Biogenic Opals of Humic Yellow Latosol and Yellow Latosol in the Amazon Region

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Summary

Various biogenic opals (plant and animal) separated out from Humic Yellow Latosol and Yellow Latosol in the Amazon region were examined to elucidate the differences in the pedological environment and pedogenic process of these two soils. The biogenic opal grains ranging in size from 10 to 200 μm were separated from the soils, and about 1,000 grains having various morphological feature were examined under an optical microscope and a scanning electron microscope (SEM).

The plant opals were divided on the basis of their morpological features into palm, tree and gramineous plant types. Each group was further subdivided according to their shape, plant subfamily, or degree of alteration as shown in Table 1. Each type of biogenic opal was expressed as % of grains present.

The results are summarized as follows:

(1) The amount of biogenic opals of 10 to 200 μm fraction in surface horizons ranged from 0.54 to 0.91%, and the difference between the two soils was not so large. (2) The majority of biogenic opals examined were of palm family origin, which amounted to 30.6 to 70.0% of total biogenic opals, followed in frequency by those from gramineous and tree plant. (3) The % of opals of gramineous family origin was widely different between the two soils; there were three to four times more opals in Humic Yellow Latosol than in Yellow Latosol. (4) The content of opals of tree origins (both deciduous and coniferous) was almost the same between the two soils but there was a difference in the ratio of deciduous to coniferous trees. (5) Altered opal grains in Humic Yellow Latosol of palm origin showed a peculair welded shape under an optical microscope, whereas altered grain in Yellow Latosol and the B horizon of Humic Yellow Latosol had a pitted surface with many small hollows. (6) Some monoaxon type sponge spicules were found only in Humic Yellow Latosol, indicating a temporary wet soil condition.

From the above results, it was concluded that Humic Yellow Latosol developed primarily from tall grasses and temporary wet soil conditions.

Patches of Humic Yellow Latosol called locally "Terra Preta do Indio" are found throughout the upland (terra firm) in the eastern Amazon region, which are highly fertile with black to dark gray colored humic surface horizons. The humic top soil contain some pieces of earthenware from pre-Columbian Indian tribes[1,2]. Regarding the genesis of this soil, two hypotheses have so far been proposed, as introduced by SOMBROEK[2]: (a) Indian tribes chose these settlements because of originally higher natural fertility, (b) the higher fertility at present is the result of prolonged Indian occupation, and previously, the soil was not as fertile as the surrounding soil. However, it would be difficult to expect an abundant accumulation of organic matter under the primitive hunting life during the pre-Columbian age and under the humic tropical climate in which organic matter decomposed rapidly. Therefore, it seems that the presence of Humic Yellow Latosol cannot be explained merely by the hypotheses mentioned above. We believe that the type and species composition of vegetation in the past was different from the present. This study was an attempt to elucidate the major plant species that have contributed to the accumulation of organic matter by examining the kind, composition and vertical distribution of various types of plant opals, and opal sponge spicules in each horizon of Humic Yellow Latosol and Yellow Latosol.

Soil samples studied

The site characteristics and profile description of two soils are as follows;

(A) Humic Yellow Latosol (terra preta do Indio)

1) Site characteristics

a. Location: Belterra, Santarem, Estado do Para, Brasil

b. Parent material: Weathering products of tertiary sediments ("Belterra clay" in Amazon)

c. Topography: Flat (on "terra firm" or upland)

d. Vegetation: Tropical rain forest; rubber trees (a wild wood), "palha" (popular name for a species of palm), "castanha do para" (para chestnut tree), etc.

e. Drainage: Good

2) Profile description

A_1 0–35 cm black (10 YR 2.5/1, wet), silty clay, loose, fine and medium subangular blocky and granular structure, many fine and medium pores, friable, slightly plastic and sticky, gradual smooth boundary.

A_3 35–70 cm dark grayish brown (10 YR 4/2, wet), silty clay loam, loose, fine and medium subangular blocky structure, many medium pores, friable, plastic and sticky, diffuse smooth boundary.

B 70–165cm brownish yellow (10 YR 6/8, wet), clay loam, loose, fine granular and subangular blocky structure, many fine and medium pores, friable.

Note: Many fine and medium roots were found in A_1 and A_3 horizons.

Observations: Some earthenwares of pre-Columbian Indio tribes are commonly found in surface horizon A_1 of Humic Yellow Latosol

(B) Yellow Latosol

1) Site characteristics

a. Location: 47.0 km east from the city of Santarem, Cuiaba-Santarem highway (on the right side of BR-165), Santarem, Estado do Para, Brasil.

b. Parent material: Weathering products of tertiary sediments ("Belterra clay" in Amazon)

c. Topography: Flat (terra firm or upland)

d. Vegetation: Tropical rain forest

e. Drainage: Good

2) Profile description

A_1 0–10 cm yellow brown (10 YR 5/4, wet), clay, loose, fine and medium granular structure, many fine pores, friable, plastic and sticky, smooth and diffuse boundary.

A_3 10–35 cm yellowish brown (10 YR 4/4, wet), clay, loose, fine and medium granular structure, many fine pores, friable, plastic and sticky, smooth and diffuse boundary.

B_1 35–75 cm yellowish brown (10 YR 6/6, wet), heavy clay, loose, fine granular structure (massive "in-situ"), many fine pores, friable, plastic and very sticky, smooth and diffuse boundary.

B_{21} 75–120 cm yellowish brown (10 YR 6/8, wet), heavy clay, loose, fine and medium pores, friable, plastic and very sticky, smooth and diffuse boundary.

B_{22} 120–165 cm yellowish brown (10 YR 6/8, wet), heavy clay, loose, fine and medium granular and subangular blocky structure, many fine and medium pores, friable, plastic and very sticky.

Note: Many fine and medium roots are found in A_1 and A_3 horizones, and some fine roots in B_1 through B_{22} horizons.

Observation: Activity of organisms (earth worms) are very high in A_1 and A_3 horizons, and common in B through B_{22} horizons.

Analytical methods

The soil samples were pretreated with 30% hydrogen peroxide to decompose organic matter and with hot acid (1 : 1 HCl) to remove free sesquioxides.

The 10 to 200 μm fractions including biogenic opals were separated from each horizon of the two soils by the SASE and KONDO's method[3], and the biogenic opal grains were separated out with Toulet's solution (s. g.=2. 30).

The opals from gramineous plants were identified by a partially modified method of TWISS *et al.*[4], and those of tree plant origins were identified by the morphological features described by KONDO[5,6] and KONDO and SUMIDA[7,8].

Approximately one thousand separate grains of biogenic opals were observed for each horizon under an optical microscope, and the contents of different types of biogenic opals expressed by grain %.

Biogenic opal specimens were also prepared by mounting them on a metal specimen holder with double stick tape and the specimen was coated with fine film of gold using an EIKO ION Spattering Unit, Model IB 3 to make it surface conducting. The specimens prepared were observed on the JELO 35 scanning electron microscope (SEM) at 15 and 25 Kv.

Results and Discussions

As shown in Table 1, plant opals separated were divided into three broad groups on the basis of the difference in plant origins, i. e. the opals from

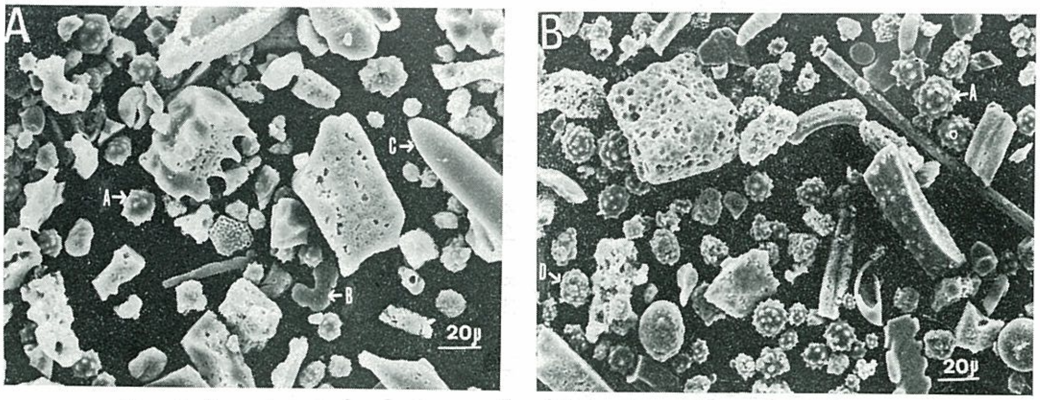

Fig. 1 Scanning electron micrographs of biogenic opals separated from the A_1 horizon of Humic Yellow Latosol (A) and Yellow Latosol (B).

A: normal opal from palm family plants, B: altered opal (welded opal) from palm family plants, C: opal sponge spicule, D: altered opal (ordinary weathered group) from palm family plants

Table 1. Biogenic opals of Humic Yellow Latosol and Yellow Latosol in Amazon Region (%)*1

Horizon	the amount of biogenic opal (oven dry matter) (%)	Opal from Palm origin*2		Sum	Opal from tree origin		Sum	Opal from gramineous origin						Sum	Ratio Palm & tree origin / Gramineous origin	Others
		A	B		Deciduous tree	Coniferous tree		Panicoid	Festucoid	Arundoid*3	Elongate	Fan shaped	Point shaped			
Humic Yellow Latosol, Anthrogenic (Terra Preta do Indio)																
A_1	0.91	34.8	21.3	56.1	5.0	0.8	5.8	2.4	1.0	2.0	5.4	3.8	1.6	16.2	3.8	12.6
A_3	0.54	32.7	22.5	55.2	4.7	tr.	4.7	0.5	0.5	1.7	5.8	10.4	0.8	19.7	2.6	22.9
B	0.14	14.8	15.8	30.6	5.4	-	5.4	0.5	0.5	0.6	7.5	17.4	1.1	27.6	1.3	36.0
Yellow Latosol																
A_1	0.75	49.1	20.9	70.0	4.5	0.4	4.9	tr.	0.8	0.7	1.9	1.1	0.4	4.9	15.3	20.1
B_1	0.17	6.5	48.9	55.4	2.4	tr.	2.4	tr.	tr.	tr.	5.1	8.5	tr.	13.6	4.2	25.4

Remark: *1 grain percent in size from 10–200 μm
*2 A: Ordinary opal (or nosmal opal), B: Altered opal (or abnormal opal)
*3 A tentative name of silica body similar to that in *Molinia japonica*, *phragmites communis* etc. belonging to Arundoideae

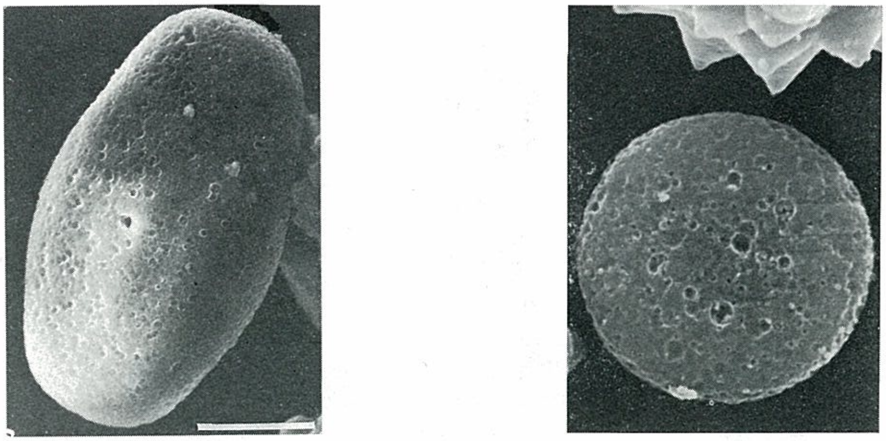

Fig. 2 Scanning electron micrographs of disc-like opals separated from the surface horizon of Yellow latosol. Scale bars: 5 μm

(a) palm family, (b) tree groups, and (c) gramineous plants. Further, opals from the palm family were subdivided into (A) the ordinary or normal and (B) altered or abnormal, including ordinary weathered group (Fig. 1). Opals of tree origin were subdivided into coniferous (needle-leaved) and deciduous (broad-leaved) tree origins.

Opals of gramineous plant origin were subdivided into six groups according to the morphological classification of SASE and KONDO[3]; i. e., Panicoid, Festucoid, Elongate, Fan-shaped and Point-shaped opals with the exception of Arundoid. Opal sponge spicules (animal opal) was found only in the surface horizon of Humic Yellow Latosol (less than 0.7%). Unidentified opals were found in both soils, and also disc-like opals were occassionally found in the surface horizon of the two soils (less than 2.2%). As shown in Fig. 2, these opals were morphologically similar to "opalin silica" described by SHOJI and MASUI[9] or "sterraster type" sponge spicules described by UTUGAWA *et al.*[10]

The biogenic opals from both soils had various shapes such as spheres (Fig. 3, Nos. 1–4), bladed form (Fig. 3, Nos. 10, 17 and 18), "Jigsaw Puzzle" (Fig. 3, Nos. 19 and 21), etc. The opals from coniferous trees were mostly cubic to polyhedral shapes (Fig. 4, Nos. 23 and 24), which were of the same pine family origin as reported previously by KONDO and SUMIDA[7]. Their amount was very small as shown in Table 1. Most opals derived from gramineous plants had the shape of a rectangle or fan (Fig. 4, Nos. 25–27) and serrated rods (Fig. 4, No. 28). Freshwater sponge spicules resembling "monoaxon type" described by HOZAWA and YADA[11] were found only in Humic Yellow Latosol, and they were also detected in other places in Humic Yellow Latosol areas, whereas they were absent in Yellow Latosol.

Most biogenic opals were of palm family origin. They were derived from the epidermal cell[5,6,7] and have a peculiar "spicky star" shape (unaltered or normal) (Fig. 3, Nos. 5 and 6). In Humic Yellow Latosol, some of the spicky star type opals have suffered a peculiar alteration, i. e., they have lost their characteristic projecting parts (abnormal) and some of the unit grains are welded together forming a cluster (Fig. 3, No. 9). The welded grains were considered to reflect the fact that the palm leaves had been burned by some cause. By contrast, this altered type was not found in Yellow Latosol. In addition, biogenic opal in Yellow Latosol and the B horizon of Humic Yellow Latosol had a "pitted surface" with many small hollows (Fig. 1), and we consider that their grain surfaces have been corroded as a result of the weathering process. The amount of the corroded opals was especially high

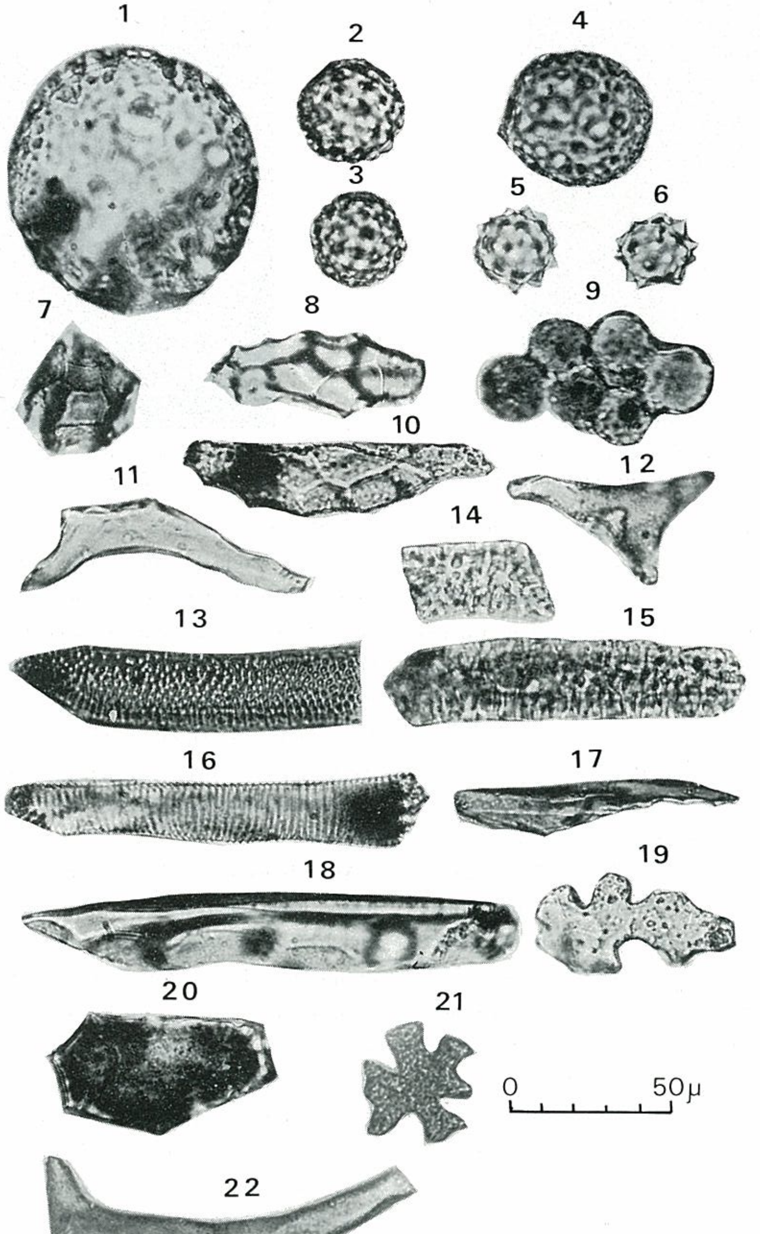

Fig. 3 Micrographs (Plane polarized transmitted light) of biogenic opals separated from Humic Yellow Latosol (Nos. 1–3, 5, 7, 10, 13–18, 20–22; opals from A_1 horizon) and Yellow Latosol (Nos. 4, 6, 8, 11, 12, 19; opals from A_1 horizon): Nos. 5, 6 and 9; opals from palm plant family, Nos. 1, 4, 7, 8, 10–12, 16, 19–22; opals from deciduous angiosperm tree, Other Nos.; opals from unidentified plants

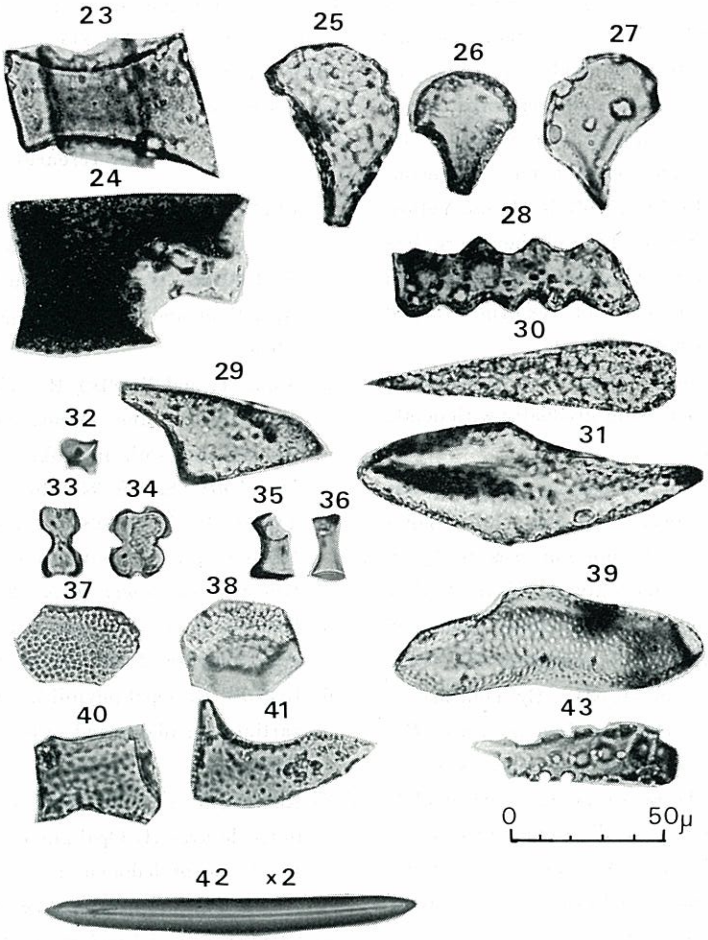

Fig. 4 Micrographs (Plane polarized transmitted light) of biogenic opals separated from Humic Yellow Latosol (Nos. 23, 24, 26–34, 37–43; opals from A_1 horizon, Nos. 27, 30, 40–43; opals from A_3 horizon): Nos. 23 and 24; opals from pine tree family, Nos. 25–34; opals from gramineous plant family (No. 32; arnudoideae, Nos. 33 and 34; panicoideae), Nos. 31, 37–41, 43; opals from unidentified plants, No. 42; sponge spicule

in the B horizon.

Opals derived from epidermal and vascular cells of deiduous trees (Fig. 3, Nos. 10, 11, 12, 16, 19, 20, 21 and 22) were fewer than those of palm family origin, and the amount in the surface horizons of the two soils were almost equal.

Besides the above mentioned types, the opals of panicoid type (Fig. 4, Nos. 33 and 34) described by TWISS *et al.*[4] and suddle-shaped opals (Fig. 4, No. 32) were also found. Point-shaped opals (Fig. 4, Nos. 29 and 30) from trichome cells also occurred commonly in both soils. In addition to the identifiable biogenic opals, many unknown members (Fig. 3, Nos. 13–15, Fig. 4, Nos. 31, 35–41 and 43) were found in the two soils. We could not specify their original plant species because not much information is available concerning opals in the Amazon region.

The amount of biogenic opals in both soils was less than 1.0% of the 10 to 200 μm fraction. Vertically, the amount was highest in surface horizons and decreased gradually with depth. The opals of palm family origin (normal and abnormal opals) dominated in both soils ranging from 30.6 to 70.0% of total opal grains. The opals from gramineous plants ranged from 16.2 to 27.6% in Humic Yellow Latosol, whereas in Yellow Latosol they were less than 13.6% (B_1 horizon) being low in the A horizon (4.9%). The amount of opals of tree origin ranged from 2.4 to 5.8% in both soils.

Unidentified opals ranged from 12.6 to 36.0% of opals in both soils, increasing gradually with depth, as shown in Table 1.

The humus content of the surface horizons was obviously different between the two soils. Total carbon content in the A_1 horizon was 5.5% in Humic Yellow Latosol, and only 0.5% in Yellow Latsol[12]. The Humic Yellow Latsol contained highly humified A-type humic acid with RF value =115 and $\Delta \log K$ value=0.535. By contrast in Yellow Latosol, humic acid was less humified P_{++} type[13]. This fact suggests that plant species contributing to the accumulation of humus (and quality of humus accumulated) were different between the two soils. In addition, IWASA noticed in rainy season a swampy surface condition in some areas with Humic Yellow Latosol.

From these results we conclude that the present soil was formed primarily from gramineous plants, and temporary wet soil conditions, which afforded an abundant supply of organic matter. A temporary wet condition is indicated also by the presence of sponge spicules from freshwater in Humic Yellow Latosol. Moreover, the presence of earthenware in Humic Yellow Latosol suggests that household garbage left by pre-Columbian Indian tribes have contributed to some extent to the development of this soil.

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アマゾン地帯の腐植質黄色ラトソルおよび黄色ラトソルの生物起源ケイ酸体

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摘 要

ブラジル，アマゾン地帯に分布する腐植質黄色ラトソルの高腐植量の表層が，どのような土壌生成過程および土壌環境下で形成されたかは明らかでない。

この点に関して，多くの仮説が唱えられているが，われわれは植物種の相違も要因の一つであったと推測し，腐植質黄色ラトソルとその隣接地に分布する黄色ラトソルの生物起源ケイ酸体組成およびその量について比較検討した。得られた結果を要約するとつぎのとおりである。

1) 腐植質黄色ラトソルおよび黄色ラトソル表層の生物起源ケイ酸体量は0.54～0.91％の範囲にあり，両土壌の間でさほど相違は認められなかった。

2) 腐植質黄色ラトソルおよび黄色ラトソル中で高頻度に分布するケイ酸体は，ヤシ科植物起源で全生物起源ケイ酸体の約30～70％を占め最も多く，ついでイネ科草本類起源，樹木起源のケイ酸体の順であった。

3) 全生物起源ケイ酸体に占めるイネ科草本類由来のケイ酸体の割合は，両土壌の間でかなり相違が認められた。すなわち，腐植質黄色ラトソルは黄色ラトソルの約3～4倍のイネ科草本類由来のケイ酸体を含有していた。

4) 腐植質黄色ラトソル A 層のヤシ科植物起源の変質ケイ酸体の多くは熔融していたが，黄色ラトソルおよび腐植質黄色ラトソル B 層のそれは正常な風化過程によって「あばた状」の表面を有していた。

5) 腐植質黄色ラトソルのみに mono-axon 型の海綿骨針が観察され，それは一時的にせよ湿った環境下にあったことを示している。

以上の結果から，腐植質黄色ラトソルは高草木の強い影響，および一時的に湿った土壌状態下で発達してきたものと考えられる。

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