These features are found in species throughout the animal kingdom, ranging from insects to primates, where males compete primarily by sperm competition[5,6].

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Submarine hot springs and the origin of life

SIR—Miller and Bada[1] argue against the idea[2] that hydrothermal vents at ocean-ridge crests would have provided suitable environments for life to originate. To their arguments one can add the lack of long-term stable microenvironments that would presumably have been needed for "biochemically inept"[3] early replicators[4] — of whatever chemistry[5]. But similar, less extreme environments are known[3,6] and could have provided suitable sources of chemical energy and nutrients as well as stable 'culture chambers'.

We have reported[6,7] fossil hot spring structures formed below 150 °C at the vent sites of 360-million-year-old hydrothermal systems driven, not by magma, but merely by heat stored in the Earth's crust[8]. These fossil vents consist of pyrite (FeS_2) tubes between 0.1 and 10 mm in diameter[6] associated with hemispherical botryoids also made of pyrite.

We have reproduced similar morphologies by passing ferrous and ferric chloride solution through a 0.5-mm aperture into a sodium sulphide solution at room temperature. Precipitated membranes in the form of narrow iron sulphide tubes and globules were the immediate result[9]. These crystallized to pyrite within 6 months.

Metallurgical separation of metallic sulphides in the froth flotation process exploits the affinity between sulphides and oils[10]; pyrite is particularly hydrophobic. Thus organic matter carried in hydrothermal solution might have adhered to, and collected in, porous iron sulphide traps. Within such locally hydrophobic environments it becomes possible to see how condensation reactions such as the polymerization of amino acids might have been brought about. It is known that amino acids can be condensed on dehydrated clay surfaces[11]. As for the original source of organic molecules, the discovery of abiogenic glycine in Red Sea hydrothermal brine pools[12] illustrates the organic–synthetic competence of mild hydrothermal environments.

It is not known whether conditions 4 × 10^9 years ago were conducive to the formation of pyrite chimneys, although Lake[13] has argued for the extreme antiquity of sulphur-metabolizing thermophilic organisms. We conclude that the arguments for the origin of life being associated with submarine hot springs remain strong enough to encourage further exploration and experimentation.

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Equable climate in the early Archaean

SIR—The impact of 20–35% lower solar luminosity on the climate of the early Earth has been discussed for almost thirty years. There is no geological evidence for early, near-global, glacial conditions[1] and climate models indicate that defrosting an (almost) completely glaciated planet requires much greater increases in solar luminosity than have occurred. Solutions to the paradox of enhanced early surface temperature despite reduced solar luminosity are radiative: either more of the (reduced) incident solar radiation must be absorbed or more of the emitted infrared radiation must be trapped. Solutions of the latter type are based on arguments that one or more greenhouse gases existed in much larger amounts in the early Archaean atmosphere than in the present one. The former suggestion that the planetary albedo was lower has, until recently, been impossible to examine because in the early Archaean, the Earth was almost certainly dominated by a near-global ocean[2].

We have integrated the standard coarse resolution Bryan–Cox–Semtner global ocean model[12] for 12 years on a Cyber 205. The only land (Fig. 1) comprises a peninsula and an island, consistent with the estimated timing of continental differentiation[2]. After 12 years the upper ocean layers had reached equilibrium. This annual-mean forcing spin-up integration used the Haney[4] surface boundary condition (newtonian cooling). The annually integrated ocean climate (Fig. 1) exhibits a strong equatorial jet, gyres near the peninsula, and sea surface temperatures of ~ 289 K at the equator with a less steep latitudinal temperature gradient than that for the present day.

The total heat transport towards the poles in the simulation differs considerably from simulated present-day values (Fig. 2), calculated with the same global ocean model (but for present-day land configuration)[5]. Poleward transport has maxima at about 60° and 20° in both cases but there are differences in magnitude: the Archaean total (largely diffusive) transport has maximum values of ~ 0.5 × 10^{15} W, compared with the modern maximum diffusive transport of ~ 1.4 × 10^{15} W (Northern hemisphere) and ~ 5.0 × 10^{15} W (Southern hemisphere). It is this much reduced poleward transport of heat that is partially responsible for oceanic equatorial temperatures not too different from today's. Indeed a simple atmospheric energy balance climate model predicts equatorial temperatures for the Archaean that are well above freezing, if the meridional transport term is reduced from the present-day value in the ratio suggested by Fig. 2.

We have subsequently performed a more complete simulation by replacing the Haney condition with a full time-dependent surface energy budget and a simple ice model. The immediate response in the Archaean simulation is a decrease in sea surface temperature of ~1.5 K and the winter–summer temperature difference over an annual cycle is ~ 0.8 K near the equator and 0.5 K in mid-latitudes. But it is important to recognize that neither the 12-year annually forced integration nor the annual-cycle diurnally forced integration are equilibrium simulations; equilibration requires very much longer integration times. An extended box diffusion model, requiring ~1/10,000 of the computer resources needed for the ocean general circulation model (OGCM), with three latitude bands per hemisphere gives relatively good agreement with the OGCM both temporally and at all latitudes; for example, we obtain low-latitude January temperatures of 288.0 K for the box model at 0°–30°, compared with 286.4 K for the OGCM at 15 °S, and mid-latitude July temperatures of 278.5 K for the box model of 30°–60° as opposed to 279.5 K for the OGCM at 40 °S.

We have considered a single aspect of

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