varieties of important crops in relation to the key natural enemies will help to enhance the naturally occurring entomophages by growing favourable cultivars. This will also help to support the natural enemy activity in augmentative releases. Semiochemicals could also be used to enhance the activity of natural enemies by direct application of synthetic kairomones or by using crude extracts from favourable host plants and host insects or their by-products. Searching ability of natural enemies could be enhanced by exposing them to kairomonal cues before releases. These semiochemicals could also be employed in mass production of natural enemies with factitious hosts, to enhance the level of parasitism by treating them with favourable kairomonal/synomonal extracts. Application of kairomonal/synomonal formulations in release areas could intensify the searching behaviour of the natural enemies and thereby enhance their potential as biocontrol agents.

B. Vasantharaj David (Sun Agro Biotech Research Centre, Chennai) discussed the present and future dimensions in the use of insecticides, outlined the important insecticides, acaricides and nematicides used in crop protection in India, the new molecules that have been registered in recent years, and molecules under development and their spectrum of activity. The combination products for control of pest complex of cotton, rice, etc. that have been introduced in the recent years and those under evaluation/development were elaborated. The status of fumigants in control of storage pests and the development of magnesium phosphide was also discussed.

Presiding over the plenary session, S. Chelliah (M.S. Swaminathan Research Foundation, Chennai), while extolling the diversity of areas covered in the meeting, emphasized the following: (a) in using combination pesticides in insect control, the long-term implications in development of cross-resistance by insects are to be taken care of; (b) as GM crops are likely to be made available for cultivation, IPM strategy on GM crop base is to be worked out soon to avoid loss of time; (c) in pursuing research on plant products as pesticides, commercial feasibility, stability and safety to non-target organisms are to be addressed; and (d) cropping systems suggested for pest management should have a broader perspective of increased income, ecological compatibility and easy marketability, besides imparting best suppression/repellence. The systems should be acceptable to agronomists and farmers at large.

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RESEARCH NEWS

Mantle convection results from plate tectonics – Fresh hypothesis reverses current views

A. V. Sankaran

Plate tectonic theory, which has revolutionized earth science, grew around the original concept of continental drift proposed in 1912 by Alfred Wegner, and ideas of sea-floor spreading advanced by Arthur Holmes in 1928. Subsequent work by British, American, Canadian and French scientists led to a full-fledged plate tectonic theory in 1968. According to this theory, the outer layer of the earth is divided into small segments or plates, which move relative to each other. It is believed that their movements are brought about by convection currents in the 2900 km thick mantle lying below and driven by radiogenic heating, hot upwellings from deep mantle and cooling of earth. Over the years, geologists invoked plate tectonism to explain global tectonics, volcanism, mantle geochemistry and a host of other geological phenomena. But, some basic features of this theory have remained unresolved even today. For example, why did plate tectonics develop on our planet, while it is presently absent in other terrestrial planets? What forces are responsible for driving the plates? Is mantle a homogeneous mixture or a set of two or more separately convecting systems? Scientists' answers to these could not explain satisfactorily the conflicting geochemical and geophysical observations about mantle dynamics and chemistry though their efforts have enhanced our knowledge about the earth's mantle.

The simple plate tectonic model is based broadly on the analogy of a boiling fluid of uniform viscosity. The thermal convection currents generated in such a fluid are characterized by a symmetrical pattern of 'cells' with similar width and depth. This convection pattern is known as Rayleigh–Bènard model, so named after these two scientists who had conducted studies on such a medium (see Box 1). As in the case of a boiling fluid, convection cells ascending from the depths of mantle are supposed to be responsible for movements of the earth's plates, since the latter are literally floating on top of the fluid mantle or the asthenosphere. However, unlike symmetrical cells developed in a boiling fluid, the earth's plates are asymmetrical and unequal, the viscosity in the mantle is non-uniform, the chemical composition heterogeneous and some of the physicochemical characteristics of plate–mantle dynamics do not conform to Rayleigh–Bènard model. These factors led to the development of new ideas about the mechanism of convection in the earth's mantle.

Presently, two modes of mantle convection are competing for recognition. One of them, the 'layered-mantle convection mode', regards earth's mantle to be stratified into two or more convecting layers, while the second or the 'whole-mantle convection' considers that the mantle convects as a whole. Questions like which of these two patterns of convection is operating in the earth's mantle and whether this pattern existed all through earth's cooling history or evolved gradually to the present pattern have led to long-drawn debates among geochemists and geophysicists[1,2].

Recent geophysical studies have favoured the layered-mantle pattern based on seismic findings of discontinuities at depths of ~ 650 km, ~ 1000 km and ~ 2200 km (refs 3, 4). But the independently convecting layered zone concept received a jolt after the development of seismic tomographic techniques in 1970s, which revealed pictures of subducting crustal slabs penetrating these discontinuities or layers and reaching deep into the mantle, a few of them even up to the core–mantle boundary (CMB). Their penetrations were taken to imply intermixing of layers, thereby supporting whole mantle convection views[3,5–7]. It was also pointed out by mineral physicists that these seismic discontinuities or stratifications may arise from phase transformations (e.g. pressure-induced phase transformation of mantle peridotites to spinel structured forms such as wadsleyite, ringwoodite and perovskite, respectively, at depths of 410, 520 and 660 km (refs 8–11)). Further, changes in chemical composition due to partial melting (e.g. presence of the 300 km-thick partial melt layer beneath south Atlantic Ocean[12,13]) and viscosity (e.g. existence of a low viscosity zone at 660 km (ref. 14)) could also cause seismic discontinuities or stratification of mantle convection, and they need not be taken as barriers for material exchange across their interfaces. At the same time, the whole-mantle convection view based on the tomographic images of the penetrating slabs has also been discounted. According to recent studies[14], these images of sinking crustal slabs discovered in the lower mantle are actually 'down-welling' or 'thermal slabs' (with no material exchange between the upper and lower mantle) created by cooling of the lower mantle by the subducted lithosphere. The arguments between layered-mantle-convectionists and whole-mantle-convectionists have now lasted for quite some time without any consensus. In spite of the opposing views their debates generated, that a relation exists between plate tectonics and mantle convection has not been discounted, though presently a new question has cropped up about which among them – plate tectonics or convection, initiated the other.

A new concept[4,15], reversing existing views about convection-generated plate tectonics has come from Don L. Anderson (California Institute of Technology, Pasadena). He has proposed that the convection pattern in the mantle is the result of plate tectonics and not due to thermal buoyancy and viscous dissipation of mantle fluid from below. As in the case of fluids, which spontaneously organize into convection cells by surface tension and other forces from the top[16] (see Box 1), it is thought that plate tectonics and mantle convection are also controlled from the top. According to him, plate tectonics need not be passive motion of the plates on top of convection cells; rather, the continents and plate tectonics organize the flow of convection in the mantle. He considers plate tectonics to be driven by unstable surface thermal boundary layer comparable to convection in fluids cooled from the top. The flow is generated by instability of the cold surface layer and near-surface lateral temperature gradients. He points out how the heat flow from the core, which is supposed to activate convection cells, is actually suppressed by the prevailing pressure there and as a result heat flow in this region is less than that at the surface, which would mean long periods of time for buoyancy effects to appear. Thus, in contrast to upper thermal boundary layer, the lower thermal boundary layer is inactive, hardly playing any role in mantle convection.

Other surface effects that Anderson invokes are the lateral temperature gradients in lithosphere slabs, which can also initiate convection. For example, at 100 km depth, there is a 400°C temperature difference between cold cratonic roots with temperature at 1000°C and the adjoining hotter asthenosphere at 1400°C, enough to set-up a vigorous convection. These types of convection flows generated by lateral temperature gradient, he feels, are responsible for the observed volcanism at the margins of continents, cratons, oceanic and continental rifts and along fracture zones, transform faults and shallow upwellings[10,17,18]. He has

Box 1. Rayleigh–Bènard model and mantle convection[4]

Henry Bènard in 1900 and Lord Rayleigh in 1916 studied convection patterns developing in fluids heated from below. They analysed the instabilities associated and derived what is today known in fluid mechanics as the Rayleigh–Bènard model. Convection in a layer of fluid heated from below is marked by the appearance of hexagonal cells and the liquid rises from the bottom of the layer in the centre and falls near the wall of each cell. Subsequent studies in the later half of the last century showed that Bènard's patterns were actually driven from the top by surface tension and not from below due to unstable thermal states and that the same pattern of convection is observed when a fluid is heated from the top and cooled from below or when heated in the absence of gravity. Top-down convection, driven by surface tension, is known as Bènard–Marangoni convection.

For the appearance of these cells, *R*, the Rayleigh number should exceed 1700 (for rigid boundaries). This number is defined by μ, the coefficient of thermal expansion of the fluid, $q_1 - q_2$, difference in temperature between top and bottom of the plane; *g*, the acceleration due to gravity; *d*, the separation of the planes; *v*, kinematic viscosity; *k*, the thermal conductivity. Thus *R* is given by:

$$\frac{a(q_1 - q_2)gd^3}{nk}$$

Convection currents appear only when *R* exceeds the critical value (1700); if it is smaller, it is difficult for convection to occur. In a fluid cooled from the above, even without surface tension, the cold surface layer becomes unstable and generates convection in the underlying fluid when the Rayleigh number of the thermal boundary layer exceeds the critical value. Cold down-welling plumes are then active while upwellings are passive reflecting mass balance and net thermal instabilities. In a spherical shell it is found that an *R* of about 10^4 is required for the convection to occur and for a whole mantle convection > 10^7, but an *R* of only 4000 is derived for the base of the mantle – a figure too small for convection. This would imply a non-convecting or sluggish layer at the base of the mantle, supporting existence of stratification in the lower mantle.

viewed plate tectonics as an open 'far-from-equilibrium dissipative self-organizing system' having the mantle as a passive provider of matter and energy which is converted to forces driving the plates. The new postulate visualizes that small changes of stress, for example, can trigger global re-organization quite independent of a convective event in the mantle.

In earth's long history, Anderson has recognized, on the basis of seismic tomographic and gravity data, different scales of mantle convection[17]. These are associated with subduction-cooling of mantle during break-up of Pangea, repeated assembly of supercontinents and a smaller scale of convection ordering due to existence of geochemical domains in the mantle. Basically, he holds that plate tectonics is driven by negative buoyancy of the earth's outer shells and this is resisted by dissipative forces like bending, deformation, faulting, sliding resistance by lithosphere and viscosity forces in the mantle[19]. Where most of the dissipation is provided by the plates, with the mantle providing only heat, matter and energy, plate tectonics becomes a self-organized system instead of being organized by mantle convection or heat from the core. Thus the upper mantle convection patterns are actually the result and not the cause of plate tectonics. An entirely different style of convection may be operating in the deep mantle where convection is more controlled by the prevailing high pressure which suppresses the effect of temperature on density, and the mantle dynamics there is very different[4].

Anderson[15] has compared the repeated organization of earth's mosaic of plates to the behaviour of foams and bubbles. Under changed conditions of porosity, temperature or other factors of stress, the bubbles always tend to rearrange themselves into a new minimum energy state through collision and jamming, in achieving harmony with the new conditions. Similarly, the present mosaic of the earth's plates is consistent with the stress field that formed it. Under new forces (thermal contraction, slab-pull, ridge-push, changes in the dips of bounding slabs, changes in strike of the boundaries, flexure and so on), the plates tend to reorganize themselves (self-organization). Thus the mosaic of plates have simple and surficial explanations rather than convective or plutonic causes. The present configuration of plates, which may be termed earth's 'ground state', has come to be organized into about a dozen large semi-rigid plates of irregular shapes and sizes. These plates move over the surface separated by boundaries, which meet at triple junction as in the example of foams and bubbles which typically display hexagonal or pentagonal shapes meeting at 120°. Essentially, the configuration of the earth's plates is surface tessellation, i.e. a sort of regular checkered surface pattern due to physical processes.

To sum up, according to Anderson's 'top-down' plate tectonic hypothesis of plate interaction and self-organization or *Platonics*, a term he coined influenced by the doctrine of '*statis and change*' of the Athenian philosopher Plato, supercontinents and other large plates generate spatial and temporal temperature variations. The migration of these continents, trenches and ridges introduces changes to surface boundary conditions for which the mantle below responds passively. Slab-created internal buoyancy of the mantle interacts with the surface to trigger break-up and drift of the plates and roll-back trenches. The driving forces on the plates which are essentially thermal and gravitational manifest as ridge-push, slab-pulls, trench suction, basal drag and the like. Contrary to the general perception that mantle activates plate reorganization, continental break-up, extensive magmatism (flood basalts) and intraplate volcanism through upwellings, Anderson feels that the state of stress in the lithosphere defines the plates, their boundaries, mid-plate volcanism and that the fluctuations in stress are responsible for global plate reorganization and evolution of volcanic chains. Hence 'if most of the buoyancy and dissipation is in the plate–slab system rather than in the mantle, then the mantle convection patterns should be regarded as the result, and not the cause of plate tectonics'. The new 'top-down' plate tectonics, understandably, is at odds on some fronts of established geological notions and its ability to explain them through platonic hypothesis remains to be tested.

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