guidance system resident in the equipment bay. It guides the vehicle till the injection of spacecraft into orbit.

The main on-board instrumentation packages used for telemetry, tracking and command are: PCM/S-band telemetry systems, S-band range and range rate transponders and C-band transponders, besides a host of power and signal conditioning packages. PSLV employs a large number of stage auxiliary systems for stage separation, heat-shield separation, jettisoning, etc.

The 294 tonne 44.4 metre tall PSLV lifted off from the launch pad at Sriharikota with the ignition of the first stage along with four strap-on motors. The remaining two strap-on motors ignited about 25 s later. It may be recalled that in the previous flights the core first stage and only two of the six strap-on motor were being ignited at lift-off and the remaining four ignited about 30 s later. This change of ignition sequence results in improved payload capability for the launch vehicle. In the flight sequence, the first set of four strap-on motors separated as planned at 68 s after lift-off and the second set of two strap-on motors separated at 90 s. The first stage separated at 119 s and the second stage ignition occurred immediately. The heat-shield was jettisoned at 159 s at an altitude of about 128 km after the launch vehicle had cleared the dense atmosphere. The second stage separation and the third stage ignition occurred at 282 s and the third stage separated at 501 s from lift-off. The last stage ignited after a long coasting at 602 s. The fourth stage cut-off occurred at 1037 s, followed by the injection of IRS-1D into orbit.

The closed-loop guidance system came into effect at about 168 s after lift-off as planned and guided the vehicle till the satellite injection. The spacecraft was placed in orbit in a three-axis stabilized mode with guided injection.

IRS-1D is the fourth of the ISRO-built operational Indian Remote Sensing (IRS) satellites. It is the first operational satellite to be launched by India's own launch vehicle. The previous operational IRS satellites, IRS-1A, IRS-1B and IRS-1C were launched by erstwhile USSR/Russian launch vehicles. IRS-1D is identical to IRS-1C except for some improvements. It has three cameras on board:

- A Panchromatic camera (PAN), which is a high resolution camera with 5.8 m resolution, operating in PAN chromatic band with a swath of 70 km; it can be steered up to ± 26° across-track, thus enabling stereoscopic imagery and revisit capability.
- A Linear Imaging Self-scanning Sensor (LISS-III) operating in four spectral bands, three in Visible/Near Infrared (VNIR) range and one in Short Wave Infrared (SWIR). It provides a ground resolution of 23.6 m in VNIR bands and 70.8 m in the SWIR band, with a swath of 142 km and 148 km, respectively.
- A Wide Field Sensor (WiFS), a coarse resolution (189 m) camara covering a wide swath of 810 km.

Note. The 10 November 1997 issue of Current Science will contain pictures beamed by IRS-1D.

– Editors

RESEARCH NEWS

Polar wander and the Cambrian biological leap

A. V. Sankaran

Two major episodes in the march of life on Earth are well debated and much written about – one of them pertains to the mass extinction during the Cretaceous–Tertiary times (an extinction event, strangely, more popular than the one of much greater magnitude that took place during the Permian–Triassic times); and secondly, the mass evolution of new and complex life forms during the Cambrian period. For millions of years since life on our planet first began[1], some 4 billion years ago, their evolution to higher forms was very slow. Almost towards the end of Precambrian, when ninety per cent of geologic time was over, metazoans or the multicellular life forms began evolving around 600 m.y. ago. This period was well marked by the enigmatic Ediacaran fauna, that had set the scientists discussing, for a long time, their precise age[2,3] and also whether they were plants or animals[4,5]. But, suddenly, around ~544 m.y. ago[6], during early Cambrian period, there was an evolutionary explosion (Figure 1), referred by paleontologists as the Cambrian 'Big Bang', which extended up to the middle of Ordovician (500–430 m.y.). The new life forms that emerged during this period had the basic patterns or templates for almost all groupings of vertebrate and invertebrate animal kingdoms yet to evolve in the future eras. But Wray *et al.*, of the State University of New York (Stony Brook), on the basis of nucleotide sequence studies, put the origin and diversification of the major phyla between 1000 and 2000 m.y. They assert that the lack of fossil records prior to the big-bang period is no negative evidence for the diversification of animal species since this may be due to preponderance of soft-bodied forms then and, perhaps, due to unsuitable fossilizing conditions. However, the development of skeletonized taxa during subsequent early to mid-Cambrian times[6,7], led to better fossilization, and hence, their abundance in the strata of the period. The rapid pace of evolutionary march during this period had caught the attention of paleontologists and evolutionary

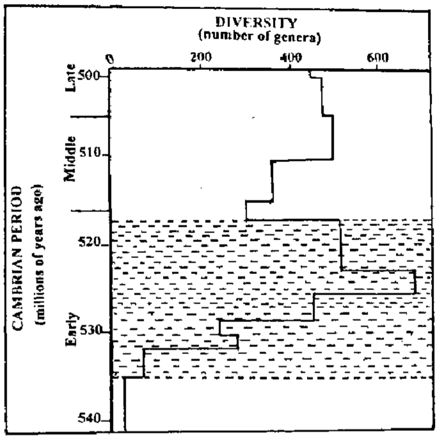

Figure 1. Generic diversity during early Cambrian coinciding with proposed true polar wander (stippled area) (after Kirschvink *et al.*[14]).

theorists who linked this spurt to some intrinsic causes, like genetic and biochemical changes, and a few extrinsic ones, such as alterations to the chemistry of environment, climate, ocean and atmosphere, as well as to development of favourable conditions in the wake of mass extinction; but none of these was acceptable to all.

According to some of the leading biologists – Jordic-Garcia Fernandez (Universitat de Barcelona, Spain), Peter Holland (University of Reading, UK), Douglas Erwin (Museum of Natural History, Washington D.C.) and David Jablonski (University of Chicago), certain uncommon genetic changes, like gene doubling, in a set of critical genes called *Hox clusters*, in some ancestor that lived around 565 m.y. ago (*Amphioxus*-like animal), served to trigger the expansion of body plans and the great biological leap of the Cambrian period was initiated. A second such gene doubling, during a later era, resulted in another outburst of more complex forms of life, many of which are still surviving[8,9]. Geerat Vermeij, formerly of University of California (Davis), linked these evolutionary pulses to massive volcanic episodes, particularly the undersea ones, around 550 m.y. during early Palaeozoic era, and again, around 200 m.y. in the Mesozoic era[6]. According to him, these submarine volcanic events led to either closure or creation of ocean basins, destruction of land, and more importantly, global greenhouse effects through release of large amounts of CO_2. The warmer climate that followed, released through the processes of weathering and erosion of continents, plenty of raw materials for meeting the nutrient and energy needs for enhanced metabolism among the life forms, and thus prepared the right scenario for the onset of the biological revolution. However, Andrew Knoll of Harvard University (Cambridge), as well as Donald Canfield and Andreas Teske of the Max Planck Institute for Marine Microbiology (Germany), view this great biological leap forward, from a different perspective and feel that an increase in O_2 levels (by 5–18% the present levels) in the atmosphere during 1000–543 m.y. period may have sparked the latter revolution[10,11]. They based the oxygen-enrichment hypothesis on indirect evidences through carbon isotopes[12,13] in buried organic matter (organic carbon burial rate increased strongly during late Precambrian, shielding their oxidation and thus increasing the O_2 levels) and sulphur isotopes[11] in biogenic sedimentary sulphides. The increase in O_2 was possibly instrumental in the manufacture of collagen (protein connective tissue), cartilage and finally, bone, all crucial for the build of advanced body framework of the larger-sized animals that started appearing.

A geophysical approach to the Cambrian revolution has been put forward recently by researchers at the California Institute of Technology[14], who say that this 'big bang' was associated with 'true polar wander' during the Precambrian times resulting in a 90° change in the direction of Earth's spin axis, relative to the continents. They speculate that this was the outcome of a major reorganization among the tectonic plates existing at that time, and consequent imbalance of the mass distribution within the planet. On a spinning planet, the movement of such positive mass anomalies towards equator, is in conformity with the laws of physics, and this is well illustrated by Tharsis volcanic province on Mars, which from its original location elsewhere, had moved to the planet's equator; similarly, they cite the largest mass anomaly on Earth, centered over New Guinea presently right on the equator, and the current movements of some of the tectonic plates also[15]. Thus, according to the Caltech group, regions that were previously N and S poles got relocated to the equator and the tropical weather of these latitudes, in combination with other favourable factors, led to evolutionary bursts (Figure 1).

The link between mass imbalance and 'polar wander' leading to reorientation of Earth's spin axis (poles) has been under study by geophysicists for several decades[16,17]. The shifts of poles due to 'movement of Earth with respect to its axis of rotation on long time scales (10^3 to 10^9 years) is called polar wander' in contrast to 'shorter term periodic or transient fluctuations which are called wobble'[15]. 'Episodes of rifting, continental drift and subduction', according to Don L. Anderson, the eminent geophysicist, 'follow periods of rapid polar wandering, which follow periods of continental stagnation.'[16] This subject of polar wander had gained considerable impetus after the development of palaeomagnetic studies during the seventies; the latter enable the geologist to infer the ancient or palaeo-orientation of the continents and their movements during those geologic times by plotting the direction of magnetic N–S poles (magnetic polarity-pattern) preserved in the magmatogenic iron-bearing minerals in the rocks formed during that period (these align themselves in the north–south directions prevailing at the time of their crystallization). The mass imbalance can also come about as a result of advance or retreat of glaciers[17], large magnitude earthquakes[18], density heterogeneity in the mantle caused by subducting plates of crustal segments and chemical stratification in the mantle due to layers of refractory residues, settled cumulates and residual fluids[16,18–21]. The resulting variations in mass distribution induce polar wander during which Earth stabilizes itself over a period of time. Though this shift in the axis of rotation is usually slow, rapid and large amplitude wander by about 90° can also be expected[22,23].

According to the Caltech group, true polar wander forces Earth to equalize mass distribution in comparatively rapid time scales by collective movement of entire solid part of planet, avoiding the internal shearing effects that impose a speed limit on conventional plate motions. The rapid movements of continents are due to 'interchange event in

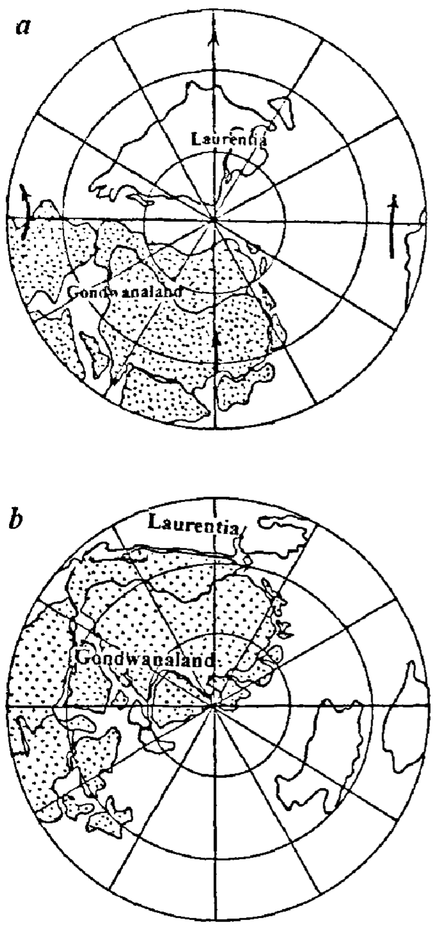

Figure 2. View (from South pole) of Earth (*a*) before and (*b*) after the proposed global tilt (after Kirschvink *et al.*[14]).

Earth's moment of inertia tensor', and both the mantle along with the overlying lithosphere move together, quite unlike plate tectonic motions involving the latter only. In the process of tilt, the entire Earth retains the original spin axis in relation to the plane of solar system. They say that such reorganization can result in large polar wander, particularly on a planet like Earth, with a major and stable mass anomaly on the equator and a more equal distribution of mass elsewhere; only slight changes of the smaller masses would be sufficient to bring about large motions. A shift, even up to 90° can be envisaged, and an inertial interchange becomes inevitable, if as a result of such changes, the maximum moment of inertia (about which the planet spins) became less than the intermediate moment of inertia (which is on the equator)[16].

As per geological evidence the Caltech group had gathered, the breakup of the megacontinent Rodinia and formation of the Gondwanaland took place almost simultaneously. Stratigraphic records of the period indicate closure of some of erstwhile oceans[24] and this is exemplified in the occurrence of ophiolites (volcanic rocks), which once formed ocean floors. These are now found exposed well inside continents such as Australia and Antarctica which were once part of the early (pre-Gondwana) mega-continent Rodinia. U–Pb isotopic ages[2,3] along with palaeomagnetic data of rocks from a number of continents now exposing the Precambrian–Cambrian and Cambrian–Ordovician boundaries, chiefly from Australia, besides other constituents of Gondwanaland like India, Africa, Antarctica as well as from Laurentia, the present day North America and Greenland have also indicated shifting of continents rapidly (≥ 30 cm/year), at rates far exceeding the normal plate tectonic motions[14,16].

The Kirschvink group says that over the 15 million years, the polar wander event took, rapid climatic changes must have taken place, with the lands enjoying cold climate moving into the tropical zones, accompanied by swings in oceanic circulation, disrupting regional ecosystems and breaking them down into smaller and more isolated communities. According to evolution-experts, such small communities constitute the ideal size for evolutionary breakthroughs. It is now known, on the basis of carbon cycles[25], that these major changes in oceanic circulation happened during early Cambrian, almost every million years, a time interval sufficient for natural selection to operate constructively. These cyclic episodes must have led to the diversification of species and evolution was supposed to have proceeded some twenty times faster than the normal rate.

The Caltech group's work, stretching over two decades, was based on palaeomagnetic studies using ultra-sensitive superconducting magnetometers and cover geological sections of Precambrian to Ordovician periods. Their inferences about the motions also agree with the types of marine sediments typical of the climatic zones they sojourned-carbonates in the tropics, clays and clastics in the high latitudes. Australia, according to their studies, provides the best-preserved sediments of this age from all Gondwanaland. They have indicated that this entire continent rotated counterclockwise by nearly 90°, starting at about 534 m.y. ago and ending during mid-Cambrian. Likewise, North America moved rapidly from its Precambrian position in the Southern Hemisphere to near about equator at about 518 m.y ago (Figure 2). Africa, Antarctica, Australia, India and South America (Gondwanaland) moved rapidly across the Southern Hemisphere. Though minor polar wanders have been noted in recent geologic times, shifts that took place during the Cambrian times appear to be quite unique in Earth's history. In fact, their data imply that at least half of Earth's continental lithosphere rotated, rather abruptly, by nearly 90° between 534 and 505 m.y. ago[26].

The views of the Caltech group have, however, not convinced certain geologists who feel that a major inference has been drawn on a small set of data that can also be interpreted in other ways, for example, the continental migration can be stretched over a much longer period. The critics feel that the changes attributed to polar wander are yet to be proved and that they may, at best, be considered as a plausible hypothesis only. As for their connection to biological outburst during the period, some of the evolutionary experts differ and point out that the initiation for the evolutionary activities had begun much earlier, towards the close of Precambrian[7], and that the Cambrian polar wander merely aided this ongoing evolutionary bout.

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COMMENTARY

A statistically valid definition of bias is needed to determine whether the *Science Citation Index*® discriminates against third world journals

Eugene Garfield

From the inception of the *Science Citation Index*® in the sixties, the question of journal coverage has been widely, and often emotionally, discussed. Imagine the hubris of my suggesting in 1964, that 'only' a few hundred core journals would satisfy the needs of most readers. Since then, I have regularly published data demonstrating this concentration effect[1]. These periodic reports illustrate the well-known Law of Scattering[2] and the less known Law of Concentration, which I first discussed in 1971 (ref. 3).

Samuel Bradford's Law of Scattering was first developed to explain the dispersion of journal articles within specific fields. Later, I discovered this was true for science journals as a whole. In other fields of human endeavour, these phenomena are sometimes referred to as the 80/20 rule, Zipf's Law, Pareto effect, etc. Derek J. deSolla Price was well aware of these distributions which have been studied by B. C. Brookes[4] and many other bibliometricians[5].

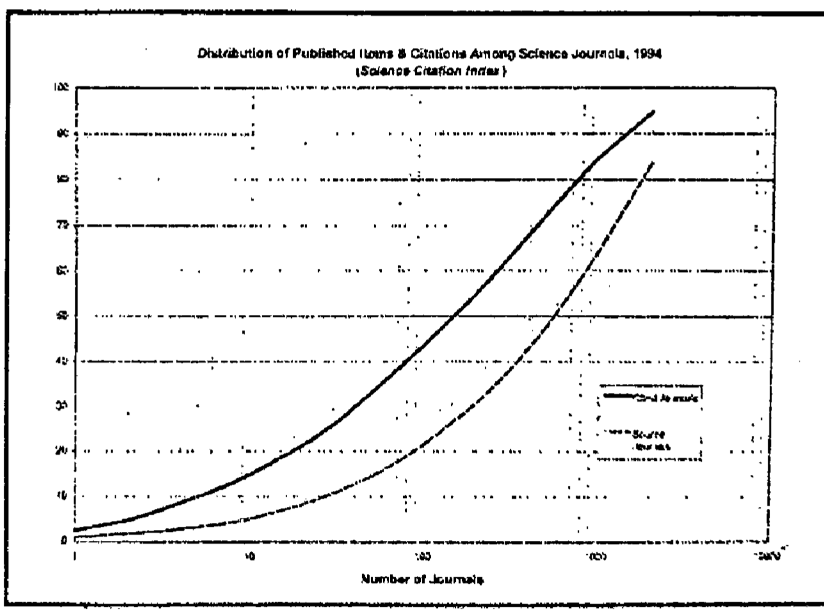

Figure 1.

Figure 1, reprinted from *The Scientist* article cited above, is important to the