Towards a new paradigm on the Earth's dynamics

*Shigenori Maruyama**

*Mineo Kumazawa***

*Shin-ichi Kawakami****

Accepted December 6, 1993

* Department of Earth and
Planetary Sciences,
Tokyo Institute of Technology,
Tokyo 152, Japan

** Department of Earth and
Planetary Sciences,
Nagoya University,
Nagoya 464-01, Japan

*** Department of Earth Sciences,
Faculty of Education, Gifu University,
Gifu 501-11, Japan

*Key words : overview, beyond plate tectonics,
whole earth tectonics, third wave*

The understanding of the life-sustaining planet Earth is on the way of revolutionary stage to be called the third wave. The first wave started in 1912, when Alfred Wegener proposed the continental drift based on a series of evidences such as the coastal lines of continents on both sides of the Atlantic Ocean. Moreover he has speculated the presence of a super-continent Pangea and a superocean Panthalassa at 250 Ma. All continents on the Earth rifted sometime at latest Paleozoic, and have drifted in various directions since then. His idea of continental drift has been rejected by geophysicists on the basis of poorly applied physics theory. However, the second wave has recalled it from the new facts in oceans occupying the 2/3 of the Earth's surface. His idea has revived as a new name "ocean-floor spreading" by Dietz (1961) and Hess (1962). When the detailed geology of major oceans became available, a new type of fault, called transform fault was found on the ocean, and the basic concept of plate tectonics was established (Wilson, 1965). Plate tectonics (Le Pichon, 1968; Morgan, 1968; McKenzie, 1969) is different from neither continental drift nor ocean-floor spreading in terms of rigid plates and their relative motions leading to the innovation of ocean bottom and the repeated redistribution of continents. While the plate tectonics is driven surely by the immanent agent of the Earth's

evolution, it is currently explained only by a phenomenological table cloth theory combined with thermal convection and its modifications.

Plate tectonics explains the orogenic aspects on the Earth as a unified self-consistent theory. For example, igneous and seismic activities at given areas far from each other more than several thousands kilometers can be simply explained by the same plate subduction. The orogenic complexities along the circum-Pacific regions can also be simply explained by a subducting oceanic plate which was born at mid-oceanic ridge far from continental margin, migrated towards continent with a speed of cm/yr, and finally subducted underneath a continent several tens of millions of years after its birth. One may believe or hope within the framework of plate tectonics to explain all of the current and past geologic features including the distributions of oceans and continents, volcanoes and earthquakes, the natural resources and even also that of various types of living creatures. This is right in comparison with the previous theories of the Earth so that the invention of plate tectonics concept is really a scientific evolution of the first order in the earth and planetary sciences.

Nevertheless, we note that there are so many factors yet to know and impossible to know within the framework of plate tectonics in principle; a set of small examples is the source material, the driving force of movement, the fate of subducted plates and their roles in the whole evolution of the whole Earth. The basic physics in a sense of logics behind the plate tectonics has been one of our major concerns, and the actual Earth history already realized and to be realized in future is surely out of the framework of plate tectonics. We have five basic tools useful in aiming at the post plate tectonic theory; (1) seismic tomography to view the detailed three-dimensional structure of the deep interior of the Earth, (2) ultra-high-pressure experiments and solid state theory to clarify the material properties and convection in the planets, (3) computer simulation to make it possible to do experiments on the evolving natures of the Earth and planets, (4) descriptive regional geology of the world or global history of plate tectonics as old as traceable, and (5) comparative planetary sciences by remote sensing and planetary explorations to the nearby bodies. The combinations of all of these will provide us with the third wave on the real or better understanding our Earth and its environments in the

solar system. The purpose of this issue is aiming at a trial of raising this third wave. Some of the papers are really substantial in a sense that they have a rigorously based ground, whereas others are merely speculative in a sense that they just present idea and prospect.

One of the simple speculative interpretations on fate of subducted plate was that it assimilates to homogenize with the surrounding mantle peridotite in the deeper mantle, and that it in turn uprises under mid-oceanic ridge when it is made warm in the deeper mantle. On the contrary, seismic tomography makes it possible to observe the entity of subducted slabs down to core-mantle boundary (Fukao, 1992). However, such visible image of mantle simply shows the seismic velocity anomaly, it may reflect either the material difference such as Fe/Mg ratio of peridotite and modal ratio of mantle minerals, temperature difference or both. The geologic records within orogenic belts and its interpretations, however, would enable us to clarify which generates such velocity anomaly, material or temperature difference, as will be shown by Fukao et al. in this issue. Seismic tomography has also clarified the mode of mantle convection which is different from that believed previously; huge mushroom-shaped columnar upwelling rather than cylindrical, and blob-shaped downwelling rather than curtain-like (Fukao et al., this issue). The coming atmosphere of the third wave is rapidly expanding and boosted to create the whole Earth tectonics by studies on the Earth's interior and surface geology dating back over 4.6 b.y. ago (Kumazawa and Maruyama, this issue).

The third wave of understanding the Earth is to make a geodynamic systematics not only including the superficial part of the Earth (plate tectonics) but also the whole mantle (plume tectonics) and the core (growth tectonics). The plume tectonics of the Earth revealed by geologic records is compared with mantle tomogram by Fukao and his collaborators. This comparison provides a speculation on (1) time-dependent nature of fate of subducted slabs and plumes in the past, at present and in the future, and (2) new schemes of continental dispersion and conversion (Wilson cycle), and (3) time-dependent mode of mantle convection as will be given by Maruyama in this issue. The development and dynamics of the Earth's core should be another aspect of the whole mantle tectonics. Mechanical and thermal interaction between the mantle and core is one of the most important topics in geodynamics. One of the big paradoxes to be resolved is when and how the early stably stratified Earth's core was collapsed to the convective state sustaining geodynamo. Kumazawa et al. hypothesized the resonance mechanism between lunar tide and inertial gravity wave in the core leading to a convecting core generating strong geomag-

netic field. Since the disruption of the stratified structure released significant amount of energy in the solid Earth, under the expense of rotational energy of the Earth. They argued that some geological consequences must be recorded in geological archives at the Archaean-Proterozoic boundary, according to Kumazawa et al.'s hypothesis (in this issue).

The other aspect of trial toward the newer view of the Earth is to examine nearby planets. The tectonic styles and geological activities of the solid objects in the solar system will provide significant insight for understanding the effects of boundary conditions on the formation and evolution of the solid objects in the solar system. A comparative study on the tectonic styles and geodynamical processes between the Earth and Venus is discussed by Fujii. The ridge network and corona array on Venus are interpreted as an initiation of plate tectonics on Venus from plume tectonics. Full range of spectrum on the size, composition, and environments of the terrestrial planets and icy satellites around the Jovian planets are discussed by Kawakami in view of the energy source, heat flow mechanisms, and the amount of tectonic stress caused by convective flow in the mantle. Degree of thermal and tectonic activities inferred from their sizes and available energy including tidal heat are compared with their shapes and surface geology. However, dependence of thermal activities on the body size is not clear for some of the Saturnian and Uranian satellites.

The dynamic behavior of solid Earth is derived through subsurface plate tectonics, plume tectonics underneath, and growth tectonics in the core (Fig. 1). Plate tectonics supplies cold slabs down to the mantle depth at 670 km, where they are stagnant for a variety of time scales, 100–400 m.y., by the endothermic nature of phase transition, until eventual penetration occurs. Occasionally a catastrophic gravitational collapse of very large scale occurs and the down-going mantle flow triggers the mantle-upwelling as a passive or cooperative response which causes rifting continent or hotspot volcanism on the surface. The mantle downwelling or cold plume also strongly modifies heat extraction from and the convection pattern in the metallic outer core. The refrigerated part of the outer core capped by the slab avalanche would form a downgoing whirlpool to yield Fe-Ni metallic crystals to accumulate on the growing solid inner core. Thus, subsurface plate tectonics, plume tectonics in the middle, and the growth tectonics in the central core, are all interrelated closely together. Among them cold plume plays the most essential part of the Earth's dynamics.

Such three-fold tectonic domains in the modern Earth are the inevitable time-dependent result of the life-sustained water planet Earth since its birth. The evolution scheme of the inner terrestrial planets is discussed by referring to the dynamic aspects by

Fig. 1. Schematic illustration of of whole earth tectonics. Plate tectonics supplies cold materials into the domain of plume tectonics. The catastrophic collapse of stagnant slabs at 670 km depth causes not only super-upwelling mantle flow to influence plate tectonics but also modification of convection patterns in the outer core to control the growth tectonics in the central core.

Kumazawa and Maruyama. The Earth has passed the dominant stage of plume tectonics, and is presently on the way of plate tectonics spreading downward with time to reduce the volume in which plume tectonics dominates. The core is still on the stage of growth tectonics which has once covered the whole Earth at 4.6Ga (Kumazawa and Maruyama, this issue).

The research direction towards exploring the unified theory of the Earth and planets as a new paradigm is surely the third wave of the trials to understand our Earth and the brother planets. We feel quite fortuitous in participating and contributing, if any, the rise of the third wave with this issue.

Acknowledgements

The special symposium "The newer view of the Earth" was held in the annual meeting of Geological Society of Japan, 1993. The editorial board of the Society, the representative Dr. S. Maiya invited us to

contribute the papers given in the symposium to this journal. Dr. T. Nakajima helped us in editing this issue and read all papers critically. We sincerely appreciate both of them.

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Maruyama, S., Kumazawa, M. and Kawakami, S., 1994, Towards a new paradigm on the Earth's dynamics. *Jour. Geol. Soc. Japan*, 100, 1-3. (丸山茂徳・熊澤峰夫・川上紳一, 1994, 地球のダイナミクスについての新しいパラダイムの確立にむけて. *地質雑*, **100**, 1-3.)

我々は今、固体地球の変動を理解する新しい規範の構築、“第三の波”の真只中にある。第一の波は1912年にアルフレッド・ウエーゲナーが大陸移動説を発表することによって始まった。この説はその後海洋底拡大説を経て、1960年代の後半に花開く第二の波、プレートテクトニクス説へと引き継がれた。第三の波では、(1) 40億年前にさかのぼる世界の表層地質、(2) 地震波トモグラフィー、(3) 超高压実験、(4) 計算機実験、(5) 惑星探査機などによる比較惑星学、それぞれの分野における新しいデータと考えを総合して、中心核、マントル、およびプレートのダイナミクスの全地球的相互作用として体系づけることを目指している。この体系を全地球テクトニクスと呼ぶことを提案する。