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SOME PALAEOENVIRONMENTAL OBSERVATIONS ON THE INFRA KROL FORMATION, LESSER HIMALAYA

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ABSTRACT

The Infra Krol succession of the Lesser Himalaya is a shale-dominant sequence and represents deposits of a low-energy tidal-flat-shallow lagoon complex of a shallow tidal sea. The shaly succession mostly shows tidal bedding, lenticular bedding with flat lenses, wavy bedding arranged in cm to dcm thick bedsets, depicting a typical mixed to muddy tidal flat environment. The sand-rich parts represent deposits of sandy intertidal flat, and show parallel bedding, small ripple bedding, lenticular and flaser bedding, ripples with mud drapes. The black shale facies show tidal bedding, lenticular bedding and laminated mud and represent deposits of a shallow lagoon with poor circulation. The Krol Sandstone shows large-scale cross-bedding, planes of discontinuity and discordances, parallel bedding, tidal bedding, horizons of mud pebbles and represents deposit of sand bars in intertidal to subtidal zone. Because of the terrigenous clastic nature, it is proposed to group the Krol Sandstone witn Infra Krol Formation. Thus, Infra Krol Formation represents terrigenous clastic succession (dominantly shaly) sandwitched between Blaini carbonate and calcareous Krol A succession.

INTRODUCTION

The Infra Krol succession is made up mostly of muddy sediments, showing rhythmic alternation of siltstone, shales, fine-grained quartzose sandstone. The black shales dominate the succession ; but grey, greenish and pink-coloured shales are also present. Though, the Infra Krol succession is assigned a status of Formation, and is recognized as an important lithostratigraphic unit of Krol belt, surprisingly little information exists on the lithology, bedding structure characteristics and its environment of deposition.

In the present study a few detailed sedimentological profiles with sedimentary structures are described in an attempt to elucidate the nature of Infra Krol sediments. The sections under discussion are Infra Krol succession around Solan, Rajpur-Mussoorie section, Kilbury—Tanki section, Nainital. Environment of deposition and lithostratigraphic relationship of the Infra Krol with the adjacent litho-units has been discussed.

LITHOSTRATIGRAPHY

Medlicott (1864), considered the Infra Krol as a separate lithostratigraphic unit. Most of the later workers, e.g., Pilgrim and West (1928), Auden (1934), Bhargava (1972) also assigned an independent status to the Infra Krol sediments.

Auden (1934) points out that Infra Krol sediments show a gradational contact with the underlying Blaini Formation and it is difficult to map Blaini and Infra Krol as independent units. The Blaini carbonate grades upward, by increase in shale content, into pink, greenish and black shales of the Infra Krol. Bhattacharya and Niyogi (1971) propose the grouping of Infra Krol with the Blaini Formation ; while Fuchs and Sinha (1974) and Rupke (1974) group the Infra Krol and Blaini in a single Formation. However, Bhargava (1972) and Bhargava and Bhattacharyya (1975) recommend an independent status of Blaini and Infra Krol Formations.

In Solan area, Infra Krol succession is followed by Krol Sandstone, and the contact between the two is transitional (see Bhattacharya and Niyogi 1971). Auden (1934) groups Krol Sandstone along with Krol Formation. In sections, where Krol Sandstone is not developed the Infra Krol shales show a gradual gradation into the marls and calcareous shales of the lower part of Krol A succession. Thus, the succession Blaini-Infra Krol-Krol represents a continuous succession without any significant breaks.

LITHOLOGY

In the lower part of Infra Krol Formation (just above the carbonate horizon of Blaini) often small-scale banding of carbonate and shale layers is present, followed by a succession of basically siltstone with thick bands of fine-grained sandstone. Auden (1934) refers this sandstone alternating with shale succession as varves. Towards the top of the succession Infra Krol is made up of carbonaceous shale without any bands of sandstone. Black shale often shows presence of pyrite. In thin section the shales are made up of quartz and sericite, with some carbonate and pyrite (Auden, 1934).

Auden (1934) gives an estimated thickness of about 160 metres for the Infra Krol sediments. Bhattacharya and Niyogi (1971) give a > 350 m (?), while Bhargava (1972) assigns a 600m thickness to the Infra Krol Formation.

Krol Sandstone is white, medium to coarse-grained sandstones, where few metre thick bands of black to gray shales and siltstones are intercalated. Auden (1934), Bhattacharyya and Chanda (1971), and Bhattacharya and Niyogi (1971) give petrological and mineralogical characteristics of the Krol Sandstone. The quartz grains of the Krol Sandstone are marked by good rounding. Bhattacharyya and Chanda (1971) and Bhattacharya and Niyogi (1971) consider the derivation of the quartz grains from a sedimentary source. Mud fragments derived from within the basin of deposition can sometimes be present in appreciable amounts. Metamorphic rock fragments are extremely rare (< 2%) (Bhattacharyya and Chanda, 1971). The rocks are mostly orthoquartzites (Quartz arenite) ; some of them can also be classed as litharenite on the basis of the content of shale pebbles, derived from within the basin. Joshi (1970) reports occurrence of lenses, laminae and pellets of phosphatic rock along the bedding planes of the Krol Sandstone. The thickness of Krol Sandstone is about 100 metres, but shows high variability even over short distances.

ENVIRONMENTAL ANALYSIS

The environmental analysis is based on the recognition of the bedding structures and their distribution in a vertical profile, and a comparison with the modern analogues. The terminology proposed by Reineck (1970) Reineck and Singh (1973), and Ginsburg (1975) has been followed.

INFRA KROL SUCCESSION AROUND SOLAN

There are good and continuous exposures of the Infra Krol around Solan township, especially on the Solan-Simla road. The lowermost exposed part of the Infra Krol is composed of shales showing dominantly colour banding and some textural banding. In this section five different units in stratigraphic order have been recognized which also differ from each other in the spectrum of their sedimentary structures.

Unit 1 : This succession is made up of greenish-gray shales showing dominantly colour banding. Within the shale 5-10 cm thick layers of silty rhythmites are intercalated (Plate I—1). There are also 10-15 cm thick layers of fine-grained sandstone, showing small ripple bedding and parallel bedding. Few cm thick units of lenticular bedding with flat, connected and single lenses are common. Detailed litholog for this unit are shown in Figs. 1 and 2. The rhythmite shows characteristics of tidal bedding, where mm thick sand layer alternates with equally thick mud layer (Reineck and Wunderlich, 1969). They can be correlated to tidal pulsations and are most abundant in the migrating channels of the intertidal flats. Lenticular bedding with flat lenses is also common in mixed flat (intertidal zone) and originates as a result of alternation

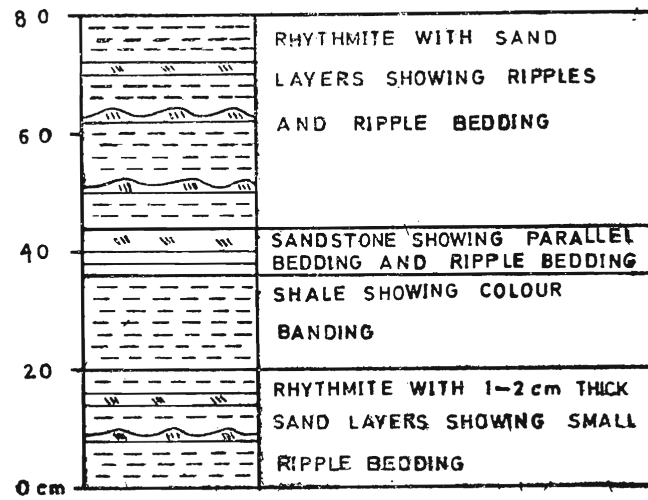

Fig. 1. Succession of sedimentary structures in the shale-rich facies of Infra Krol near Solan.

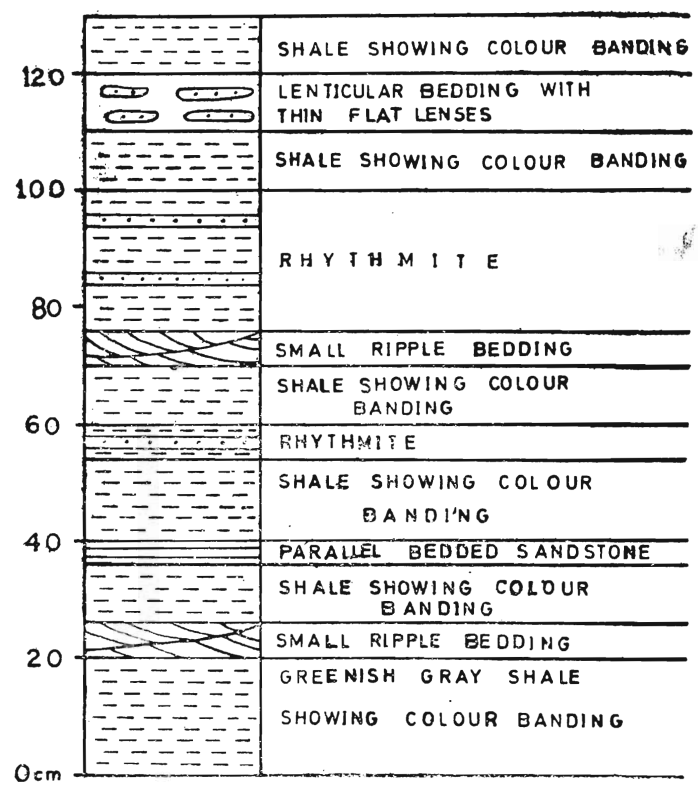

Fig. 2. Succession of sedimentary structures in the shale-rich facies of Infra Krol near Solan.

in current or wave action and slack water in a tidal cycle (Häntzschel, 1936 ; Reineck, 1960). In appearance this unit shows good similarity with the muddy to mixed intertidal flat deposits (compare with Reineck, 1975).

Unit 2 : This succession is sandier than the Unit 1, and contains upto 20 cm thick sand layers, showing small ripple bedding. Interbedded are several metre thick units of lenticular bedding with thick lenses and wavy bedding. Otherwise, the sequence is made up of rhythmites (tidal bedding) (Plate I—4), which sometimes show mud cracks. In lenticular and wavy bedding, sand layers are about 1 cm thick. Single rippled layers with mud drapes are also present. Few thick sandy horizons (20-30 cm) show large-scale cross-bedding. Detailed succession of sedimentary structure in this unit are shown in Figs. 3 and 4.

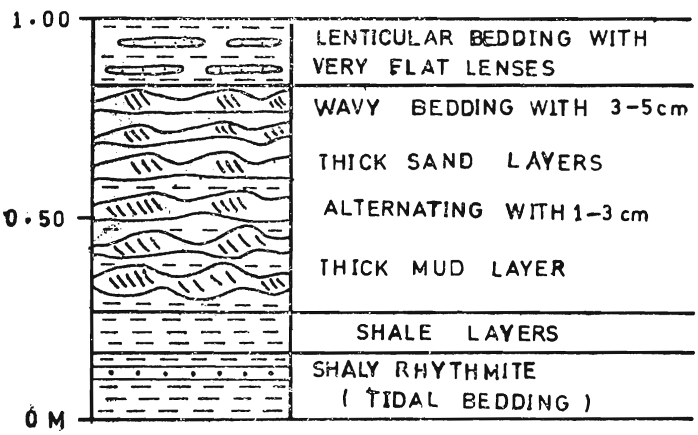

Fig. 3. Succession of sedimentary structures in mixed flat facies of Infra Krol near Solan.

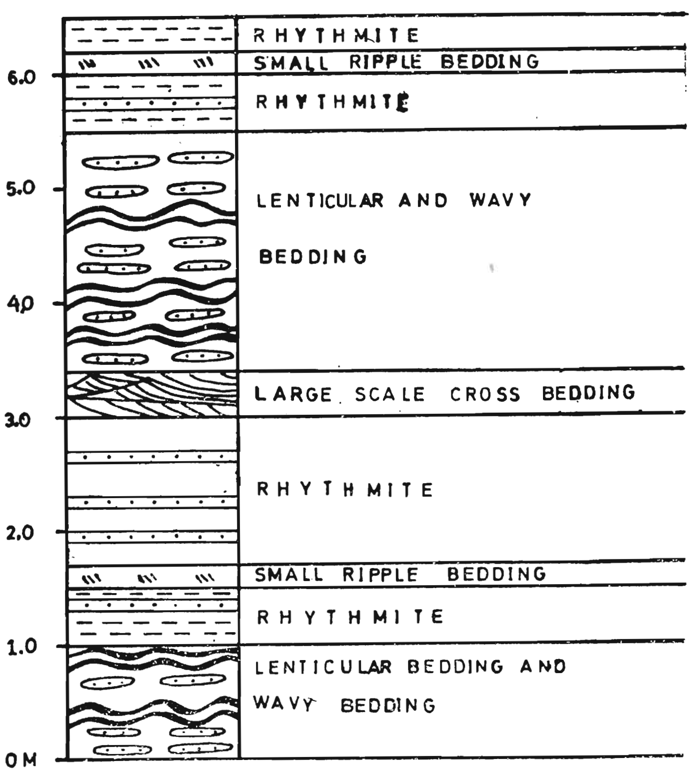

Fig. 4. Detailed litholog showing distribution of sedimentary structures in Infra Krol near Solan.

This unit shows features of a sandy to mixed intertidal flat. Presence of mud cracks suggests intermittent subaerial exposure of the sedimentation surface. The thicker sand layers seem to represent deposits of storm weather conditions, when due to increased energy thicker sand layers can be deposited on a tidal flat. The frequent changes in the bedsets in the vertical profile are a result of changes in the intensity and direction of wind and wave activity (Reineck and Wunderlich, 1969).

Unit 3 : This unit is characterized by the quick alternation of sand-rich and shale-rich successions. The shale-rich succession is similar to unit 1 in its build up and shows mostly shales showing colour and textural banding. Rhythmites (tidal bedding) is most prominent, where 1-2 cm thick sand layers are iı terbedded exhibiting small ripple bedding (Plate I—2, 3).

Sand-rich part contains abundant 10-15 cm thick sand layers showing parallel bedding; in a few cases small ripples are also developed.

This unit represents deposits of a channel in a mixed flat.

Unit 4 : This succession is made up of massive, ferruginous shale which grades upwards into black siltstone, interbedded with thin bands of streaky gray siltstone. The streaky gray shale layers show parallel laminated siltstone (Plate I—5), tidal bedding, lenticular bedding with flat lenses. In sandier parts sand lenticles are thicker and show foreset laminae. Fig. 5 shows a characteristic profile of this facies.

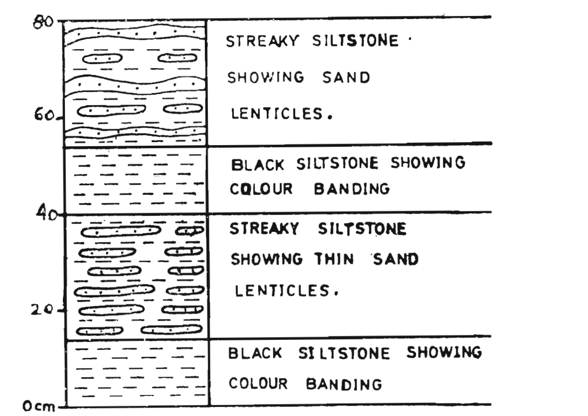

Fig. 5. Detailed succession of bedding structures in the black siltstone of fra Krol near Solan.

This unit represents deposits of reducing milieu due to poor circulation. A very shallow lagoonal pond with tidal influences, but with poor circulation seem to be the site of deposition of this facies.

Unit 5 : The black siltstone is followed by a thick sequence of gray shales and silts alternating with black shale and silts. In this unit few cm thick sand layers are intercalated. In the upper part this unit becomes sandier, and the succession is made up of tidal bedding layers alternating with the layers showing lenticular bedding with flat lenses, and layers showing wavy bedding (Figs. 6, 7). A few 1-2 cm thick sand layers are intercalated showing small ripple bedding. Near the top, this unit contains frequent 5-10 cm thick sand layers. Rarely, thinly laminated siltstone contains thin bands of black phosphorite.

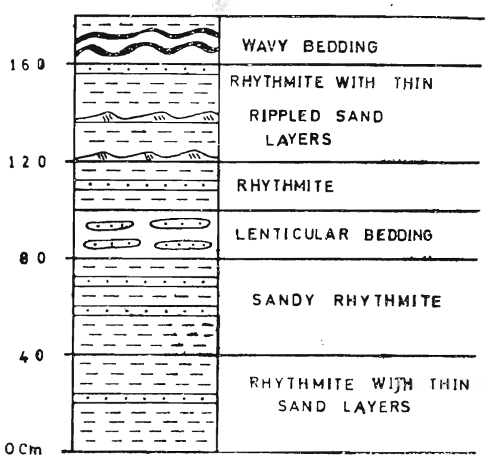

Fig. 6. Succession of sedimentary structures in the upper part of Infra Krol succession near Solan.

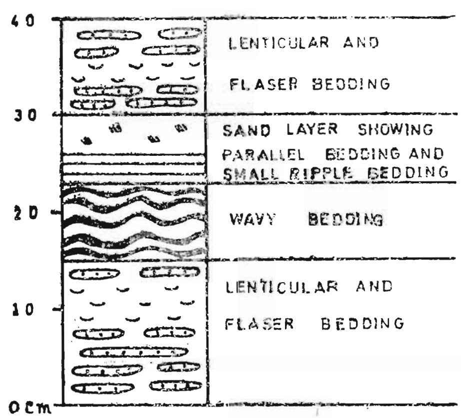

Fig. 7. Succession of sedimentary structures in tne topmost part of Infra Krol near Solan.

It seems that the shallow lagoon of Unit 4 continued to exist during deposition of Unit 5. However, due to increase in energy, sand influx increased producing thicker sandy layers.

Upwards, Unit 5 passes into Krol Sandstone, made up of thick sandy units with thin horizons showing rhythmites etc.

On Delgi-Solan bridle path the contact between Blaini and Infra Krol Formations is exposed. The basal part of Infra Krol, located just above the Blaini carbonate, is represented by the calcareous silty shale, followed by a sequence of black shale, and succeded by green-gray shale/siltstone. This succession is made up of mostly rhythmites with thin sandy intercalations. Upwards, the sand content of succession increases. This succession represents deposits of a mixed tidal flat subtidal channels.

INFRA KROL SUCCESSION IN MUSSOORIE AREA

In Rajpur-Mussoorie section a 50 m thick sequence of dark-coloured shales is exposed. The base of this succession is not well-exposed, upwards this shale sequence grades into calcareous shale, marls and limestone bands of Krol A. These shales are finely laminated showing textural and colour banding. No significant sand layers are present. The sequence represents deposition in a rather low-energy area where mainly fine-grained material accumulated. Possibly a protected coastal lagoon represents the site of sedimentation of this succession which changed over to a tidal flat environment and carbonate precipitation with the beginning of Krol A.

In Raipur-Maldeota section Infra Krol sediments consists of greenish, brown shales and sandy shales. The sandy shale contain several cm thick sand layers. 10-15 cm thick sand rich and shale-rich successions alternate with each other. In shale- rich successions lenticular bedding and wavy bedding are common, along with thin units of rhythmites. Sand-rich successions show flaser bedding, thin lenticular bedding. Thicker sand layers show small ripple bedding and parallel bedding. Planes of discontinuity are quite common. The succession represents deposits of mixed to sandy intertidal flats with moderate energy.

INFRA KROL SUCCESSION IN KILBURY-NAINITAL SECTION

Above the pink-coloured dolomite of the Blaini Formation follows a sequence of violet shale, greenish shale and silty sand, partly calcareous. These shales show fine lamination (rhythmite) and contain thin to thick (few mm to few cm) calcareous bands. Often mm thin graded beds and graded rhythmites are present. The succession represents transition between Blaini and Infra Krol Formations.

Upwards, calcareous bands are absent and the sequence is made up of violet to green shales with sandy layers, showing small ripple bedding. These sediments pass upwards into black, carbonaceous shales with thin sandy intercalations. The shaly bands mostly show fine textural and colour lamination, and tidal bedding. Intercalated are units made up of lenticular bedding with thin sand lenses of flat and disconnected nature. This succession of black shale is about 40 m thick and represents deposits of a reducing milieu of low-energy area. They seem to be the deposits of a shallow coastal lagoon with tidal effects.

Upwards, the black shales pass into gray silty shale (15-20 m thick), which ultimately acquire thin bands of carbonate and calcareous shales and grade into Krol A.

KROL SANDSTONE

In the area around Solan, a thick sandy succession is present between Infra Krol shales and the carbonate facies of Krol A. These sandstones are dominantly pure orthoquartzites, and also contain several metre thick succession of dark-coloured shales, showing rhythmites interbedded with sandy layers.

KROL SANDSTONE SUCCESSION AT THE BASE OF KROL HILL

The Unit 5 of the Infra Krol (page 28) passes upwards into a sand dominated sequence. A 6 m thick sequence is depicted in Fig. 8, showing characteristic features of a sand bar/channel deposit of a tidal flat. Thick sandy layers are interbedded with shale, sand/shale alternation, showing wavy bedding (Plate I—7). Thin horizons of tidal bedding are also present. The thick sand layers are made up of small ripple bedding, and large-scale cross-bedding (Plate I—6). A few thin sand layers show parallel bedding, exhibiting low-angle discordances. Within the sandy layers rolled, well-rounded phosphorite pellets are present. The sequence shows several planes of discontinuity and channeling (Plate I—8). The sandstone shows fribale and compact units (see also Bhattacharyya and Chanda, 1971), made up of well-rounded and well-sorted quartz grains, with negligible amount of clay content.

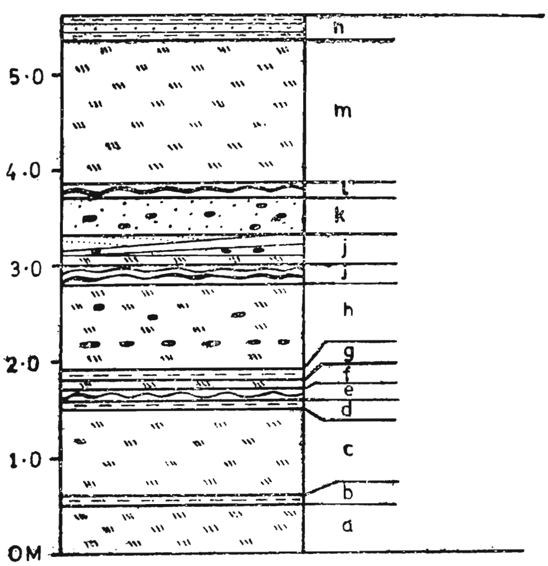

Fig. 8. Succession of sedimentary structures in Krol Sandstone, Krol hill, Solan. In this sequence planes of discontinuity and channels are quite common. These features are not depicted in the litholog. a—fine-grained sandstone, faint small ripple bedding ; b—shaly tidal bedding ; c—fine-grained sandstone, small ripple bedding ; d—shale layer ; e—wavy bedding ; f—sandstone, small ripple bedding, parallel bedding ; g—hales layer, h—sandstone, small ripple bedding, black phosphorite pellets ; i—wavy bedding. j—sandstone ripple bedding, parallel bedding with low-angle discordances ; k—loose sand with black pellets ; l—wavy bedding ; m—sandstone, small ripple bedding ; n—silty tidal bedding.

Upwards this sandy unit grades into a 20 m thick succession of silty rhythmites, containing 10 cm-1 m thick sandstone layers, showing small ripple bedding. Horizons of mud pebbles are present. This susccession represents deposits of a tidal flat. Upwards follows a several metre thick succession of coarse-grained sandstone showing large-scale cross-bedding, interbedded with shaly bands exhibiting wavy bedding.

Ultimately, the arenaceous sequence grades upwards into shaly limestone showing shale, limestone alternations of Krol A. In Krol A thick limestone units showing mainly parallel lamination is interbedded with thin black shale bands. There are also horizons of algal mat carbonates with incomplete stromatolites.

DEPOSITIONAL ENVIRONMENT

INFRA KROL

Niyogi and Bhattacharya (1971) assign a transitional deltaic environment to the Infra Krol sediments, and consider them to be deposits of a delta front on the basis of sedimentary structures. Rupke (1974) has not described any sedimentary structures but considers the Infra Krol succession to represent turbidite deposits. He assumes that fine-grained dark-coloured shales of Infra Krol represent deposits of submarine dust associated with fluxoturbidites. The analysis of Rupke (1974) seems to be based on his assumed turbidite nature of the Blaini Formation, which show interfingering relationship with the Infra Krol. However, Singh and Tangri (1976) show Blaini Formation to be the deposits of a shallow water environment, mainly on the basis of supratidal deposit characteristics (algal mat facies) of the Blaini carbonate, tidal flat characteristics shown by the associated quartzites and siltstones, and 'mud flake conglomerate'.

Both Blaini and Infra Krol Formations fail to show any turbidite sequences or any other features characterizing a deep-sea environment.

Moreover, detailed observations on the bedding characteristics convincingly demonstrates that Infra Krol sediments represent deposits of a low-energy muddy to mixed tidal flat and lagoon of a shallow tidal sea. Tidal bedding (rhythmites), lenticular bedding with flat lenses, wavy bedding are the most common bedding structures of the Infra Krol sediments. The existing data fails to show any deltaic sequences in the Infra Krol Formation.

KROL SANDSTONE

Auden (1934) considered the Krol Sandstone to be of aeolian origin on the basis of the good rounding of the quartz grains. Bhattacharyya and Chanda (1971) discussed that the coarse-grained quartz grains of the Krol Sandstone also show good rounding, while the wind action can not produce rounding in coarse-sand size. Moreover, high-angle aeolian cross-bedding is absent. On the contrary, shallow-water bedding types are profusely present. Thus, aeolian origin for the Krol Sandstone can be totally rejected. Bhattacharyya and Chanda (1971) suggest that Krol Sandstone represent deposits of a shallow marine basin with often high energy conditions. Bhattacharya and Niyogi (1971) describe presence of planar cross-bedding, channels, ripple bedding, clay pebble conglomerates from the Krol Sandstone and assign a neritic/littoral environment, while the interbedded lenses of black shale represent deposits of euxinic lagoons and tidal flats ; some parts represent deposits of fluvial environment.

The present study indicates that the thick sandstone units of Krol Sandstone represent deposits of sand bars in intertidal to subtidal zone. The sand bar was subjected to moderate wave and current energy. The shale-rich deposits are the product of deposition on mixed to sandy tidal flats, where extensive reworking and migration of channels and sandbars took place, resulting into a complex facies relationship and presence of abundant planes of discontinuity. The environment can be compared with the sand bar/channel deposits of the North Sea (Dorjes *et al.*, 1970 ; Reineck and Singh, 1973).

STUDY OF THE SURFACE FEATURES OF THE QUARTZ GRAINS OF KROL SANDSTONE

In recent years study of quartz grain surface features with the help of scanning electron microscope has been made to decipher the depositional environment (see Krinsley and Doornkamp, 1973). Quartz grains were separated from two samples of the Krol Sandstone : from a friable layer, and from a semi-lithified layer and were studied under SEM.

The quartz grains from the friable layer are only feably affected by silica diagenesis, and the overall shape of the quartz grains is well-preserved. However, fine surface texture of the grains has been obliterated due to development of minute scales and plates of silica (Plate II—9,10,11). The quartz grains from the semi-lithified layer show strong effects of silica diagenesis, obliterating the fine surface textures and also making it difficult to decipher the original grain shape (Plate II—12). The grain surface is covered by silica plates and scales growing and coalescing systematically (Plate II—13) or showing a somewhat diffused arrangement (Plate II—14) (see Waugh, 1972 ; Pittmann, 1972 ; Singh, 1974).

The quartz grains of the Krol Sandstone are very well-rounded with high sphericity showing strong effects of mechanical abrasion suggesting that the quartz grains had undergone a prolonged history of reworking and abrasion in the sandbars of the tidal sea before they were finally deposited. Due to obliteration of the fine surface textures during diagenesis, no precise interpretation of the environment, on the basis of surface features, can be attempted.

CONCLUSIONS

From the foregoing observations it becomes quite evident that Infra Krol succession starts without any break over the Blaini Formation. Invariably lower part shows few calcareous bands. The main succession of Infra Krol is essentially a fine-grained shaly succession, where often black shales dominate. This succession shows tidal bedding, lenticular bedding with flat lenses, wavy bedding, small ripple bedding, and parallel bedded sandstone and depict a build-up characteristic of a low-energy muddy to mixed tidal flat and lagoon deposits. In some areas near the top of the Infra Krol succession a sandy succession (Krol Sandstone) is present, representing deposits of sandy to mixed tidal flats and sand bar and channels in a tidal complex with moderate to locally high energy conditions. Ultimately, Infra Krol or Krol Sandstone grade into overlying calcareous Krol A succession, representing deposits of a carbonate tidal flats. Therefore, due to the terrigenous clastic nature of the Krol Sandstone, it can be conveniently grouped with the Infra Krol Formation. The Infra Krol succession must be assigned an independent Formation status. The lower contact can be taken at the top of Blaini carbonate, while the upper contact is taken at the base of Krol A, marked by the beginning of carbonate sedimentation. Thus, Infra Krol Formation represents essentially a terrigenous clastic succession, mostly shaly ; locally with sandstone facies, and marked by the absence of any significant carbonate sediments, and dominance of black silt and shale.

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REFERENCES

AUDEN, J. B. 1934. The Geology of the Krol Belt. *Rec. Geol. Surv. India.* **67** : 357-454.

BHARGAVA, O. N. 1972. A reinterpretation of the Krol Belt. *Himalayan Geology.* **2** : 47-81.

BHARGAVA, O. N., BHATTACHARYA, B. K. 1975. The Blaini Formation of Himachal Pradesh and Uttar Pradesh. *Bull. Ind Geol. Assoc.* **8**(2) : 71-99.

BHATTACHARYYA, A. AND CHANDA, S. K. 1971. Petrology and origin of the Krol sandstone around Solan, Himachal Pradesh, *Jour. Geol. Soc. India.* **12**(4): 368-372.

BHATTACHARYA, S. C AND NIYOGI, D. 1971. Geologic evolution of the Krol Belt in Simla hils, H. P. *Himalayan Geology.* **1** : 178-212.

DÖRJES, J., GADOW, S., REINECK, H. E., AND SINGH, I. B. 1970. Sedimentologie und Makrobenthos der Nordergründe und der Aussenjade (Nordsee), *Senckenbergiana Marit.* **2** : 31-59.

FUCHS, G. AND SINHA, A. K. 1973. Preliminary note on the Geology of the Nainital region. *Abst. 4th. Him. Geol. Sem., Wadia Inst. Him. Geol.* 9-10.

GINSBURG, R. N. 1975. *Tidal Deposits, A case book of Recent examples and Fossil counterparts.* Springer-Verlag, Berlin. 428 p.

HÄNTZSCHEL, W. 1936. Die Schichtungs—Formen rezenter Flachmeer-Ablagerungen. *Senckenbergiana.* **18** : 316-356.

JOSHI, V. K. 1970. Phosphate deposits in Krol sandstone. *Ind. Min.*, **24** : 359-363.

KRINSLEY, D. H. AND DOORNKAMP, J. C. 1973. *Atlas of quartz grain surface textures*. Cambridge University Press, Cambridge. 91p.

MEDLICOTT, H. B. 1864. On the geological structure and relations of the southern portion of the Himalayan ranges between the rivers Ganges and the Ravee. *Mem. Geol. Surv. India.* **3** : 1-212.

PILGRIM, G. E. AND WEST W. D. 1928. The structure and Correlation of Simla rocks. *Mem. Geol. Surv. Ind.* **53** : 1-140.

PITTMANN, E. D. 1972. Diagenesis of quartz in sandstones as revealed by scanning electron microscopy. *J. Sediment.* Petrol. **42** : 507-519.

REINECK, H. E. 1960. Über die Entstehung von Linsen-und Flaserschichten. *Abh. Deut. Akad. Wiss.* **3**(1) : 370-374.

REINECK, H. E. 1970. Ed. *Das Watt, Ablagerungs-und Lebensraum.* Kramer. 142 p.

REINECK, H. E. 1975. German North Sea Tidal Flats. *In :* Ginsburg, R. N. (ed.) *Tidal deposits, a case Book of Recent Examples and Fossil Counterparts.* Springer-Verlag, Berlin Heidelberg. Section 1 : 5-12.

REINECK, H. E. AND SINGH, I. B. 1973. *Depositional sedimentary environments.* Springer Verlag, Berlin. 439 p.

REINECK, H. E. AND WUNDERLICH, F. 1969. Die Entstehung von Schichten und Schichtbänken in Watt. *Senckenbergiana Marit.* **1** : 85-106.

RUPKE, J. 1974. Stratigraphic and structural evolution of the Kumaon Lesser Himalaya. *Sed. Geol.* **11**(2-4) : 81-265.

SINGH, I. B. 1974. Mineralogical studies of Gondwana Sediments from Korba Coalfield, Madhya Pradesh, India. Part II-Scanning electron microscopy of sand grain surface features. *Geophytology.* **4** : 60-82.

SINGH, I. B. AND TANGRI, A. K. 1976. Some observations on the sedimentology of the Blaini formation, Himachal and U. P. Himalayas. *Proc. 125th Anv. Celebr. G.S.I., Symposium, Lucknow.* (Preprint).

WAUGH, B. 1970. Formation of quartz overgrowths in the Penrith Sandstone (Lower Permian) of northwest England as revealed by scanning electron microscopy. *Sedimentology.* **14** : 309-320.

EXPLANATION OF PLATES

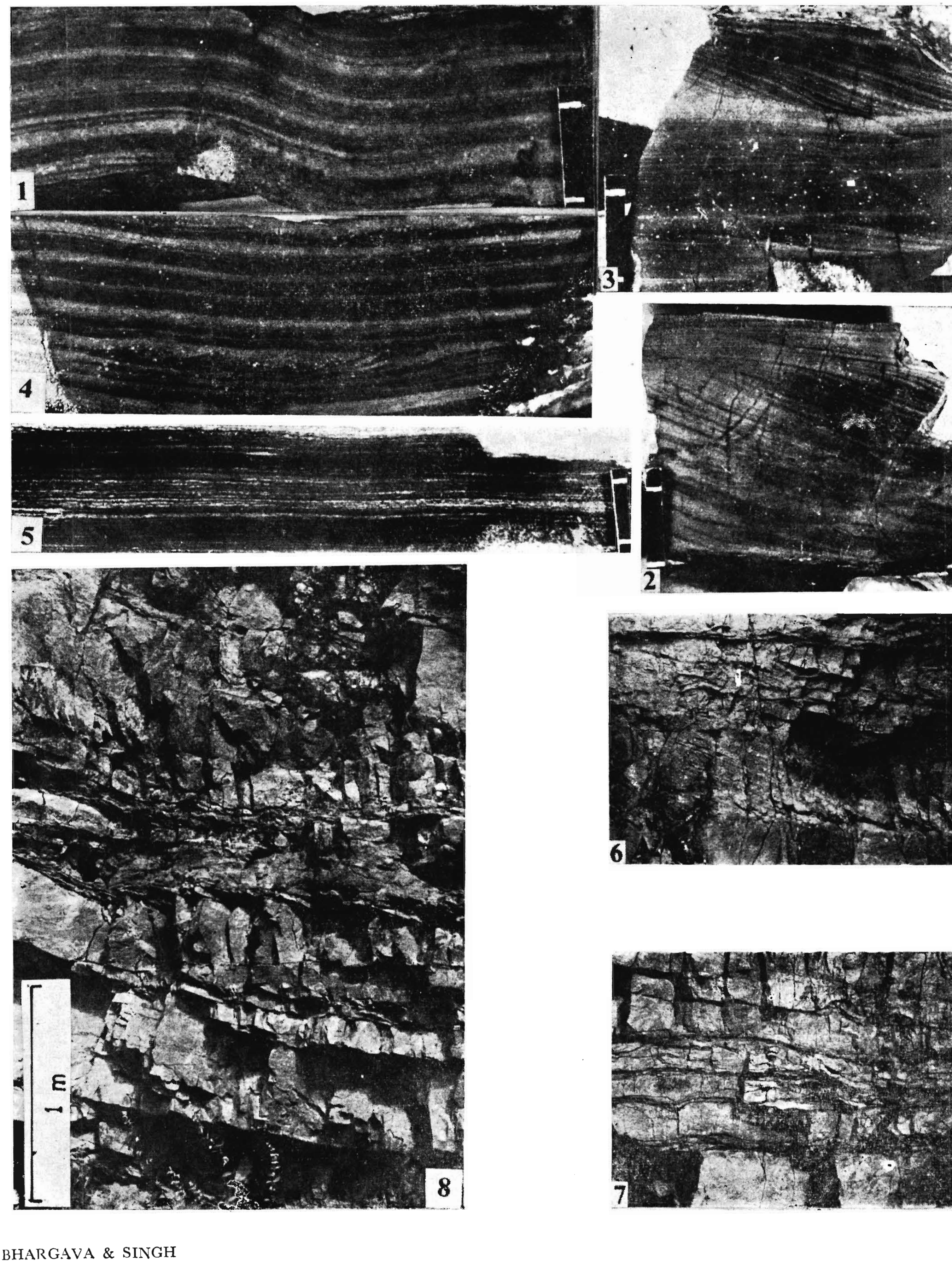
PLATE I

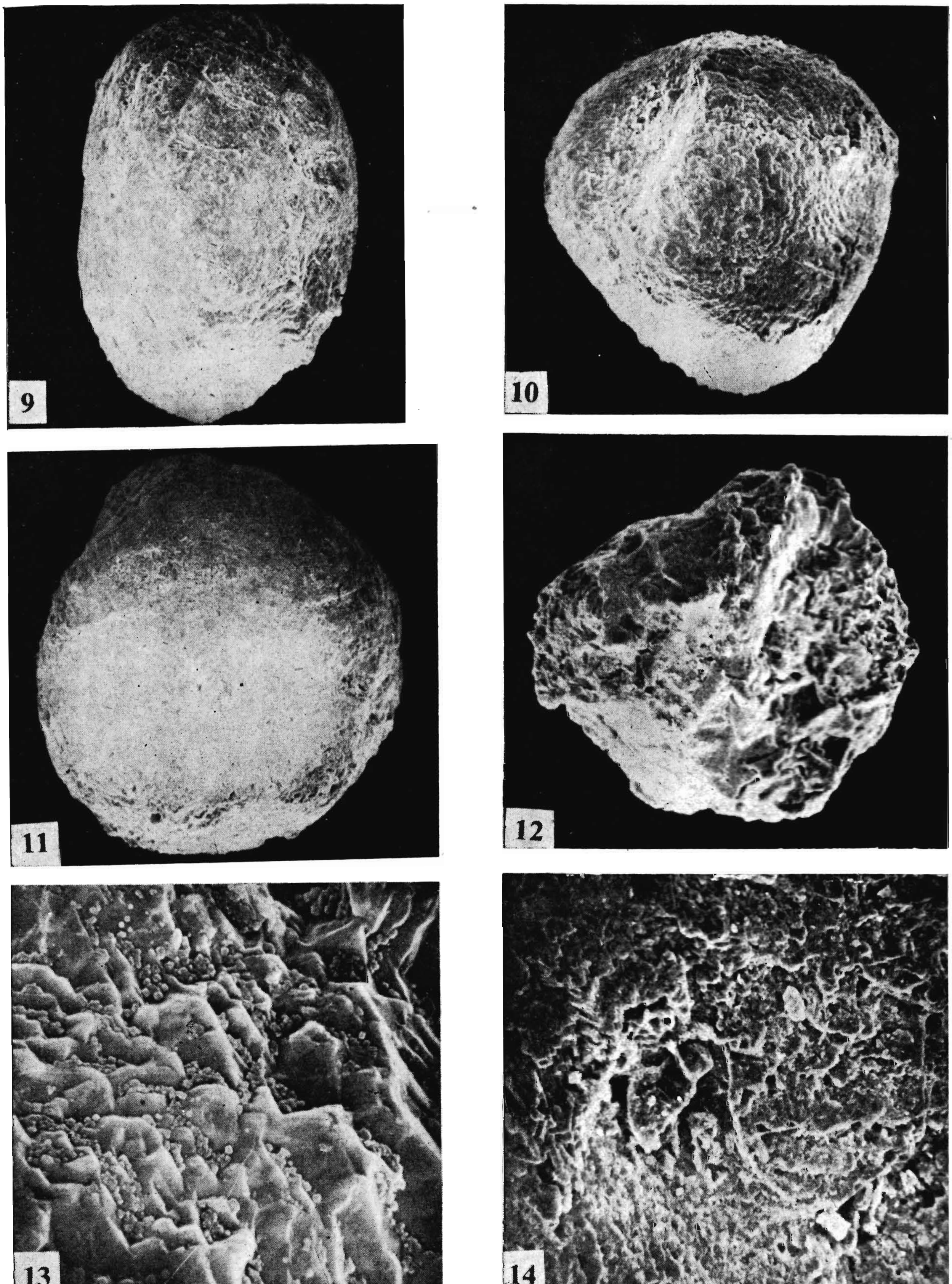
1. Sandy tidal bedding. Mud-rich bands show fine lamination. 1 div. of scale = 1 cm.
2. Thin ripple bedded layer. 1 div. of scale = 1 cm.
3. Thin ripple bedded layers interlayered with tidal bedding. 1 div. of scale = 1 cm.
4. Rhythmic tidal bedding with a thin sand layer showing faint foreset laminae. Height of the photograph about 3 cm.
5. Fine lamination in black siltstone. 1 div. of scale = 1 cm.
6. Large-scale cross-bedding in Krol Sandstone, Krol Hill. Thickness of the cross-bedded unit approx. 30 cm.
7. Lenticular, wavy bedding and shale layers in the Krol Sandstone, Krol hill. 1 div. of scale = 1 cm.
8. Channeling, planes of discontinuity in the Krol Sandstone.

PLATE II

9. SEM photograph of a well-rounded quartz grain from the Krol Sandstone. The surface has been slightly modified during silica diagenesis causing development of minute plates. Magnification 600 ×.
10. SEM photograph of a quartz grain from Krol Sandstone showing good rounding and smoothened edges. The quartz grain surface shows slight coating of secondary silica in the form of minute plates, thus obliterating the delicate primary surface textures. Magnification 800 ×.
11. SEM photograph of a well rounded quartz grain of the Krol Sandstone. Magnification 640 ×.
12. SEM photograph of a originally well-rounded quartz grain of the Krol Sandstone which has been substantially modified due to deposition of secondary silica. Magnification 1400 ×.
13. Details of a quartz grain surface affected by growth of minute quartz crystals coalescing together. Krol Sandstone. Magnification 8000 ×.
14. Details of a quartz grain surface showing minute irregular plates and a few crystals of quartz coalescing together to produce a irregular surface. Magnification 2000 ×.

PLATE I





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