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Petrogenesis of Bedded Chert of the Triassic Adoyama Formation

By

Yasuji Saito

Department of Geology, National Science Museum, Tokyo

The origin of bedded chert has long been a controversial problem since the studies by Davis (1918) and Bramlette (1946). Debate has centered on the mode of deposition and the source of silica, namely whether significant volume of bedded chert is resulted from accumulation of siliceous organic remains or from inorganic precipitation of silica from sea water and/or devitrification of volcanic glasses (see Grunau, 1965; Wise and Weaver, 1974). The probable mode of origin of bedded chert has been inferred from the studies of thin and polished sections of altered or weakly metamorphosed rocks in land-based sedimentary sequences. The observation under scanning electron microscope, however, distinctly demonstrated that the bedded chert consists mainly of such siliceous skeletons as radiolarians and sponge spicules (Imoto and Saito, 1973) and that the sedimentary textures observed in the bedded chert are similar to those of normal clastic rocks (Imoto *et al.*, 1973; Nisbet and Price, 1974; Imoto and Fukutomi, 1975; Saito and Sekine, 1976, 1977). On the other hand, studies of a great variety of heterogenous cherts in sediments of present-day ocean basins made possible to infer their source of silica and their early history of diagenesis, both which are obscured in treating the bedded chert. According to Wise and Weaver (1974) and von Rad and Rösch (1974), it is confirmed that siliceous organic remains are of most important direct source for silica consisting oceanic chert and that formation of the chert can best be explained by transformation of the biogenous opaline silica through various stages of porcelanite and finally to true chert.

In this paper the bedded chert of the Triassic Adoyama Formation of the Ashio Mountains, a representative of bedded cherts, are described on the basis of scanning electron microscope study, and its formation process is discussed.

Adoyama Formation: The Adoyama Formation distributed in the Kuzuu district of the Ashio Mountains forms as a whole a large and gentle synclinal structure with approximately NE-SW running and southwesterly pitching axis. This formation is composed, in ascending order, of basal limestone breccia (1–7 m), greenish grey shale (2–5 m) and grey to dark grey bedded chert (70 m+) which is sometimes intercalated with thin layers of black shale and rarely contained limestone blocks of probably oristoliths. The bedded chert is never associated with volcanic material, suggesting that the chert was not derived from a volcanogenous source. The bedded chert is succeeded upwards by coarse- to medium-grained sandstone. The bedded chert and the matrix of the basal limestone breccia have yielded abundant gnathoid and gondolellid conodonts of Ladinian to early Carnian (CONODONT RESEARCH GROUP, 1974). In the district, the Adoyama Formation lies unconformably upon the middle Permian Nabeyama Formation consisting mainly of limestone and dolomite, one of the Permian type sections of Japan.

Samples examined and method: Specimens of the bedded chert of the Adoyama Formation were collected in Karasawa and Hanezuru of the Kuzuu district. The chert layers of 1–5 cm thick separated by shaly films have dense and vitreous appearance, and are grey to dark grey in color. Macroscopically fine laminations are commonly observed in the chert. The operid and actinommid radiolarian remains are visible as minute transparent spherules. In thin sections the chert consists mostly of cryptocrystalline to microcrystalline quartz and contains a small amount of clayey material such as illite and chlorite. Whereas radiolarian remains composed of microcrystalline quartz are distinguished from the surrounding 'matrix' of cryptocrystalline quartz, sponge spicules are hardly done from the 'matrix'. All specimens of the bedded chert, *i.e.* chips smaller than 1 cm in diameter, were etched by 10 to 20% hydrofluoric acid solution, then washed with running water, and cleaned up by ultrasonic vibration in order to remove dusty materials from HF-treated surface. The chips coated with gold in a vacume evaporator were examined under the scanning electron microscope.

Scanning electron microscopy: Although the bedded chert of the Adoyama Formation was transformed into true quartz chert probably because of recrystallization, original texture of constituting material has well been retained. On the etched surface of the chips of chert, abundant radiolarian skeletons are exposed, their interstices being filled up with sponge spicules (Plate 1). In a voluminous proportion, majority of the bedded chert consists of fine sponge spicules. No detrital grains of sand- to silt-size nor volcanic glass shards are recovered.

Scanning electron micrographs of the 'matrix' composed of interstices between radiolarian spherules are shown in Plate 2. The 'matrix' consists principally of abundant sponge spicules and interspaces between them are filled with very fine-grained materials (Pl. 2, figs. 1 and 2). The spicules were altered into aggregates of xenomorphic microcrystalline quartz (fig. 3). Merely based upon these micrographs, it is difficult to judge whether the origin of the siliceous material filling the interspaces is biogenous or inorganic. Nevertheless, the presence of clay minerals and broken fragments of spicules in the filling material suggests no direct precipitation from sea water but accumulation of siliceous organic remains. Absence of volcanic glass shards and of their alteration products denies the possibility of volcanogenous origin of the filling material. If a 'chert' is composed of the glass shards, it must be regarded as a glassy tuff instead of the 'chert'. Seemingly scanty siliceous microfossils in thin sections of bedded chert under optical microscope don't always indicate inorganic chemical precipitation of silica or devitrification of volcanic glasses, because fine sponge spicules, in particular their fragments, are hardly discerned.

Comparison of bedded chert with recent sponge spicules: The probable primary texture of the bedded chert of the Adoyama Formation was compared with aggregates of recent siliceous sponge spicules in order to consider a petrogenesis of the bedded chert (Plate 3).

A mass of recent siliceous sponge was steeped in conc HNO_3 solution for the purpose to remove the organic matter contained. As a result, the sponge mass was separated into whitish lower deposit of siliceous spicules and light brown upper one of decomposed organic matter with a minor amount of clay. The former was examined under the scanning electron microscope (Pl. 3, fig. 1) and by X-ray diffraction analysis. The sponge spicule mass in situ is different from compact bedded chert as being highly porous so that the deposit was compressed for a direct comparison with the bedded chert (fig. 2). Most of sponge spicules were broken (figs. 3, 4 and 5) and the compressed texture resulted in became similar to that of the bedded chert (for example in figs. 2 *vs.* 6 in Pl. 3; 3 *vs.* 7; 4 *vs.* 8). In a further compressed specimen, it is difficult to distinguish broken fragments of the spicules from volcanic glass shards because the original shape of the spicules is retained no more (fig. 5). X-ray powder diffraction analysis of the recent siliceous spicules shows that they are low crystallized rather than true amorphous silica.

Lithification features: Contact between constituent grains such as spicules or radiolarians were observed on the polished and slightly etched surfaces of the bedded chert in order to infer lithification of organic origin siliceous sediments. While siliceous microfossil grains are in direct contact with each other in a case, interstitial filling are intercalated in the other case (Plate 4). Microfossil grains showing direct contact are composed exclusively of coarser-grained quartz crystals devoid of small quartz grains as shown in figure 1 of Plate 4. This suggests that no quartz grains newly formed along such contacts, where dissolution of silica may have occurred and rugged surfaces of microfossils are now retained. Similar contacts between fine-sized spicules and radiolarian shells are illustrated in figures 3 and 4. On the other hand, figure 2 shows a part of radiolarian shell consisting of coarser-grained quartz and its interior part and surrounding interspaces precipitated by granular microcrystalline quartz. Secondarily precipitated microcrystalline quartz is considered to have been derived from the silica dissolved once along the surfaces of the spicules. From these features, the following interpretation can be derived. The increase of confining pressure due to the progressive accumulation of overlying materials liberates potassium from clayey minerals so that pH increases to make silica soluble. Dissolved silica from microfossils may be transported following with a chemical gradient and finally precipitated at such portions with lower pH as pore spaces between siliceous microfossil grains. This process is similar to that of pressure solution of quartzose sandstone. Many petrographic studies on the pressure solution of quartz grains (HEALD, 1950, 1956; THOMPSON, 1959; PETTIJOHN, *et al.*, 1972, etc.) reveal the presence of the presolved zone where occur the partial dissolution and interpenetration between adjacent grains under increased pressure and of the unpresolved zone filled up with secondarily precipitated silica. In the instance of the Adoyama bedded chert, the direct contacts between microfossil grains, probably accompanying with partial dissolution of silica, may correspond to the presolved zone and the microcrystalline quartz in surrounding interstices, representing secondary precipitation of the dissolved silica, to the unpresolved zone of sandstone.

Source of silica: Scanning electron microscopic observation of the Adoyama bedded chert leads to the enumeration of the following possible sources of silica: 1) sponge spicules, 2) radiolarian remains, 3) silica secondarily derived from them, and 4) silica liberated by decomposition of clayey substances.

1) Siliceous sponge spicules have played an essential role for the bedded chert formation. They are observed to be abundant in HF-treated surface of bedded cherts. In general the spicules are scarcely observed in thin and polished sections. The absence of siliceous precipitates of inorganic origin in ordinary sea water is interpreted due to the pronounced silica undersaturation, implying that the siliceous precipitates here considered is of organic origin (CORRENS, 1950; DEGENS and EPSTEIN, 1962; KRAUSKOPF, 1956, 1959; SIEVER, 1957).

2) Radiolarian remains were formerly regarded as one of most important constituents of bedded chert but, so far as the Adoyama chert is concerned, they are of subordinate importance.

3) Silica secondarily derived from spicules and radiolarians owes the dissolution to pressure solution effect under thicker burial depth and the precipitation of dissolved silica fills interspaces of siliceous microfossil grains.

4) During the process of diagenetic alteration, montmorillonite is disintegrated into illite and/or chlorite accompanied by the liberation of free silica (SIEVER, 1962). The experimental results on differential flocculation and areal distribution of clay minerals reveal that montmorillonite can be suspended in sea water for longer duration compared with other clay minerals, and tends to settle down in calmer environment rather than in near shore where illite and kaolinite sink rapidly by flocculation (SHIOZAWA, 1969, 1970). Because of fine-grained size, sponge spicules may have been deposited in a calmer condition together with montmorillonite. The clay minerals in the Adoyama chert are illite and chlorite without any remains of montomorillonite from which a minor amount of silica was liberated by disintegration and precipitated in interspace of siliceous microfossil grains during diagenesis.

These evidences explanates that the bedded cherts in question were siliceous sediments derived from post biolysis sponge colonies settled on sea floor, where many radiolarian skeletons, conodonts, and minor clay minerals were associated, concentrated in a sponge bank environment and that interspaces of the sediments were subsequently filled up with secondarily derived silica through such process as explained in 3) and 4) items.

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Explanation of Plates

Plate 1

Scanning electron micrograph (SEM) of the bedded chert of the Triassic Adoyama Formation. The HF-treated surface illustrated here consists mainly of sponge spicules, radiolarians and their fragments, came from Hanezuru, Kuzuu district, Ashio Mountains.

Plate 2

SEM of fine-grained part without radiolarians.

Figs. 1 and 2. Abundant sponge spicules and interspaces filled with very fine-grained suliceous material.

Fig. 3. Spicules altered into aggregates of xenomorphic microcrystalline quartz and enclosing matrix.

Plate 3

SEM of primary textures of the bedded chert and recent siliceous sponge spicule aggregates for comparison. Length of bars; 1, 2 and 6: 0.1 mm; 3 and 7: 0.05 mm; 4, 5 and 8: 0.01 mm.

Fig. 1. Recent siliceous sponge spicules.

Figs. 2, 3 and 4. Spicules broken by compression.

Fig. 5. Fragments of spicules broken by compression, indistinguishable from volcanic glass shards and detrital grains.

Figs. 6, 7 and 8. Bedded chert etched by a solution of hydrofluoric acid; its majority consisting mainly of siliceous sponge spicules.

Plate 4

SEM showing grain to grain contacts in the bedded chert. Length of bars: 0.005 mm.

Fig. 1. Sutured contact between relatively large spicules.

Fig. 2. A part of radiolarian shell and interstices filled with a secondary siliceous cement.

Figs. 3 and 4. Contact between fine-sized spicules and radiolarian shells.


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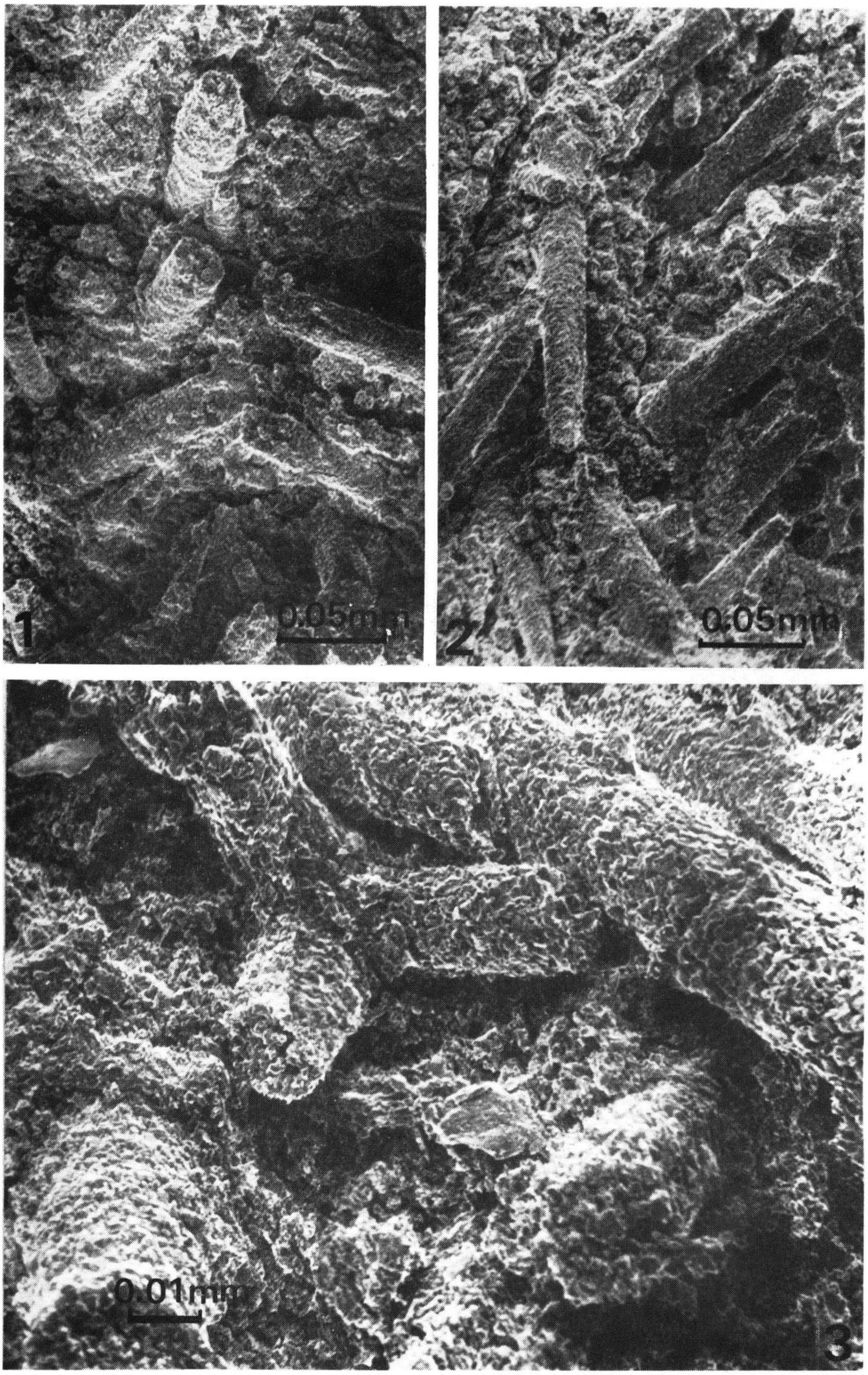
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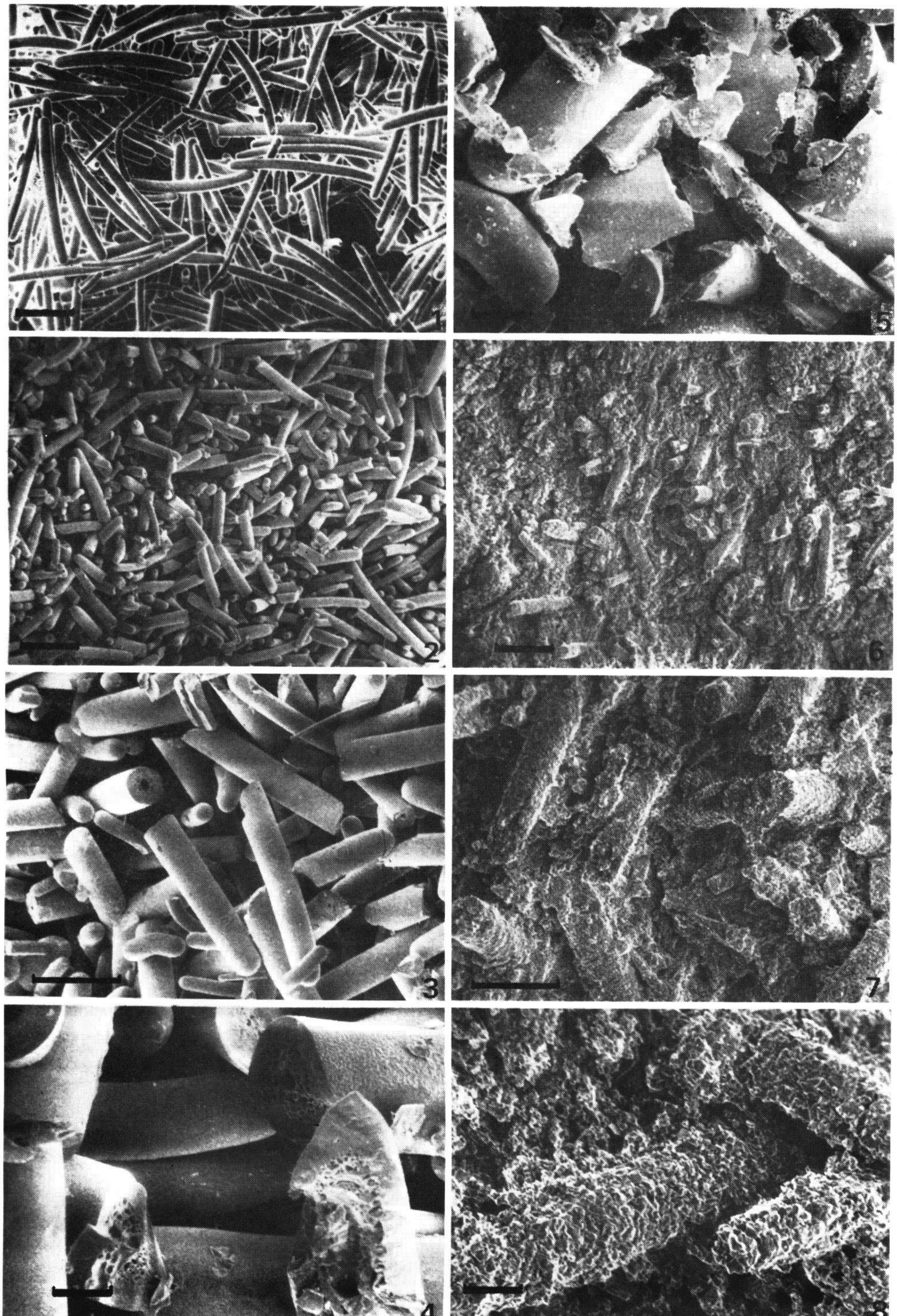
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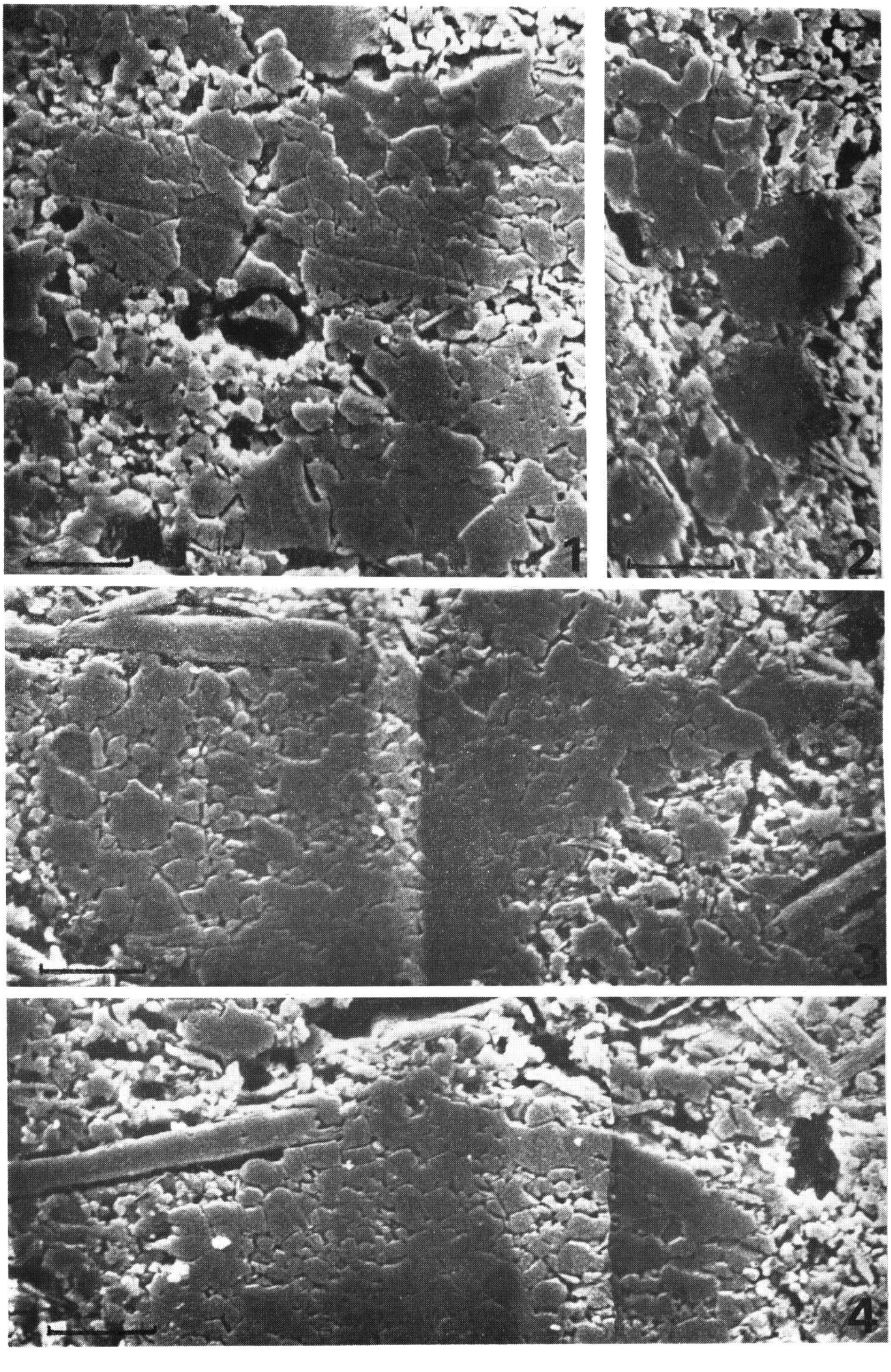
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