is friable with selenite crystals distributed throughout. At places coal seams are developed. The coal is profitably mined in the central and eastern Salt Range areas, generally two workable coal seams are found in these areas. The coal seams invariably contain inpersistant clay bands. The stratigraphic position of these coal seams is the middle part in the Patala Formation. Limestone is usually dark grey, pyritiferous medium bedded, silty, partly nodular and fossiliferous.

At the type locality, the formation is conformable with underlying Lockhart Formation and gradational with overlying Eocene formation except in the eastern Salt Range, where at places, the base is unconformable with the Hangu or older formations but top is conformable. In the central Salt Range, thick shale beds mark the base of the formation, while usually sandstone forms the bottom of the Patala Formation. The top of the formation is gradational and the contact is placed at the limestone above which bluish grey shale of the Nammal Formation occurs.

In the Salt Range and the Surghar Range the formation is richly fossiliferous and contains abundant layers of foraminifera, gastropods and ostracods. On the basis of larger forams, the age of the formation is upper Paleocene. The following fossils have been reported (Ibrahim Shah 1980).

Kathina nammalensis,

Lochortia off diversa,

Anomalina bandy,

Globigerina linaperta,

Epistominella dubia,

Punjabia patalensis,

Valvalina traingularis,

In the Salt Range, the thickness of the Patala Formation varies from 27 meters at Balkassar to 109 meters in the type locality. In the Surghar Range the thickness varies from 30 meters to 77 meters with 66 meters at Chichalli Pass section. In Kohat area it is 31 meters to 185 meters. In Hazara the thickness varies from 60 meters to 183 meters (Kuzagali section). In Kala Chitta Range, minimum thickness of 21 meters has been measured.

2. SCOPE OF STUDY

The objective of present work was to study the character of clay minerals present in the Patala Formation of the region. To investigate the paleoenvironments, trend and comparative depth of the basin at different place, close sampling was done along various section. The study reveal correlation of various clay minerals, indicated the shape, depth and trend of the deposition basin. In addition this study will also help in locality the coal measures of the areas, and to demarcate the clay horizons useful in ceramics.

3. CORRELATION OF THE PATALA FORMATION

In the Salt Range, the Patala Formation extends from east to west with varying thicknesses and various lithological units. Starting from Gandhala area in the east, the thickness of the formation gradually increases towards west. Lithologically it mainly consists of calcareous shales and interbedded limestone in the area. In the western Salt Range the Patala Formation is 40 meter thick at Nammal Gorge, the thickness at Choha Saidan Shah is about 20 meters. In the Surghar Range, the formation attains a thickness of 46 meters. The lithology of the formation consists of shale and marl with subordinate limestones and sandstone. The shale is dark greenish grey, selenite bearing carbonaceous and calcarceous at places, marcasite nodules are also present. The colour of limestone is white to light grey and texturally it is nodular. The sandstone is yellowish brown in color.

3. GEOLOGY OF THE PATALA FORMATION - PRESENT WORK

The formation exposed in the Gandhala Nala eastern Salt Range, displays ferrogeneous sandy beds at its base. The ferrogeneous sands and marls lie unconformably on top of the Permian shales/ Sardhai Shales. The Patala Formation at Gandhala Nala area displays several thin coaly bands but only one coal seam has been developed as an exploitable coal horizon in the Patala Formation. The formation displays marls and nodular limestone leness towards its top. The Patala Formation is conformably overlain by the Nammal Formation of Eocene age. A bed of Pelecypods, mark the contact between the Patala Formation and the Nammal Formation. The formation is about 20 meters thick at Gandhala Nala (fig. 2.10).

The Patala Formation exposed in Nilawahan Gorge, consists of sandstone beds at its base, which are greenish grey in colour. The formation displays bluish grey to greenish grey and dark black grey shaly horizons interlayering the lenticular sandstones and marls towards the top. The formation is about 23 meters thick at Nilawahan Gorge (fig. 2.11). The formation is overlain by the Nammal Formation with conformable contact.

The Patala Formation exposed in the Katha area is mostly faulted, covered and can be studied only in parts at places. The formation consists of poorly bedded shales with lenticular coal seams, sandstones, marls and limestones towards the top. The formation is about 20 meters thick. The coal seams contain mostly sandy and clayey partings and make the coal uneconomical at places. The formation is overlain by the nodular limestone of the Nammal Formation with conformation contact (fig. 2.12).

The Patala Formation exposed at Kala Chitta is about 56 meters thick, and consists of marls, dark clays and argillaceous fossiliferous limestones. The formation lies conformably on the sandstones of Palaeocene age. It is conformably overlain by the Eocene marly limestones (fig. 2.9).

4. MATERIALS COLLECTED FOR PRESENT WORK

About 109 samples were collected for the present studies. The samples were collected from Gandhala Nala eastern Salt Range (fig. 2.10), Nilawahan Gorge, Central Salt Range (fig. 2.11), Katha area, central Salt Range (fig. 2.12) and Kala Chitta Range (fig. 2.9), representing the stratigraphic thicknesses in the representative areas.

5. PREVIOUS WORK ON CLAY MINERALS IN COAL.

Stout (1923), and Logan (1942) have discussed the genesis of seatearths clay mineralogy and stated their authigenic nature. Grim and Allen (1938) studied Illinois underclays and found that the clays were mostly kaolinite.

Brammal , Leech (1943) and Hicks, Naglschmidth (1943), studied the petrology of roof and clod from three anthracite and bituminous coal mines in South Wales. They concluded that anthracitic samples contained more mica and less kaolinite and less carbonate than the non-anthracitic samples.

Endell, J.(1954) identified the clay minerals in bituminous and brown coals as illite and kaolinite. Woltman (1956), investigated the clay mineralogy of blue band of Illinois coal and he observed that illite, kaolinite and chlorite were the dominant clay minerals indicating normal clay sedimentation processes. Woltman (1956), also concluded that the normal clay sedimentation rather than derivation form volcanic ash was the origin of the clay at Illinois. Mc Millan (1956) studied the petrology of the Nodaway under-clays (Pennsylavanian).

Burger (1956), described the disseminated clay minerals in coals as similar to the normal subaqueous dispersion of weathering products, a view supported by Scheers (1957). Schullare (1956) and Hoehne (1957), studied in detail about the crystallinity of clay minerals and found that it is equivalent to siliceous petrification.

Webb (1961) studied the clay minerals environments and suggested that there was upward increase of mixed-layer clay mineral and decrease in kaolinite and chlorite from older to younger sediments. Comparsion of the mineralogy between under clays and over lying roof rocks of marine shales exhibits that underclays contain more kaolinite and expandable clay minerals and less illite and chlorite (Baqri, 1977).

Huddle and Patterson (1961), have suggested that seatearth formation was a stage in the development of a coal swamp. Perham (1962), studied the < 2u fraction of Illinois underclays, and reported that the mineralogical changes are of depositional facies variations. Pietzner and Werner (1963) proposed that all constituents of the clay minerals in coal may be the oxidation products of the organic material. He also observed that thorium and phosphorous are two trace elements which are abundant in clay minerals of shale facies. Kossovskey et al. (1964) observed that the perfect crystallized kaolinite was developed in an acid environment during slow deposition.

Wilson (1965), studied underclays from the South Wales coalfield and found no significant changes in clay mineralogy. Marston (1967), concluded that the genesis of seatearth depended primarily on the physical control of sedimentation. He also observed that kaolinite reflect the rate of deposition, i.e the more kaolinite, slower the rate of deposition. Gluskotor (1967), found a significant amount of well crystallized kaolinite, illite and expandable minerals and observed that pyrite was disseminated as a cleat filling mineral matter, in Illinois coals.

Moore (1968) concluded that the three factors which control the mineralogical and chemical composition of Seatearths are, i) degree and nature of weathering before transportation, ii) diagenetic changes and iii) effects of aerobic and anaerobic conditions.

Hosterman et al (1970) discussed the diagenesis of the underclays in detail. They claimed that alteration of clay takes place by leaching processes of accumulation and proposed three types of underclays i) plastic ii) semiflint iii) and flint.
In modern marine sediments, distribution of clay minerals has been related to the lithologies and the weathering regimes in the continental source areas (Griffin et al 1968). Keller (1970),

Dunoyer de Segonzac (1970), Dixon and weed (1977), have discussed the source lithology and weathering regime controls on clay mineral formation. Their studies are summarized on the bases of clay mineral occurrences as follow;

i. Smectites are developed by continental or submarine alteration of basic igneous rocks;

ii. Chlorites are developed by physical weathering of basic source rocks, and are especially common in glacial environments;

iii. Illites are developed by moderate weathering of acidic source rocks, in temperate climates;

iv. Kaolinites are developed by intense chemical weathering in warm, humid climates.

In older sedimentary sequences, the occurrences of these clay minerals can be modified by diagenesis. A diagenetic sequence for clay rich sediments undergoing burial and increased temperatures was described by Hower et.al.(1976). The sequence was recognized and characterized by the conversion of smectite to successively better-ordered forms of illite in the temperature range of 70°-190°C. The degree of illite ordering, which indicates either the abundance of physically weathered detrital illite or the extent of thermal diagenesis can be determined by X-ray diffractrometry (Weaver, 1960; Dunoyer de Segnozac, 1970; Guthrie et.al. 1986).

The abundance of various illite polytypes carries similar informtion, with the disordered 1Md illite polytype dominating most sedimentry clays, while the ordered 2 meter illite polytype dominates physically weathered detrital illite and illites that have experienced high temperature diagenesis (Dunoyer de Segonzae,1970, Maxwell & Hower, 1967; Velde, 1981).

Other workers have demonstrated that smectite to chlorite transition can be a dominant reaction (Potter et al ; 1980), but smectite to illite and smectite to chlorite transitions do not occur simultaneously in the same stratigraphic horizon. Kaolinite is rarely developed by diagenesis in clay rich deposits, and does not form under the conditions that favour illite or chlorite formation.

Hughes (1971) studied the mineralogy and environments of Illinois underclays and grouped the clays on the basis of mineralogy into; i) the first group contained poorly crystallized kaolinite, illite, chlorite, expandable mineral and oxidizing soil activity; ii) the second group contained dominant illite and chlorite; iii) the third group represented the authigenic phase. Reeves (1971) conducted research on British Carboniferous seatearths from the northern coalfields and observed that kaolinite was the dominant clay mineral. He claimed that the rate of deposition, degree of weathering, and source material before deposition could not account for the degree of modification of the original clay mineralogy. Hughes (1971) extracted the inorganic fractions of the coal by the low ashing technique of Gluskoter (1967), and found a significant amount of well crystallized Kaolinite, illite and expandable minerals.

B. METHODS OF INVESTIGATION

1. PREPARATION OF X-RAY SLIDES AND DIFFERENT TREATMENTS.

All clay sample were crushed and finely grounded upto soapy touch. A group of oriented clay samples were prepared by dispersion of the powder samples in water for 30 minutes and later on sampled from a depth of 5 centimeterm. This yields material upto 5 μ e.s.d, which was put onto glass slides and allowed to dry. All slides, were prepared and subjected to the following treatments.

i. Normal slides : Diffraction patterns of all the air-dried original materials were recorded before further treatment.

ii. Glycolated slides : The clay on some slides was glycolated with ethylene glycol at 60°c for one hour in an oven. In special cases different intervals of time were used for glycolation. Certain organic molecules of ethylene glycol can enter the lattices of clay minerals such as montmorillonite, halloysite, vermiculite and some mixed-layer clay minerals, which causes expansion. But certain clay minerals do not expand on glycolation, such as kaolinite, illite and most of the chlorite. This technique is an important criterion for the recognition of some clay minerals.

iii. Heat treated slides : All slides were heated at 550°c for two hours. Kaolonite minerals undergo structural changes at this temperature which cause the basal reflections to disappear. The 001 reflections of the chlorite minerals show enhancement at 14Å. The illite minerals show no change except that the main 001 peak of illite at 10.1Å becomes symmetrical. Montmorillonite minerals collapse at 9.6Å.

2. PREPARATION OF COAL SAMPLES

The inorganic mineral-matters were separated from the organic matters by floating in carbon tetrachlorite. The specific gravity of the carbon tetrachlorite (1.63) is greater than that of coal (average 1.45) and less than that of the mineral matters. The samples were thoroughly shaken in carbon tetrachloride space and centrifuged for 20 - 30 minutes at 2500 - 3000 r.p.m.to produce two distinct layers at the top and at the bottom of the test tubes. The thick coal layer at the top of the test tube was gently removed. Centrifuging was repeated two or three times to remove most of the light, coaly matter. Finally the remaining inorganic fraction, with some carbon tetrachloride, was placed in an evaporating dish and allowed to dry at room temperature. This dried, inorganic fraction was thoroughly mixed with hydrogen peroxide and gently heated to oxidize the remaining organic matter. The inorganic fraction obtained in this way, was finally grounded and some of it was used to obtain the "RANDOM POWDER" data and then preserved as a reference sample. The rest of the powder was used to prepare the normal, glaycolated and heated slides according to the procedure given above for clay samples.

IDENTIFICATION OF CLAY MINERALS

The clay minerals are generally identified by through x-ray different analyses, by measurement of basal lattice spacings obtained from a basally oriented chart of the clay fraction. The random powder data may be needed for more precise identification. Changes of the d-spacings are observed after different treatments, such as glycolation, heating and acid-digestion. The most important criteria for the recognition of important clay mineral groups are provided in detail in Brown (1961).

4. IDENTIFICATION OF NON-CLAY MINERALS.

Identification of non-clay minerals by X-ray diffraction was carried out on a random powder sample scanned between 2°θ and 65° 2°θ . This range the important reflections of the common minerals occur. The d-spacings were listed with their intensities and the A.S.T.M. powder data file was used to identify the minerals. Standard charts were prepared for the recognition of commonly occurring non-clay minerals, associated with clays.

The commonest non-clay minerals are quartz, dolomite, calcite, feldspars, pyrites and gypsums.

5. COMPARATIVE CRYSTALLINITY INDICES

The crystalline nature of clay mineral has been investigated by many workers. Weaver (1960,1961) measured the crystallinity ratios of the 10Å illite peak. Kubler (1964) stated that the crystallinity of illite indicates the deep diagenesis Jaron (1967) concluded that crystallinity of illite decreases upwards in weathered rocks. Dunoyer de Segonzac (1969) found changes in crystallinity of illite due to weathering which is the influence of palaeogeographic condition.

In the present work, the crystallinity index of illite and kaolinite are determined by measuring the width of half height of the (001) kaolinite reflection at 7.13Å and 10.04Å. Figure 1.2 represents the (001) reflection of kaolinite and illite width in 2°θ at half height measures the crystallinity

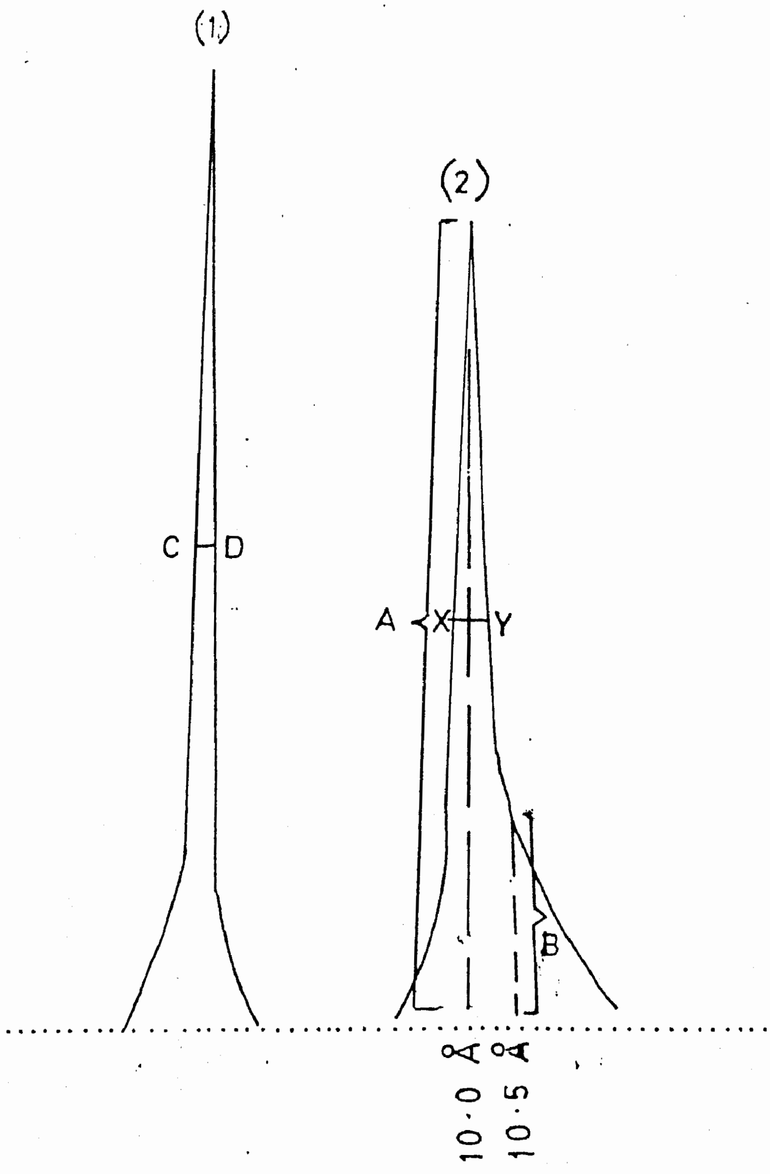


Fig.1.2 Measurement of the crystalinity of Kaolinite (1) and Illite (1) at 7.13 and 10.04Å respectively.

index (indicating CD). Crystallinity index has an invers relation to the true crystallinity of kaolinite and illite so

the small valves here indicates a high degree of crystallinity.

6. SEMIQUANTITATIVE ESTIMATION OF CLAY MINERALS

Intensities of reflections in X-ray diffractometry are proportional to the quantity of the mineral in the sample, times disorder effects, particle size and interference from minerals with similar spacings.

Johns, Grim and Bradley (1954) suggested a method based on the comparison of the (003) peak of illite, the (002) peak of kaolinite and the (004) peak of chlorite and concluded that the equal quantities of each mineral have the same area of reflections.

Weaver (1958) and Schultz (1960), used the illite peak area as standard peak. They are determined the crystallinity of the kaolinite by using the ratio area/ height of the (001) reflection. The reflecting power of the (001) peak of kaolinite is considered to be three times that of illite, if the value was below one. However, if the value was between 1.0 and 1.5, the reflecting power of (001) kaolinite was to be twice of (001) illite. For chlorite, the (002) reflection taken the twice reflecting power of the (001) illite peak, when chlorite and kaolinite are both present in the same sample. Their relative amounts can be estimated by running an "acid digested slide" glycolated montmorillonite (001) gives a reflection at 17.0Å with four times the reflecting power of (001) illite.

The proportion of random mixed layer clay minerals is difficult to determine. The (001) peak of the mixed layer clay minerals may be taken as two to three times that of (001) illite for the equal amounts of glycolated illite/ montmorillonite interstratification.

In the present semi-quantitative analysis of the clay mineral, the peak area of the first order of basal reflection are directly compared with illite. The illite peak area is normalized and all the other basal peak areas compared directly with illite except that the area of glycolated samples, is divided by four for mixed-layer clay minerals. The peak area of kaolinite is measured on "acid digested" slides when samples containing both kaolinite and chlorite.

The ratios given in this work are not claimed as accurate quantitative determinations but as comparative indices obtained by applying a standard procedure to similar materials.

RESULTS

A. X-RAY DIFFRACTOGRAM DATA FOR CLAY AND OTHER MINERALS OF THE PATALA FORMATION IN KALA CHITTA RANGE AND SALT RANGE

1. PATALA SHALES FROM THE KHAWRI KHAWAR (Kala Chitta Range).

(X-ray diffraction data (random powder) of the samples, given in appendix – A.

<u>Sample no-1/KKP</u>

The sample mainly consists of calcite as it gave all the reflections of calcite.

Weak reflections of quartz were also observed.

<u>Sample no-2/KKP</u>

The sample contains mainly calcite as it gave all the reflections of calcite in the random powder. A random mixed layer clay mineral (illite/montmorillonite) is present in traces, since weak reflections were observed at the place of the mixed layer clay mineral.

Quartz also gave weak reflections.

<u>Sample no- 3/KKP</u>

The illite mineral gave weak reflections in the normal slide but better reflections were observed in the acid-digested slide. Reflections of illite at 10Å increased in intensity on heating up to 550 °C for two hours. Mixed layer clay mineral gave its reflection in the range 17.65-13.58Å, which expanded on glycolation and contracted on heating. It is probable that a random mixture of illite/montmorillonite is present. Weak reflections were observed at the position of the main peak of chlorite, which disappeared on heating and existed in acid

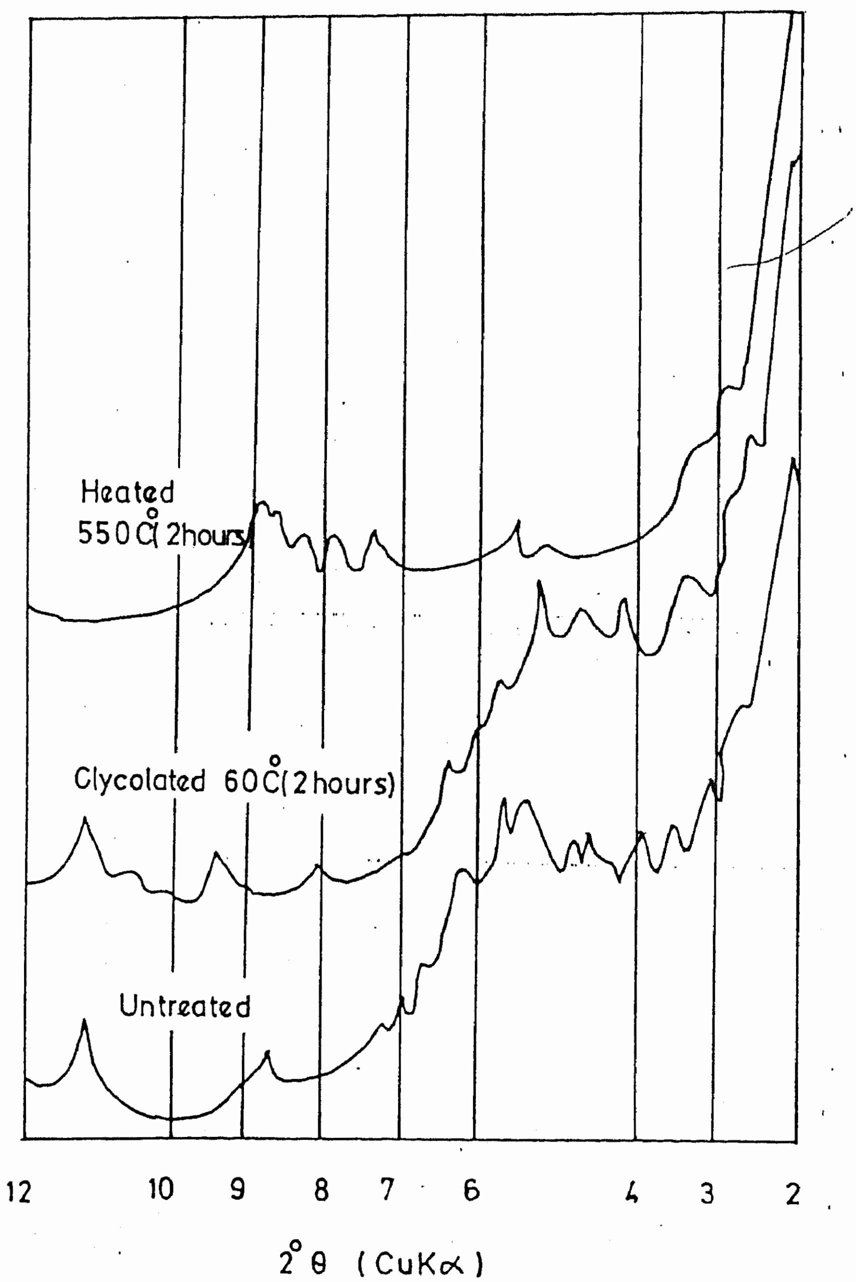


Fig:2.1 X-ray diffractograms of interstratified clay mienral showing peak position at different treatments.

digested slides. It may be due to the presence of mixed layer clay mineral. It is also probable that a coarse grained chlorite is also present. Reflections of calcite, quartz, feldspars and pyrite were observed (fig. 2.1).

Sample no-4/KKP

This sample contains mostly calcite and quartz according to the reflections given by the random powder data (appendix -A).

Sample no-5/KKP

The reflections of kaolinite mineral were not observed in normal slides. Illite gave a broad reflection at 10.04Å. A reflection was noted at the position of the chlorite peak. This did not show any change on glycolation and acid-digested slide and could be a mixed layer clay mineral. On heating upto 550 °C for two hours it did not disappear. It is possible that some chlorite may be present in traces. Normal slides gave reflections for the mixed layer clay mineral and similarly acid-digested slides gave weak reflections in the range of 22.07-12.61Å, which expanded on glycolation and contracted on heating. It is concluded that a random and regular mixture of illite/montmorillonite may be present.

Reflections of quartz, calcite, feldspars and pyrite were also observed.

Sample no-6/KKP

The sample contains calcite and traces of mixed layer clay mineral. Weak reflections of quartz were also observed.

Sample no-7/KKP

The normal oriented slide gave also reflections for kaolinite, illite and mixed-layer clay mineral. The acid-digested slide also gave very weaker reflection for kaolinite, illite and mixedlayer clay minerals. The mixed-layer clay mineral gave expansion on glycolation. The mineral may be a random mixture of illite/montmorillonite. Strong reflections of quartz, calcite and weak reflections of feldspars, and pyrite were noted in the Random powder data.

Sample no-8/KKP

Kaolinite gave poor basal reflections in the oriented slides. Very weak reflections of illite were observed and the mineral may be in traces. Mixed layer clay mineral reflections were also observed in the glycolated and acid-digested slides. The mixed layer clay mineral may be a random mixture of illite/montmorillonite clay mineral. Other reflections of quartz, calcite, feldspars and pyrite were also observed in the random powder data.

Sample no-9/KKP

The sample contains calcite. Illite mineral might be present in traces. Mixed-layer clay mineral (illite/montmorillonite) is also present in traces.

Reflections of quartz were also observed.

Sample no-10/KKP

Kaolinite was observed from its main basal reflection. Illite gave reflection at 10Å. A mixed layer clay mineral was recognized by a long tail of illite towards low angle 2°θ and this is probably a random mixture of illite/montmorillonit. A weak reflection was noted at the position of chlorite peak in heated and acid-digested slides and also did not disappear on glycolation, probably chlorite is present in traces. Random mixtures of illite/montmorillonite may be present in traces as very weak reflections were observed in one of the slides.

Reflections of quartz, calcite, feldspars and pyrite were also observed.

Sample no-11/KKP

Kaolinite was recognized from its main basal reflection at 7.13A. Random powder data did not give good reflections for kaolinite. Illite mineral gave very weak reflection at 10.04A. Normal and glycolated slides did not give any observable reflection at 14A for chlorite, but heated slide gave a reflection in 14.01A, which confirms the presence of chlorite in the sample. Mixed-layer clay mineral gave its higher spacing reflections in range from 22.07-28.47A. Mixed-layer clay mineral may be a random mixture of illite/montmorillonite or montmorilonite/swelling chlorite.

Random data gave the reflections of quartz, calcite, anhydrite and pyrite.

Sample no-12/KKP

The random powder data showed that sample contains kaolinite mineral, mixed-layer clay mineral (illite/montmorillonite) in traces. Calcite and quartz were also observed.

Sample no-13/KKP

The mineral illite gave weak reflections in normal slides but its intensity was increased on heating at 550 °C and better reflections were observed in the acid-digested and glycolated slides. A broad reflection was noted in the range of 12.98-16.98Å, which did not show any change on glycolation and heating upto 300 °C. When heated at 550 °C for two hours, an intense peak was observed at 13.75Å. The reflection did not disappeared in the acid-digested slide and it may be due to the presence of some coarse-grained Mg chlorite. Mixed layer clay mineral gave its higher spacing reflections as a long tail of illite towards low angle 2°θ degrees. Other lower spacing reflections of the mixed layer clay mineral were also observed. These reflections expanded on glycolation and contracted on heating. It may be the random mixture of illite/chlorite and illite/montmorillonite or illite/swelling chlorite.

The better reflections of the quartz, calcite, and feldspars were observed in the random powder data.

Sample no-14/KKP

Kaolinite gave very weak reflections at 7.13Å and 3.57Å. Illite gave its main basal reflections at 10.04Å. The other reflections of illite were also observed at 4.97Å and 4.48Å. The mineral chlorite was recognized from its reflection at 14Å, which survived on heating. A mixed layer clay mineral was recognized by a longe tail of illite towards low angle 2°θ and this is probably a random mixture of illite/montmorillonite.

Reflections of feldspars, quartz, calcite, and pyrite were also observed.

Sample no-15/KKP

Illite gave its main basal reflection at 9.81Å. It showed a more

or less stable peak on heating towards low angle 2°θ. Normal sedimented slide gave distinguished reflection for a mixed layer mineral. It is possible that the traces of a mixed layer clay mineral of the illite/montmorillonite may be present.
Reflections of quartz, calcite and feldspars were also observed in random powder data.

Sample no-17/KKP

The sample contains illite, chlorite and mixed layer clay mineral. A weak reflection was noted for chlorite at 14Å. This reflection did not disappear on heating. Acid-digested slide did not give any reflection at the position of the chlorite main peak. The mixed layer clay mineral may be a random mixture of illite/montmorillonite.
Reflections of quartz, calcite and feldspars were also observed in random powder data.

Sample no-18/KKP

The sample contains mainly chlorite and illite with kaolinite in traces. The normal slide gave a reflection for chlorite at 14Å. This reflection did not show any change on glycolation and on heating. It is probable that a coarse-grained Mg chlorite is present. The mixed layer clay mineral may be present in traces. In other minerals, quartz and calcite gave good reflections. Weak reflections of feldspars, were also observed.

Sample no-19/KKP

Kaolinite gave weak reflections at 7.13 and 3.57Å. Illite was recognized by its main basal reflection at 10.04Å. The intensity of illite reflections increased on heating. In addition to the main reflection, other prominent reflections of illite were observed at 4.97, 4.48 and 1.49Å. The presence of 4.97 and 1.49Å reflections generally indicate the di-octahedral nature of illite. Mixed layer clay mineral gave a broad reflection at 16.05-13.38Å. They showed a little expansion on glycolation and contracted on heating.It is probable that the random mixture of illite/montmorillonite is present.

Reflections of quartz, feldspars and calcite were also observed.

Sample no-20/KKP

Kaolinite was recognized by its main basal reflection at 7.13Å. The intensity of kaolinite peak was weak and broad in normal slides as compared to the acid-digested slides. Illite gave its main basal reflection at 10.04Å. Other reflections of illite were noted at 4.97, 4.48, 1.52 and 1.49Å. The illite may be of dioctahedral and trioctahedral nature. Mixed layer clay mineral gave weak higher spacing reflections. Chlorite gave better reflections in normal slide at 14.24Å. on heating up to 550 °C for two hours this reflection did not disappear so chlorite is present in this sample. The mixed layer clay mineral may be random mixture of illite/ montmorillonite, montmorllonite/ chlorite.

Sample no-21/KK

Kaolinite was recognized from its main basal reflections in acid-digested slide in traces. Reflections of illite were observed at 10.04Å. Mixed layer clay mineral is present as a random mixture of montmorillonite/ swelling chlorite, or illite/montmorillonite.

Reflections of quartz, calcite, and pyrite were also observed.

Sample no-22/KK

Illite was recognized by its main basal reflections. The intensity of illite reflections increased on heating. Mixed layer clay mineral gave its reflection as a long tail to the illite but in the direction of low angle 2°θ. They showed a little expansion on glycolation and contracted on heating. It is probable that the mineral is a random mixture of illite/montmorillonite.

Reflections of quartz, calcite, and feldspars were also observed in the random powder data.

Sample no-23/KKP

Kaolinite gave its main reflections at 7.13 and 3.57Å. Reflections were noted at the place of illite in normal slide. On heating the intensity of the illite was increased. Chlorite reflection was observed at 14Å in normal slide. The said reflection was missing in acid-digested slide. The mixed layer clay mineral may be a random mixture of illite/chlorite.

Reflections of quartz, calcite and feldspars were observed in random powder data.

Sample no-24/KKP

The sample displayed reflections of illite, chlorite and mixed layer clay mineral in oriented slides. Reflections of quartz, calcite and pyrite were noted in random powder data.

Sample no-25/KKP

The sample contains chlorite, illite and mixed layer clay mineral. The mixed layer clay mineral appeared as a "tail" to the illite 10Å reflection towards low angle 2°θ and showed expansion on glycolation and contraction on heating in probably consists of illite/montmorillonite.

Reflections of quartz, calcite, feldspars, and pyrite were also observed.

Sample no-26/KKP

Oriented slides did not give strong reflections for the clay minerals, only glycolated slide gave a sharp reflection for the illite at 9.92Å. Random mixture of illite/montmorillonite may be present in traces.

Random data gave the reflections of quartz, calcite feldspars and pyrite minerals.

Sample no-27/KKP

Illite gave its main reflection at 10.04Å. The reflection is weak to medium. A random mixture of illite/montmorillonite may also be present in traces.

Reflections of quartz, calcite, feldspars and pyrite were also observed.

Sample no-28/KKP

Illite showed the basal reflection at 9.81Å. Other reflections were noted at 4.87 and 4.48Å. The illite reflection decreased in intensity on glycolation and acid-digestion but not on heating. The illite reflections at 9.81Å showed a decrease in their intensity after glycolation. When the slide was heated all the mixed layer clay mineral reflections contracted and a more or less symmetrical peak of illite appeared at 10.04Å (fig. 2.2).

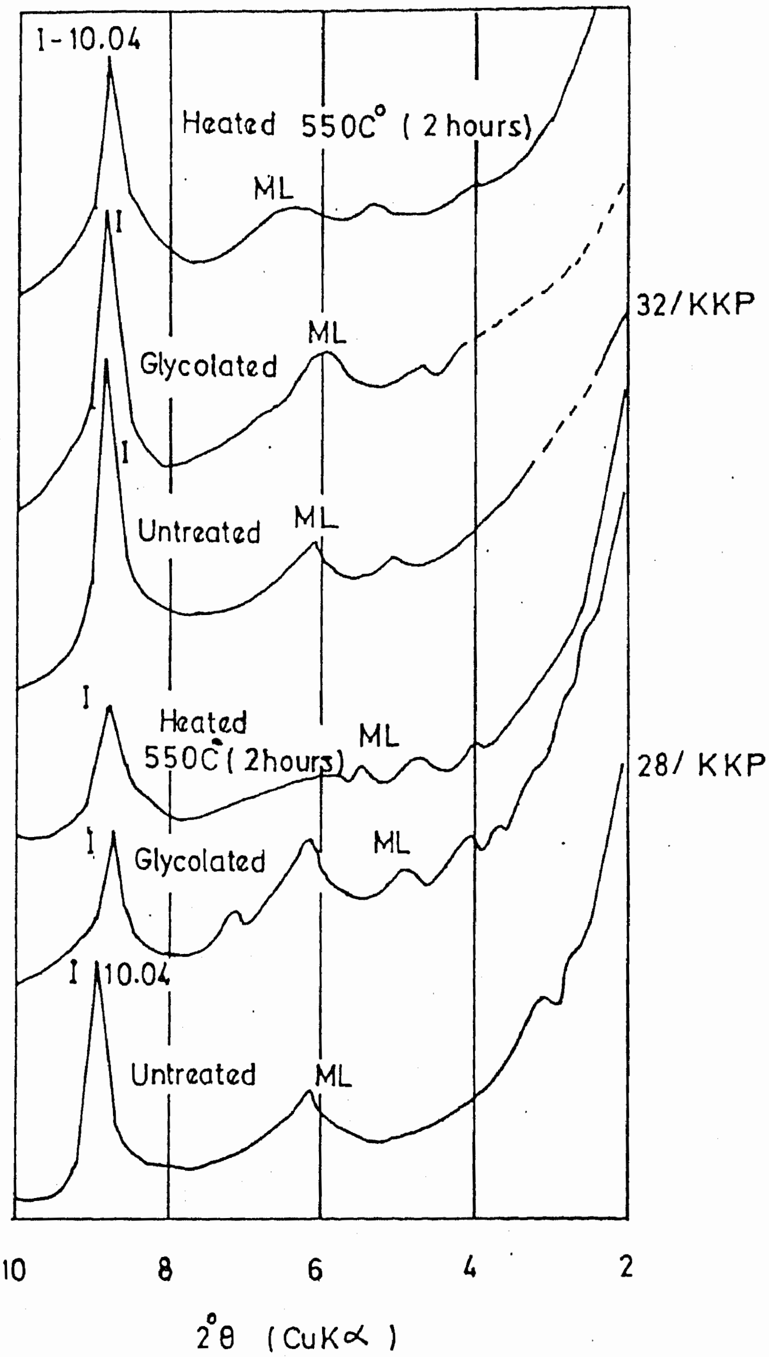


Fig:2.2 X-ray diffractogram of well-crystalline illit(I) and Mixed layer clay mineral showing Peak position at different treatment.

The mixed layer clay mineral may be a random mixture of illite/montmorillonite.

Quartz, feldspars, calcite and pyrite reflections were also observed in random powder data chart.

Sample no-29/KKP

Reflection of illite was observed at 10.04Å with a long tail towards low angle 2°θ. Weak reflections for a mixed layer clay mineral were noted as tail of illite. The mixed layer clay mineral may be a random mixture of illite/montmorillonite.

Random powder data gave the reflections of quartz, calcite and feldspars.

Sample no-30/KKP

Illite gave its main basal reflections at 10.04Å. Broad and weak reflection was noted at 14.01Å in the normal slides. This reflection was not observed in the acid-digested slide. The mineral chlorite is present. Mixed layer clay mineral was observed as a long tail of illite towards low angle 2°θ degree. These reflections gave some expansion on glycolation and disappeared on heating. The mixed layer clay mineral may be a random mixture of montmorillonite/illite.

Reflections of quartz, calcite and feldspars were also observed.

Sample no-31/KKP

The mineral illite gave its main reflection at 10.04Å. Random mixture of illite/montmorillonite may be present in traces as a tail of illite towards low angle 2°θ.

Reflections of quartz, calcite and feldspars were also observed.

Sample no-32/KKP

Kaolinite gave its basal reflections at 7.18 and 3.57Å. The reflection were very weak. Illite gave a sharp basal reflection at 10.04Å. Weak reflections were noted for a mixed layer clay mineral as a tail of illite. The reflections did not show any change on glycolation but contracted on heating. The mixed layered mineral may be present in traces.

In other minerals quartz, feldspars, and pyrite were observed.

Sample no-33/KKP

Kaolinite gave its main basal reflections at 7.13 and 3.57Å. Illite mineral gave medium reflections. It is probable that some iron-rich chlorite may be present in the sample.

Reflections of quartz, feldspars and calcite were also observed.

Sample no-34/KKP

Illite gave medium to weak reflection at 10.04Å. Random powder data also gave the other prominent reflections for illite mineral. Random mixture of illite/montmorillonite may be present in traces as a tail of illite towards low angle 2°θ.

Reflections of gypsum, feldspars, quartz and pyrite were also observed.

Sample no-35/KK

The reflections for illite was weak in the oriented slide, but the intensity increased on heating and the acid-digested slide gave weak reflection for illite. It is probable that illite mineral is present in traces. Very weak reflection was noted at the position of chlorite peak which did not show any change on glycolation and also existed on heating for two hours at 550 °C.

It is possible that some coarse-grained Mg chlorite may be present. Normal slide did not give any reflection for the mixed layer clay mineral but acid-digested slide gave weak reflection in the range 22.63-24.52Å which expanded on glycolation and contracted on heating. It is concluded that the traces of some random mixture of illite/montmorillonite may be present.

Reflections of quartz, calcite, gypsum, feldspars, and pyrite were also observed.

Sample no-36/KKP

The sample contains chlorite and illite. Mixed layer clay mineral showed a broad reflection as a tail of the illite 10Å reflection towards low angle 2°θ.

Reflections of quartz, feldspars, calcite, and pyrite were also observed in the random powder data.

Sample no-37/KKP

Illite reflection appeared from medium to low background. On heating and glycolation, the intensity of illite decreased. The mixed layer mineral may be a random mixture of illite/ monmorillonite and is present in traces.

Reflections of quartz, calcite, feldspars and pyrite were also observed.

Sample no-38/KKP

Reflections of kaolinite minerals were observed in oriented slide which were very weak and may be present in traces. Weak reflections were observed for illite at 10.04Å. The intensity of illite increased on heating. Random mixture of illite/montmorillonite may be present in traces as a tail of illite towards low angle 2°θ.

Reflections of calcite, feldspars, quartz and pyrite were also observed.

Sample no-39/KKP

The sample contains mostly illite and chlorite. Mixed layer clay mineral may be a random mixture of illite/montmorillonite. Reflections of quartz, calcite and pyrite were also observed in random powder data.

Sample no-40/KKP

The sample gave poor reflections for clay minerals and those of kaolinite were not detected, although illite gave very weak reflections and may be present in the form of traces. Reflections of quartz, feldspars, calcite, and pyrite were also observed in random powder data.

Sample no-41/KKP

This sample mainly consists of calcite with pyrite. Reflection for gypsum were also observed at 7.62Å. Mixed layer clay mineral may be present in form of traces.

Reflections of chlorite and illite were also observed.

Sample no-42/KK

Kaolinite gave weak to medium reflections at 7.13 and 3.57Å. Illite gave weak reflections at 10.04Å. A mixed layer clay mineral was recognized by a long tail of illite towards low angle 2°θ and this is probably a random mixture of illite/

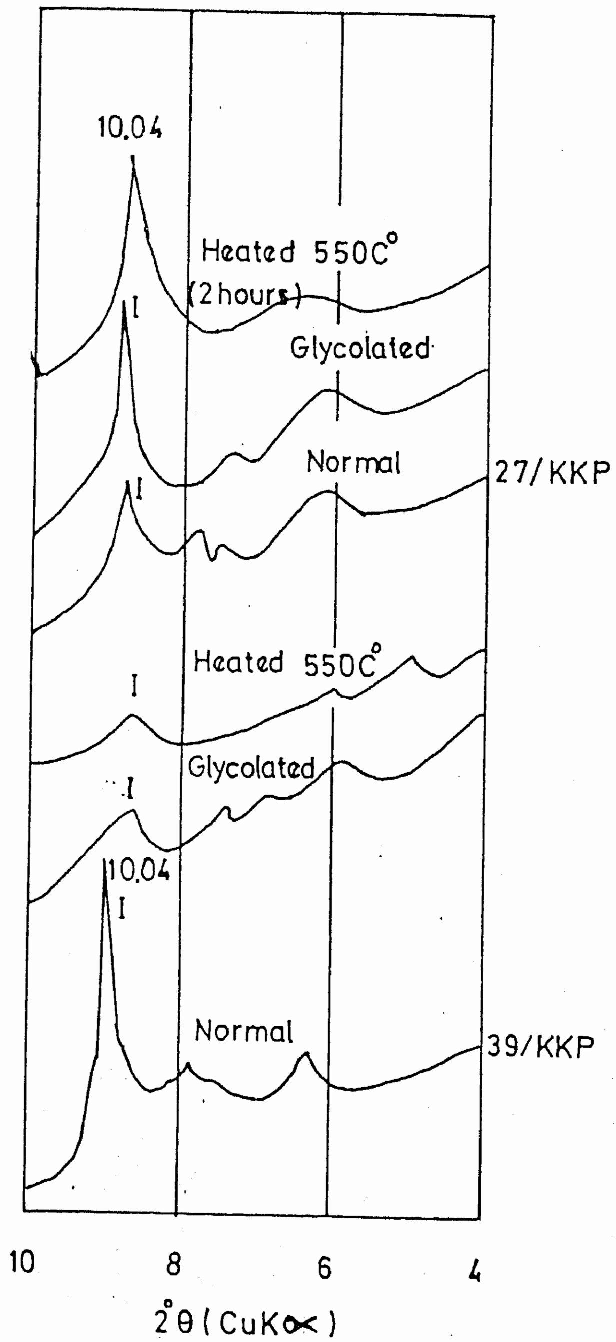


Fig:2.3 X-ray diffractogram of medium to well crystalline illite showing different treatment.

montmorillonite. Very weak reflections were observed at the position of the main peak of chlorite.

Reflections of other minerals such as gypsum, quartz, calcite, feldspars and pyrite were also observed.

Sample no-43/KKP

The sample contains mainly calcite. Mixed layer clay mineral may be a random mixture of illite/montmorillonite. Weak reflections for quartz mineral were also observed.

Sample no-44/KKP

Kaolinite was recognized due to its main basal reflections. very weak reflections were noted at the place of illite 10.04Å. The reflections were so weak that illite may be only in traces.

Chlorite reflection was observed at 14.24Å in normal slides. A weak reflection was observed in acid-digested and heated slides at 13.79Å and it is likely that the chlorite is a magnesium rich chlorite. Mixed layer clay minerals did not give prominent higher spacing reflections. Some weak reflections were noted at 24.52-21.53Å. They showed some expansion on glycolation and contraction on heating. Mostly the reflections of mixed layer clay mineral were noted as a long tail of illite toward low angle 2°θ. The mixed layer clay mineral may be the random mixture of illite/montmorillonite, illite/chlorite.

In other minerals very weak reflections of quartz, gypsum, feldspars and pyrite were also observed.

Sample no-45/KKP

The sample contains mostly calcite with some quartz. Weak reflection of mixed layer clay mineral were also observed in the random powder data.

Pyrite and feldspars were also detected by random powder data chart. Appendix (A) provides the respective reflections of the above mentioned minerals.

2. PATALA SHALE FROM GANDHALA NALA (Eastern Salt Range)

(X-Ray diffraction data (random powder) of the samples, given in Appendix - B)

Sample no-1/GNP

Koalinite mineral gave very strong reflections in this sample at 7.13A (fig.2.4). Illite gave medium to weak reflection at 10.04Å. Random powder data gave the prominent reflection at 7.13 and 3.57Å for kaolinite mineral. On heating the intensity of illite decreased.

Reflections of quartz, calcite and dolomite were also observed.

This sample contains comparatively less kaolinite then calcite and dolomite. Mixed layer clay mineral is probably a mixture of illite and montmorillonite (fig. 2.5).

Sample no-2/GNP

Kaolinite gave its main basal reflections at 7.24Å and 3.58Å. Illite mineral was present in traces. The reflections of mixed layer clay mineral were observed at 25.22, 21.02, 20.06Å, which showed expansion on glycolation and acid-digestion. Mixed layer mineral is probably a random mixture of illite/montmorillonite.

The reflection of gypsum and quartz were also observed.

Sample no-3/GNP

The mineral kaolinite gave its main basal reflections at 7.24Å and 3.57Å. Illite is present in traces. Mixed layer clay mineral gave very weak high spacing reflections in the range 22.07 - 13.79Å, which expanded on glycolation and contracted on heating. The mixed layer clay mineral is a mixture of illite and

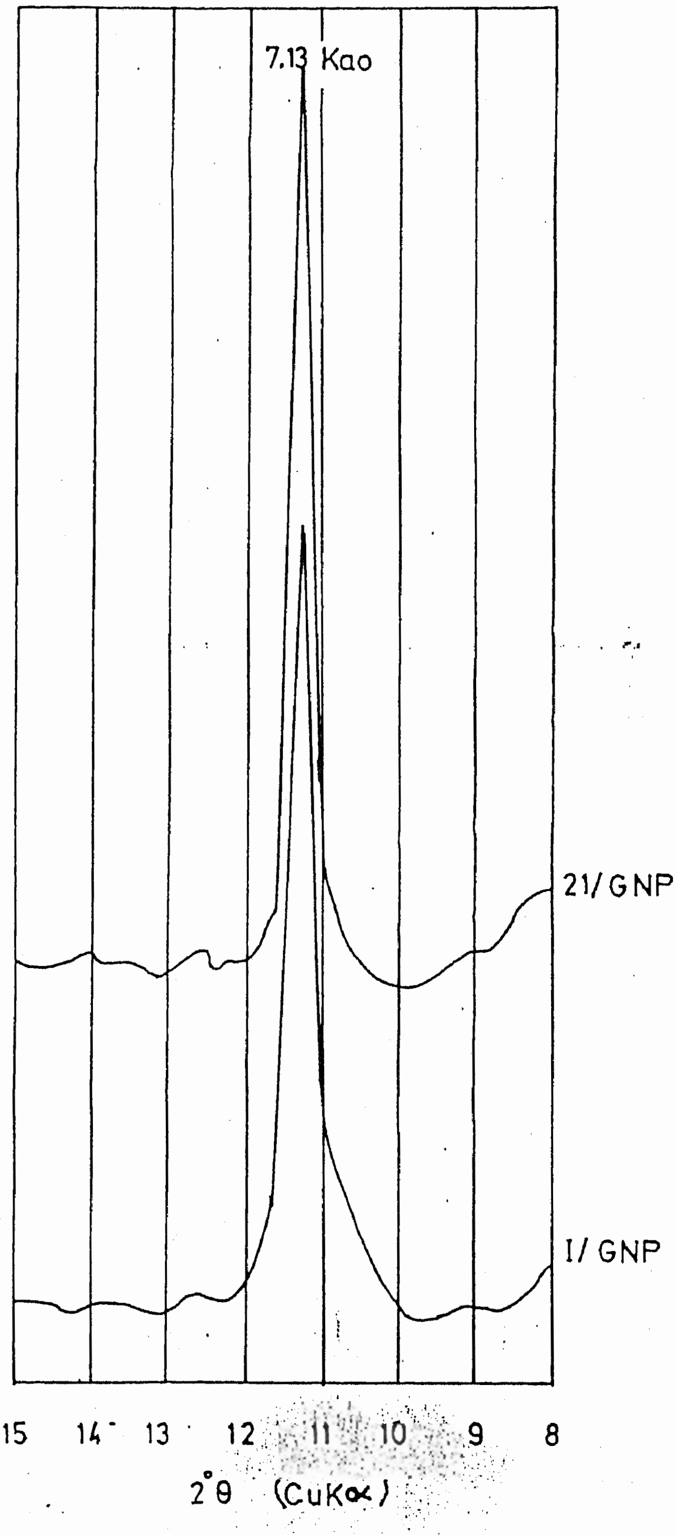


Fig.2.4 X-ray diffractograms of well-crystalline Kaolinite (Kao).

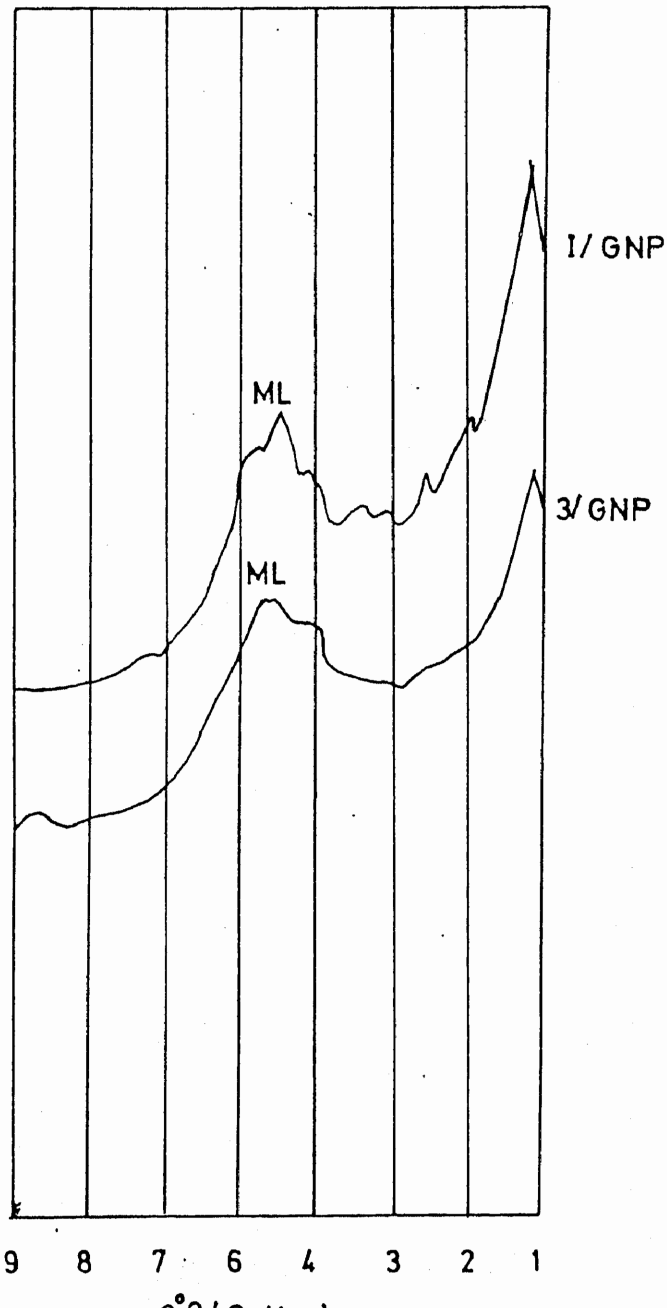


Fig:2.5 X-ray diffractograms of Mixed layer clay mineral of illite/ montmorillonite.

montmorillonite (fig. 2.5).

Weak reflections of gypsum and quartz were also observed.

Sample no-4/GNP

Kaolinite mineral was recognized from its basal reflections at 7.13 and 3.57Å. Illite gave its reflection at 10Å. A broad reflection of mixed layer clay mineral was observed at 12.61 - 22.07Å. These reflections expanded on glycolation and contracted on heating. This reflection was not effected by acid-digestion.

In other minerals, gypsum, quartz and feldspars were also observed.

Sample no-5/GNP

Kaolinite minerals was recognized due to its main basal reflections at 7.13Å and 3.57Å. The reflections given by oriented slide suggested, the presence of a medium to poorly crystalline kaolinite. Illite gave basal reflection at 10.04Å. On heating at 550 °C for two hours the intensity of illite increased. Traces of mixed-layer clay mineral of illite/montmorillonite may be present.

Reflections of quartz were also observed.

Sample no-6/GNP

Kaolinite mineral gave very weak reflections at 7.14Å and 3.57Å. Illite is present in traces. The sample mostly consists of quartz and feldspars.

Sample no-10/GNP

Kaolinite gave its main basal reflections at 7.13Å and 3.57Å. The mineral illite was recognized by its reflection at 10.04Å. A random mixture of clay minerals of illite/montmorillonite may be present in traces as a tail of illite towards low angle 2°θ. Reflections of quartz and pyrite were also observed in random data powder.

Sample no-11/GNP

The sample mostly contains kaolinite and traces of illite. Quartz is also observed.

Sample no-12/GNP

Kaolinite gave its main basal reflections at 7.13Å and 3.57Å. Illite gave its main reflection at 10.04Å. The intensity of illite reflections increased on heating and acid-digestion. Mixed layer clay mineral gave reflections which produced a long tail to the illite 10Å reflection towards low angle 2°θ. They showed a little expansion on glycolation and contracted on heating. On glycolation the mixed layer clay mineral gave a broad reflection between 12.61 - 22.07Å. It is possible that the mineral is a random mixture of illite/montmorillonite.

Reflections of quartz, gypsum and calcite were also observed.

Sample no-14/GNP

Kaolinite gave its main basal reflections at 7.13Å and 3.57Å. Very weak reflections were observed at the place of illite and may be present in traces. A broad reflection of mixed layer clay mineral was observed between 22.07Å - 12.26Å. On heating and acid-digestion it contracted. This mixed layer is probably a random mixture of illite/montmorillonite.

Reflections of gypsum and quartz were also observed.

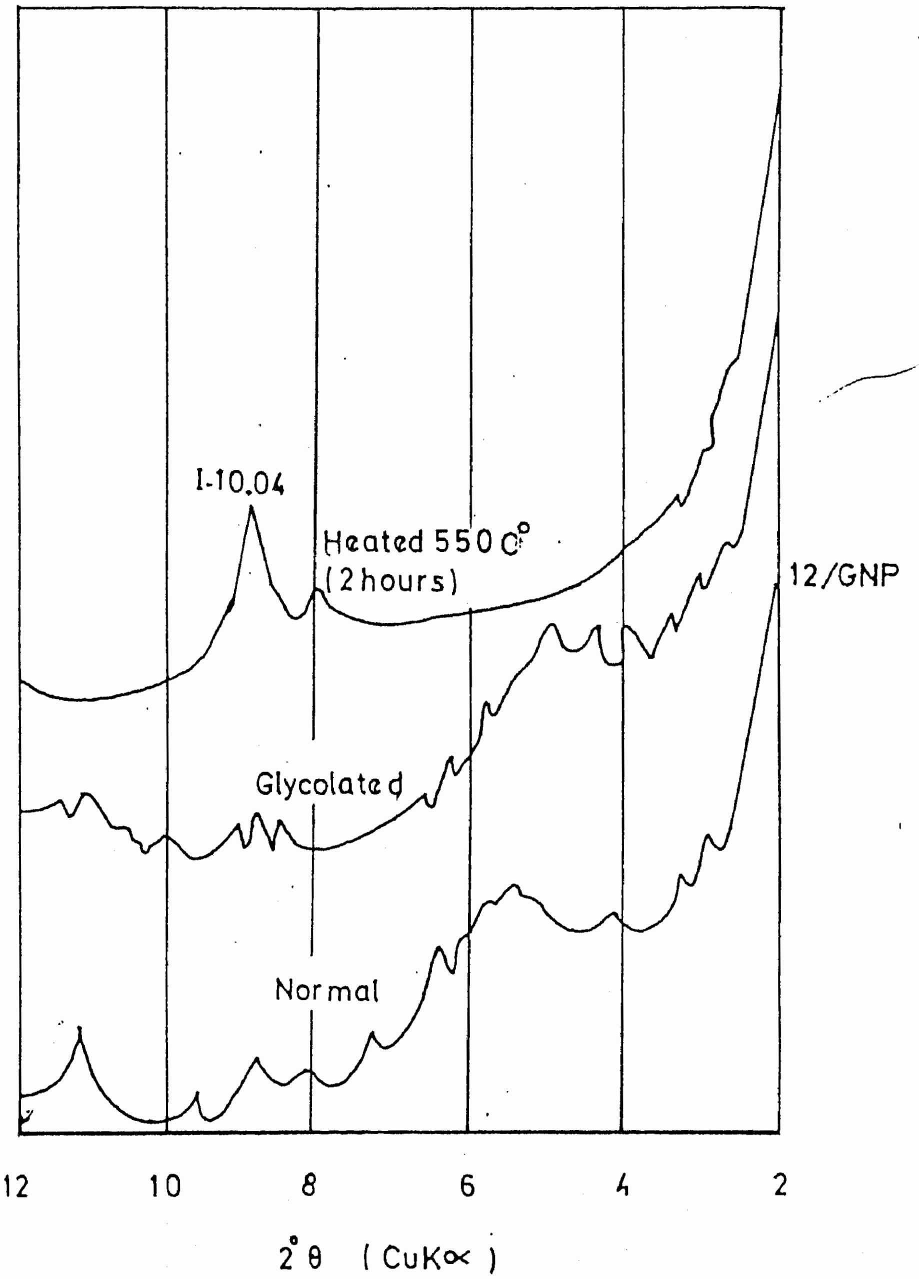


Fig:2.6 X-ray diffractograms of degraded illite showing-Peak points at different treatments.

ample no-15/GNP

Kaulinite was recognized by its main basal reflections. Illite gave its main basal reflection at 10.04Å. The intensity of illite main reflection decreased on heating. Mixed layer clay mineral gave reflections which produced a long tail to the illite mineral reflection but in the direction of low angle 2°θ. This showed a little expansion on glycolation and contracted on heating. It is a random mixture of illite/montmorillonite minerals.

Reflections of quartz, gypsum, feldspars and calcite were also observed in the random powder data.

ample no-16/GNP

Kaolinite was recognized from its main basal reflection at 7.14Å and 3.57Å. Illite gave weak reflection at 10Å. The reflections of gypsum, quartz and feldspars were also observed.

ample no-17/GNP

Kaolinite mineral was recognized by its main reflections. Illite reflection was also observed at 10.04Å. The intensity of the illite was increased after acid-digestion and on heating at 550 °C for two hours. Reflections of feldspars nd quartz were also observed.A broad reflection of mixed layer clay mineral was also observed at 24.52Å - 26.75Å. It is probable that the mixed layer clay mineral is a random mixture of illite/montmorillonite.

ample no-18/GNP

Kaolinite gave weak reflections at 7.13Å and 3.57Å. The mineral illite gave a reflection at 10Å. A broad reflection was noted in the range 12.61 - 17.65Å, which did not show much change on glycolation and slightly expanded. When heated at 550 °C for two hours. it disappeared. The mixed layer clay mineral may be a mixture of illite/montmorillonite. Weak reflections of calcite and quartz were also observed.

Sample no-19/GNP

Kaolinite mineral is present in traces as very weak reflections were observed. Illite reflection was observed at 10.04Å. Sample mainly consists of gypsum and quartz minerals.

Sample no-20/GNP

The sample contains kaolinite and illite. A broad reflection was observed in the range 14.71 - 22.07Å. It is possible that a mixed layer clay mineral illite/montmorillonite is present. Gypsum and quartz minerals were also observed by their reflections.

Sample no-21/GNP

Kaolinite mineral was recognized from its main basal reflections at 7.13 and 3.57Å. Illite mineral gave its reflection at 10.04Å. A mixed layer clay mineral was recognized by a long tail of illite towards low angle $2°\theta$ and this mixed layer clay mineral is probably a random mixture of illite/montmorillonite. Reflections of quartz, feldspars and pyrite were also obtained.

Sample no-22/GNP

Oriented slides gave very weak reflections at the place of kaolinite, but random powder data gave medium basal reflections at the place of kaolinite. The mineral kaolinite may be present in traces. Illite mineral may be present in traces. The gypsum minerals is the most dominant mineral in this sample. Reflections of quartz and feldspars were also observed.

3. PATALA SHALES FROM NILAWAHAN GORGE (Central Salt-Range).

(X-Ray diffraction data (random powder) of the samples, given in Appendix - C).

Sample no-1/NWP

The sample contains mostly kaolinite. Illite mineral is present in traces. Mixed layer clay mineral showed broad reflection as a "tail" of the illite 10.04Å reflection towards low 2°θ. Reflections of quartz and feldspars were also observed in random powder data.

Sample no-2/NWP

Kaolinite gave very weak reflections at 7.18Å and 3.57Å so this mineral may be present in traces. Illite mineral also gave weak reflections but on heating the intensity of the illite mineral was increased. Mixed-layer clay mineral may be a random mixture of illite/montmorillonite.

Sample no-3/NWP

Kaolinite gave very sharp reflection at 7.18 and 3.57Å. Illite is present in traces. Mixed-layer clay mineral showed expansion on glycolation and could be a random mixture of illite/montmorillonite.

Reflections of quartz and feldspars were also observed in the random powder data.

Sample no-4/NWP

A strong reflection was observed at the place of chlorite at 14.24Å, which did not showed the change on heating and glycolation, this reflection is due to chlorite and mixed layer clay mineral. Reflections of quartz and feldspars were present.

Sample no-5/NWP

Sample contains illite, traces of chlorite, quartz and feldspars.

Sample no-6/NWP

This sample contains illite and mixed-layer clay mineral. On heating the intensity of the illite was increased. Mixed-layer clay mineral may be a random mixture of illite/montmorillonite. Reflections of quartz and feldspars were also observed.

Sample no-7/NWP

Illite gave weak reflection at 10.04Å. A mixed-layer clay mineral was recognized by a long tail of illite towards low angle 2°θ and this is probably a random mixture of illite/montmorillonite. Random powder data gave the reflections of quartz, dolomite and feldspars.

Sample no-8/NWP

Kaolinite was absent in this sample. Illite gave its main basal reflection at 10.04Å. Mixed-layer clay mineral is probably a random mixture of illite/ montmorillinite.

Reflections of quartz, feldspars and gypsum were also observed in random powder data.

Sample no-9/NWP

Kaolinite gave very weak reflections. It may be present only in traces. Illite gave an enhanced reflection in acid-digested slide. In this slide illite reflection produced a long tail towards low angle 2°θ. It is likely that a random mixture of illite/ montmorillonite is present.

Reflections of quartz and feldspars were also obtained in random powder.

Sample no-10/NWP

Kaolinite was absent in this sample. Illite gave its reflection at 10.04Å. The intensity of illite increased on heating and glycolation. Mixed-layer clay mineral is probably a random mixture of illite/ montmorillonite.

Reflections of quartz and feldspars were also observed in the random powder.

Sample no-11/NWP

Kaolinite was recognized by its main basal reflections. Illite is present in traces. The mixed-layer clay mineral gave a broad reflection between 10.04Å to 17.65Å, which partially shifted and expanded to 12.61-22.07Å on glycolation. It is probable that a random mixture of illite/montmorillonite is present. Reflections of quartz, gypsum and feldspars were also observed.

Sample no-13/NWP

This sample gave the reflections for kaolinite, illite and mixed-layer clay mineral (fig. 2.7). Traces of chlorite may be present. Mixed-layer clay mineral gave a broad reflection at 11.32-19.19Å which expanded on glycolation at 12.61-22.07Å. It is probable that a random mixture of illite/montmorillonite is present. Random powder data gave reflections of quartz and feldspars.

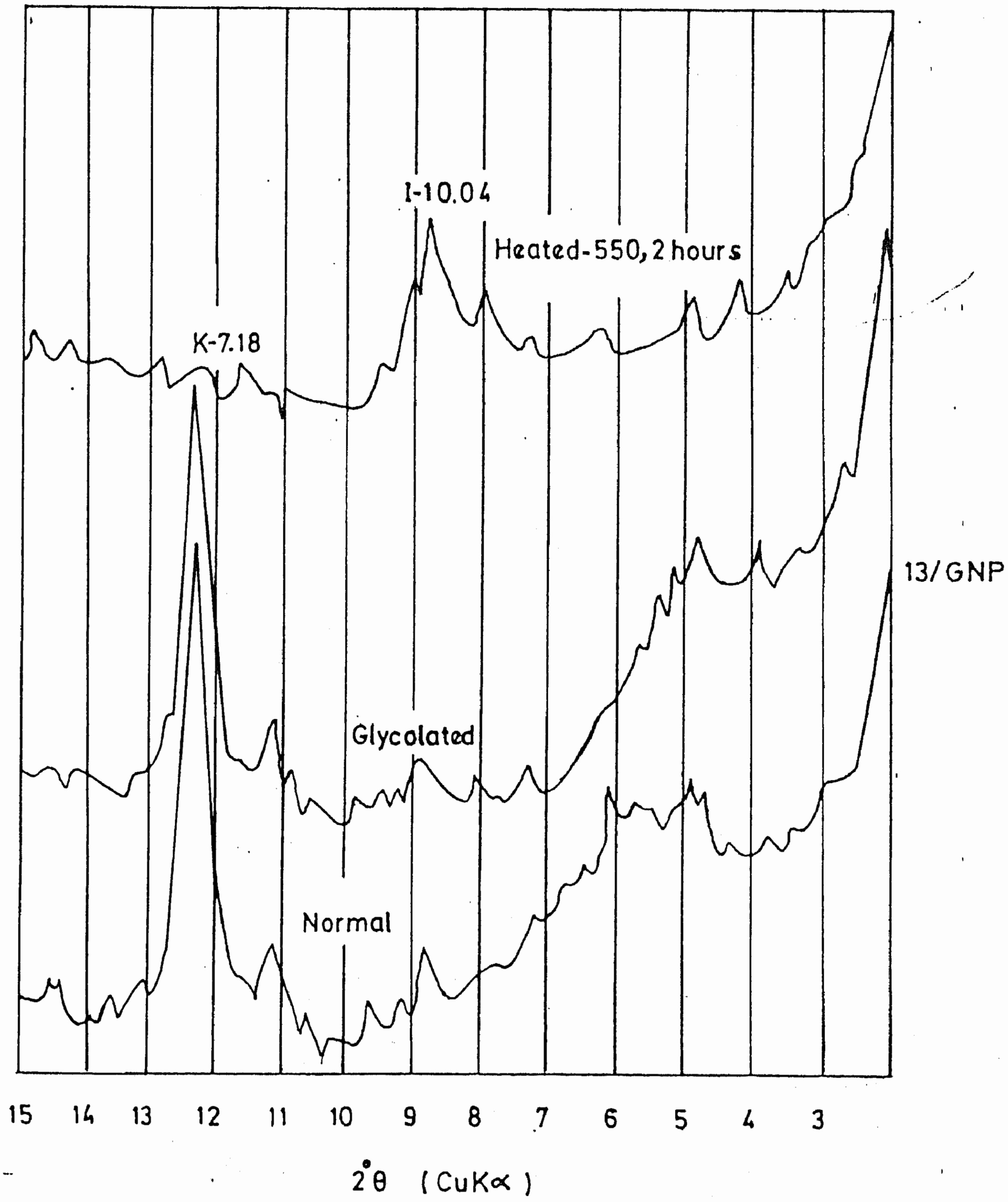


Fig:2.7 X-ray diffractograms showing well-crystalline Kaolinite (K)-Mixed layered mineral (ML) and Illite (I) peaks at different treatments.

Sample No-14/NWP

This sample contains mostly mixed-layer clay mineral which is probably a mixture of illite/montmorillonite. Kaolinite and illite minerals were absent in oriented slides.

Reflections of quartz, feldspars and gypsum were also obtained from random powder.

Sample No-15/NWP

Kaolinite was recognized by its main basal reflections at 7.18Å and 3.57Å. Illite gave its reflection at 10.04Å. Mixed layer clay mineral gave a reflection between 12.98Å to 16.35Å in untreated slide, but on glycolation, it expanded and reflections were noted at 14.71-22.07Å. It is probable that a random mixture of mixed-layer clay mineral is present.

Reflections of quartz, feldspars are present in random powder.

Sample No-16/19/NWP

Sample contain mostly kaolinite. The kaolinite is well crystallized and gave reflections at 7.18Å and 3.57Å. Illite mineral is present in traces. On glycolation the mixed-layer clay mineral gave reflection at 16.66Å but in acid-digested and heated slides such reflections were not observed at same point. It is probably a random mixture of illite/montmorillonite.

Sample no-17/NWP

Kaolinite, illite and mixed-layer clay minerals were present in this sample. A broad reflection was also observed at 14.24Å, which is changed on glycolation and disappeared on heating. It gave a broad reflection in glycolated slide. Mixed-layer clay mineral is present and the mixture may be a mixture of illite/ montmorillonite/ chlorite.

Reflections of quartz and feldspars are observed in random powder data.

Sample No-18/NWP

The sample contains kaolinite with mixed-layer clay mineral. The illite mineral is present in traces. The mixed-layer clay mineral may be a mixture of illite/ montmorillonite. Reflections of quartz and feldspars were also observed in random powder data.

Sample no-21/NWP

Sample contains mainly kaolinite with traces of illite and mixed-layer clay mineral. The mixed-layer clay mineral is a mixture of illite/ montmorillonite.

Reflections of quartz and feldspars were also observed in random powder data.

Sample no-22/NWP

This samples contain mostly kaolinite with traces of illite and mixed-layer clay mineral. The mixed-layer clay mineral is a mixture of illite/ montmorillonite .

Reflections of quartz and feldspars were also observed.

Sample No-23/NWP

The sample contains mostly kaolinite with traces of illite and mixed-layer clay mineral. Mixed-layer clay mineral is a random mixture of illite/ montmorillonite.

4. PATALA SHALES FROM THE KATHA AREA (Central Salt Range)

(X-Ray diffraction data (random powder) of the samples, given in Appendix - D)

Sample No-1/KTRP

Sample contains kaolinite, mixed-layer clay mineral and traces of illite. The mixed-layer clay mineral gave its reflections between 10.27Å and 22.6Å, which expanded on glycolation to 12.6Å and 22.6Å, leaving a symmetrical illite peak. Mixed-layer clay mineral is a random mixture of illite/ montmorillonite.

Reflections of feldspars, quartz and calcite were observed in random powder.

Sample no-2/KTRP

Kaolinite was recognized from its main basal reflections at 7.18Å and 3.57Å. Illite gave its reflection at 10.04Å. Illite may be present in traces. The mixed-layer clay mineral gave a broad reflection between 10.27-21.53Å, which expanded on glycolation towards low angle 2° θ in the range of 13.38-23.23Å. A random mixture of illite/ montmorillonite is present.

Random powder data gave a reflections of quartz, feldspars and calcite mineral.

Sample No-3/KTRP

This sample contains kaolinite with traces of illite. Mixed-layer clay mineral is a mixture of illite/ montmorillonite.

Reflections of quartz, feldspars and calcite were obtained in random powder data.

Sample No-4/KTRP

Kaolinite was recognized by its main basal reflections. The illite gave its reflections in normal, glycolated and heated slides. Mixed-layer clay mineral gave its broad reflections in range of 12.61-25.96Å, which expanded on glycolation but on heating and acid-digestion it disappeared. A random mixture of illite/ montmorillonite is present as a "tail of illite towards low angle 2°θ.

Reflections of quartz, feldspars and gypsum were also observed.

Sample No-7/KTRP

The sample contains mainly kaolinite, illite and traces of mixed-layer clay mineral. A broad reflection was noted between 21.53-11.04Å, which did not disappear on heating but expanded on glycolation from 12.44-27.58Å. This broad reflection may be a swelling chlorite. The mixed-layer clay mineral is a random mixture of swelling chlorite/ montmorillonite, illite/ montmorillonite. Reflections of quartz, feldspars and gypsum were also observed in random powder data.

Sample No-8/KTRP

This sample have the similar description as in sample no-7/KTRP.

Sample no-9/KTRP

This sample consists of kaolinite and traces of illite (fig 2.8). Mixed-layer clay mineral gave broad reflection which expanded on glycolation but partly disappeared on heating. It is probable that a random mixture of illite/ montmorillonite is present.

Reflections of quartz and feldspars mineral were observed from the random powder data.

Sample No-10/KTRP

Kaolinite was recognized by its main basal reflections at 7.13Å and 3.57Å. Illite mineral was present in traces (fig. 2.8). The mixed-layer clay mineral gave a broad reflections at 10.27–19.9Å, which expanded on glycolation to 13.38–22.07Å, towards low angle 2°θ.

Sample no-11/KTP

Kaolinite gave its basal reflections at 7.18Å and 3.57Å. Illite mineral is present in traces. The mixed layer clay mineral gave reflections between 10.63–22.07Å. This reflection was slightly shifted towards low angle 2°θ at the range between 11.04–23.23Å. The mixed-layer clay mineral is a random mixture of illite/ montmorillonite.Reflections of quartz, feldspars and gypsum were observed in random powder data.

Sample no-12/KTRP

This sample contains kaolinite, illite and mixed-layer clay mineral (fig. 2.8). Mixed-layer clay mineral gave its reflections between 12.98–19.19Å, which slightly expanded on glycolation to 14.24–19.19Å, but disappeared on heating at 550 °C for two hours. The mixed-layer clay mineral is present as illite/ montmorillonite. Reflections of quartz, feldspars and gypsum were observed in random powder data.

Sample no-13/KTRP

kaolinite was recognized due to basal reflections. Illite gave a reflection at 10.04Å. Mixed-layer clay mineral gave a broad reflection between 9.8–22.02Å. These reflections expanded on glycolation towards low angle 2° θ, in range 12.98Å to 29.42Å (fig. 2.8). Mixed-layer clay mineral is a random mixture of

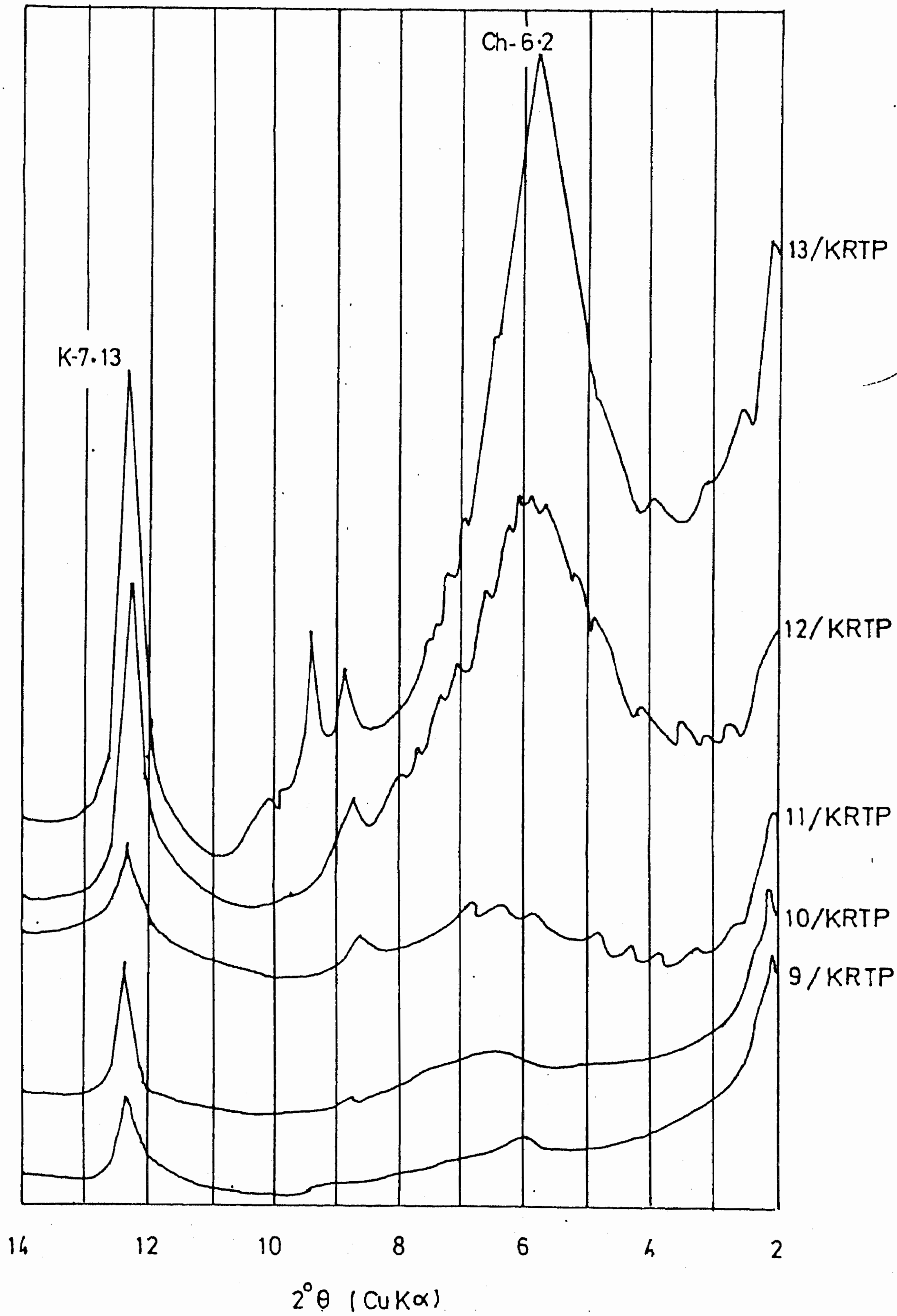


Fig:2.8 X-ray diffractograms of Kaolinite (K) and Chlorite (Ch) in different sample from the Katha Section (Central Salt Range) showing-degraded to well crystaline minerals.

illite/ montmorillonite. Random powder data gave the reflections of quartz, feldspars and gypsum.

Sample no-14/KTRP

Kaolinite and illite were recognized by its main reflections at 7.13Å and 10.04Å respectively. The intensity of the illite mineral increased on heating at 550 °C for two hours. A broad reflection was observed for mixed-layer clay mineral in range 11.04Å to 22.07Å, which expanded on glycolation in range from 12.98-23.23Å, towards low angle 2°θ, indicating random mixture of illite/ montmorillonite.

Reflections of quartz, feldspars and gypsum were also observed in random powder data.

Sample No-15/KTRP

This sample contains kaolinite and mixed-layer clay mineral. Illite mineral is present in traces. Mixed-layer clay mineral gave broad reflections between 11.32Å to 22.07Å which expanded on glycolation and was not affected on acid-digestion, and disappeared on heating. It is a random mixture of illite/ montmorillonite.

Reflections of quartz, feldspars and gypsum were also observed in random powder data.

ample no-16/KTRP

Sample contains mostly kaolinite, illite and mixed-layer clay minerals. Mixed-layer clay mineral gave a broad reflection between 11.32Å to 22.07Å in untreated slide but on glycolation the reflection at 11.32Å shifted in range 12.61-22.07Å. On acid-digestion it did not change but disappeared on heating. It is probable that mixed-layer clay mineral is illite/ montmorillonite.

Reflections of gypsum, feldspars, quartz and calcite were also obtained in random powder data.

Sample No-17/KTRP

Kaolinite was recognized due to 7.18Å and 3.57Å reflections in the oriented slides. Illite gave its reflection at place of 10.04Å. The intensity of illite increased on heating and acid-digestion. Mixed-layer clay mineral gave a broad reflections in untreated and acid-digested slides, in range 11.62-22.02Å. On glycolation these reflections were observed between 12.98-25.96Å. It is probable that the mixed-layer clay mineral is a random mixture of illite/ montmorillonite.

Reflections of quartz, calcite and feldspars were also observed in random powder data.

Sample no-18/KTRP

Kaolinite, illite and mixed-layer clay minerals are present in this sample. Mixed-layer clay mineral gave broad reflections between 11.32, 15.22-23.23Å. These reflections were also observed after acid-digestion between 12.26, 15.76-22.02Å and on glycolation in range of 12.61-16.66-26.75Å, but disappeared on heating at 550 °C for two hours. It is probable that mixed-layer clay mineral is a random mixture of illite/ montmorillonite.

Reflections of quartz, feldspars, calcite and gypsum were also observed in random powder data.

Sample No-19/KTRP

Kaolinite and mixed-layer clay minerals are mainly present in this sample. Mixed-layer clay mineral gave a broad reflection between

9.8-19.19Å in untreated slide and in acid-digested slide it gave a reflection between 9.6-22.02Å. On glycolation, it partially shifted towards low angle 2° θ between 12.88Å to 24.52Å, but disappeared on heating. It is probable that the mixed-layer clay mineral is illite/montmorillonite.Reflections of quartz, feldspars and calcite were also observed in random powder data.

B. DISCRIPTION OF CLAY AND OTHER MINERALS.

1. KHAWRI KHAWAR (Kala Chitta Range)

a. General clay mineralogy

The clay minerals were investigated in thirty five samples for identification and semiquantitative anlysis of clay minerals distributed in the Patala Formation, exposed in Khawri Khawar area.

KHAWRI KHAWAR (Kala Chitta Range).

i. Kaolinite

Kaolinite was recognised due to its main basal reflections at 7.13Å and 3.57Å. The random powder data of the samples gave other additional reflections for kaolinite minerals. The kaolinite mineral is not continuously distributed in the Patala Formation from its base to the top as it was not detected in many samples. Its distribution is scattered and generally it increases towards the base of the formation showing depositional and diagenetic variations. The mineral increases in shaly and coaly parts of the formation. Its mean percentage is 5.6 percent in the Patala Formation in the Khawri khawar with 10.077 standard errors (S.E) and 11.7 standard deviation (S.D). The maximum kaolinite in samples of the Khawri Khawar (Kala Chitta Range) is 31 percent to 7 percent. The kaolinite was not detected in twenty four samples. The details of the individual samples have been given in previous section.

Table 2.1 provides the semiquantitative analysis of the kaolinite mineral in individual samples of the Patala Formation and (fig. 2.9) shows its distribution from base to the top. Appendix-A provides the position of reflections given by kaolinite in random powder data. The behaviour of kaolinite

Table: 2.1

THE SEMIQUANTITATIVE ANALYSIS OF CLAY MINERALS OF THE PATALA FORMATION EXPOSED IN KHAWRE KHAWAR (KALA CHITTA RANGE) (THE CRYSTALLINITY INDICES OF KAOLINITE & ILLITE (C.I) ARE ALSO PROVIDED)

S.No.	Sample No.	Kaol %	I %	Chl %	ML %	Kao C.I	I C.I
1	1 /KKP	-	-	-	-	-	-
2	2 /KKP	-	-	-	-	-	-
3	3 /KKP	31	16	32	21	0.8	0.4
4	4 /KKP	-	-	-	-	-	-
5	5 /KKP	0	31	16	53	0	0.3
6	6 /KKP	-	-	-	-	0	0
7	7 /KKP	18	27	0	55	0.5	0.4
8	8 /KKP	0	24	48	28	0	0.5
9	9 /KKP	-	-	-	-	0	0
10	10 /KKP	29	32	23	16	0.4	0.3
11	11 /KKP	0	40	0	60	0	0.3
12	12 /KKP	-	-	-	-	0	0
13	13 /KKP	0	58	21	21	0.8	0.3
14	14 /KKP	23	31	23	23	0.7	0.4
15	15 /KKP	0	66	13	21	0	0.5
16	16 /KKP	-	-	-	-	0	0
17	17 /KKP	0	28	43	29	0	0.4
18	18 /KKP	11	34	33	22	0.3	0.2
19	19 /KKP	12	31	26	31	0.4	0.3
20	20 /KKP	0	33	48	19	0.5	0.5
21	21 /KKP	7	56	23	14	0.5	0.1
22	22 /KKP	0	18	55	27	0	0.3
23	23 /KKP	21	24	38	17	0.3	0.4
24	24 /KKP	0	52	26	22	0	0.4
25	25 /KKP	0	57	24	19	0	0.4

continued:-

26	26 /KKP	0	32	41	27	0	0.5
27	27 /KKP	0	50	31	19	0	0.5
28	28 /KKP	0	51	28	21	0	0.3
29	29 /KKP	0	51	26	23	0	0.4
30	30 /KKP	0	34	43	23	0	0.2
31	31 /KKP	0	50	26	24	0	0.4
32	32 /KKP	9	64	18	9	0.5	0.3
33	33 /KKP	15	40	24	21	0.5	0.4
34	34 /KKP	0	31	23	46	0	0.1
35	35 /KKP	0	46	38	16	0	0.4
36	36 /KKP	0	58	20	22	0	0.5
37	37 /KKP	0	69	8	23	0	0.4
38	38 /KKP	0	40	27	33	0	0.6
39	39 /KKP	0	63	23	14	0	0.2
40	40 /KKP	0	35	29	36	0	0.5
41	41 /KKP	-	-	-	-	0	0
42	42 /KKP	0	64	13	23	0	0.6
43	43 /KKP	-	-	-	-	0	0
44	44 /KKP	31	20	23	26	0.4	0.4

Index:

Kao :kaolinite

I :illite

Ch :chlorite

ML :mixed-layer clay minerals

C.I:crystallinity

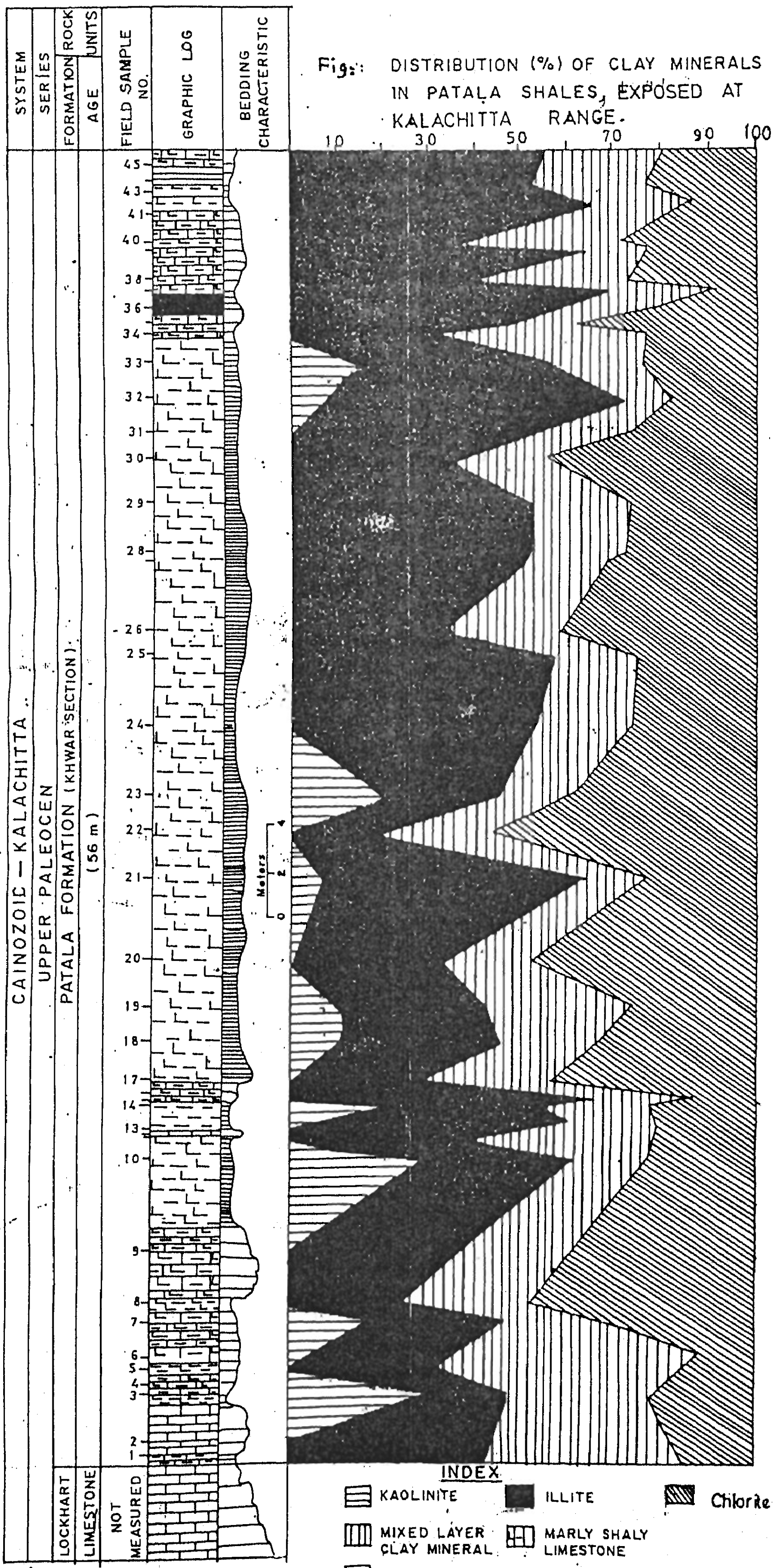


Fig.: DISTRIBUTION (%) OF CLAY MINERALS IN PATALA SHALES, EXPOSED AT KALACHITTA RANGE.

reflections in the oriented slides to the heat treatment, acid-digestion and glycolation has been given for individual samples in previous section.

Crystallinity indices of kaolinite was determined in the samples, in which reflections of kaolinite were recognized. The width of the kaolinite peak at 1/2 height was measured in at 7.13Å. The crystallinity indices of kaolinite samples of Khawri Khawar indicate that kaolinite is not well crystallized and the mean crystallinity indices is 0.26 with 0.27 standard deviation (S.D). The maximum crystallinity indices of kaolinite in the Patala Formation is 0.8 and minimum is 0.3.

ii. Illite

The illite mineral was found in thirty five samples in considerable quantity, in Khawri Khawar (Kala Chitta Range). Illite was recognised due to its main basal reflection at 10.04Å. Quantitatively, illite appeared to be a dominant mineral in the Patala Formation in the Khawri Khawar (Kala Chitta Range). Illite mineral is distributed in the Patala Formation in Khawri Khawra from base to the top and was also detected in all samples. It generally increases towards the top showing depositional and diagenetic variations. The illite "tail" towards low angle 2° θ degrees in shales showed some expansion on glycolation and its intensity increased on heating (fig. 2.2). Due to the presence of the mixed-layer clay mineral, the illite (001) reflection at 10Å is diffused towards low 2°θ angles in most of the samples. In some cases glycolation treatment pushed the mixed-layer clay mineral reflection towards low 2°θ angles by expansion. sometimes the mixed-layer clay mineral contracted on heating, indicate collapse into the illite reflection (fig. 2.2, 28/KKP).

Its mean percentage is 42 percent with 2.77 standard errors (S.E) and 16.41 standard devision (S.D). Table. 2.1 provides the semiquantitative analysis of the illite mineral in individual samples of the Patala Formation and fig. 2.9 shows its distribution. The illite mineral increases from its base to the top of the formation. Appendix-A give the positions of illite reflections from the random powder data.

The illite is not well crystallized. The mean crystallinity index is 0.37 millimeter with 0.122 standard deviation (S.D). The maximum crystallinity index of illite is 0.5 and the minimum is about 0.1. The samples showed no systematic variations in the crystallinity index of illite with depth. Figure 2.3 provides the detailes of the behaviour of reflections after glycolation, acid-degestion and heat treatments.

iii. Chlorite

Chlorite was found in thirty two samples in considerable quantities, but as traces were present in many other samples. chlorite was recognised due to its basal reflections at 14Å. The random powder data gave other additional reflections for chlorite mineral (appendix-A). The chlorite is mostly distributed in the Patala Formation, exposed at Khawri Khawar section in the Kala Chitta Range from base to the top and was not detected only in few samples. Generally it increases from base towards the top of the formation, showing depositional variations. The mineral increases in shaly and coaly parts of the formation. Its average percentage is 20.5 percent with 2.11 standard error (S.E) and 12.49 standard deviation (S.D). The maximum amount of chlorite found in the samples is 55 percent and minimum quantitaty is

8 percent in the Kala Chitta, (Khawri Khawar section) samples.

iv. Mixed-layer clay mineral

Most of the samples gave reflections of a mixed-layer clay minerals in the Khawri Khawar, (Fig.2.1) shows the behaviour of mixed-layer clay minerals on glycolation and on heat treatment. The samples, contain a random mixture of mixed-layer clay mineral, which shows expansion on glycolation and contraction on heating. Most of the samples exhibit some of the higher spacing reflections of mixed-layer clay minerals. These high speing reflections generally occur in the range between 16-28Å, wich show some expansion on glycolation and contraction on heating. Possible mixed layer clay minerals are illite/ montmorillonite, illite/ chlorite, illite/ swelling chlorite and montmorillonite/ chlorite.

b. Other minerals Present

i. Quartz

Quartz reflections were observed in all the samples in the Patala Formation exposed at Kala Chitta Range, Khawri khawar section (appendix-A).

ii. Feldspars

Weak reflections were observed in most of the samples for feldspars (appendix-A).

iii. Gypsum

The reflections of gypsum were observed occasionaly. Some of sample shows the reflections of gypsum in (appendix-A).

iv. Pyrite

Pyrite is a well known mineral associated with black shales. It was detected in forty samples from the measured section. (appendix-A).

v. Calcite

Calcite was found in most of the samples. Reflections observed in twenty seven samples (appendix-A).

In addition to the above minerals, reflections of the iron oxides, dolomite and several other minerals were detected in the individual samples. The details are provided in the (appendix-A).

2. GANDHALA NALA (Eastern Salt Range).

a. General Clay Mineralogy.

The mean analysis and variations of clay minerals of all the samples from Gandhala Nala Eastern Salt Range, are given in table (2.2). Kaolinite is the dominant clay mineral with appreciable illite and with some amount of a mixed-layer clay mineral but the chlorite is absent. The comparison with the Kala chitta shales shows that kaolinite is more abundant in this section of the Salt Range.

i. Kaolinite

The distribution of kaolinite in Gandala Nala Eastern Salt Range samples is shown in figure 2.10 and the average value is 38 percent (table. 2.2). Sharp reflections of kaolinite were observed in all samples. The kaolinite has a maximum quantity of 75 percent in (sample No. 12/15/GNP). Its distribution is scattered throughout the formation, showing the deposition and diagenetic variations. However the amount of this minerals increase in the coaly and shaly part of the formation. The crystallinity of kaolinite was better. The mean crystallinity index is 0.2. Table 2.2 shows the semiquantitative analysis of the kaolinite mineral.

Figure 2.7 provide the behaviour of kaolinite reflections in the oriented slides to the heat treatment, acid- digestion and glycolation for the individual samples.

ii. Illite

The distribution of illite in all Gandhala Nala samples of the Patala Formation is shown in figure 2.10. The mean value of illite is 38 percent which is reported in table. 2.2 together

Table: 2.2

THE SEMIQUANTITATIVE ANALYSIS OF CLAY MINERALS OF THE PATALA FORMATION EXPOSED IN GANDHALA NALA - EASTERN SALT RANGE. (THE CRYSTALLINITY INDICES OF KAOLINITE & ILLITE (C.I) ARE ALSO PROVIDED).

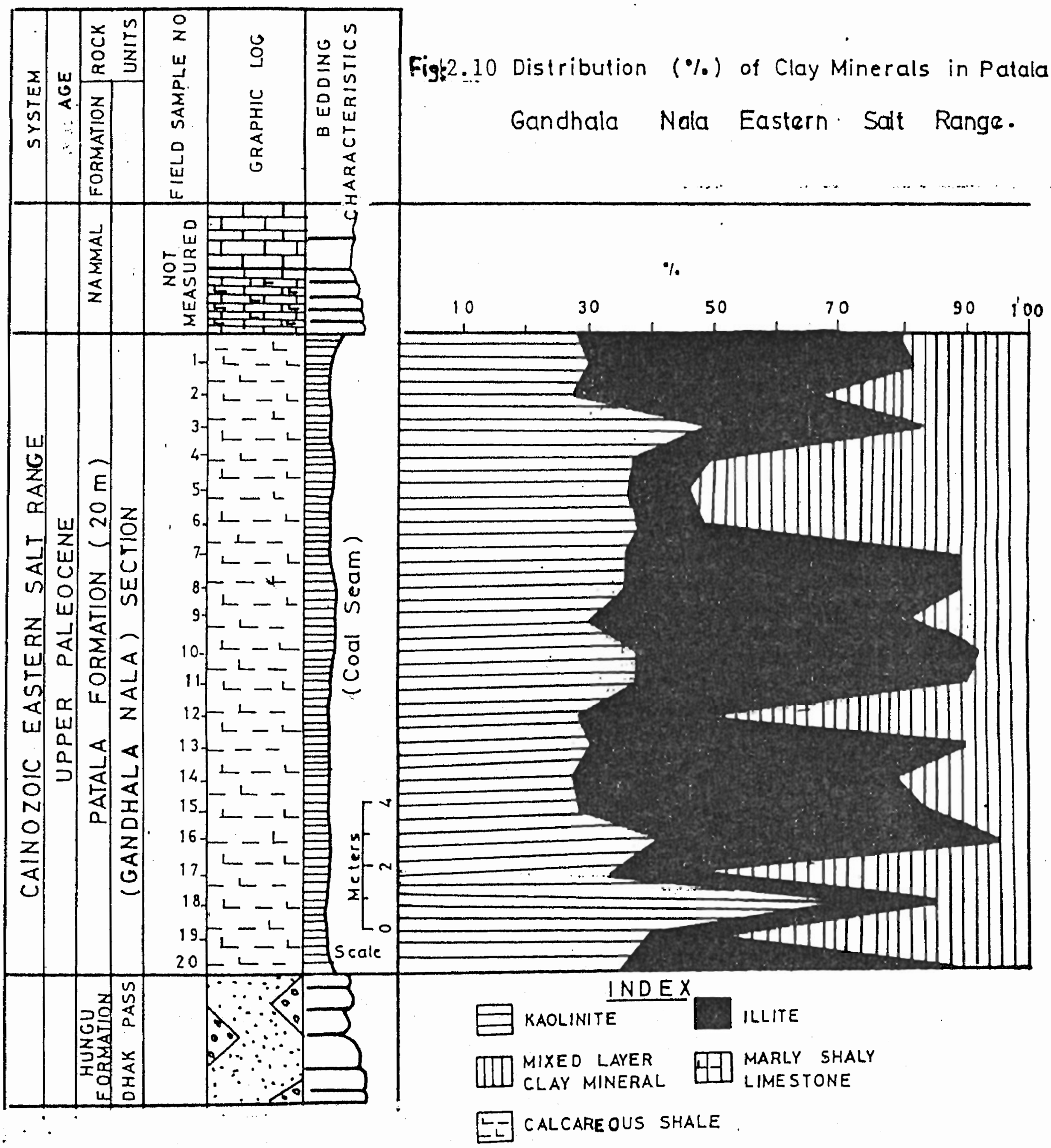
S.No.	Sample No.	Kao %	I %	ML %	Kao (C.I)	I (C.I)
1	1 /GNP	30	52	18	0.2	0.1
2	2 /GNP	28	38	33	0.2	0.1
3	3 /GNP	50	33	17	0.3	0.2
4	4 /GNP	37	12	51	0.4	0.3
5	5/GNP	37	9	55	0.2	0.1
6	6 /GNP	38	10	52	0.2	0.1
7	7 /GNP	36	53	11	0.2	0.1
8	8 /GNP	36	53	11	0.3	0.4
9	9 /GNP	31	50	19	0.3	0.4
10	10 /GNP	38	54	8	0.3	0.2
11	11 /GNP	38	52	10	0.4	0.4
12	12 /GNP	29	19	52	0.3	0.1
13	13 /GNP	31	59	10	0.4	0.3
14	14 /GNP	28	51	21	0.3	0.2
15	15 /GNP	29	54	17	0.3	0.1
16	16 /GNP	42	53	5	0.2	0.1
17	17 /GNP	34	13	53	0.2	0.3
18	18 /GNP	75	10	15	0.2	0.2
19	19 /GNP	40	10	50	0.3	0.2
20	20 /GNP	36	51	13	0.3	0.2
21	21 /GNP	41	53	6	0.3	0.2
22	22 /GNP	31	56	13	0.2	0.2

Index:

Kao :kaolinite C.I :crystallinity indices

I :illite ML :mixed-layer (ML).

Fig 2.10 Distribution (%) of Clay Minerals in Patala Shales, Gandhala Nala Eastern Salt Range.



with 19.43 standard deviation (S.D) and 4.14 standard error (S.E). It is the dominant clay mineral and is present in all samples. It increases in reasonable amount from base to the top of the formation. The intensity of illite was increased on heat treatment but no change was observed on acid-digestion and glycolation. Appendix-B provides the reflections of illite of random powder data saples.

The crystallinity index shows no significant variations. The average crystallinity index is 0.2. The maximum amount of illite isfound in sample No-13/GNP, and minimum 9 percent observed in the sample No-5/GNP.

iii. Mixed-layer clay mineral

Reflections of the mixed-layer clay mineral were observed in all samples from the Gandhala Nala as a long "tail" to 10Å illite reflection making it asymmetric towards low angle $2°\theta$ degree. These reflections generally showed peaks which expanded on glycolation and contracted after heating. The mixed layer clay mineral is probabaly a random mixture of illite and montmorillonite in various proportions. The average content of mixed-layer clay mineral in this section is 25 percent.

iv. Chlorite

The chlorite mineral was not detected in the Gandhala Nala.

b. Other minerals

i. Quartz

Quartz is the most abundant mineral. Quartz peaks were observed with medium to strong intensities in the random powder data (appendix-B).

ii. Feldspars

Reflecions of the feldspar group minerals were observed in most of the samples.

iii. Pyrite

Pyrite gave its reflections in most of the samples. The pyrite is an important mineral for its diagenetic development in the coal environment. Appendix B, provides the reflections given by pyrite mineral in various samples.

iv. Calcite/ dolomite

reflections of calcite and dolomite were also observed in most of the samples (appendix-B).

v. Gypsum.

The mineral gypsum gave its reflections in most of the samples (appendix-B).

In addition to the reflections given by the above mineral, several other minerals gave thire reflections in the random powder chart. Appendix-B provides the details of other reflections.

3. NILAWAHAN GORGE (Central Salt Range)

a. General clay mineralogy.

Identification and semiquantitative analysis of clay mineral was done for 23 samples of the Patala Formation collectd from Nilawahan gorge, Central Salt Range.

i. Kaolinite

Kaolinite was recognised due to its main basal reflections at 7.18Å and 3.57Å. The average value of 43 percent is reported in table. 2.3 with 7.31 standard error (S.E) and 35.07 standard deviation (S.D). Kaolinite was not detected in six samples. The maximum value was 90% in black coaly shale, sample No-22/NWP and minimum value is 5 percent in the sample No-5/NWP. Though its distribution is scattered an increaseing trend towards the base of the formation shows depostional and diagenetic variations.

Crystallinity index of kaolinite was determined in the samples in which its reflections were recognised. Indices show that the mineral is well crystallized. The mean crystallinity is 0.2.

ii. Illite

Illite was recognised due to its reflection at 10Å. The random powder data of the samples gave other additional reflections for illite mineral. The illite in Nilawahan area is not continuously distributed however minor increase towards the base and top of the formation showing depositional and diagenetic variations. The mineral increases in shaly part of the formation. Its average value is 15 percent in the analysed samples with 5.05 standard error (S.E) and 24.25 standard deviation (S.D).

Table 2.3 provides the semiquantitative analysis of

Table: 2.4

THE SEMIQUANTITATIVE ANALYSIS OF CLAY MINERALS OF THE PATALA FORMATION EXPOSED IN KARTHA AREA CENTRAL SALT RANGE. (THE CRYSTALLINITY INDICES OF KAOLINITE & ILLITE (C.I) ARE ALSO PROVIDED).

S.No	Sample No.	Kao %	I %	ML %	Kao (C.I)	I (C.I)
1	1 /KTRP	36	31	33	0.4	0.5
2	2 /KTRP	52	9	39	0.4	0.2
3	3 /KTRP	69	5	26	0.3	0.2
4	4 /KTRP	44	24	32	0.4	0.4
5	5 /KTRP	68	11	21	0.3	0.3
6	6 /KTRP	63	9	28	0.3	0.4
7	7 /KTRP	64	14	22	0.5	0.4
8	8 /KTRP	74	8	18	0.4	0.3
9	9 /KTRP	48	7	45	0.3	0.2
10	10 /KTRP	39	6	55	0.2	0.2
11	11 /KTRP	24	11	65	0.4	0.2
12	12 /KTRP	22	11	67	0.3	0.8
13	13 /KTRP	24	7	69	0.3	0.3
14	14 /KTRP	39	8	53	0.2	0.3
15	15 /KTRP	47	8	45	0.3	0.4
16	16 /KTRP	52	10	38	0.3	0.4
17	17 /KTRP	64	6	30	0.3	0.4
18	18 /KTRP	63	8	29	0.4	0.2
19	19 /KTRP	75	13	13	0.5	0.3

Index:

Kao : Kaolinite

C.I : crystallinity indices

I : Illite

ML : Mixed layer

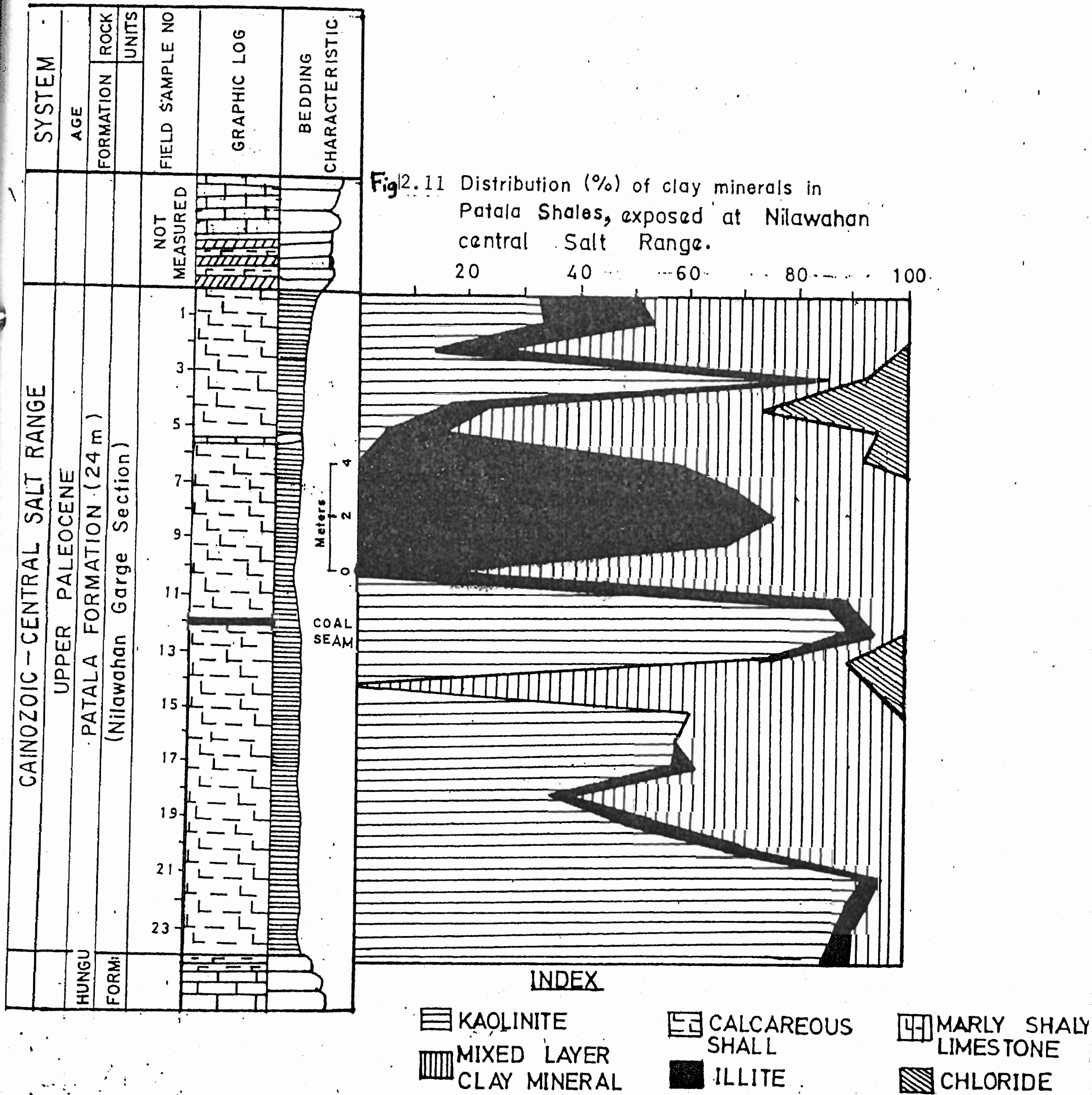


Fig 2.11 Distribution (%) of clay minerals in Patala Shales, exposed at Nilawahan central Salt Range.

the illite mineral in individual samples and (fig. 2.11) shows its distribution from base to the top of the formation. The behaviour of the illite reflections in the oriented slides to the heat treatment, acid-digestion and glycolation has been given for individual samples in the previous section.

iii. Mixed-layer clay mineral

The mixed layer clay mineral was recognized as a long tail of illite towards low angle 2θ degrees in all the samples. This mineral gave prominant reflections and was found in comparatively higher quantities. Table 2.3 provides the semiquanantitative mineral analyses and displays that in some samples it is as high as 100 percent. Figure 2.11 gives its distribution in the Nilawahan Gorge from base to the top, while (fig. 2.7) provide the nature of the reflections givens by the mixed layer clay mineral. The mixed layer clay mineral appears to be a mixture of illite-montmorillonite as it shows some expansion on glycolation. It could be a mixture of illite/montmorillonite and chlorite also. It is increase in this section as compared to the Gandhala Nala.

iv. Chlorite

The mineral chlorite was observed in seven samples only. It varies between 3 percent to 25 percent. Table. 2.3 gives the percentages of chlorite observed in the samples from the Nilawahan area, (Fig. 2.11) gives its distribution according to its stratigraphic positions in the Patala Formation. The nature of chlorite reflections and its behaviour with the acid and heat treatments indicate that the chlorite was deposited as a detrital mineral. The reflections of chlorite existed after heating at 550 °C and disappeared after acid digestion in most of the samples, (Fig. 2.8) provides the nature of chlorite reflections after various treatments. The mineral chlorite in the Nilawahan Gorge also displays its mixtures with other clay minerals, such as illite, montmorillonite etc.

b. Other Minerals

The random powder gave the reflections of several other minerals in the smaples from the Nilawahan Gorgea. The minerals are mentioned as below:-

i. Quartz

The reflections of quartz were found in all the samples Appendix-C, provides the details of these reflections.

ii. Feldspars

Reflections of the feldspar group minerals were observed in all the samples and can be observed in appendix-C.

iii. Calcite/dolomite

Reflections of calcite and dolomite were also noted in many samples. Appendix-C provides the details of the reflections.

iv. Gypsum

Reflections of gypsum were also noted in many samples. Appendix-C gives the details of these samples.

v. Pyrite

Reflections of pyrite were also observed in many samples. Appendix-C gives the details of the reflections and the samples.

iv. Several other minerals were noted in the random powder charts and the details of the reflections of other minerals are given in appendix-C.

4. KATHA AREA (Central Salt Range)

a. General clay mineralogy.

Identification and semiquantitative analysis of clay minerals was done for nineteen samples of the Patala Formation exposed from Katha area Central Salt Range.

i. Kaolinite

Kaolinite was recognised due to its main basal reflections at 7.13Å and 3.57Å. The random powder data of the samples gave additional reflections for kaolinite minerals. The minerals is not continuousely distributed from base to top in the Patala Formation in Katha area. Its distribution is scatterad, showing depositional and diagenetic variations. The mineral increases in shaly and coaly parts of the formation. Its mean percentage is 53% in the formation with 3.91 standard error (S.E) and 17.05 standard deviation (S.D).

Table 2.4 provides the semiquantitative analysis of the kaolinite mineral in the individual samples and (fig. 2.12) shows its destribution from the base to the top. Kaolinite is a dominant clay mineral this section. The behaviour of kaolinite reflection in oriented slides to the heat treatment, acid-digestion and glycolation has been given for individual samples in previous section. The maximum amount of kaolinite was 80 percent (observed in sample no. 19/KTRP) and minimum is 22 percent (observed in sample 12/KTRP)

Crystallinity indices was determined in the samples in which reflections of kaolinite were recognised. The kaolinite is not well crystallized and mean crystallinity indices is 0.4 with 0.08 standard deviation (S.D) with maximum crystallinity indices of 0.5 and minimum crystallinity indices of 0.2. It should be

Table:- 2.3

THE SEMIQUANTITATIVE ANALYSIS OF CLAY MINERALS OF THE PATALA FORMATION EXPOSED IN NILAWAHAN GORGE CENTRAL SALT RANGE. (THE CRYSTALLINITY INDICES OF KAOLINITE & ILLITE ARE ALSO PROVIDED)

S.No.	Sample No.	Kao %	I %	Chl %	ML %	Kao (C.I)	I (C.I)
1	1 /NWP	34	19	0	47	0.2	0.2
2	2 /NWP	14	10	0	76	0.2	0.1
3	3 /NWP	81	4	8	7	0.4	0.4
4	4 /NWP	17	8	25	50	0.2	0.2
5	5 /NWP	5	4	5	86	0.0	0.0
6	6 /NWP	0	49	8	43	0.0	0.1
7	7 /NWP	0	70	0	40	0.0	0.3
8	8 /NWP	0	76	0	24	0.0	0.5
9	9 /NWP	0	67	0	33	0.0	0.7
10	10 /NWP	0	17	0	83	0.0	0.5
11	11 /NWP	87	3	3	10	0.5	0.2
12	12 /NWP	64	17	23	6	0.3	0.4
13	13 /NWP	72	4	10	14	0.4	0.2
14	14 /NWP	0	0	0	100	0.0	0.0
15	15 /NWP	61	0	0	39	0.3	0.0
16	16 /NWP	59	0	0	41	0.4	0.0
17	17 /NWP	58	4	0	38	0.3	0.2
18	18 /NWP	36	0	0	64	0.4	0.0
19	19 /NWP	50	4	0	46	0.2	0.2
20	20 /NWP	68	2	0	30	0.3	0.0
21	21 /NWP	93	2	0	5	0.3	0.3
22	22 /NWP	90	4	0	6	0.2	0.4
23	23 /NWP	88	3	0	9	0.2	0.3

Index:

Kao :kaolinite
ML :mixed layer clay mineral
C.I:crystallinity indices
I :illite
Ch :chlorite

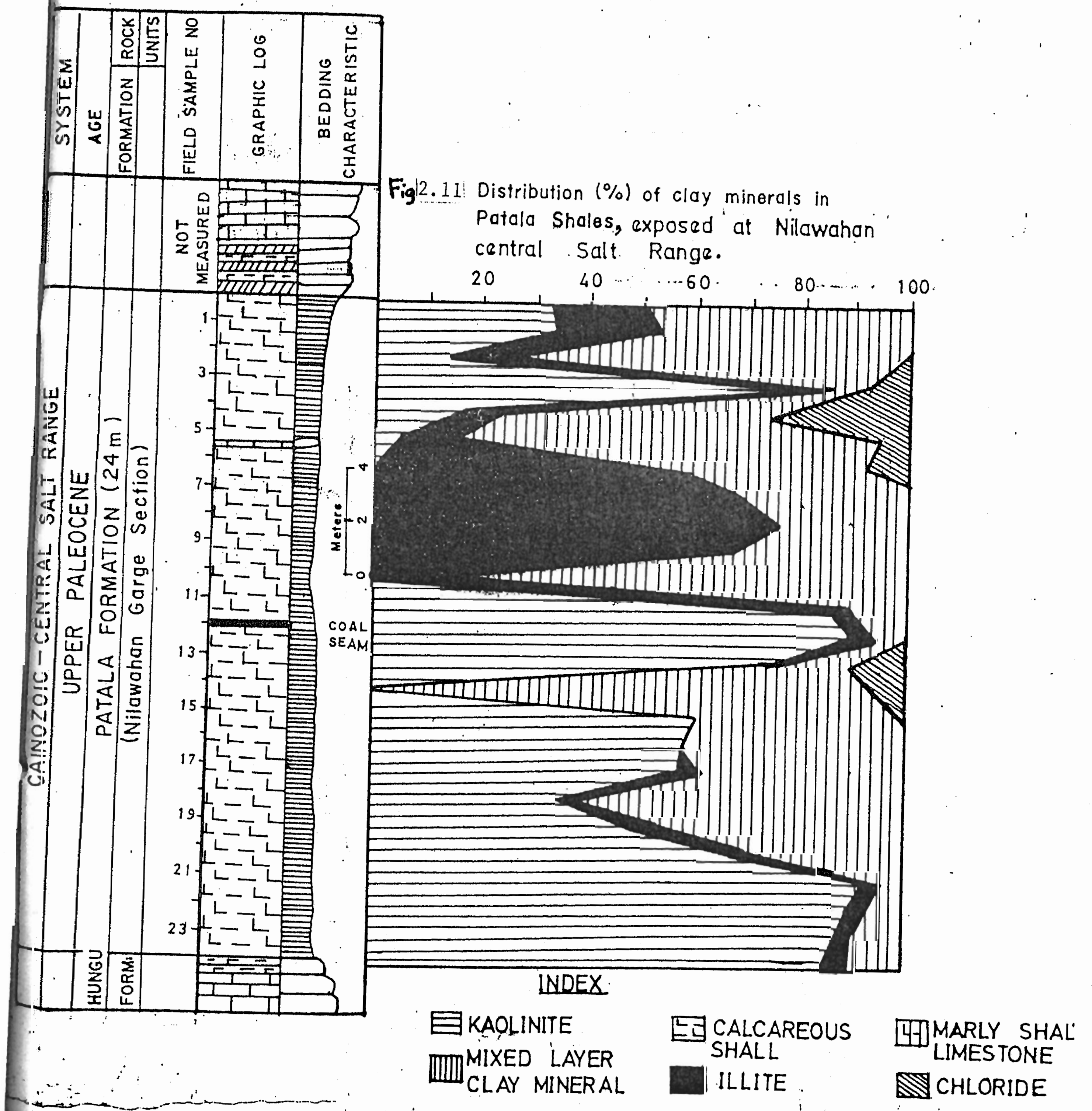


Fig 2.11 Distribution (%) of clay minerals in Patala Shales, exposed at Nilawahan central Salt Range.

pointed that the crystallinity indices is inversely proportional to the real crystallinity of the mineral.

ii. Illite

The distribution of illite in Katha area is shown in (fig.2.12). The mean value is 11 percent and is provided in table 2.4 togather with 6.43 standard deviations (S.D) and 1.47 standard errors (S.D). The mineral is not continuously distributed in the Patala Formation from base to the top and was detected in traces in most of the samples. Its distribution is scattered showing depositional and diagenetic variations. Table 2.4 provides the semiquantitative analysis of the illite mineral in the individual samples of the Patala Formation, and reflects its distribution from the base to the top of the formation. Appendix-D provides the position of reflections given by illite in random powder data chart. The behaviour of illite mineral in oriented slides to the heat treatment, acid-digestion and glycolation has been given for individual samples in previous section.

The crystallinity indices of illite is 0.3 which shows that the illite is not a well crystallized mineral. The maximum crystallinity indices is 0.8 minimum as 0.2 table. 2.4.

iii. Mixed-layer clay mineral

Reflections due to mixed-layer clay mineral were found in shale samples diffractograms as a "tail" to the 10Å illite reflection towards the low 2θ degree angle. These reflection generally expanded on glycolation and contracted on heating. Mixed-layer clay mineral may be a random mixture of illite and montmo-rillonite.

The average value for the abundance of mixed-layer clay mineral showed variations in Katha area. Its mean value observed is 38 percent with 3.88 standard error (S.E) and 16.93 standard deviation (S.D). Table 2.4 provides the semiquantitative analysis of the mixed-layer clay mineral in individual samples and (fig. 2.12) shows its destribution from the base to the top of the formation. The maximum value of the mixed layer clay mineral is 65 percent and minimum value is 13 percent in the samples of the Katha area table 2.4. The mixed layer mineral increases in the center of the formation.

b. Other minerals

Quartz, feldspars, dolomite and pyrite reflections were also observed in the samples of Katha section of the central Salt Range in the Patala Formation which has been mentioned below;

i. Quartz

The mineral quartz gave its sharp reflections and were found in all samples (appendix-D).

ii. Feldspars

The reflections of the feldspar group minerals were observed in most of the samples. Appendix-D provides the details of these reflections.

iii. Calcite/dolomite

Reflections of calcite/dolomite/ankerite were also observed in many samples. Appendix-D provides the details of the reflections.

iv. Pyrite

The mineral pyrite gave its reflections in several samples. Appendix-D provides the details of the reflections with the respective samples.

v. Gypsum

Reflections of the mineral were observed in the charts of the random powder data. Appendix-D provides the details of the samples.

vi. Other Minerals

In addition, reflections of other minerals were also observed (appendix-D).

CHAPTER - III

INTERPRETATION OF RESULT

, GENERAL

The distribution of the clay minerals was investigated and interpreted in the samples from eastern, central and western Salt Range to understand the horizontal variations in the Patala Formation from east to west. The average percentage of clay minerals from four sections of the Salt Range were studied and compared. One section from north of the area was sampled from the Kala Chitta Range to understand the distribution of clay mineral from south (Salt Range) to the north of the Potwar basin (Kala Chitta Range). The east-west variations of the clay minerals indicate that the kaolinite gradually increases towards the western Salt Range, indicating gradual changes in the depositional environments and showing that the acid environments (Kossovekey et al.,1964) were existed during the deposition of the Patala Formation from east to west (Salt Range area). In the present Potwar basin the kaolinite gradually increases towards west and it could be due to late diagenetic changes after the burial of the coaly and shaly sediments and sedimentary process of brackish waters to shallow marine origin.

Weaver (1958) pointed out that generally the illite deposited in basins are detrital in nature and depositional media do not provide sudden structural changes. It is most likely that the illite mineral found in the Salt Range areas has a detrital nature. The illite mineral gradually decreases in amount towards west indicating that it is a detrital mineral which was brought due to erosion of the sediments in the east and south. This indicates a gradual deepening and subsidence of the basin of deposition from east to west, with local ridges and troughs. It is also probable that the distribution of illite reflects a shore line or parallic deposition (fig. 3.1).

The mixed-layer clay mineral gradually show an increase towards west and it could be due to diagenetic changes in the montmorillonite and illite. It is also possible that the montmorillonite mineral acquired K+ ions from the ocean and early diagenetic waters during the early burial stages gave rise to a mixed-layer clay mineral of illite/ montmorillonite composition and occasionally illite - montmorillonite - chlorite composition.

The chlorite mineral was detected in some samples of Nilawahan area indicating some local diagenetic conditions where Mg++ ions were available in the sea water and early diagenetic waters locally gave rise to the chlorite mineral. It may be partly due to closing of the basin and hence concentration of the Mg++ ions. It is also probable that the detrital chlorite was brought into the depositional basin from the erosion of local rocks/ridges in south of Nilawahan. The distribution of average clay minerals of the Patala Formation of Salt Range from the Gandhala Nala in the east to the Nammal Gorge in the west, is given in (fig. 3.1).

The variations in the clay mineral distribution of the Potwar basin from the south to the north show systematic sedimentational changes in the depositional basin which was deepening towards the north, these variations are shown in (fig. 3.2).

The mixed-layer clay mineral did not show much variations, it could be due to early or late diagenetic changes

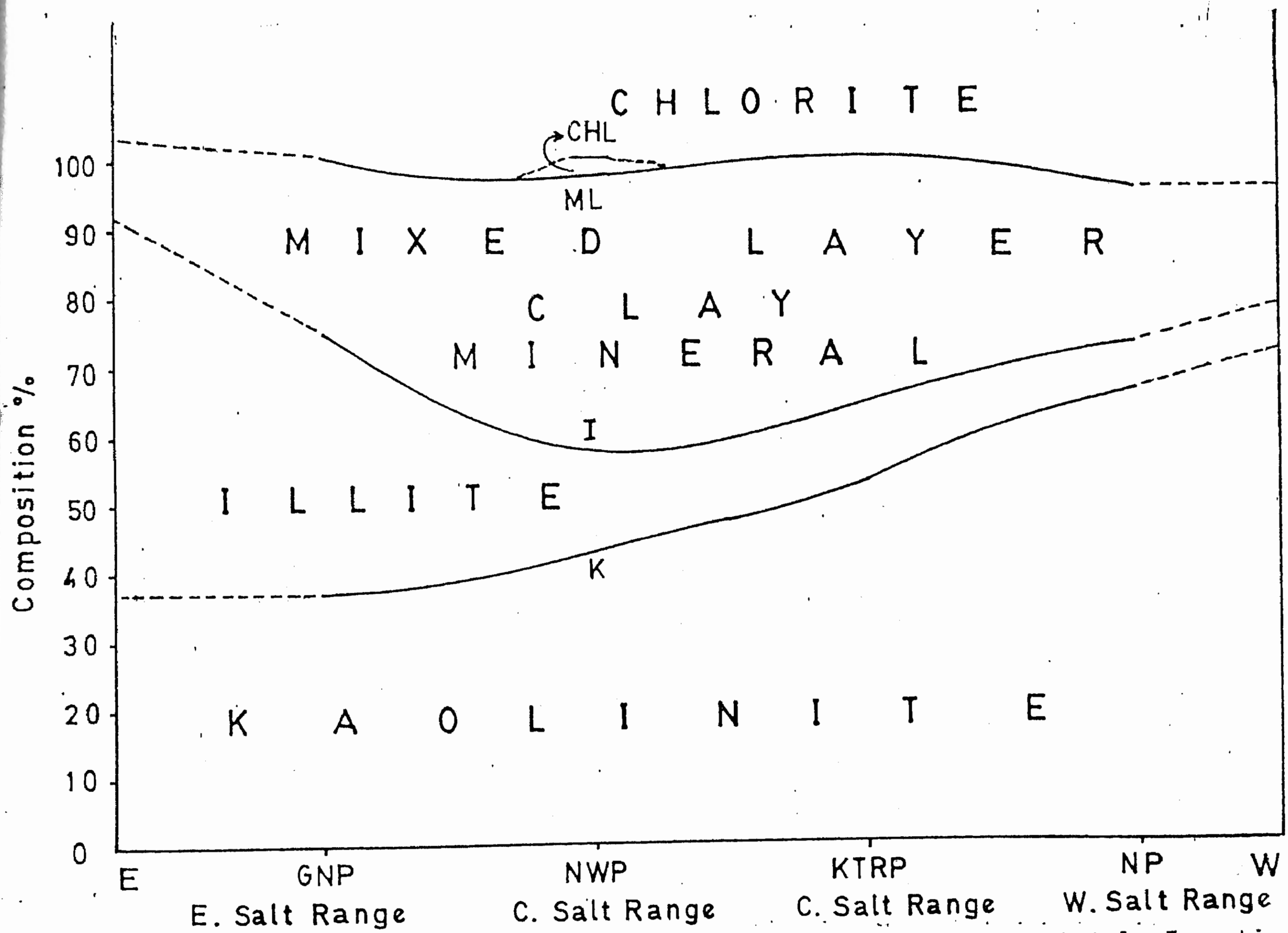


Fig:3.1 The distribution of average clay minerals in Patala Formation Salt Range from Gandhala Nala area in the east to the Nammal Gorge in the West.

Note: Horizontal scale is Schematic.

Index

Assumed ----

Actual ——

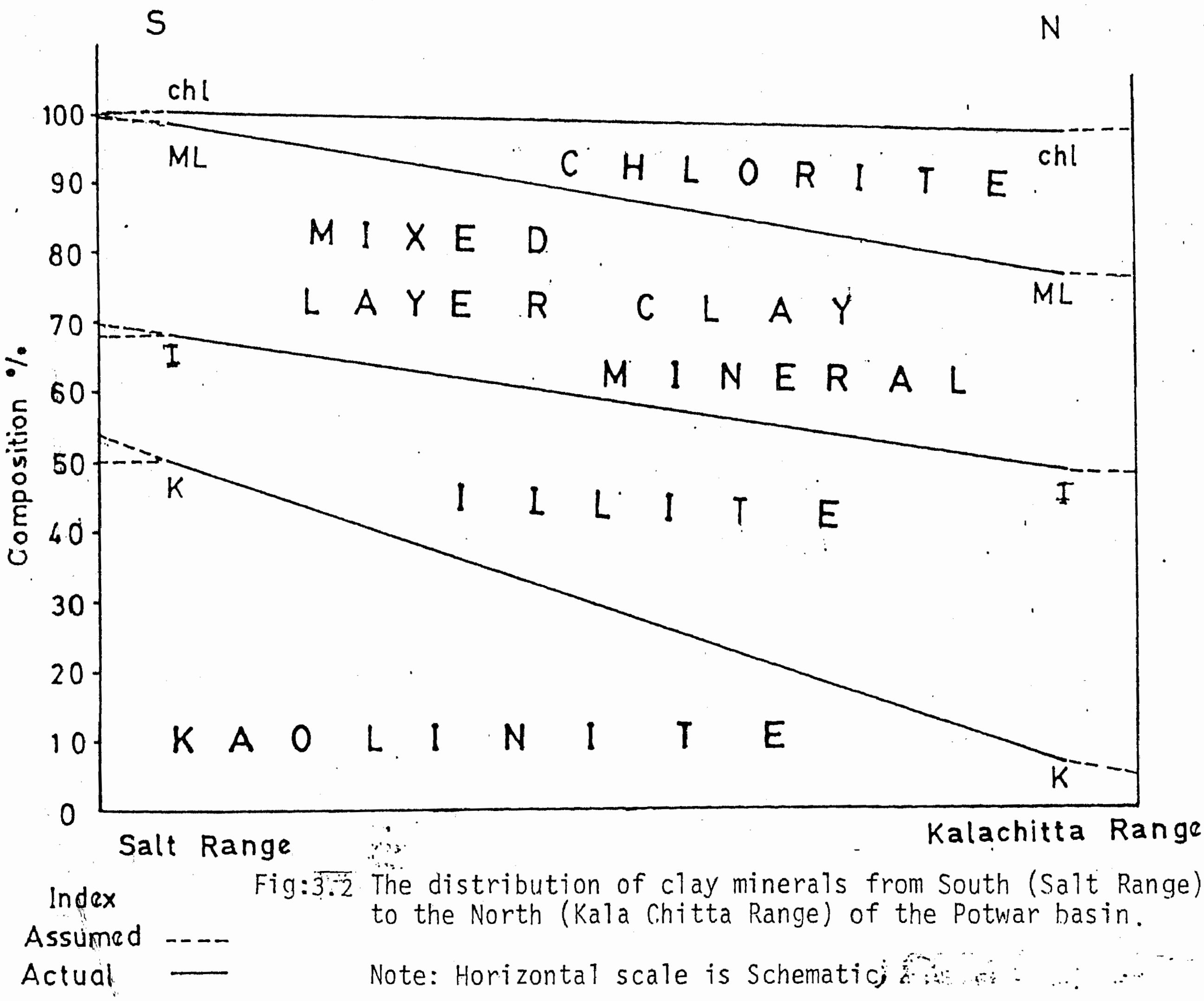


Fig:3.2 The distribution of clay minerals from South (Salt Range) to the North (Kala Chitta Range) of the Potwar basin.

Note: Horizontal scale is Schematic.

of the smectite type mineral (fig. 3.1). The clay minerals from the Salt Range are better crystallized as compared to the clay minerals from the Kala Chitta Range. The average crystallinity indices of kaolinite in Salt Range, is about 0.26 millimeter for 64 samples (fig. 3.3), while the average crystallinity indices of kaolinite in the Khawri khawar (Kala Chitta Range) samples is 0.77 average for 12 samples. This indicates a significant difference in the crystallinity indices of kaolinite amongst the Salt Range and Kala Chitta Range samples, and also indicates the distribution of crystallinity during its transportation in the deeper parts of the basin from the south (southern continent). The crystallinity of illite was determined in all samples from the Salt Range (fig. 3.4) and found to be 0.23 (average of 64 samples) while the mean crystallinity of illite from Kala Chitta Range is 0.37 (average of 35 samples). This indicates the sharp difference in crystallinity indices of illite from the Salt Range and Kala Chitta Range showing the disintegration of the minerals due to transportation from south to north.

The less crystalline nature of kaolinite mineral in Kala Chitta Range may be due to its detrital nature, it is assumed that it was transported by the sedimentary processes from erosion of the soils in the southern shallow continental parts. It is probable that the stratigraphic horizons rich in kaolinite may represent the horzions of organic rich matters brought from the southern part of the continent, and may be responsible for the origin of the gas and oil. Additional work on clays and quantitative analysis for the organic matter would be more useful to understand these important processes of the generation of oil and gas in the Patala Formation.

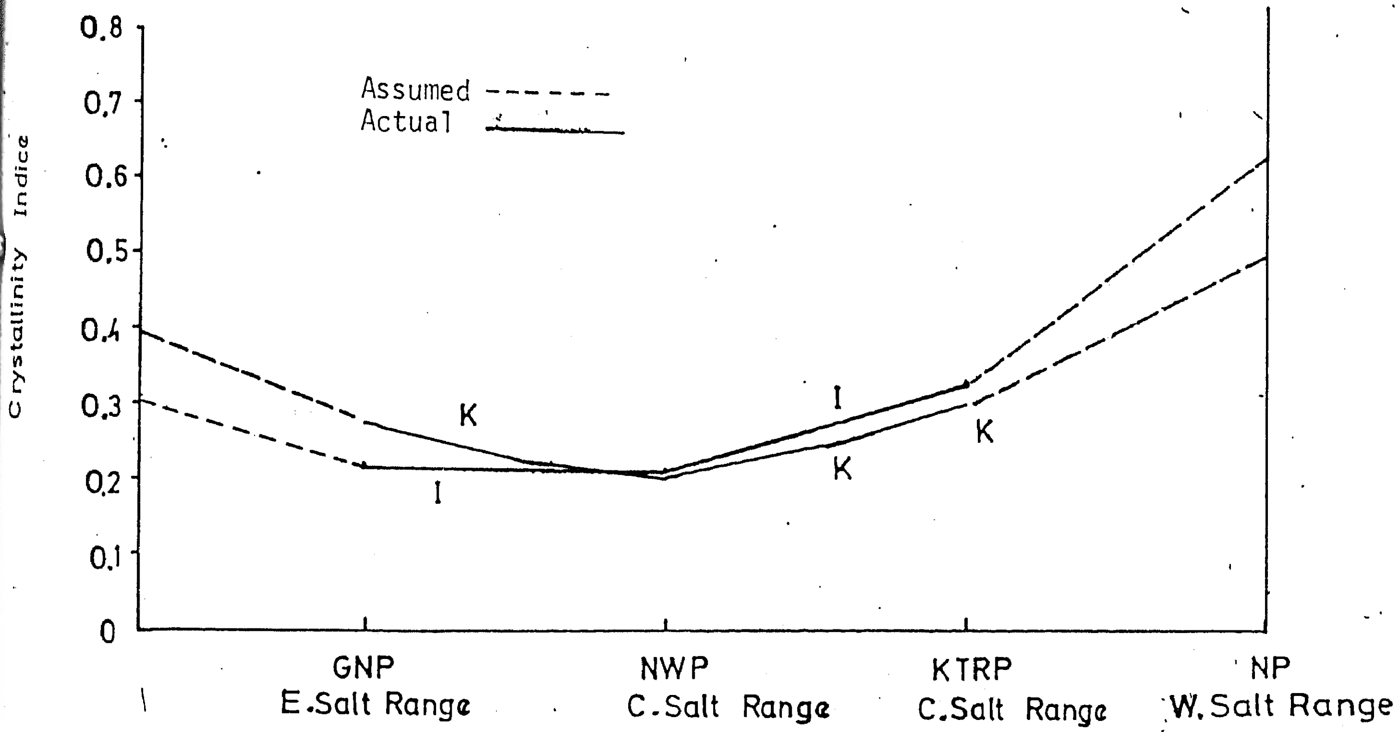


Fig:3.3 Crystallinity indices of illite (I) and Kaolinite (K) from the Salt Range, indicating the local transportation, directions of the basin (local depression).

GNP - Gandhala Nala
NWP - Nilawahan
KTRP - Katha
NP - Nammal

Note: (Horizontal scale is Schematic.)

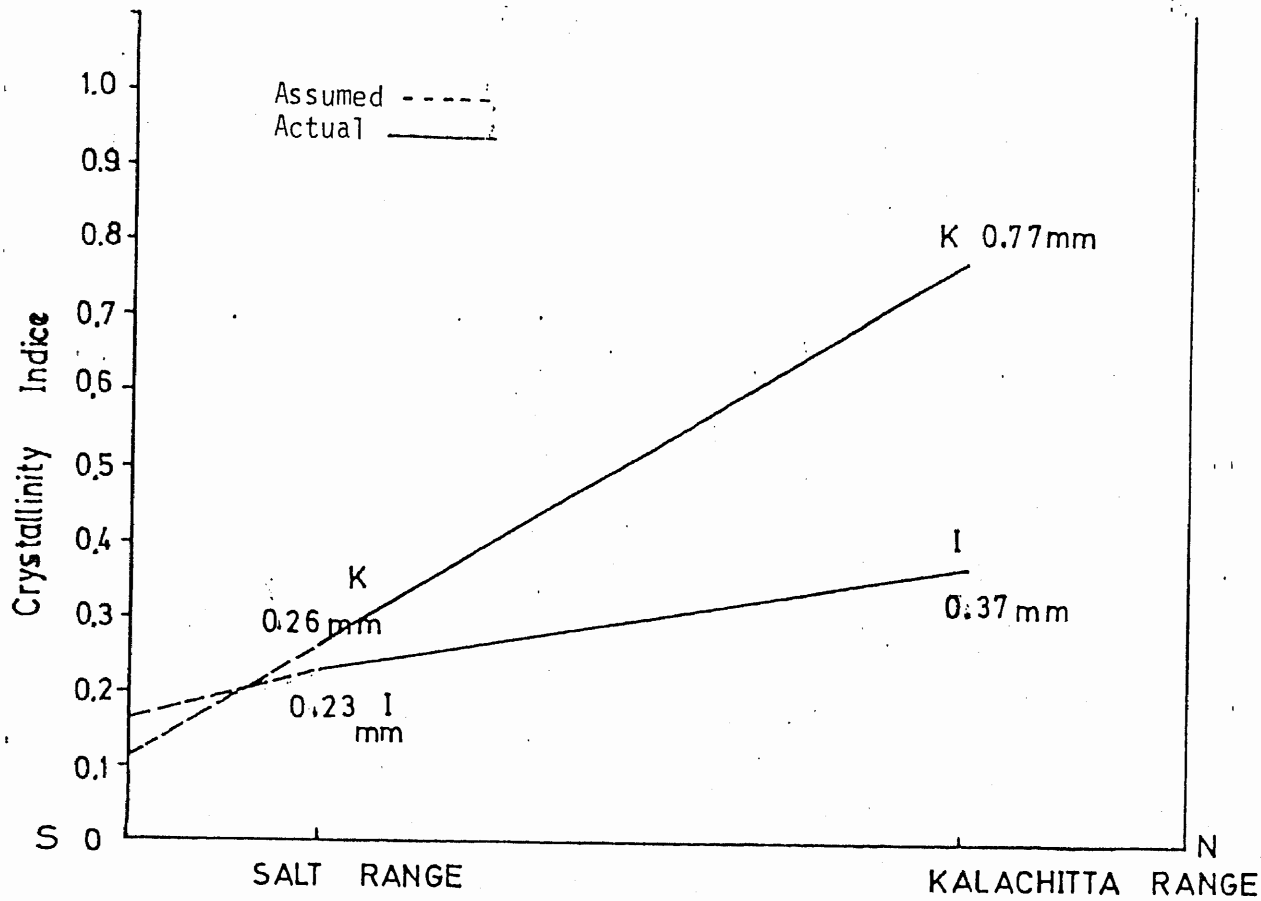


Fig: 3.4 The variation in the crystallinity indices of illite (I) and kaolinite (K) in the samples of the Patala Formation from Salt Range to the Kala Chitta Range indicating the direction of transportation.

The deposition of the Patala Formation in the Salt Range, Potwar basin, and Kala Chitta Range, took place initially within uplifted shallow continent towards south -southeast, where the uplifted parts were eroded and ferrogeneous sandstones with goethite mineral were deposited. This is evident by the presence of the ferrogenous sandstone at the base of the Patala Formation, in Gandhala Nala and other areas in the eastern Salt Range. This ferrogenous sandstone indicates conglomeratic unconformable sequence below the Patala Formation at Choa Saidan Shah, and hence it reflects an uplifted area towards south - southeast. At the same time this depositional basin was gradully deepening towards west with local uplifted and depressed areas, where the Khairabad Limestone was in the final stages of its deposition/precipitation. Similarly the basin was comparatively deeper towards north (present Potwar basin) and Kala Chitta Range where Khairabad Limestone was also in its final stages of depostion/ precipitation. The tropical, rain forest were gradually developed in the southern uplifted areas, which were finally submerged and transported towards north and northwest, and gave rise to the parallic deposition of the coaly/ organic materials many of which gave birth to the local coal seams. The deltaic condition were not as common as parallic conditons for the deposition of the coal (limestone intercalations), but the deltas existed during the Paleocene times and gave rise to the thick sequences with coaly partings. The tropical rainy climates were gradually altered by hot evaporating conditions with occasional submergence of the uplifted parts in the southwest, which resulted in the deposition of limestone beds within the Patala Shales. Finally, the hot climate prevailed with abundant marine life such as pelecypods and gastropods and the deposition of Nammal limestone and marls was initiated.

1. KHAWRI KHAWAR (Kala Chitta Range)

kaolinite mineral was detected in only 12 samples of the Patala Formation, collected from the Khwari Khawar section in Kala Chitta Range. The Patala Formation of the Khwari Khawar section lies on the Lockhart limestone, while the top of the section is partly covered. The distribution of the kaolinite from base to the top is not uniform. The samples from the base of the Patala Formation generally show more kaolinite as compared to the samples from the middle part of the formation. Similarly, the samples from the top of the formation, display more kaolinite as compared to the middle part of the formation (fig. 3.6) and table (2.1). This increase and decrease in amount of the kaolinite in the samples indicate the changes in environmental condition at the source area. The erosion of kaolinite rich rocks were followed by the non-kaolinite rich rocks.

The illite mineral was detected in all the samples of the Patala Formation exposed in the Khawri Khawar. Illite appears to be a detrital mineral brought from the southern shallower part of the basin of deposition by transportation and increased due to sedimentational sorting processes (fig. 3.5). This mineral does not show a uniform distribution due to changes in depositional environments from stable to changing basin conditions. The stable conditions existed during the precipitation of the carbonates where marine life such as large forams, ostrocods, and gastropods were present. The illite is the maximum detritus found in the shaly parts of the Patala Formation and is about 42 percent (average) in the samples. It indicates that during the

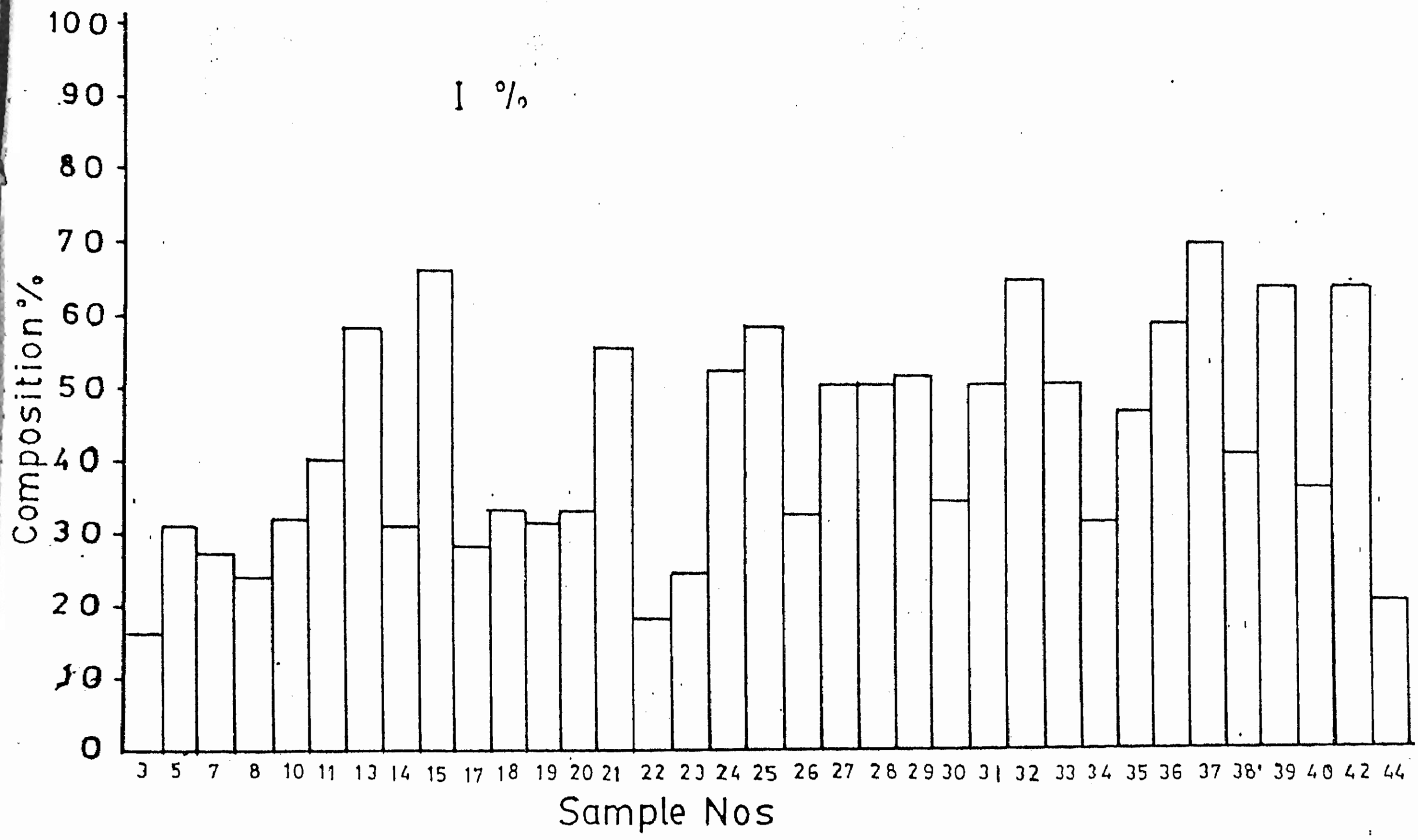


Fig: 3.51 Histogram showing the Illite % composition in the samples from Kala Chitta Range. (Khawri Khawar Section).

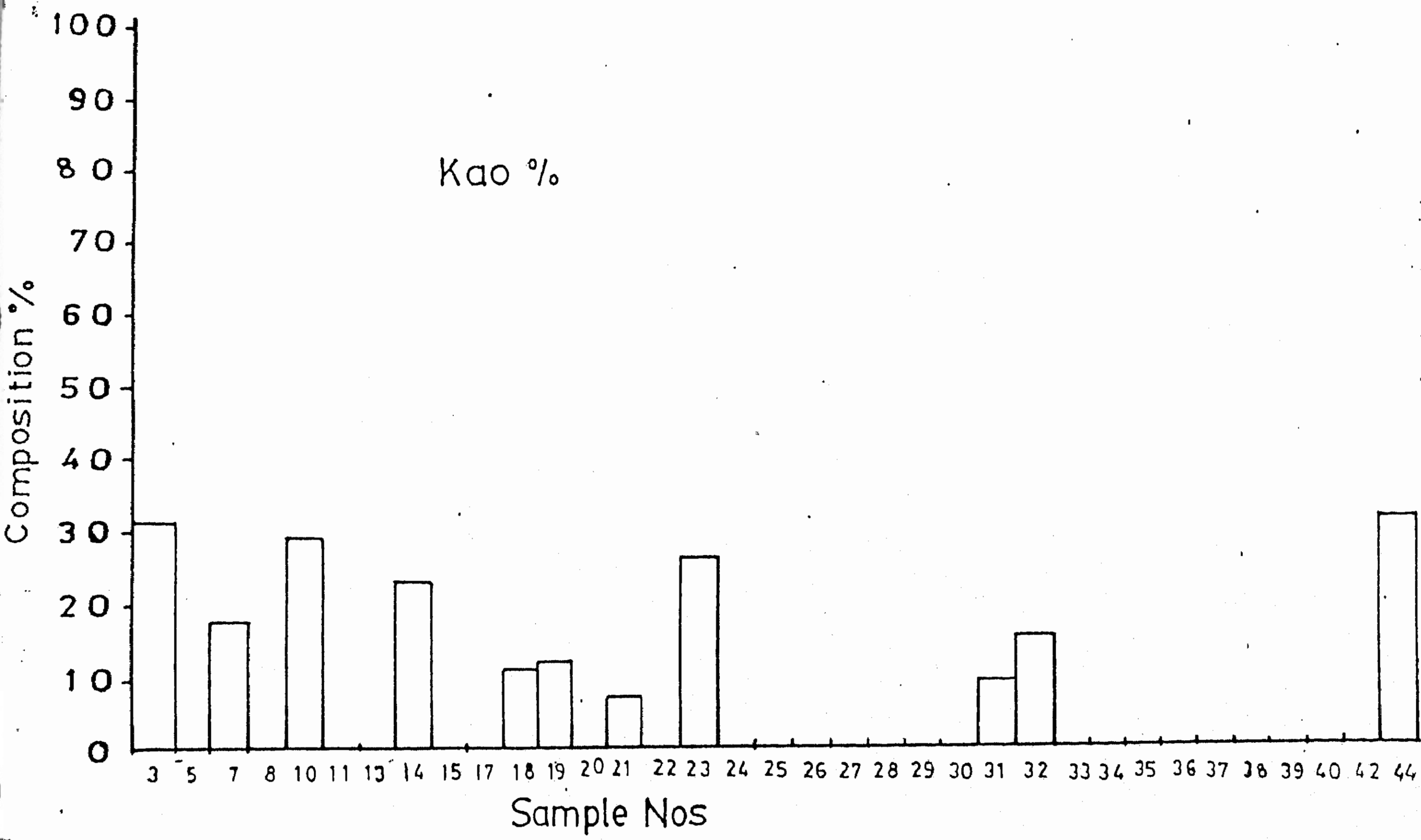


Fig: 3.61 Histogram showing the Kaolinite % composition in the samples from the Kala Chitta Range. (Khawri Khawar Section).

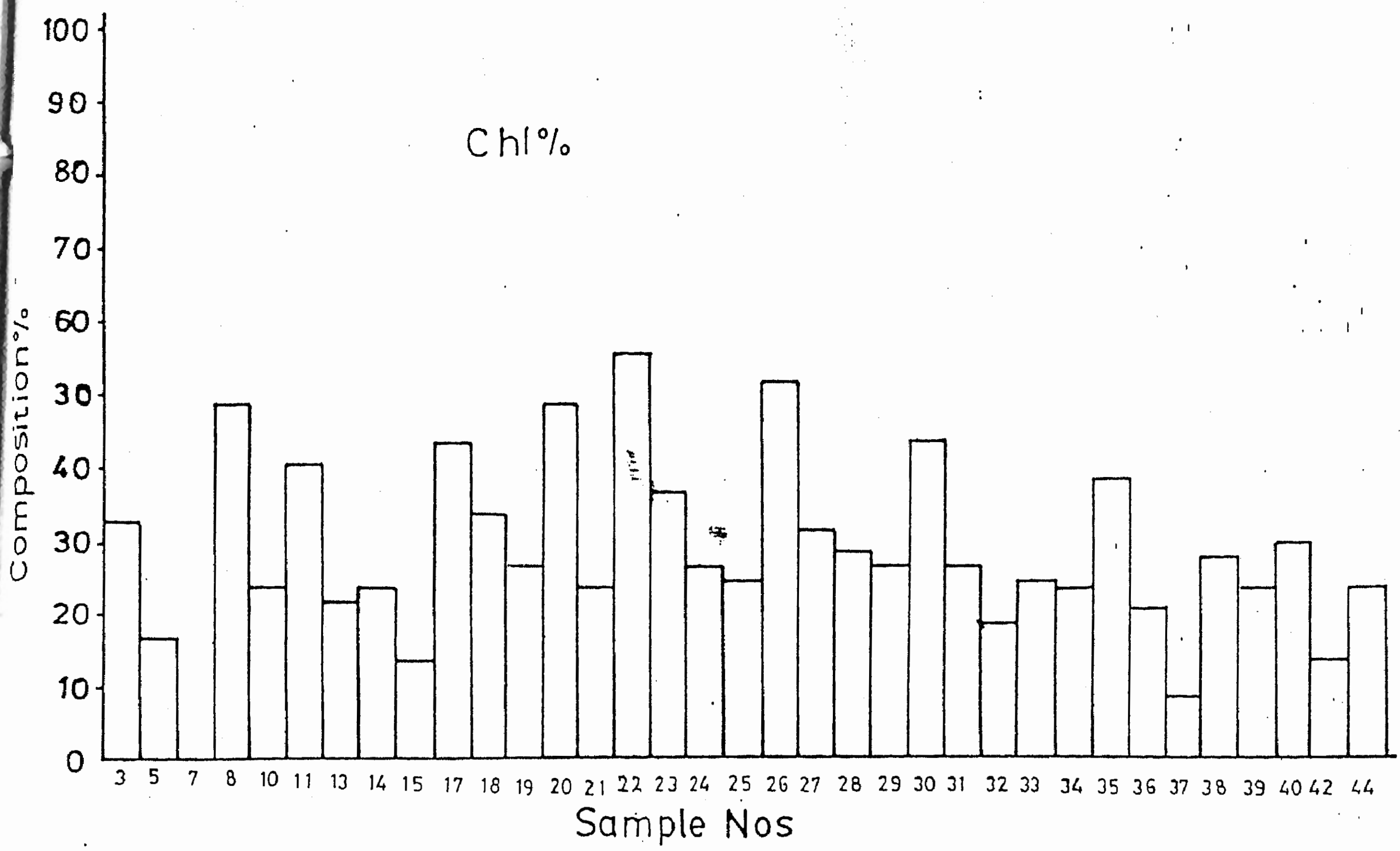


Fig: 3.7 Histogram showing the % composition of Chlorite in the samples from Kala Chitta Range. (Khawri Khawar Section).

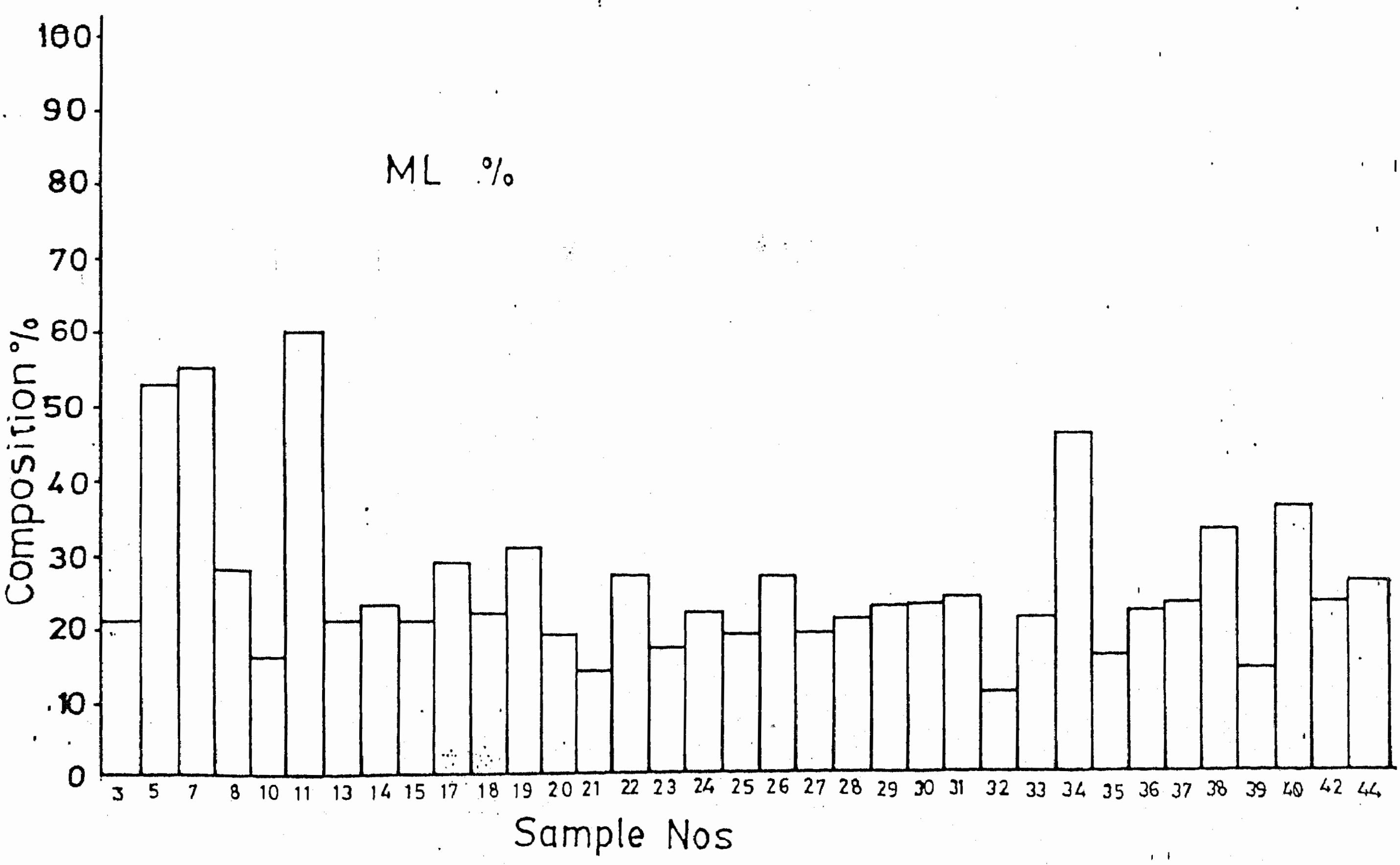


Fig:3.8 Histogram showing the % composition of the mixed layer clay mineral in the samples from the Kala Chitta Range (Khawri Khawar Section).

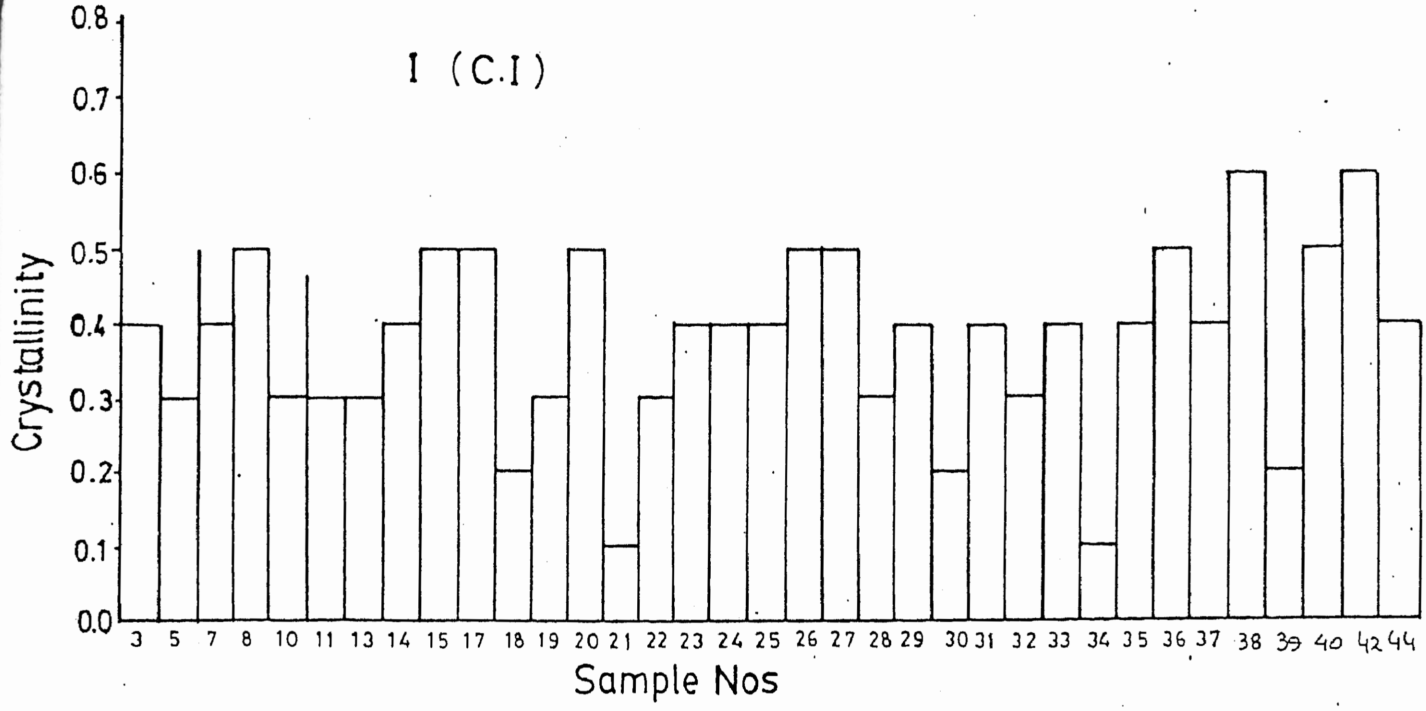


Fig:3.9 Histogram showing crystallinity index of illite in samples from-Kala Chitta Range.

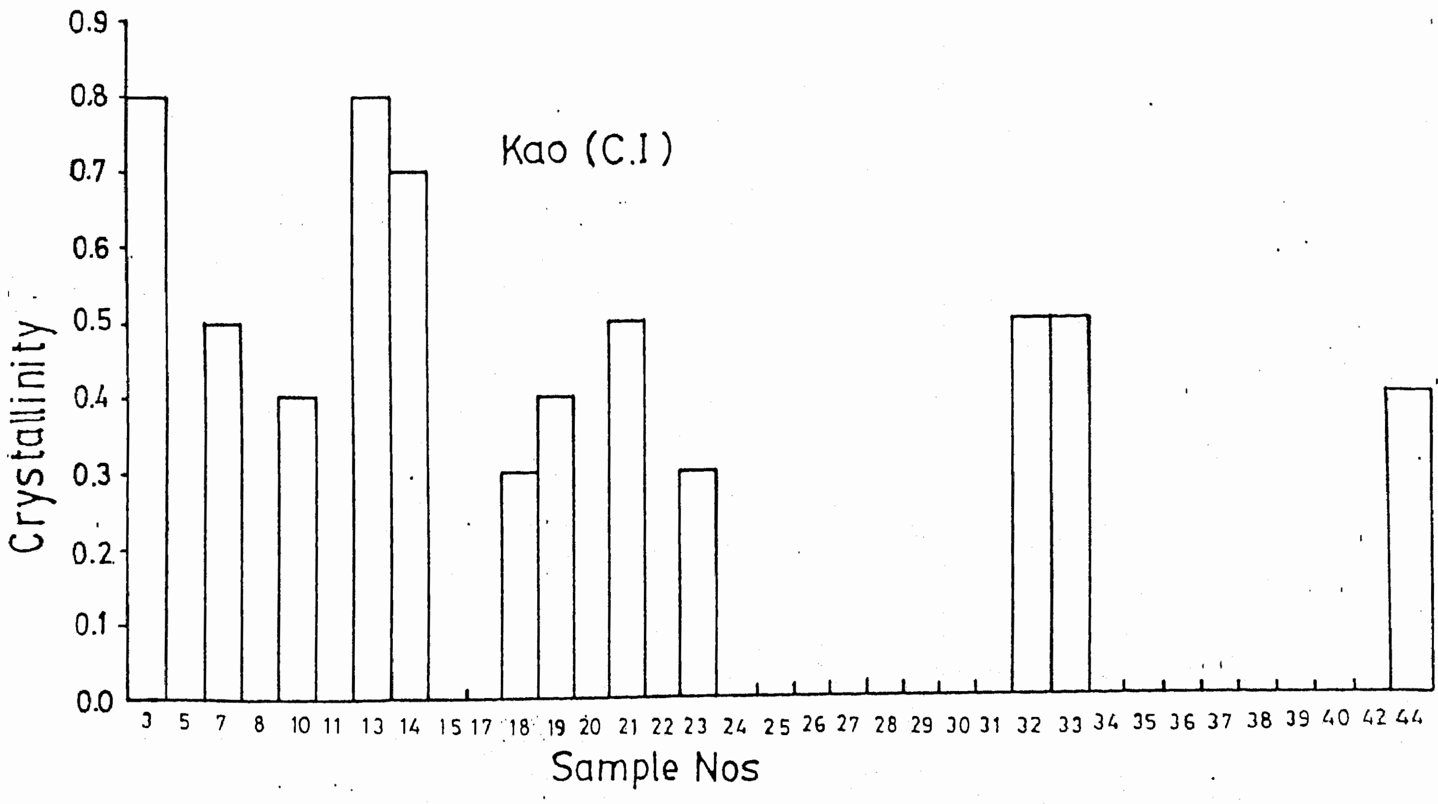


Fig: Histogram showing crystallinity index of Kaolinite from Kala Chitta Range..

deposition of the Patala Formation either metamorphosed sediments were being eroded or the sediments rich in illitic meterial were brought into the depositional basin. The illite shows a gradual increase from south to north and reflects the sedimentary processes.

The mixed-layer clay mineral is present in all the samples (fig. 3.8). It is about 26 percent (average) in the Patala Foramation, of Khawri Khawar. It shows a sudden increase in the samples from the base of the formation but the increase is random in the samples from the top. The mixed-layer clay mineral appears to be diagenetic, formed due to alteration of smectite minerals by the addition of K^{++} ions from the sea water and diagenetic solution during early and late diagenesis. The mixed-layer clay mineral is a random mixture of illite/ montmorillonite, illite/montmorillonite / chlorite, which shows expansion on glycolation and contraction on heating.

The smectite mineral were most likely a product of weathering of the volcanic ashes and basalts in the southern part of the basin.

The chlorite mineral was brought into the depositional basin due to erosion . Chlorite increased from south to the north due to its fine grained nature. It is the second dominant mineral in the Patala Formation after illite (fig. 3.7) and is about 27 percent (average). The mineral was found in the shale samples but was not detected in the carbonate rich samples. Chlorite is a detrital sedimentry mineral brought to the basin of the deposition from the southern shallow continental part of the basin. Some chlorite rich sediments may be altered basalts, which were eroded during the deposition of the Patala Formation in Kala Chitta Range. The increase of chlorite in the samples from the northern part of the area show, comparatively deeper part of the basin in northern area than south.

Figures 3.9 and 3.10 showing the crystallinity indices of kaolinite and illite from the Khawri Khawar samples.

2. GANDHALA NALA (Eastern Salt Range)

The clay mineral composition of the samples of the Patala Formation from Gandhala Nala (Eastern Salt Range) is kaolinite, illite, and mixed-layer caly minerals. The kaolinite is detected in all the samples and varies from 22 percent to 75 percent with average of 37 percent in 22 samples. The mineral kaolinite appears to be dominantly diagenetic. The highly crystallized kaolinite is assumed to be a diagenetic mineral found in comparatively acidic environments Kossovskey et al. (1964). The kaolinite of lesser crystallinity is assumed to be of detrital nature. The clay mineral composition of the Gandhala Nala indicates acidic environment containing organic matter and soils eroding and depositing closer to the source area. The distribution of clay minerals from base to the top of the analysed section shows the maximum kaolinite percentages at the base and the minimum at the top, which may be due to more acidic environments at the base. The continuous distribution is not uniform, indicating abrupt increase of kaolinite at various intervals, specially in the samples from the base and top of the section. It was also noted that the kaolinite increases in the coaly horizons indicating again acidic environments. The distribution of kaolinite in the samples of the Gandhala Nala sections is given in (fig. 3.12) and table 2.2 provides the semiquantitative analysis of kaolinite.

The crystallinity of kaolinite was determined in all

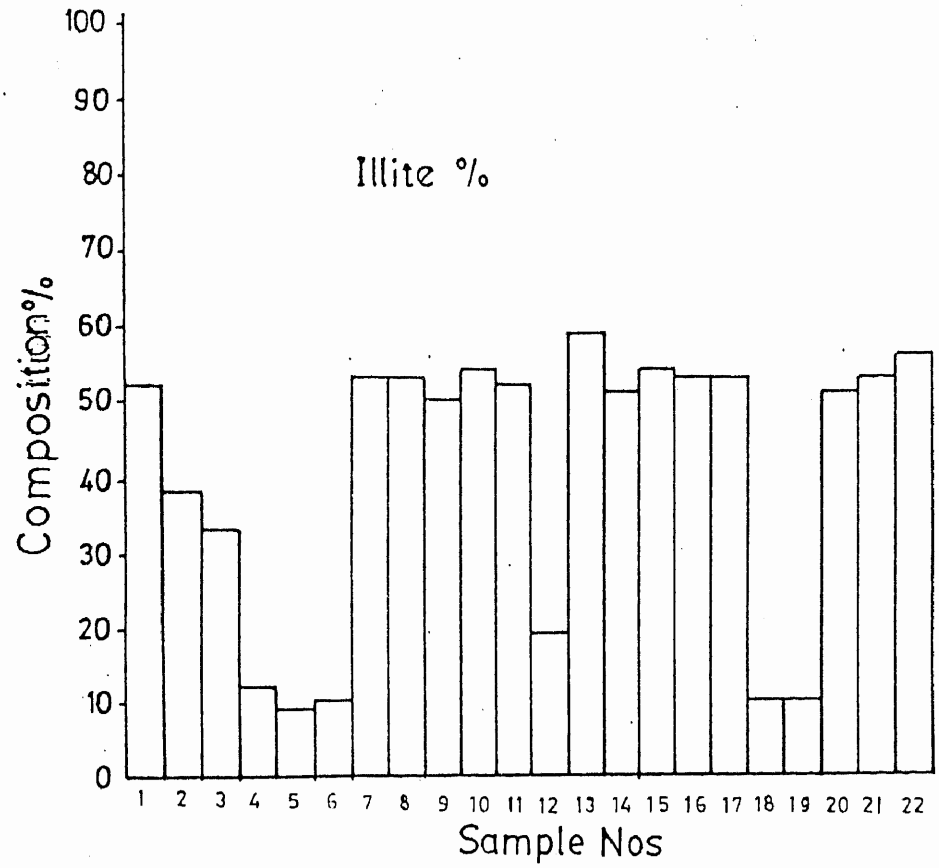


Fig.3.11 Histogram showing Illite % composition in samples of Gandhala Nala (Eastern Salt Range).

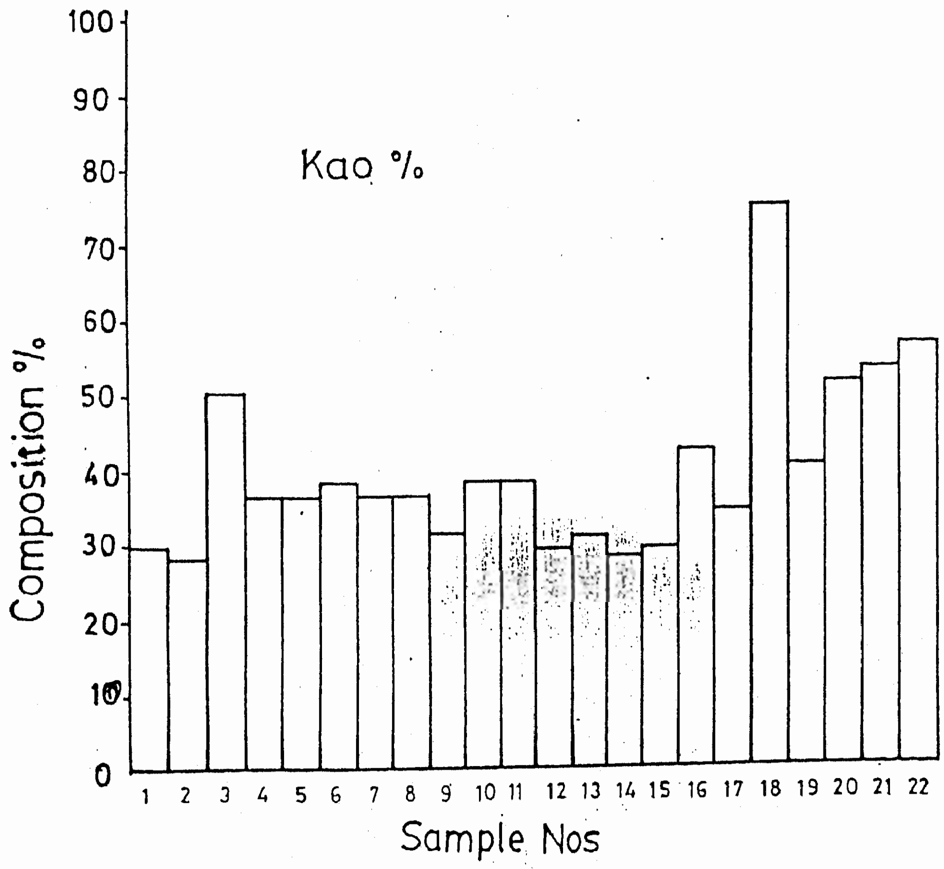


Fig: Histogram showing the Kaolinite % composition in samples of Gandhala Nala (Eastern Salt Range).

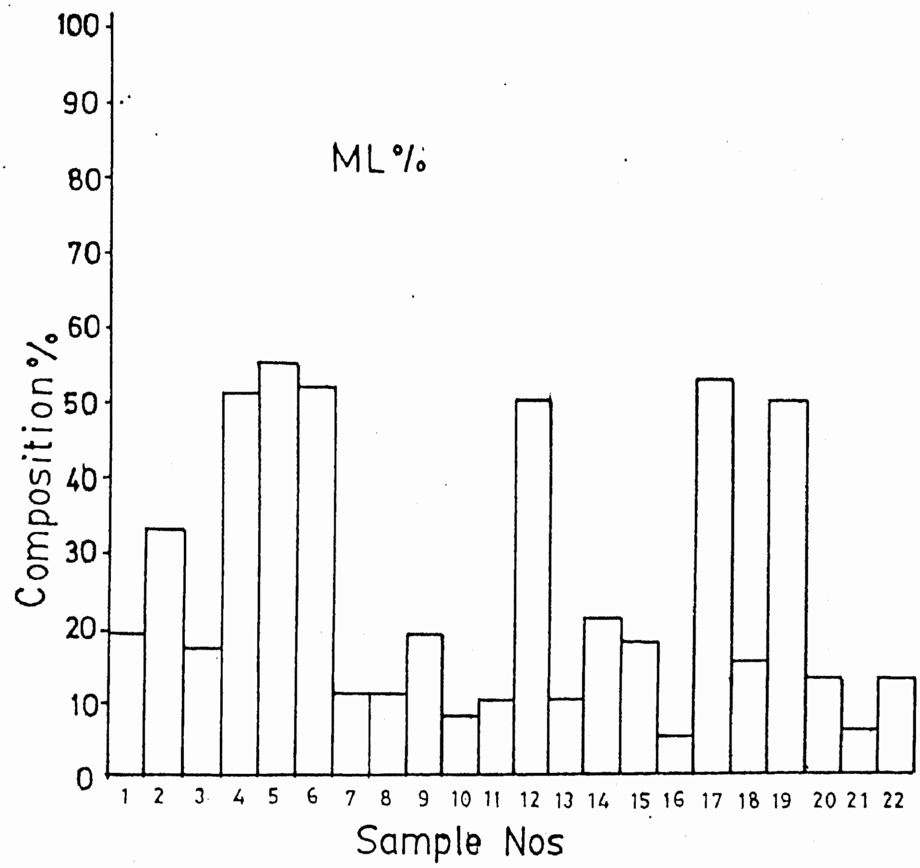


Fig. 3.13 Histograms showing mixed-layer clay mineral % composition of Gandhala Nala (Eastern Salt Range).

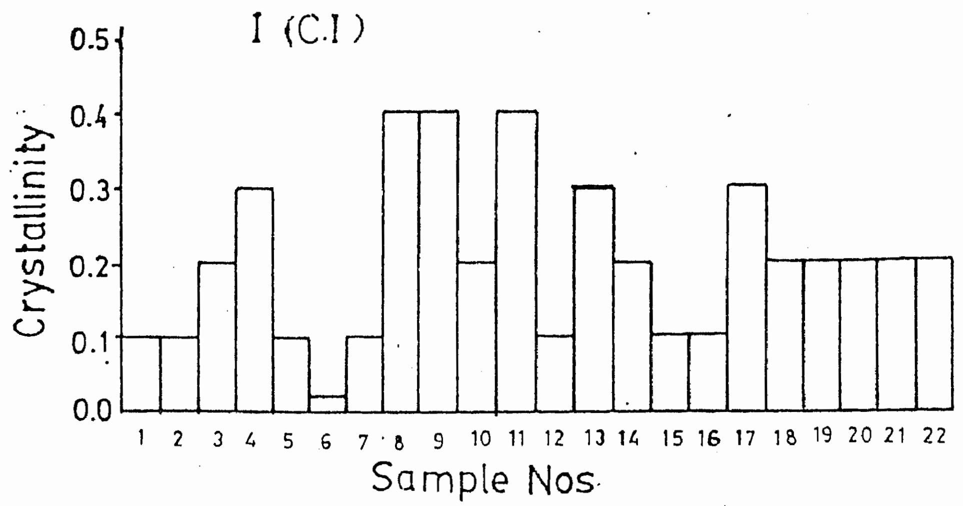


Fig:3.14 Histograms showing the crystallinity Indices of Illite mineral Gandhala Nala (Eastern Salt Range).

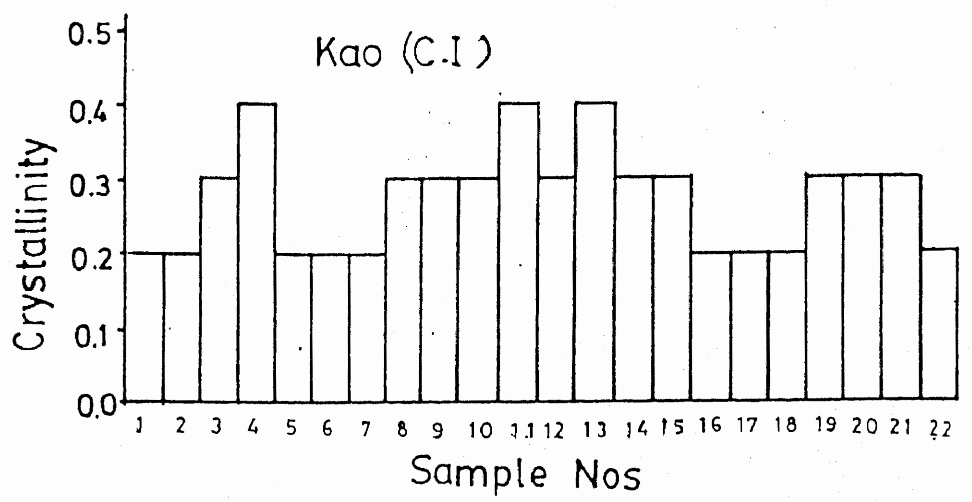


Fig:3.15 Histogram showing crystallinity Indices of Kaolinite mineral Gandhala Nala (Eastern Salt Range).

the samples from the Gandla Nala area. It appears that the crystallinity changes in samples from the stratigraphic horizon to horizon, may be due to the change in the depositional environments and fluctuations of the depositional conditions from acidic to less acidic or basic conditions (fig. 3.15).

The illite mineral is observed in most of the samples and shows variation from the base to the top of the measured section, (fig 3.11). It is about 38 percent (average) in 22 samples and display variations stratigraphically from horizon to horizon. It is the most dominent mineral and probably was brought into the depositional basin by sedimentational processes and appears to detrital in nature. The source rock was not very far from the depositional basin, as it is comparatively better crystalline (fig 3.14). The variation in crystallinity of illite from horizon to horizon depends on the distance from the source rock, better crystallized illite was transported from a nearer source while the lesser crystallized came from the source rocks far away from the depositional basin.

The mixed-layer clay mineral was detected in most of the samples from Gandhala Nala area (fig 3.13). It is a mixture of illite/ montmorillonite. It is likely that the mixed-layer clay mineral was transformed from the weathered material after its deposition into shallow waters. The K^+ ions were added from the marine water to provid the stability to the montmorillonite structure and to convert it into a mixture of illite/ montmorillonite. It is most probable that the mixed layer clay minerals were diagenetic in nature.

The mixed-layer clay minerals show fluctuations from the one stratigraphic horizon to another horizon and it could be due to availability of the K^{++} ions during the early and late diagenesis (fig. 4.1).

3. NILAWAHAN AREA (Central Salt Range)

The kaolinite was detected in most of the samples with the exception of 6 samples. It varies between 5 percent to 93 percent and was observed as a dominent clay mineral in the Patala Formation at Nilawahna area (fig. 3.17). The distribution of kaolinite is variable in this section. It is dominant in the carbonaceous samples and decreases in the carbonate samples, which indicates increase and decrease in acidic and basic environments, respectively.

The kaolinite mineral is highly crystallized in coaly, carbonaceous horizon (fig. 3.21) and less crystallized in carbonate horizon (Gluskotor 1967) and therefore, indicates its diagenetic origin in acidic environment.

The illite mineral was found in most of the samples rich in carbonaceous material (fig. 3.16) indicating that it is not a diagenetic mineral associated with the acidic environment. It was detected mostly in the samples from the top of the formation indicating that the rate of transportation of the illite increased at the end of deposition of the Patala Formation. The crystallinity indices of illite mineral display variations in the measured section (fig. 3.20) and vary from stratigraphic horizon to horizon and reflect the distance from the source rock to the depositional basin. The more crystalline illite was transported from near by source rock as compared to the less crystalline illite brought due to erosion of the far away source rocks.

The mixed-layer clay mineral is the second dominant mineral after kaolinite and was detected in all the samples. The

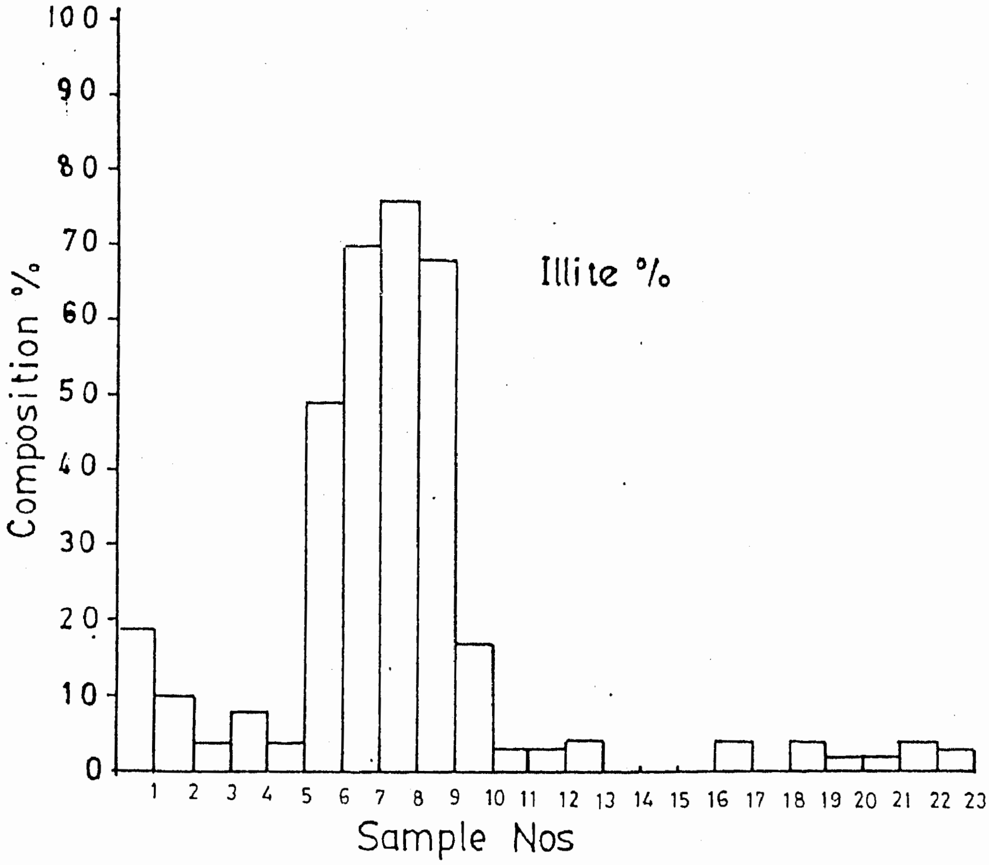


Fig 3.16 Histogram showing the Illite % composition in samples from Nilawahan (Central Salt Range).

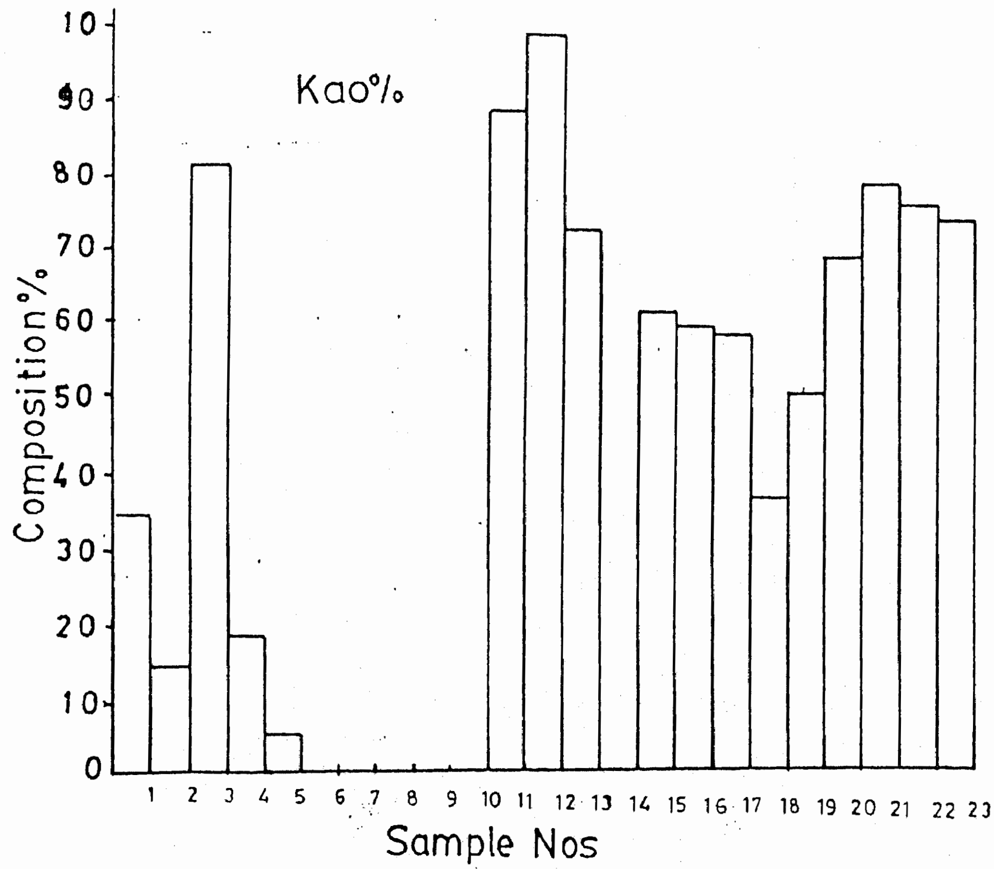


Fig 3.17 Histogram showing the Kaolinite % composition in samples from Nilawahan (Central Salt Range).

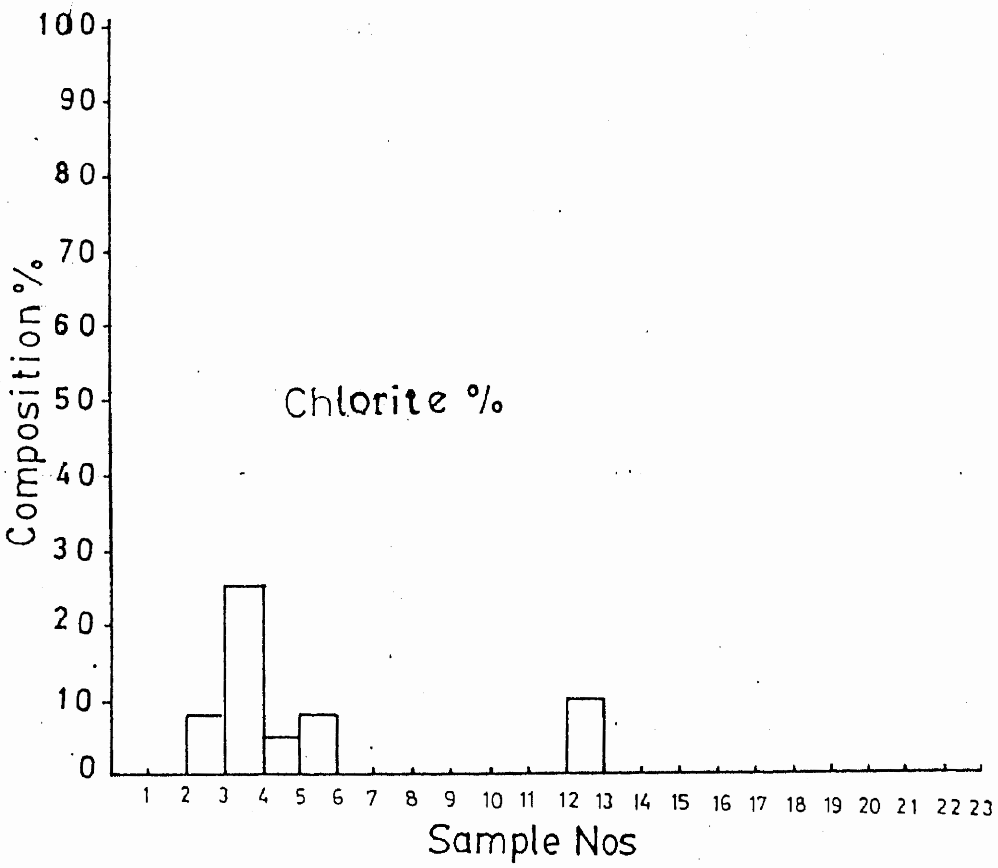


Fig.3.18 Histogram showing the chlorite % composition in samples from Nilawahan (Central Salt Range).

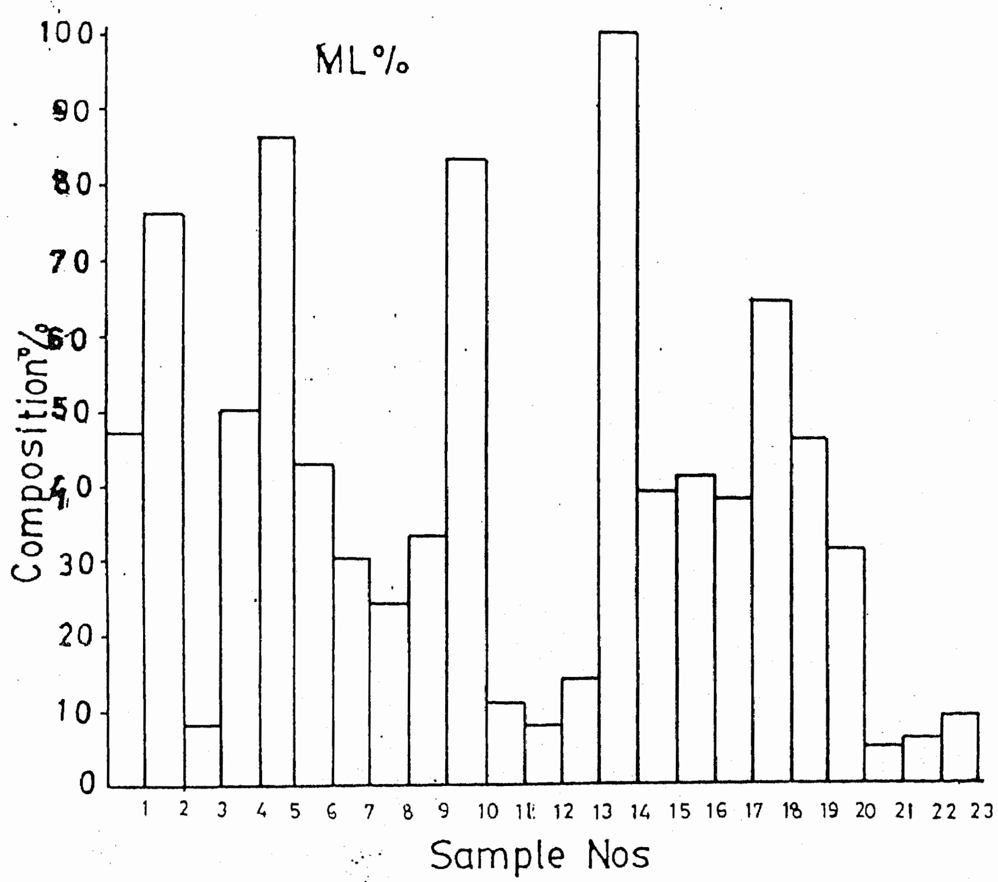


Fig.3.19 Histogram showing the mixed layer % composition in samples from Nilawahan (Central Salt Range).

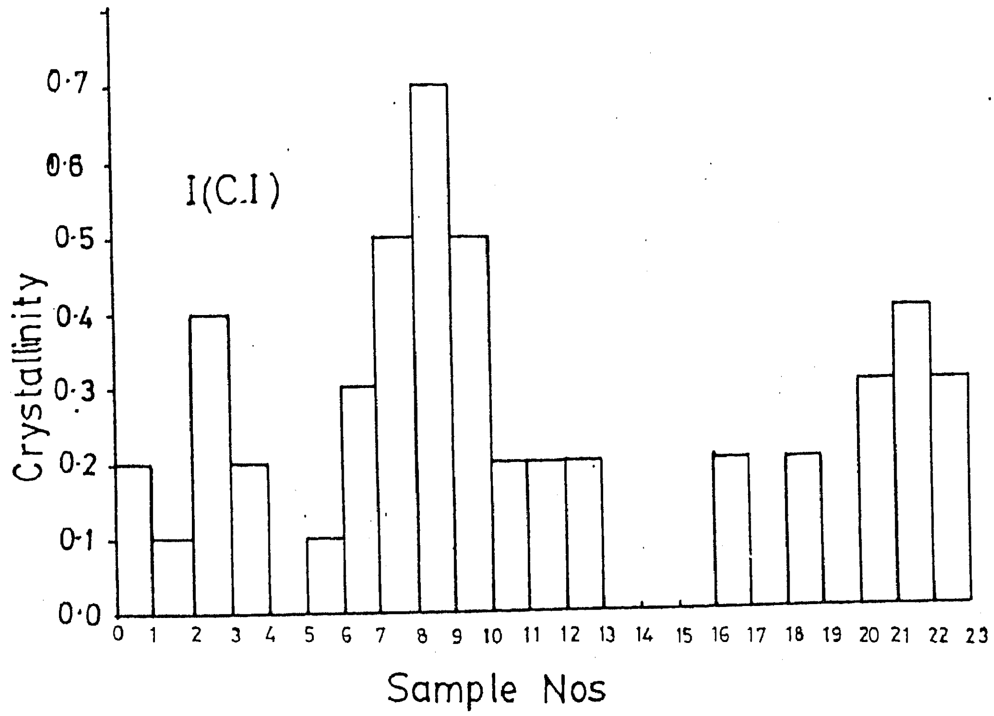


Fig:3.20 Histogram showing crystallinity indices of Illite in samples from Nilawahan section, (Central Salt Range).

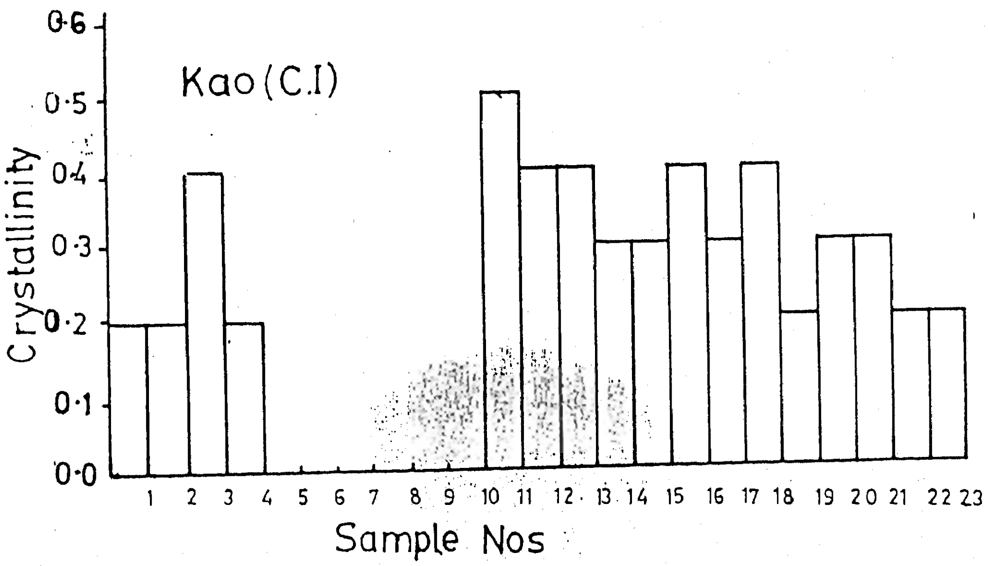


Fig:3.21 Histogram showing crystallinity indices of Kaolinite in samples from Nilawahan section (Central Salt Range).

mineral varies from 5 percent to 100 percent (fig. 3.19). Its association with feldspars indicate its removal from the basaltic types of rocks. It is likely that the feldspars were originally brought into the basin of deposition with smectites which were converted into the mixed-layer clay mineral after the addition of K++ ions, during early and late diagenesis. The mineral chlorite was found only in the five samples and varies from 5 percent to 22 percent (fig. 3.18). The presence of chlorite mineral could be due to alteration of smectite minerals after deposition but it is also likely that chlorite was transported into the depostional basin due to erosion of the chlorite rich source rocks. It is probable that the fine-grained chlorite could not be setteled in the shallower part of the basin and was transported to the deeper part of the basin.

4. KATHA AREA (Central Salt Range).

The kaolinite mineral is found in all the samples of the Patala Formation from the Katha area (central Salt Range), which varies from 22 percent to 75 percent (fig. 3.23). It is the most dominent mineral in the formation and is about 53 percent of the total percentage. Quantatively the samples showed more kaolinite compared to the other sections of the Patala Formation, Nilawahan section, Gandala Nala section (cenral Salt Range), Khwari Khawar (Kala Chitta Range). It is highly dominant at the top and the base of the formation and showed gradually decrease in the middle part. The kaolinite appears to be mostly diagenetic but some of detrital nature. The increase of kaolinite mineral in the carbonaceous horizon indicates diagenetic origin in acidic evironments (Kossovskey,1964).

The crystallinity indices varies between 0.2-0.5

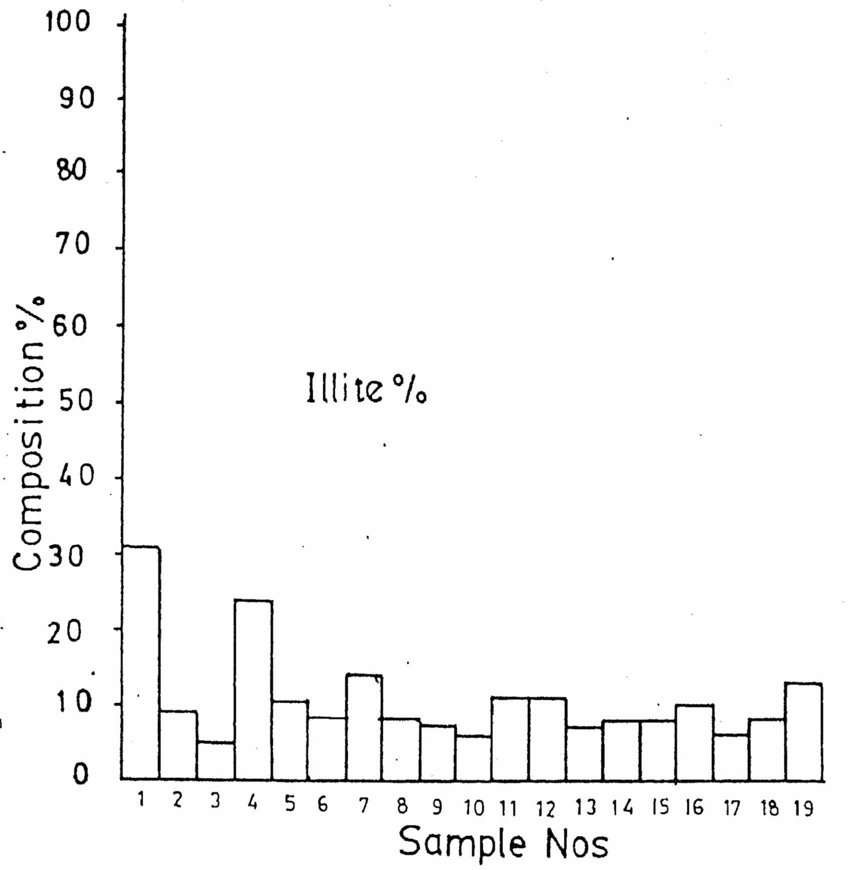


Fig:3.22 Histogram showing the Illite % composition in samples from Katha area (Central Salt Range).

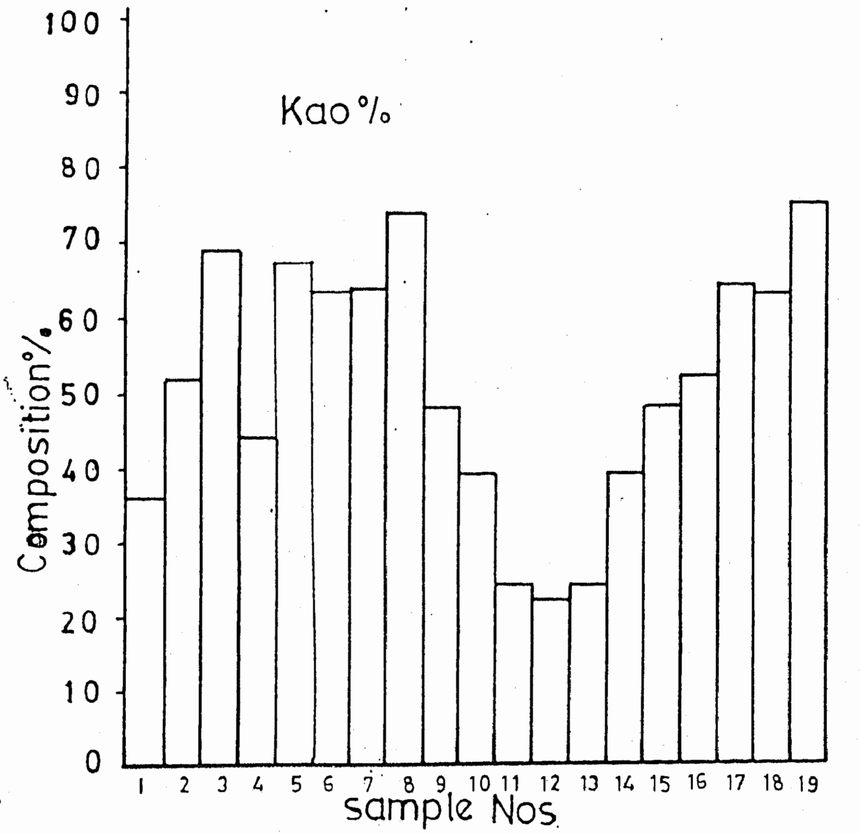


Fig:3.23 Histogram showing the Kaolinite % composition in samples from Katha area (Central Salt Range).

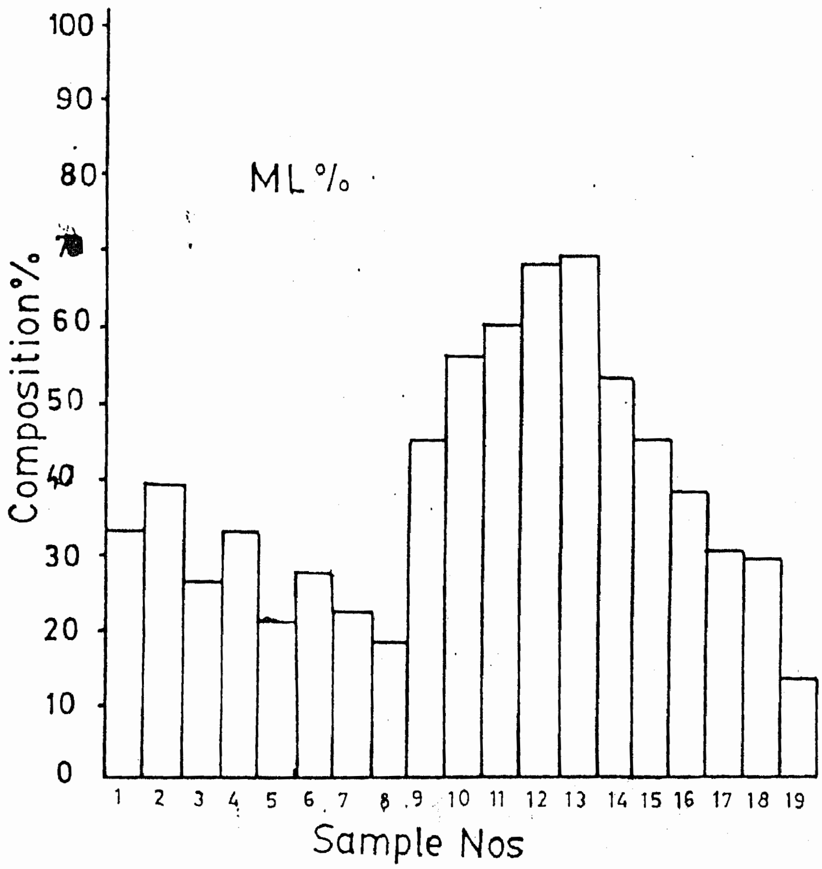


Fig:3.24 Histogram showing the mixed layer clay mineral % composition in samples from Katha area (Central Salt Range).

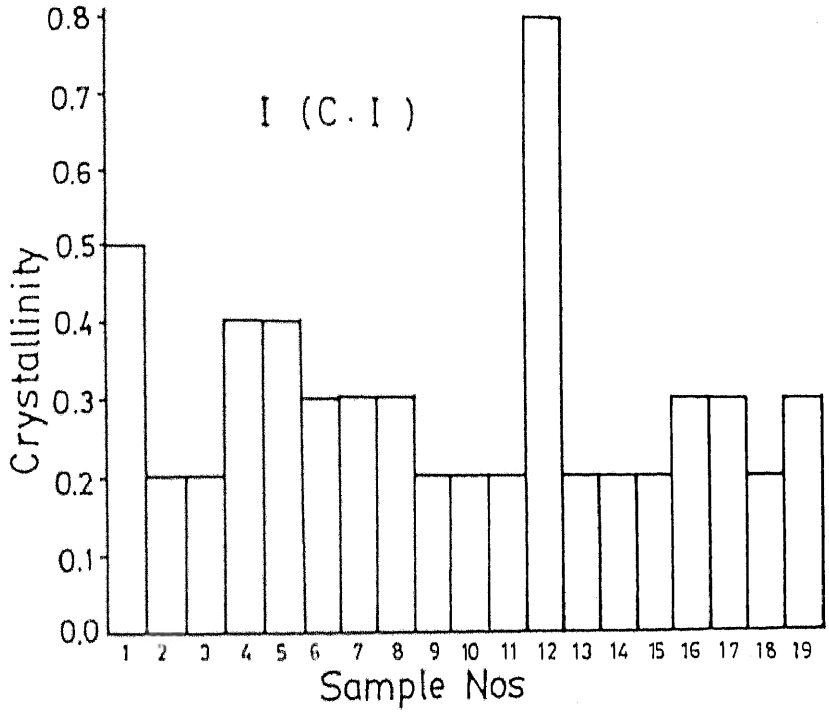


Fig:3.25 Histogram showing crystallinity indices of Illite Katha area (Central Salt Range).

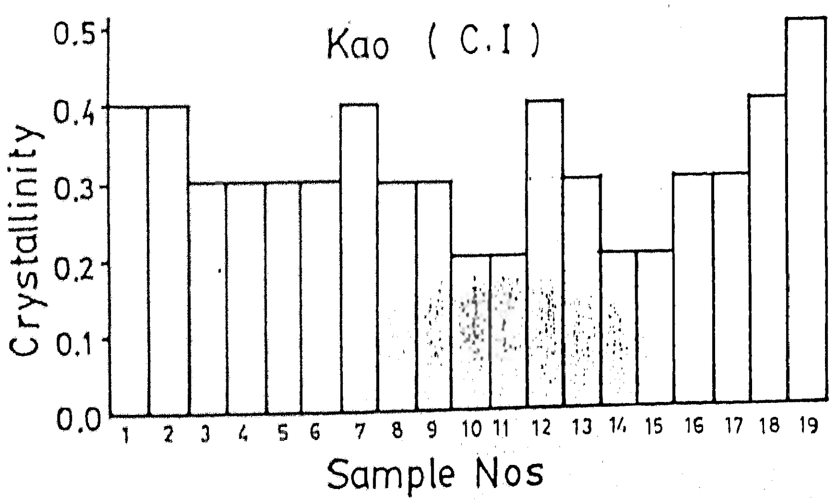


Fig:3.26 Histogram showing crystallinity indices of Kaolinite mineral Katha area (Central Salt Range.

reflects the variations in the depositional basin from acidic to basic, marine environments (fig. 3.26).

The mineral illite was observed in all samples with the exception of coal samples (fig. 3.22). It is considered that the illite is a detrital mineral which was brought in to the depositional basin by sedimentry processes. The variations in the crystallinity indices of the illite (fig. 3.25) and table. 2.4 reflect its distance from the source rocks. The more crystallized illite was transported from the near by source material while the less crystallized brought from the source rocks located far away from the depositional basin.

The mixed-layer clay mineral is the second dominent clay mineral. It varies from 18 percent to 69 percent in the samples and is 38 percent (average) of 19 samples (fig. 3.24). The mixed-layer clay mineral is a random mixture of illite/ montmorillonite which was found due to diagenetic alteration of smectite due to addition of the K^{++} ions from the marine waters in early and late diagenetic stages.

CHAPTER - IV

DISCUSSION

The principal clay minerals analys..ed from the Patala Shales of the Salt Range and Kala Chitta Range section are kaolinite, illite, mixed-layer clay mineral. In addition calcite, quartz, feldspars, chlorite, dolomite and pyrite are also observed during the x-ray diffractogram analysis of the rock samples.

In general the kaolinite may have either a detrital or a digenetic origin. Detrital kolinite is an important indicator of the proximity of the shoreline and thus of paleogeography. Detrital kaolinite is formed by erosion of weathered rocks in leached acidic environments, the process of lateritization producing kaolinite in tropical regions. When primary silicates of alumina are subjected to chemical weathering at a pH between 5 and 7, in oxidizing conditions, kaolinite is the most likely mineral to be formed. Erosion and subsequant sedimentation may deposit this mineral in favourable areas and give rise to sedimentary kaolin deposits.

Kaolin minerals can be destroyed during diagenesis, either by replacement or by deep burial. Dunoyer de Segonzac (1969) studied the Siluro-Devonian rocks of the Sahara desert and concluded that calcite of fossils was replaced by kaolinite which was subsequantly destroyed and gave rise to pyrophyllite. Illitization of kaolinite is claimed as a common replacement process in which interstitial solutions play an important role in the transformation of kaolinite into illite. Dunoyer de Segonzac (1970) explained illitization of kaolinite in Triassic sandstones as a result of the influence of saline waters.

Kossovekey et al. (1964) observed that the perfect crystallized kaolinite was developed in acid environment during slow deposition.

Glass (1958) investigated the clay mineralogy of Pennsylvanian sediments from Southern Illinois in a comparative study of cores and outcroups of different facies. He found more kaolinite in sandstones than in the shales and demonstrated the post-depositional formation of kaolinite. He also observed that shales and sandstones below coal seams, being non-marine, contained more kaolinite than the marine shales above coal seams.

Fuchtbaur and Goldschmidt (1963) studied the changes in clay minerals of the sediments with increasing depth. He found the disordered kaolinite in shales and crystallized kaolinite in sandstones, up to a depth of 3000m. Burial depth indicates the decrease of kaolinite and increase of chlorite and quartz. Stout (1923) and Longan (1942) have discussed the origin of clay and seatearths and pointed out that the kaolinite increases in seatearths as compared to the other clay minerals. Grim and Allen (1938) investigated the underclay from the Illinois basin and reported that the underclays were mostly kaolinite.

Brammal and Leech (1943) found that the seatearths and roof shales of high volatile matter coals contained more kaolinite.

Endell (1954) investigated the clay minerals in bituminous coals, and found illite and kaolinite as the dominant clay minerals. Webb (1961) concluded that the underclays contained more kaolinite, and expandable clay minerals, and less illite, and chlorite. Huddle and Patterson (1961), have suggested that the formation of seatearths was the first stage in the development of a coal swamp.

Pietzner and Werner (1963) proposed that all constituents of the clay minerals in coal may be the oxidation products of organic material.

Gluskoter (1967) found a significant amount of well crystallized kaolinite, illite, and expandable minerals, and observed that pyrite was disseminated as the cleat filling matter in Illinois coal. Moor (1968) concluded that three factors control the mineralogical and chemical composition of seatearths which were as follows;

i. Degree and nature of weathering before transportation,

ii. Diagenetic changes,

iii. The aerobic or anaerobic conditions.

Larsen and Chillinger (1967) studied diagenesis of clay minerals with increasing temperatures and pressures at depth and the time of burial. They investigated up to the depth of 10,000m from pre-burial stage up to the metamorphic boundary. They found that kaolinite increased in the shallow burial stages, but decreased and finally disappeared below the depth of 5000m. Montmorillonite also disappeared at the depth of 5000m, but chlorite increased with the depth. Winkler (1967) stated that when shales containing kaolinite were subjected to low temperature metamorphism, kaolinite disappeared but pyrophyllite appeared at the expense of kaolinite and quartz. But Perry and Hower (1969), who studied clay mineral diagenesis in Gulf coast pelitic sediments down to about 4500m, found no systematic variations of kaolinite with depth.

Dunvyer de Segonzac (1970) studied the effects of diagenetic processes of kaolinite. He found that the crystallographic evolution of kaolin mineral may take place in the order of kaolinite -kaolinite/ dickite -dickite/ nacrite and nacrite in deep diageneses. Hodson (1971) studied the samples from some boreholes of Namurian of Poland and divided the formation into three mineral zones. He concluded, that kaolinite was more abundant in the stratigraphically youngest zones, while chlorite and illite were the dominant clay minerals in middle and lower zones, respectively.

The above mentioned review support the concluations drawn by the auther from the analysed samples of the Patala Formation. The kaolinite mineral present in the samples of the Patala Formation in the Eastern part of the Salt Range, is relatively coarse grain and show comparative decrease in amount towards the deeper part of the basin during deposition. Different grain size distribution and variablity in the amount of kaolinite towards Central and Western part of the Salt Range indicate local ups and downs in the basin of deposition.

The crystallinity index may be a good indicator for differenciating between the well crystallized (either of diagenetic or of detrital nature with minimum transport) and poorly crystallized kaolinite of detrital character (transported for long distance). It is noted that the crystallinity indices for kaolinite remain high for all the studied samples from the Salt Range. In addition the presence of carbonaceous shales suggest the transportation of kaolinite mineral with carbonaceous detritus was local and may be present into nearby close basins. All these properties of kaolinite from the Eastern Salt Range suggest that it is mostly detrital in character. However in local deeper part of the basin in Central and Western Salt Range, the kaolinite may be partly detrital and partly diagenetic.

The amount and grain size of kaolinite decrease towards northwest, in Kala Chitta Range. In addition the crystallinity index of kaolinite is also low 0.77 millimeter. This clearly suggest a detrital character of kaolinite, which is deposited in the Kala Chitta Range after being transported for a long distance from the source in south.

Grim and Johns (1954) studied recent sediments from the northern Gulf of Mixico and concluded that with increasing salinity, a gradual loss of montmorillonite results in the formation of poorly crystalline chlorite and illite. The illite was formed by fixation of potassium between montmorillonite layers. Milne and Earley (1958) observed the formation of illite from montmorillonite in the Mississipi delta. Weaver (1958c) concluded that the majority of clay minerals in sedimentary rocks have a detrital origin reflecting the character of the source material with only slight modification imposed by the depositional environment. White House and McCarter (1958) reported that illitic clay minerals can develop from smectite in the marine environment. Weaver (1959c) observed that when vermiculite and montmorillonite were subjected to mild treatment with KOH, they changed to illite. The clay minerals in the present-day oceans absorb more sodium and magnesium than potassium and that the younger sediments generally have more sodium and montmorillonite and less illite than older sediments. Weaver (1967) concluded that much of the Palaeozic and Precambrian illite was formed on land rather than in the ocean.

Grim (1951) investigated Palaeozoic shales in Illinois and concluded the dominant clay mineral to be illite. Chlorite was also found in relativly small amount. Kaolinite was rarely observed but no montmorillonite was found. He concluded this evidence to various diagenetic stages in a marine environment.

The first stage was the rapid deveolpment of well crystallized mica from degraded illite and chlorite and secondly a slow change of montmorillonite and chlorite into illite. Grim (1958) explained these changes during diageneis and suggested that transformation from montmorillonite into mica and chlorite depends on the availability of potassium and magnesium.

Millot (1963) proposed alteration of kaolinite to illite in the presence of saline water during diagenesis.

Burst (1959) suggested diagenetic conversion of montmorillonite with depth. Weaver (1960) studied the sediments from Ouachita mountains of Oklahoma and the buried structural belt of East and South Texas. He concluded that by measuring the 10Å illite peak on the X-ray diffractometer, it is possible to determine the relative degree of metamorphism within the metamorphic geosynclinal facies. Dunoyer de Segonzac (1970) has described the five zones of diagenesis on the basis of illite crystallinity and chemistry:

1. The zone of sedimentation: Erosion and weathering of sediments on the continent gave rise to illite, which in marine aggradation can produce disordered 1Md illite.

2. Early diagenesis: This zone does not show marked changes in illite due to the lack of magnesium ions and illite remains heterogeneous.

3. Late diagenesis: due to increased temperature and compaction, a re-ordering of the illite lattice occurs and absorption of potassium begins. This stage may consists of two zones, an upper zone. where the crystallinity is variable and all the polymorphic variations exist, and lower zone, where the crystallinity is highly uniform, and independent of lithology.

4. The anchizone: This is a transtion zone towards metamorphism. In this zone illite and chlorite are the dominant caly minerals.

5. The epizone: Here the illites are generally transformed to white mica called sericite. The illite minerals of this zone may contain sodium.

Weathering also effects the illite crystallinity. The weatherd illite rich rocks have the more degraded crystallinity of mineral. The glacial climate has a less weathering effect and produce better crystalline illite than in a hot climate. Fine grained particals are much more sensitive to degradation and hydration during weathering, in deep diagenesis.

Robinson et al. (1990) carried out detailed investigations for the crystallinity of illite. He gave the details for the preparation of samples by centifugal of clay fractions, ballmill crushing and ultrasonic dissaggration. He concluded that the analysis for precision of the illite crystallinity of the closely spaced samples can give the reliable result.

Robinson et al. (1989), investigated the illite crystallinity and pointed out its importance as the indicator of very low grade matamorphism.

Wright et al. (1991) carried out work on the paleoclimatic condition of the Paleosoles in South Wales using the clay minerals as Paleoclimate indicators. They found annual clay minerals assamblages from early Carboniferrous in paleosoles which contains the three components kaolinite/chlorite material smectite mixed layer clay. They interpreted it as the product of ferrolysis, a complex processes invloving dissolution of clay and subsequent production of inter layered varities.

The illite is the dominant mineral in the Salt Range and Kala Chitta Range of the Patala Formation. In the Salt Range, the Gandhala Nala section shows more illite (38 %) than the other sections i.e Nilawahan (15 %) and Katha (11 %). However, the illite content is higher in the Khawari Khawar section of Patala Formation from the Kala Chitta Range. This indicates the more saline nature of depositional medium than the Nilawahan and Katha of Certral Salt Range. Generally from the analyzed samples in all the four sections, the illite content shows an increase towards the top of the profiles. It has been observered that the illite mineral is well crystallised in the roof shales than the seatearths and poorly crystallised in or near the coaly beds. The distribution of illite in the Gandhala Nala (Eastern Salt Range), NilaWahan (Central Salt Range), Katha (Central Salt Range), and Khawari Khawar section from the Kala Chitta Range) reflects its detrital nature and transportation from the South to North.

This may indicate the deposition which ultimately becomes more saline and gave rise to the illite dominated roof shales (Edmunds 1975). This may be explained by the availability of K^+ ions, which resulted in potassium fixation and better crystallinity. Fixation of potassium in illite leads to better crystallinity. It would be expected that in the coal environments the potassium is leached out and hence a less structured illite is formed (Salter 1964).

The crystallinity of illite also indicates the degree of transportation from the continental areas to the deeper part of the basin. It is well crystallized in shallow and continental areas and looses its crystallinity in the deeper parts of the ocean. In the area of investigation it is found that the crystallinity of illite decreases toward the deeper part of the depositional basin (fig, 4.2).

The crystallinity of illite mineral in Salt Range indicates that the area was not a uniform area but the local depressions existed during deposition of Patala Formation in the Salt Range area, with the general deepening of basin toward west. The direction of the marine basin of deposition, on the basis of illite mineral concentration appears from Southeast to Northwest.

Weaver (1956) suggested that mixed-layer clay minerals are usually derived from the degradation or aggredation of pre-existing clay minerals. Burst (1959) found evidence of systematic diagenetic changes in this mineral with depth. The mixed-layer clay mineral in the areas of the Salt Range and Kala Chitta Range was interpreted as diagenetic mineral and thought to be the product of alteration of smectite followed by early and late diagenetic stages. The mixed-layer clay mineral is a random mixture of illite/ montmorillonite, displays expansion on glycolation and contraction on heating. Weaver (1958) studied the clays and alteration of the clay mineral lattice and concluded that interlayer changes were to be excluded from diagenesis. Dunoyer de Segonzac (1970), reviewed the diagenesis of clay minerals and postulated the following stages.

i. Early diagenesis or shallow burial stage in which some mixed-layer clay minerals undergo aggradation by adsorption of Mg, K and Na.

ii. Middle diagenesis, argillaceous sediments compacted with 50% of their connate water. Many types of replacements take place due to the circulation of interstitial water. Some detrital minerals such as biotite are unstable in this stage.

iii. Deep or late diagenesis, temperature increases more than 100°C. Pressure increased and the porosity is reduced. Montmorillonite and regular mixed-layer clay minerals disappeared.

iv. Anchizone, the temperature increases upto 200°C. It may be regarded as a transitional zone towards metamorphism. Illite and chlorite are dominant minerals.

Read and Watson (1962) defined diagenesis as a process by which all the changes occur in sediments after deposition with increasing temperature and pressure and later passes into metamorphism. Burst (1969) concluded that swelling clay gradually changed into non-swelling clay with depth, showing quantitative changes of swelling lattice into mixed non-swelling lattices clays against burial depth in samples from Gulf Coast sediments. Dorste, Bhattacharya and Sunderman (1962) investigated the soil profiles and found that chlorite completely altered into montmorillionite with intermediate stages of random mixed-layer chlorite-vermicullite-montmorillonite, and also observed that some illite changes to montmorillonite through random mixed-layer illite/montmorillonite.

Scherp (1963) found that illitization took place before burial diagenesis. The clay minerals were studied from boreholes at different places (Libya, Tunisia, Sicily, Italy) by Long et al. (1964, 1966), and Long and Neglia (1968). They observed that montmorillonite finally disappeard. Muffler and White (1969) studied the clay mineralogy of the Salton Basin in California, where the geothermal gradient was high and observed a gradual change of montmorillonite to illite, passing through a stage of disordered mixed-layer clay mineral. The mixed-layer minerals were stable in the range of 80–200 °C which prevailed at depth of 1,000–3,000m.

Dunoyer de Segonzae (1970), concluded that "all mixed layers, whatever their oigins, were inevitably pass to illite and chlorite in deep diagenesis".

The mixed-layer clay mineral in the Salt Range is mainly a random mixture of illite/montmorillnite, but in Kala Chitta Range the mixed-layer clay mineral was random mixture of Illite/montmorillonite/chlorite. It indicates that more Mg^{++} ions were available in the northern part of the basin as compared to the Southern part, and were probably derived from the chlorite and ocean water carbonates, rich in Mg^{++}. It is most likely that the mixed-layer clay mineral in Salt Range and Kala Chitta Range originated due to diagenesis of smectite and chlorites.

The mineral chlorite was detected in the samples from the Patala Formation exposed in Nilawahan, Central Salt Range and Kala Chitta Range at Khawri Khawar. The chlorite mineral was generally absent in samples from the Gandhala Nala, Eastern Salt Range, Katha and Nilawahan area Central Salt Range. It indicates that the chlorite is a fine grain mineral which was transported further into the deeper part of the basin towards north. Sudden increase of chlorite in samples of Kala Chitta Range gives a self explanation of the sedimentational controls of the fine grained material. It may be stated that coarse grain materials are always deposited into the shallower part of the basin while finer grain materials move away towards the deeper parts of the depositional basin. Grim an Johns (1954) studied the recent sediments from the Gulf of Mexico and obseved that montmorillonite gradually changes into illit/chlorite. Chlorite can be produced from montmorillonite by treating it with magnisium. White House and Mc

Carter (1958) prepared illite and chlorite from montmorillonit by treating it with artificial sea-water at ordinary temperature, prеssure and found that transformation of montmorillonite depends on the K:Mg ratio. Sawhney (1960), Barnhisel and rich (1963) treated smectite with various aluminium Salts at moderate temperature and observed the development of a 14Å chlorite structure.

Chlorite can also be produced by the diagenesis of other clay mineals. Burst (1959) investigated diagenesis in the sediments of the Wilcox formation of the Gulf Coast. He observed that the chlorite appeared to be the more dominant constituent at depth, and thermal stability increases with depth. Webb (1961) investigated several Pennsylvanian sections from the East Central United states, the chlorite abundance decreased upward in some underclays. Parham (1964) demonstrated the lateral variations in clay minerals of Pennsylvanian underclays from the Illinois and Ohio coal basins and found that the kaolinite, illite, chlorite, vermiculite, montmorillonite and mixed-layer clay minerals were present in different proportions, according to their palaeogeographic locations. Kaolinite decreases from nearshore to basinwards, while illite is absent in nearshore region and then appears towards the basin. Chlorite was reached its maximum and showed a basin ward increase. Vermiculite is present in areas containing dominantly illite and mixed- layer clay mineral. Mixed layer clay mineral were observed in all the samples.

Dunoyer de Segonzac (1970) stated that in early diagenesis, montmorillonite may be transformed to chlorite via Corrensite while chlorite becomes more regular and stabilized during late diagenesis and becomes the major mineral in the epizone, taking up iron and magnesium. Wilson (1965) showed that underclays of upper coal measures of South Wales contained more chlorite and illite and less Kaolinite than the underclays in the lower and middle coal measures. He concluded that chlorite in the underclays of the upper Coal measures was of primary detrital origin.

In view of the findings mentioned above, the chlorite from the Patala Formation may be a chlorite which was transported into the depositional basin due to erosion of the rocks rich in chlorite minerals, in the South. The chlorite minerals therefore appears to be detrital minerals in the Patala Formation exposed at Nilawahan and Kala Chitta Range at Khawri Khawar area. The clay mineral show a systematic depositional pattern according to grain size. The coarse clays are generally deposited in the shallow part of the basin and finer clays are deposited towards the deeper part of the basin. The kaoline mineral are generally known to be coarser clays while the chlorite, illite and mixed-layer clay minerals are known to be finner clays. In any huge depositional basin, when the coarse materials such as quartz, feldspars, tourmaline etc. are not tranported further away into the basin, the clay minerals are the only minerals which provide the sedimentational control during the deposition in an extensive basin. The kaoline minerals are generally deposited in the shallow part of the basin and the illite, chlorite and mixed-layer clay minerals are increased in the deeper parts of the basin. It is therefore concluded that the clay minerals are mainly controled by sedimentational processes and partly controled by diagenetic alteration during early and late diagenetic phases in Salt Range and Kala Chitta Range.

CORELATION OF CLAY MINERALS BETWEEN SALT RANGE AND KALA CHITTA RANGE

The distribtion of clay minerals in different sections of the Patala Formation measured from east to west in the Salt Range displays sudden increase of kaolinite representing the changes in environments suitable for the formation of kaolinite. The mineral kaolinite is distributed throughout measured sections of the Patala Formation exposed in Salt Range, except the Nilawhan section. The different sections of the southern Salt Range measured form east to the west can be correlated on the basis of distribution of mineral kaolinite. Four different horizons are distinguished throughout the area, where coal or carbonaceous shales can be expected, (fig. 4.1). Although the coal is not found in the Patala Formation in westren Salt Range but these correlation could be very usefull for the exploration of coal in the westren Salt Range. The kaolinite rich horizon represent the seatearth/ underclays or roof shales in the western Salt Range from where the coal was either being eroded away or thinly deposited which needs to be explored. The kaolinite generally decreases towards the deeper part of the depositional basin. Baqri (1977) investigated the underclays in the South Wales coal field and observed that the kaolinite de-creases from east to west, the direction for the deepening of the basin. It is most likely that the kaolinite in the Potwar area was also partly controled by the sedimentational processes as it decreases from south (Salt Range) to the north (Kalachitta Range, Fig. 3.2).

The correlation of the illite mineral present in the

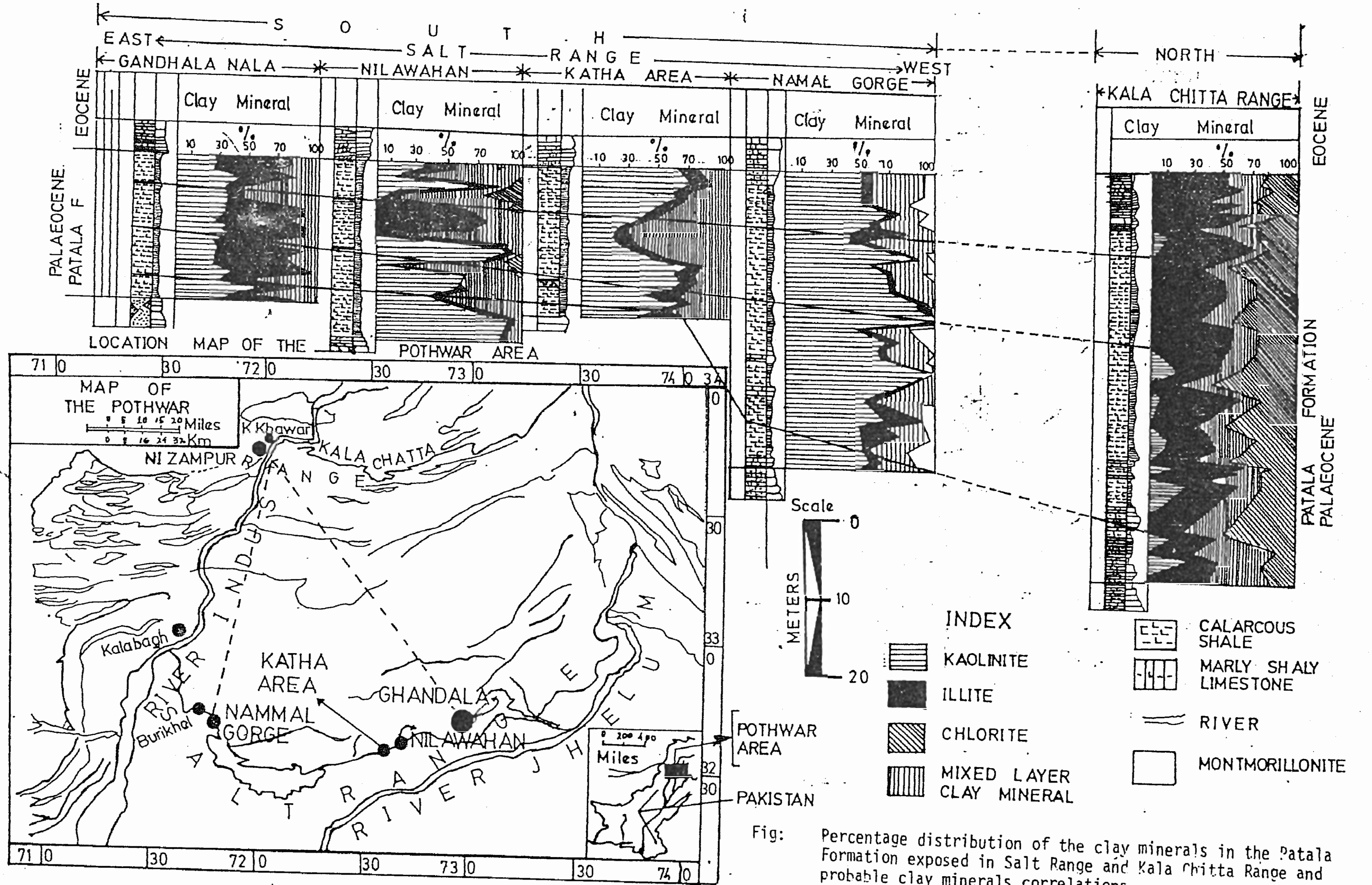


Fig: Percentage distribution of the clay minerals in the Patala Formation exposed in Salt Range and Kala Chitta Range and probable clay minerals correlations.

measured sections indicates the gradually decrease towards west, suggesting local variations due to local depressions.

The correlation of the mixed-layer clay mineral from east to west indicates an increas towards west. The mixed layer clay mineral of illite/ montmorillonite towards west is formed by the addition of K^{++} ions in the montmorillonite. The presence of montmorillonite in the west supports this view, Baqri (1990, personal communication).

The same correlation is true from south to north, between Salt-Range to Kala Chitta Range.

CHAPTER - V

CONCLUSION

1. The average clay mineral composition of the Patala Formation exposed in Gandhala Nala (Estern Salt Range) includes kaolinite 37 percent, illite 38 percent and random mixture of mixed layer clay mineral illite/montmorillonite 25 percent. The crystallinity index of kaolinite is 0.27 and illite is 0.2 . The minerals are more crystalline in this section. The illite is detrital in origin. kaolinite is partly detrital and partly diagenetic. Mixed-layer illite/ montmorillonite clay mineral is most likely early and late diagenetic in origin.

2. The average clay mineral composition of Patala Formation exposed at Nilawahan gorge (Central Salt Range) is kaolinite 43 percent, illite 15 percent and Chlorite 3 percent. The kaolinte is partly detrital and partly diagenetic. The illite is detrital. Mixed-layer illite/montmorillonite mineral is diagenetic and authigenic. Chlorite is found mainly as the alteration product as observed by the analysis.

3. In Katha area the average clay mineral composition show that the Kaolinite is 53 percent, illite is 11 percent and mixed-layer clay mineral, a random mixture illite/ montmorillonite is 38 percent. The illite is detrital, While Kaolinite is diagenetic in nature. The mixed-layer clay mineral illite/montmorillonite is diagenetic/authigenic. The crystallinity indices show better crystalline state of minerals.

4. The average clay minerals of Khawri Khawar section exposed at Kala Chitta Range include illite 42 percent, kaolinite 6

percent, chlorite 27 percent, and a random mixed-layer clay mineral illite/montmorillonite, illite/montmorillnite/ chlorite which is 26 percent. The illite, chlorite and kaolinite are probably detrital minerals. The mixed-layer clay minreal is diagenetic/authigenic in origin.

5. The kaolinite mineral shows a decrease in amount from Salt Range to Kala Chitta Range indicating the direction of deepening of basin.

6. The illite and Chlorite show an increase in amount from Salt Range (south) to Kala Chitta Range, also indicating the direction of deepening of basin.

7. The crystallinity indices of illite in Salt Range show a decrease in crystallinity from east to west, indicating a general direction for the deepening of the basin with local depressions.

8. The crystallinity indices of illite from Salt Range to Kala Chitta Range showed the sudden decrease in crystallinity, indicating the deepening of basin. The crystallinity index of kaolinite in Salt Range also showed a general decrease towards west, representing the general deepening of basin with a minor local depression.

9. The crystallinity index of kaolinite in Salt Range is 0.26, and show a decrease in Kala Chitta Range which is 0.77. The crystallinity index of illite in Salt Range is 0.17, and show decrease in Kala Chitta Range to 0.37.

10. The depositional basin during the deposition of the Patala Formation extended from southeast to northwest, where the detritus was transported from the continent in the South.

11. The distribution of clay minerals in the Patala Formation is

mainly controlled by the simple sedimentary processes and partly by early and late diagenetic processes.

12. The distribution of clay mineral in Salt Range and Kala Chitta Range display the stratigraphic control, where increase of kaolinite and illite may be correlated significantly. This would be very useful for the exploration of coal.

This work indicates that the Patala Formation towards west and north-west would include more marine deposits with high organic matter and should be explored for the generation of oil as a potential source rock. The mineral kaolinite was recognised in abundant quantities as seatearths and roofshales in the sections of Eastern and Central Salt Range, which is a useful mineral for the economic exploitation and ceramic materials. The seatearths and roofshales can be economically exploited after the investigation of their "thixo-tropic" properties.

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<u>APPENDIX - A</u>

X-RAY DIFFRACTION DATA (RANDOM POWDER SAMPLES) FOR THE GENERAL MINERAL ANALYSES OF PATALA FORMATION, KHAWRI KHAWAR (Kala Chitta Range).

Sample no-1 /KKP
Rock: Lime stone.

S.No	2° θ	A°	Minerals	Remarks
1	20.8	4.26	qartz	lime stone
2	23.1	3.84	calcite	
3	26.6	3.34	quartz	
4	29.4	3.03	calcite	
5	36.0	2.46	quartz	
6	43.1	2.09	calcite	

Sample no-2 /KKP
Rock: Limestone.

S.No	2° θ	A°	Minerals	Remarks
1	20.8	4.26	quartz	limestone
2	23.1	3.84	calcite	
3	26.6	3.34	quartz	
4	29.4	3.03	calcite	
5	36.0	2.46	calcite	
6	43.2	2.09	clcite	
7	47.5	1.90	clcite	

Sample no-3 /KKP
Rock: Marly Shales.

S.No.	2° θ	A°	Mineral	Remarks
1	4-4.7	22.07-18.78	mixed-layer	
2	6.2	14.24	ML/chl (probable)	
3	8.8	10.04	illite	
4	19.8	4.48	illite	
5	20.8	4.26	quartz	
6	23.0	3.86	calcite	
7	24.0	3.70	feldspar group	
8	25.4	3.50	feldspar group	
9	26.6	3.34	quartz	
10	29.4	3.03	calcite	
11	31.5	2.83	feldspar group	
19	47.2	1.92	pyrite	
20	48.6	1.87	calcite	
21	50.1	1.81	quartz	
22	56.6	1.63	pyrite	
24	60.8	1.52	pyrite	
25	64.8	1.43	feldspar group	

Sample no-5 /KKP
Rock: Marly shales.

S.No	2° θ	A°	Minerals	Remarks
1	4 - 6.2	22.07-12.61	mixed-layer	
2	8.8	10.04	illite	
3	18.8	4.71	feldspar group	
4	19.8	4.48	illite	
5	20.8	4.26	quartz	
6	23.0	3.86	calcite	
7	24.0	3.70	feldspar group	
8	26.6	3.34	qurtz	
9	29.4	3.03	calcite	
10	32.4	2.76	pyrite	
11	35.5	2.52	feldspar group	
12	36.0	2.49	calcite	
13	36.6	2.46	quartz	
14	47.2	1.92	pyrite	
15	50.1	1.81	quartz	
16	56.6	1.63	pyrite	

Sample no-6 /KKP
Rock: Limestone.

S.No	2°θ	A°	Minerals	Remarks
1	19.8	4.48	illite	
2	20.8	4.26	quartz	
3	23.1	3.84	calcite	
4	26.6	3.34	quartz	
5	29.4	3.03	calcite	
6	31.5	2.83	calcite	
7	42.5	2.12	quartz	
8	50.1	1.81	quartz	
9	57.5	1.60	calcite	

Sample no-7 /KKP
Rock: Marly shales.

S.no	2°θ	A°	Minerals	Remarks
1	4-7.4	22.07-11.93	mixed-layer	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	18.8	4.71	feldspar group	
5	19.8	4.48	illite	
6	20.8	4.26	quartz	
7	24.0	3.70	feldspar group	
8	26.6	3.34	quartz	
9	29.4	3.03	calcite	
10	32.4	2.76	pyrite	
11	50.1	1.81	quartz	
12	56.6	1.63	pyrite	

Sample no-8 /KKP
Rock: Marly Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	5-6.2	17.65-14.24	mixed-layer	
2	8.8	10.04	illite	
3	19.8	4.48	illite	
4	20.8	4.26	quartz	
5	24.0	4.70	feldspar	
6	26.6	3.34	feldspar	
7	29.4	3.03	calcite	
8	34.9	2.56	feldspar	
9	36.0	2.49	calcite	
10	47.2	1.92	pyrite	
11	48.6	1.87	calcite	
12	50.1	1.81	quartz	
13	56.6	1.63	pyrite	
14	60.8	1.52	pyrite	

Sample no-9 /KKP
Rock: Marly shales.

S.No.	2°θ	A°	Mineral	Remarks
1	19.8	4.48	illite	
2	20.8	4.26	quartz	
3	23.1	3.84	calcite	
4	26.6	3.34	quartz	
5	29.4	3.03	calcite	
7	36.0	2.49	calcite	
8	50.1	1.81	quartz	

Sample no-10 /KKP
Rock: Shales.

S.No.	2°θ	A°	Mineral	Remarks
1	6.2	14.24	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	18.8	4.71	feldspar group	
5	19.8	4.48	illite	
6	20.9	4.24	quartz	
7	23.1	3.84	calcite	
8	24.0	3.70	feldspar group	
9	25.3	3.51	feldspar group	
10	26.6	3.34	quartz	
11	29.4	3.03	calcite	
12	47.2	1.90	pyrite	
13	50.1	1.81	quartz	
14	56.6	1.63	pyrite	

Sample no-13/ KKP
Rock: Marly Shales.

S.No.	2 θ	θ	Mineral	Remarks
1	4.0 - 6.6	22.07 - 13.3	mixed-layer	
2	8.8	10.04	illite	
3	12.4	7.13	Kaolinite	in form of traces.
4	17.7	5.06	illite	
5	18.8	4.74	feldspar	
6	19.8	4.48	illite	
7	20.8	4.26	quartz	
8	24.0	4.70	feldspar	
10	26.6	3.34	quartz	
11	29.4	3.03	calcite	
12	34.7	2.57	feldspar	
13	44.9	2.01	calcite	
14	50.1	1.81	quartz	

Sample no-14 /KKP

Rock: Calcareous Shales.

S.No.	2 θ	θ	Minerals	Remarks
1	6.0	14.71	chlorite	
2	12.3	7.18	chlorite	
3	8.8	10.04	illite	
4	11.1	7.96	feldspar	
5	12.4	7.13	kaolinite	
6	19.8	4.48	illite	
7	20.8	4.26	quartz	
8	24.0	3.70	feldspar	
9	24.9	3.57	kaolinite	
10	26.6	3.34	quartz	
11	33.0	2.71	pyrite	
12	35.0	2.56	feldspar	
13	50.1	1.81	quartz	
14	56.4	1.63	pyrite	

Sample no-15 /KKP
Rock: Marly shaly limestone.

S.No.	2 θ	θ	Mineral	Remarks
1	5 - 7	17.65 - 12.61	mixed-layer	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	17.8	4.97	illite	
5	19.8	4.48	illite	
6	20.8	4.26	quartz	
7	23.0	3.86	calcite	
8	24.0	3.70	feldspar	
9	20.8	4.26	quartz	
10	24.9	3.57	kaolinite	
11	26.6	3.34	quartz	
12	29.4	3.03	calcite	
13	34.9	2.56	feldspar	
14	36.6	2.49	calcite	
15	47.2	1.92	pyrite	
16	50.1	1.81	quartz	
17	56.6	1.63	pyrite	
18	59.9	1.54	quartz	
19	61.7	1.49	kaolinite	
20	64.7	1.43	feldspar	

Sample no-17 /KKP
Rock: Marly shales.

S.No.	2 θ	θ	Minerals	Remarks
1	6.2	14.24	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	18.8	4.97	feldspar	
5	19.8	4.71	illite	
6	20.8	4.26	quartz	
7	24.0	3.70	feldspar	
8	26.6	3.34	quartz	
9	24.9	3.57	kaolinite	
10	29.4	3.03	calcite	
11	34.7	2.58	feldspar	
12	41.2	2.19	calcite	
13	50.1	1.81	quartz	
14	53.7	1.70	kaolinite	
15	54.9	1.67	feldspar	
16	59.9	1.54	quartz	

Sample no-18 /KKP
Rock: Marly shales.

S.No.	2 θ	θ	Mineral	Remarks
1	6.1	14.24	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	17.8	4.97	illite	
5	18.8	4.71	feldspar	
6	19.8	4.48	illite	
7	20.8	4.26	quartz	
8	23.1	3.84	feldspar	
9	24.1	3.70	feldspar	
10	24.8	3.57	kaolinite	poor crystallized
11	26.6	3.34	quartz	
12	29.4	3.03	calcite	
13	36.0	2.49	calcite	
14	37.5	2.39	feldspar	
15	50.1	1.81	quartz	
16	57.4	1.60	calcite	

Sample no-19 /KKP
Rock: Marly shales.

S.No.	2 θ	θ	Minerals	Remarks
1	4 - 6.2	22.0 - 14.24	mixed-layer	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	in form of traces
4	17.8	4.97	illite	
5	18.8	4.71	feldspar	
6	19.8	4.48	illite	
7	20.8	4.26	quartz	
8	24.0	3.70	feldspar	
9	24.8	3.57	kaolinite	
10	25.3	3.51	feldspar	
11	26.6	3.34	quartz	
12	29.4	3.03	calcite	
13	34.9	2.56	feldspar	
14	48.6	1.87	calcite	
15	50.1	1.81	quartz	
16	60.0	1.54	quartz	

Sample no-20 /KKP
Rock: Marly shales.

S.No.	2 θ	θ	Minerals	Remarks
1	6.1	14.71	chlorite	
2	8.8	10.04	illite	
3	11.2	7.89	gypsum	
4	12.4	7.13	kaolinite	
5	17.8	4.97	illite	
6	18.8	4.71	feldspar	
7	19.8	4.48	illite	
8	20.4	4.26	quartz	
9	24.0	3.70	feldspar	
10	24.9	3.57	kaolinite	
11	26.6	3.34	quartz	
12	38.8	2.31	feldspar	
13	43.2	2.09	calcite	
14	50.1	1.81	quartz	
15	56.6	1.63	pyrite	
16	60.0	1.54	quartz	
17	60.9	1.52	pyrite	

Sample no-21 /KKP
Rock: Marly shales.

S.No.	2 θ	θ	Minerals	Remarks
1	6.2	14.24	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	17.8	4.97	illite	
5	18.6	4.76	feldspar	
6	19.8	4.48	illite	
7	20.8	4.26	quartz	
8	24.0	3.70	feldspar	
9	24.9	3.57	kaolinite	
10	25.3	3.51	feldspar	
11	26.6	3.34	quartz	
12	29.4	3.03	calcite	
13	34.9	2.56	feldspar	
14	48.6	1.87	calcite	
15	50.1	1.81	quartz	
16	56.6	1.63	pyrite	
17	60.9	1.52	pyrite	
18	64.0	1.45	kaolinite	

Sample no-22 /KKP
Rock: Marly shales.

S.No.	2 θ	θ	Minerals	Remarks
1	4.5-6.5	19.61-13.58	mixed-layer	
2	8.0	11.04	mixed-layer	
3	8.8	10.04	illite	
4	12.4	7.13	kaolinite	
5	17.9	4.95	illite	
6	18.8	4.71	feldspar	
7	19.8	4.48	illite	
8	20.8	4.26	quartz	
9	22.4	3.96	feldspar	
10	24.0	3.70	feldspar	
11	24.8	3.57	kaolinite	
12	26.6	3.34	quartz	
13	29.9	3.03	calcite	
14	45.0	2.01	calcite	
15	50.1	1.81	quartz	
16	54.9	1.67	quartz	

Sample no-23 /KKP
Rock: Marly shales

S.No.	2 θ	θ	Minerals	Remarks
1	6.2	14.24	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	in form of traces.
4	17.8	4.97	illite	
5	18.8	4.74	feldspar	
6	19.8	4.48	illite	
7	20.8	3.34	quartz	
8	24.0	3.70	feldspar	
9	24.8	3.57	kaolinite	
10	25.3	3.50	feldspar	
11	26.6	3.34	quartz	
12	27.9	3.19	feldspar	
13	29.4	3.03	calcite	
14	48.5	1.87	calcite	
15	50.1	1.81	quartz	
16	60.0	1.54	quartz	
17	64.0	1.45	feldspar	

Sample n0-24 /KKP
Rock: Marly Shales.

S.No	2 θ	ϑ	Minerals	Remarks
1	6.2	14.24	chlorite	
2	8.8	10.04	illite	
3	17.8	4.97	illite	
4	19.8	4.48	illite	
5	20.8	4.26	quartz	
6	24.0	3.70	feldspar	
7	25.3	3.53	chlorite	
8	26.6	3.34	quartz	
9	29.4	3.03	calcite	
10	28.4	3.13	pyrite	
11	35.0	2.56	feldspar	
12	39.5	2.28	quartz	
13	43.2	2.09	calcite	
14	47.5	1.91	pyrite	
15	50.1	1.81	quartz	
16	54.9	1.67	feldspar	
17	56.6	1.63	pyrite	
18	61.6	1.50	pyrite	

Sample no-25 /KKP
Rock: Marly Shales.

S.No.	2 θ	ϑ	Mineral	Remarks
1	6.2	14.24	chlorite	
2	8.8	10.04	illite	
3	12.4	7.07	chlorite	
4	17.8	4.97	illite	
5	19.8	4.48	illite	
6	20.8	4.26	quartz	
7	23.1	3.86	calcite	
8	24.0	3.70	feldspar	
9	26.6	3.34	quartz	
10	27.9	3.19	feldspar	
11	29.4	3.03	calcite	
12	34.9	2.56	feldspar	
13	43.3	2.09	calcite	
14	47.5	1.91	pyrite	
15	48.6	1.87	calcite	
15	50.1	1.81	quattz	
16	54.9	1.67	feldspar	
17	56.6	1.63	pyrit	

Sample no-26 /KKP
Rock: Marly Shales.

S.No.	2 θ	d	Minerals	Remarks
1	6.2	14.24	chlorite	
2	8.8	10.04	illite	
3	12.2	7.18	Kaolinite	in form of traces.
4	17.8	4.97	illite	
5	19.7	4.48	illite	
6	20.8	4.26	quartz	
7	23.0	3.86	calcite	
8	24.0	3.70	feldspar	
9	24.8	3.57	kaolinite	
10	26.6	3.34	quartz	
11	29.4	3.03	calcite	
12	39.9	2.28	pyrite	
13	40.3	2.24	quartz	
14	47.1	1.92	pyrite	
15	50.1	1.81	quartz	
16	54.9	1.65	feldspar	
17	56.6	1.63	pyrite	
18	59.0	1.56	pyrite	
19	63.1	1.47	feldspar	
20	64.7	1.43	feldspar	

Sample no-27 / KKP
Rock: Marly Shales.

S.No.	2 θ	d	Minerals	Remarks
1	6.1	14.47	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	in form of traces.
4	17.8	4.97	illite	
5	19.9	4.48	illite	
6	20.8	4.26	quartz	
7	23.1	3.84	calcite	
8	24.0	3.70	feldspars	
9	26.6	3.34	quartz	
10	27.8	3.19	feldspars	
11	28.3	3.13	pyrite	
12	29.4	3.03	calcite	
13	32.0	2.79	pyrite	
14	42.3	2.09	calcite	
15	47.2	1.97	pyrite	
16	50.1	1.81	quartz	
17	56.6	1.63	pyrite	

Sample no-28 /KKP
Rock: Marly Shales.

S.No.	2 θ	θ	Minerals	Remarks
1	6.1	14.71	mixed-layer	
2	8.8	10.04	illite	
3	12.4	7.18	kaolinite	
4	17.8	4.97	illite	
5	19.8	4.48	illite	
6	20.8	4.26	quartz	
7	24.0	3.70	feldspars	
8	26.6	3.34	quartz	
9	28.0	3.18	feldspars	
10	29.4	3.03	calcite	
11	32.9	2.71	pyrite	
12	34.9	2.56	feldspars	
13	39.5	2.28	calcite	
14	47.2	1.92	pyrite	
15	50.1	1.81	quartz	
16	56.6	1.63	pyrite	
17	64.7	1.43	feldspars	

Sample no-29 /KKP
Rock: Marly Shales.

S.No.	2 θ	θ	Minerals	Remarks
1	6.3	14.01	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	18.8	4.71	feldspars	
5	19.8	4.48	illite	
6	20.9	2.26	quartz	
7	23.1	3.84	calcite	
8	24.0	3.70	feldspars	
9	26.6	3.34	quartz	
10	29.4	3.03	calcite	
11	34.7	2.58	feldspars	
12	42.4	2.13	feldspars	
13	43.3	2.08	calcite	
14	50.1	1.81	quartz	
15	54.9	1.67	feldspars	

Sample no-30 /KKP
Rock: Marly Shales.

S.No.	2 θ	θ	Minerals
1	4.0-6.8	22.07-12.98	mixed-layer
2	8.8	10.04	illite
3	12.4	7.13	kaolinite
4	17.8	4.97	illite
5	18.8	4.71	feldspars
6	19.8	4.48	illite
7	20.8	4.26	quartz
8	23.1	3.86	calcite
9	24.0	3.70	feldspars
10	24.9	3.57	kaolinite
11	26.6	3.34	quartz
12	29.4	3.03	calcite
13	50.1	1.81	quartz
14	54.9	1.67	feldspars

Sample no-31 /KKP
Rock: Marly Shales.

S.No.	2 θ	θ	Minerals	Remarks
1	6.2	14.71	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	chlorite	
4	17.8	4.97	illite	
5	18.7	4.71	feldspars	
6	19.8	4.48	illite	
7	20.8	4.26	quartz	
8	24.0	3.70	feldspars	
9	25.3	3.51	chlorite	
10	26.6	3.34	quartz	
11	29.4	3.03	calcite	
12	34.7	2.58	feldspars	
13	43.2	2.09	calcite	
14	48.5	1.87	calcite	
15	50.1	1.81	quartz	
16	54.9	1.67	feldspars	
17	60.1	1.45	quartz	

Sample no-32 /KKP
Rock: Marly Shales.

S.No.	2 θ	θ	Minerals	Remarks
1	4 - 7	22.07-12.61	mixed-layer	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	18.8	4.71	feldspars	
5	19.8	4.48	illite	
6	20.8	4.26	quartz	
7	23.1	3.86	calcite	
8	24.0	3.70	feldspars	
9	26.6	3.34	quartz	
10	29.4	3.03	calcite	
11	34.7	2.56	feldspars	
12	43.3	2.08	calcite	
13	48.6	1.87	calcite	
14	50.1	1.81	quartz	
15	54.9	1.67	feldspars	

Sample no-33 /KKP
Rock: Marly Shales.

S.No.	2 θ	θ	Minerals	Remarks
1	6.2	14.24	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	17.8	4.97	illite	
5	19.8	4.48	illite	
6	20.8	4.26	quartz	
7	24.0	3.70	feldspars	
8	24.9	3.57	kaolinite	
9	26.6	3.34	quartz	
10	29.4	3.03	calcite	
11	34.9	2.56	feldspars	
12	43.3	2.08	calcite	
13	50.1	1.81	quartz	
14	54.9	1.67	feldspars	

Sample no-34 /KKP
Rock: Marly Shales.

S.No.	2 θ	Å	Minerals	Remarks
1	6.2	14.47	chlrite	
2	8.8	10.04	illite	
3	11.6	7.62	gypsum	
4	12.4	7.13	kaolinite	
5	18.8	4.71	feldspars	
6	19.8	4.48	illite	
7	20.8	4.26	quartz	
8	24.0	3.70	feldspars	
9	24.9	3.57	kaolinite	
10	26.6	3.34	quartz	
11	29.4	3.03	calcite	
12	43.2	2.09	calcite	
13	47.5	1.91	feldspars	
z14	50.1	1.81	quartz	
15	54.9	1.67	feldspars	
16	56.6	1.63	pyrite	

Sample no-35 /KKP
Rock: Shales.

S.No.	2 θ	Å	Minerals	Remarks
1	5.3-6.6	16.6-13.3	mixed-layer of mont/chlorite	
2	7.8	11.62	Gypsum	
3	8.8	10.04	illite	
4	11.6	7.62	Gypsum	
5	12.4	7.13	kaolinite	
6	19.8	4.48	illite	
7	20.8	4.26	quartz	
8	23.1	3.86	calcite	
9	24.0	3.70	feldspars	
10	25.3	3.51	chlorite	
11	26.6	3.34	quartz	
12	29.4	3.03	calcite	
13	35.0	2.56	feldspar	
14	43.2	2.09	calcite	
15	47.4	1.90	pyrite	
16	50.1	1.81	quartz	
17	54.9	1.67	feldspars	
18	56.6	1.63	pyrite	
19	61.5	1.50	pyrite	

Sample no-36 /KKP
Rock: Shales.

S.No.	2 θ	θ	Minerals	Remarks
1	6.1	14.47	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	Kaolinite	in form of traces.
4	17.8	4.97	illite	
5	19.8	4.48	illite	
6	20.8	4.26	quartz	
7	24.0	3.70	feldspars	
8	24.8	3.57	kaolinite	
9	25.3	3.50	chlorite	
10	26.6	3.34	quartz	
11	29.4	3.03	calcite	
12	35.0	2.56	feldspars	
13	43.2	2.09	calcite	
14	47.2	1.92	pyrite	
15	50.1	1.81	quartz	
16	56.6	1.63	pyrite	
17	61.5	1.50	pyrite	

Sample no-37 /KKP
Rock: Shales.

S.No.	2 θ	θ	Minerals	Remarks
1	5.0-6.6	17.65-13.38	mixed-layer	
2	8.8	10.04	illite	
3	11.6	7.62	Gypsum	
4	12.4	7.13	kaolinite	
5	17.8	5.06	illite	
6	19.8	4.48	illite	
7	20.8	4.26	quartz	
8	23.1	3.84	calcite	
9	26.6	3.34	quartz	
10	29.4	3.03	calcite	
11	34.8	2.56	feldspars	
12	43.2	2.09	calcite	
13	47.2	1.92	pyrite	
14	50.1	1.81	quartz	
15	54.9	1.67	feldspars	
16	56.6	1.63	pyrite	
17	61.5	1.50	pyrite	
18	64.0	1.45	calcite	

Sample no-38 /KKP
Rock: Shales.

S.No.	2 θ	Å	Mineral	Remarks
1	5.0-7.0	17.65-12.61	mixed-layer	
2	8.8	10.04	illite	
3	17.8	4.97	illite	
4	19.8	4.48	illite	
5	20.8	4.26	quartz	
6	23.1	3.86	calcite	
7	24.0	3.70	feldspars	
8	26.6	3.34	quartz	
9	29.4	3.03	calcite	
10	34.9	2.56	feldspars	
11	40.3	2.23	pyrite	
12	43.2	2.08	calcite	
13	50.1	1.81	quartz	
14	54.9	1.67	feldspars	
15	56.7	1.63	pyrite	
16	64.7	1.43	feldspars	

Sample no-39 /KKP
Rock: Shales.

S.No.	2 θ	Å	Minerals	Remarks
1	6.2	14.24	chloride	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	17.8	4.97	illite	
5	18.6	4.76	feldspar	
6	19.8	4.48	illite	
7	20.8	4.26	quartz	
8	23.1	3.86	calcite	
9	24.0	3.70	feldspars	
10	24.8	3.57	kaolinite	
11	26.6	3.34	quartz	
12	29.4	3.03	calcite	
13	31.5	2.83	feldspar	
14	34.8	2.57	pyrite	
15	43.2	2.09	calcite	
16	47.2	1.92	pyrite	
17	50.1	1.81	quartz	
18	56.6	1.63	pyrite	
19	60.0	1.54	quartz	
20	60.7	1.52	pyrite	

Sample no-40 /KKP
Rock: Marly Shales.

S.No.	2 θ	θ	Minerals	Remarks
1	5.0-7.0	17.65-12.61	mixed-layer	
2	11.6	7.62	Gypsum	
3	12.4	7.13	kaolinite	in form of traces.
4	17.7	4.97	illite	
5	19.8	4.48	illite	
6	20.8	4.26	quartz	
7	23.1	3.86	calcite	
8	23.5	3.70	feldspars	
9	26.6	3.34	quartz	
10	29.4	3.03	calcite	
11	33.4	2.68	feldspars	
12	34.9	2.56	feldspars	
13	36.0	2.49	calcite	
14	43.2	2.09	calcite	
15	47.2	1.92	pyrite	
16	50.1	1.81	quartz	
17	56.6	1.63	pyrite	
18	61.6	1.50	pyrite	
19	64.9	1.43	kaolinite	

Sample no-41 /KKP
Rock: Marly Shales.

S.No.	2 θ	θ	Minerals	Remarks
1	5.0- 7.0	17.65-12.61	mixed-layer	
2	8.0-10.5	11.04- 8.41	mixed-layer	
3	11.6	7.62	Gypsum	
4	20.8	4.26	quartz	
5	23.1	3.86	calcite	
6	26.6	3.34	quartz	
7	29.4	3.03	calcite	
8	31.5	2.83	calcite	
9	33.0	2.71	pyrite	
10	36.0	2.49	calcite	
11	43.2	2.09	calcitr	
12	47.2	1.92	pyrite	
13	50.1	1.81	quartz	
14	56.6	1.63	pyrite	
15	58.3	1.58	pyrite	
16	60.8	1.52	pyrite	
17	61.1	1.50	pyrite	

Sample no-42 /KKP
Rock: Marly Shales.

S.No.	2 θ	θ	Minerals	Remarks
1	6.2	14.24	mixed-layer	
2	8.8	10.04	illite	
3	11.6	7.62	Gypsum	
4	17.8	4.97	illite	
5	18.8	4.71	feldspars	
6	19.8	4.48	illite	
7	20.8	4.26	quartz	
8	23.1	3.86	calcite	
9	23.4	3.79	Gypsum	
10	24.0	3.70	feldspars	
11	25.4	3.50	feldspars	
12	26.6	3.34	quartz	
13	29.4	3.03	calcite	
14	35.0	2.56	feldspars	
15	40.4	2.23	pyrite	
16	42.4	2.13	quartz	
17	45.2	2.01	Gypsum	
18	50.1	1.81	quartz	
19	56.6	1.63	pyrite	
20	57.6	1.59	pyrite	

Sample no-43 /KKP
Rock: Limestone.

S.NO.	2 θ	θ	Minerals	Remarks
1	20.8	4.26	quartz	
2	23.1	3.84	calcite	
3	26.6	3.34	quartz	
4	29.4	3.03	calcite	
5	31.5	2.83	calcite	
6	36.0	2.46	quartz	
7	43.2	2.09	calcite	
8	50.1	1.81	quartz	
9	56.7	1.62	calcite	
10	64.8	1.43	calcite	

Sample no-44 /KKP
Rock: Marly Shales.

S.No.	2 θ	θ	Minerals	Remarks
1	5 -6.2	17.65-14.24	mixed-layer	
2	11.6	7.62	Gypsum	
3	8.8	10.04	illite	
4	17.8	4.97	illite	
5	19.8	4.48	illite	
6	20.8	4.26	quartz	
7	24.0	3.70	feldspars	
8	26.6	3.34	quartz	
9	29.4	3.03	calcite	
10	31.3	2.85	feldspars	
11	34.8	2.56	feldspars	
12	36.6	2.46	quartz	
13	50.1	1.81	quartz	
14	56.6	1.63	pyrite	
15	57.4	1.60	pyrite	
16	60.0	1.54	quartz	

Sample no-45 /KKP
Rock: Limestone.

S.No.	2 θ	θ	Minerals
1	20.8	4.26	quartz
2	23.1	3.84	calcite
3	26.6	3.34	quartz
4	29.4	3.03	calcite
5	31.5	2.86	feldspars
6	43.2	2.09	calcite
7	47.2	1.92	pyrite
8	48.6	1.87	calcite
9	50.1	1.81	quartz
10	56.6	1.63	pyrite
11	60.8	1.52	pyrite
12	61.5	1.50	pyrite
13	64.8	1.43	quartz

APPENDIX - B

X-RAY DIFFRACTION DATA (RANDOM POWDER SAMPLES) OF THE GENERAL MINERAL ANALYSES OF THE PATALA FORMATION, GANDHALA NALA SECTION (Eastern Salt Range).

Sample no-1 /GNP
Rock: Calcareous Shales.

S.No.	2°θ	A°	minerals	Remarks
1	5.4	16.05	mixed layer	
2	5.8	15.22	chlorite	
3	6.3	14.01	chlorite	
4	8.8	10.04	illite	
5	11.5	7.68	gypsum	
6	12.3	7.13	kaolinite	
7	17.7	5.06	illite	
8	19.8	4.48	illite	
9	20.8	4.28	quartz	
10	23.3	3.81	calcite+gypsum	
11	24.8	3.57	kaolinite	
12	29.4	3.03	calcite	
13	34.9	2.56	illite	
14	37.7	2.38	kaolinite	
15	54.8	1.67	kaolinite	
16	62.3	1.48	kaolinite	

Sample no-2 /GNP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	4 - 7	22.07-12.61	mixed-layer	In normal slide
2	8.8	10.04	illite	the mixed-layer
3	11.5	7.68	gypsum	mineral,reflection
4	12.3	7.13	kaolinite	observed at 25.22,
5	17.8	4.97	illite	21.02. 20.06A.
6	19.8	4.48	illite	
7	20.8	4.26	quartz	
8	23.5	3.81	gypsum	
9	24.8	3.57	kaolinite	
10	26.6	3.34	quartz	
11	29.1	3.06	gypsum	
13	34.9	2.51	kaolinite	
14	45.8	1.98	kaolinite	
15	50.1	1.81	kaolinite	
16	62.2	1.48	kaolinite	

Sample no-3 /GNP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	4 - 6	22.07-13.79	mixed-layer	
2	8.8	10.04	illite	
3	11.5	7.68	gypsum	
4	12.4	7.13	kaolinite	
5	19.7	4.48	illite	
6	20.8	4.26	quartz	
7	23.4	3.81	gypsum	
8	24.8	3.57	kaolinite	
9	26.6	3.34	quartz	
10	36.4	2.46	illite	
11	40.2	2.24	illite	
12	45.7	1.98	kaolinite	
13	50.1	1.81	quartz	
14	62.2	1.49	kaolinite	

Sample no-4 /GNP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	3-7	29.42-12.61	mixed-layer clay mineral	
2	8.8	10.04	illite	
3	11.6	7.68	gypsum	
4	12.4	7.13	kaolinite	
5	17.8	4.97	illite	
6	20.8	4.26	quartz	
7	23.3	3.81	gypsum	
8	24.8	3.57	kaolinite	
9	26.6	3.34	quartz	
10	29.0	3.07	gypsum	
11	33.4	2.68	gypsum	
12	36.5	2.45	kaolinite	
14	50.1	1.81	qurtz	

Sample no-5 /GNP
Rock: Calcareous Shales.

S.NO.	2°θ	A°	Minerals	Remarks
1	3-7	29.42-12.61	mixed-layer clay minerals	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	19.8	4.48	illite	
5	20.8	4.26	quartz	
6	24.8	3.57	kaolinite	
7	26.6	3.34	quartz	
8	35.9	2.50	kaolinite	
9	50.0	1.81	quartz	
10	62.2	1.49	kaolinite	

Sample no-6 /GNP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Mineral	Remarks
1	12.4	7.13	kaolinite	
2	18.8	4.71	feldspars	
3	20.8	4.26	quartz	
4	24.0	3.70	feldspars	
5	24.8	3.57	kaolinite	
6	28.6	3.11	pyrite	
7	32.9	2.72	pyrite	
8	50.0	1.82	quartz	
9	56.6	1.63	pyrite	
10	64.2	1.46	kaolinite	

Sample no-7 /GNP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	3 - 7	29.42-12.61	mixed-layer clay minerals	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	19.8	4.48	illite	
5	24.4	3.57	kaolinite	
6	26.2	3.41	apatite	
7	34.4	2.60	apatite	
8	38.0	2.36	feldspars	
9	42.0	2.14	feldspar	

Sample no-8 /GNP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	2 - 9	22.07-9.1	mixed-layer	
2	12.4	7.13	kaolinite	
3	19.8	4.48	illite	
4	20.8	4.26	quartz	
5	24.8	3.57	kaolinite	
6	26.6	3.34	quartz	
7	34.8	2.56	illite	
8	35.9	2.49	kaolinite	
9	37.7	2.39	kaolinit	
10	39.4	2.28	kaolinite	
11	45.8	1.98	illite	
12	50.1	1.81	quartz	
13	59.9	1.54	quartz	

Sample no-9 /GNP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	3 - 7	42.29-12.61	mixed-layer	
2	8.8	10.04	illite	
3	11.6	7.62	gypsum	
4	12.4	7.13	kaolinite	
5	19.8	4.48	illite	
6	20.8	4.26	quartz	
7	24.8	3.57	kaolinite	
8	26.6	3.34	quartz	
9	34.8	2.57	kaolinite	
10	45.8	1.98	kaolinite	
11	50.0	1.81	quartz	
12	59.9	1.54	quartz	

Sample no-10 /GNP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	8.8	10.04	illite	
2	12.4	7.13	kaolinite	
3	19.8	4.48	illite	
4	20.8	4.26	quartz	
5	24.8	3.57	kaolinite	
6	26.6	3.34	quartz	
7	28.9	3.12	kaolinite	
8	29.4	3.03	calcite	
9	40.2	2.24	pyrite	
10	45.8	1.98	illite	
11	50.0	1.81	quartz	
12	54.8	1.67	kaolinite	
13	56.6	1.63	pyrite	

Sample no-11 /GNP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	12.4	7.13	kaolinite	
2	18.7	4.74	feldspars	
3	20.6	4.26	quartz	
4	24.8	3.57	kaolinite	
5	26.6	3.34	quartz	
6	42.2	2.24	feldspar	
7	45.6	1.98	kaolinite	
8	50.0	1.82	quartz	
9	56.7	1.62	feldspars	

Sample no-12 /GNP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	2 - 7	22.07-12.61	mixed-layer	
2	11.5	7.68	Gypsum	
3	12.4	7.13	kaolinite	
4	19.8	4.48	illite	
5	20.8	4.26	quartz	
6	23.1	3.86	calcite	
7	24.8	3.57	kaolinite	
8	26.6	3.34	quartz	
10	29.4	3.03	calcite	
11	48.5	1.87	calcite	
12	50.0	1.81	quartz	
13	62.5	1.49	kaolinite	

Sample no-13 /GNP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	3 - 7	29.42-12.61	mixed-layer	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	19.8	4.48	illite	
5	20.8	4.26	quartz	
6	24.8	3.57	kaolinite	
7	26.6	3.34	quartz	
8	34.8	2.57	illite	
9	38.5	2.33	kaolinite	
10	50.0	1.81	quartz	
11	54.9	1.67	kaolinite	

Sample no-14 /GNP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals
1	2 - 7	22.07-12.26	mixed-layer
2	11.8	7.68	gypsum
3	12.4	7.13	kaolinite
4	20.8	4.26	quartz
5	23.1	3.86	calcite
6	24.8	3.57	kaolinite
7	26.6	3.34	quartz
8	29.4	3.03	calcite+gypsum
9	47.6	1.91	kaolinite
10	48.6	1.87	kaolinite
11	50.0	1.81	quartz

Sample no-15 /GNP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	2 - 7	22.0-12.61	mixed-layer	
2	8.8	10.04	illite	
3	11.6	7.68	gypsum	
4	12.4	7.13	kaolinite	
5	20.8	4.26	quartz	
6	23.0	3.86	calcite	
7	24.8	3.57	kaolinite	
8	26.6	3.34	quartz	
9	29.4	3.03	calcite+gypsum	
10	48.6	1.87	calcite	
12	50.0	1.81	quartz	
13	64.00	1.45	kaolinite	

Sample no-16 /GNP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	2 - 7	22.0-12.61	mixed-layer	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	20.8	4.26	quartz	
5	23.1	3.86	calcite	
6	24.0	3.72	feldspars	
7	24.8	3.57	kaolinite	
8	26.6	3.34	quartz	
9	29.4	3.03	calcite	
10	36.5	2.46	illite	
11	50.0	1.81	quartz	
13	64.0	1.45	kaolinite	

Sample no-17 /GNP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	3 - 7	29.42-12.61	mixed-layer	In normal slide the the broad reflection observed at 24.52 - 26.75 for mixed-layer clay mineral.
2	8.8	10.04	illite	
3	11.6	7.68	gypsum	
4	12.4	7.13	kaolinite	
5	19.8	4.48	illite	
6	20.8	4.26	quartz	
7	23.3	3.81	gypsum	
8	24.8	3.57	kaolinite	
9	26.6	3.34	quartz	
10	45.7	1.98	kaolinite	
11	50.0	1.81	quartz	
12	54.8	1.67	kaolinite	

Sample no-18 /GNP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	3 - 7	29.42-12.61	mixed-layer	
2	8.8	10.04	illite	
3	11.5	7.68	gypsum	
4	12.4	7.13	kaolinite	
5	17.8	4.48	illite	
6	19.8	4.48	illite	
7	20.8	4.26	quartz	
8	24.8	3.57	kaolinite	
9	26.6	3.34	quartz	
10	27.5	3.24	feldspars	
11	38.3	2.34	feldspars	
12	50.0	1.81	qurtz	
13	54.8	1.67	kaolinite	
14	63.9	1.45	kaolinite	

Sample no-19 /GNP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	3 -7	29.42-12.61	mixed-layer	sample is mostly
2	23.2	3.83	gypsum	contain gypsum
3	26.6	3.34	quartz	and quartz.
4	29.5	3.01	gypsum	
5	36.2	2.49	gypsum	
6	39.6	2.26	gypsum	
7	43.4	2.08	gypsum	
8	47.8	1.90	gypsum	
9	48.8	1.86	gypsum	
10	50.0	1.81	quartz	
11	57.8	1.59	gypsum	
12	61.2	1.51	gypsum	

Sample no-20 / GNP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	5.6	15.22	mixed-layer	
2	8.8	10.04	illite	
3	11.6	7.62	gypsum	
4	12.4	7.18	kaolinite	
5	17.8	4.97	illite	
6	20.8	4.26	quartz	
7	24.8	3.57	kaolinite	
8	26.6	3.34	quartz	
9	29.5	3.01	gypsum	
10	50.0	1.81	quartz	

Sample no-21 /GNP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	3 - 7	29.42-12.61	mixed-layer	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	17.8	4.97	illite	
5	19.9	4.48	illite	
6	20.8	4.26	quartz	
7	24.8	3.57	kaolinite	
8	26.6	3.34	quartz	
9	29.4	3.03	calcite	
10	36.5	2.45	pyrite	
11	38.5	2.33	kaolinite	
12	47.4	1.91	kaolinite	
13	50.0	1.81	quartz	
14	55.3	1.65	kaolinite	
15	56.6	1.63	pyrite	
16	64.0	1.45	kaolinite	

Sample no-22 /GNP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	3 -7	29.42-12.61	mixed-layer	kaolinite, illite minerals are not observed.
2	20.8	4.26	quartz	
3	23.1	3.84	gypsum	
4	26.6	3.34	quartz	
5	29.4	3.03	gypsum	
6	36.0	2.49	gypsum	
7	39.5	2.27	calcite	
8	43.2	2.09	gypsum	
9	47.6	1.90	calcite	
10	48.6	1.87	gypsum	
11	57.6	1.60	gypsum	

APPENDIX - C

X-RAY DIFFRACTION DATA (RANDOM POWDER SAMPLES) OF GENERAL MINERAL ANALYSES OF PATALA FORMATION, NILAWAHAN GORGE (Central Salt Range).

Sample no-1 /NWP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	5.9	14.96	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	17.8	4.97	illite	
5	19.8	4.48	illite	
6	20.8	4.26	quartz	
7	22.0	4.01	feldspars	
8	24.8	3.57	kaolinite	
9	25.6	3.47	feldspars	
10	26.6	3.34	quartz	
11	27.9	3.19	feldspars	
12	50.1	1.81	quartz	

Sample no-2 /NWP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	5.9	14.96	chlorite	
2	12.3	7.18	kaolinite	in form of traces
3	19.7	4.48	illite	
4	20.8	4.26	quartz	
5	23.6	3.76	feldspars	
6	26.6	3.34	quartz	
7	27.5	3.24	feldspars	
8	30.8	2.90	feldspars	
9	34.6	2.59	chlorite	
10	36.5	2.46	chlorite	
11	50.1	1.81	feldspars	

Sample no-3 /NWP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	8.8	10.04	illite	
2	12.3	7.18	kaolinite	
3	19.9	4.48	illite	
4	20.8	4.26	quartz	
5	24.9	3.57	kaolinite	
6	26.6	3.34	quartz	
7	35.0	2.56	feldspars	
8	50.1	1.81	quartz	

Sample no-4 /NWP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	6.0	14.71	Chlorite	
2	12.4	7.13	kaolinite	
3	19.9	4.48	illite	
4	20.8	4.26	quartz	
5	22.0	4.03	feldspars	
6	23.6	3.76	feldspars	
7	24.0	3.70	feldspars	
8	26.6	3.34	quartz	
9	27.5	3.19	feldspars	
10	36.4	2.46	quartz	
11	50.1	1.81	quartz	

Sample no-5 /NWP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	5.9	14.96	Chlorite	illite, kaolinite mineral are not observed.
2	19.7	3.60	feldspars	
3	20.8	4.26	quartz	
4	23.6	3.76	feldspars	
5	24.1	3.68	feldspars	
6	26.6	3.34	quartz	
7	27.9	3.19	feldspars	
8	33.1	2.71	feldspars	
9	50.1	1.81	quartz	
10	59.9	1.54	quartz	

Sample no-6 /NWP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	6.0-6.2	14.71-14.24	ML/Chl/Mt	
2	8.8	10.04	illite	
3	19.8	4.48	illite	
4	20.8	4.26	quartz	
5	22.0	4.03	feldspars	
6	23.5	3.78	feldspars	
7	24.3	3.67	feldspars	
8	26.6	3.34	quartz	
9	27.9	3.19	feldspars	
10	34.7	2.58	chlorite	
11	50.1	1.81	quartz	
12	61.5	1.50	chlorite	

Sample no-7 /NWP
Rock:Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	8.8	10.04	illite	kaolinite not observed.
2	13.8	6.36	feldspars	
3	19.7	4.48	illite	
4	20.8	4.26	quartz	
5	22.0	4.03	feldspars	
6	24.2	3.65	feldspars	
7	26.6	3.34	quartz	
8	27.9	3.19	feldspars	
9	34.6	2.59	illite	
10	50.1	1.81	quartz	
11	61.5	1.48	illite	

Sample no-8 /NWP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	8.8	10.04	illite	kaolinite not observed.
2	19.9	4.48	illite	
3	20.8	4.26	quartz	
4	22.0	4.03	feldspars	
5	24.2	3.67	feldspars	
6	26.6	3.34	quartz	
7	33.2	2.70	feldspars	
8	50.1	1.81	quartz	

Sample no-9 /NWP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	8.8	10.04	illite	kaolinite not observed.
2	17.8	4.97	illite	
3	19.8	4.48	illite	
4	20.8	4.26	quartz	
5	22.1	4.01	feldspars	
6	24.3	3.65	feldspars	
7	26.6	3.34	quartz	
8	27.5	3.24	feldspars	
9	30.8	2.90	illite	
10	33.1	2.70	illite	
11	34.7	2.59	illite	
12	50.1	1.81	quartz	

Sample no-10 /NWP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	13.9	6.36	feldspars	clay minerals are not observed.
2	19.9	4.48	feldspars	
3	20.8	4.26	quartz	
4	22.0	4.03	feldspars	
5	23.0	3.86	feldspars	
6	24.0	3.70	feldspars	
7	26.6	3.34	quartz	
8	27.9	3.19	feldspars	
9	50.1	1.81	quartz	
10	64.0	1.45	quartz	

Sample no-11 /NWP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	8.8	10.04	illite	
2	12.3	7.13	kaolinite	
3	19.9	4.48	illite	
4	20.8	4.26	quartz	
5	24.9	3.57	kaolinite	
6	26.6	3.34	quartz	
7	31.9	2.89	feldspars	
8	35.0	2.56	feldspars	
9	38.4	2.34	feldspars	
10	50.1	1.81	quartz	

Sample no-13 /NWP
Rock: Calcareous Shales.

S.No.	2°θ	A°	Minerals	Remarks
1	8.8	10.04	illite	
2	12.3	7.18	kaolinite	
3	19.9	4.48	illite	
4	20.8	4.26	quartz	
5	24.9	3.57	kaolinte	
6	26.6	3.34	quartz	
7	28.5	3.12	pyrite	
8	33.1	2.70	pyrite	
9	35.9	2.49	kaolinite	
10	37.2	2.42	pyrite	
11	47.4	1.91	pyrite	
12	50.1	1.81	quartz	
13	62.4	1.48	kaolinite	

Sample no-14 /NWP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	5.9	14.96	mixed-layer	kaolinite mineral not observed.
2	19.8	4.48	illite	
3	20.8	4.26	quartz	
4	26.6	3.34	quarz	
5	27.9	3.19	fedspars	
6	29.4	3.03	calcite	
7	30.6	2.91	chlorite	
8	33.2	2.70	pyrite	
9	34.8	2.58	chlorite	
10	35.6	2.51	feldspars	
11	47.1	1.92	pyrite	
12	50.1	1.81	quartz	
13	61.5	1.50	chlorite	

Sample no-15 /NWP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	6.0	14.24	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	19.9	4.48	illite	
5	20.8	4.26	quartz	
6	24.0	3.70	feldspars	
7	24.9	3.57	kaolinite	
8	26.6	3.34	quartz	
9	33.0	2.70	feldspars	
10	35.0	2.56	feldspars	
11	50.1	1.81	quartz	
12	61.4	1.50	kaolinite	
13	61.6	1.48	chlorite	

Sample no-16 /NWP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	5.9	14.96	chlorite	
2	8.8	10.04	illite	
3	12.3	7.18	kaolinite	
4	13.4	6.41	feldspars	
5	19.9	4.48	illite	
6	20.8	4.26	quartz	
7	22.9	3.88	feldspars	
8	24.0	2.70	feldspars	
9	24.8	3.57	kaolinite	
10	26.6	3.34	quartz	
11	33.1	2.70	pyrite	
12	56.6	1.63	pyrite	

Sample no-17 /NWP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	6.0	14.24	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	19.9	4.48	illite	
5	20.8	4.26	quartz	
6	21.0	4.22	feldspars	
7	24.9	3.57	kaolinite	
8	26.6	3.34	quartz	
9	27.4	3.24	feldspars	
10	34.9	2.56	feldspars	
11	35.6	2.52	kaolinite	
12	50.1	1.81	quartz	
13	62.3	1.50	chlorite	

Sample no-18 /NWP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	6.0	14.24	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	19.9	4.48	illite	
5	20.8	4.26	quartz	
6	22.0	4.41	feldspars	
7	24.9	3.57	kaolinite	
8	26.6	3.34	quartz	
9	33.2	2.70	feldspars	
10	34.8	2.56	chlorite	
11	35.6	2.52	kaolinite	
12	50.1	1.81	quartz	
13	61.5	1.50	chlorite/kaolinite	

Sample no-19 /NWP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	6.0	14.96	chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	19.9	4.48	illite	
5	20.8	4.26	quartz	
6	24.8	3.57	kaolinite	
7	26.6	3.34	quartz	
8	27.9	3.19	feldspars	
9	35.0	2.56	feldspars	
10	50.1	1.81	quartz	

Sample no-20 /NWP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	6.0	14.24	chlorite	
2	8.8	10.04	illite	
3	12.3	7.18	kaolinite	
4	13.8	6.36	feldspars	
5	19.8	4.48	illite	
6	20.8	4.26	qurtz	
7	22.0	4.03	feldspars	
8	24.9	3.57	kaolinite	
9	35.0	2.56	chlorite	
10	50.1	1.81	quartz	

Sample no-21/NWP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	8.8	10.04	illite	illite , kaolinite observed in form of traces.
2	12.3	7.18	kaolinite	
3	13.8	6.36	feldspars	
4	19.9	4.48	illite	
5	20.4	4.34	feldspars	
6	20.8	4.26	quartz	
7	24.2	3.56	feldspars	
8	24.9	3.57	kaolinite	
9	26.6	3.34	quartz	
10	27.4	3.25	feldspars	
11	50.1	1.81	quartz	

Sample no-22 /NWP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	6.0	14.24	chlorite	illite observed in traces.
2	8.8	10.04	illite	
3	12.3	7.18	kalonite	
4	13.8	6.36	feldspars	
5	20.8	4.26	quartz	
6	24.1	3.65	feldspars	
7	24.9	3.57	kaolinite	
8	26.6	3.34	quartz	
9	27.9	3.21	feldspars	
10	50.1	1.81	quartz	
11	59.9	1.54	quartz	

Sample no-23 /NWP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	8.8	10.04	illite	illite observed in traces.
2	12.4	7.13	kaolinite	
3	13.8	6.36	feldfspars	
4	19.9	4.48	chlorite	
5	20.8	4.26	quartz	
6	23.1	4.03	feldspars	
7	24.9	3.57	kaolinite	
8	26.6	3.34	quartz	
9	29.9	3.19	feldspars	
10	38.4	2.33	feldspars	
11	50.1	1.81	quartz	

APPENDIX - D

X-RAY DIFFRACTION DATA (RANDOM POWDER SAMPLES) OF THE GENERAL MINERAL ANALYSES, OF PATALA FORMATION KATHA AREA (Central Salt Range).

Sample no-1 /KTRP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	6.2	14.24	Swelling chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	17.8	4.97	illite	
5	19.8	4.48	illite	
6	20.8	4.26	quartz	
7	23.1	3.84	feldspar group	
8	24.9	3.57	kaolinite	
9	26.6	3.34	quartz	
10	27.5	3.24	feldspar group	
11	29.4	3.03	calcite	
12	42.4	2.09	calcite	
13	50.1	1.81	quartz	

Sample no-2 /KTRP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	3.0-6.0	21.53-10.27	mixed-layer	illitete/montmorillonit
2	8.8	10.04	illite	mixed layer observed.
3	12.4	7.13	kaolinite	
4	19.9	4.48	illite	
5	20.8	4.26	quartz	
6	23.1	3.84	feldspar group	
7	24.9	3.57	kaolinite	
8	25.3	3.50	chlorite	
9	26.6	3.34	quartz	
10	27.8	3.24	feldspar group	
11	29.4	3.03	calcite	
12	36.0	2.49	calcite	
13	50.1	1.81	quartz	
14	57.4	1.60	calcite	
15	64.0	1.45	quartz	

Sample no-3 /KTRP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	6.0	14.76	Swlling chlorite	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	19.9	4.48	illite	
5	20.8	4.26	quartz	
6	24.9	3.57	kaolinite	
7	27.9	3.19	feldspar group	
8	29.4	3.03	calcite	
9	47.6	1.90	calcite	
10	50.1	1.81	quartz	

Sample no-4 /KRTP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	6.0	14.76	mixed-layer	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	17.8	4.97	illite	
5	19.9	4.48	illite	
6	20.6	4.26	quartz	
7	24.9	3.57	kaolinite	
8	25.3	3.50	chlorite	
9	26.6	3.34	quartz	
10	35.0	2.56	chlorite	
11	50.1	1.81	quartz	

Sample no-6 /KTRP
Rock: Calcarcous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	6.0	14.76	mixed-layer	
2	8.8	10.04	illite	
3	12.4	7.13	kaolinite	
4	17.8	4.97	illite	
5	19.9	4.48	illite	
6	20.8	4.26	quartz	
7	24.9	3.57	kaolinite	
8	25.3	3.50	chlorite	
9	26.6	3.34	quartz	
10	29.4	3.03	calcite	

11	36.0	2.49	calcite	
12	50.1	1.81	quartz	

Sample no-7 /KTRP
Rock: Calcarcous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	8.8	10.04	illite	
2	12.3	7.18	kaolinite	
3	19.9	4.48	illite	
4	20.8	4.26	quartz	
5	24.8	3.57	kaolinite	
6	26.6	3.34	quartz	
7	33.0	2.71	pyrite	
8	35.0	2.63	feldspar group	
9	37.1	2.41	pyrite	
10	37.8	2.38	illite	
11	38.4	2.34	kaolinite	
12	47.4	1.91	pyrite	
13	56.6	1.63	pyrite	

Sample no-8 /KTRP
Rock: calcareous Shales

S.No.	2° θ	A°	Minerals	Remarks
1	12.3	7.18	Kaolinite	
2	19.9	4.97	illite	
3	24.9	3.57	kaolinite	
4	26.6	3.34	quartz	
5	32.0	2.79	feldspar group	
6	35.0	2.56	feldspar group	
7	42.2	2.13	quartz	

Sample no-9 /KTRP
Rock: Calcarceous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	5.9	14.96	mixed-layer	
2	9.3	9.40	talc	
3	12.3	7.18	kaolinite	
4	17.4	4.97	illite	
5	20.8	4.26	quartz	
6	24.0	3.70	feldspar group	
7	26.6	3.34	quartz	

8	29.0	3.07	talc	
9	37.8	2.37	feldspar group	
10	50.1	1.81	quartz	
11	64.0	1.45	kaolinite	

Sample no-10 /KTRP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	5.9	14.96	mixed-layer	
2	9.4	9.40	talc	
3	12.4	7.13	kaolinite	
4	19.9	4.48	quartz	
5	20.8	4.26	quartz	
6	24.0	3.86	feldspar group	
7	24.9	3.57	kaolinite	
8	26.6	3.34	quartz	
9	27.4	3.24	feldspar group	
10	29.0	3.06	talc	
11	33.3	2.69	talc	
12	50.1	1.81	quartz	

Sample no-11 /KTRP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	6.6	14.96	mixed-layer	
2	11.8	7.62	gypsum	
3	12.4	7.13	kaolinite	
4	19.9	4.48	illite	
5	20.8	4.26	quartz	
6	21.2	4.18	kaolinite	
7	23.4	3.81	feldspar group	
8	24.8	3.57	kaolinite	
9	26.6	3.34	quartz	
10	27.4	3.26	feldspar group	
11	34.8	2.56	feldspar group	
12	50.1	1.81	quartz	

Sample no-12 /KTRP
Rock: Calcareous Shales.

S.No.	2 θ	A	Minerals	Remarks
1	5.9	14.76	mixed-layer	
2	8.8	10.04	illite	
3	12.3	7.18	kaolinite	
4	17.8	4.96	illite	
5	19.9	4.48	illite	

6	20.8	4.26	quartz	
7	24.9	3.57	kaolinite	
8	26.6	3.34	quartz	
9	27.6	3.21	feldspar group	
10	35.0	2.56	feldspar group	
11	50.1	1.81	quartz	

Sample no-13 /KTRP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	5.8	14.96	mixed-layer	
2	8.8	10.04	illite	
3	9.4	9.40	talc	
4	11.8	7.62	gypsum	
5	12.4	7.13	kaolinite	
6	17.8	4.97	illite	
7	19.8	4.48	illite	
8	20.8	4.26	quartz	
9	24.0	3.70	feldspar group	
10	26.6	3.34	quartz	
11	27.7	3.21	feldspar group	
12	50.1	1.81	quartz	

Sample no-14 /KTRP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	5.9	14.96	mixed-layer	
2	9.4	9.40	talc	
3	11.6	7.55	gypsum	
4	12.3	7.13	kaolinite	
5	17.8	4.96	illite	
6	19.9	4.48	illite	
7	20.8	4.26	quartz	
8	24.0	3.86	feldspar group	
9	24.9	3.57	kaolinite	
10	26.6	3.34	chlorite	
11	27.5	3.24	feldspar group	
12	37.7	2.38	talc	
13	50.1	1.81	quartz	

Sample no-15 /KTRP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	6.0	14.24	mixed-layer	
2	8.8	10.04	illite	
3	11.8	7.62	gypsum	

4	12.4	7.13	kaolinite	
5	19.9	4.48	illite	
6	20.8	4.26	quartz	
7	24.0	3.70	feldspar group	
8	24.8	3.57	kaolinite	
9	26.6	3.34	quartz	
10	29.4	3.03	calcite	
11	35.0	2.56	feldspar group	

Sample no-16 /KTRP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	6.0	14.24	mixed-layer	
2	8.8	10.04	illite	
3	11.6	7.62	gypsum	
4	12.4	7.13	kaolinite	
5	19.9	4.48	illite	
6	20.8	4.26	quartz	
7	23.3	3.81	feldspar group	
8	24.9	3.57	kaolinite	
9	26.6	3.34	quartz	
10	27.5	3.24	feldspar group	
11	29.4	3.03	calcite	
12	35.0	2.56	feldspar group	
13	50.1	1.81	quartz	

Sample no-17 /KRTP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	5.6	16.05	mixed-layer	
2	6.2	14.24	chlorite	
3	8.8	10.04	illite	
4	12.4	7.13	kaolinite	
5	17.8	4.97	illite	
6	19.9	4.48	illite	
7	20.8	4.26	quartz	
8	21.3	4.16	kaolinite	
9	24.9	3.57	kaolinite	
10	26.6	3.34	quartz	
11	29.6	3.03	calcite	
12	50.1	1.81	quartz	

Sample no-18 /KTRP
Rock: Calcareous Shales.

S.No.	2° θ	A°	Minerals	Remarks
1	5.8	15.76	mixed-layer	

2	11.6	7.62	gypsum
3	12.3	7.18	kaolinite
4	19.9	4.48	illite
5	20.8	4.26	quartz
6	21.2	4.16	kaolinite
7	24.9	3.57	kaolinite
8	25.2	3.51	kaolinite
9	26.6	3.34	quartz
10	29.9	3.03	calcite
11	35.0	2.56	feldspar group

Sample no-19 /KTRP
Rock: Calcareous Shales.

S.No.	2°θ	Å	Minerals	Remarks
1	8.8	10.04	illite	
2	12.3	7.18	kaolinite	
3	19.9	4.48	illite	
4	20.8	4.26	quartz	
5	21.4	4.16	kaolinite	
6	23.0	3.86	feldspar group	
7	24.9	3.57	kaolinite	
8	26.6	3.34	quartz	
9	29.4	3.03	calcite	
10	35.0	2.56	feldspar group	
11	36.0	2.49	calcite	
12	39.4	2.28	quartz	
13	50.1	1.81	quartz	