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MICROTHERMICS OF LATERITES AND BAUXITES CAPPING DECCAN TRAP BASALTS IN WESTERN INDIA

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Abstract

Thirty-five samples of laterites and bauxites representing both the high-level (elevation > 1000 m) and low-level (elevation < 100 m) deposits in western India have been examined by scanning electron microscopy. Megascopically, laterites exhibit vesicular, spongy and pisolitic textures, whereas bauxites display pisolitic, massive and nodular textures. Laterites, as well as bauxites are commonly characterized by framework microtexture produced by a three dimensional arrangement of crystallites. Locally, the laterites and bauxites exhibit crystalline-webby microtexture formed by a web-like arrangement of stacks of lamellar crystals. The individual crystals in the matrix of laterites and bauxites display anhedral forms and they range in size from about 0.5 µm to 20 µm. Crystals larger than 20 µm in size generally occur as linings of the vugs, in channels and veins, and they are usually euhedral. Pisolites and nodules in laterites and bauxites are composed of material generally finer than the material in the matrix around them. Platy morphology is most common for the minerals in laterites and bauxites. Gibbsite occurs in various forms ranging from prismatic, stubby slab-like to lath-shaped crystals.

The variations in textures of high-level and low-level deposits of laterites are characterized by similar textures. The variations in textures of bauxites are also found to be independent of the elevation of the deposits.

Key Words: Laterite, bauxite, vesicular macrotexture, pisolitic macrotexture, Deccan Trap, framework microtexture.

Introduction

The first comprehensive study of the microtextures of bauxites was conducted by Bardossy et al. (1978). They surveyed sixty-five samples from the major bauxite-deposits of the world, including four samples of lateritic bauxites from India. Bardossy et al. (1978) found significant differences in the microtextures of karstic and lateritic bauxites. They also pointed out that the high-level lateritic bauxites often display a higher degree of crystallinity and larger grain size than the low-level deposits. This paper is a detailed investigation of the microtextures of the high-level and low-level laterites and bauxites from western India. The terms "laterite" and "bauxite" are used in this paper following Bardossy’s (1982) definition. Accordingly, laterization is the superficial weathering of rocks resulting in a product with marked enrichment of Al, Fe, and Ti over other elements. Bauxite is the weathering product with predominance of aluminum minerals, whereas laterite is the general term for all the products of laterization. Thirty-five samples of laterites and bauxites representing four deposits have been studied. The objectives of this study are (1) to describe the microtextures of these laterites and bauxites; and (2) to examine whether the microtextures of high-level deposits are distinct from those of the low-level deposits.

Materials and Methods

Geographic locations of the bauxite deposits under study are shown in Figure 1. Twenty samples of laterite and bauxite were collected from the high-level deposits at Nangrataswadi and Panhala Fort that occur at an elevation of about 1000 m. Fifteen samples were obtained from the low-level deposits at Ratangiri and Srivardhan that occur at an elevation of about 80 m. All the above deposits are residual or primary in nature, i.e., formed by in-situ weathering of the underlying Deccan Trap basalts. Locations, depth of occurrence, physical characteristics (color and texture) and mineral compositions of the samples are given in Table 1. The mineral composition of the samples of laterites and bauxites was determined by x-ray powder diffraction using a Philips dif-
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64°-82° fractometer. The relative proportions of various minerals were estimated by comparing their integrated peak intensities with those of pure standard phases under the consideration of their mass absorption coefficients. Microtextures of the rocks and morphological features of their constituent minerals were examined on a JEOL JEM 100-CX Analytical Electron Microscope equipped with an EG & G ORTEC EEDS-II energy dispersive x-ray analyzer.

Description of the Textures

Megascopic textures of laterites and bauxites in western India were previously described by Sahasrabuddhe (1978). He identified five textural varieties of laterites, namely: vesicular, pisolitic, compact (massive), brecciated and conglomeratic. Sahasrabuddhe also described five textural varieties of bauxites, viz. pisolitic, nodular, compact (massive), concretionary and brecciated. In the samples under study, three textural types each of laterites and bauxites were recognized and they are described below.

Laterites

Three macrotextures were observed in the laterites: (1) vesicular texture that character-

Table 1. Description and Mineralogy of Laterites and Bauxites

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Locality</th>
<th>Depth in m</th>
<th>Brief physical description</th>
<th>Mineral composition* (in decreasing proportion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-level deposits:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D1-D4</td>
<td>Nangrataswadi</td>
<td>0-2</td>
<td>brick-red vesicular laterite</td>
<td>hm,gt,gb,kt,an</td>
</tr>
<tr>
<td>D5</td>
<td>Panhala Fort</td>
<td>0-2</td>
<td>pinkish-red spongy laterite</td>
<td>gb,hm,gt,kt,an</td>
</tr>
<tr>
<td>D6-8</td>
<td>Nangrataswadi</td>
<td>1-3</td>
<td>brownish pisolitic laterite</td>
<td>gb,hm,kt,an,gt</td>
</tr>
<tr>
<td>D9</td>
<td>Panhala Fort</td>
<td>2-3</td>
<td>creamy pisolitic bauxite</td>
<td>gb,an,kt,hm,gt</td>
</tr>
<tr>
<td>D10-D12</td>
<td>Nangrataswadi</td>
<td>3-4</td>
<td>ferruginous pisolitic bauxite</td>
<td>gb,an,gm,gt,kt,bo</td>
</tr>
<tr>
<td>D13</td>
<td>Panhala Fort</td>
<td>3-4</td>
<td>buff-white massive bauxite</td>
<td>gb,kt,an,hm,gt</td>
</tr>
<tr>
<td>D14-D18</td>
<td>Nangrataswadi</td>
<td>4-7</td>
<td>grayish-white massive bauxite</td>
<td>gb,an,bo,hm,kt</td>
</tr>
<tr>
<td>D19</td>
<td>Panhala Fort</td>
<td>4-6</td>
<td>grayish-white nodular bauxite</td>
<td>gb,kt,an,hm,gt</td>
</tr>
<tr>
<td>D20</td>
<td>Nangrataswadi</td>
<td>5-6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low-level deposits:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D21</td>
<td>Ratnagiri</td>
<td>0-1</td>
<td>brick-red vesicular laterite</td>
<td>hm,gt,kt</td>
</tr>
<tr>
<td>D22</td>
<td>Srivardhan</td>
<td>0-1</td>
<td>brownish-red vesicular laterite</td>
<td>hm,gt,gb,kt</td>
</tr>
<tr>
<td>D23</td>
<td>Ratnagiri</td>
<td>1-2</td>
<td>purplish-red spongy laterite</td>
<td>gb,hm,gt,kt,an</td>
</tr>
<tr>
<td>D24</td>
<td>Srivardhan</td>
<td>1-2</td>
<td>dark brown pisolitic laterite</td>
<td>gb,hm,gt,kt</td>
</tr>
<tr>
<td>D25-D28</td>
<td>Srivardhan</td>
<td>2-3</td>
<td>light gray pisolitic bauxite</td>
<td>gb,an,kt</td>
</tr>
<tr>
<td>D29-D31</td>
<td>Ratnagiri</td>
<td>2-3</td>
<td>yellowish-white massive bauxites</td>
<td>gb,kt,an,hm,gt</td>
</tr>
<tr>
<td>D32-D34</td>
<td>Srivardhan</td>
<td>3-4</td>
<td>pinkish-white massive bauxites</td>
<td>gb,an,km,gt,kt</td>
</tr>
<tr>
<td>D35</td>
<td>Srivardhan</td>
<td>3-4</td>
<td>buff-white nodular bauxite</td>
<td>gb,an,kt,km</td>
</tr>
</tbody>
</table>

*hm-hematite; gt-goethite; gb-gibbsite; kt-kaolinite; an-anatase; bo-boehmite

Fig. 1. Map of India showing sample locations in western India.
izes the duricrust (hard crust) laterites at the top of laterite profiles; (2) spongy texture that is typical of the relatively soft laterite underlying the duricrust; and (3) pisolith texture that is found in the lower portion of the laterite horizons in laterite profiles. Vesicular and spongy textures are common and equally well developed in both the high-level and the low-level deposits under study. However, pisolithic texture is found only in the low-level deposit at Ratnagiri and in the high-level deposit at Panhala Fort.

Vesicular laterites from the high level deposits at Nangrataswadi and Panhala Fort (samples 01-05), and those from the low-level deposits at Ratnagiri and Srivardhan (samples 021-022) are brick-red to brownish in color. A typical vesicular laterite obtained from the low-level deposit at Srivardhan is displayed in Figure 2. The laterite is highly porous and composed of fine-grained material that predominantly consists of hematite and goethite. The vesicles vary in shape from irregular to subrounded and range in size from less than 1 mm to 3 cm. The vesicles may or may not be interconnected. They are locally filled by whitish- or orange-colored fine granular material that is composed of gibbsite, hematite and goethite.

The highly porous nature of vesicular laterite in hand-specimen is well reflected at the submicroscopic scale too, as indicated in Figure 3. The micropores are subangular, subrounded or linear, and range in size from 1 to 50 µm. The laterite matrix is composed of dense microgranular aggregates of hematite, goethite and minor amounts of gibbsite, kaolinite and anatase. These minerals form a three-dimensional framework (Figure 4). Hematite, gibbsite, kaolinite and anatase occur as submicron-sized irregular platelets, while acicular goethite crystallites that are up to 2 µm in size are dispersed in the microgranular aggregates (Figure 4). Whitish colored material filling the vesicles consists of lamellar aggregates of gibbsite (Figure 5). The micropores between these aggregates are partially filled by platelets of goethite and spherules of an iron mineral, possibly hematite (Figure 5). A close view of a micropore (Figure 6) reveals that the goethite platelets are about 0.3 µm or less in size, whereas the hematite (?) spherules are about 4 µm in diameter.

Spongy laterites from the high-level deposit at Nangrataswadi (samples 06-08) and those from the Ratnagiri low-level deposit (sample 023) are pinkish-red to purplish-red in color. The pores

Fig. 2. Polished surface of a vesicular laterite (sample 022 from the low-level deposit at Srivardhan).

Fig. 3. A close view of the surface of vesicular laterite (Fig. 2, encircled area) displaying vesicles and micropores that range in size from 1 to 50 µm.

Fig. 4. The laterite matrix (magnified from encircled area in Fig. 3) consisting of submicron-sized crystallites of hematite, kaolinite and gibbsite. Acicular goethite crystals are found dispersed in the matrix.
in these laterites resemble those in the vesicular laterites in shape. However, the vesicles are mostly filled by yellow, dark brown or pinkish fine granular material, thereby leaving a rock with a network of extremely minute open pores. This gives a spongy appearance to the vesicle-fillings in laterite. Solution channels are often present, and are cemented by yellowish-brown fine granular material. A typical specimen of spongy laterite from the high level deposit at Nangrataswadi is illustrated in Figure 7. A close view of the surface of spongy laterite is presented in Figure 8. Micropores and microchannels in spongy laterite are commonly lined by goethite platelets that are often arranged as rosettes (Figure 9). The individual goethite particles range in size from 0.1 to 1 µm. Rarely, well developed hexagonal crystals of gibbsite are found in the vugs in spongy laterites. Figure 10 displays such gibbsite crystals that range in size from 1 µm to 10 µm. The laterite matrix is similar in microtexture and mineral composition to that described earlier for vesicular laterites. Locally, the laterite matrix is composed of closely packed, randomly oriented stacks of tabular crystals of gibbsite and hematite that vary in size from about 2 to 20 µm (Figure 11). This microtexture resembles the crystalline-webby microtexture reported by Bardossy et al. (1978).

Pisolitic laterites from the high-level deposit at Panhala Fort, and those from the low-level deposit at Ratnagiri (samples D9 & D24 respectively) are composed of spheroidal to elliptical pisolites that are embedded in a matrix of fine-grained material. Figure 12 exhibits a typical pisolitic laterite from the Panhala Fort high-level deposit. The pisolites are light brown, purple, dark brown, pinkish-red or buff-white in color, and vary in diameter from 1 mm to 1 cm. The pisolites are internally composed of alternating light and dark colored layers. The individual layers are about 1 mm or less in thickness. The fine granular material in the matrix around pisolites is usually dark red or brown in color, and is mainly composed of hematite and goethite. Subangular or subrounded, and internally structureless concretions are often associated with pisolites. The microtextures of pisolitic laterites are identical to those of pisolitic bauxites which are described in the next section.

Bauxites

Bauxites occur as pockets and lenses within the laterite horizon and exhibit pisolitic, massive and nodular textures. Pisolitic bauxites intermingle with pisolitic laterites. They grade downward into massive bauxites. Nodular bauxites usually are found within the massive bauxites or occur below them. All three textural varieties of bauxite are well developed at the Nangrataswadi high-level deposit and the low-level deposit at Srivardhan. However, nodular bauxites are absent in the high-level deposit at Panhala Fort and in the Ratnagiri low-level deposit. Also, pisolitic bauxites are not developed at the Ratnagiri low-level deposit.

Pisolitic bauxites in the high-level deposits at Nangrataswadi and Panhala Fort (samples D10-D13), and those at the Srivardhan low-level deposit consist of cream-white, gray or pale-pink pisolites embedded in a light-gray or yellowish fine-granular matrix. The other megascopic textural features of pisolitic bauxites are similar to those of pisolitic laterites. SEM examination of broken pisolites reveals that the bauxitic, as well as lateritic pisolites exhibit framework microtexture formed by three dimensional packing of aggregates of submicron sized, sub-rounded to irregular shaped platelets of gibbsite, anatase, kaolinite and hematite. Figure 13 shows the framework microtexture of a bauxitic pisolite from the low-level deposit at Srivardhan. Gibbsite predominates in the whitish pisolites, while the reddish pisolites are mainly composed of hematite. The matrix surrounding the pisolites is commonly similar to the pisolites in mineral composition and microtexture. But the average crystallite size in the matrix is always greater than in the pisolites. Figure 14 displays the framework microtexture of a pisolite from the Srivardhan low-level deposits (samples 029-031) where the crystallites range in size from about 0.6 µm to over 2 µm. Locally, there are patches in the matrix that contain large, stubby crystals of gibbsite up to 25 µm in size, as shown in Figure 15. Large, platy crystals of gibbsite are found to form crusts at the contact between the two pisolites (Figure 16). Such crusts of gibbsite only occur at the contact of some of the pisolites, and do not form continuous rims on the pisolites.

Massive bauxites from the high-level deposits at Nangrataswadi (samples D14-D18) and Panhala Fort (sample D19), and those from Ratnagiri and Srivardhan low-level deposits (samples D29-D31) and D32-D34 respectively) are composed of dense aggregates of creamy, light-gray or yellowish-white fine granular material. Irregular patches and veins of ferruginous fine granular material are locally present. Figure 17 displays a typical sample of massive bauxite from the Srivardhan low-level deposit. SEM examination of massive bauxites reveals that they most commonly exhibit framework microtexture, and are composed of irregular platelets of gibbsite, anatase, and kaolinite that range in size from less than 1 µm to about 5 µm. Relatively larger, slab-like aggregates of gibbsite are often present as patches in the bauxite matrix (Figure 18). Such slabs attain a size of over 100 µm at places. Massive bauxites locally exhibit crystalline-webby microtexture (Figure 19). Here, the gibbsite platelets range in size from 5 to 50 µm. Hematite, which is a minor component of massive bauxites, usually forms frambooidal aggregates that cement the micropores as shown in Figure 19. Former vugs filled by massive aggregates of gibbsite platelets are common in the massive bauxites (Figure 20). Euhedral crystals of gibbsite that range in size from 5 µm to about 100 µm are often found in the voids in massive bauxites. Figure 21 displays such euhedral gibbsite crystals that are much larger than the crystals of gibbsite in the bauxite matrix. Gibbsite laths similar in morphology to plagio-clases in the unweathered Deccan Trap basalts are frequently found in the massive bauxites, as shown in Figure 22.
Microtextures of Laterites and Bauxites

Fig. 5. Pore-filling in a high-level vesicular laterite at Panhala Fort (sample DS) consisting of a framework of lamellar aggregates of gibbsite platelets with micropores (P) filled by spherules of an iron mineral.

Fig. 6. An enlarged view of the spherules of an iron mineral (amorphous iron oxide or hematite?) and platelets of goethite from a micropore (P) in Figure 5.

Fig. 7. Polished surface of a high-level spongy laterite at Nangrataswadi (sample D7).

Fig. 8. A close view of the surface of spongy laterite (encircled area in Fig. 7). The micro-channel in laterite is cemented by spherules of an iron mineral and goethite platelets.

Fig. 9. A further magnified view of goethite platelets (arrow in Fig. 8) that are arranged in the form of rosettes.
Fig. 10. Typical euhedral crystals of gibbsite occurring as cement in a vug in the high-level spongy laterite at Nangrataswadi (sample D6).

Fig. 11. Web-like packing of tabular gibbsite (G) and hematite (H) aggregates in a spongy laterite from the low-level Ratnagiri deposit (sample D23).

Fig. 12. Polished surface of a high-level pisolithic laterite (sample D9) from the Panhala Fort deposit. Besides pisolithes, laterite also contains some nodules, concretions and fragments.

Fig. 13. Internal texture of a pisolite in a low-level bauxite (sample D25) that consists of an intimate mixture of gibbsite, anatase and kaolinite.

Fig. 14. A close view of the matrix around the pisolite (in Figure 13) displaying a coarser crystal-size than the pisolite.
Fig. 15. Patches of coarse, columnar recrystallized gibbsite in the matrix of pisolitic bauxite at Panhala Fort (sample D13, high-level deposit).

Fig. 16. Bladed crystals of gibbsite that have formed crusts at the contact between two pisolites (P1 and P2) in a laterite at Ratnagiri low-level deposit.

Fig. 17. Polished surface of a massive bauxite from the low-level deposit at Srivardhan (sample D32).

Fig. 18. A close view of massive bauxite (encircled area, Fig. 17) showing a large slab-like aggregate of gibbsite platelets embedded in a mosaic of submicron-sized crystals of gibbsite, anatase, hematite and kaolinite.

Fig. 19. A web-like arrangement of interlocked lamellar aggregates of gibbsite (G) in a low-level bauxite at Ratnagiri. The micropores are cemented with frambooidal aggregates of an iron mineral (hematite ?, H).
Nodular bauxites from the high level deposit of Nangrataswadi (sample D20) and those from the Srivardhan low-level deposit (sample D35) are composed of internally structureless, irregular shaped concretions (nodules) embedded in a matrix of fine granular material. Nodular bauxites are very similar to the pisolithic bauxites in their other megascopic properties, and exhibit identical microtextures. However, the individual nodules are frequently found to be composed of microgranular aggregates of subhedral crystals of gibbsite that vary in size from about 0.1 µm to 0.5 µm (Figure 23).

Conclusions

Laterites and bauxites representing four high-level and low-level deposits in western India exhibit similar textures and morphologies at all scales from megascopic down to submicroscopic. Presence or absence of a particular texture does not depend on whether the laterites or bauxites are high-level or low-level deposits. Also, a texture that is well developed in one high-level (or low-level) deposit may be missing at another high-level (or low-level) deposit.

Most of the laterites and bauxites that are characterized by different megascopic textures...
Microtextures of Laterites and Bauxites

Microtextures exhibit framework microtexture. The latter is produced by the three dimensional packing of crystallites. It is postulated that the framework microtexture is the fundamental texture of the laterites and bauxites that formed residually from the Deccan Trap basalts.

Acknowledgements

Sincere thanks are due to Dr. A. G. Dessai, Lecturer in Geology, University of Poona, India, and Dr. Y. S. Sahasrabuddhe, Ex-Director, Western Region, Geological Survey of India, for their guidance in the collection of samples, and many useful discussions during the initial stage of preparation of this paper. Thanks are also due to the authorities of the Indian Aluminum Company, Nangratabad for permission to collect samples from their bauxite mine. We would like to specially thank Drs. W. D. Keller, University of Missouri, Columbia, J. B. Comer, University of Tulsa, Oklahoma, and R. E. Hughes, Illinois Geological Survey, for their valuable reviews.

References


Discussion with Reviewers

J. B. Comer: What is the origin of the vesicles? Are they inherited from the parent basalts or produced by selective leaching?
Authors: Some of the vesicles found in the laterites may be inherited from the parent basalt. However, the other vesicles formed by selective leaching of the basalts during laterization.

J. B. Comer: Is there a genetic link between the progressive filling of vesicles and the formation of pisoliths and nodules?
Authors: We did not observe any features suggesting such a relationship.

J. B. Comer: Can the authors make any deductions about the processes of weathering and alteration of the parent basalt based on the mineralogy and texture of (a) the matrix and (b) the material in vesicles, vugs or channels?
Authors: The framework microtexture and the minerals present in the laterite matrix formed by residual weathering of basalts. The minerals precipitated in the vesicles, vugs and channels are, however, related to the remobilization of Al and Fe from the already formed laterite.

W. D. Keller: Are the findings of this paper in contradiction with Bardossy et al. (1978) as regards the textural differences between the high-level and low-level lateritic bauxites?
Authors: Our results in this study do not agree with the conclusions that Bardossy et al. (1978) reached after examining samples from a larger number of bauxite deposits. Considering Bardossy's experience and observations with the world-wide occurrences of bauxites, we can only say that our observations may be an exception to the general trend proposed by Bardossy et al. (1978).