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ON SOME SEDIMENTOLOGICAL AND PALAEOECOLOGICAL ASPECTS OF SUBATHU— DAGSAI—KASAULI SUCCESSION OF SIMLA HILLS

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ABSTRACT

Primary sedimentary structures, lithological associations and trace fossils of the Subathu-Dagsai-Kasauli Succession (Eocene-Miocene) of Simla hills are studied. The Subathu-Dagsai-Kasauli Succession represents a more or less continuous deposition without any significant time break or unconformity in between, and it is possible to characterize the three formations on the basis of distinct trace-fossil assemblages. The Subathu Sediments show characteristic features of an open sea deposits (shelf mud, tidal flats and sand bars), partly with hypersaline and reducing conditions. Trace fossils of the Subathu Formation are few stout, horizontal *Thalassinoides*, *Chondrites*, and *Tigillites*. The open tidal sea of Subathu times changed to an estuarine complex with extensive mudflats under marine influences in which Dagsai sediments are deposited. The Dagsai Formation shows various types of *Thalassinoides* burrows, *Chondrites*, and minute feeding burrows in abundance. The estuarine complex of Dagsai period changed to an alluvial plain with swiftly shifting braided streams during sedimentation of the Kasauli sediment, which is characterized by the horizontal burrows of various insects, e.g. beetle and cricket.

INTRODUCTION

The Lower Tertiary sediments of the lesser Himalayan zone are well-developed in Simla region acquiring an estimated thickness of approx. 4000 m. Medlicott (1864, 1879) named this succession as Sirmur Series made up of Subathu, Dagsai, and Kasauli without any unconformity in between. This three fold subdivision was accepted by most of the subsequent workers (Pilgrim and West, 1928, Auden, 1934, Chaudhri, 1968). However, it was not easy to decipher the three successions in some of the sections. This fact led Raiverman and Raman (1971) to suggest that Subathu, Dagsai and Kasauli show intertonguing relationship, and are made up of basically three facies ; namely, green, red and gray. They proposed the name Subathu Group for the complete succession and suggested that the name Dagsai be dropped altogether.

The Subathu rocks contain well-developed macro- and microfauna and are assigned a Palaeocene to Upper Eocene age (Datta *et al.*, 1965). Dagsai sediments have failed to yield any definite fauna or flora ; however, they are assigned an Oligocene age. The Kasauli sediments have yielded fresh water molluscs and angiosperm leaves, i.e., *Sabal major* and assigned a Middle Miocene age (Sahni, 1953).

Stratigraphical, mineralogical and sedimentological aspects of the lower Tertiary sediments of the Simla Hills have been discussed by Chaudhri (1968, 1972a, b, 1975), Raiverman and Seshavataram (1965), Raiverman and Raman (1971) with generalized comments on the environment of deposition. Environmental interpretation has also been attempted by Medlicott (1864), Oldham (1893), Bhatia and Mathur (1965), Bhandari and Aggarwal (1966).

The present paper deals with litho-facies, primary sedimentary structures, trace fossils, palaeoecology and depositional environment of the Subathu-Dagsai-Kasauli succession exposed around Dharampur, Kasauli, and Subathu. The road sections studied include Dharampur-Kumarhatti road section, Dharampur-Garkhal-Kasauli road section, Dharampur-Subathu road section, Dharampur-Kalka road section, and Subathu-Kakarhatti road section. As only limited road sections have been visited, the regional aspects of environmental analysis should be regarded as preliminary one. The environmental analysis is based mainly on the study of primary sedimentary structures, and the terminology as given in Reineck and Singh (1973) and Ginsburg (1975) is followed.

SUBATHU FORMATION

The Subathu Formation is a fossiliferous sequence of olive green, khaki, variegated shales, thin to thick shell (bioclastic and reefal) limestone bands, along with fine-grained limestone and sandstone bands. In the basal part gypseferous, pyritiferous, and carbonaceous shales with thin coal bands are commonly present. Kharkwal (1964) describes the shell limestone bands of Subathu as coquinite and Kharkwal (1966) reports glauconite from these sediments. In the road sections studied the following lithofacies are recognized.

(i) OLIVE-GREEN SHALE

This is made up of alternating bands of hard (carbonate-bearing) and soft green shale. The shales are very fine-grained and are characterized by faint colour banding, absence of textural banding, rare few cm thick bands of shell limestone, and thin bands of red shales.

These sediments represent deposition below wave base in quiet water (without any wave and current activity) in shelf mud zone, few tens of metre deep where only fine-grained suspended material was coming. Rarely stroms and gales brought broken shell material from the coastal area and deposited as thin bands within the shelf mud.

(ii) SANDY GREEN SHALE WITH THIN LIMESTONE BANDS

This facies is made up of silty shales and sandy intercalations showing characteristics of a tidal sequence (Fig. 1). It contains dcm thick silty units showing parallel bedding, and wavy bedding. Shaly bands show vertical and inclined burrows. The limestone bands are mostly shell limestone and show extensive bioturbation, sometimes burrows from the base of a limestone band penetrate down into the underlying shales. Within the shale layers small pockets of oyster shells are present in the form of balls. Dcm thick sandstone bands showing low-angle large scale cross-bedding are also intercalated.

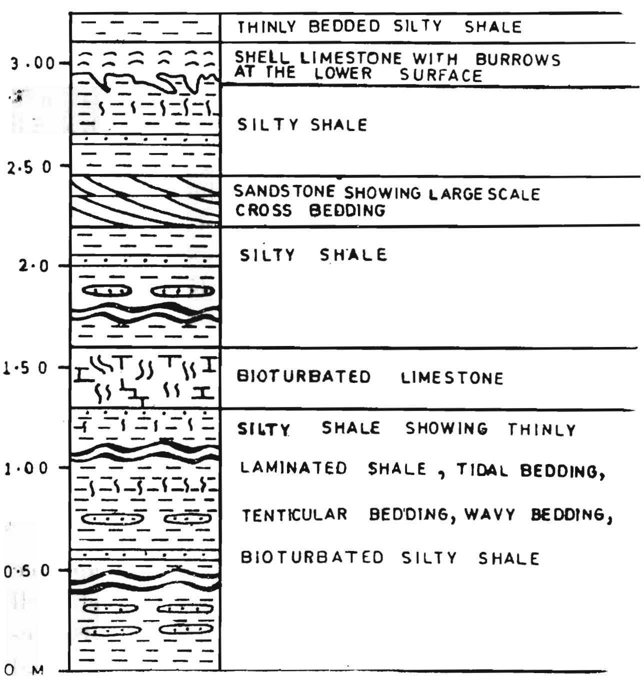

Fig. 1. Succession of sedimentary structures in Subathu sediments (Sandy green shale with thin limestone bands). Near Dharampur town.

This succession represents deposition in subtidal-intertidal zone with abundant bottom-dwelling fauna.

(iii) RED SHALE WITH BANDS OF GREEN-COLOURED SILTSTONE AND FINE-GRAINED SANDSTONE

This facies exhibits dominantly thin lenticular bedding, small ripple bedding, and tidal bedding. Pieces of bones, shale pebbles, and coaly material are also present with siltstones.

They represent deposits of a protected mud flat.

(iv) GREENISH-GRAY SHALE WITH 2-3 CM THICK SHELL LIMESTONE BANDS, MOSTLY ASSOCIATED WITH 1-2M THICK SHELL LIMESTONE BANDS.

This facies is very rich in fossils. The fossils occur both in shales and limestone bands. The limestone bands are mostly bioclastic limestone made up of foraminifers, gastropods, and lamellibranchs where oyster shells are quite common. Shells occur as articulated double valves, as well as broken shells.

This facies is the product of deposition in the shelf mud zone. The bioclastic limestone bands are made up of shells brought in during stroms. The reefal oyster limestone bands represent *in situ*reefal growth of oysters in subtidal zone shelf mud.

Near Dharampur, there is an interesting succession of this facies made up of shale, shaly limestone and shell limestone (Fig. 2). Thick shell limestone bands are mostly made up of only one type of shells. *Turritella* is most abundant in shale bands. There is a limestone band containing shells of *Physa* and *Planorbis* in abundance which are fresh water gastropods. However, sediments immediately succeeding this band contain *Turritella* in abundance, a typical marine form inhabiting mostly shelf mud below wave base. Bhatia and Mathur (1965) report fresh water gastropods *Bullinus*(?) = *Physa* and

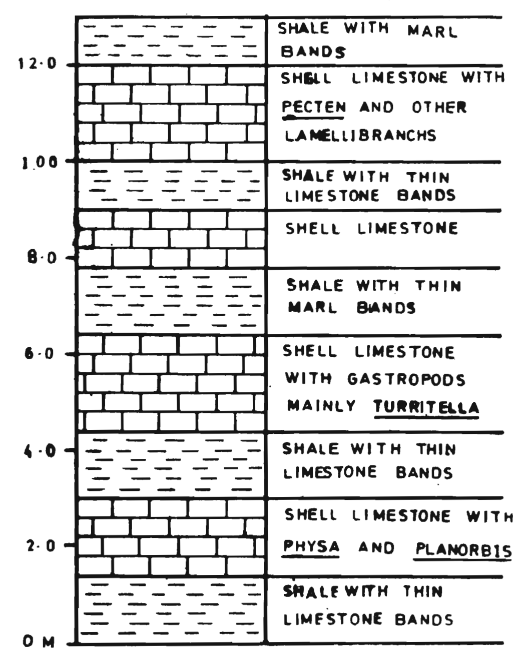

Fig. 2. Lithological succession showing interbedded limestone and shale layers in Subathu sediments. Limestone band containing fresh water gastropods is overlain by the sediments containing marine *Turritella*. Dharampur-Kalka road section, about 1.5 km from Dharampur,

Planorbis from the upper part of the Subathu sediments and consider the upper part of Subathu and the succeeding Dagsai sediments as fresh water deposits.

However, the horizon containing fresh-water gastropods is preceded and succeeded by the sediments containing *Turritella*, a typical marine form. It is suggested that the fresh water gastropods were living in the coastal lagoon and ponds. During stroms erosion and transportation of these fresh water gastropods took place from the coastal areas into shelf mud, inhabited by *Turritella* etc. Such processes are common in the present-day shelf sediments. For example, the shelf mud of Gulf of Gaeta, Mediterranean Sea is inhabited dominantly by *Turritella communis*. However, some parts of shelf mud and transition zone are extremely rich in shells of *Lentidium mediterraneum*, a fresh water mollusc inhabiting the coastal areas. Transportation of this fresh water mollusc from coastal areas into transition zone-shelf mud takes place during storms and heavy rainfall (Hertweck, 1971). Similarly, storm sand layers in the shelf mud of the North Sea are often rich in *Hydrobia ulvae*, a gastropod normally inhabiting intertidal zone and brought into the shelf mud along with sand during storms (see Reineck and Singh, 1973).

(v) RED-MAROON SHALE WITH THICK LIMESTONE BANDS

Shales of this facies are dominantly red-coloured. The intercalated limestone bands also contain thin stringers of shale, gray to purple in colour. Some thin greenish sandy and silty bands, showing faint small ripple bedding are present.

This succession represents deposition in a rather shallow part of a protected embayment with somewhat oxidizing milieu.

(vi) FINE-GRAINED GREENISH SANDSTONE WITH OYSTER REEF

This facies shows lensoid bodies of oyster limestone. The associated fine-grained sandstone shows features of a tidal deposit. Small ripple bedding mostly of herringbone type is most common (Plate 1—2). Some sandy units also show parallel bedding and low-angle cross-bedding of beach bar type.

The environment of deposition oft his facies is a sandy tidal flat with patchy reefal colonies of oysters.

(vii) RED SHALE ALTERNATING WITH GREEN SANDSTONE AND QUARTZITE

This facies is made up of 5-6 cm thick sandstone layers alternating with ca.1 cm thick shale bands. Occasionally, thick sandstone units are present which contain abundant green or red mud pebbles, dcm thick conglomeratic bands containing red shale pebbles and some quartzite pebbles. The thick sandy units show mega-ripple bedding, small ripple bedding, planes of discontinuity, and low-angle discordances. Associated with this succession are thick units of thinly interlayered sand/shale bedding, i.e. rhythmites and tidal bedding.

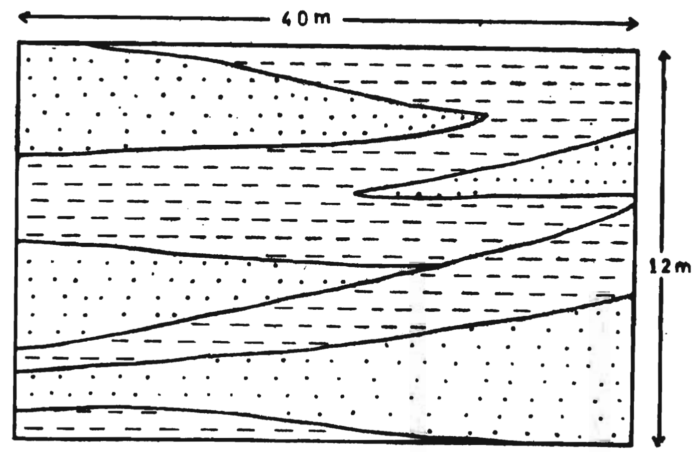

Fig. 3. Schematic representation of intertonguing relationship between medium-grained sandstone and shale units in the Subathu-Dagsai transition beds near Suki Johri, Dharampur.

This facies represents deposits of a high-energy zone in a coastal complex. The thick sandy units show features of shoal/beach bar environment, shale/sand alternations are product of deposition in mud flat environment. May be, fluvial action played some role in sedimentation of this facies.

(viii) THICK GREENISH GRAY SANDSTONE ALTERNATING WITH THICK UNITS OF GRAY-VIOLET SHALE

At Suki Johri near Dharampur a 50 m thick succession of sandstone/shale showing intertonguing is exposed (Fig. 3). The sandy bands are up to 5 m thick, medium-grained, greenish gray in colour, mostly homogenous, partly streaky. Near the top of sandy units faint small ripples are developed. This succession most probably marks the Subathu/Dagsai transition.

This facies represents deposition in rather high-energy conditions under the influence of rapidly flowing rivers meeting in the embayment. The shales denote deposits of an embayment, while the sandy units represent quick deposition of the sand brought into the embayment by the rivers.

TRACE FOSSILS

Trace fossils can be helpful in characterization of facies, and palaeoecological interpretation as they always occur *in-situ*, and cannot be transported. Häntzschel (1962), Crimes and Harper (1970), and Frey (1975) provide useful summaries on the study of trace fossils.

Trace fossils are not common in Subathu sediments, however, they are often recorded in the sandy green shale with limestone band facies, a deposit of the tidal flat environment. Following types of trace fossils are recorded.

(*a*) *Thalassinoides :* These are ramifying cylindrical burrows (1-2 cm in diameter) showing Y-shaped branching, and swelling at the points of branching. They show limited lateral extent. These burrows do not show any preferred orientation, though mostly they are horizontal and occur in limestone bands. They are assigned to the burrowing activity of the crabs. (Plate I—1).

(*b*) *Chondrites :* It consists of ramifying burrow system with tunnels of 1-2 mm in diameter and running in different directions. Only few occurrences are recorded.

(*c*) *Vertical tubular burrows* They are vertical burrows mostly made for dwelling purposes by different organisms. Three types are recorded.

(1) *Tigillites*—Simple vertical burrows occurring singularly, 10-15 cm in length, ca. 1 cm in diameter. The burrow filling is annulated (Plate I—3).

(2) *Skolithos*—Vertical tubes, 0.2-0.5 cm in diameter, straight, 4-5 cm in length. They are quite rare.

(3) *Vertical pockets*—3-4 cm long conical pockets at right angles from the bedding planes.

(*d*) *Rhizocorallium :* They are U-shaped tubes with transverse sprites, running oblique to the bedding plane.

In Subathu sediments *Thalassinoides* and *Tigillites* are most common ; other burrows are rather rare.

ENVIRONMENTAL ANALYSIS

The Subathu sediments are considered by most workers as product of deposition of a shallow marine basin with local mud flats, evaporitic and euxinic conditions (Bhandari and Aggarwal, 1966 ; Chaudhri, 1968, 1975 ; Raiverman and Raman, 1971). Chaudhri (1975) considers that there are three cycles of fluctuations (transgression-regression cycles) within the Subathu. Raiverman and Raman (1971) consider that marine, coastal transitional and fresh water facies are present in the Subathu succession and they show intertonguing. Bhatia and Mathur (1965) regard Subathu succession as marine with topmost part as fresh water deposits.

The present study reveals that Subathu sediments represent deposits of a shallow sea with some tidal characteristics, most probably an embayment with a well-developed shelf mud zone, and extensive tidal flats and ill-developed alluvial plains. During early period of Subathu sedimentation euxinic and evaporitic conditions developed in the protected lagoons of the embayment. Most of the sediments were laid down in shelf mud, tidal flats, and coastal sand bars ; only a minor part of the succession was probably deposited by the rivers draining into the embayment.

In Subathu sediments anhydrite grains are present in the heavy mineral fraction (Chaudhri, 1970). Most probably, in the coastal areas gypsum and anhydrite was reworked and transported into the off-shore parts as detrital grains during storms. Similarly, dead shells of fresh water molluscs were also sometimes transported from coastal areas into the self mud.

DAGSAI FORMATION

The Dagsai Formation is characterized by its unfossiliferous nature and consists of purple to brown shale, siltstone, marls, dirty to greenish gray sandstones (medium to fine-grained). Red-violet coloured marls, siltstone are considered to be the most characteristic lithology of the Dagsai Formation. Ganju and Srivastava (1961) discuss petrology of the Dagsai sandstones, Chaudhri (1970) gives the heavy minerals of Dagsai sediments and discusses its provenance. In the road-sections around Dharampur, Garkhal and Kumarhatti following lithological associations (lithofacies) are present :

(i) MEDIUM-GRAINED GREENISH-GRAY SANDSTONE WITH THIN SHALE INTERCALATIONS

The sandstone is mostly apparently massive with faint parallel lamination. The sandstones often show extensive mottling due to bioturbation. Large and small irregular burrows are commonly present.

(ii) GRAY COLOURED MEDIUM TO COARSE-GRAINED SANDSTONE AND SAND/SHALE ALTERNATIONS

This facies shows coarsely interlayered sand/mud bedding, low-angle cross-bedding (Plate IV—15, 16), parallel bedding, graded bedding with about 1 cm thick units (Plate IV—17) low-angle discordances, planes of discontinuity, large-scale cross-bedding showing bipolar direction and channels. Lateral pinching out of sand and shale layers is a common feature. In the channels near the base mud pebbles of red shales are concentrated.

Intercalated within the thick sandstone units are thin units of red mottled shale showing extensive bioturbation. The sandstones do not exhibit much bioturbation ; nevertheless, few small burrows are present.

Associated with the coarse-grained sandstones are 4-5 m thick units of fine sand, silt/shale alternations. These units contain abundant rippled surfaces of various types, including falling water-level ripples and shallow-water ripples, e.g. washed ripples, ripples with rounded crests and pointed troughs. The sandy layers show evenly laminated sand, small ripple bedding (Plate II—9). Silty bands are often mottled showing mostly feeding burrows.

This sequence represents deposition in a coastal sand complex of a shallow tidal sea. The coarse-grained sandstone exhibits features of sand bars of a tidal sea. The fine-sand, silt/shale alternations are deposits of a tidal flat mainly in the intertidal zone.

(iii) FINE-GRAINED SANDSTONE WITH SHALE LAYERS

This facies exhibits essentially a sequence of sandy siltstone, violet-red and gray coloured shale, sand/shale alternations and occasional thick units of fine-grained sandstone showing high degree of bioturbation. The sandy units mostly show parallel bedding and small ripple bedding (Plate II—7). In thicker sandstone layers mud pebbles are very common. Sometimes up to 1 m thick conglomerate horizons are present, made up of abundant mud pebbles, rock fragments, and coarse-grained particles (Fig. 4).

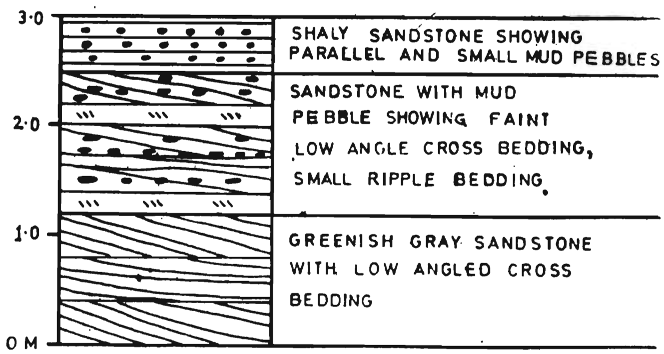

Fig. 4. Succession of sedimentary structures in the fine-grained sandstone with shale layers facies of Dagsai sediments. Note the abundance of mud pebbles in the succession. Dharampur-Sanawar road section.

Some of the sandstone and associated shale units are carbonaceous and micaceous. Mud pebbles of these sandstone units are made up of carbonaceous shale. The feeding burrows are quite common in these sediments. The degree of bioturbation is more in the silty shale and shale layers. Some of the shaly bands (1-2 m thick) appear mottled due to extensive churning by the burrowing organisms (Fig. 5).

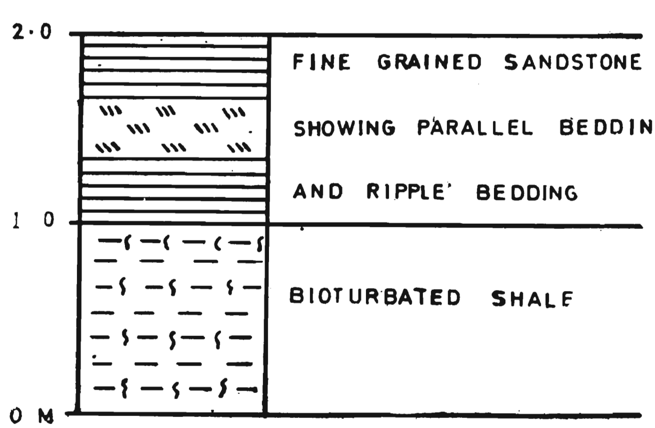

Fig. 5. Succession of sedimentary structures in the Dagsai sediments. Dharampur-Kumarhatti road section.

The environment of deposition of these sediments seems to be an estuarine coastal complex with protected low-energy areas, where normally muddy sediments were deposited, densely populated by benthonic organisms. Because of the low-rates of sedimentation the organisms had sufficient time to produce completely bioturbated mottled shales. At periodic intervals sand was supplied by the rivers which was redistributed by waves and currents. During these phases of increased energy reworking of the muddy sediments led to the formation of mud pebbles in abundance.

(iv) RED SHALES ALTERNATING WITH MASSIVE WHITE SANDSTONE

This facies is characterized by the absence of burrows both in the shale and sandstone layers. Shales are finely laminated with faint textural banding. Several metre thick sandstone units show cross-bedding, parallel-bedding, and erosional discordances (Fig. 3).

This succession represents deposition within a coastal complex with increased energy of sedimentation where benthonic organisms were unable to produce bioturbation structures, either due to rapid rate of deposition or unfavourable ecological conditions for benthonic organisms or both.

(v) MOTTLED RED SHALE, SILTSTONE, VARIEGATED SHALE AND SANDSTONE

This facies is characterized by the extensive bioturbation of the shale and siltstone units, imparting a mottled and nodular appearance. The burrows are mostly crab-burrows of *Thalassinoid* type. There are also other smaller burrows of different shapes and sizes, and feeding burrows, resembling fucoid markings. The larger burrows are filled with white carbonate material, and upon weathering break up into carbonate nodules of different shapes and sizes. The bioturbated silt-shale succession alternates with non-bioturbated sandy units (Fig. 6). The sandy units show faint parallel bedding

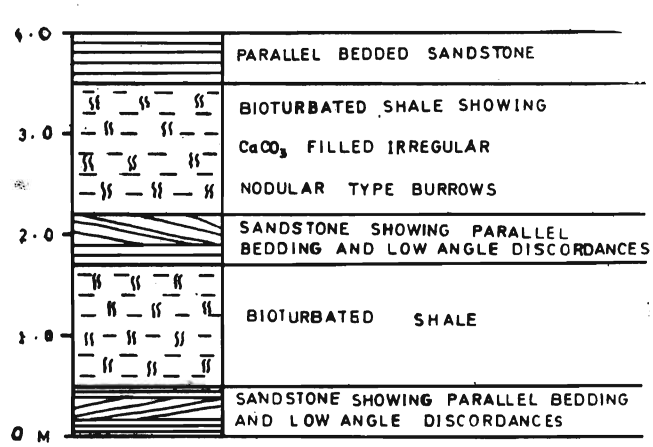

Fig. 6. Succession of sedimentary structures in the Dagsai sediments. Dharampur-Kumarhatti road section.

and low-angle erosional discordances. In some cases sandy units also show large and small crab-burrows.

Thick sandy units show large-scale cross bedding, low-angle discordances, and channelling (Fig. 7). Pebbly conglomerate horizons showing cross-bedding are also present (Plate I—5). The pebbles are often concentrated in the channels and are made up of mostly carbonate nodules. This is the most prominent and characteristic facies of the Dagsai succession.

This facies denotes deposition in extensive mud flats of an estuarine coastal complex. Bioturbated silt-shale represent deposits of the upper part of intertidal zone, densely populated by crabs. The sandy units represent deposits of the lower part of intertidal to subtidal zone. The dominant red colouration of these sediments indicates that the climate might have been the one with seasonal draughts or semi-arid.

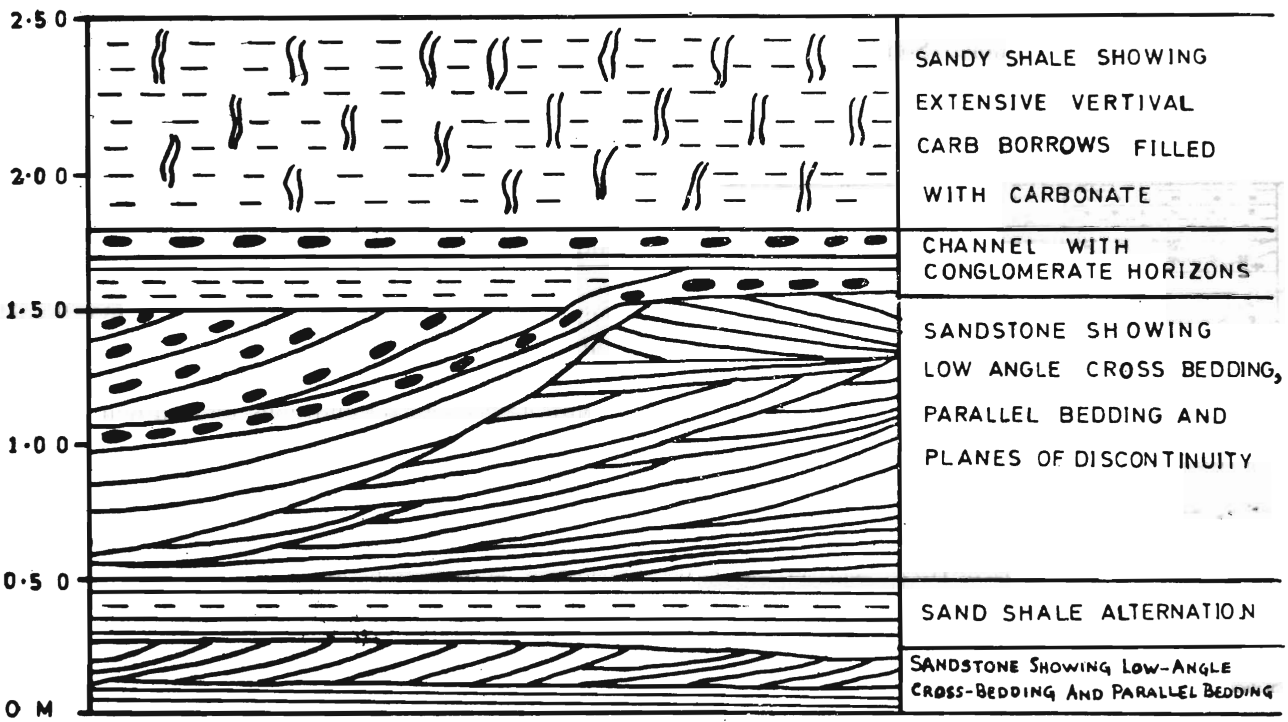

Fig. 7. Succession of sedimentary structures in the mottled red-shale, siltstone, variegated shale and sandstone facies of Dagsai sediments. Near Garkhal.

TRACE FOSSILS

The sediments of Dagsai Formation are characterized by the common occurrence of trace fossils (lebenspuren). The shaly and silty units are extensively bioturbated. Sandy units also show trace fossils but in lesser abundance. Following types of trace fossils are identified :

(i) *Thalassinoides :* They are branched burrow and tunnel systems showing Y-shaped branching and swelling at the points of branching. Burrows of this group can acquire different sizes and orientation. In the Dagsai sediments following types of *Thalassinoides* burrows are present.

(*a*) Dominantly vertical *Thalassinoides* burrows, without prominent branching (Plate III—12). The burrows are mostly filled with gray to white carbonate. Burrow diameter is 1-2 cm, length is 15-20 cm. Some of the burrows resemble *Ophiomorpha* burrows, but lack granular ornamentation.

(*b*) Dominantly horizontal *Thalassinoides* burrows of large size (Plate III—13). It shows characteristic branching and swelling. Burrow diameter is 1-2 cm and the length between two points of branching is 10-20 cm.

(*c*) Horizontal *Thalassinoides* burrows of small size (Plate I—4). The burrow diameter is 0.2-0.5 cm showing characteristic Y-shaped branching and swelling.

All the three types of *Thalassinoides* are abundant in the red shale faci s.

(ii) *Chondrites :* Ramifying plant-like burrow system with tunnels of 1-2 mm in diameter. It occurs closely associated with the horizontal Thalassinoides burrows of small size.

(iii) *Chevron trail :* They are linear series of nested chevrons. The trails are about 1 cm wide and curvilinear in nature (Plate I—6).

(iv) *Minute feeding burrows :* These are minute burrows without any distinctive patterns. It includes <1 cm in size point-like circular-oval burrows ; 2-3 cm long 1 cm wide burrows ; and $<$ 1 cm wide and 10 cm long burrows. These types of burrows usually occur in highly bioturbated shales (Plate II—8, 10, 11). Minute feeding burrows also occur in sandy beds, but their abundance is very low (Plate III—14).

Few medium-grained sandstones exhibit horizontal burrows and small circular, vertical burrows which resemble the patterns formed by *Heterocerus* and *Tridactylis* (Chamberlain, 1975). These burrows are considered to be formed in fluvial sediments, and are most abundant in Kasauli sediments.

ENVIRONMENTAL ANALYSIS

The early workers mostly considered the Dagsai sediments as deposits of brackish water to salt water lagoons (for example, Oldham, 1893 ; Wadia, 1932 ; Hayden, 1933). These sediments have failed to yield any definite marine or fresh water fauna. Raiverman and Raman (1971) designate these sediments to be deposits of transitional environment. However, Chaudhri (1968, 1975) considers the Dagsai to be fresh water deposits.

The present study shows that Dagsai sediments represent deposits of an estuarine complex ; where main sedimentation took place in the extensive mud flats, inhabited profusely by crabs ; producing *Thalassinoides* burrows. Some parts were deposited in the sand bodies of the estuary under the influence of marine processes. Characteristic fluvial fining upward sequences and associated sedimentary structures are absent. However, rarely few sand bodies show burrow-patterns of freshwater affinity.

KASAULI FORMATION

The Kasauli Formation is made up of several metre thick units of medium-grained, greenish-gray micaceous sandstone alternating with dark gray siltstone and shales, often nodular in appearance. Chaudhri (1969a, 1970) discusses the petrological characteristics of the Kasauli Formation. Plant remains and fresh water molluscs have been recorded from the Kasauli Formation (Sahni, 1953 ; Chaudhri, 1969b).

The Kasauli sediments exposed around the Kasauli township exhibit features of a fluvial deposit. The characteristic fining upward sequences of fluvial deposits, though present, are not well defined. Within a single sandy unit near the base abundant mud pebbles (greenish-gray in colour) and coarse sedimentg rains are present. This part of the sandy units shows large-scale cross-bedding, and parallel bedding with rather thick laminations. Upwards, the sandy units become more fine-grained and usually lack mud pebbles, and are usually parallel bedded with faint laminations. However, in the top most part of the sandy units horizontal burrow-patterns are quite abundant.

On the top of a sandy unit, usually a 1-2 m thick succession of fine sand/silt follows ; showing small ripple-bedding and parallel-bedding (Fig. 8). Generally, 1-3 cm thick small-ripple bedding alternates with equally thick units of parallel bedded fine sand. This type of bedding association has been reported from the natural levee and point bar deposits of the Gomti River (Singh, 1972). Associated with the silty units are few cm thick shale bands, showing faint fine lamination. Horizontal burrow-patterns are quite common in silty and shale bands. The silty units often show nodular appearance, probably due to the development of Kankar-like concretions.

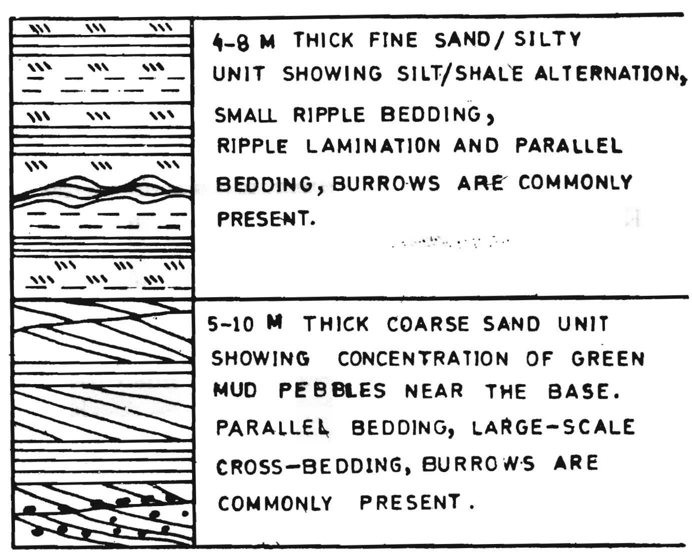

Fig. 8. Schematic diagram showing sandy and muddy facies of the Kasauli sediments. Kasauli township.

An important characteristic of the Kasauli sediments is that both sandy and silty units are greenish-gray in colour, and muddy sediments are uncommon.

TRACE FOSSILS

Trace fossils are not commonly found in the fluvial deposits ; but when present, they are mostly surface burrows of various insects, molluscs etc. made during their movement on the muddy flood plain sediments (see Chamberlair, 1975). In the Kasauli sediments trace fossils are fairly common in the upper part of sandy units and in the silty-muddy units.

The sandy units show a characteristic bioturbation pattern (Plate IV—18, 20). It is made up of horizontally running burrows, about 0.5 cm in diameter, linear or curved, often meeting and branching out from a 1-2 cm wide (circular to irregular in shape) burrow depression. There are also circular to irregular depressions, about 1 cm wide and 0.5 cm deep. Sometimes, pattern becomes quite irregular. The burrowing density is highly variable. These burrow patterns show a general resemblance with the patterns made by the *Tridactylis* (a sand cricket), the Mole cricket described by Chamberlain (1975). In the fossil record these patterns show some resemblance to *Scoyenia* (see Häntzschel, 1962).

In the muddy units faint burrows, about 1-3 mm wide are present running over several centimetres and showing branching at various angles. They resemble the pattern made by mud-loving beetle *Heterocerus* (Chamberlain, 1975). Besides, about 1 cm wide burrows meeting at a common depression are present and are identical to those present in the sandy units. These burrows show minute segmentation by rings which often appear as chevron patterns (Plate IV—19). Minute depressions, about 1-2 mm wide are also common.

ENVIRONMENTAL ANALYSIS

There is a complete unanimity, amongst various workers that Kasauli Formationr epresents freshwater deposits (see Chaudhri, 1975). According to Chaudhri (1969a) the Kasauli sediments are deposits of a shallow fast sinking fresh water basin.

The present study reveals that the environment of deposition of Kasauli sediments was an alluvial plain of moderate slope. The rivers were of braided nature with very shallow channels. In other words, there was no well-marked distinction between flood plain and channel sediments. The channels were quickly abandoned, so that the sediments were inhabited by various organisms, especially the insects making the bioturbate structures. The flood plain sediments were also inhabited by similar organisms, thus producing similar burrow patterns. The quick shifting of the shallow channels was also partially responsible for the fact that the flood plain sediments did not get sufficient time for oxidation and change in colour. Thus, both sandy and silty units are greenish in colour. It may be mentioned here, that in Siwalik sediments, the flood plain muddy facies is reddish-brown in colour, while the channel facies is greenish-gray in colour (Singh, 1975).

DISCUSSION

As already described the Subathu, Dagsai and Kasauli Formations of the Simla hills are distinct horizons, each with a characteristic lithological association, sedimentary structure, fauna, and trace fossils assemblage. Trace fossils can be useful in identifying Subathu, Dagsai and Kasauli Formations. The Subathu Formation contains only few trace fossils in limestone bands and sandy green shale represented by more or less horizontal stout *Thalassinoides*, *Chondrites* and *Tigillites*. The Dagsai Formation contains abundant trace fossils. The red shales are characterized by large vertical *Thalassinoides*, small and large horizontal *Thalassinoides* and *Chondrites*. The sandstones of the Dagsai Formation are characterized by abundant minute feeding burrows. The Kasauli Formation contains few trace fossils namely the horizontal burrows produced by different insects, e.g., mud-loving cricket *Hetrocerus*, *Tridactylis* etc.

The Subathu sediments are deposits of a shallow open tidal sea, most probably associated with an estuarine complex with normal salinity. In coastal lagoonal parts, sometimes hypersaline conditions developed leading to precipitation of gypsum. Locally, reducing milieu also existed and led to the deposition of black shale facies. However, tidal flat and shelf mud deposits dominate over other facies.

The change from Subathu to Dagsai Formation is accompanied by a change from open tidal sea to an estuarine complex with well-developed mud flats and sand bars, where deposition took place dominantly under marine influence.

The contact between the Subathu and Dagsai Formations is gradational and marked by a shifting of the coastline. Medlicott (1864), Bhatia and Mathur (1965), Raiverman and Seshavataram (1965), Chaudhri (1968) also regard the contact between Subathu and Dagsai Formations as gradational. However, Pilgrim (1910) proposed an unconformity between Subathu and Dagsai sediments, a view later supported by Burrard and Hayden (1933), Pascoe (1964), Khan (1969), Wadia (1966), Krishnan (1968). The concept of presence of an unconformity between Subathu and Dagsai Formation seems to be purely speculative, and not supported by field, sedimentological or palaeontological evidences. Nevertheless, Dagsai Formation is a distinct unit, and suggestion of Raiverman and Raman (1971) for dropping the name Dagsai needs reconsideration.

The contention of Krishnaswamy and Swaminath (1965) and Saxena, *et al.* (1968) that lower Tertiary sediments (Subathu-Dagsai-Kasauli) represent deposits of a geosynclinal cycle has no validity, because, the complete Lower Tertiary succession of Simla hills has been laid down in a shallow sea—estuarine-alluvial plain complex under stable shelf conditions. The view proposed by Raiverman and Seshavataram (1965) that red clays of Subathu and Dagsai sediments were brought into the basin of deposition by the turbidity currents has also to be discarded, as no where in the succession features of turbidites are visible. Nevertheless, Raiverman and Raman (1971) also rejected the idea of contribution by turbidity currents during deposition of lower Tertiaries, consider them to be deposits of shallow water environment.

CONCLUSIONS

1. Subathu-Dagsai-Kasauli succession represents a more or less continuous sedimentation without any major breaks (unconformity) in between.

2. Subathu-Dagsai-Kasauli succession is characterized by definite trace-fossil associations. The Subathu sediments show few *Thalassinoides*, *Chondrites*, and *Tigillites*. The Dagsai sediments show abundant *Thalassinoides* burrows of various types, *Chondrites*, bioturbated horizones, and minute feeding burrows. The Kasauli sediments show horizontal surface burrows of various insects, e.g., cricket and beetle.

3. The Subathu sediments represent deposits of an open tidal sea, with varied sub-environments resulting into development of different facies. The Dagsai sediments are deposits of an estuarine complex with strong marine influences and extensive mud flats. The Kasauli sediments represent deposition in an alluvial plain with rapidly shifting shallow braided streams.

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EXPLANATION OF PLATES

PLATE I

1. Stout *Thalassinoides* burrows in the limestone of Subathu sediments. Dharampur. 1 div. of scale=1cm.
2. Fine-grained sandstone showing small ripple bedding, mostly of herringbone type (marked with ink). Subathu sediments. Dharampur-Kumarhatti road section.
3. Vertical *Tigillites* burrow in the green shale of Subathu sediments. 1 div. of scale =1cm.
4. Horizontal *Thalassinoides* burrows of small size in Dagsai sediments. Few Chondrites burrows are also present. Dharampur-Kumarhatti road section 1 div. of scale=1 cm.
5. Pebbly conglomerate horizons in the mottled red shale of the Dagsai sediments. Garkhal. Length of hammer=30 cm.
6. Chevron trail in the sandstone of the Dagsai sediments. Dharampur-Sanawar road section.

PLATE II

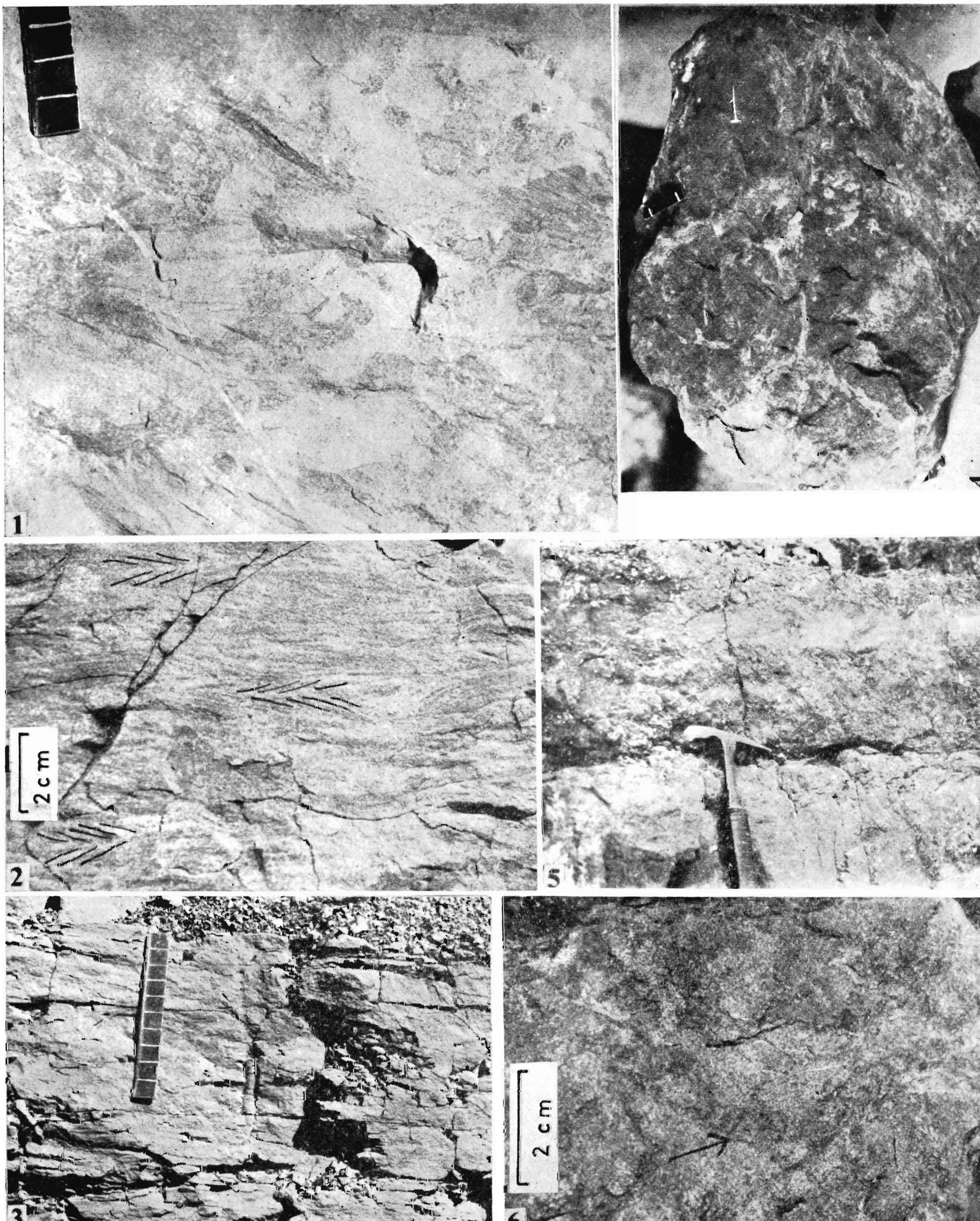
7. Parallel bedded sandstone with small ripple bedded units on the top. Dagsai sediments. Dharampur-Sanawar road section. Length of hammer=30 cm.
8. Minute feeding borrows in highly bioturbated shale of Dagsai sediments. Dharampur-Sanawar road section. Length of pen=15 cm.
9. Small ripple bedding in the sandstone of Dagsai sediments. Sanawar. Length of pen-cap=5 cm.
10. Well-developed feeding burrows in the siltstone of Dagsai sediments. Dharampur-Sanawar road section. Length of pen-cap=5 cm.
11. Bioturbated, mottled siltstone of Dagsai sediments. Dharampur-Sanawar road section. 1 div. of scale=1 cm.

PLATE III

12. Vertical *Thalassinoides* burrows filled with carbonate in the red shale. Dagsai sediments. Garkhal. Length of pen=15 cm.
13. Horizontal *Thalassinoides* burrows showing prominent branching. Dagsai sediments. Dharampur-Kumarhatti road section. 1 div. of scale=1 cm.
14. Some feeding burrows in the sandy bed of the Dagsai sediments. Dharampur-Kumarhatti road section.

PLATE IV

15. Parallel bedding with low-angle discordances. Sandstone of the Dagsai sediments. Dharampur-Kumarhatti road section. 1 div. of scale=1 cm.
16. Low-angle cross-bedding. Sandstone of the Dagsai sediments. Dharampur-Kumarhatti road section. 1 div. of scale=1 cm.
17. Graded bedding in the sandstone of Dagsai sediments. Dharampur-Kumarhatti road section. 1 div. of scale=1 cm.
18. Horizontal running branched burrows resembling *Tridactylis* burrows. Kasauli sediments. Kasauli. Length of scale=2 cm.
19. Burrow pattern in the sandy facies of the Kasauli sediments. Kasauli. Length of pen-cap=5cm.
20. Burrow pattern in the muddy facies of the Kasauli sediments, resembling those of *Heterocerus*.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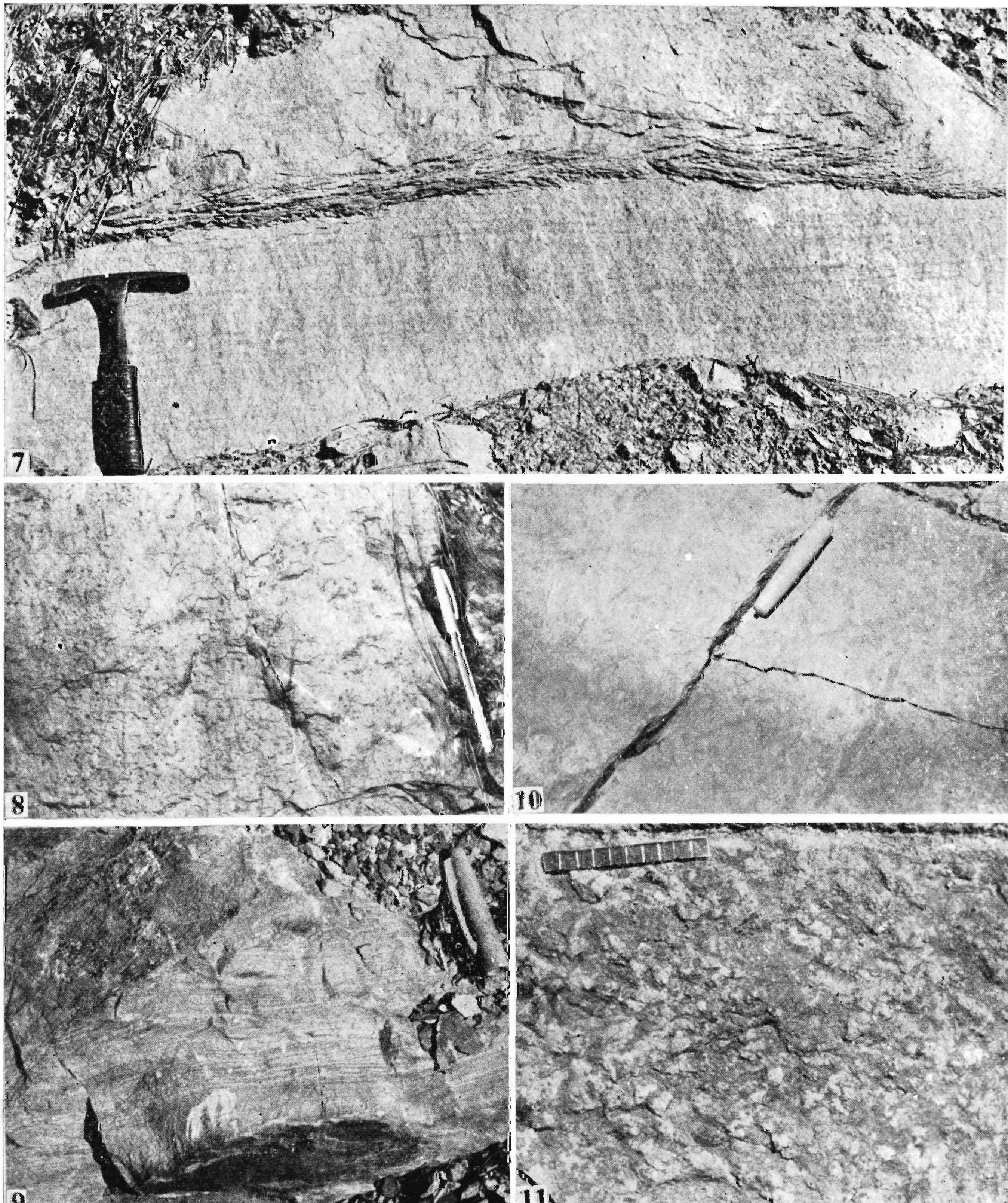
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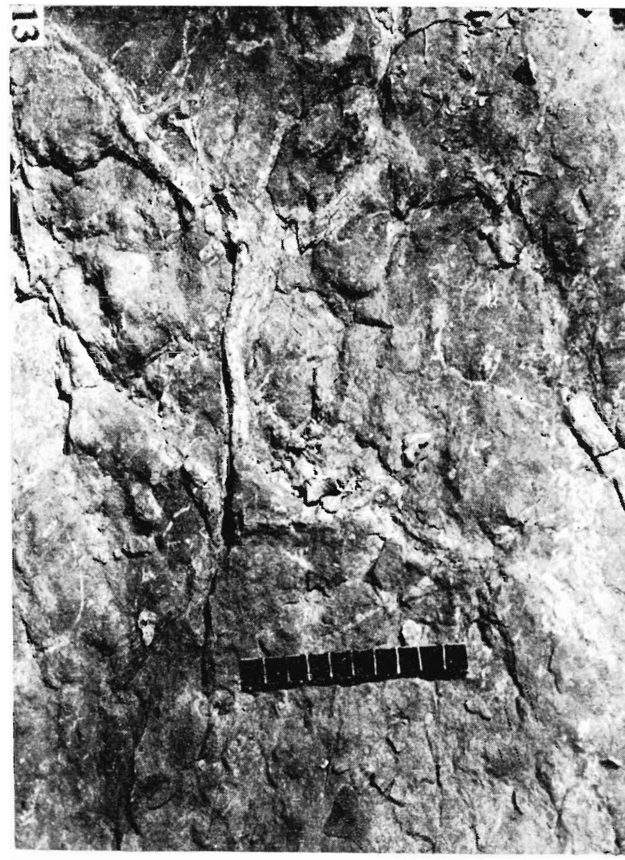

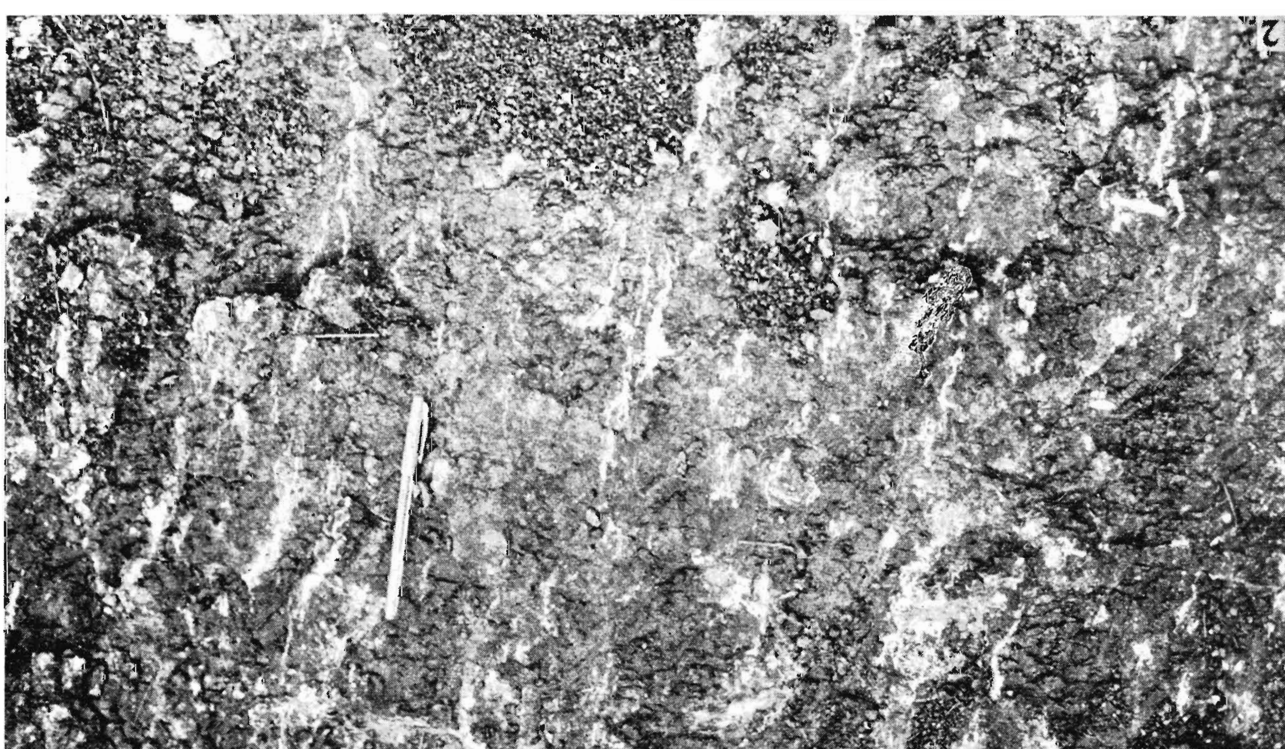

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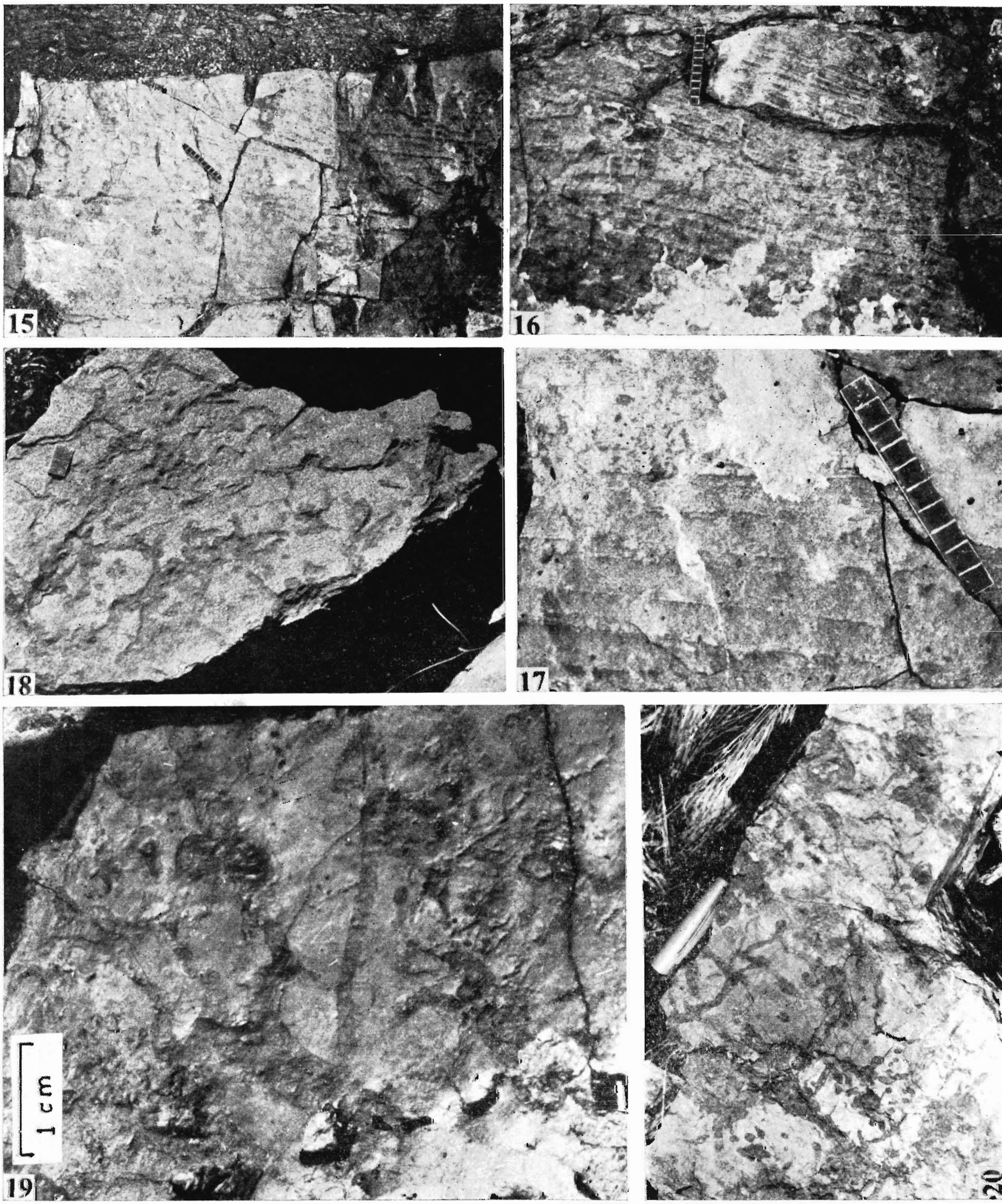
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