The source of water on the early Earth

A. V. Sankaran

The accretionary origin of planets, more than 4.6 billion years ago, involved high velocity collisions of planetessimals, the embryos of planets. This process lasted for about 10^8 million years, and one such accreted silicate-rich body constituted our planet Earth. Even from its formative phase, the Earth is believed to have carried about 500–1000 ppm H_2O, which though relatively a small amount, is taken to support the 'wet accretion' hypothesis of our planet's beginnings[1]. Earth's upper mantle carries 200–500 ppm OH (by weight) within minerals like the pyroxenes and smaller amounts (1–50 ppm) within garnets, olivine and a few other minerals, together forming major repositories for the Earth's water, all these constituting just about 0.025% H_2O by weight, over the whole Earth.

The abundant presence of hydrous mineral phases in the Earth is taken to support the wet accretion hypothesis for its origin[2]. Some, however, doubt this origin as the accretionary embryos were rather close to the Sun for any water to have survived and hence Earth's surface is presumed to have been quite dry when it accreted first. It is also claimed that the snowline (the distance from the Sun beyond which liquid water is preserved) was closer during early Solar system times favouring retention of OH (ref. 3). Also, Earth's beginnings were known to have been highly turbulent, replete with recurrent bolide impacts, the heat from which could have boiled away whatever primary water the Earth had acquired. In spite of these known dry-birth scenarios, our Earth is referred as the blue planet, a description arising from the presence of abundant surface waters – the blue oceans. Obviously, the Earth must have acquired most of its water during the eras following its turbulent birth phase. Alternately, some are of the view that the snowline or the distance from the Sun beyond which surface water remains stable, was closer[3] during early Solar system which would have enabled retention of OH.

The origin of water on Earth has thus remained a much discussed subject and views in favour of both indigenous and exogenous sources have been proposed. Presently, it is assumed that the precursor objects or the embryos of the planets, bodies such as the chondrites, comets and interplanetary dust particles, all may have been the sources for Earth's water[4]. According to a view called the 'late veneer scenario', some of the water-rich comets and planetary embryos populating the Kuiper Belt, located ~ 5 a.u. away (one a.u. is the distance between Sun and the Earth) could have drifted inward and collided with the Earth, thus contributing its water[1,3,5,6]. However, this view was replaced when subsequent studies revealed that the terrestrial D/H isotopic ratio, a reliable ratio known to have remained unchanged in spite of the vigorous early Earth processes, is much higher than in the comets. Also, the ratios of their O, Os, Ar/H_2O and Kr/Xe isotopes are not mutually comparable, a strong indication that the building blocks of Earth must be different, perhaps unsampled 'Earth chondrites'[5,7]. In view of these findings, fresh searches were initiated by astronomers for tracking such water contributors and they soon detected quite a few water-rich bodies in orbit between Mars and Jupiter, some of which could be slowly nudged into earth-colliding orbits to deliver its water.

Among the assorted types of bodies orbiting in the asteroid belt, carbonaceous chondrites present in its outer regions, at a distance of 2.5–4 a.u. are generally water-rich and are known as hydrated carbonaceous chondrites[1]. These hydrated bodies were initially suspected to be comets because of their physical resemblance to them, but subsequent spectroscopic and other studies showed them to be different and their tail consisted of essentially water, supposed to have sublimated from its interior. These look-alike or 'pseudo-comets', are referred as 'main-belt comets' (MBCs), believed to have formed within the warmer regions of the inner solar system, inside the orbit of Jupiter. These MBCs have flat circular orbits unlike the elongated orbits of comets. Perturbations to their orbits induced by the neighbouring giant planets, Jupiter and Saturn are presumed to have pushed some these MBCs inwards only to be slowly pulled to collide ultimately with the Earth, resulting in the delivery of water. Estimations based on laboratory simulation of earth's formation indicate that this delivery of water by these asteroids occurred quite early, probably between the first 10 and 35 Ma of evolution when earth was about 50% of its current mass.

In 2005, a relatively large asteroid was sighted among MBCs and this was identified as Ceres having a spherical shape, the latter considered an indication of its differentiated or layered interior with a distinct crust and a core[1]. Also, from the asteroid's overall low density, it was inferred that its crust must be rich in hydrous minerals. Recent examination of the reflectance spectra through powerful infrared telescope had revealed absorption bands characteristic of water–ice and a few organic compounds present on one such large asteroid body, 24-Themis[8,9], orbiting the Sun at a distance of 3.1 a.u. The existence of such water-rich bodies has prompted the view that Earth's water may have come from the hydrated carbonaceous chondrites, besides from the solar nebula. This source seems likely since it is well known that comets and other water-bearing bodies were bombarding Earth during its early evolution.

The sustained presence, perhaps for thousands of years, of deposit of frost or ice uniformly over the regolith grains on the surface of 24-Themis, in spite of the latter's orbit so close to the Sun, though puzzling, is attributed to constant replenishment of OH from the asteroid's interior. Calculations, considering the distance of the orbit of 24-Themis from the Sun and presence of water over its various latitudes, its obliquities and corresponding temperatures indicate that the water present at a depth of even a few meters can survive for thousands of years[8,11]. This water is presumably the left over primary water that had accreted on to the asteroid when it first formed in the solar system[8,10,11]. Astronomers are now expecting to come across more such water-bearing asteroids, and incidentally, the recent find of water–ice and organics on another nearby 192 mile wide asteroid called 65-Cybele[7] has spurred their hopes for embarking even manned flights to explore such nearby bodies.

Scientists are now of the opinion that the water formed initially (primordial water), during the first billion years of Earth's evolution, must have been vapourized by the intense heat that had enveloped the early Earth during episodes of the late heavy meteorite (bolide) bombardment (LHB) 3.9 billion years ago. Therefore, they feel that it may be unproductive to search for this ancient embryonic water, which if at all present, must be locked up somewhere in the deep mantle. Considering the fact that the Earth had a turbulent beginning, all surface records of its early period including traces of the primitive water on the surface must have long been obliterated, except perhaps some retained as inclusions within a few of the early formed minerals like the 4.38 billion years old zircon grains that had crystallized around the time when Earth formed. These inclusions of quartz are considered good evidence for the presence of water even during the harsh environment that had prevailed over the early Earth. This aquatic medium is required for mineral crystallization and hence it is unlikely that all of the early water would have boiled away under the intense heat from the LHB collisions.

According to the current thinking, Earth acquired its water during the process of formation from the nebula stage till the accretionary phase, though the bulk could have come from the final phase of its accretion. The latter seems likely as seen from the D/H ratio, which is comparable to the members of the outer asteroid belt known to carry the building blocks of many planets. At the same time some scientists have expressed that similarity in the D/H of water in the carbonaceous chondrites and oceans does not necessarily support the origin of ocean's water from these chondrites, nor the discrepancy of D/H ratio a rejection of nebular origin of water[12].

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A. V. Sankaran lives at No. 10, P&T Colony, I Cross, II Block, R.T. Nagar, Bangalore 560 032, India.
e-mail: av.sankaran@gmail.com