Coring the earth

Drilling through our planet's crust may happen in the next decade, says s ananthanarayanan

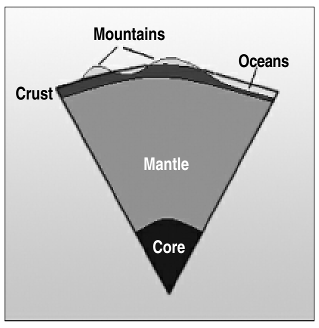
WE have sent any number of probes to the surface of the moon and now have a satellite to take a close look at the surface of Mercury, 150 million km away. But the information we have about our own planet, just six kilometres below the surface, is not a lot better. This is because drilling kilometres down through the rock and dirt of earth's crust is as challenging as putting a spacecraft into orbit! The journal *Nature* carries a review of the technology and plans for drilling down to earth's mantle, the layer below the crust.

Earth's interior, as worked out by indirect investigations, has a structure that is divided into layers, as one goes deeper. The outermost is the crust, five to 75 km thick, consisting mostly of silicates, followed by the rocky mantle, 2,890 km thick, and then the iron-rich core, which is 50 to 120 km thick. While the crust is solid and rigid, the rocky mantle is viscous, though predominantly solid. The crust, in fact, is considered to have been formed by some elements, rich in silicates and aluminium, separating from the partly melted mantle and floating up, to cool and solidify. The mantle, the layer that lies below, is typically richer in magnesium and iron.

The separation of the layers of mantle and crust was discovered by observing the speed of mechanical waves, called *seismic waves*, which arise during earthquakes, through the earth. In 1901, Croatian geologist Andrija Mohorovi?i? noticed that the speed of the waves changed abruptly, causing both reflection as well as change in direction, along a surface some 30 km deep — now recognised as the separation of the mantle and the crust. This was perhaps the first investigation into earth's interior. Further studies have revealed that this rocky region below the crust gets progressively more plastic and another change in the speed of seismic waves takes place at about 220 km, when the mantle becomes noticeably more plastic.

Detailed studies, based on seismology, have yielded more information about the possible composition of the mantle at different depths, right down to the core. Apart from seismic studies, variations in the force of gravity and magnetic fields also provide hints to what lies below. The core, which lies below the mantle, is the denser, iron-rich area — the outer core being liquid and the inner core solid because of the greater pressure at that depth.

In terms of volume, the mantle occupies some 84 per cent, with the core forming 15 per cent, of earth's volume. We can see that the crust, which is where mining and exploratory activity is confined, is a mere one per cent. The mantle, being plastic, also allows some movement of material, or currents, and brings about a mixing and transfer of heat from the molten core through more than the 3,000-odd km to the surface. The mantle could thus be a nearly inexhaustible source of not only minerals but also of heat energy. Information about the mantle would also enrich an understanding of how earth and the other planets evolved.



Out of reach

But the mantle remains hidden below the crust, up to 60 km below the continents and six kilometres thick under the oceans. Drilling through the crust and bringing up samples of the mantle would yield direct experience of the mantle as opposed to deductions from seismic observations. Obtaining such samples from even six kilometres below the bottom of the sea has been likened to obtaining a sample of rock from the moon. The challenge is also about the same.

As the crust is often thinnest where the sea is deepest, it becomes impractical to erect a "drilling rig" and drilling has to be done from a *drilling ship*. With a floating platform, like a ship, comes the problem of *drift* and the drilling column getting wrecked. And once controlling the drift has been tackled, there's the challenge of a shaft three kilometres down to the bottom of the sea and then another six kilometres down to the mantle.

For a shaft to work while it is six to eight kilometres long, it needs to be strong, and this translates to *thick and heavy*. And the drilling ship, or its helper ship, needs to carry sections of six- to nine-kilometre shaft to the place of drilling. And then there are the challenges of clearing the debris during drilling, firming the sides of the channel… over months and years of drilling, from the ship, in rough and fair weather.

Drilling operations in 1961. Courtesy Time Life *magazine.*

Project Mohole

The first serious plan to drill down to the mantle (named *Mohole* after Andrija Mohorovi?i?) was developed in the 1950s by a group of members of the US National Academy of Science, primarily Harry Hess, a pioneer of the theory of plate tectonics, and Walter Munk, who conducted the first studies into winds driving ocean currents and explained why it was the same face of the moon that we always see from earth. This was still before deep water drilling by petroleum companies and the group developed the first "dynamically positioned" ship, which had propellers at its sides, to keep the vessel from drifting.

In March-April 1961 the group raised the first few metres of basalt from 170 metres under the bottom of the Pacific Ocean, 3,800 metres below the surface. The project had cost $40 million, converting to 2009, and the accomplishment was reported in *Time* magazine, by John Steinbeck, novelist and amateur oceanographer, who had accompanied the mission!

The project ran into management and funding problems and continued no further. But this was just the time when the theory of plate tectonics got accepted and interest in the evolution of earth's crust, below the oceans, was on the rise. Project Mohole had shown that drilling in the crust at the sea floor was possible and the next 40 years were rich in international collaborations and ocean-drilling research.

Current plans

Technology has greatly developed since that first drill 50 years ago. The *Chikyu*, a Japanese drilling ship launched in 2002, has a system of an outer pipe that surrounds the steel drilling pipe for the most efficient retrieval and disposal of cuttings, both for analysis as well as to go deeper. The ship is capable of carrying 10 km of drilling pipes and can carry out drilling in 2.5 km of water. This now needs improvement to work at pressure of 2,000 atmospheres, temperatures of 300? Celsius and four kilometres deep.

The Integrated Ocean Drilling Programme Expedition 355 is due to sail shortly to a site off Costa Rica, where the upper crust is thinner than elsewhere. Three earlier missions drilled 1.5 km down and it is now proposed to go 400 metres deeper. This would extract the deepest type of rock so far from below the ocean floor. This is thanks to the structure of the ocean floor at this spot, although the deepest hole yet was 2.1 km deep, off Colombia.

The drill will still be 3.5 km short of earth's mantle, but it will answer a number of scientific questions: how magma from the mantle enters the lower crust, the geometry and vigour of how sea water can pull heat from the lower oceanic crust and the contribution of the lower crust to marine magnetic anomalies.

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Dosage compensation

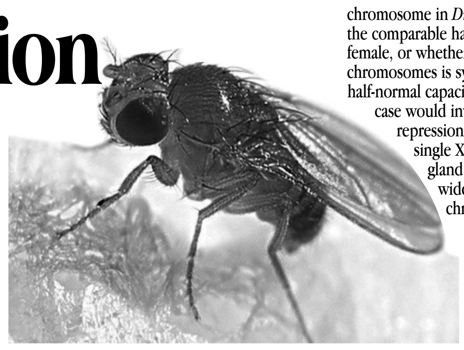
A single X chromosome in the salivary gland cells of the male is nearly as wide as the two paired X chromosomes in the female, writes tapan kumar maitra

OUR contention that chromosomes behave as functional units is strengthened by our knowledge and understanding of the phenomenon of dosage compensation. It is generally observed that the amount of gene product bears a rather precise relationship to the number of autosomal genes responsible for the product. If one gene makes x amount of product, two genes or alleles will make 2x and so on. This, however, is not true for X-chromosome-linked genes. Here the two X female products the same amount of gene product as does the one X male rather than twice as much. Loci on the X chromosome that behave in this fashion are said to compensate. That this is a chromosomal rather than a gene function, however, is indicated by the fact that the genes compensated appear to have no direct responsibility for sex determination or differentiation and may involve a variety of different phenotypic expressions ranging from enzyme structure to eye colour and bristle form.

First discovered in *Drosophila*, dosage compensation has also been clearly established in a number of mammals, including man, but it seems clear that it operates differently in different species. In mammals, the phenomenon appears to be by way of the "Lyon", or perhaps more correctly the "single active X" mechanism. In the human female inactivation of one of the X chromosomes occurs in somatic cells at about the 16th day after fertilisation of the egg. Prior to this both X chromosomes are active and are necessary for normal sexual differentiation. Inactivation does not occur in germinal tissue. When more than two X chromosomes are present, all but one are inactivated. The result is genetic inactivity of all but one of the X chromosomes in a somatic cell. Thus the XX female has but one functioning X chromosome in each of her somatic cells, whereas the single X of the male functions in all cells. Whether the Y chromosome remains operative in a transcriptional sense is not known, although its effect on sex determination is established.

There is, therefore, a correlation between X chromosome inactivation and somatic differentiation. At the onset of differentiation, one of the two X chromosomes, selected at random unless one of the X chromosomes is abnormal, becomes genetically inactive in the sense that it apparently ceases to transcribe at the same time that its ability to replicate remains unimpaired. If one of the X chromosomes is abnormal, that is, is deleted or is a ring, it is selectively inactivated and only the "normal" X functions. Replication of the inactivated X is delayed in relation to the remainder of the chromosomes in the complement, and it is usually the last member to complete its DNA synthesis. During inter phase the inactive X may be observed as the heteropyknotic "Barr body," or sex chromatin in somatic cells of human females. Elegant genetic experiments by Childs and his colleagues on the cells of human females heterozygous for two kinds of glucose-6-phosphate dehydrogenase have established the randomness of the inactivation process to produce the single active X chromosome.

In human beings inactivation of the X chromosome *appears* to be an all-or-none phenomenon. Variations of this are known, however, in other organisms. In the mouse a number of X-chromosome genes show compensation and others do not, suggesting only partial inactivation. In the bandicoot, an Australian marsupial, one X chromosome is rendered inoperative by its elimination from all somatic cells, thereby obviating the need for continued replication of an inactive element. A somewhat different system characterises the creeping vole, *Microtus oregoni*. The male germ line is OY, the male soma XY, the female soma XO and the oocyte XX. Males develop from XY fertilised eggs with the X being subsequently eliminated from the germ line.



Many X chromosome loci in Drosophila melanogaster *demonstrate dosage compensation whereas those in autosomes do not.*

Females arise from XO fertilised eggs, and no elimination occurs, so that male and female somatic tissues possess a comparable X chromosome composition. The oocyte, prior to meiosis, is presumed to have acquired its XX state through selective nondisjunction of the single X chromosome in the germ line. It would appear, therefore, that inactivation of chromosomes in part or whole, elimination of chromosomes and late replication are but varied expressions of the same phenomenon of dosage compensation.

Many X chromosome loci in D. *melanogaster* demonstrate dosage compensation whereas those in autosomes do not. Here, however, differential inactivation of one of the X chromosomes does not occur, and the equality of phenotypes in males and females must be accounted for in other ways. Two general hypotheses have been advanced each one having some experimental support. Muller has proposed a system of modifying genes on the X chromosome which, through enhancement or repression, alter the expression of those genes which he studied. Goldschmidt, on the other hand, has denied the existence of special modifying loci, and instead advanced the notion that compensation is a consequence of the different development systems characteristic of the male and female cellular milieu. Unequivocal experiments to distinguish between these hypotheses, or to test their validity, have not been done.

Whether the synthetic rate of the single X chromosome in *Drosophila* males is twice that of the comparable haploid X chromosome in the female, or whether each of the female X chromosomes is synthesising its gene product at half-normal capacity, is not known. The former case would involve enhancement, the latter repression. It is known. however, that the single X chromosome in the salivary gland cells of the male is nearly as wide as are the two paired X chromosomes in the female, even through the amount of DNA per chromosome remains constant. The increase in size in the male must be due, therefore, to some kind of a generalised puffing that extends throughout the length of the chromosome. Furthermore, it has been recently shown that the single X chromosome in the males produces nearly as much RNA, as measured by the uptake of titrated uridine, as do the two X chromosomes in the female. The difference, consequently, is expressed quantitatively at both morphological and biochemical levels. No qualitative differences in compensation have yet been discovered. When compensation is examined at a genetic rather than a chromosomal level, it is clear that both of the alleles are operative in a female *Drosophila*. Selective inactivation of alleles cannot, therefore, be the cause of compensation in *Drosophila* as it is in mammals and some as yet undiscovered mechanism must be responsible.

As in the cases of the X autosome translocations and of the *D. hydei* Y chromosome these observations suggest that the X chromosome is unique in its control of formation of gene products. The control in all instances appears to be via transcription rather than through control of translation or some more remotely removed step in synthesis. Why an equivalence of gene products in the two sexes is a necessary feature of development is not immediately evident, because most enzymatic systems seem to process a fair margin of safety. It may well be that dosage compensation is a reflection of selective forces associated with the retention of sex-determining mechanisms which have been preserved intact in the X chromosome.

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Designer of my dreams and nightmares

When rona munro **started to research the history of space travel for a new play, she discovered an unsung star of the skies**

I'VE just devoted three years of my life to writing a play about the Soviet space programme. Of course I interspersed it with other things, but I've been living with stories of cosmonauts and rocket engineers since 2007. If you're going to write on that scale you'd better love the work. Why that play? Why that history?

When I was a little girl, the grown-ups seemed to be making a new world. We were going to grow up to travel faster than the speed of sound and live in the stars. I spent a significant part of my early childhood worrying about floating in zero gravity and breathing bottled oxygen while staring at the black infinity of space. And that wasn't the only terror that haunted my childhood. We had the very clear prospect of being engulfed in a nuclear holocaust to enliven our nightmares.

Maybe every generation peoples its past with titans, in the same way that everyone who moved house in childhood remembers their first home as a vast, magically huge world. In my memory spacemen still float above us on shining metal cords and we're going to Mars any day now.

When I began writing my play, *Little Eagles*, I wanted to write about the history I remembered and that had inspired me. I remembered the fear I felt, as a very young girl, hearing the news of the disaster that befell Apollo 1, all three astronauts trapped and burnt to death during a routine test on the launch pad. Space explorers were heroes risking their lives. That was clear. I remembered hearing the words of *Genesis*, read from lunar orbit as Apollo 8 came out of the darkness no one else had ever seen, on the far side of the moon. The astronauts were up there in the same dark that God inhabited; that, too, was clear to an eight-year-old. I remembered the grainy images of Neil Armstrong bouncing down those steps and on to the soil of an alien world, and I remembered really believing he was doing it for peace and for all of us. I hadn't made the connection between my nightmares of mushroom clouds and the race between the Soviets and the Americans to reach the moon.

IN SEARCH OF TITANS: Rona Munro

Of course this familiar story grew smaller as it was re-examined, as a huge childhood bedroom turns out to be a shabby boxroom when you revisit after 40 years. It was still compelling – I read every space-geek book I could get my hands on – but at some point in the wonderful, exciting, indulgent process of research, I thought, "I'd better just check out what the Soviets were doing."

And I found titans. I found darkness. I found stories I'd never heard before that still affected me as they might a child, with terror and wonder. I found history I'd lived through and never known. I was reminded of people who were already diminishing into history as I grew up: Stalin, Krushchyev, Yuri Gagarin (the first man in space), Valentina Tereshkova (the first woman in space)... and behind them all, one man I'd never heard of, that no one heard about while he was alive, the mysterious chief designer of the Soviet space programme, Sergei Pavlovich Korolyov. He called his cosmonauts "Little Eagles".

Maybe it's the unfamiliarity of this story that allows it to keep its scale for me. Maybe it's the passage of time; the Soviets' amazing success, putting the first human beings into space, predates my conscious memory.

Sergei Pavlovich Korolyov.

In June 1938, Korolyov, a young aeronautical design engineer, was arrested in one of Stalin's purges and sentenced to life (and almost certain death) in a Siberian labour camp. As war with Germany threatened and his expertise was required, he was summoned to Moscow. It was a journey of more than 4,000 miles and he had to walk most of it. From Siberia. A few years after his epic journey, Korolyov would develop intercontinental ballistic missiles and put the first satellite into orbit. Korolyov, I learned, was the chief designer and creator of both my childhood dreams and nightmares. Everyone's history is full of titans who diminish under scrutiny. But – flawed and tragic and human though he was – Korolyov still seems larger than most of the ghosts out there.

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