SEDIMENTARY STRUCTURES OF THE JUTANA DOLOMITE AND THE BAGHANWALA FORMATION

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ABSTRACT

The Jutana Dolomite and the Baghanwala Formation are well exposed in the Khewra Gorge, the type locality for the Cambrian sequence in the Salt Range. The Jutana Dolomite conformably overlies the Khussak Formation and is conformably overlain by the Baghanwala Formation.

The two formations represent deposition during Early to Middle Cambrian and in fact form a part of a megacycle which started with the deposition of the Salt Range Formation under arid and well oxygenated environment and culminated with the deposition of the Baghanawala Formation which was also deposited under the same environments.

In the two formations, several primary, secondary and organic structures are well preserved. In this paper the writer has described some of the most interesting and conspicuous primary, secondary and organic structures well preserved in the underlying Jutana Dolomite and the overlying Baghanwala Formation.

GENERAL FEATURES

Sedimentary structures are the larger textural features, best observed in the field rather than in hand specimens or thin sections. The structures formed during the deposition of the sediments constitute primary or syngenetic structures, those developed after the deposition, constitute secondary or epigenetic structures, while those formed as a result of biogenic processes are called as organic structures.

Various types of sedimentary structures observed in the Jutana Dolomite and the Baghanwala Formation include the structures, characteristic of clastic sedimentary rocks, which indicate that there has been slight transportation of the material before the final deposition in case of the Jutana Dolomite, whereas the structures observed in the Baghanwala Formation are indicative of extensive transportation and reworking. Various structures observed in the two formation are following.

Primary Structures

a) Stratification.
b) Cross-beding.
c) Ripple Marks.
d) Soft sediment folding *
e) Salt Pseudomorphs **
f) Mud cracks **

Secondary Structures

a) Stylolites *

Organic Structures

a) Worm Burrows.

STRATIFICATION

Stratification is the most fundamental and characteristic structure of the sedimentary rocks. The individual layers formed as a result of stratification are termed as strata or beds. The term stratum is applied for any type and thickness of the layers while the term bed is restricted to layer greater than 1 cm. In thickness. The strata less than 1 cm thick are termed as laminae. Each stratum can be separated from the above and or underlying stratum by the presence of a boundary calld stratification plane or bedding plane. Presence of stratification indicates a change in the depositional conditions and transportation, while presence of laminae is suggestive of prevalence of calm and quiet environments of peposition.

The Jutana Dolomite shows well developed and well defined stratification from bottom to top. The lower dolomite is thinly bedded and also contains

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* Observed only in the Jutana Dolomite.

** Observed only in the Baghanwala Formation.

very thin argillaceous strata. Thick bedding is also noticed at some stratigraphic levels. The middle shale bed is very thinly bedded and contains abundant shaly intercalations. The upper dolomite is very thickly stratified and is mainly composed of carbonate minerals. Very little amount of argillaceous and arenaceous material is observed in the upper dolomite. Extremely thin laminations are abundant at many stratigraphic levels in the Jutana Dolomite, and at places as much as 100 laminae can be counted in one inch thick layer of dolomite. Overall mode of stratification suggests slight variation in the condition of deposition. However, much arenaceous and argillaceous material was brought into the basin of deposition during the time when lower part of the Jutana Dolomite was being deposited. Presence of very thin laminations at many stratigraphic levels, nevertheless suggests absence of any bottom currents.

The Baghanwala Formation is also well stratified and the strata vary from thin to thick beds. However, thin strata are dominant. Very thin laminations are also observed at various stratigraphic levels. Gray, flaggy sandstone lenses are abundantly interbedded and constitute the characteristic features of this formation. Presence of abundant thin strata are suggestive of rapid fluctuation in the depositional environments, which is also verified by presence of varying lithological units of sandstone, silstone, and shales. Planoconvex bodies of channel sands are observed at about 35 feet from the base of the formation. Iron leaching is most prominent in the upper part and at places alternating laminae of olive, maroon, and gray sandstone, siltstone and shales are common. Overall mode of stratification indicates that calm water conditions were dominant. Rapid fluctuations in the deposition of various constituents, indicated by thin strata, may be the result of the difference in the grain size, roundness, and sphericity of the clastic particles.

CROSS BEDDING

Cross bedding is the internal structure preserved in the strata. Current bedding is the genetic name for cross-bedding, nevertheless, later is the most common term used by the recent workers. Although cross-bedding is characteristic of sandstones, it can be observed in any type of clastic sedimentary rocks. It is a vectorial feature and indicates the direction of transport of the material and the nature of the site of penultimate deposition. It is also an important critarion for the determination of top and bottom of an upside down sequence of strata. However, for the study of such hydrodynamical environments and structural complexities, regional examination of cross bedding is a must, because local variations in the attitude of the cross-bedding is observed frequently in the field. The writer, therefore, confines himself to the brief description of coss-bedding exposed in the outcrops of the two formations in Khewra Gorge.

Cross-bedding is observed at many stratigraphic levels within the Jutana Dolomite and the Baghanwala Formation. Very thin cross laminations sharply truncated by the stratification planes are observed. The acute angle formed by the truncation of these cross laminations by stratification planes varies, the larger angle marking top of the strata. Field observation of this feature indicated that both the formations are right side up.

Cross bedding characterises successive addition of sediments on the down current side, and is favoured by shallow and turbid environments. Such condition, however, did not prevail for longer periods during the deposition of the Jutana Dolomite and the Baghanwala Formation, which is suggested by the cross bedding only observable in thin strata. Nevertheless, slightly turbid or agitated and shallow conditions of deposition prevailed during the sedimentation of these formations, and calm and shallow conditions prevailed during the time when the major thickness of the two formations was being laid down. The presence of ghost structures and textures (after odite/pissolite) at some stratigraphic levels and their absence from others prove the writer's view.

RIPPLE MARKS

Ripple marks are the small scale directional structural features of clastic sedimentary rocks, preserved on the stratification planes. Ripple marks constitute low ridges and troughs, and may be the result of wind currents, water currents, or wave action. Wind current ripples can be easily distinguished by their gentle stoss side slope. Water current and wave action ripple marks can be recognised because of their symmetry. Current ripple marks being asymmetrical, while wave ripple marks are symmetrical. The ripple marks observed in the Jutana Dolomite and the Baghanwala Formation are symmetrical in sculpture, and hence wave ripple marks. Such symmetrical ripple marks are often referred as oscillation ripple marks. The observed oscillation ripple marks have same wavelength and amplitude over sufficient extent. Majority of these have small wavelength, but at places in the Jutana Dolomite a wavelength of as much as 3 feet was measured. The crests were comparatively sharper than the troughs, which were broad and well rounded (smoothly concave). It is mainly because of their symmetrical nature that the wave direction could not be ascertained, nevertheless they indicate a particular wave velocity below and above which oscillation ripple marks are not formed.

As already stated, oscillation ripple marks are the result of wave action, it is, therefore natural that these are not developed at greater depths because... "wave generated movement dies out rapidly with depth" (Pettijohn, 1957, p. 186). It is also a well known fact that oscillation ripple marks are formed as a result of disturbance of noncoherent granular sediments (Shrock, 1948, p. 95). Moreover,..." they indicate standing water at the time the ripples were formed" (Dunbar and Rodgers, 1966, p. 189). Thus the constituents of the Jutana Dolomite, at the time of deposition, were in granular form, indicating transportation. While there can be no question about the granular nature of the constituents of the Baghanwala Formation. The presence of oscillation ripple marks in the Jutana Dolimite and the Baghanwala Formation, therefore leads the writer to conclude shallow conditions of depositions or not deep enough conditions (below the reach of current action) in marine and standing water environments. However, for a much more plausible conclusion a detailed work is necessary.

Asymmetrical ripple marks were observed only at a few stratigraphic levels in the Baghanwala Formation, which indicate that more shallowing of the basin occured which allowed the currents to reach the upper surface of the depositing sediments. Thus very shallow conditions and probably high energy environments must have prevailed during the deposition of atleast a portion of the Baghanwala Formation.

A block from the Jutana Dolimite indicated that large ripple marks were formed at first which were superimposed by a set of younger and small scale ripple marks. The asymmetry of these ripple marks indicates that they are current ripple marks. These ripple marks therefore, suggest that during the deposition of a part of the Jutana Dolomite very shallow conditions prevailed which allowed the current action to reach the bottom sediments.

SOFT SEDIMENT FOLDING

Soft sediment slumping, rolling, folding or convolution is the result of penecontemporaneous deformation and is variously called as slump bedding.

"There are four main mechanisms that may cause solt sediment deformation; (a) gravity forces acting on a succession of strata showing a reverse density gradient, i. e. with denser sediment layers overlying less dense layers; (b) liquefaction of the sediments; (c) gravity movement of sediments deposited on a slope (slumping); (d) shear stress exerted on recently deposited sediments by a flow moving above it. In many cases it seems that two or more of these mechanisms act together to produce the observed deformation (Anketell and others, 1970) (Blatt, Middleton, and Murray, 1972, p. 170).

True slump structures ... "are not always easy to distinguish in the field from load or liquefaction structures involving no downslope movement from structures formed by shear stress exerted by fluid flow or from structures formed by diastrophism" (Blatt; Middleton and Murray, 1972 p. 171). The criteria used for distinguishing slump include distorted and overturned stratification, with sufficient evidence that the sediment was plastic enough at the time of deformation (the swell and pinch structure are suggestive of plastic nature of sediments), striated fold and fragments, "slump balls" consisting of rolled up fragments of strata, "pullapart structures", "and in some cases, an eroded top of the slump structures with a thin graded bed deposited above the erosion surface. It is regrettable that it is so difficult to distinguish true slumps from other structures in ancient sediments because their presence together with orientation of the slump folds is one of the few direct indicators of palaeoslopes" (Blatt, Middleton, and Murray, 1972, p. 171).

Soft sediment folding observed in the Jutana Dolomite is mostly preserved in the more aluminous layers, sandwiched between hard dolomite layers. This is indicative of the fact that the deformation is the result of gravity sliding or compaction. The most plausable explanation for the penecontemporaneous deformation observed is that the more aluminous layers can retain more water and remain more softer than those which are non-aluminous and do not retain water. It is because of their soft nature that such aluminous layers slump very quickly under slight gravity action or they may be easily distorted due to the weight of the above lying strata. It is also very likely that both the factors, i. e. gravity sliding and compaction, might have operated simultaneously, because rolling or slumping is observed in the softer layer, and disturbances in the lower bedding plane of the upper layers is also observed.

SALT PSEUDOMORPHS

Cubic pseudomorphs after salt crystals are abundantly present in the Baghanwala Formation. It is because of their abundance that the formation was formerly called "Salt Pseudomorph Beds". The size of the cubic pseduomorphs after salt crystals, observed in the Baghanwala Formation, ranges from the fraction of a cubic centimeter to as mueh as 5 cubic centimeters. Presence of these cubic pseudomorphs suggests that the salinity and temperature in the basin of deposition increased to such an extent that cubic salt crystals were formed. However, this does not indicate prevalence of a totally arid climate because salt can crystallize...... "in shallow intermittently flooded areas even in regions of abundant rain fall" (Pettijohn, 1957, p. 601). However, in the case of the Baghanwala Formation, the abundance of pseudomorphs after salt, dominantly red colour, and with the exception of worm burrows and of a few fucoid markings, no significant forms of life is preserved. Apprarently the increased salinity coupled with the aridity and perhaps high temperatures proved a deterant for the flourishing of any significant from of life.

Presence of these cubic pseudomorphs also suggests that the intermittent flooding took place after a time when already deposited sediments had been sufficiently indurated. This is indicated by the fact that the perfect boundaries of the molds are very prominent, and they are rarely disturbed. The boundaries of a cubic pseudomorph after salt crystal are shared by both the upper and lower stratigraphic units, which indicate that the salt crystals were dissolved slowly. Moreover these pseudomorphs are mostly abundant in more fine grained argillaceous strata which is suggestive of absence of bottom disturbances.

MUD CRACKS

Mud cracks, typical of argillaceous strata, are an important criterion for the determination of top and bottom of lhe strata. Presence of mud cracks in the Baghanwala Formation indicates that the sediments were exposed to strong sunshine causing desiccation, which in turn caused shrinkage. Under tense shrinkage cohesive nature of the clay minerals resulted in the formation of cracks. These cracks were later on filled with younger sediments. Thus conical or wedge like ends of the crack-filling sediments point towards the base of the strata. Such observations indicated that the Baghanwala Formation is lying right side up in the Khewra Gorge.

STYLOLITES.

Stylolites are the sutured surfaces which develope chiefly parllell to the bedding and less commonly are inclined to the bedding. These sutured surfaces are the result of pressure-solution effects. The stylolite seams thus constitute a sequence of sutured rows. These rows may extend over a length of few millimeter to as much as many meters. Similarly the sutured surfaces may vary from the fraction of a millimeter to as much as many centimeters. Most commonly these end by marging into the bedding planes without a stylolitic seam.

Stylolites are commonly observed throughout the Jutaha Dolomite, but they are more prominent and abundant in the middle and upper parts of the formation. Most of the stylolitic seams are parallel to the bedding planes. However, some vertical stylolites have also been observed by the writer. Most of these extend over a length of many meters, while columns and sockets have corrosponding height and depressions of less than one centimeter. Close examination of various stylolitic seams revealed the presence of a thin film of carbonaceous and ferrogenous clay at the tip of the columns and depressions of the sockets. This is suggestive of solution effects and marks the insoluble residue left after solution effects.

The origin of stylolites has been a matter of dispute for a long period of time and many theories have been put forward by different authors. However, the most widely accepted view is that the stylolites are thc result of pressure-solution phenomenon in the consolidated rocks (Stockdale, 1922). Thus the formation of stylolites is a post-consolidation effect and involvss solution of the rock in which they are noticed. Although they are chiefly observed in limestones and dolomited, they can also be observed on a limited scale in quartzite, gypsum, shale and chert (Sloss and Feray in Twenhofel, 1950, p. 612). According to Stockdale (1922) solution under pressure of the overlying strata, is mainly responsible for the production of stylolites and is controlled by the pressure difference, which in turn effects solubility. Since the directed pressure is maximum at the summits and troughs of the columns and sockets, respectively, the solution effects are maximum at these points. This results in an increasing relief between columns and sockets. Extensive solution effects result in the striated columns and sockets. The striated columns and sockets are noticed at some stratigraphic levels in the Jutana Dolomite, suggesting extensive solution effects under pressure at these levels.

Since stylolites record interstratal solution they are of great significance in estimating the amouut of rocks dissolved. In this concern thin films of clayey minerals containing quartz sand and silt grains are of particulate interest. The concentration of these grains in stylolitic seams compared with their distribution in the surrounding rocks gives the amount of dissolved rocks. At places oblique displaced veins ending across the stylolites may also be used for the estimation of dissolved material. Even if the average amplitude is taken as a measure of minimum quantity removed, the aggregate reduction in thickness of a carbonate bed may be as much as 40 percent of the origional thickness (Stockdale 1926 in Pettijohn, 1957 p. 216). However, the writer could not estimate the amount of dissolved material in the Jutana Dolomite, because it needs much more detail and precision work.

WORM BURROWS

Burrows are the preserved bores made by the burrowing animals, Since the worms are dominant burrowing animals, these bores are frequently assinged as worm burrows. In the Jutana Dolomite worm burrows were only observed at the base of Middle Shale bed. Besides these worm burrows tracks and trails made by crawling animals, particularly trilobites Genus Redlichia have been observed and discussed in detail by Schindewolf and Seilacher (1969). In the Baghanwala Formation, besides worm burrows, fucoid markings were also observed.

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