Aravalli Supergroup of India: an example of the Lower Proterozoic rift tectonics and sedimentation

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Accretion of the Aravalli volcaniclastic and chemogenic sediments and the igneous suite along the northwestern margin of the Indian Peninsular Shield, represents an excellent example of Lower Proterozoic rift tectonics and sedimentation. The entire sequence of Aravalli sedimentary rocks in both the deep sea and the shelf environments accumulated in several stages evolved through tectonic movements associated with the rifting in this part of the globe. The basement got cracked as a result of tensional tectonic setting and a number of curvilinear faults, pouring basic lava from the mantle plumes, were produced. In the type locality of the Aravalli Supergroup around Udaipur City, a fault-controlled trough acquired the shape of an epicontinental sea in which shelf sediments deposited. The interplay of tectonism and sedimentation continued till the entire basin was completely filled up by sediments and fluvial conditions evolved in its place.

Key words: Lower Proterozoic, rifting, epicontinental sea, shelf sediments, fluvial sediments.

Introduction

The bedrock geology of the Udaipur and surrounding areas in Rajasthan, Northwest India (Fig. 1) represents one of the most ancient shorelines of the world. This region, known as the type locality of the Aravalli rocks (Early Proterozoic 1900–2500 m.y., Roy et al., 1988) exposes a fascinating sequence of meta-sediments associated with greenschist (altered basic lavas and tuffs), talc–tremolite–serpentine schist (altered ultrabasic intrusives), metagabbro and several plutons of granite and granitic gneisses.

The distribution of different rocks around Udaipur City, in particular, that of dolomite with stromatolitic rock phosphate, according to Roy and Paliwal (1981), is controlled by the sea floor topography, suggesting the presence of an epicontinental sea. Further, Roy and Paliwal (1981) described the Aravalli sequence deposited within the epicontinental sea, and the depositional basin along the rifted continental margins off the east coast of North America has been envisioned as a modern analogue of the Aravalli type depositional basin.

In this paper depositional features of the Aravalli sequence are described and tectonic evolution of the Aravalli basin is discussed in relation to sedimentation.

Regional geologic setting

Growth of the Precambrian crust in the northwestern part of the Indian Shield evolved through accretion of several sedimentary sequences, which were deposited at intervals around a nucleus of gneissic rocks; here it is a heterogeneous rock assemblage known as the Banded
Gneissic Complex (3500 m.y.) of Heron (1953) and the Berach Granite, as a result of tectonic changes and subsequent marine transgressions and regressions. The oldest sedimentary sequence which overlies the gneissic basement with a profound erosion unconformity is the Aravalli Supergroup. The Raialo, the Delhi and the Vindhyan Supergroups are the successively younger sedimentary units (Fig. 2) which, together with the Aravallis and the gneisses, constitute the Precambrian mosaic of Rajasthan.

Since Heron (1953) proposed a four-fold classification of the Precambrian rocks into the Banded Gneissic Complex (BGC), Aravalli System, Raialo Series and Delhi System, several revisions have been suggested during the last quarter century (Poddar, 1965; Sen, 1970; Banerjee, 1971; Roy and Paliwal, 1981; Roy et al., 1984, 1988; Naha and Halyburton, 1974; Naha and Roy, 1983). These revisions notwithstanding, the basic framework of stratigraphy established by Heron (1953) remains unchanged. The controversy,
Fig. 2. Map showing regional distribution of Precambrian rocks in the Udaipur area (based on Geological Survey of India, 1969).

however, prevails on the geographic extent of different formations.

Detailed distribution of the Aravalli Supergroup and its basement in the study area is shown in Fig. 3. The lithologic features of each stratigraphic unit are described as follows in ascending order:

**Basement rocks** The basement rocks comprise a heterogeneous mixture of gneissic complex with granitic components partly reconstituted and a group of metasediments. Important constituents include peridotics and basaltic komatiites, norites, rocks of charnockite series, quartz-hypersthene diorites, hypersthene diorites, leucocratic and melanocratic granulites, ortho- and para-amphibolites, banded gneisses, streaky gneisses, porphyritic gneisses, augen gneisses, quartzo-feldspathic and calc-silicate granofels, marbles and intrusives like pegmatites, aplites and granites ranging to granodiorites, trondhjemites and even tonalites.

**Aravalli Supergroup** The Aravalli Supergroup unconformably overlies the eroded and peneplaned basement rocks. All along the unconformable contact bauxitic paleosols now altered to white mica form pockets. The Aravalli rocks belong to two distinctly separate sedimentary facies: (A) a shelf sequence of sand and carbonates deposited in the epicontinental sea and also on pericontinental slope (Roy and Paliwal, 1981) and (B) a deep-sea sequence dominantly of shale with some sandstones now metamorphosed to phyllites and schists with quartzite bands. The shelf sequence has been subdivided into three lithostratigraphic units: Lower, Middle and Upper Aravalli Groups (Fig. 4).

**Lower Aravalli Group** The Lower Aravalli Group comprises two formations. The Formation I consists predominantly of a volcaniclastic sequence of basic lavas and tuffs now altered to greenschists and amphibolites followed by local conglomerates with quartzose or arkosic matrix (ferruginous at the base), dolomite and green-schist with intercalated dolomite bands.

The Formation II is exclusively a calcareous facies comprising quartzite–dolomite facies variation, dolomite with phosphatic and non-phosphatic algal stromatolites (Fig. 5), marble, sideritic marble, carbonaceous phyllite and slate with uranium mineralization, slate–phyllite–mica–
Fig. 3. Detailed geological map of the Aravalli Supergroup around Udaipur City, the type locality.
1-Basement granites, granitic gneisses and amphibolites (Banded Gneissic Complex), 2-White hydrous mica
(pyrophyllite of Roy and Paliwal, 1981), 3-Greenschist, 4-Conglomerate with quartoze/arkosic matrix, 5-
Banded-hematite-quartzite, 6-Quartzite/arkose, 7-Dolomite, 8-Carbonaceous phyllite and slate with copper
and uranium, 9-Dolomite with rock-phosphatic and sideritic marble, 10-Slate-phyllite-mica schist with
carbonate bands, 11-Conglomerate with greenshist matrix, 12-Conglomerate with phyllite matrix, 13-Wacke-
phyllite-lithic arenite rhythms, 14-Conglomerate with quartzose matrix, 15-Wacke-phyllite laminites, 16-
Quartzite, 17-Polymictic conglomerate with quartzose matrix, 18-Orthoquartzite-silty arenite, 19-Metadolerite
and metagabbro, 20-Direction of younging.
Fig. 4. Stratigraphic succession of the Aravalli Supergroup in the type area around Udaipur City. Not true to scale.

Fig. 5. Algal stromatolites in dolomite of Jhamarkotra rock phosphate deposit at Jhamarkotra. Coin size 22 mm.

Fig. 6. Upward reduction in thickness of beds in wacke-phyllite rhythmites near Machala Magra Hill.
Middle Aravalli Group The Middle Aravalli Group starting with basic volcanics consists of two formations belonging to two different facies: lower clastic association (Formation III) and upper carbonate association (Formation IV).

The Formation III in the central part of the basin around Udaipur City is represented by conglomerate with phyllitic matrix (Bhupalpura Conglomerate) passing to wacke–phyllite–lithic arenite rhythms of Udaipur City and wacke–phylite laminites on the peripheral region around Machala Magra Hill (Fig. 6). The peripheral region is represented by conglomerate with greenschist matrix or diamicrites (Fig. 7), polymictic conglomerate with quartzose and arkosic matrix and quartzite.

The Formation IV consists of lead–zinc–bearing dolomite and associated carbonaceous phyllites and slates passing upward to phyllites with quartzose bands.

Upper Aravalli Group The Upper Aravalli Group comprising a fluvial sequence (Formation V) around Udaipur City rests unconformably over the Formation III of the Middle Aravalli Group. The sequence starts with lenticular bodies of conglomerate with quartzitic matrix, a thick pile of orthoquartzite and argillite–silty arenite displaying a large variety of depositional and penconemporaneous deformational structures, characteristics of fluvial environment (Fig. 8).

The Aravalli rocks are intruded by ultra-mafics of the Kherwara–Dungarpur area, Nai and Zawar dolerite dykes and post–Aravalli granites.

Structural style of Aravalli rocks

The Aravalli rocks in the type area around Udaipur City reveal a polyphase deformational history resulted out of two major and several minor tectonic episodes (Fig. 9) (Roy et al., 1971;
Paliwal, 1988). A set of isoclinal folds, usually of reclined geometry with a strong lineation and a penetrative schistosity, typifying the Aravalli rocks, is the result of the earliest deformation in the area.

A series of N-S trending upright and steeply inclined isoclinal, tight and gentle folds, accompanied with the development of crenulation cleavage, axial planar to them, mark the second major deformation. The third fold movement produced small and intermediate scale folds, varying in geometry from round hinged to kink bands and conjugate folds, on the limb of large upright folds of second generation and a set of subhorizontal, discrete, axial plane crenulation cleavage.

Upright to gently inclined folds, broad warps, kink bands and conjugate folds with a set of weakly developed E-W trending axial plane crenulation, cleavage, represent the last deformation affecting rocks of the area. A strong shearing movement, prior to the first fold movement, is clearly reflected in the region.

**Depositional history and palaeogeography:** cracking of proto-continent and invasion of the sea

Evidence stands in favour of formation of Pangea, its fragmentation and reassemblage prior to the great continental drift of Permo-Carboniferous Period (Condie, 1976). Early Proterozoic fragmentation of super-continent caused cracking of continental margins (Fig. 10) and development of curvilinear faults pouring basic lavas from mantle plumes as a result of tensional tectonic setting in the region.

Opening of the Aravalli sea as a result of marine invasion (transgression) produced small epicontinental seas (fault-controlled troughs) and shallow epeiric seas, all along western and northwestern margin of the Indian Peninsula. Formation of the epicontinental sea around the Udaipur area (Roy and Paliwal, 1981) is an example in which shelf sequence of the Aravalli Supergroup was deposited.

**Early volcanlastic phase** Deposition of the Aravalli rocks commenced with the development of some linear trough, bounded by a series of high angle curvilinear faults (Fig. 11, Stages I, II). In the area, two subparallel belts of volcanic rocks (lava flows and tuffs, now altered to green schists) furnish evidence of faulting affecting the basement rocks. The westernmost belt of volcanic rocks which runs from Morwania to Inia Magra, is actually the line which divides the epicontinental sea to the east from the pericontinental and deep sea to the west (cf. Roy and Paliwal, 1981) (Fig. 12A). The second volcanic belt runs along the Aravalli-Banded Gneissic Complex contact to the east of Udaipur City.
Fig. 11. East–west cross-sections showing the evolutionary stages of deposition of the Aravalli Supergroup in the type area around Udaipur City.
The volcanic rocks have undergone severe deformation, and as such no undoubted pillow-like structures have been preserved in the study area. Evidence for submarine volcanism, however, comes from the intriguing possibility that the thin beds of dolomite within the green schists are marine intertrappean beds. Vesicular structures in the volcanic rocks also suggest a very shallow cover of water.

Within the green schists there is a persistent horizon, about 2 to 3 m thick of a very finely laminated rock. The thickness of individual lamina is spectacularly uniform and is almost paper thin. A fine micrograding is often present in these laminites. The characteristic features of the laminites, particularly, their fineness and lateral continuity, probably resulted from under-water deposition of fine volcanic clasts (ash falls derived from distal source).

Almost simultaneous with the initial volcanic eruptions, coarse detritus including pebbles, started being shed from the nearby land areas, as a result of newly developed paleogeography, depositing conglomerate and sandstone followed by thin dolomite beds of the Formation I.

Evidence, such as alternation of greenschists and quartzite or dolomite (Fig. 9) in some parts of the area where facing of rocks indicates that this repetition is not due to folding, clearly suggests intermittent recurrence of volcanicity during the entire sequence of clastic deposition.

**Early peneplanation phase** Perhaps, the volcanoes calmed down completely as the carbonate precipitation (Formation II) took over.
the scene. With this, there was a sharp fall in
the supply of terrigenous detritus and restoration
of a more stable tectonic condition (Fig. 11,
Stage III). Presence of beds of orthoquartzite
merging laterally to carbonates is the evidence of
interruptions in the continued deposition of
carbonates.

The depositional sites of carbonates were more
extensive than that of the previous units, and
covered all the shallow seas adjacent to the land
areas. The sea had apparently encroached upon
the land areas which had been eroded down to a
considerable degree.

An extremely irregular shoreline configuration
is clearly reflected in the complex geometry of
the carbonate body (Fig. 3). The distribution of
stromatolitic (Fig. 5) rock phosphate and carbo-
naceous phyllites, as facies variant of dolomitic
limestone suggests control of sea-floor topogra-
phy. Carbonaceous phyllites as black muds were
deposited in some local “deep” basins, possibly
grabens between submarine horsts within dolom-
ite belts. Phosphates, on the other hand, were
deposited in somewhat restricted shallow to very
shallow water environmental conditions in
different parts of tidal flats (Chauhan, 1979;
Banerjee et al., 1980). Studies made by Roy and
Paliwal (1981) indicate that the development of
stromatolitic rock phosphate was entirely restric-
ted to the epicontinental areas, where the
conditions favoured algal activities. Some ooid-
like structures have, however, been recorded in
the dolomite of the western sea (pericontinental
sea).

Besides the formation of stromatolitic rock
phosphates, a very shallow water depositional
environment is also attested to, in the presence
of thinly bedded argillaceous limestones (Neu-
man, 1968), particularly, in the upper part of the
dolomite sequence (Fig. 3). Presence of cross-
bedding and ripple marks might also indicate a
shallow water condition.

Subaerial exposure of carbonates in the
northern part (particularly around Iswal) for a
considerable period caused lateritization and
formation of “red beds” (red ochre) marking an
erosional unconformity at the top of carbonates
(Formation II). On the other hand, in the south-
ern part fine clastics (shale) were deposited.

Rejuvenated tensional tectonic setting Rejuve-
nation in the tensional tectonic setting reactivated
the faults and further sinking of the basin floor
of the epicontinental sea (Fig. 11, Stage IV). The
appearance of argillites at the top of the dolomite
sequence marks the beginning of a fresh deepen-
ing of basin floor and gradual replacement of
carbonates by clastics. Initially, only the finer
clastics were deposited in both the epicontinental
and pericontinental sea areas. As a result, once
again lavas started pouring out along marginal
areas of the further deepened epicontinental sea.
Simultaneous with the rejuvenated volcanic
eruption, coarse clastics including pebbles,
boulders and larger angular fragments started
flooding into the lava mulls from the nearby land
areas. As the process continued, there was flood,
of terrigenous detritus consequent upon widening
of the areas of provenance and unroofing of new
zones (cf. Bassett, 1963; Walker and Pettijohn,
1971). Conglomerates so formed (greenschist
diamictites) closely resemble the gravity slide
breccias and testify the presence of steep slopes
along which they have been rolled down.

The diamictites show an assorted mixture of
matrix-supported angular and rounded clasts.
The angular fragments indicate an origin similar
to submarine talus (cf. Friedman and Sanders,
1978). By contrast, the rounded variety of pebbles
suggests a longer transport and probable rework-
ing.

Major clastic phase This was followed by
dumping of clasts including poorly sorted but
fairly well rounded boulders and pebbles, drawn
from different sources, embedded in a matrix,
which is dominantly feldspathic in the lower part
(Fig. 11. Stage V). Petrographic character of
conglomerates suggests rapid deposition and
unroofing of new source areas.

As the irregularities in the source areas
gradually wore on, the pebbles of polymictic
conglomerates became considerably finer in size, well sorted, and spread along layers alternating with pebble-free beds of orthoquartzites. The pebble beds of this sort probably testify minor pulses of vertical movement.

Conditions became quieter in the next stage when sands started depositing. Subangular nature of the quartz grains and fair sorting probably indicate a beach environment (cf. Friedman and Sanders, 1978). Presence of large trough-shaped and normal type cross-bedding (Fig. 8) in some quartzites probably attests to a high energy environment, prevalent in surf zone of beaches.

In the central part of the epicontinental sea deposition of wacke-slate-phyllite (Formation II) was preceded by dumping of large, well-rounded boulders, cobbles and pebbles into argillite mud. The diamictite that formed out of these have lensoid outcrops. Study of petrography of the larger clasts suggests presence of granitic islands, which supplied the material to be swept into adjacent deeper areas by turbidity currents as channel deposits. With the deepening of the basin, at a later stage, the sea flooded the islands, and a continuous sequence of wacke-phyllite rhythmites was deposited in the entire epicontinental sea (Fig. 12B).

Rhythmic sequence of graded-bedded wacke-phyllite is attributable to transport by cyclic turbidity currents and deposition below an agitated wave base (Poddar and Mathur, 1965).

A sharp fall in the supply of turbidite sediments is reflected in the gradual reduction in individual thickness of fine laminites which occur higher up in the wacke-phyllite sequence (Fig. 6). As deposition of wacke-phyllite sequence came to a halt, the sea gradually withdrew from the epicontinental areas and land emerged around Udaipur. As a consequence, the area to the east of Morwania-Inia Magra line became an integral part of continent. The western sea, however, continued to receive sediments, at least for sometime.

Peneplanation phase Though sea withdrew from the Udaipur area, because of complete infilling of the basin with sediments, conditions favourable for the precipitation of carbonates still prevailed in southern parts depositing dolomite (with lead and zinc)-carbonaceous shale-orthofeldspar sequence (Formation V) around the Zawar mines area. Simultaneous with the carbonaceous shales, sandy layers (Tidi phyllites) accumulated further west in deeper parts (Fig. 11, Stage V).

Appearance of fluvial conditions Emergence of land around Udaipur favoured the occurrence of fluvial conditions, depositing conglomerate with quartzose matrix and thick pile of orthoquartzite-silty arenite sequence (Formation V) of the Upper Aravalli Group (Fig. 11, Stages V, N).

In addition to the string type pattern and a fining-upward cycle, different sedimentary structures present in silty arenite unit indicate very shallow water conditions and periodic emergence. Bed forms, typical of river channel bars, are common in the unit.

Operation of Wilson Cycle in the Proterozoic Period The Aravalli rocks from deposition to deformation represent the Wilson (1966) Cycle in the Proterozoic Period. Cracking of proto-supercontinent, opening of the Aravalli sea, formation of fault-controlled troughs, accumulation of clastics and chemogenic sediments, together with volcanic material, complete infilling of the basin, and closing of the sea by compressional phenomenon, causing a very strong shearing, prior to the earliest fold movement and an intense AF, folding, marking closing of the Aravalli Orogeny, are the stages of the Wilson Cycle in Proterozoic Period in this region.

Conclusion

The pattern of sedimentation noted in the rocks of the Aravalli Supergroup reflects repeated changes in palaeoenvironments, and a strong interplay of tectonism, erosion and sedimentation (Fig. 3) is clearly recorded in the vertical sequence (cf. Visher, 1965; Pettijohn, 1975) (Fig. 11). The stages reflect to: (i) volcanicity associated with relief following peneplanation, (ii) a stable and quiet condition, (iii) a period of marginal
upwarding associated with strong relief, and (iv) completion of trough filling with eventual return to nonmarine conditions (cf. Basset, 1963; Roy and Paliwal, 1981). The tectonic movement appears to be the main motive force behind all the phases of the Aravalli sedimentation. The rhythm noted here matches fairly well with the Krynine’s model (Krynine, 1942) for the Appalachian rocks. It is really intriguing that such a similarity should exist in the evolution of different orogenic belts which are so apart both in time and space.

In summary, the accumulation of the Aravalli Supergroup in the northwestern part of the Indian Peninsular Shield exhibits an excellent example of Proterozoic rift tectonics and sedimentation on the globe. During the initial stages of the tensional tectonic setting, the Archaean Shield comprising the Banded Gneissic Complex and the basement granites, got cracked and a number of curvilinear, deep-seated normal faults were produced.

Grabens and half grabens evolved through these multiple faults and the associated rotational movement in a plane perpendicular to the fault surfaces, gave rise to a number of long but narrow troughs, all along the western margin of the shield. In the type locality of the Aravalli Supergroup around Udaipur, a similar fault-controlled trough was formed giving rise to an epicontinental sea, in which the basic lava poured out from the mantle plumes through these deep-seated high angle gravity faults together with the coarse clastics from the adjacent elevated areas—the horsts. This was followed by a rapid influx of terrigenous sediment in the epicontinental sea so evolved. During the peneplanation, carbonates together with stromatolitic rock phosphate and carbonaceous shale followed the deposition of fine clastics and tuffaceous sediments.

Rejuvinated tensional tectonic setting in this part not only reactivated the existing faults but also produced a series of new normal faults parallel to them. Once again the basic lava from the mantle plumes started pouring out through these faults. Coarse clastics supplied subsequently from the elevated source areas in the surroundings, together with the volcanic material, gave rise to volcanioclastic and coarse clastic sediments of the Debari area in the type locality. Contemporary to this the deposition of diamicite–wacke–shale sequence of the Udaipur valley extending southward up to Zawar, represents the failed arm of the rift and aulacogen. Fluvial sequence of the Machala Magra and Pratap Smarak area representing the topmost unit of the Aravalli Supergroup, deposited on the diamicite–wacke–shale sequence of the Udaipur valley and which also mark the complete filling of the Aravalli epicontinental sea, suggests the presence of a failed triple junction in the region along which the great Aravallian river flowed during the Early Proterozoic Period and accumulated fluvial sediments in the area.

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インド, アラヴァリ超層群—原生代初期の地殻テクトニクスと堆積作用

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要 旨

インド軽状地北西縁に沿うアラヴァリ火砕岩・化学的沈積岩の付加現象は原生代初期の地殻テクトニクスと堆積作用の相場を示している。深海～陸棚環境に堆積したアラヴァリ堆積岩は全体として本地域における地殻形成を伴った造構運動と密接に関連しながら幾つかの段階を経て発達した。基盤には展展場における構造状変断層の形成があり、マントル・ブルーム起源の塩基性岩の流入をみた。ウダイプール一帯のアラヴァリ超層群模式地では断層によって規制されたトラフが陸棚を発達させた。この堆積盆は次第に堆積物で堆積され、遂に陸上河川環境の発達にいたった。