SOME PROBLEMS CONCERNING THE STUDY OF SEDIMENTARY ROCKS IN THE PRECAMBRIAN*

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ABSTRACT

Metamorphosed sediments form an appreciable part of the Precambrian successions. Some of the Precambrian basins exhibit well-preserved sedimentary sequences, but they have been rarely studied from the geochemical-sedimentological aspects. Thus, our knowledge about the sedimentation patterns during the early history of the earth is inadequate.

The principle of uniformitarianism holds good only in broad sense during Precambrian, but several periods during Precambrian are marked by unique sedimentation and weathering conditions. The traditional approach of stratigraphic subdivision to the Precambrian on the basis of orogenies needs to be supplimented and revised by sedimentological studies.

Precambrians are marked by some unique rock associations (for example, orthoquartzite basic igneous rocks) which are unknown in the post-Cambrian period. Some of the Proterozoic sedimentary basins e.g. Vindhyan basin, exhibit extremely stable conditions over long periods (several hundred million years) maintaining the same depositional environments. Shallow marine basins with exceptionally stable conditions seem to dominate the Precambrian (especially the Proterozoic) where deposition took place in the tidal flats, estuary and coastal sand areas. Precambrian sediments are often marked by the occurrences of unique chemical sediments, which are absent in the later history of the earth. These sediments include banded iron-ore, banded manganese ore, bedded cherts, phosphorite-stromatolite rock etc. It is suggested that some stable periods in Precambrian were marked by the pronounced chemical weathering on the continents and chemical precipitation in the waters, with assistance from abundant primitive life.

INTRODUCTION

It is considered that the earth is ca 5000 M yrs old. So far the oldest rocks recorded are the gneisses from Greenland, U.S.A. and U.S.S.R. which date back to some 3,500—3000 M yrs B. P. These gneisses are regarded to be metamorphosed sediments, suggesting that the process of sedimentation started quite early in the earth's history.

Although the process of sedimentation was active from the early part of the earth's history, the geological setting exhibited by the pre- and post-Cambrian eras were different from chemical, biological and sedimentological point of view. The post-Cambrian rocks being well documented with records of fossils have a better control for subdivision and correlation, while the Precambrian rocks lack significant fossil record and its history is vague and patchy.

The Precambrian areas have suffered metamorphism of varying degrees and are riddled with igneous rocks. The striking preponderance of the metamorphics and the igneous rocks in the Precambrians not only led to the earlier workers to make a detailed study of them only which gave rise to the present state of most of the concepts of igneous and metamorphic petrology, but also swayed their interest in overlooking the sedimentological aspects of the Precambrian sequences, which no doubt have similar important position in formulating the history of any Precambrian basin.

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Unfortunately, Precambrians remained a taboo for sedimentologists and, barring few exceptions, no detailed and systematic sedimentological studies were undertaken. Thus, today we are deprived of a systematic knowledge of sedimentation processes operative during the early history of the earth. As sedimentaries, though metamorphosed, do also have an important bearing on the history of the period, it is highly desirable that less metamorphosed Precambrians are investigated from sedimentological point of view, i.e. determination of environment of deposition, palaeogeography, sedimentary tectonics, and basinal history.

In this paper an attempt has been made to bring to the notice of the "Precambrian Geologists" through examples from general as well as particular areas the problems and peculiarities encountered during the study of the sedimentary rocks of the Precambrians, especially in India.

Because, at present, we do not have enough data to suggest any reasonable sedimentation model, the approach has been not to provide any model for Precambrian sedimentation, but only to highlighten the peculiarities of the Precambrian sedimentary rocks of India.

THE PRINCIPLE OF UNIFORMITARIANISM

The principle of uniformitarianism conveys broadly that the laws governing the various processes active today are the same which existed in the geological past.

It is believed that the conditions were somewhat different at the beginning of the earth, when differentiation between core, mantle and crust took place and only a thin solid layer (crust) was formed. In the last few years new concepts have been put forward suggesting geochemical evolution of primeval earth crust (see SHAW, 1972 ; GLIKSON & LAMBERT, 1973; ANHAEUSSER, 1973). These studies suggest that the earliest rocks were ultrabasic and basic in composition, on which a thin crust of sialic composition developed, the thickness of the crust having increased with time during the early Precambrian period. Geochemical studies of basic rocks from Dharwars by NAQVI AND HUSSAIN (1973) also suggest that in early Precambrian (3000—2400 M yrs B. P.) the crust was very thin and dominantly basic in composition. Later on the subsequent development of granites and gneisses resulted in the thickening of the crust.

RONOV (1972) gives an account of the geochemical evolution of the sedimentary shell of the earth. He suggests a continuous change in the geochemical nature of the sedimentary rocks, which seems to be rather over-simplified.

There are also speculations that earth's earliest atmosphere consisted essentially of CH_4, CO_2, H_2, N, and H_2O vapours, and O_2 was lacking or present in minor amount. It is presumed that primitive life originated some 3500—3000 M yrs B. P., and during this period more oxygen became available in the atmosphere. The well-defined algal structures in rocks as old as 2600 M yrs B. P., is convincing evidence that rather early in the earth's history (ca 3000 M yrs B. P.) oxygenated atmosphere came into existence.

There is very little sedimentological and biological information regarding the period before 2500 M yrs B. P. where most of the rocks are highly metamorphosed (granulite facies, green schist facies of igneous rocks). It is likely, that 3000 M yrs B.P., biological processes present had a subordinate role in comparison to the inorganic processes and the relief of the earth's surface was insignificant. The sedimentary-weathering processes produced mainly fine-grained clayey sediments, with subordinate amount of carbonates. During the 3000—2500 M yrs B. P. period organic processes became more important, the sediments produced being mainly clays, lithic sandstones, carbonates and other chemical sediments and calc-silicates. The occurrences of marbles and calc-granulites in the Charnockite terrain of South India also supports this contention. Nevertheless, the absence of orthoquartzites and felspathic sandstones during early Precambrian is not yet explainable.

It will not be very far-fetched to suggest that during Proterozoic (2500—600 M yrs B. P.) primitive life was present in abundance ; and perhaps even the land surface must have been covered by primitive life. As there was negligible competition with the higher life forms, primitive life (bacteria, algae) flourished in upper soil horizons and waters. And there is every possibility that these factors played decisive roles in the weathering and depositional processes.

There are reasons to believe that in a broad sense the *principle of actualism* holds good also for the Precambrian period. The physical and chemical laws were the same yet they may not be working with the same intensity through all the time, i.e. some of the periods being dominated by the importance of certain processes, e.g. the topography, climate zone distribution, biological processes, weather, weathering characteristics must have been quite different than what we are used to at present.

SUBDIVISION OF PRECAMBRIAN

The Precambrian has been subdivided into two parts : Archean (3500—2500 M yrs B.P.), and Proterozoic (2500—±600 M yrs B.P.), and their further subdivisions are based on the orogenies, grades of metamorphism, and the periods of granitic activity.

Attempts have also been made to subdivide the Precambrian on a world wide basis, with periods of orogenies and/or quiescence. However, such attempts have often failed. No doubt, there are periods of quiescence during Precambrian, but their occurrence and duration differ even in the different parts of a single shield. For example, sedimentation of Vindhyans took place under very quiescent period during 1400—700 M yrs B. P., but during the same period in the adjoining Sakoli and Dongargarh areas there are at least three cycles of orogeny and metamorphism (SARKAR, 1957-58). This example suggests that grade of metamorphism, and degree of disturbance alone cannot be taken as a measure of stratigraphic position. Unfortunately, the least metamorphosed Precambrians, i.e. part of Delhis, Cuddapahs, and Vindhyans have been traditionally put as the younger Precambrians, though the new available radiometric age data does not support this contention. Therefore, stratigraphy of the Precambrian can be established only when we have sufficient age data obtained from systematic sampling.

It is possible to subdivide and study the Precambrians from another aspect also, i.e. to delineate the more stable and less stable parts, and prepare a map of the Peninsular Shield depicting the areas according to their relative stability during Precambrian. Each of such areas ought to show differences in the sedimentation history. It is likely that some parts of a sedimentary basin have been involved in extensive metamorphism and tectonism, while the other parts have remained unaffected from disturbances. In such less metamorphosed parts of a single basin an attempt can be made to subdivide it with the help of sedimentological parameters. This would require recording of important sedimentological and climatological events during depositional history of a basin, e.g. deposition of iron beds, bedded cherts, red beds, stromatolitic horizons, etc.

If the sedimentation history in unmetamorphosed parts is ascertained with *Index-horizons*, the correlation with metamorphosed parts can be attempted and palaeogeography and basin configuration can be determined. Using this method depositional history of the individual basins can be ascertained which can ultimately help in the correlation of different contemporaneous basins. This would also help in better palaeogeographical reconstructions for different Precambrian periods. Recording and identification of sedimentological events is comparatively simpler than ascertaining the igneous activities.

The current tendency of delimiting a sedimentary basin on the basis of metamorphism and tectonic disturbances has to be given up. In other words, the Precambrian should not be studied only to establish stratigraphy in the conventional terms.

PRECAMBRIAN ROCK ASSOCIATIONS

Precambrian areas show certain lithological associations, which are either unknown or not so well-developed in the later part of the history of the earth. Such associations have not been given any emphasis, as sedimentologist have been mostly studying the post-Cambrian sediments.

For example, let us take a common Precambrian association namely the orthoquartzite/amphibolite (lava flows) association. Normally, the basic igneous rock is considered to be associated with deep sea flysch facies sediments, while the orthoquartzites are shallow water deposits under stable conditions. There are several examples of this association in Dharwars. Berinag Quartzites of Pithoragarh, Kumaon Himalayas is also typically an orthoquartzite/amphibolite association (Valdiya, 1962 ; Misra & Kumar, 1968). Sundernagar quartzite in Mandi area, Himachal Pradesh shows the same association.

A similar association of orthoquartzite/amphibolite is present in parts of the Precambrian of Southern Norway-Telemark Suite (Dons, 1960 ; Singh, 1969). But up till now a plausible explanation of igneous activity under stable shelf conditions has not been put forward. Perhaps, the existence of the crust predominantly of basic composition during Precambrian has some bearing on it.

Another problem is that of red bed association. In the post-Cambrian period, the red beds are only known from continental deposits, although the climatic conditions for their development are disputed. The major controversy is whether red beds are product of desert climate or of warm humid climate. Probably, red beds are formed under both climatic conditions. In Precambrian areas, there are thick successions of red beds typically of shallow, marine environments. Rewa sandstones, and Bhander sandstones are deposits of shoal and tidal flat environments respectively (unpublished data). Both of them are extensively red coloured sandstones. Khaira quartzites of the Shali belt in Himalayas are extensively red coloured, but they are also of shallow marine environment.

Other examples of red beds of shallow marine deposits from Precambrian of India are red beds of Kurnool, red beds of Chhattisgarh basin, and most probably the red quartzites of the Aravallis.

Reasons for widespread occurrences of red beds in shallow marine deposits of Precambrian are not yet known. The important factors seem to be weathering characteristics on the continents during sedimentation and the aging of the sediments.

CONGLOMERATE HORIZONS

Precambrian successions often show thick horizons of conglomerates (Srinivasan & Sreenivas, 1968). Some of these horizons attain thicknesses of 50 metres or more, and they have wide areal extent. Such conglomerate horizons can be useful in correlation. Moreover, study of the gravels of the conglomerates would provide information for still older rocks, which may not be exposed in the area.

Quartz pebble conglomerates are often reported from the Precambrians, and most of them are said to have suffered deformation leading to the flattening of the quartz pebbles.

A detailed study of a flattened quartz pebble conglomerate from Southern Norway by SINGH (1968) demonstrated that such conglomerates are actually thick successions of lenticular and related bedding which upon metamorphism have been converted into "pseudo-conglomerates". Such horizons are typical deposits of tidal flat environment. Some of the flattened quartz pebble conglomerates from the Peninsular India need to be seen in the light of the above observation.

SEDIMENTARY TECTONICS AND DEPOSITIONAL ENVIRONMENTS

Study of sedimentary tectonics means study of relationship between tectonism and sedimentation, i.e. study of behaviour of the earth's crust during sedimentation. It controls the nature and thickness of the sediments in a basin. Information about sedimentary tectonics can be obtained only by detailed study of a sedimentary basin.

Whatever data about the Precambrian sedimentary basins is available, it points out that many basins were characterized by extreme stable conditions maintained over several million years. Vindhyan basin, Cuddapah basin, Chhattisgarh basin, and parts of Dharwar all represent deposits of shallow marine environments under exceptionally stable conditions maintained over several hundred million years. Of course, some of the basins (parts of Dharwar) represent extremely mobile conditions with flysch type of sedimentation.

However, it is the preponderance of the ultra-stable shallow marine basins which attracts the attention in the Precambrians. Such stable sedimentary basins are not present in the post-Cambrian period.

An excellent example of an ultra-stable sedimentary basin is the Vindhyan basin. Vindhyans range in age from ca 1400—700 M yrs B. P., i.e. a time interval of approx. 700 M yrs is involved from lower to the upper part of the Vindhyan. Detailed environmental analysis of the Vindhyans has revealed that deposition of the Vindhyans took place in tidal flats, lagoons and shoals of an exceptionally stable coastal area (SINGH, 1973). Throughout the Vindhyans, there is no development of vertical sequences with changes from deeper to shallower water and vice versa. Only the above mentioned three geomorphic units of sedimentation are repeated again and again, while there is no significant break in sedimentation throughout the Vindhyans (a period of ca 700 M yrs). The preservation of sedimentary features is excellent; even the minute surface features are well preserved. Sometimes, one has the feeling that the Vindhyans were deposited only few days back. Even during the post-depositional history, this ultra-stable basin was not much disturbed. Today, Vindhyans show low dips without any significant tectonic disturbance.

From our studies in the present day sediments, it is very difficult to imagine how for such long periods (several hundred million years) stable and slightly fluctuating environmental conditions could be maintained. The available information seems to show that the shallow marine deposits are most common during Precambrian. Terrestrial and fluvial deposits are rather rare. It is quite likely that during most of the Precambrian period the land surface lacked any prominent relief. The peneplaned land surface had only ill-developed river systems. At the same time the marine coastal regions were extensive. Moreover, vegetation plays an important role in the building up of the flood basins and deltas, and as the extensive vegetational cover was absent flood basins and deltas could not develop. Absence of plant cover on the land surface caused the transport of the sediments into sea. The rivers of peneplaned land surface while meeting sea led to the extensive development of the estuaries and tidal flats. This may be the reason for common occurrences of the thick and extensive tidal flat deposits during Precambrian.

Algal mats are calcareous deposits showing irregular banding formed by the growth of algae. Stromatolites are organo-sedimentary structures made up of superimposed fine laminae of mostly carbonates, making columnar structures. They are produced predominantly by the growth of algae. In other words, if the algal mat growth results in well-defined structures they are called stromatolites.

Stromatolites mostly occur in carbonate sequences, often in association with dolomites. They are mostly found in the carbonate tidal flat deposits, being most abundant in the intertidal and supratidal zones. Carbonate successions of the Precambrian often show development of stromatolites and algal mats, and they have been successfully used for correlation and subdivision of the late Proterozoic, where they show profuse development and diversity of forms. In India stromatolites are abundant in all the Precambrian areas, e.g., Precambrian of lesser Himalayas (Valdiya, 1969), Vindhyan basin (Valdiya, 1969 ; Kumar, 1976), Cuddapah basin (Viswanathiah & Aswatha Narayana Rao, 1967), Aravalli (Banerjee, 1971a), Chhattisgarh basin (Schnitzer, 1971). In Vindhyan stromatolites are profusely developed in all the carbonate horizons, excepting the Rohtas limestone, where only ill-developed algal mats are present.

Such profuse growth of algal mats and stromatolites is not found in the post-Cambrian times. The probable reasons are that during Proterozoic times conditions were well suited for life, but only algae and bacteria were abundantly present, whereas highly evolved life was either insignificant or totally absent. Due to lack of competition from higher life, the primitive forms of life developed profusely, the algae abundantly grew to produce algal colonies resulting into stromatolitic bioherms.

CHEMICAL SEDIMENTS

Precambrian areas are marked by the development of thick deposits of chemical sediments in associations, which are not known in the later part of the earth's history. These chemical sediments are phosphorites, magnesite, chert, iron ores, manganese ores. At the same time, any significant salt deposits are absent in the Precambrian.

Phosphorite deposits

Concentration of phosphate in sedimentary rocks is taken as an indication of organic processes, especially the activity of bacteria, etc. Earlier, it was believed that phosphate deposits older than Cambrian are absent. However, thick phosphorite deposits have been found in the Precambrian of China, U.S.S.R. and India.

Phosphorite deposits have been considered as a good depth indicators, as they are found mostly at moderate depths in the muddy facies of the continental shelf. However, this association is not present in the Precambrian phosphorites. The Precambrian phosphorites of Chinese platform and India (Aravallis) are associated with supratidal to intertidal limestones and dolomites (Banerjee, 1971b). In Precambrian Gangolihat limestones of Himalayas, phosphorite is associated with magnesite (Valdiya, 1972). These Precambrian phosphorites are closely associated with stromatolites. On the basis of stromatolite assemblage the Aravalli phosphorites have been assigned a late Proterozoic age (ca 1000 M yrs B. P.). Valdiya (1972) suggests that phosphorite was precipitated along with the carbonates due to double action of algae. However, it seems more probable that phosphorite was precipitated by bacterial action in a carbonate biohermal environment with profuse life activity.

The most important point seems to be that phosphorites were produced during quiescent periods of Precambrian. During such periods, mechanical weathering on the continents was subdued and supplied very little terrigenous material to the sedimentation basin. At the same time increased plant life activity led to the high production of phosphorous, which was preferentially precipitated by the bacterial action in the bioherms.

Magnesite deposits

Magnesite deposits are mostly of hydrothermal origin. However, in the Precambrian there are examples of extensive bedded magnesite deposits (Sinian magnesite of U.S.S.R. and China). In Pithoragarh District, Kumaon Himalayas, there are extensive deposits of bedded magnesites, associated with stromatolitic dolomites (Valdiya, 1968). The magnesites are most probably primary precipitate or early diagenetic in origin. Such extensive bedded magnesites are not known in post-Cambrian times.

Bedded chert deposits

In many well-developed sedimentary successions of the Precambrian thick horizons of bedded cherts are present. Most of these bedded cherts are interbedded with carbonates. They are present in Dharwar sediments (Srinivasan & Sreenivas, 1968), Chhattisgarh basin, Cuddapah, and Kurnool (Schnitzer, 1971). Some of the cherts of Kurnool and Chhattisgarh basins show *micro-organisms*, which resemble radiolarians (Schnitzer, 1971). Precambrian cherts in other parts of the world have also yielded micro-organisms. This fact suggests that precipitation of chert in Precambrian is partly biogenic in nature. It seems that during Precambrian, there were periods when precipitation of silica (chert) was active, partly in association with the activity of the micro-organisms.

Extensive chert deposits are also found associated with banded iron-ore deposits, where chert bands alternate with iron oxide bands.

Banded iron-ore deposits

Precambrians are marked by the important iron-ore deposits, which are mostly of banded type. Banded type of iron-ores do not occur in the later history of the earth. Iron oxide bands alternate with thin silica bands. They are chemical precipitates in response to high supply of iron and silica from the continents. It is postulated that there were stable periods in the earth's history during Precambrian when extensive chemical weathering took place on the continents, thus releasing iron, silica and other elements in huge quantities. Iron and silica were transported to the sea by special mechanisms, may be in colloidal form, and were precipitated most probably by biochemical processes. Such conditions were repeated only few times during Precambrian. Detailed sedimentological-geochemical studies of these deposits may give insight into the weathering/deposition conditions which led to the development of banded iron-ores.

Manganese deposits

Thick manganese deposits of sedimentary origin are another important type of chemical deposits found in the Precambrians. Manganese ores occur in thick and thin layers interbedded with cherts. Its occurrence is analogous to the occurrence of banded iron-ores. Thus, genesis of these deposits seems to be under similar conditions to those of banded iron-ores, i.e. releasing of manganese from continents by extensive chemical weathering under stable conditions, and precipitation by specific biochemical processes.

GENERALIZATIONS CONCERNING CHEMICAL SEDIMENTS IN PRECAMBRIAN

From the above discussion it becomes quite apparent that some periods in the Precambrian are marked by the extensive development of chemical sediments and insignificance of the terrigenous sedimentation. It is postulated that these periods represent very stable phases without any pronounced relief on the land surface. Most probably under the influence of bacteria and algae chemical weathering dominated the scene and in the depositional basins only negligible amount of detrital material was received. The dissolved ions were profusely received in the basin and depending upon the physico-chemical and bio-chemical conditions certain ions were preferentially precipitated. Bacteria and other primitive life must have played an important role during precipitation of various elements.

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