

The Works of Living Social Insects as Pseudofossils and the Age of the Oldest Known Metazoa

Abstract. *Living organisms are known to create structures in ancient rocks that are indigenous but not primary and that have been mistaken for fossils. Examination of burrows recently reported as fossils from 10⁹-year-old sedimentary rocks indicates that they are not the same age as the rocks but were probably made by termites working down after water. The burrows are partially filled with material from a modern lateritic surface from which they descend into steeply dipping, decomposed siltstones of the Zambian Copperbelt. In fact, no authentic record of Metazoa that are demonstrably coeval with rocks older than 680 million years is known.*

The oldest convincing and well-dated records of differentiated multicellular animal life, Metazoa, are about 680 million years old. Although more than 200 older occurrences have been reported, none has withstood scrutiny. Examination of the evidence shows either that the rocks are misdated, that the objects are not of biological origin or, if biological, that they were not produced by Metazoa or were not of the same age as the rocks in which found (1).

The noncoeval burrows and imprints include those of modern organisms that live on or in ancient sedimentary rocks. Such traces, although indigenous, are not contemporaneous with the deposition of the parent sediments of the rocks. That is, they are not primary in a geological sense. The imprints of the bases of bee's nests found on the bedding and joint surfaces of ancient calcareous rocks are an example (2). Another is structures described in a recent paper on

Zambian burrows thought to be 10⁹ years old (3).

The author of that report (3) illustrated convincing metazoan traces from sedimentary rocks in the middle part of the Roan Group of the Zambian Copperbelt. He summarized evidence that the age of these rocks is well established radio-metrically as about 10⁹ years and concluded that the burrows are of the same age.

The details described and illustrated (3) unequivocally support the interpretation that the structures are the work of Metazoa, but our curiosity as to their time of incorporation into the stratigraphic sequence and, therefore, their significance for the metazoan record and the origin of the copper deposits, was aroused by two peculiarities: (i) the fact that the enclosing rocks appear to be 300 million years older than the oldest previously well-documented Metazoa, and (ii) the reported color contrast between burrow fillings and surrounding rock. Cloud subsequently studied the specimens at Leeds University in 1977 where he also was shown the color transparencies of the outcrop area.

Cloud at that time suspected that the contrast in color and grain size between burrow fillings and matrix was related to introduction of the former from a geologically young lateritic surface. Later Gustafson and Watson came to share his interpretation on the basis of their knowledge of Zambian geology and termites, respectively. We agreed that the matter was a subtle and difficult one, meriting fuller discussion than it had received (4).

Although the burrows occur in a pale beige to cream-colored sedimentary rock, which is soft, porous, deeply leached and bleached, thin-bedded, silty, and probably once calcareous, the fillings of some burrows are predominantly banded in alternating brick-red and pink laminae. The banded burrow fillings also contain quartz grains that are coated with surface films of ferromanganiferous "desert varnish" and are conspicuously larger than the grains in the adjacent pale

matrix. The burrow fillings resemble substances found on laterized surfaces in the seasonally wetted tropics. If they were primary features of the rock, they, like it, should have been bleached during the deep weathering that affected the subsoil rocks of this region under tropical weathering conditions similar to those prevailing there at present. Other burrows or galleries, which may be hollow or contain backfilling matter, are coated by a black ferromanganiferous substance that also suggests a relation to a geologically young surface.

If these burrows or galleries are related to the present or a geologically recent surface, as we suspect, their reported concentration on bedding surfaces and in particular sedimentary layers (at the base of the Orebody Member, Mixed Formation, middle of the Roan Group) must be explained, as well as their location at depths of some tens of meters below the surface. Any hypothesis of their origin must also explain the flattened, oval cross sections of the so-called type A burrows (3), their variations in width, their commonly laminated wall structure, the pelletal texture of parts of the burrow fillings, the arcuate backfilling pattern, and terminal pockets or culs-de-sac. It must also account for the locally scrambled texture, which suggests biological reworking (bioturbation), and the hollowness of type B structures (3) with an indurated rim.

Since the originally horizontal strata are now folded, are steeply dipping, and are deeply weathered to a soft material, it is not difficult to imagine how burrowers could have preferentially penetrated the softer strata and followed them down in the direction of the dip.

Whatever made the type A burrows was not a single animal, for the widths of the burrows vary, contracting and swelling along their lengths, and the profiles are compressed ovals rather than sub-



Fig. 1. Upper gallery of *Drepanotermes diversicolor* from Soudan Station, Australia; it is an open gallery similar to the figure of a type A burrow in (3). The top of the photograph is up in nature. About natural size.

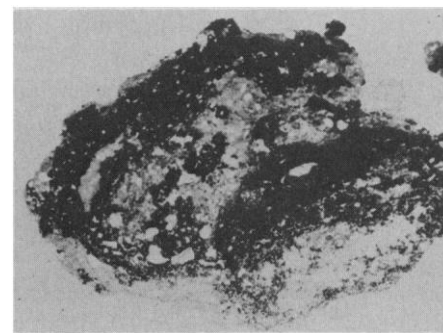


Fig. 2. Cross section of Zambian burrow with manganiferous backfilling (black) and pelletal structure (especially lower edge); modern termites make similar burrows. Light areas are grains of quartz, sericite, and microcline. Burrow width, 7 mm.

circular. Most likely many small animals using the same passageways were involved. Animals that make such passages are found among the social insects, many of which excavate or build tunnels, galleries, and nests of varying diameters, shapes, and depths in the soil (5, 6). We considered termites, ants, and bees but ruled out bees because their burrows are mostly circular in cross section and of regular diameter.

It is well known, however, that termites and, to a lesser degree, ants may excavate deep burrows or shafts in search of water (5, 6). Although many species of termites inhabit arid regions, they have little resistance to desiccation and lose water rapidly in dry conditions. As a populous modern termite colony may include 1 to 10 million insects and weigh several tens of kilograms, its requirements for water can be substantial. Metabolic water supplies only part of this requirement, and termites often burrow down to the water table to satisfy their needs from ground water. During recent droughts in the Sahel states of sub-Saharan Africa, lowering of the water table forced termites to burrow to depths of 45 to 55 m (7). To reach the water table, termite galleries have penetrated to measured depths as great as 70 m (8), and Luscher (6) reported vertical penetration by termites of about 100 m. Ants also burrow to substantial depths. Some, such as *Monomorium*, burrow down as far as 10 m after moisture. The penetration of modern termite burrows to depths of 70 to 100 m or more is not improbable and is well below the depths of the described Zambian burrow samples, all of which reportedly came from a single open-pit mine, the Mindola North Pit. Moreover, termite-burrowed

lateritic soils that are petrologically similar to the fillings of the type A burrows are prevalent in the Zambian Copperbelt (9).

Termites build their gallery walls by lining the tunnels with soil that they carry in their mouths and moisten with saliva, with drops of moist fecal material, or with a combination of the two. A pelletal microstructure similar to parts of the Zambian burrow fillings is, therefore, common in termite constructions and is present in the arcuate backfillings of galleries in and outside of nests and mounds.

The relation between the type A and type B burrows reported in (3) is not established. Type A burrows resemble galleries of the kind in which some harvester termites, such as the Australian *Drepanotermes* (10), store forage (Fig. 1); or they may have been parts of the diffuse, subterranean nests that many termites build. Type B burrows resemble the exploratory tunnels that termites build against firm surfaces. Their microstructures (Fig. 2), as judged by thin sections of burrows collected by Gustafson, resemble those of termite galleries in that they are essentially lenticular and contain small, discrete, pellet-like masses of materials that are complex and contain several components that often differ in composition from adjacent masses. Some are ferromanganiferous, others are aggregates of mineral grains (mostly quartz, sericite, and microcline) that are probably derived from mechanical breakdown of arenites such as occur nearby in the stratigraphy.

The general parallelism to bedding of the Zambian burrows could be a function of the local dip of the strongly folded strata in which they occur and of prefer-

ence by the burrowers for the softer, more intensely decomposed layers. Weathering of thinly bedded siltstones would produce differences among the beds in hardness and permeability, reflecting differences in carbonate and sulfate content of individual beds. Resulting differences in water-bearing characteristics would also induce selectivity by termites. The stratigraphic limitation could also be more apparent than real. Because of the deep soil cover in the area, the rock is exposed only in mine openings, and the weathered rock from which burrows are reported is limited to surface openings. No burrows have been reported from the much more extensive underground workings below the weathered zone or outside the Mindola North Pit.

Figure 3 is a schematic representation of the way in which the distribution of termite burrows could have been controlled by bedding in the weathered zone above the water table. It is only a rough approximation to the geologic situation at Mindola as we have no information on the distribution and lithologies of units in the footwall of the ore shale.

We conclude that the Zambian Copperbelt burrows reported in (3) are those of Metazoa and that they do occur naturally in weathered rocks 10⁹ years old, but they are neither the same age as the rocks nor of great antiquity. The lateritic and texturally distinctive aspect of the burrow fillings in combination with the lateritic surface above them indicate that they were derived from a geologically young surface and weathering profile. Although we are unable to associate the burrows with particular species or genera of insects, we suggest that they were most likely excavated by the termites that form such abundant and large colonies throughout the Zambian Copperbelt.

If we have correctly interpreted these Zambian trace fossils as probable termite burrows, the subtlety could understandably mislead anyone not familiar with the natural history of burrowing insects or acutely alert to the potential pitfalls in the biological assessment of the pre-Phanerozoic record. Indeed this occurrence has already been reported as authentic in a recent widely used textbook of biology (11). It is clear that one must be very careful in assessing supposedly new records of metazoan life believed to be older than about 680 or 700 million years.

Another consequence of our conclusion is that it removes what would otherwise be a constraint on much dis-

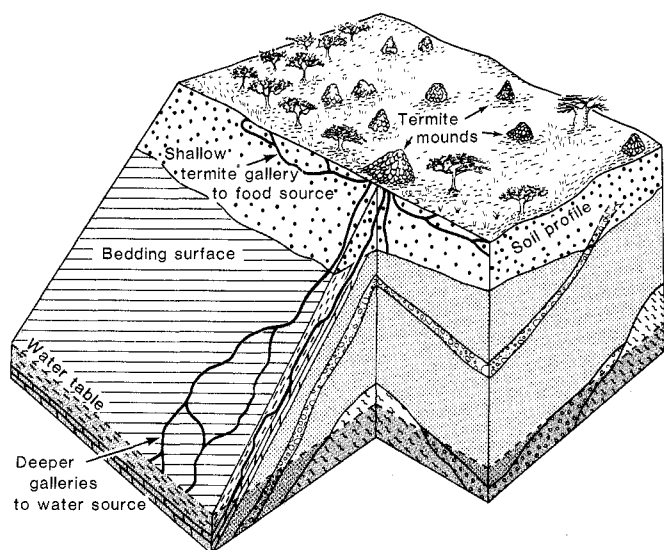


Fig. 3. Schematic block diagram illustrating how burrows of geologically recent origin might be introduced into deeply weathered sedimentary rocks of the Zambian Copperbelt.

puted theories of the origin of the extensive stratiform copper ores of the Zambian Copperbelt. These theories call for introduction of large amounts of copper into sediments from some kind of solution either during or subsequent to sedimentation.

The burrows discussed here are in well-mineralized sediments that contain roughly 1 percent copper in the oxidized zone and higher values in the sulfide zone down dip. The question of when this mineralization occurred is crucial to understanding the processes of ore formation. Because copper at more than trace concentrations in ionic, and to a lesser degree in complexed, form is lethal to most or all organisms, its introduction during or immediately after sedimentation would be negated by evidence of active, contemporaneous burrowing of the enclosing sediments. As the burrows appear not to be contemporaneous with sedimentation, however, the timing of introduction of the copper-bearing solutions is not constrained by their presence.

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Io: Ground-Based Observations of Hot Spots

Abstract. *Observations of Io in eclipse demonstrate conclusively that Io emits substantial amounts of radiation at 4.8 and 3.8 micrometers and a measurable amount at 2.2 micrometers. Color temperatures derived from the observations fit blackbody emission at 560 K. The required source area to yield the observed 4.8-micrometer flux is approximately 5×10^{-5} of the disk of Io and is most likely comprised of small hot spots in the vicinity of the volcanoes.*

The existence of warm regions on Io discovered by the Voyager infrared spectroscopy and radiometry (IRIS) instruments (1) and the occasional 5- μ m outbursts (2) call into question the assumption (3) that all of Io's normal flux between 2 and 5 μ m is reflected sunlight. A test of this assumption has been carried out by performing K, L, and M (2.2, 3.8, and 4.8 μ m) photometry of Io as it is eclipsed by Jupiter.

To see if this is really a test, we first consider what might be the expected flux from known sources when Io is eclipsed. The temperature of 135 K or less inferred for the surface outside eclipse from measurements at wavelengths beyond 10 μ m (4) would add only 0.02 percent to the reflected sunlight at M wavelengths and even less in the L and K bands. Another source of residual flux from an eclipsed satellite is sunlight that is incident on the satellite after being refracted in the upper atmosphere of Jupiter. This effect, called the refractive tail, has been studied (5) at wavelengths as long as 1.05 μ m for Ganymede, for which an eclipse proceeds more slowly than it does for Io. Computations (6) of the refractive tail at 1.05 μ m yield a dimming of 7.5 magnitudes (1000 times) 16 minutes after immersion for Ganymede and 10 minutes after immersion for Io. Observations in-

dicate additional dimming of several magnitudes due to aerosol scattering and molecular absorption. Although both these dimming effects are wavelength-dependent, the reflected sunlight component should nearly vanish in the K, L, and M bands when Io is eclipsed.

Our first observations of an eclipse of Io at K, L, and M wavelengths were made on 15 December 1979 simultaneously with the 3-m Infrared Telescope Facility (IRTF) and the 3.8-m United Kingdom Infrared Telescope (UKIRT) at Mauna Kea, Hawaii. Before and after immersion, both telescopes independently cycled through the K, L, and M filters, but during the rapid immersion phase UKIRT observed in K and IRTF observed in M. The observations (Fig. 1) show that the decreases in flux were only 6.5, 2.3, and 1.0 magnitudes (factors of 400, 8, and 2.5) at K, L, and M, respectively, and that there was no further decrease from immediately after immersion until the end of observing nearly 30 minutes later. The constancy of the flux while Io was in eclipse disagrees with calculations for a refractive tail, but is exactly what would be expected from hot spots on the surface of Io.

The sensitivity of the photometric equipment was such that we could easily find Io and maximize the infrared signal long after the satellite had disappeared visually. We made tests for light scattered from Jupiter by moving away from Io in several directions and then returning to it. The fluxes measured by the two telescopes, before and after eclipse, agree within 10 percent at all wavelengths. Subsequently, two of us (W.M.S. and A.T.T.) made additional observations of eclipses with the 2.2-m telescope of the University of Hawaii. The results from three eclipses are shown in Table 1.

From the flux that remains after entrance into eclipse, we conclude that Io has sources of emission other than the thermal radiation at 135 K characteristic of most of its surface. From the residual fluxes in the K and L and in the L and M bands, we determined a color temperature for this emission. Using Wien's approximation, which differs from the Planck formula by less than 1 percent for

Table 1. Photometry of three eclipses in the K, L, and M bands.

Bands	Date (1979) and time (U.T.)*		
	15 December 15:58	22 December 17:51†	24 December 12:20
<i>Preimmersion magnitude</i>			
K	3.96	3.89	3.67
L	3.98	3.92	3.65
M	3.87	3.62	3.42
<i>Postimmersion magnitude</i>			
K	10.61	10.61	10.54
L	6.28	6.42	6.24
M	4.85	4.90	4.54
<i>Reflectance</i>			
p_K	0.70	0.72	0.87
p_L	0.62	0.62	0.79
p_M	0.77	0.93	1.10
p_K (corrected)	0.70	0.72	0.87
p_L (corrected)	0.54	0.56	0.72
p_M (corrected)	0.50	0.64	0.71

*Time at midpoint of immersion.

†See (14).