portrayed by the color Sea-Viewing Wide Field-of-view Sensor (SeaWiFS) visible band image at 1800 UTC 14 May 1998; see http://modarch.gsfc.nasa.gov/fire_atlas/MEXICO/SeaWiFS/may1498.jpg.
24. A Geostationary Operational Environmental Satellite (GOES) visible image at 2245 UTC 15 May 1998 showing the massive smoke plume is available at http://cimss.ssec.wisc.edu/goes/misc/980515_2305_g8vis.GIF.
25. K. L. Cummins, personal communication. This conclusion is based on extensive analyses by Global Atmospherics Inc. of the performance of the NLDN since major upgrades were incorporated during 1994–1995.
26. K. L. Cummins, personal communication. The sudden surge of +CGs in the NLDN during April 1998 prompted extensive checks by the Network Control Center staff. No malfunctions were found. Single-sensor data were studied showing storms in the smoky air over southern Texas with 85% positive CGs, whereas other storms in clean air hundreds of kilometers to the north showed 5 to 10% positive polarity.
27. The massive pall of smoke from the 1997 Indonesian fires, occurring in a region characterized by high thunderstorm rates, may have induced a similar response. Unfortunately, political unrest in that nation has temporarily prevented retrieval of data from lightning detection networks covering this area.
28. Increased CCN in forest fire plumes were reported by P. V. Hobbs and L. F. Radke [*Science* **163**, 279 (1969)]. Actual changes in droplet spectra in smoke-contaminated clouds were noted by Y. J. Kaufman and T. Nakajima [*J. Appl. Meteorol.* **32**, 729 (1993)].
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31. Boundary-layer forward trajectories from the fire regions were operationally produced by the Air Resources Laboratory of the National Oceanic and Atmospheric Administration (http://www.arl.noaa.gov/ready/aq.html).
32. Supported in part by NSF, NASA, and the U.S. Department of Energy. Special thanks are extended to Global Atmospherics Inc. and K. Cummins in particular for facilitating the analyses of the NLDN data. We also thank G. Vali and A. Detwiler for suggesting several valuable literature citations.

8 July 1998; accepted 1 September 1998

Triploblastic Animals More Than 1 Billion Years Ago: Trace Fossil Evidence from India

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Some intriguing bedding plane features that were observed in the Mesoproterozoic Chorhat Sandstone are biological and can be interpreted as the burrows of wormlike undermat miners (that is, infaunal animals that excavated tunnels underneath microbial mats). These burrows suggest that triploblastic animals existed more than a billion years ago. They also suggest that the diversification of animal designs proceeded very slowly before the appearance of organisms with hard skeletons, which was probably the key event in the Cambrian evolutionary explosion, and before the ecological changes that accompanied that event.

There are two seemingly contradictory views about the early history of metazoans. The "Cambrian explosion" scenario is based on Cambrian shelly fossils and Burgess-type lagerstätten. This scenario suggests that animal phyla originated rather suddenly ~540 million years ago (Ma) during the Proterozoic-Phanerozoic transition. This view was first modified by the discovery of Ediacaran fossils of late Proterozoic (Vendian) age in many parts of the world. Although most of these fossils are nonmetazoan [according to the Vendobionta hypothesis (*1*)], the presence of true, but soft-bodied, triploblasts in Ediacaran biota is now documented by worm burrows, by radular markings and body impressions (*2*) of early mollusks, and by phosphatized embryos (*3*). These discoveries lengthened the paleontological record of animals to ~580 Ma. The alternative "slow burn" scenario suggests that animals developed more slowly (*4*)—according to some molecular analyses (*5*), beginning more than 1 billion years ago (*6*).

These two scenarios are not incompatible, because they are based on different concepts. In paleontology, phyla are defined as bauplans that are typified by modern representatives. Because hard skeletons are an essential element of construction in many of these bauplans, it is reasonable to assume that many of them had their origin in the Cambrian skeletonization event. Molecular analyses, in contrast, include any ancestor in the lineage, irrespective of its morphology. Also, the calculated age of the last common ancestor is highly model dependent.

Paleontologists can document the hypothesized pre-Ediacaran animals in the following ways. (i) If it is true that early metazoans were minute larviform planktics (*7*), their remains could be preserved in cherts; so far, however, these cherts have yielded only unicellular organisms. (ii) Larger, but soft-bodied, forms can be expected in black shales, in which only macroalgae have been found so far. (iii) Clastic sediments should preserve the trails and burrows of benthic animals. Pre-Ediacaran trace fossils [summarized in (*8*)], however, are scarce and have not been very convincing. The worm burrows described here suggest that a preservational bias may also be involved in the Precambrian trace fossil record.

Trace fossils are best preserved in sedimentary rocks that have not been metamorphosed. One suitable site for trace fossils is the Vindhyan Supergroup in the Son valley, central India, where continuous sequences of nonmetamorphosed Proterozoic sandstones, shales, and algal limestones can be studied in continuous outcrops (Fig. 1). The Chorhat Sandstone, from which our trace fossils originate, appears to have been deposited in a shallow marine setting. It mainly consists of centimetric storm sands that are topped by oscillation ripples. However, unlike in younger tempestites, event layers have not become cannibalistically amalgamated but remain separated even when there are no mud drapings between them. The reason for this strange behavior is the presence of microbial mats (*9*). These mats transformed the upper millimeters of the sand into a leathery, erosion-resistant coating, so that the next storm sand could, on its sole, form a direct replica of the previous ripples. If the second storm bed was no thicker than the preexisting ripple relief, it filled only the former troughs with starved ripples of a different direction [palimpsest ripples (*10*)].

The matground state of Proterozoic sea bottoms (as opposed to the bioturbational mixground state of later times) has not only been responsible for strange sedimentary structures but may also have led to the strange life-styles (*11*) and preservation (*12*) of Ediacaran organisms and the scarcity of trace fossils in the Proterozoic rocks.

When studying pre-Phanerozoic trace fossils, it is crucial to distinguish true biogenic sedimentary structures from pseudotraces whose shapes are purely (or mainly) formed from physical processes. Among these struc-

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tures, syneresis cracks (*10*) are the most deceiving. They open because of early diagenetic dewatering (within the sediment rather than at the surface). In Proterozoic times, the ubiquity of mucus glue caused not only muds but also silts and sands to shrink in a cracking mode. Of the various crack patterns observed in the Chorhat Sandstone, some are particularly intriguing. Syneresis cracks tend to start as isolated fusiform fissures. After such incipient cracks had been filled with coarser sediment from the layer above, subsequent compaction caused the less compactible fillings to bulge out laterally. As a result, the casts look much like the almond-shaped resting traces of bivalves (*Lockeia*). Longer incipient cracks could also be mistaken for the bases of spreite burrows (*Diplocraterion*), if they are preserved as grooves on a sandstone top. An even more intriguing crack pattern results from the combination of syneresis with oscillation ripples. In this situation, cracks originate in the ripple troughs, whose contours they follow with a strikingly sinusoidal course. Such structures have repeatedly been described as the body casts, or traces, of early worms, particularly if they bear parapodia-like corrugations on their flanks (*13*). The name "Manchuriophycus" (referring to an earlier interpretation as fossil algae) is used for this sediment structure, which is particularly common in Proterozoic matground environments.

Following an earlier report (*14*), we found the structures described here (Figs. 2 to 4) in considerable numbers on top of sandstone beds along the road east and west of Chorhat village. Chorhat burrows are too irregular to be syneresis cracks, too sharply delineated to be wrinkles, and too large to be attributed to protists or fungal rhizoids. Also, diameters vary, but they remain constant within systems. When we first found these structures in 1996, we suspected that they were modern artifacts caused by plant roots (in which secondary branchings should be narrower) or by termites, because they occurred only on weathered surfaces. We revisited the site in 1997, hoping to find grooves that pass into a ridge (such reversal of relief commonly occurs when soft sediment is burrowed along a sand-mud interface, and this phenomenon would be impossible in modern rock perforations). Instead, we found other evidence disproving a modern origin. (i) The margins of the burrows are sometimes elevated above the surrounding surface (Fig. 3a). This could be due to the pushing up of soft sediment or to a diagenetic halo that was more resistant to weathering. (ii) In one place (Fig. 4), the burrows became visible only on the weathered rock surface; the burrows are absent in adjacent areas of the same bedding plane that had been less exposed or protected by an overlying sandstone bed. (iii) One of the burrows [arrow in Figs. 2 and 4 (inset A)] is still partly covered by a small remnant of the original sandstone veneer. (iv) Cross sections (Fig. 5) reveal that this veneer has a larger amount of dark matrix between the sand grains.

This evidence demonstrates that these are original burrows, but they are in an unusual mode of preservation. We suggest that the veneer represents the microbially bound biomat, which served as a food source as well as an oxygen mask for the wormlike animals that were exploiting its decaying base. They probably wedged themselves through the sediment by peristalsis, because the burrows are

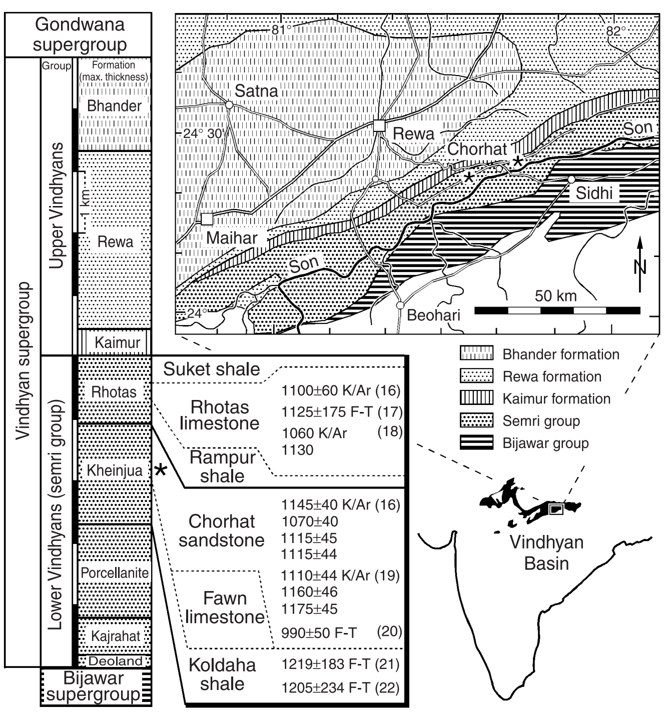
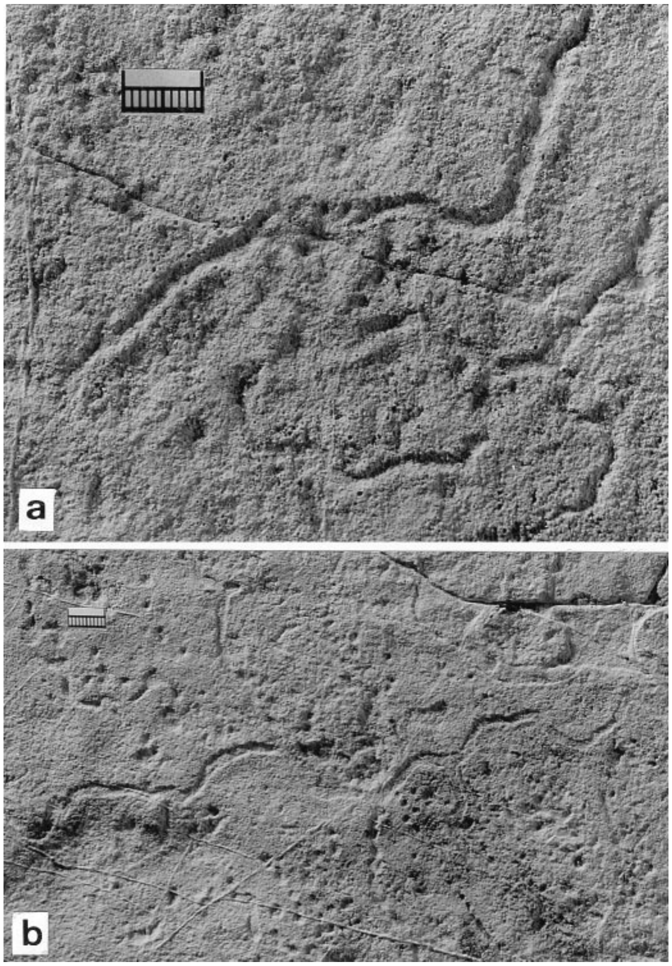
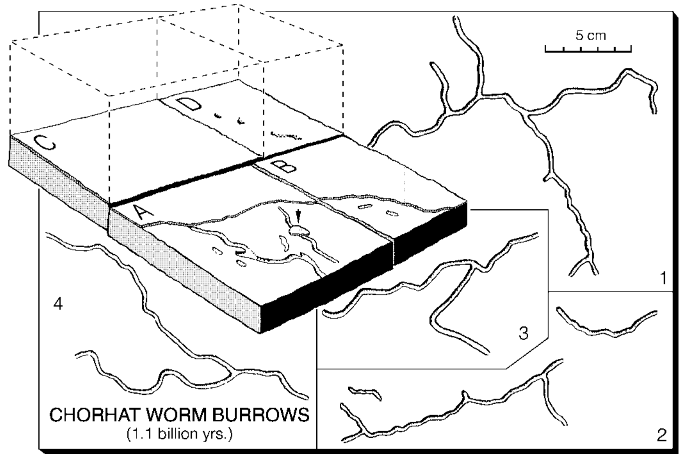


Fig. 1 (left). The Vindhyan Supergroup, central India, with stratigraphic context, location of metazoan burrows (stars), and published ages with references. Ages are millions of years ago and calculated by the potassium/argon method (K/Ar) or by fission tracks (F-T). **Fig. 2 (right).** Worm burrows from the Mesoproterozoic Chorhat Sandstone of central India support the claim of molecular biologists that triploblastic metazoans existed twice as long ago as the assumed Cambrian evolutionary explosion of modern animal phyla. A remnant of the original sand veneer cover (arrow) shows that the burrows are not modern artifacts (Yale specimen YPM 37665). (Photograph by W. Sacco)





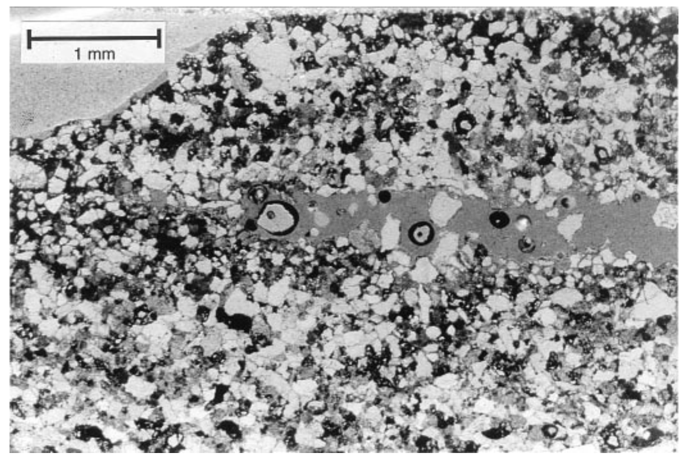


Fig. 3 (left). Chorhat worm burrows on a weathered top surface. The patterns are unlike syneresis cracks, and (**a**) elevated rims provide evidence that these burrows are not modern artifacts. (**b**) Elevated crack fillings suggest the thickness of veneer that has been weathered away (casts in Tübingen collection, GPIT 1847/1-2). (Photograph by W. Gerber) **Fig. 4 (top right).** The burrows [block diagram of Fig. 1 drawn from the outcrop situation and the cast in the Tübingen collection (GPIT 1847/3)] become visible only after the top millimeter of the sandstone bed has been weathered away. Fresh surfaces lack such burrows except for less distinct collapse structures. Therefore, we assume that the wormlike maker was an undermat miner [part of the burrow that is still covered by the original sand veneer is indicated by the arrow (see Fig. 2)]. Panels 1 to 4 show further examples, which were drawn from casts and field photographs, and insets A to D show different blocks of the bed. **Fig. 5 (bottom right).** A thin section of the trace-bearing bed (Fig. 4, inset A). The grains are less closely packed (and have a larger amount of dark matrix) in the upper 2 mm, where they were microbially bound. The section broke at about the level of the burrows during preparation.

not actively backfilled. The open tunnels later collapsed, as indicated by faint depressions on the unweathered bed surface (Fig. 4, inset D).

Often such undermat burrows cannot be seen on unweathered sandstone surfaces, where trace fossils would be best preserved in later rocks. If the biomat veneer had the same structure as the underlying sand, they might not even weather out.

The Chorhat burrows, unlike other claimed trace fossils of similar age (*8, 15*), can only be explained as the works of macroscopic wormlike animals. Because they always follow a bedding plane, which is only a few millimeters below the original surface, we suppose that their makers were undermat miners. From the common occurrence of branchings, and of occasional collapse structures (Fig. 4, inset D), one may assume that the tunnels did not become actively backfilled. Apart from branching and tier-keeping, their makers had not yet developed the systematic search behaviors (meandering and so forth) that one observes in later undermat miners. Burrowing was probably performed by peristaltic movements, which would suggest the presence of a coelom. Because pore water below biomats tends to be in a reduced state, we must also consider that these animals used the mat not only as a food source but also as an oxygen mask.

In any case, these burrows suggest the existence of fairly large (up to 5-mm-wide) triploblastic metazoans as early as 1.1 billion years ago, in agreement with molecular data. The burrows also indicate that animal body plans changed very little before the explosive emergence of new designs in the Precambrian-Cambrian transition and before the onset of a more competitive style of Darwinian evolution.

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23. Trips to India were made possible by the Crafoord Prize (1992) of the Swedish Academy and through support by Coy Squires (Houston). We also thank E. Klitzsch, H. Luginsland, S. Sarkar, and E. Seilacher for assistance in the field. Photographs were taken by W. Gerber (Fig. 3) and W. Sacco (Fig. 2), and word processing was completed by E. Seilacher.

24 April 1998; accepted 29 July 1998

ROSAT X-ray Detection of a Young Brown Dwarf in the Chamaeleon I Dark Cloud

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Photometry and spectroscopy of the object Cha Hα 1, located in the Chamaeleon I star-forming cloud, show that it is a $\sim 10^6$-year-old brown dwarf with spectral type M7.5 to M8 and 0.04 ± 0.01 solar masses. Quiescent x-ray emission was detected in a 36-kilosecond observation with 31.4 ± 7.7 x-ray photons, obtained with the Röntgen Satellite (ROSAT), with 9σ detection significance. This corresponds to an x-ray luminosity of 2.57×10^{28} ergs per second and an x-ray to bolometric luminosity ratio of $10^{-3.44}$. These are typical values for late M-type stars. Because the interior of brown dwarfs may be similar to that of convective late-type stars, which are well-known x-ray sources, x-ray emission from brown dwarfs may indicate magnetic activity.

A brown dwarf (BD) is an object with a mass ≤ 0.08 solar masses ($M_\odot$), which is insufficient to sustain nuclear fusion of hydrogen (*1*). Lacking this source of energy against self-gravity, which provides the long-term stability of main-sequence stars, a BD shrinks in size until electron degeneracy halts further contraction. Because a BD becomes cooler and less luminous with age (*2*), some BD searches in the nearby (~125 pc) and young ($\sim 10^8$ years) Pleiades cluster were successful (*3*). In ρ Ophiuchi (ρ Oph), a region with ongoing star formation, several low-mass objects were identified (*4*), including the object ρ Oph 1623-2426, a 3 to 10×10^6 year old BD (*5*). Stellar evolution theory predicts that stars with masses ≤ 0.3 $M_\odot$ are fully convective (*6*). Given the central role of convection for magnetic activity and x-ray emission in low-mass stars, a BD may emit x-rays by the same mechanism as low-mass stars. However, until now, no BD has been detected in x-rays.

In a survey of the Chamaeleon (Cha) I dark cloud, near-infrared (NIR) photometry and low-resolution, low signal-to-noise ratio (S/N) spectroscopy were obtained for several new faint cloud members (*7*), so that objects 1 to 6 [table 4 of (*7*)], called Cha Hα 1 to 6 here, all showing Hα emission lines in their spectra, could be plotted in the Hertzsprung-Russell diagram, assuming 160 pc as distance, which is the mean of the distances of three T Tauri stars in Cha I measured by Hipparcos, and a spectral type to temperature conversion for cool stellar photospheres (*8*, *9*). According to pre–main-sequence evolutionary tracks (*10*), these six objects are near and some are possibly below the stellar mass limit of 0.08 $M_\odot$.

After identifying these BD candidates, we retrieved the ROSAT pointed observations 200207 (31 ks) and 200046 (5 ks) from the ROSAT data archive. Both observations are centered on the Cha I cloud and were obtained in 1991 with the ROSAT Positional Sensitive Proportional Counter (PSPC) (*11*). We performed standard source detection with the Extended Scientific Analysis Software to reduce the merged data set (Fig. 1). Because of the ROSAT boresight offset, a few arc seconds offset can be allowed between the x-ray and the optical positions for source identification.

The object Cha Hα 1 is identified with the x-ray point source RXJ 110716-773552, whereas Cha Hα 3 and Cha Hα 6 are marginally detected. There are no other objects from SIMBAD, the Hubble Space Telescope Guide Star Catalog, or the NASA Extragalactic Database within 80 arc sec around these x-ray sources. None of these objects were detected in a less sensitive Einstein Observatory x-ray image of the same region (*12*). They were also not detected in an earlier analysis of the 5-ks PSPC pointing (*13*). However, Cha Hα 1 was detected in an earlier analysis of the 31-ks PSPC pointing, object XP 30 in (*14*), and it was tentatively identified as a faint stellar object of unknown class (*14*).

Given the spectral resolution of the PSPC, one can define several energy bands and calculate the so-called hardness ratios of detected x-ray sources. If $Z[a, b]$ is the count rate between energies a and b, then hardness ratios are defined as

$$HR1 = \frac{Z[0.5, 2.1] - Z[0.1, 0.4]}{Z[0.5, 2.1] + Z[0.1, 0.4]}$$

$$HR2 = \frac{Z[0.9, 2.1] - Z[0.5, 0.9]}{Z[0.9, 2.1] + Z[0.5, 0.9]}$$

To obtain x-ray fluxes for the detected objects as well as x-ray upper limits for undetected objects (Table 1), the count rates have to be divided by the appropriate energy conversion factor, namely, 10^{11} counts cm^{-2} erg^{-1}.

Because Cha Hα 1 is detected in the x-ray observation and because it is a good BD candidate in view of the previous data (*7*), we obtained low-resolution, high S/N spectra of this object with the 3.5-m New Technology Telescope (NTT) of the European Southern Observatory (ESO) on La Silla, Chile, in the visible [using the ESO Multi-Mode Instrument (EMMI), with resolution of ~1250 at 800 nm] and the NIR [using Son of Isaak (SOFI), an infrared spectrometer and array camera, with resolution of ~500 at 2 μm] in May 1998.

Both spectra (Fig. 2) show features typical of cool photospheres (≲3000 K). Most prominent in the visible is the Hα emission line with an equivalent width of 6.5 nm and many TiO and VO absorption lines. In the NIR, the CO absorption lines and the broad depression between 1.5 and 2.0 μm due to H_2O absorption also suggest a temperature below 2000 K. The strength of the gravity-sensitive Na I absorption feature at 819 nm is intermediate

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Triploblastic Animals More Than 1 Billion Years Ago: Trace Fossil Evidence from India

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Science **282**, 80 (1998);
DOI: 10.1126/science.282.5386.80