nanotubes is high and the current challenge is the search for a low-cost industrial method of preparation of these nanotubes. Recently, Kang *et al.*[11] have reported a one-step water-assisted synthesis of high-quality CNTs directly from graphite. For the transformation of graphite into pristine CNTs, two things are essential: (i) to get necessary power that can make the graphite sheets crimp and (ii) to wrap the honeycomb pattern back on top of itself and let the edges join by the C–C σ-bonds.

Kang *et al.*[11] employed a water-assisted method that realizes the above two processes. Graphite rods were rapidly heated to red-hot (above 800°C) in air and then dipped into cold water (0°C). The water turned a little turbid after a slight explosion. The process was repeated several times and MWNTs formed were separated. From TEM measurements, the yield was found to be > 40%. On immersing the hot graphite rod into cold water the temperature of the graphite surface was lowered, but the internal temperature was still very high that provided enough power for the graphite sheets to crimp (Figure 1). Though it is well known that many complex chemical reactions occur between red-hot carbon and water, the detailed mechanism for the formation of CNTs in such conditions is yet to be understood. However, it seems that water plays an important role in the connection of the edges[11].

Recently, a chemical route to carbon nanoscrolls (with two free edges, one inside and the other outside the tube) has been reported[12]. In this method graphite was intercalated with potassium and exfoliated with ethanol. Upon sonication, the exfoliated graphite sheets curled onto themselves, forming nanoscrolls. That the product obtained by the one-step water-assisted process[11] was MWNTs and not the simple carbon nanoscrolls was established from the following observations: (i) TEM image shows that the wall-to-wall distance is uniform, 0.34 nm, which is akin to the 002 distance of graphitic carbon; (ii) the electron diffraction patterns of the products are single crystalline, which is not possible with a scroll; (iii) the Raman spectral bands resemble those reported for nanotubes with concentric multi-wall layers of hexagonal carbon lattice.

The study by Kang *et al.*[11] reveals that graphite can be transformed into pure and high-quality pristine CNTs using a one-step treatment, with the assistance of water at atmospheric pressure without any catalyst.

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Methane fuse for Cambrian mass evolution, volcanism for mass extinction: Proponents review their hypotheses

A. V. Sankaran

Life began on earth, close to 4 billion years (b.y.) ago, but its progress to higher forms was haltingly slow to begin with, and suddenly at the end of the Proterozoic period, about 550 million years ago, there was a burst in its progress. Complex multicellular forms began to evolve at a rate some 20 times the rate observed in the younger Mesozoic period, triggering a veritable 'evolutionary big bang' or the 'Cambrian explosion of life'. The march of life thereafter was not unimpeded either for it periodically experienced extinction *en masse*. Explanations, so far, for these phenomena were not entirely convincing, but now, in the wake of accumulating new data, two papers published recently have underscored the role of sudden and voluminous bursts of methane for the Cambrian evolution[1] and the periodic flood basalt volcanism in earth's history for repeated global extinction of life[2].

In 1997, Kirschvink, along with Ripperdan and Evans[3], had claimed that a unique event, known as the True Polar Wander (TPW) (see Box 1) involving change in direction of earth's spin axis, relative to the continents, occurred intermittently during Vendian–Cambrian period and this promoted development of congenial scenarios for rapid expansion of life. They explained how the balance of mass within the earth was disturbed due to the TPW and how all continents remaining stable till then were forced to shift to different latitudes. These TPW shifts, unlike those that occurred in later geologic times, were unique in earth's history, as they had resulted from interchange events in earth's moment of inertia tensor termed – Inertia Interchange True Polar Wander or IITPW (see Box 1). The authors suppose that at least half of Earth's continental lithosphere rotated by nearly 90° between 534 and 505 m.y. ago. Their movements were rapid (≥ 30 cm/yr), far exceeding tectonic motions of a few cen-

Box 1. True polar wander.

Studies of earth's magnetic field (palaeomagnetic data) have enabled the palaeogeographic reconstruction of various continents at different geologic periods relative to earth's magnetic north pole. Such studies by Kirschvink and colleagues[3] revealed that during a short period (540–515 Ma) in the Cambrian, some of the continents had shifted very rapidly to new positions and virtually the entire earth's surface turned by 90°. They theorized that these motions were due to True Polar Wander or TPW, whereby continents were forced to reorient themselves rapidly in a few million years to achieve new positions of stability in the wake of shifts that occurred in the earth's spin axis.

TPW motions arise from redistributions of mass within plastically deformable earth[25]. The spin axis, which keeps earth in a stable rotation, is its principal moment of inertia. However, due to density shifts or mass redistribution inside earth, it may so happen that the spin axis is no longer the principal moment of inertia and an intermediate moment of inertia now becomes the principal axis. Thus, the erstwhile spin axis will be unable to keep earth's spin stable and will be forced to shift its axis of rotation to the new or an intermediate position to achieve stability. In other words, there is an inertial interchange and this event is termed by Kirschvink's group as Inertial Interchange True Polar Wander or IITPW. They conceive that this IITPW can take place in 'discrete bursts of TPW up to 90° in geologically short intervals of time if the magnitudes of the intermediate and maximum moments of inertia cross'[3]. During such events, the solid part of the earth, i.e. the mantle and crust, are forced to move together rapidly relative to the remainder of earth, i.e. the core, at a viscosity layer like the *D″* layer. There have been multiple events of this nature during Vendian and Cambrian which are clearly reflected in the palaeomagnetic pole positions for some of the lands of the times, features that defy explanation by other geological processes. Climatic shifts, changes in sea level, ocean circulation patterns and in the biosphere are some of the impacts of such TPW-induced reorientation of lands.

timeters per year, pushing in geologically rapid time scales, lands in cold wet regions of high latitudes into tropical equatorial zone and *vice versa*[3]. Such climatic shifts are supposed to have disrupted regional ecosystems and created isolated communities, which are considered ideal layout for rapid diversification of life through natural selection.

Inferences by Kirschvink and colleagues about these shifts, which coincided with the Cambrian biological diversification[3,4], are supported by uranium-lead isotope ages[5,6], paleomagnetic data and by the nature of sedimentary rocks occurring at Precambrian–Cambrian and Cambrian–Ordovician boundaries in Australia, India, Africa, Antarctica (assembled as Gondwana continent) as well as Laurentia (present day North America) and Greenland. However, critics felt that the continental migrations could as well have taken place over larger periods and that the biotic and climatic changes due to TPW lacked confirmation. Also, the evolution that climaxed in the Cambrian period had actually begun much earlier, towards close of Precambrian, and hence according to them, the TPW event at best must have merely hastened its progress[7,8].

Expanding earlier views[3], Kirschvink and Raub have now identified certain bio-geochemical events occurring subsequent to the TPW-induced continental shifts, which, they say, aided rapid expansion of life in a short period of < 100 million years during the Cambrian[1]. Their fresh conclusions were based on fluctuating values of $\delta^{13}C$ in the marine carbonates of the period. Such fluctuations of the carbon isotopes, occurring almost once in a million years during early Cambrian, reflected trends in marine biosphere[9], climate, geomorphic processes[10] and shifts in deep-ocean current circulation, all of which, the authors explain, are related to TPW[3]. Following the rifting and breakup of the early supercontinent Rodinia between 850 and 750 Ma, new sedimentary basins formed along the rifted continental margins and these basins received vast deposits of organic carbon derived from the lands[11]. Their conversion to methane by methanogenic archaeobacteria and the release of voluminous amounts of accumulated methane into the atmosphere, the authors conclude, led to global warming and initiated the proliferation of life.

Tracing the sequence leading to the 'explosion of life', Kirschvink and Raub explain how during the first phase of TPW in the Vendian times, Laurentia and the rifted margins of West Gondwana moved to high latitudes (above 60°). Here chilly conditions of ocean bottom waters converted the methane accumulations in the bottom sediments to solid methane hydrates. These hydrates are stable only at < 7°C and > 50 atm (300 metre ocean depth) but destabilize above this range. For example, owing to the continuous sedimentation from above, they get pushed to further depths where under the prevailing higher temperature due to geothermal gradient they become gaseous and remain trapped under very high pressure in the sediments, virtually as 'time-bombs'. Even a small earthquake or any IITPW-induced seabed disturbing geological process could trigger sedimentary failure and precipitate explosive destabilization of the hydrates. Such destabilizing events are believed to have occurred when lands were pushed into warm equatorial region and all hydrates held at ocean bottom and as terrestrial permafrost were released in large amounts into the atmosphere. Methane being nearly 20 times more potent than CO_2 in global warming ushered in ideal biochemical conditions favouring faster biochemical metabolism kinetics helped by the higher temperature and thereby led to burst in speciation. The multiple IITPW events that occurred exposed different continental margins to climatic excursions at different times which is evident from the intermittent perturbation in the carbon isotopes, a dozen times between 575 and 500 m.y. or the Vendian–late Cambrian period[3,12].

While the massive methane release is attributed to the Cambrian explosion of life, a recent contribution by Courtillot and Renne[2] has highlighted how flood basalt volcanism was responsible for 4 out of 7 major mass extinctions in the last 300 million years[13]. In fact, they have found that every flood basalt volcanism in earth history was associated with either a minor or the second-degree extinction or a major climatic event or an ocean anoxia. The volcanism–extinction coincidences have been noticed more than three decades ago[14], but at that time their correlation could not be endorsed by reliable ages and paleomagnetic data. Further, in the wake of the proven bolide-impact produced end-Cretaceous or K/T mass extinction, interest of the scientists got diverted to searches for similar evidences for all other extinction events that the earth witnessed[15], though their attempts did not yield indisputable results[16]. However, pursuing their conviction about the role of volcanism in producing mass extinctions, Courtillot and Renne, in their latest résumé have shown how massive flood basalt volcanism could drastically affect the earth's ecosystems, its hydrosphere and atmosphere through emissions of aerosols, CO_2, methane, SO_2, HF and other climate-modifying volatiles. They have elaborated how these could extinguish life through a chain of reactions like global warming, ocean anoxia, reduction of atmospheric oxygen and changes in the ocean current circulation, the harsher their impact the greater the magnitude of the volcanic event[13,17,18].

Continental flood basalts (CFB) or traps (which along with oceanic plateaus are termed Large Igneous Provinces or LIPs) are relatively rare massive volcanic flows. These are essentially tholeiite basalts, erupted rapidly in a mere ~10 million years and the bulk (about 80%) of the flux emplaced in just about a million years[2]. They are believed to be manifestations of plume-related volcanism and in earth's history as many as 31 well established CFB-events have been recognized[19,20], which include possible LIPs dating back to 3.8 Ga, remnants of which are today seen as ultramafic and mafic volcanics of greenstone belts around the world. Presently only a dozen of them, erupted in the last 300 million years, are preserved over both continental and oceanic lithosphere[2] (Figure 1).

Courtillot and Renne have evaluated the duration of eruption, their spread, volume, impact on climate, ecology and biosphere for 14 well-known LIPs and concluded that, (i) all major extinctions since mid-Cambrian (300 m.y. ago) correlate well with trap eruptions whereas, only the end Cretaceous or K/T mass extinction event exhibits a clear meteorite impact connection; (ii) biologic and climatic disruptions are associated with every flood basalt event but these are absent in several recorded extraterrestrial impacts. Further the claimed extinction of living species through adverse climatic and ecological changes due to dust haze shutting out sunlight during the K/T bolide event is doubted[21]; (iii) Deccan volcanism was already underway since 2–3 million years prior to the K/T impact and therefore this event must have only hastened the extinction of species already stressed by volcanism[22–24]; (iv) So far, the following CFB have shown compelling evidence to link with extinction events (Figure 1) – Siberian traps (~250 Ma) and Permian/Triassic (P/T) extinction, Central Atlantic Magmatic Province (~200 Ma) and Triassic/Jurassic (T/J) extinction, Deccan (~65 Ma) and Cretaceous/Tertiary (K/T) extinction and Emeishan Traps (~258 Ma) and the mid- to late-Permian extinction; (v) mass extinctions can be graded as ultra-short caused by bolide impacts, geologically catastrophic and slow (10^5–10^6 yrs) caused by flood basalts and slow (10^7 yr) induced by regression and transgression of seas[2].

While earthbound or endogenic causes undoubtedly appear to have spurred Cambrian explosion of life, there is an endless debate about which of the two main contenders – volcanism or exogenic earth-impacting bolides was responsible for the mass extinctions. A consensus on this issue is difficult, as long as competing evidences for the two 'killers' are ill balanced. This pertinent point was highlighted by Walter Alvarez in the Rubey Colloquium recently[16], and he showed how in terms of preserved areas for evidences, CFBs present a better scenario with their availability spread over 10^5–10^6 km^2 as against 10^3–10^4 km^2 only for impacts. Secondly, impact events are of short duration and hence chances for worldwide signatures could only be sparse or likely to be diluted in the strata and often masked or falsified by CFBs whose eruptions are spread over a few million years encompassing the impact event[13]. Perhaps, as observed by Courtillot and Renne, CFB volcanism may have been the main agent for Phanerozoic (Cambrian–Recent) mass extinctions, and impacts for extinction in earth's first billion years. However, unless and until a global effort to compile and assess various evidences for these two major agents of mass extinctions is undertaken, impact versus volcanism debate will remain inconclusive.

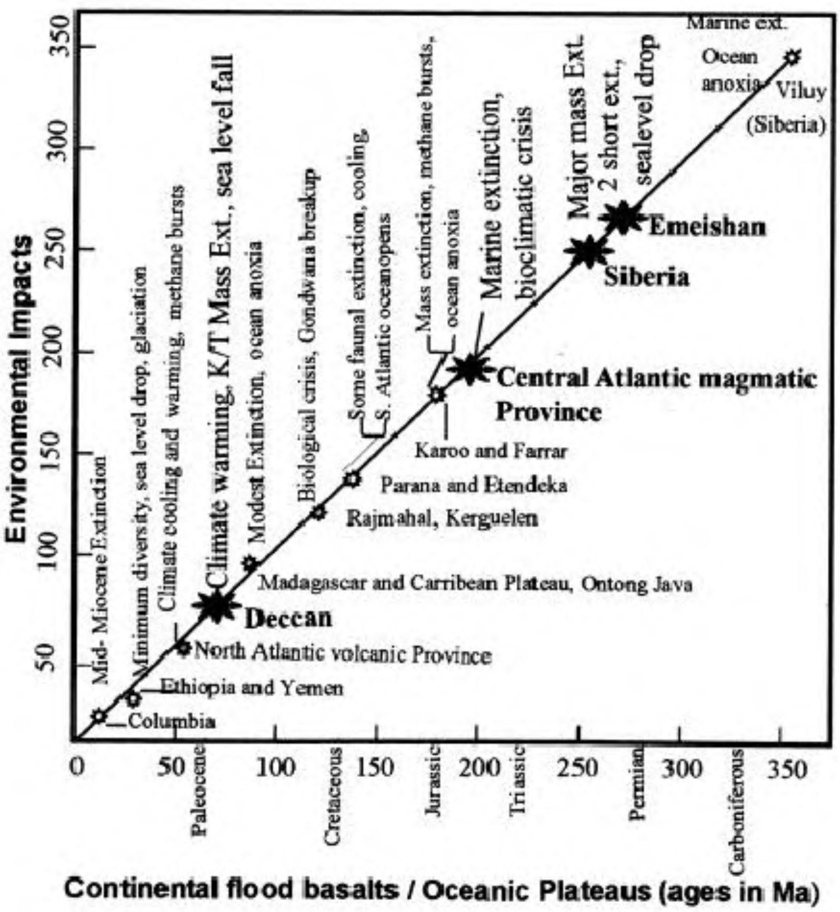

Figure 1. Major continental flood basalts (CFB) or oceanic plateaus during last 350 million years and their impact on the environment. Larger dots represent the four major extinction events coinciding with CFB volcanism. (Adapted from ref. 2.)

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FROM THE ARCHIVES

CURRENT SCIENCE

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Science and the Censor

Scientists in general and physicians in particular will be disturbed by the correspondence which has passed between the postal censor and Dr. J. McKeen Cattell, Editor of *Science*, and which appears in the current issue of that Journal. That censorship in war is necessary no one will deny. But was the censor justified in deleting from *Science* an item on a new sulfa drug which can be used with good effect in such intestinal infections as dysentery, because our enemies in tropical regions might learn how to return the afflicted men rapidly to the fighting line? From time immemorial military surgeons have made no distinction between friend and foe in dealing with wounds and disease. In 1917 both the Surgeon-General of the Army and the Secretary of War decided that for humanitarian reasons publication of information about an antitoxin developed in this country to combat the bacillus of gas-gangrene, then highly destructive on the Western Front, was permissible. Thousands are now dying of typhus in occupied Middle Europe, but if the censor has his way they cannot be saved by the dissemination of any new knowledge acquired here.

We detect no such narrowness of view in the few German medical and scientific publications that have reached this office since the attack on Pearl Harbor, nor in the pages of *Nature*, which is apparently permitted to exercise its discretion and which prints communications of the very type that have been expunged from *Science*. The censor was certainly on slippery ground when he deleted references to indium because that metal can provide a satisfactory lining for shaving-cream and tooth-paste tubes. The Germans know as much about indium as we. So with the suppression of an item on a method of spraying walls of mines to prevent mercury poisoning. Some of the material to which the censor objected in the case of *Science* had been published in newspapers from Maine to California, so that nothing whatever was gained by deletion. To make matters worse, there is no appeal from this decision.

Probably Dr. Cattell is right in holding that the editors of scientific periodicals are better judges of what may or may not be of value to the enemy than technically incompetent postal authorities. If the policy to which he objects is carried out consistently, new scientific books and periodicals must be suppressed. Astrophysicists, biologists, plant and animal breeders, organic chemists who are trying to isolate vitamins and hormones, designers of new electron microscopes, inventors of materials that will resist fire, mathematicians who devise techniques that can be applied in solving the problems of designing engineers—all make discoveries that have some application in totalitarian war.

– The New York Times