SEDIMENTOLOGY OF SILICEOUS SANDSTONE CONCRETIONS FROM THE UPPER VINDHYAN SYSTEM, JABALPUR DISTRICT, MADHYA PRADESH, INDIA

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In this paper the author reports for the first time a detailed sedimentology of the large siliceous sandstone concretions enclosed in the Upper Bhander sandstone of the Vindhyan System (pre-Cambrian age) in India. The studies of concretions and the enclosing rock reveal that the concretions have resulted due to local replacement of the ferruginous cement of the enclosing rock by siliceous solutions. The over-all increment in size, roundness and sphericity observed in the concretions has been interpreted as due to secondary growth of silica over the original grains of the enclosing rock. The field relationship of the concretions with the enclosing rock indicates that the former have been formed *in situ* and are of epigenetic origin.

INTRODUCTION

Since the beginning of the geological investigations of the Vindhyan System in India, a great variety of sedimentary structures like ripple marks, current bedding, flute casts, load cast, etc., have been described together with their geological significance concerning the depositional environment. Recently, the author has come across large siliceous concretions more than 2 ft in diameter, enclosed in the Upper Bhander sandstone of this system. Such concretions do not seem to have been previously described from the Vindhyans.

These concretions are found at a point about half a mile NE. of Managawan village (22° 02′ : 88° 42′, Topo sheet No. 64 A/2), situated in Sihora tahsil of Jabalpur district, Madhya Pradesh, India. They occur enclosed in the Upper Bhander sandstone which forms the youngest litho-unit of the Bhander Series of the Upper Vindhyan System. The Vindhyan System consists of sandstones, shales and limestones with a total thickness of over 14,000 ft and covering an area of over 40,000 sq. miles, mostly in Central India. The Upper Bhander sandstone is typically a soft massive and fine-grained sandstone of characteristic deep red and purple or brown colour, speckled with patches of white to pale pink colour.

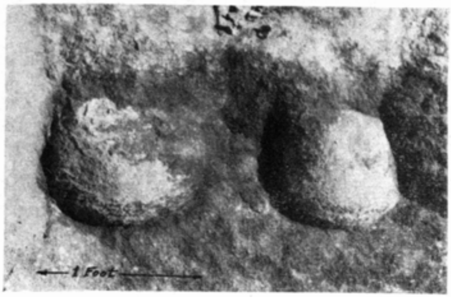

FIG. 1. Siliceous concretions exposed in a vertical section in a sandstone quarry, enclosed in massive speckled sandstone.

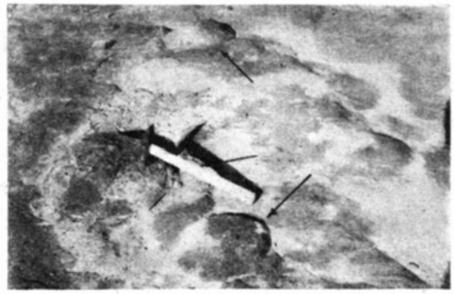

FIG. 2. Siliceous concretions exposed on the surface owing to differential erosion.

FIG. 3. Concretions of different shapes and sizes (the length of scale in the photograph is 1 ft).

FIG. 4. Diagram showing typical shapes of concretions: (A) Concretions of spherical shape with small protuberances and trace of bedding planes on the upper surface; (B) Well-rounded concretions enclosed in massive sandstone provided with few cracks on the upper surface; (C) '8'-shaped concretions provided with well-developed bedding plane, passing through both individual concretions.

Previous Work

The author has not come across any literature describing such concretionary structures except a short mention of 'pebble layer'. Pascoe (1959) has briefly described the occurrence of such 'pebble layer' in some sections of the Upper Bhander sandstone. However, he did not mention anything concerning their significance and possible interpretation, specially from the sedimentary point of view.

Misra and Awasthi (1962) have described a number of sedimentary structures from the great Vindhyan System of India, without any mention of such concretionary structures.

Saxena (1965) has also noted similar pebble layers at several horizons in the Upper Bhander sandstone in the Bhopal area (Bhopal city about 200 miles due west of the present area) and concluded them to be 'sandstone concretions'. The concretions are of smaller size, with spherical shape and smooth surface, varying from a few mm to 5 to 6 cm in diameter.

Concretions similar to those in the Vindhyans are described in the siltstone from the Champlain formation of the Connecticut Valley, U.S.A. (Tarr 1935).

Field and Megascopic Features

Colour

In general, the concretions are white with a faint tinge of yellow, pink or brown in colour. The central portion is much lighter than the outer. The enclosing sandstone is red with white specks, and immediately adjacent to the concretions is dark brown due to increased ferruginous cement.

Shape

The concretions are usually spherical, spheroidal, disc or lens shaped. Some of them are so nearly spherical that they appear to have been artificially rounded. Field observations indicate that the spherical concretions are found enclosed in the most massive and homogeneous sandstones free from traces of bedding planes or textural variation (Figs. 1, 2, 3, 4 and 7).

Some of the concretions are '8'-shaped and exhibit a bilateral symmetry, which passes through the centre along the longest axis, perpendicular to the bedding plane (Fig. 4C).

Size

The concretions vary in diameter from a few inches to 2 ft, but mostly about 3/4 to 1 ft. Smaller concretions are usually flat and are generally 5 to 6 inches in diameter along the bedding plane and 2 to 3 inches in thickness in the centre, giving rise to lens-shaped form. The large size concretions more closely approach a spherical shape (Fig. 3).

Surface Features

Most of the concretions have smooth surface. Some are characterized by the presence of small protuberances uniformly distributed over the surface (Fig. 4A). A few of them exposed to the surface due to weathering and erosion have a rough and dark surface traversed by minor cracks. The cracks are insufficiently oriented in radial pattern. These cracks seem to have been produced by the mechanical process due to sudden temperature variation, which is the usual erosion process of Vindhyan sandstone (Fig. 4B).

Relationship of Concretions with the Enclosing Rock

A section of the concretion along the vertical plane passing through the centre was polished with the hope to study nucleus and concentric zoning, if any. No nucleus, in the form of a foreign matter, was found. Also, there is no trace of any concentric zoning suggesting that they form part of a uniform and homogeneous rock, from where there has been an almost complete removal of ferruginous cement.

Most concretions show traces of bedding planes, which pass uninterrupted through from the enclosing rock. The above-mentioned observation led to the conclusion that the formation of the concretion is the result of local cementation of the original rock, and the process of concretion formation should have taken place after the deposition and compaction of the Bhander sandstone. There is no indication of overarching or crumpling of the bedding plane of the enclosing rock at the contact of the concretions.

The contact of the concretions with the enclosing rock is mostly quite sharp and the balls can be easily separated. The concretions are tougher and more resistant to erosion than the enclosing rock (Figs. 1 and 2). The thin section study indicates that this is due to the presence of siliceous cement which has developed in crystallographic and optical continuity with the quartz grains.

Microscopic Studies

The microscopic studies of the enclosing rock and concretions clearly reveal their interrelationship.

Enclosing Rock (Bhander Sandstone)

Microscopically, the sandstone is fine grained with sub-angular to sub-rounded grains, with good compaction and good sorting. The important mineral constituents are quartz, microcline, plagioclase and altered subordinate turbid orthoclase. The accessory minerals include zircon, biotite, scarce staurolite and rare garnet.

The cementing material is siliceous and ferruginous. The former has developed optical continuity with the detrital quartz grains to a limited extent.

The ferruginous cement is uniformly distributed, except in scattered white patches, and forms a thin coating of iron over the quartz grains. A section passing through the white specks indicates total absence of ferruginous cement in it.

Concretions

Under the microscope the concretions are similar to the enclosing sandstone in all respects, except more compactness and practically total absence of ferruginous cement in the former.

The important microscopic feature of the concretions, which distinguishes it from the enclosing rock, is the high degree of secondary enlargement of the detrital quartz grains. The siliceous cement has developed crystallographic and optical continuity with the detrital quartz grains. A thin brown coating of iron on the original grains clearly defines their original shape.

A thin section, taken from the contact of the concretion with the enclosing rock, indicates a very clear and sharp boundary between the two, with a higher concentration of ferruginous cement in the enclosing rock immediately adjacent to the concretion.

A comparative study of the petrography of concretions and the white specks present in the Bhander sandstone clearly demonstrates that the specks do not have any genetic relationship with the concretions as the detrital quartz grains in the former have not developed optical continuity with the siliceous cement. Perhaps, the specks may have resulted by segregation of ferruginous cement at the time of diagenesis.

Sedimentological Studies

The sedimentological studies of the enclosing rock and the concretions include qualitative heavy mineral analysis, thin section mechanical analysis and visual estimation of roundness and sphericity, and standard classical procedures have been adopted (Krumbein 1935, 1941 and Rittenhouse 1943).

The assemblage of heavy minerals is identical in the concretions and the enclosing rock demonstrates that the latter has inherited the constituents of the former without change.

The estimation of grain size, roundness and sphericity has been made on about 600 grains in each thin section, and the results plotted on cumulative curves. The average size, roundness and sphericity between the enclosing rock and concretions have also been computed. The cumulative curves of the three major textural elements of the concretions run more or less parallel to those of the enclosing rock. The concretions show a marked increment in grain size, and improved roundness and sphericity which is attributed to secondary growth around the original quartz grains of the sandstone (Figs. 5 and 6 and Table I).

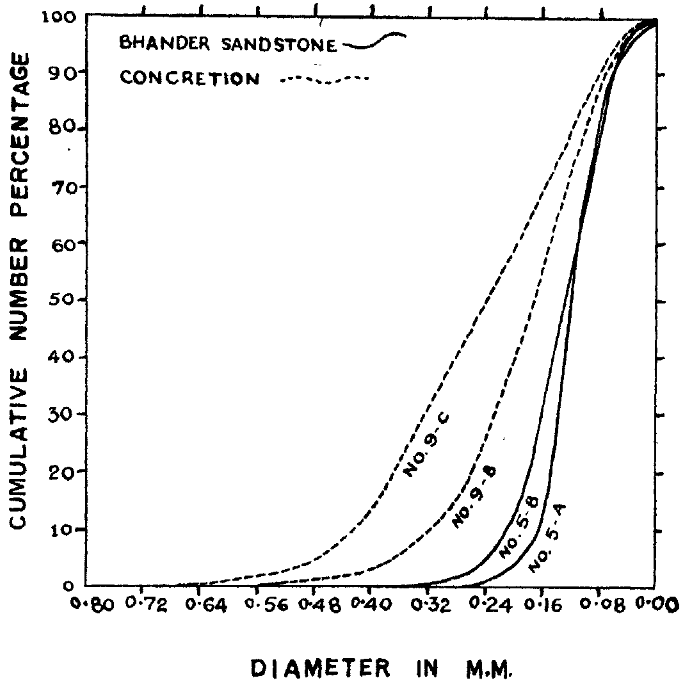

FIG. 5. Cumulative curves showing size variation of the detrital quartz grains between enclosing rock (Bhander sandstone) and concretions.

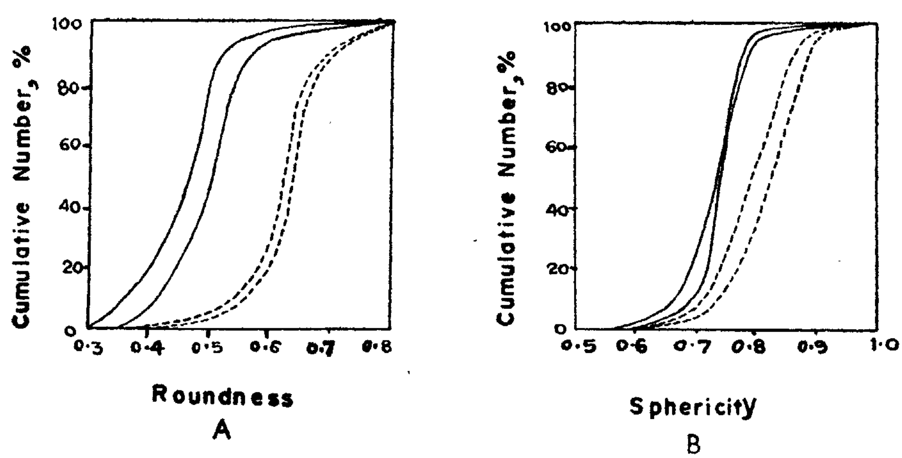

FIG. 6A-B. Cumulative curves showing difference in roundness and sphericity between the detrital quartz grains of enclosing rock (Bhander sandstone) and concretions. Enclosing rock shown by smooth line, while the concretions by dashed lines.

TABLE I

Comparative values of size, roundness and sphericity of the quartz grains between enclosing rock and concretions
(E.R. = Enclosing rock and Con. = Concretion)

Sample No.	Size			Roundness			Sphericity		
	Median diameter	Difference	Increment in per cent	Average	Difference	Increment in per cent	Average	Difference	Increment in per cent
E.R. Bh. 5–A	0·149	0·088	59	0·498	0·149	29·90	0·742	0·044	4·6
Con. 9–B	0·237			0·647			0·788		
E.R. Bh. 5–B	0·167	0·146	87	0·550	0·133	24·20	0·745	0·027	9·6
Con. 9–C	0·313			0·683			0·817		

Origin

The detailed studies of the morphological features, texture and mineralogical composition and their relationship with the enclosing rock lead to the conclusion that the concretions are of epigenetic origin and have been formed *in situ* due to concentration of siliceous cement around the centres and subsequent outward movement of ferruginous cementing material. Some of the important criteria helpful in proving their epigenetic origin are given below (following Twenhofel 1926).

1. There is no curvature and crumpling of the overlying and underlying laminae adjacent to the concretions.
2. The stratigraphic planes of the enclosing rock pass uninterruptedly through the concretions.
3. There are close petrographic similarities of the concretions and enclosing rock.

The physical characteristics of the enclosing rock, especially the porosity and permeability, also throw some light on their process of formation and their epigenetic origin. The present porosity and permeability of the enclosing rock are low as the inter-granular space has been more or less completely filled with the siliceous and ferruginous cement. In addition, the silica cement has developed optical continuity with the detrital quartz grains and, although it is to a lesser degree than in the concretions, it still reduces permeability to a high degree. To account the origin of concretions by replacement process, perhaps, the following explanation may prove true.

Quite possibly, the initiation of concretion formation might have started just after the induration or lithification of the sandstone. At that time the porosity and permeability must have been much higher than at present, permitting the movement of siliceous solutions towards the initial concretions and subsequent overgrowth of the concretion by replacement of ferruginous cement. The higher concentration of silica cement in the concretion and a concentric layer of higher ferruginous cement at the contact of the enclosing rock provide a concrete evidence for the above explanation. The mutual replacement process is further supported by the fact that the cementation by silica does not exceed the available pore space and the space earlier occupied by ferruginous cement, before replacement.

During the process, as the porosity and permeability of the enclosing rock would gradually be reduced due to compaction and the secondary enlargement of quartz grains, the rate of growth of the concretions would also be reduced accordingly. Ultimately the process would completely stop when the whole rock had become completely compacted with more or less complete filling of the pores and subsequent removal of water.

Considering the geo-chemical process it can be said that the whole process took place under water and the 'solutions' have played an important role, rather than diffusion. As mentioned by Moore and Maynard (1929) the silica may be transported principally as silica hydrosol and the iron in the form of ferricoxide hydrosol, and the same condition may be applied here also.

Formation of the Various Shaped Concretions and Their Relationship with the Enclosing Rock

As described above, the concretions are mainly of 3 types, namely well-rounded spheroides, lens-shaped and '8'-shaped—exhibiting bilateral symmetry. Many authors, especially Tarr (1935) and Twenhofel (1926) have described many factors controlling the shape and size of concretions. Some of the important factors are: (1) porosity and permeability of the enclosing rocks, (2) supply of the cementing material and (3) the presence of weak planes like bedding planes.

In the case of the concretions described in this paper as mentioned earlier the most nearly spherical are enclosed in the most massive part of the bed with uniform texture which is free from traces of bedding planes. Due to this uniform texture the movement of solutions would be uniform in all directions towards the centre and spherical concretions would result (Fig. 7).

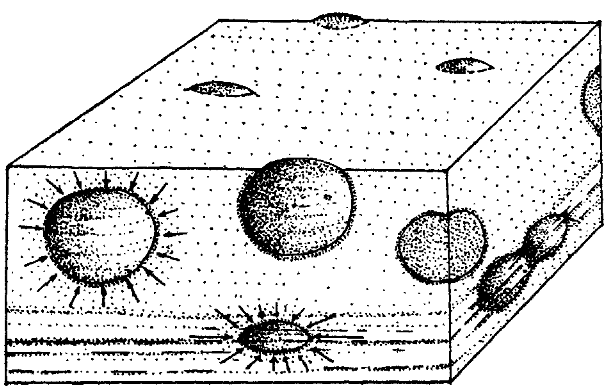

FIG. 7. Relationship of the shape of concretions with the enclosing rock. Spherical concretions occur in the more massive part, while the lens- or disc-shaped concretions are common along the bedding plane. Arrows in the block diagram indicate direction of movement of siliceous solutions. The length of arrow is proportional to the rate of movement of solutions.

The lens-shaped concretions are most common near or along the bedding plane with their greatest diameter parallel to the bedding plane of the enclosing rock. This shape is attributed to higher permeability along the bedding planes than across. The concretions found in the zone between the bedding plane and more massive portion have the shape of flat spheroids.

The '8'-shaped concretions are exactly of the same shape as described by Tarr (1935) although larger. Their shape can be explained in the same way as described by Tarr, i.e. by the lateral union of two independently growing simple concretions adjacent to each other.

No recent growth of the concretions has been noticed, indicating that the concretions should have formed long ago just after the consolidation of the enclosing rock, during diagenesis.

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