can adjust their activity in relation to the changes in oxidative stress.

In the symposium VIII, Pravin Sharma (S.M.S. Medical College and Hospital, Jaipur) gave a talk on ‘Laboratory analysis in diagnosis and management of diabetes mellitus’. The speaker informed the audience that diabetes in Indians under different set ups suggests that the prevalence of the disease has grown ten-fold during the last 30 years from 1971 to 2001, much higher compared to any other ethnic group. By the year 2025, out of every 15 subjects with diabetes, there will be three Indians. This increase in prevalence of diabetes is due to metabolic and life-habit risk factors. The Diabetes Control and Complications Trial and UK Prospective Diabetes Study have demonstrated that optimization of glycaemic control reduces the risk of microvascular complications.

About 28 participants attended the conference. An exhibition was also organized along with the conference.

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RESEARCH NEWS

Natural radioactivity: Extant and extinct

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Two recent articles – one in *Nature* by Araki *et al.*[1] and the other in *Science* by Boyet and Carlson[2], are landmark contributions on the natural radioactivity of the earth – a phenomenon recognized shortly after the discovery of radioactivity of uranium ores in 1896 by Henri Becquerel. The *Nature* article with nearly 100 authors, is the first report on the present concentration of uranium and thorium in the entire earth, based on the detection of antineutrinos produced by the radioactive decay of these elements. The *Science* article is on a subtle isotopic signal left in the rock record by the fossil or extinct samarium isotope, ^{146}Sm and its implication for a profound chemical differentiation in the earth's silicate mantle within 30 million years (my) of solar system formation.

The two articles build on the following key assumptions. The specific mix of stable and unstable (radioactive) isotopes in the nebular cloud destined to form the solar system must reflect contributions from many different types of stars, including ‘last minute’ injections of short-lived nuclides (^{26}Al, ^{129}I, ^{146}Sm, etc.) from nearby supernovae. The uniform isotopic composition of many elements (not involved in nuclear transmutations) in terrestrial and extraterrestrial samples requires that different stellar components were thoroughly mixed in the nebular cloud before its condensation into the first formed solid objects (planetesimals) of the solar system. Primitive meteorites known as chondrites best represent the raw materials condensed from the solar nebula. The earth's overall chemical make-up at the time of its formation reflects that of chondrites, especially in elements refractory enough not to boil-off the planet during a possible high temperature phase very early on.

Of the numerous radioactive isotopes inherited by the earth at its formation, only six pertain to the two papers. They are listed in Table 1 together with their decay scheme-products-energy and half life (in my), where α, β, $\bar{\nu}$ are alpha, beta and antineutrino particles respectively.

The decay energy per nuclide in units of Mev is large in the nuclear scale, but extremely small in the human scale. One Mev (1.6×10^{-13} J) is less than a thoudsandth of the kinetic energy of a small ant crawling at a speed of about 2 mm/s. With the half-lives of ^{146}Sm and ^{235}U being much shorter than the age of the earth (approximately 4500 my), the former became extinct in the first 200–300 my of the earth's formation, while the latter has become nearly extinct now with a residual presence of only 0.7%. One wonders whether nuclear reactors and atomic bombs would have been possible had the half-life of ^{235}U been about 50% shorter. ^{146}Sm and ^{147}Sm decay by alpha emission directly to two stable isotopes of neodymium, ^{142}Nd and ^{143}Nd respectively. ^{40}K decays mostly and directly to stable ^{40}Ca, emitting a beta particle (electron) and an antineutrino in the process. Unlike alpha and beta particles, antineutrinos and their counterpart neutrinos have no electrical charge, almost no mass and interact exceedingly rarely with matter and hence are extremely difficult to detect. U and Th nuclides do not decay directly to the three stable isotopes of lead (Pb), but through a chain of intermediate radioactive daughter isotopes to produce a number of alphas, betas and antineutrinos, and much higher decay energy.

A particular combination of decay products, energy and half-life is unique to each radionuclide as mediated by extremely short-range nuclear forces. Hence it is remarkable that they seem to be purpose-created for both priming and timing the physical and chemical processes in the earth on all spatial and temporal scales. The daughter nuclide with a genetic line-

Table 1. Radioactive isotopes relevant to the two papers

$^{146}\text{Sm} \rightarrow {}^{142}\text{Nd} + \alpha$	(2.55 Mev, 103)
$^{147}\text{Sm} \rightarrow {}^{143}\text{Nd} + \alpha$	(2.31 Mev, 106000)
$^{40}\text{K} \rightarrow {}^{40}\text{Ca} + \beta + \bar{\nu}$	(2.31 Mev, 1250)
$^{238}\text{U} \rightarrow {}^{206}\text{Pb} + 8\alpha + 6\beta + 6\bar{\nu}$	(47.4 Mev, 4468)
$^{235}\text{U} \rightarrow {}^{207}\text{Pb} + 7\alpha + 4\beta + 4\bar{\nu}$	(45.2 Mev, 704)
$^{232}\text{Th} \rightarrow {}^{208}\text{Pb} + 6\alpha + 4\beta + 4\bar{\nu}$	(39.2 Mev, 14010)

age to its parent and sharing very little of the decay energy, ends up close to its dead parent within the crystal lattice of the host mineral or rock. So their accumulation since their parent nuclides were incorporated in a mineral is the basis of quantitative geochronology (terrestrial rocks) or cosmochronology (extraterrestrial samples). What is usually measured (as, for example, reported in the *Science* article) is not the absolute abundance of residual parent or accumulated (radiogenic) daughter isotopes, but their ratio to one of the nonradiogenic (time-invariant) isotopes of the daughter element in a mass spectrometer.

Alpha particles or the beta–antineutrino pairs carry almost the entire decay energy. Alpha and beta particles penetrate the surrounding rocky medium to variable distances before dissipating their energy as heat in this medium. Radiogenic heat so generated from U, Th and K decays represents a large fraction of the earth's energy budget. Antineutrinos from these decays – aptly called geoneutrinos – sail through the entire earth unscathed, taking away a substantial fraction of radiogenic energy in the process. They may therefore appear to have no role to play either in or about earth processes. But there have been a few suggestions[3,4] in the last three decades that detection of these elusive and ghostly geoneutrinos near the earth's surface could illuminate some aspects of deep earth geophysics – the so-called neutrino-geophysics. Neutrinos have been detected in large underground nuclear detectors long ago. But detection of geoneutrinos specifically has not been possible. It is in this context that the report of Araki *et al.*[1] in *Nature* on the first ever glimpse of geoneutrinos is exciting.

Araki *et al.* used the Kamioka Liquid-scintillator Antineutrino Detector (KamLAND) that was purpose-built for geoneutrinos. This detector is located in a mine 1 km below the summit of Mt. Ikenoyama in the Japanese island, Honshu. Antineutrinos are occasionally captured by protons in KamLAND's 1 kilotonne, 13 m diameter scintillator detector in a process known as inverse beta decay to produce a neutron. Combination of this neutron with a proton results in a deuteron and a characteristic gamma ray with an energy of 2.2 Mev. The light signal produced by this gamma ray in the scintillator volume is recorded as an electrical pulse by a large array of photomultipliers. Statistical analysis of data gathered over 749 days revealed between 4.5 and 54.2 geoneutinos at 90% confidence level. The higher count implies a radiogenic heat power from only U and Th decays at 60 TW (one terawatt is 10^{12} watts). A central or mean estimate is 16 TW.

The total heat energy dissipated from the earth's interior is estimated between 30 and 44 TW. The large spread in the estimated heat generation arises from differences between global models of heat flow at the earth's surface, complicated by hydrothermal circulations along the globe-straddling mid-ocean ridge system. The first-order inventory of geoneutrinos would then seem to account for only about half of even the lower limit of surface heat loss. But the results reported are admittedly preliminary, subject to uncertainties regarding residual radioactive impurities in the detector and contributions from nuclear reactors even a few hundred kilometres away. Also, KamLAND cannot now detect geoneutrinos from K decays – a major radiogenic heat source within the earth. In fact, some recent studies[5] suggest that the earth's iron core could contain substantial potassium. It is hoped that this exciting technique will be refined further to provide a firm estimate of the earth's uranium, thorium and also potassium inventory and hence define the fractional contribution of radiogenic heat to the total energy budget. The other fraction must necessarily represent residual energy from the earth's formation, e.g. from accretion and decay of very short-lived nuclides like ^{26}Al. The pioneering results from KamLAND have already prompted a meeting soon between particle physicists and geoscientists to discuss the promise and prospects of neutrino-geophysics – for example, construction of geoneutrino tomographic maps of the earth.

The focus of the work by Boyet and Carlson[2] reported in *Science* is also natural radioactivity not as a heat source, but as a tracer of chemical evolution of the earth from its infancy. The earliest major chemical differentiation in the earth is the segregation of iron and related siderophile (preferring iron to silicates) elements into a cental core and the remaining elements into a thick silicate blanket called Bulk Silicate Earth (BSE) by geochemists. Based on a small excess of ^{182}W from the decay of the short-lived ^{182}Hf in the BSE, core formation is now estimated to have been completed within 30 my of the solar system formation[6]. After core formation and possibly some loss of volatile elements from the earth, relative abundances in the newly minted BSE or primitive mantle would have differed from those in the earth as a whole, except in the case of chemically coherent, refractory lithophile (preferring silicate to iron) elements, in particular the two rare-earth elements, Sm and Nd. The subsequent chemical evolution of the BSE was mainly due to partial melting in its upper parts. Magma (melt) generated in such melting would preferentially carry the so-called 'incompatible elements' like U, Th, K and rare-earth elements before erupting volcanically on top of the BSE to form the thin veneer of the earth's crust. The decay of long-lived ^{147}Sm into ^{143}Nd would gradually increase the abundance of the latter relative to any nonradiogenic isotope of Nd, like ^{144}Nd. Crustal rocks derived from the BSE or mantle at different times would reflect this evolving ^{143}Nd/^{144}Nd ratio in the BSE, and hence facilitate comparison with chondritic Nd isotope evolution at corresponding time windows.

With a ^{147}Sm/^{144}Nd ratio of 0.1966 (equivalent to an elemental ratio of 0.302), ^{143}Nd/^{144}Nd ratio in chondrites has increased from 0.50677 about 4500 my ago to the present value of 0.51264 (an increase of ~1%). Whereas this ratio in very old crustal rocks falls strikingly close to the above chondritic trend, those of younger rocks deviate systematically and increasingly from it. For example, magma erupting at present all along the mid-ocean ridge system (called MORB for Mid-Ocean Ridge Basalt), exceed the present-day chondritic Nd ratio by about 1000 parts per million (ppm), implying that Sm/Nd ratio has increased from an initial chondritic ratio of 0.302. This is now well understood as due to the slightly higher incompatibility of Nd relative to Sm during partial melting, and hence its slightly higher uptake in the melt and eventually into the growing crust. In geochemical parlance, the mantle reservoir becomes progressively depleted in incompatible elements to form a complementary crustal reservoir enriched in these elements. Mass balance considerations indicate that the portion of the primitive mantle that would have to melt to generate the present-day crustal mass was a third to half with the rest viewed as still pristine, unmelted rock with a chondritic Sm/Nd ratio.

A few observations could not, however, be reconciled with the above simple and neat picture of the chemical history of the mantle. For example, survival of pristine material presumably in the lower mantle is not consistent with whole mantle convection. Secondly, and more directly, ^{143}Nd/^{144}Nd ratio in a few old rocks exceeds the chondritic reference trend requiring an episode of incompatible element depletion in the BSE prior to its long-term depletion outlined above. If such a differentiation took place before the short-lived ^{146}Sm became extinct, one should see an excess of its decay product, ^{142}Nd in very old crustal rocks. However, detection of the necessarily small excess in ^{142}Nd is easier said than implemented, due to formidable experimental difficulties.

It is only in the last few years that ^{142}Nd/^{144}Nd could be measured reliably and with the required precision in 3800 my old Greenland rocks, which showed a slight excess (~30 ppm) relative to chondrites[7]. This was not exactly a smoking gun, but a hot enough gun barrel to prompt Boyet and Carlson to undertake a meticulous measurement of ^{142}Nd/^{144}Nd ratios in many meteorites and crustal rocks – not only old but also young. Their results show that an excess of ~20 ppm in ^{142}Nd content is actually ubiquitous in nearly all earth rocks (both young and old) relative to their new and very precise data for chondrites[2]. This implies (in the words of the authors) that either (i) the BSE has a Sm/Nd ratio higher than in chondrites or (ii) all terrestrial rocks were derived from a mantle reservoir with a high Sm/Nd ratio established during the short lifespan of ^{146}Sm, i.e. in the first 300 my of solar system formation.

Authors do not rule out the first possibility, but favour the second scenario. They first estimate that this early or primordial mantle differentiation must have taken place within 30 my of the solar system formation (almost on the heels of core formation) for it to be consistent with well-established ^{143}Nd/^{144}Nd evolution over the long term.

If the long-term chemical differentiation of the mantle led to the present-day crust enriched in incompatible elements, what about the crust that must have been spawn from the primordial mantle differentiation characterized by a complementary deficit in ^{142}Nd/^{144}Nd ratio relative to chondrites? As rocks with such a signature or isotopic label have not yet been found, the authors infer that this crust was later subducted deep into the mantle and has since been residing at the base of the mantle at a depth of ~2700 km. Seismic tomography indicates that a ~200 km thick layer above the core–mantle boundary – the so-called D″ layer – is extremely heterogeneous, with seismic velocities differing from the adjacent mantle. An intriguing possibility is that the D″ layer is actually the deeply subducted primitive crust. If so, the thin D″ layer could contain as much as 43% of the earth's U, Th and K, producing ~9 TW of heat within its small volume. This hot radioactive layer could act as a warm blanket around the core to keep its outer part molten, even this late in the earth's evolution and continue energizing the geomagnetic field. This layer could also be the heat source to mantle plumes, that produce intraplate volcanic chains like in Hawaii. A link between this hidden layer and mantle plumes is hinted by a small deficit of ^{142}Nd recently reported in some volcanic layers from the Deccan province[8].

Both articles demonstrate that natural radioactivity, discovered more than a century ago, will continue to surprise earth scientists, and that creative imagination coupled with consummate experimental skills is bound to be rewarding.

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