ORIGIN OF THE EARTH'S CRUST AND ITS EVOLUTION

by

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(with 22 text-figures)

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Abstract

The granitic rocks including migmatite, gneiss and palingenetic plutonics found in the axial core of the representative orogenic belts such as the Abean and Hidaka belts in Japan are now believed to have been originally geosynclinal deposits re-formed by syn-orogenic igneous activities in a wide sense. From the authors' own observation in the course of mapping in the respective fields above mentioned in Japan, and based on laboratory works, the authors now stand to accept a theory of granitization in making up granitic crust through orogenic process. As a matter of fact, not only in cratonic, sub-cratonic or older orogenic belts in the continental mainland of Asia, but also even in such younger mobile belts as the Japanese islands, the foundation is chiefly composed of granitic rocks of the Precambrian age. Thus, the earliest stage of the geologic time became a problem to be discussed in the present paper as to the formation of granitic crust, since the source area for geosynclinal deposits must have eventually existed even in such an ancient day, and the depositional sea should have been also present, so far as the origin of the oldest granitic rocks are concerned. Thus, the earliest ocean and continent prior to the geologic time came to be a problem. Based on the recent progress of the Precambrian geology, the ur-continent might be existed in the present Pacific, as will be stated later on, while the present continent may have been under the sea water, viz. the ur-ocean. This assumption seems to be well consistent with the well known model for the structure, and interior movement of the early stage of the earth, presented by F.A. VENING MEINESZ in 1964. Namely, one hemisphere was a continent, while the other side was an ocean, caused by a single cell convective movement of the interior of the earth, when the core was not yet differentiated from the mantle. This may be called as the lunar stage of the earth's history.

The third stage is the geological age in which ur-ocean became continent composed of terrestrial crust step by step, while ur-continent became ocean, the ancestral basin of the present Pacific. The principal course of development of the

crust since the Late Precambrian may be assumed to have been a reformation of the terrestrial crust caused by new orogenic movements, and also by oceanization in a wide sense. The ocean might be also repeatedly reformed by the appearance of rises, ridges and troughs in accordance with orogenies in the continent. The principal cause of these movements may have been and is still in the movement of the interior of the earth. The convective movement itself might be however complex more and more through ages by the growth of the core.

Eventually, the observable features of the earth of the present day are merely momentarily recognized. These features, as a matter of fact, have been brought from a long complicated history of the past. The crust itself is the historical being as well as the core and the mantle of the earth. The mutual relationship is now well established as having been ever intimate between the crustal movement and the interior movement of the earth.

From various sources of geological information, the authors now stand to accept the existence of horizontal movement of the crust and repeated reformation o' the crust in various ways in the geologic past, even though the details of the authors' view may not be entirely as similar as the hypotheses of the continental drifting and ocean floor spreading.

Foundation of the young orogenic belts

Certain geologically young mobile belt like an island arc is actually a product of polycyclic orogenic movements ranging from the Variscan to multiple phases of the Alpine movements. The Japanese islands are one of such examples, where the Abean (≒ Variscan), Honshu (≒ Indosinian), Hiroshima (≒ Yenshan) and Hidaka (≒ Himalayan) movements occurred in succession. The complex structure brought by these repeated orogenic movements above mentioned in the Japanese islands was finally reformed by the youngest orogenic movement in the Neogene and Quaternary time to bring forth the so-called island arc structure (M. MINATO, M. GORAI & M. HUNAHASHI (editors), 1965).

Now, the Paleozoic deposits in Japan are now believed to have been evidently deposited on the basement complex of the Precambrian. At least this may be the case for the Honshu, Shikoku and Kyushu islands through various geologic evidences. Although the gneissic rocks supposed to have been originally belonging to the Precambrian complex in Japan do show rather young absolute age such as $420–320 \times 10^6$ys (K-Ar age) old. However, this may have been resulted from either repeated reactivation, progressive or retrogressive metamorphism and taphrogeny during the later orogenic movements. As a matter of fact, such imaginary Precambrian rocks are only locally cropping out in Japan. To be sure, these rocks have been brought to the surface by faulting, thrusting and igneous activity from the depth. It may be however eventually almost indisputable on the former wide development of the Precambrian rocks in Japan as a basement complex, prior to the deposition of the Paleozoic formations. (M. MINATO, 1966, 1968)

Large island Borneo may be counted as another such example, and the large peninsula Kamchatka may be also belonging to a similar case like Japan in concern to the problem on basement complexes. In New Zealand, the Precambrian rocks are evidently developed in wide area being covered by the fossiliferous Cambrian formation. In the progress of geologic reconnaissance in future, existence of the basement complex of undoubted Precambrian age will be further proved in many islands belonging to island arcs.

Such being the case, it is a quite dogmatic view to assume distinction on the foundation between the young mobile belts and the Caledonian, Variscan and older Alpine belts in the continent. Thus, there may be originally no difference in foundation between cratonic, sub-cratonic and orogenic belts, since the foundation is chiefly composed of granitic rocks of Precambrian age, in both stable and mobile belts.

There may be however perhaps young island arcs among the islands in the intra Pacific, which may apparently lack the granitic foundation, as a result of reformation of the terrestrial crust, as will be stated later on.

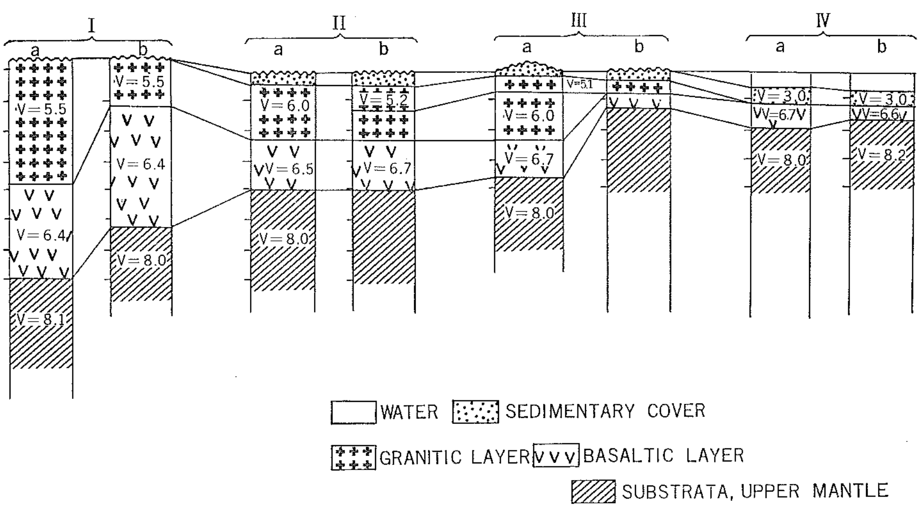

Fig. 1 Thickness of crust

I.	MOUNTAINS,	a.	PAMIRS	b.	TIAN-SHAN
II.	PLAINS,	a.	CENTRAL ASIATIC PLATFORM,	b.	RUSSIAN PLATFORM
III.	ISLAND ARC,	a.	JAPANESE ISLANDS (HONSHU),	b.	KURILE ISLANDS
IV.	OCEANIC BASIN	a.	SEA OF OKHOTSK,	b.	PACIFIC OCEAN

Formation of granitic crust

In the following, orogenic process will be brought into consideration. For any orogenic belt, principal course of development may be similar with each other, and it can be briefly summarized as to start from geosynclinal deposits including basic effusives and intrusives, and various kinds of volcanic rocks. These geosynclinal deposits were later on granitized in the depth along the axial core. On both sides of the axial core, the geosynclinal deposits were also synchronously metamorphosed either locally or regionally, and were generally intruded by ultra-basic rocks.

In other words, orogenic belt began in the deposition of the geosynclinal type accompanied by initial magmatic activity in general. Namely, such geosynclinal deposits were rebuilt into ultra-metamorphic complex like migmatite, gneiss and palingenetic granitic intrusives in the depth of the axial core, by the large scale ascension of the thermal level and volatile materials from the depth, probably from the level of the upper mantle. Their effects are of so energetic ones that the metamorphic condition shift to the state of partial fusion to attain a capacity of mobilization. Palingenetic intrusions are thus carried in the axial core of the orogenic belt. Further, the geosynclinal deposits were also metamorphosed in various grade in the area, a little apart from the core. Further, geosynclinal deposits brought in the marginal area became more or less deformed and displaced by folding and faulting through orogenic process.

As a result, the axial core of geosyncline turned to gradually upheave through buoyancy resulted from difference in density of rocks between axial and marginal parts of a geosyncline; the old and wider geosynclinal sea became accordingly separated into narrower basins distributed in both sides of axial core, in which sediments of the flysch type were deposited. The axial core further tended to rapidly upheave, and migmatitic, gneissic and granitic rocks forming the axial core became finally exposed on the surface. In accordance with this movement, molasse type of deposits unconformably rest either on the folded flysch sediments or older geosynclinal deposits and filled up the localized basins developed along the basins filled with deposits of the flysch type. The source material of the molasse sediments are chiefly brought from the older axial core of geosyncline.

Accordingly, two fundamental processes can be safely concluded in the development of orogenic belt. Topographically, older and wider geosynclinal sea turned into narrower basins which finally became filled up with sediments and were replaced by land. At the same time, the axial belt of geosynclinal sea became mountain chains where granitic rocks are exposed. (1) Briefly speaking, sea became mountain. Geologically, thick geosynclinal deposits were rebuilt into granitic rocks either large or small in scale at the depth along the axial core of the older geosynclinal sea. (2) Namely, geosynclinal deposits have been eventually reformed into granitic rocks in the core.

In the continent, especially in various paraplatform regions in China, Mesozoic eu-geosynclinal deposits, non-marine in origin, are extensively known. It is accordingly not important problem in this concern, whether or not the geosynclinal deposits were built under the sea water. Eventually, the depositional basin became mountain, and sediments including volcanics turned into granitic rocks.

Now, the recent rapid progress of the Precambrian geology reveals that the foundation of cratonic area or the originally cratonic area like platform or paraplatform were built through repeated orogenic movements of the Archean and the older Proterozoic prior to Sinian or Riphean time. Actually the granitic crust of the older Precambrian age in the cratonic and subcratonic area is chiefly composed of the remnant of the axial core of such older orogenic belts barely escaped from erosion of the later geologic age. The similar process may be accordingly deduced in concern to formation of granitic rocks of the Precambrian either in the cratonic or sub-cratonic area, like orogenic belts of the younger geologic ages.

It must be also emphasized that chief constituent rocks of the younger Proterozoic are clastic, while that of the middle or older Proterozoic are chemical sediments like limestone, dolomite, chert, iron and manganese bearing sediments, besides clastic and comparatively less amount of volcanic rocks. In contrast, the Archean rocks are dominantly composed of volcanic rocks in origin, although carbonate and clastic rocks are not entirely lacking. Thus, evolutional change in constituent of geosynclinal deposits through ages must not be overlooked (fig. 5). At present, nature on the original rocks of the oldest geological time is not well known. Nevertheless, high content of basic volcanics among them may be beyond doubt.

In putting aside a problem on the oldest rocks built in the earliest geological time for a while, so far as the oldest granitic rocks including gneiss and migmatite are concerned, their origin may have been eventually geosynclinal deposits with high content of basic volcanic rocks. If the matter were so, there might be already sea and land at that time, because presence of source area for sedimentary material must be eventually presumed to have existed and existence of depositional area for sedimentation must be also assumed even in the oldest geological time. Then, what was source material for the first geosynclinal deposits? How the earth became differentiated into land and sea, viz. topographically high and low area in the earliest geological time? What kind of place became land or sea in those days? Before stepping into this problem, the present writers, however wish to especially place stress on an assumption that orogenic process was necessary to form granitic rocks even in the earliest geologic age.

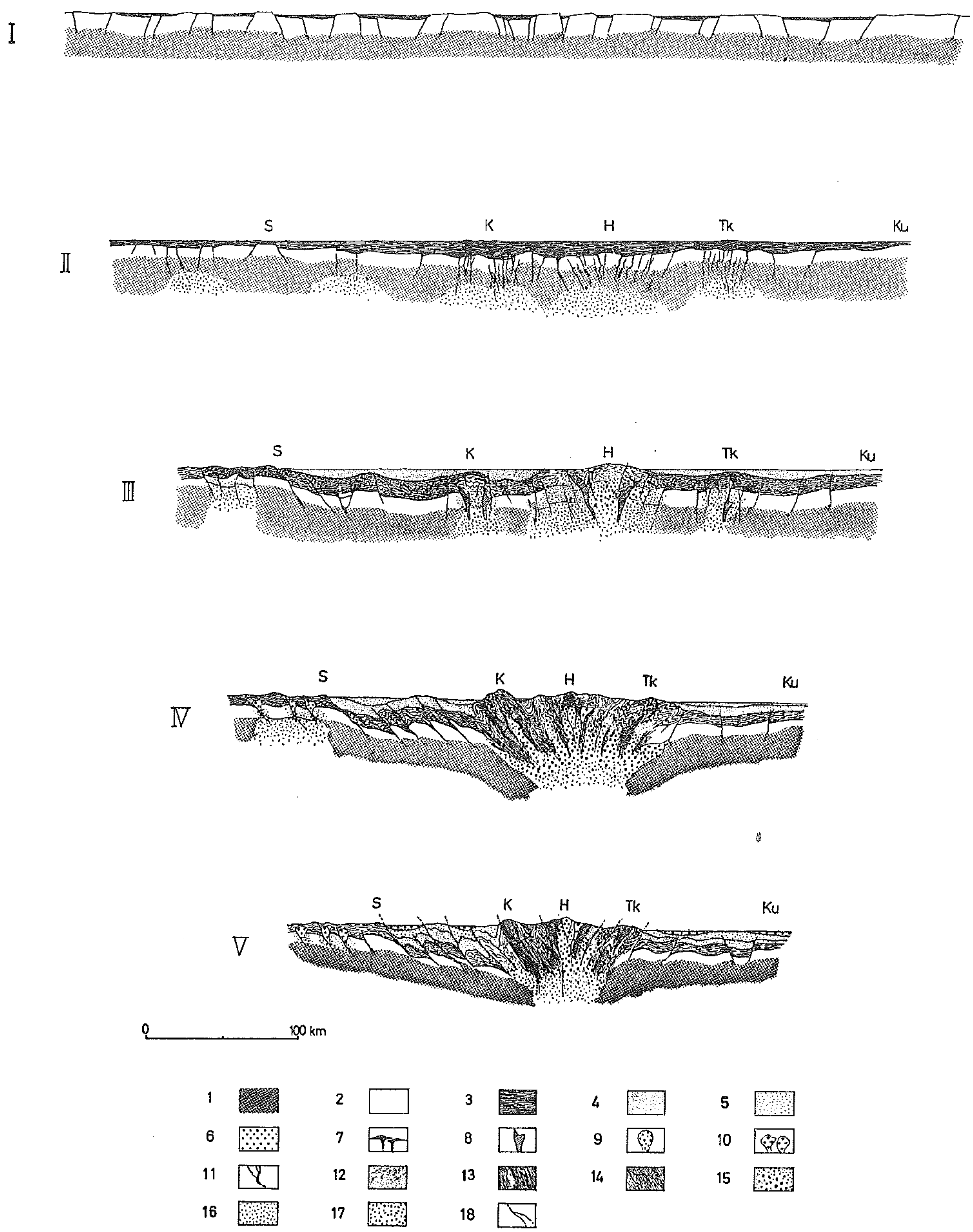
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Fig. 2

Geologic development of the Hidaka orogenic belt of the axial part of Hokkaido.

I. The beginning stage of the geosynclinal condition, in which crust became widely fractured by faulting caused by ascending convective current of the mantle, possibly in the Jurassic age.

II. The early geosynclinal stage, perhaps in the Late Jurassic to the Early Cretaceous, in which chiefly diabase and lesser amount of keratophyre intruded into the geosynclinal deposits along the faults ; volatile matter and basic magma may have been ceaselessly supplied from the depth by the ascending current of the mantle matter.

III. The early flysch stage, perhaps the Middle Cretaceous. By great rise of geothermal level, the geosynclinal deposits deeply sunken were extensively metamorphosed to hornfels. Further, gabbroic intrusives intruded into the geosynclinal deposits, the origin of which may have been as similar as the diabase, the earlier representative of the igneous activity in this belt.

In the course of this igneous activity, the axial part of the geosyncline gradually tended to upheave, and the eugeosynclinal sea became separated into flysch basins on both sides of the central belt.

IV. The Late flysch stage, perhaps the Late Cretaceous to the Early Tertiary.

The greatly sunken geosynclinal deposits became highly mobilized and finally granitized into either migmatitic or gneissic rocks by rapid upheaving of geothermal level accompanied by supply of volatile substance. Further, palingenetic granite intruded into the axial core of the older geogynclinal deposits from the highly mobilized part of the axial core of the geosynclinal deposits. Also crystalline schist may have been formed in this state along external belt of the axial core. The flysch basins became filled up with fine grained sediments.

V. The molasse stage, the Neogene Tertiary to the Recent. As the axial core of the older geosyncline became to have been greatly replaced by granitic rocks, the axial core accordingly rapidly upheaved through buoyancy in this phase ; sometimes, the granitic bodies may have been greatly thrusted up. Thus, the older geosyncline became mountain chain and the granitic rocks finally became exposed to the surface of the summit of mountains, which became the source material for the molasse deposits, the basin for which were distributed in the outer belt along the flysch basins.

1. Mantle 2. Crust 3. Geosynclinal deposits 4. Flysch type of deposits (the earlier phase) 5. Flysch type of deposits (the later phase) 6. Molasse type of deposits 7. Diabase 8. Gabbroic intrusives 9. Tonalitic intrusives 10. Granitic intrusives 11. Serpentinite 12. Hornfels 13. Crystalline schist 14. Gneiss 15. Migmatite 16. Basic melt 17. Mobilized crustal materials 18. Fault

S : Sapporo City K : Kamuikotan structural belt H : Hidaka mountains Tk : Tokoro structural belt Ku : Kushiro City

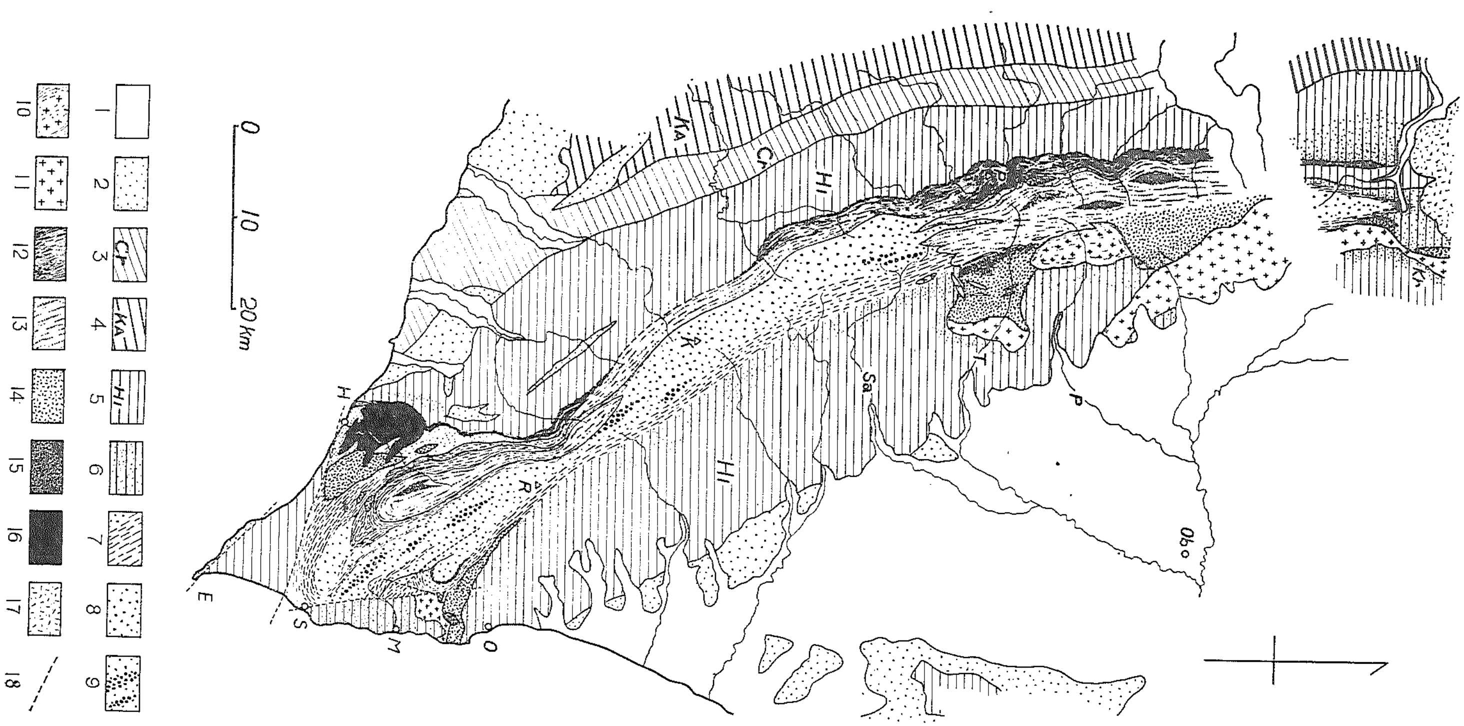


Fig. 3 Geological sketch map of the Central Hokkaido.

1. Quaternary
2. Tertiary (Molasse)
3. Cretaceous (Cr) (Flysch)
4. Kamuikotan structural belt (Ka)
5. Hidaka group (Hi) (geosynclinal deposits)
6. Hornfels
7. Gneiss
8. Migmatite
9. Tonalite
10. Gneissose granite
11. Granite
12. Gabbro amphibolite
13. Gneissose gabbro
14. Gabbro
15. Olivine gabbro
16. Peridotite
17. Saussurite gabbro
18. Thrust and fault

H.—Horoman, E.—Erimo, S.—Shoya, Ob.—Obihiro O.—Oshirabetsu M.—Meguro Kr.—Karikachi pass.

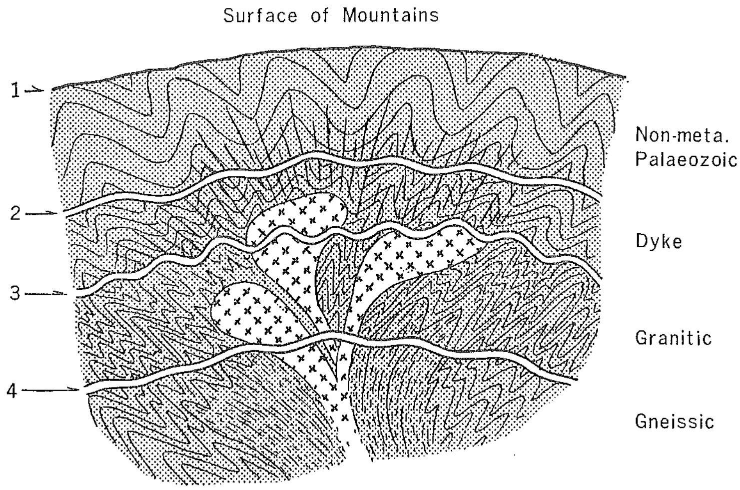
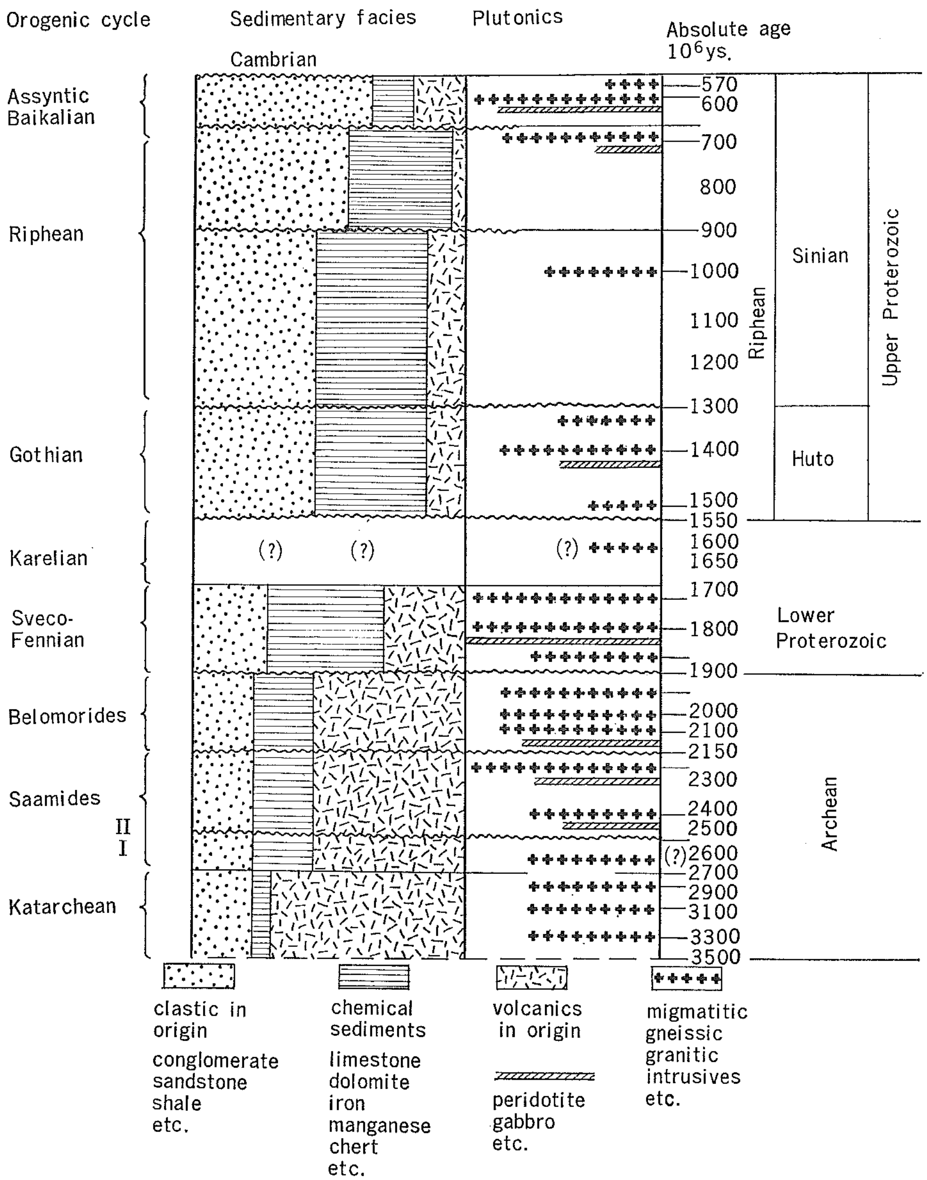


Fig. 4
Schematic profile of the Abean mountain range under denudation.
(1) At first, none-metamorphosed rocks with dykes cropped out on surface, (2) then metamorphosed rocks accompanied by dykes and intrusive bodies are exposed, (3) next, still deeply seated plutonic masses and metamorphic rocks are exposed on surface, and (4) finally migmatitic rocks and plutonics, together with highly metamorphosed rocks are unveiled on the top of mountains.
After M. MINATO in M. MINATO et al. 1965.

Movement of interior of the earth

Former view on major topography and structure of the earth has become greatly revised through recent progress of marine geology. Our conviction on presence of convective movement of mantle material has become firmer step by step, especially by discovery on new evidences either on detailed topography and structure of oceanic ridge with high heat-flow and trough with low heat-flow. The oceanic crust has been however, still remained unknown about its true structure and rock constituent, since P-wave velocity profile may be only available to infer layerd structure, at least in its deeper part. Nevertheless, existence of convection current below the earth's crust may be almost indisputable, because of various geophysical information on oceanic floor.

Oceanic ridge, for example, has been concluded to be an area, where hot mantle matter has been and is now still ascending by convective current from the depth, while oceanic trough is now believed to be an area, where cold material is streaming down after horizontal flowing. A scheme of movement below the earth's crust above stated seems to be too much simplified than the truth, but there is no basis to fully deny the existence of convective movement in the mantle.


Orogenic cycle
Sedimentary facies
Plutonics
Absolute age 10^6ys.
Cambrian
Assyntic Baikalian
Riphean
Gothian
Karelian
Sveco-Fennian
Belomorides
Saamides
II
I
Katarchean
(?)
(?)
(?)
570
600
700
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Riphean
Sinian
Huto
Upper Proterozoic
Lower Proterozoic
Archean
clastic in origin
conglomerate
sandstone
shale
etc.
chemical sediments
limestone
dolomite
iron
manganese
chert
etc.
volcanics in origin
peridotite
gabbro
etc.
migmatitic
gneissic
granitic
intrusives
etc.

Fig. 5

Now, appearance of the Darwin rise is now believed to have been in the Cretaceous; birth of the living southeastern oceanic ridge of the Pacific may be also some time in the Jurassic-Cretaceous; while beginning of growth of the Mid-Atlantic ridge may be dated as early as Jurassic in age. Such being the case, beginning of the present oceanic ridge may be almost synchronous with beginning stage of geosyncline in the Alpine-Himalayan-Laramian belts; more precisely, beginning of geosynclinal sea in the Hidaka-Himalayan-Laramian movements might be almost synchronous with the first appearance of the present oceanic ridge. The arctic ridge in the Arctic sea may be probably of the same age in its first appearance. Therefore, there may be no basis to deny the contemporaneity of crustal movement between terrestrial and oceanic crust, at least so far as the Hidaka-Himalayan-Laramian orogenic movement is concerned.

According to the writers' own opinion, existence of fossil rise, oceanic ridge and trough in the more older geologic time, which may be however hardly traceable in the present ocean, should be deduced, and similar contemporaneity of crustal movement between terrestrial and oceanic crust in such older geologic time must be also deduced. In this regard, contemporaneity of orogenic movements world over must be noted first of all. In addition, many synchronous transgression and regression of global scale have been well established in historical geology.

Let us suppose a great rise or oceanic ridges in the ocean. When the ocean floor is greatly upheaved, it follows as a necessary consequence the rise of sea level. This could be a cause of global contemporaneous transgression. While appearance of great troughs or oceanic basins will be a cause for world wide contemporaneous regression.

As a matter of fact, contemporaneity on global transgression and regression have been well proved in various geological time, as above stated, since the well known work of H. STILLE, 1924. Such geologic phenomenon may not be well explained based on a cause having been only resulted from either local sinking or upheaving of each continent. Even in a geosynclinal sea, which has been apt to be misunderstood as a continous sinking area by students unfamiliar to geology many stratigraphical breaks through erosion and renewal of transgression have been widely proved in deposits (fig. 6). Such regression and transgression of geosynclinal sea synchronously occurred with regression and transgression proved in the epicontinental sea. Accordingly, the writers are now of the opinion that oceanic rise, ridge and trough must have repeatedly appeared and disappeared in geologic time. Changing in major topography in ocean may have accordingly controlled sea level and caused transgression and regression of global scale, as stated in the foregoing lines. Convective movement below the oceanic crust must be also assumed to have repeatedly generated again and again, although either scale or geographical position of the convective cells might be different through geological ages.

Then, how was convective movement under the terrestial crust? There is no doubt about its presence in the geological past, too. In this concern, it may be

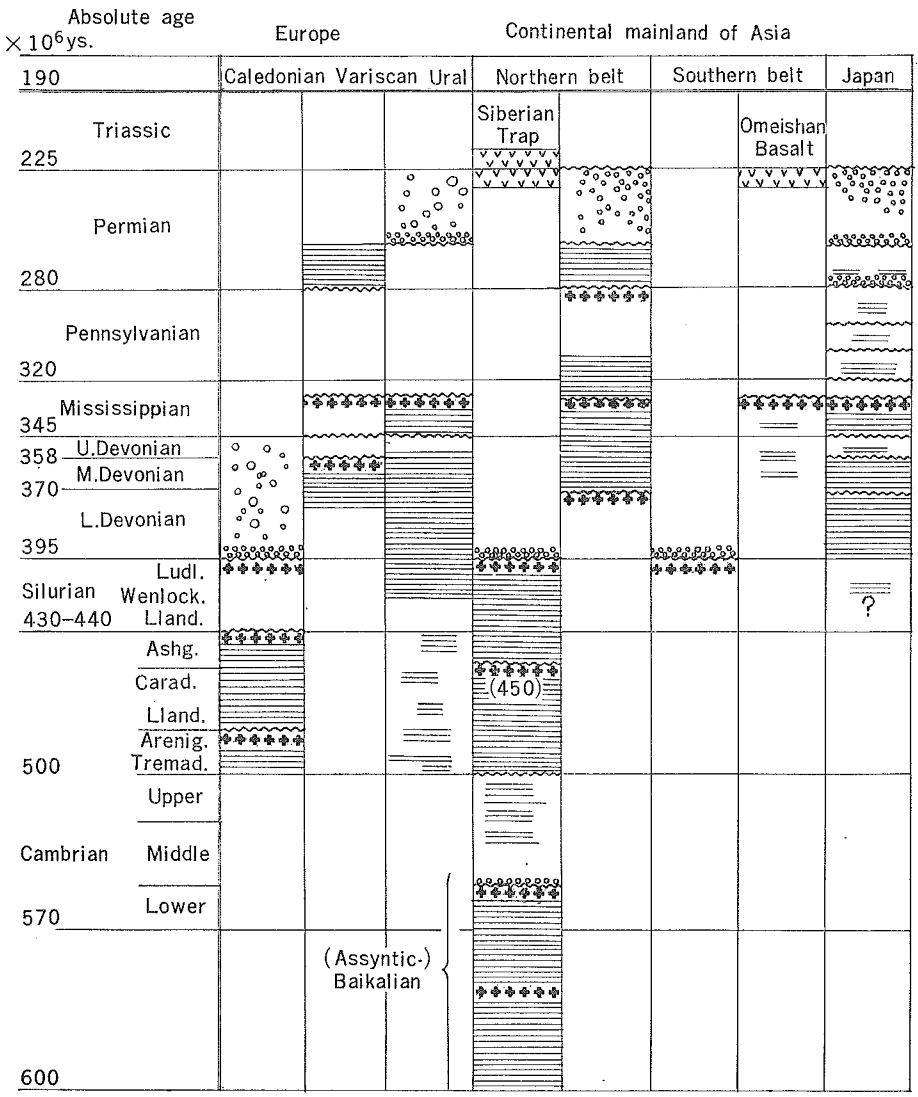


Fig. 6
Correlation of the Caledonian and Variscan movements between Europe and Asia.

Horizontal lines:	Geosynclinal condition
Circle:	Molasse deposits
Cross:	Syn-orogenic plutonisms, granitic intrusion
Wave line:	Unconformity of global scale.

very suggestive to see that the oceanic ridge developed in the northwestern Indian ocean seems to merge into the Red sea and further continue into rift valley of the East Africa. Namely ridge in the oceanic crust merges into faulted belts of the terrestrial crust, where typical "graben" structure is observable, besides ruined and younger volcanoes, chiefly composed of basic effusives, which are in fact distributed along the fault lines.

Thus presence of convective movement below the terrestrial crust may be also indisputable, although geologic phenomenon brought forth by convective current on the terrestrial crust is and may have been greatly different from that on the oceanic crust.

As a matter of fact, beginning of geosynclinal sea of the Baikalian, Caledonian, Variscan and Alpine movements in Asia, is concluded to have opened with faulting, followed by volcanic activity at least so far as the axial core of each orogenic belt is concerned. Needless to say, all these older mobile belts were born on the terrestrial crust.

Prior to transgression in the geosynclinal sea of these orogenic belts, foundation chiefly composed of migmatitic and gneissic rocks of the Archean and the Lower Proterozoic there, are thought to have been already well consolidated and attained to be fairly thick. Still such a granitic crust seems to have been more brittle and fragile than plastic oceanic crust for ascending current from the depth. As a result, faulted belts appeared just above the ascending current which became eventually sinking area, because of unstable condition of the depth and tended into a stage of volcanic activity by high energy continuously supplied by ascending convective current below the terrestial crust.

This might be an origin of geosyncline in the Baikalian and post Cambrian orogenic belts. A series of geologic process in orogenic movement briefly stated in the preceding part entitled as " Formation of granitic crust " must be thought over from the view point of an intimate mutual relationship between crust and mantle.

Namely, granitic rocks were in fact chiefly originated from tremendous volume of geosynclinal deposits: basic effusives and intrusives brought forth from the depth at the beginning of geosynclinal condition of each orogenic belt, besides sedimentary rocks. To be sure, there are some granitic rocks, which may have been directly derived from basic magma through the process of crystallization-differentiation, although such granitic rocks may be eventually of only minor amount. In the course of deposition, important rôle of weathering must be, first of all, emphasized: all the source rocks of geosynclinal deposits, either igneous or sedimentary in origin may have been weathered on the surface of the earth before transportation into geosynclinal sea.

In the weathering process, source rocks may be thus mechanically or chemically decomposed into various state or grade either from climatic condition of the surface in concern or from mineral composition. Eventually, originally fresh rocks may have been more or less leached in the weathering. In this process, Mg, Ca, Fe, Na and K were more soluble than Si and Al with certainty. Therefore one of the chemical terminals of the sediments came to be enriched in Al and Si, while the another terminal became to be rich in the residuals of the leached material, with high content of soluble metals. Further, biogenic activity may be more estimated in the rôle of weathering of original rocks than has been commonly viewed by until recent. Anyhow, there might be various kinds of sedimentary material of different chemical and mineralogical constituents among the geosynclinal deposits, besides intrusives or effusive bodies of igneous rocks intercalated with the sedimentary rocks. It may be, however, especially stressed that most of slate, sandstone, graywack etc. among the geosynclinal deposits show similar chemical composition with that of granitic rocks, including migmatite and gneiss.

Now, the deeply sunken bottom of the axial core of the geosyncline seems to have been eventually brought into high thermal condition by continuously ascending convective current: perhaps volatile substance were ceaselessly carried up from the depth by current, besides certain amount of basic magma itself. In the course of this process, thermal gradient became higher and the geosynclinal deposits must have been reformed into either hornfels, gneiss, migmatite in succession. In all probability, the axial core, accordingly, came to be highly mobilized through this process, and palingenetic granite may have further intruded into the geosynclinal deposits of the axial core as a final product of magmatic activity. This is the fundamental course of the birth of granitic rocks in the orogenic belt, at least their major parts are concerned. *Without geosynclinal deposits, almost no granitic rocks were ever formed without doubt through the earth's history.*

As a matter of fact, there exists a large mass of granitic batholith in various orogenic belts, but origin of such intrusives is doubtlessly from the result of reactivation of granitic rocks being built in the earlier geologic time in the depth of the crust.

Although there may be nothing new in the authors' explanation on the formation of granitic rocks in the orogenic belt and syn-orogenic magmatic activity in the depth of the axial core of geosyncline, (H. STILLE, 1940, C.E. WEGMANN, 1935) they tried however, to present geological process some in detail in combination of the convective current in the mantle. If we ignore a rôle of ascending convective current in the mantle below the geosyncline, nothing may be plausibly explainable as to geologic processes in well established mountain building theory in geology.

Now, if our assumption is correct on the axial core of geosynclinal sea as an area having been just positioned above the culminating belt of ascending current from the depth, convection current of the older geologic time will be traceable on the geographical map to some extent.

One of the authors (M. M.) newly compiled geographical distribution of the orogenic belts in Asia ranging from the Baikalian to the Alpine movements, except for that of the Neogene and Pleistocene time (fig. 21). This map may also show axial belt of the ascending current from the depth for each orogenic time. According to this map, geographical extension and direction of convective current is concluded to have been greatly changing through ages, at least so far as the Upper Proterozoic and following ages are concerned.

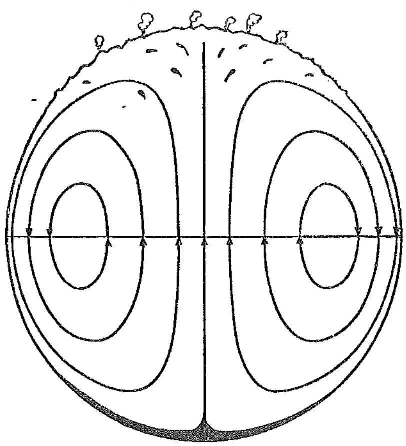
Then, how was about the Archean and Lower Proterozoic time in Asia? It may be very difficult at present to correctly trace the axial core of orogenic belts of such an older age, because of insufficient information on geology in this field, even though it is not absolutely impossible in future. Nevertheless, the Archean and Lower Proterozoic ultra-metamorphic and metamorphic rocks are widely developed in Asia, especially in the shield Anbar, and Aldan of the East Siberia, and the peninsula India, besides in the platform of the West Siberia and in many paraplatforms in China, which will be enumerated below: Northeast China paraplatform, Sino-Korean Paraplatform, South China paraplatform, Tarim paraplatform and Tibet-West Yunnan paraplatform (T.K. HUANG, 1960). The recorded oldest rocks for each unit in the cratonic and sub-cratonic areas above listed are ranging in age from 2,800 to 3,500 $x10^6$ ys old. In addition, the Archean and Lower Proterozoic complexes are either extensively or narrowly developed in many orogenic belts of various ages in Siberia (A.M. SMIRNOV, 1968) as a foundation.

It may be worth while mentioned that such older rocks show east-west direction in their general structural trend in Siberia and China, while north-south trend is predominant in the peninsula India, besides the Arabian upland. Further in Australia, representative structural trend in the Archean rocks seems to be also meridional. Therefore, major structural trend of the Archean and Lower Proterozoic rocks may be different in general between the Eurasia and Gondwana. In other words, in such vast area, only special directions seem to be predominant in the structural trend of the older geologic complexes: east-west in the northern continent, while north-south in the southern continent.

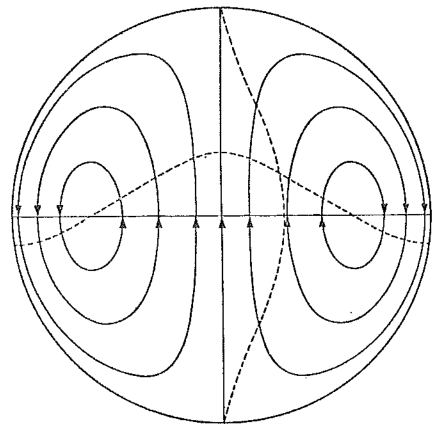
From this fact, movement of interior of the mantle may be concluded to have been more uniform or simple for a long period of time in the Archean and Lower Proterozoic, compared to the younger Proterozoic and post Cambrian time. To be sure, convective movement below the crust became complex step by step through geological ages, either in their extension or direction. Even more, origin of ascending current may have been gradually changing in its depth through ages. Such being the case, the earliest and most simple convective current might be of only single cell in the entire interior of the earth, like the model presented by F.A. VENING MEINESZ. In such an age, core of the earth might not be born yet and this might be perhaps prior to the geologic age of the earth (fig. 7).

Now, let us return to the earliest geologic stage of crust in the earth. Before stepping into this problem the source area for the geosynclinal deposits of the Baikalian belt, for instance, will be however first brought into consideration. This

Fig. 7
Single-cell convective movement of the interior of the earth in the lunar stage. After V. MEINESZ, (1964) and H. H. HESS (1962). Continent was formed by effusion of mantle material carried by ascending movement of the interior of the earth, while ocean was formed in the sinking basin caused by descending current.



After H. H. HESS, slightly modified.



First-order current in a fluid undifferentiated earth during an early stage of its history; dashed curves give the velocity distribution in axis and equator of the current system.
After F. A. V. MEINESZ, 1964.

might be somewhere in the cratonic area developed along the Sinian and Riphean sea. As for the Caledonian, the source area of the geosynclinal deposits might be also definite region in the well consolidated cratonic area plus half-consolidated Baikalian belts. Similarly, for the Variscan and Alpine belts, source area is now well determined through various geologic method and this was eventually in definite region either in cratonic, subcratonic or older orogenic belts.

Then, how was the condition the earlier geologic time, or the earliest geologic time. In Asia, the Archean rocks are found out nearly everwhere in the shield, platform and paraplatform, besides in many mobile belts. Accordingly, as a source of deposits for the Archean orogenic belts, somewhere in the exterior of the present continent must be assumed, viz. in somewhere in the present ocean. Especially, so far as the oldest granitic rocks are concerned, their source area of original sedimentary rocks must be concluded to have been in outside of the present continent. This must have been in certain regions of the present ocean.

From this view point, the authors are now in belief that major topography on the earth must have been once quite opposite to the present condition. *Namely, the present continent was ocean, and the present oceanic area was continent in the earliest geologic time.* Inspite of apparent youth of the present oceanic floor, the

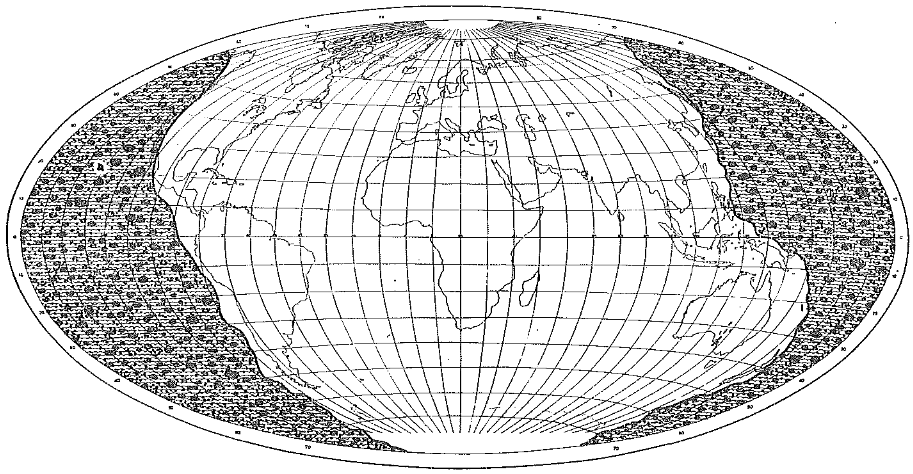


Fig. 8
Distribution of ur-continent (wave lines) and ur-ocean (white colour) in the lunar stage of the earth. The ur-continent was covered by the basaltic volcanoes and their volcanic products, while the ur-ocean might be filled with shallow ur-sea water in those days. Ur-air might be also present. Scheme of distribution of volcanoes in those days is shown by dots in black colour.

writers are sure that the present ocean was once topographically high and formed large continent. Otherwise, the distribution of the cratonic and sub-cratonic area in the present continent or evenmore, the entire terrestrial crust of the earth may not be well explained. In contrast, sea must have been once widely spreading to cover the entire area composed of terrestrial crust of present. The young aspect of the present oceanic floor may be resulted, as before stated, from repeated circulation of oceanic crust caused by convection current below the crust.

Notwithstanding of this, the fact should be awared that the recorded oldest rocks found out in the ocean were collected, near the Mid-Atlantic ridge (the St. Paul's rock), which have been practically dated as 4,500x10^6 years old (J.D. BERNAL, 1967). The rock above stated is reported as almost pure peridotite, and now believed to have been brought up to the surface by igneous activity of the far younger geological age, from the depth, probably from the mantle.

The age of this rocks is eventually much older than the oldest rocks having been ever known from the present continent.

Before going further into the problem on the origin of the earth's crust, horizontal movement or shifting of the earth's crust must be however discussed, which will be briefly described in the following part (fig. 8).

Shifting of crust through geological ages

a) Actual presence of horizontal movement at present

The latitude observatory at Mizusawa, Northern Honshu, has made observations on the changing of latitude for more than a half century. Nowadays, the horizontal movement is well established by the similar observatories located along about 39° N parallel in Pulkovo (USSR), Carlofronte (Italy), Mizusawa (Japan) and Utah (Western USA). The change in the Utah observatory latitude is most significant. For instance, according to YE. N. OBREZKOVK's computations (after P.N. KROPOTOKIN, 1960), it is increasing 10.0047' per year, on the average, between 1900 and 1934.

As a matter of fact, at Pulkovo, its latitude has not changed for last 50 years, or has decreased by not over 0.00005' per year on the average (P.N. KROPOTOKIN, 1960). This means 10 to 15 cm a year in horizontal movement. This is much

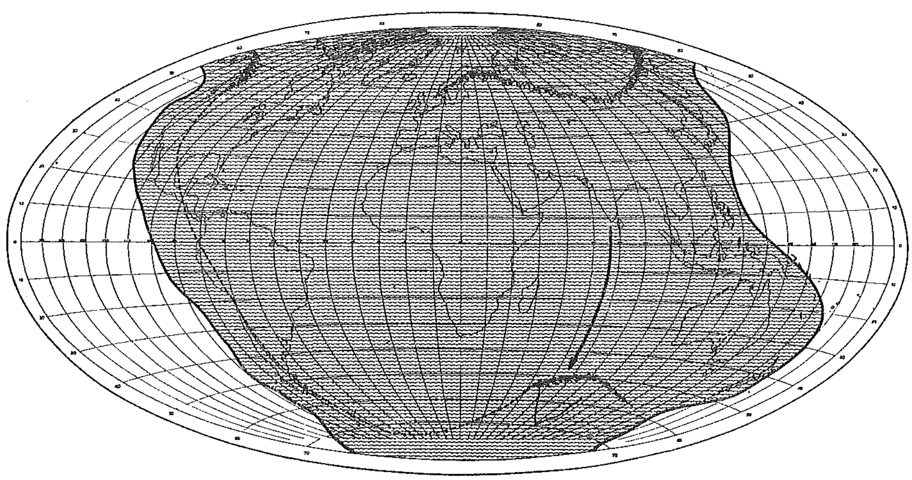


Fig. 9
Distribution of the terrestrial crust (wave lines) and oceanic crust (white) in the Late Precambrian time. The Baikalian mountains might be born along the rift in the continent at the beginning, although their prolongation into the ocean of those days can be hardly traced in the present ocean. The present distribution of the Baikalian mountains or Assyntic orogenic belts is fairly well traceable in Asia, Gondwana, besides North America, Africa and Europe to some extent, as is suggested by the presence of the Latest Precambrian granitic intrusives. However, the geographical position of the cratonic and subcratonic regions might be greatly different in the Late Precambrian time. In this map the area composed of oceanic crust is shown by white colour. However, shallow epi-continental sea was widely spreading even in the continent in the younger Proterozoic time, besides oceanic basin itself. Arrow indicates the position of India of those days.

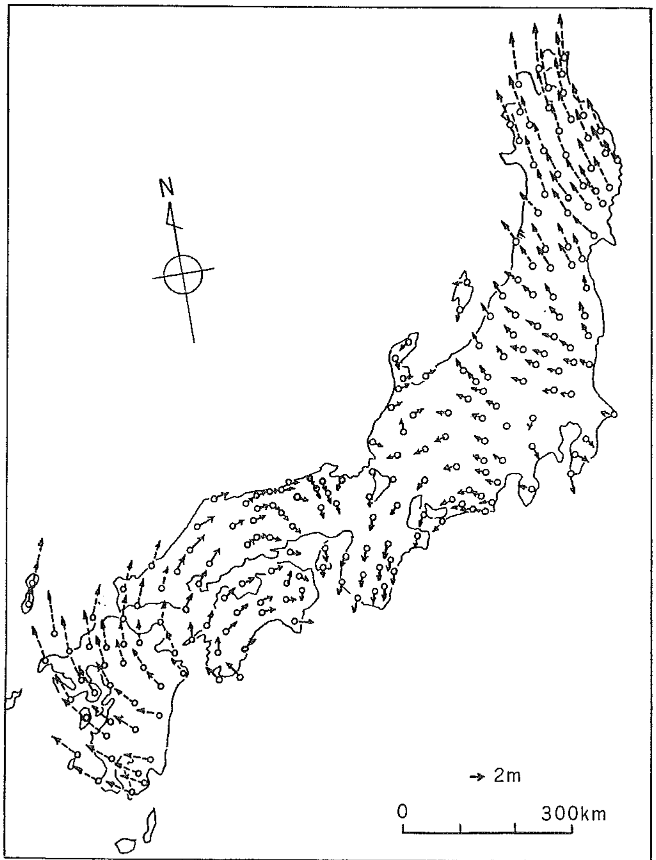


Fig. 10
Horizontal movement in Japan within past 60 years. Arrows indicate the direction and amount of movement. Dotted lines indicate the ones probably affected by the error in measurement. After HARADA (1967).

larger than the shifting assumed by the paleomagnetic data which amounts 2–3 cm a year in the last 100 million years.

Data on precise leveling in Japan, repeatedly made all through her territory, show that the horizontal movements occurred in Japan. This is well established as the fig. 10 shows. Naturally, up and down movements occurred in Japan in many places, certain of which were observable by eyes, especially by the earthquakes of the greater magnitude. Vertical movement should be accompanied by horizontal movements. It may be accordingly no wonder if horizontal movements were proved by geodetic study.

Fig. 10 shows the horizontal displacement occurred in Japan, in the past 60 years. This map is compiled on the preposition that Tokyo was stable and not moved in these 60 years, and the relative distance of horizontal displacement and direction measured from the definite point of Tokyo are shown in this map. The length of an arrow and direction, means the amount of displacement and direction of movement at the given points, measured from Tokyo.

According to this map, three horizontal movements are recognizable in Japan, viz. in the northern Japan, it tends towards north or north-north-west, while in the southern Japan, including island Kyushu and Shikoku, western part of Honshu, and Kinki area, shows the vortex-like movement in anti-clockwise. In the meantime the central part of Honshu and southern region of northern Honshu shows rather a little movement: still those areas show movement-directions somewhat divergent towards northwest and northeast, although the movement of the peninsula Boso tends south and south-eastwards.

Eventually, the results of stadia survey which is now going on seem to well establish the presence of horizontal movements in Japan, the maximum displacement is 8 to 10 meters in 50–60 years; thus 13–16 cm/year: this amount is surprisingly great, although generally the mean value may be estimated as 3 cm/year or a little less.

Naturally neither vertical nor horizontal movement is steadily or continuously going on, but it occurs from time to time, as is well observable at the occasion of earthquakes; the general tendency of horizontal movements, now in progress in Japan, may be also viewed as such.

b) Paleomagnetic data

Changing of paleolatitude has been well established in Japan on the basis of basaltic rocks, magnetite sandstones and red shales sampled in various localities in the north and south Japan, including Hokkaido, ranging from the Devonian until

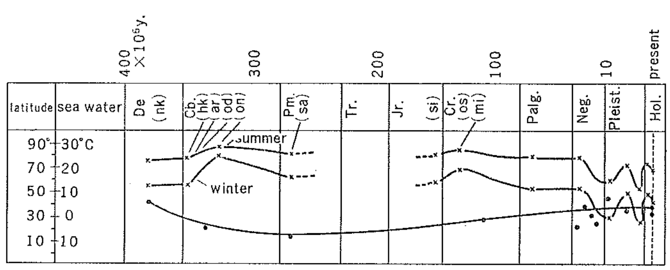


Fig. 11

Change of latitude and temperature of sea water in the Northeast Honshu including the Kitakami mountains through geological ages. De: Devonian, (nk): Nakazato stage, Cb: Carboniferous, (hk): Hikoroichi stage, (ar): 'Arisu stage, (od): Ohdaira stage, (on): Onimaru stage, Pm: Permian, (sa): Sakamotosawa stage, Tr: Triassic, Jr: Jurassic, (si): Shishiori stage, Cr: Cretaceous (os):, Ohshima stage, (mi): Miyako stage, Palg: Paleogene, Neg: Neogene, Pleist: Pleistocene, Hol: Holocene. After MINATO and FUJIWARA (1964).

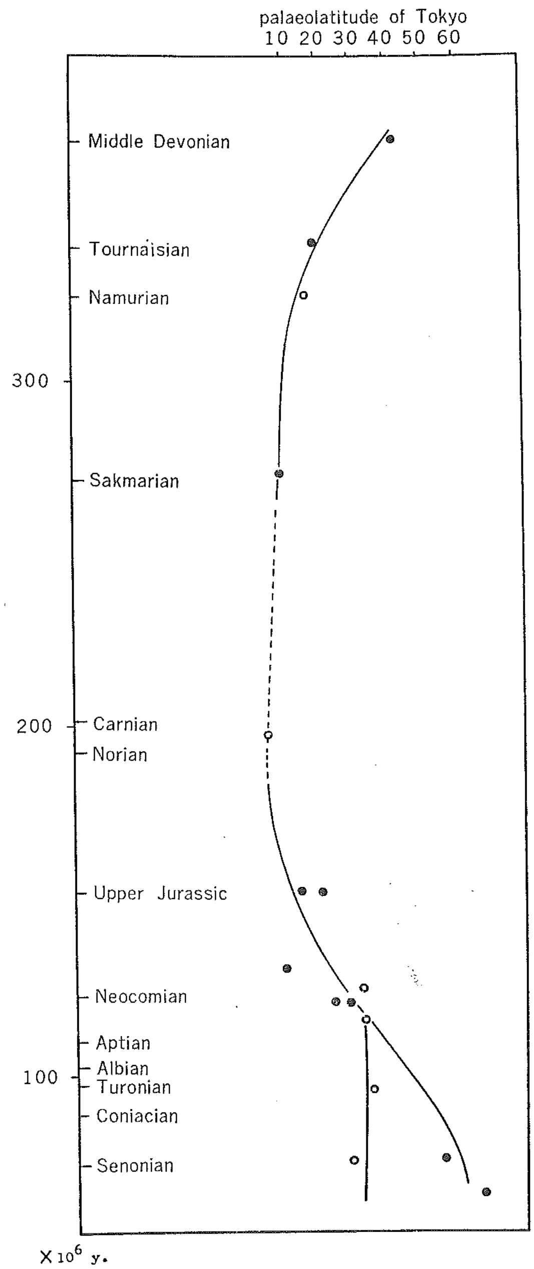


Fig. 12
Changing of the palaeolatitude of Tokyo through the Palaeozoic and Mesozoic estimated from the paleomagnetic studies on the Japanese rocks. After Y. FUJIWARA, 1969. Solid circle: rocks sampled from Northeast Honshu and Hokkaido, while white circle: samples from the southwestern Japan including Kyushu island.

the Pleistocene formations. The established facts on the paleomagnetic study based on the Japanese rocks may be briefly outlined below:

(1) The paleopole was apart from that of the present in the Paleozoic, and Mesozoic, and closer to the present position of pole inferred from the Cenozoic, especially by the Neogene and the Pleistocene rocks.

(2) Paleolatitude inferred from the Japanese rocks, is positioned relatively higher in the Devonian, and tended towards lower during the Mississippian and Permian. The Permian time shows Japan to have been in its southernmost position (fig. 11); while it again became to be higher through the Mesozoic and Paleogene, and finally shows to settle at the present state during the Pliocene or Pleistocene time.

(3) However, the rate of changing of latitude seems to have been different between north and south Japan, since the early Cretaceous (N. KAWAI et al. 1969) (Y. FUJIWARA, 1969). Namely, in the southwest Japan, no remarkable changing in paleolatitude may be inferred from the paleomagnetic data since the early Cretaceous, while the north Honshu and Hokkaido show to have gradually moved northward during the Cretaceous and Cenozoic time and finally reached the present state (fig. 12).

(4) The changing paleolatitude in the Japanese islands may well explain the changing of climate in the geological past. Namely, the time when the paleolatitude is inferred to have been lower than present, ranging from the Lower Permian to Middle Triassic, marine fauna in the Japanese Permian and Triassic also shows that the climate may have been tropical, as is indicated by the dominant presence of reef building corals. This is also suggested by the dominance of carbonate rocks, as well. The paleomagnetic data are lacking in the Upper Visean: still the Lower Mississippian and Pennsylvanian and also the Jurassic and Neocomian rocks show the paleolatitude to have been a little lower than the present and, this fact may be in good accordance with the faunal assemblage of each geological time in Japan. The subtropical or a little warmer climate of the Palaeogene and Early Miocene inferred from the faunal and floral association in Japan is also well in harmony with the position of paleolatitude. Further, the cool or rather colder condition in the Late Miocene also well coincides with the changing of palaeolatitude inferred from the rocks mentioned above. In short, the changing of paleolatitude inferred through the paleomagnetic study on the Japanese islands may plausibly explain the changing of the climate in the geological ages in Japan (M. MINATO and Y. FUJIWARA, 1964) (fig. 11).

(5) The changing of paleolatitude deduced in Japan on the basis of the Japanese rocks has the same inclination or tendency as the changing of paleolatitude in Australia. Namely, when the Japanese islands show high latitude, similarly Australia shows to have been close to equatorial region; while the Japanese islands show low latitude, Australia become to show high latitude in the southern

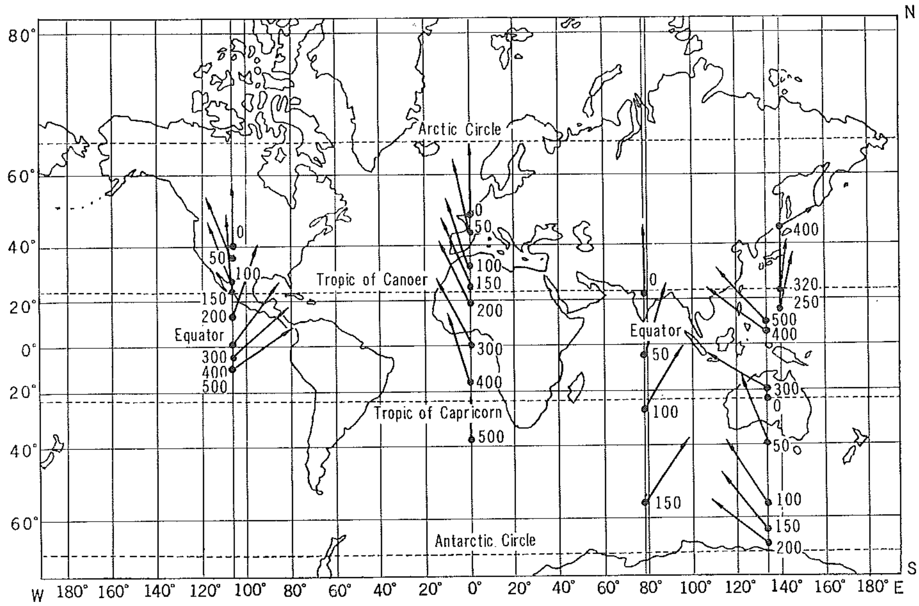


Fig. 13

The palaeolatitude and orientation of North poles estimated by the rocks developed in various continents (Europe, Australia and North America) (after BLACKETT et al. 1960) and the Japanese islands in various ages during the Upper Paleozoic (M. MINATO and Y. FUJIWARA, 1965). The number of each point indicates its age in unit of million years.

hemisphere. In the lower Permian, for instance, the Japanese islands were located close to the equator, and Australia is ascribed to have been in polar region in the southern hemisphere in the same age (M. MINATO and Y. FUJIWARA, 1965) (fig. 13). The observed fact above stated can be explained by the shifting of the pole position through the geological ages. As a matter of fact, the pole positions deduced from various localities in the world are generally widely scattering, however.

As it is so well known that it may not be necessary to mention, the pole positions of the Lower Permian for instance, determind by rocks sampled in different localities of the different continents fall in vast extent of area, in spite of showing nearly same age of these rocks (fig. 14) (G.F.L. DIETZEL, 1960). Thus the horizontal shifting of the localities where samples were obtained must be assumed; in other words, great changing of relative distance of the sampled localities must have been assumed. As a result so-called continental drifting, or the relative horizontal movements of continent or islands may be concluded to have really occurred in the geological past, since there is no way to find a plausible explanation about the wide scattering of pole positions as a result of paleomagnetic study.

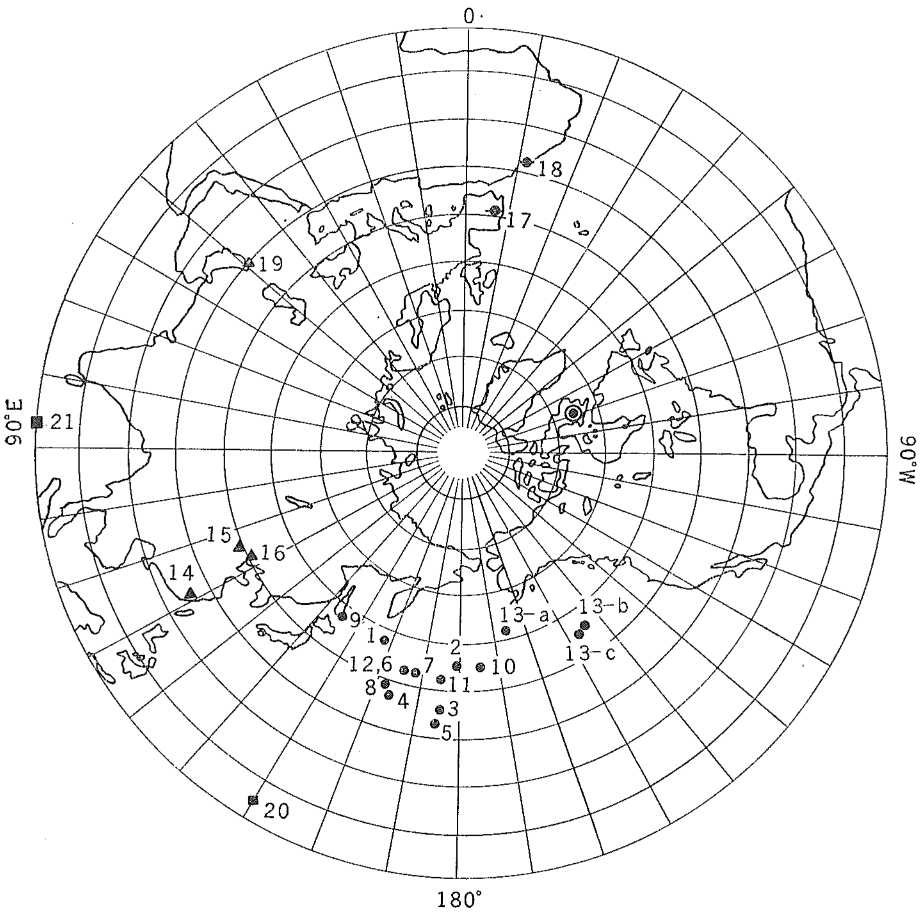


Fig. 14
Positions of Permian magnetic poles on the northern hemisphere.
● Inferred from European rocks.
▲ Inferred from American rocks.
◆ Inferred from Australian rocks.
■ Inferred from African rocks.
⊙ Inferred from N. E. Japan (65°N, 67°W)
After G. F. L. DIETZEL (1960) slightly modified.

c) Compaction of folded belts in the geological past

A considerable shrinking or decreasing of width of the original basins in the folded belts is obvious. In the Ishikari coal field in Hokkaido in Japan, may be one of the best mapped areas in Asia. The coal bearing Paleogene formations are intensely folded, faulted and thrusted there.

The late Dr. K. OTATSUME (1951), and later on Dr. S. TAKAO (1952), etc. tried to restore the folded structure of the coal bearing formation to the original

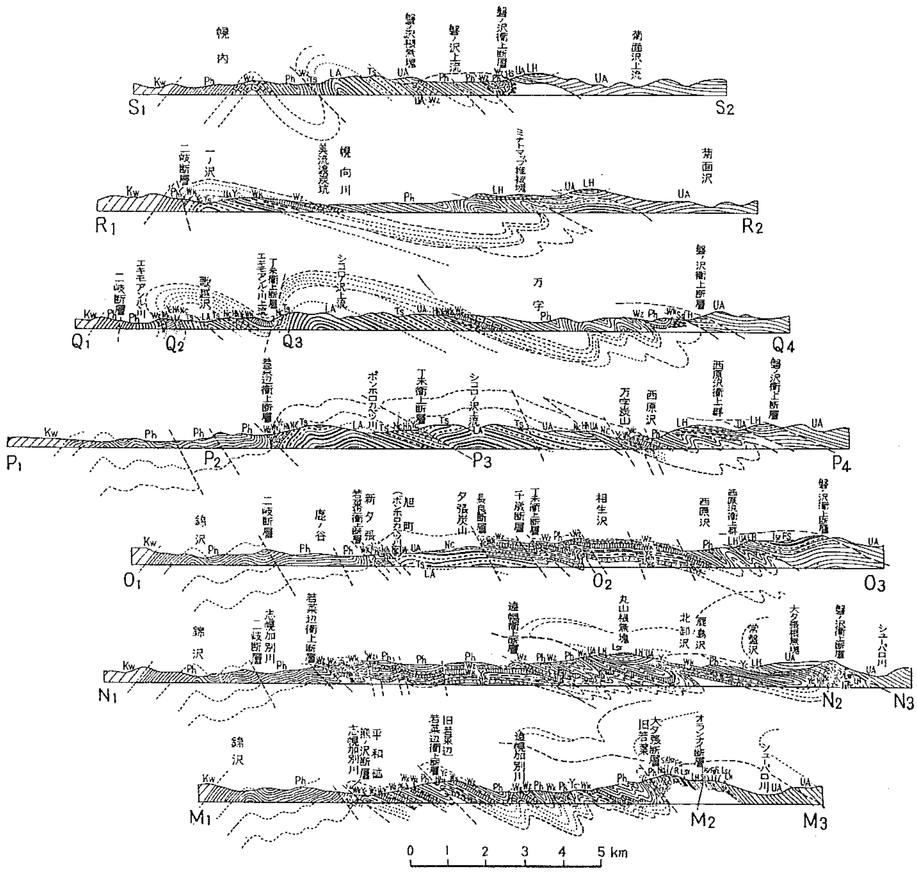


Fig. 15

Geologic profile of the Ishikari coal field in the Yubari district, Hokkaido. Kw: Kawabata formation, Miocene, Ph: Poronai-formation, Oligo-Eocene, Wz: The Woodwardia sandstone formation, Eocene, Wk: the Wakkanabe formation, Eocene, Yc: the Yubari coal-bearing formation, Eocene, Hh: the Horokabetsu shale formation, Nc: the Noborikawa coal-bearing formation, Eocene, Ss: the Sanushibe sandstone formation, Upper Cretacesous, Usr: the upper sandy shale formation, Upper Cretaceous, FS: the Fukaushi sandstone formation, Upper Cretaceous, Lsy: the lower sandy shale formation, Upper Cretaceous, Oh: the lower Hakobuchi formation, Upper Cretaceous, Ua: Upper Ammonite formation, Upper Cretaceous, Ts: the Trigonia sandstone formation, Middle Cretaceous. After K. OTATSUME 1951.

state as much as possible (fig. 15). And they concluded that the original coal basin must have been reduced in width at least 1/2.5 by either intense folding or faulting including thrusting, after the deposition of the Paleogene formations. As a matter of fact, the structure in the western part of this coal field, is generally rather gentle, while in the central area, the Paleogene formations become to show intense folding with high angle, and further to the east, they tend to show isoclinal folding with accompanying thrusts and faults.

In the area where the isoclinal folding with thrusting is repeated, a certain amount of compaction of each bed is suggested. However, the total width of the original basin must be concluded to be 2-3.0 times wider, than the present. As a mean value, 2.5 times wider basin may be conclusive. The writers accordingly believe that the decreasing or considerable reduction of width of the original basin may have really occurred during the process of folding. Thus, it is doubtless that the horizontal shifting of the folded belt perpendicular to the direction of the majority of fold axis and trend of faulting may have been occurred.

In a similar way, one of the authors (M. M.) and his coworkers in the Paleozoic-Mesozoic field in the Kitakami mountains, in NE Honshu, after fairly detailed mapping, tried to reconstruct the original state of the basin. As a result, they have concluded, the original Paleozoic basin must have been more than 6 or even 10 times wider than the present folded belt exposed on the surface, even they brought a certain amount of compaction of rocks into consideration.

Not only that, one of the authors (M. M.) noticed the different trends of fold axes through ages there. Namely, the Silurian, Devonian and Mississippian formations except for the Upper Visean (roughly corresponding to the Chesterian) are folded and faulted along NE-SW direction, while the formations ranging from the Upper Carboniferous to Upper Permian are folded along the NW-SE in direction. Further, the Triassic, Jurassic, Lower Cretaceous formations are folded along the axis in trend of NNW to SSE in general.

Naturally, the older formations show more complicated structure than the younger ones both in folding and faulting, and are actually more or less repeatedly deformed and displaced by the later movements. Nevertheless, the result of detailed mapping revealed that the major structural trends are different between the old and new formations.

It may be accordingly not impossible to regard the changing of general trend of fold axis observed in the mapped area in the Kitakami mountains to have certain relationship with the direction of horizontal movements, deduced from paleomagnetic data. Shifting certainly occurred during the Devonian to the Permian from north to south, and the another horizontal movement occurred in the Mesozoic and Cenozoic from south to north. To be sure, the major direction of the horizontal movements might be almost perpendicular to the axis of folding.

Thus, the writers are quite sure of existence of horizontal movements in the geological past, and also considerable reduction of width of mobile belt in the process of orogenic movements. Nevertheless, the authors' assumption or conclusion on the observed facts does not involve any intimate relationship to the old concept of the shrinking theory, proposed by the *older* Swiss geologists, since the

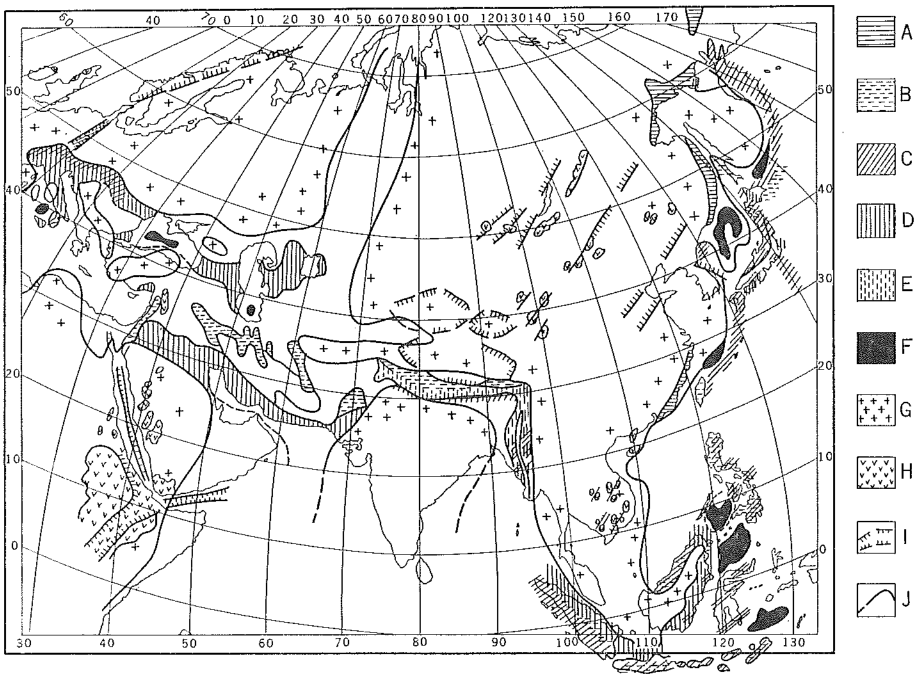


Fig. 16

The Neo-Tethys.

A : Continental volcanic belt of the Late Cretaceous and Paleogene.
B : Marine Late Cretaceous and Paleogene volcanic belt.
C : Neogene and Quaternary volcanic belt.
D : Thick marine Paleogene and Neogene deposits
E : Marine Paleogene deposits without marine Neogene deposits
F : Continent during the Late Cretaceous and Paleogene and later became to sea and " oceanic crust " is supposed to be present below the young sedimentary cover.
G : Cratonic or sub-cratonic region or the continent in the Paleogene.
H : Plateau basalt in the Tertiary and Quaternary.
I : Major fault and typical graben structure.
J : Boundary between cratonic, sub-cratonic and orogenic belt ; shore line either of the Paleogene or Neogene time.

authors do not postulate that the lowering of temperature caused the observed reduction of width of depositional basins.

Here, the authors only mention the observable fact in shrinking or reducing of width of depositional basins caused by folding and faulting including thrusting. Deformation or displacement of sedimentary rocks may be caused either by the process of sinking or rising of the sedimentary basin by orogeny, and may be also caused by the horizontal movement.

Now, no doubt the scale of the folded system of the Assyntic, Baikalian, Caledonian, Variscan, and various phases of the Alpine movements in Asia, are indeed great, compared to that of the Hidaka orogenic belt or the Abean mountains in Japan. These latter areas have long been mapped by the authors.

With respect to such great folded belts as the Baikalian, Caledonian, Variscan, and Himalayan, the greater reduction of width of the depositional basins in their final stage of movements must be naturally assumed. The width of the Tethys, either Prototethys (late Proterozoic), Paleotethys (Paleozoic) or Mesotethys (Mesozoic) especially in the Central Asia must have been at least 6-10 times wider than the present width of each orogenic belt; further the Neotethys (Cenozoic) should have been also far wider than the present Iranian-Himalaya-Malaya-Indonesian mobile belts. Under such circumstances, the remnant of the great continent of Gondwana such as Ur-India plus Eo-India, must have been located far south of its present location, and at the same time, Australia may have been once situated further south than the present position.

This assumption seems to be well consistent with the hypothesis on shifting of the peninsula India inferred from the palaeomagnetic data. The peninsula India is now believed to have been relatively rapidly or slowly ever shifted from south to north: the palaeolatitude of Bombay for instances is calculated as 44°S in the Jurassic, 39° S or so in the Late Cretaceous and Eocene, about 12°-14° S in the post Eocene time, about 5° N in the Miocene, although it is now located about 18° N.

As is schematically shown in the fig. 22, shifting of the peninsula India, faulting and effusion of basaltic lava flow in the Deccan plateau on the granitic crust through Mesozoic and Tertiary time, formation of wide geosynclinal sea of the Himalayan orogenic belt, and shrinking of its geosynclinal deposits and igneous rocks by shifting, folding and faulting in the course of orogeny may be plausibly explained by the mutual relationship between the movement of the interior of the mantle and granitic crust of India.

On the granitic crust, the ascending convective current of the mantle matter caused faulting and volcanism, at the beginning, as the Deccan plateau shows.

In the area like the Himalayan orogenic belt, geologic process from geosynclinal sea to mountain chains was successively advanced one after another. Since shifting was so slow down there through relatively longer period of time that geosynclinal deposits were perfectly reformed by plutonisms and metamorphisms at its cores until the time when shifting was again rapidly proceeding.

The rate of shifting can be definitely calculated in this case by palaeomagnetic data on the Deccan trap and absolute age of volcanic activities.

Now, in the area where the convective current of the mantle came to stream down, the basaltic layer below the granitic crust must have been also dragged into the mantle to some extent.

Although the superior geosynclinal deposits may have greatly folded into narrow belts caused through shifting, the major basaltic layer and also granitic layer beneath the geosynclinal deposits should have been also dragged into the mantle to some extent.

In the course of the movement above stated, the crust positioned in the opposite side, viz. located in the northern area, seems to have strongly thrusted up on the crust shifting from south to north which may have accelerated upheaving of the Himalayan belt of the present day more and more, since the beginning of the Neogene until recent (fig. 22). To be sure, the thick molasse deposits of the Siwalik formation may have been brought just to the place of the descending current of the mantle.

It may be especially worthy of note that the syn-orogenic igneous activity may be concluded to have originally occurred in the depth of geosyncline in far more unconsolidated and more loosely spaced state of wall rocks than usually imagined.

This could be one of the solution for the space problem on plutonic intrusion. Further, the relatively high heat-flow observed in the oceanic crust may be explained by possibility of mixing of sialic matter with mantle material, since the terrestrial crust may be likely dragged into the mantle by descending convective current to some extent as above stated.

Eventually the role of horizontal movement or shifting of granitic crust, which has existed and still exists without doubt from the view point of paleogeography and palaeomagnetism, is very important. This is well consistent with hypothesis of convection currents in the mantle, ever existed since the ancient days of the history of the earth.

Origin of crust and origin of Ur-continent and Ur-ocean

The authors stated in the foregoing pages that the granitic crust was formed step by step through long geologic history, which now forms thick foundation of either cratonic or subcratonic continent, and orogenic belts of either old or young. In the next, origin of granitic crust was stated somewhat in detail to have been originally geosynclinal deposits and major part of such deposits have been chiefly supplied from the area being topographically high into the geosynclinal sea. Further, the authors especially stressed on the fact on changing of material of geosynclinal deposits through ages (fig. 5). If it were so, the constituent of the continent, viz. the source area must have become different in its rock constituent through ages. Now, the oldest Precambrian rocks show to have been largely of volcanic rocks in every cratonic area: especially high content of basic volcanics among them is almost doubtless.

Such being the case, the continents existed in that time must have been composed of tremendous number of volcanoes built chiefly of basaltic rocks. The erosional product of such volcanic rocks seem to have been transported from such continents into the ur-ocean, the first depositional area, surrounding the continents of that time.

To be sure, the beginning stage of the earth was a body of concourse composed of cosmic material, as usually held as a current theory. Then, the interior of the earth came to be gradually warmer by vast energy generated either from a great mass of material of cosmic matter itself or from heat caused through radioactive disintegration. Although a problem on historical development of the interior of the earth is beyond the scope of the present article, the primary convective current first developed in the interior of the earth must have been of only single cell throughout the entire earth and movement itself might be very slow. Ascending current was likely to face towards one hemisphere of the earth, while descending current towards the opposite side (F.A. VENING MEINESZ, 1964) (H.H. HESS, 1962). In those days core might not be differentiated yet from the mantle in the interior of the earth (S.K. RUNCORN, 1962).

The ascending current successively brought forth mantle matter from the depth to the surface of the earth either by explosion or effusion, through which gaseous matter became ur-air or ur-sea water, and lavas and tuffs were procured by a great number of vents above the culminating zone of ascending current.

Thus the continent gradually became wider and higher by continuous volcanic activity. As a matter of fact this continent must have been formed by countless volcanoes and volcanic products (fig. 8).

In contrast, in the opposite side of the earth, where convective current was continuously descending down and the earth's surface there came to be sunken to form a basin. This basin became also wider and gradually deeper in accordance with the volcanic activity occurred in another hemisphere of the earth and became gradually filled up with ur-sea water.

Namely at the first stage of primary convection current of the interior of the earth, one hemisphere of the earth became ur-continent surrounded by volcanoes, while the opposite side of the earth finally became ur-ocean. The major topography of the earth's surface might be accordingly as similar as the surface of the present moon: one hemisphere is chiefly represented by large basin, although it is dry, while the other is large continent with small basins. The earliest state of the surface of the earth may be accordingly called the lunar stage.

In the course of growing of the core of the earth, convective current became gradually complex, the primary oceanic ridge may have accordingly appeared from place to place in the oceanic basin, while fault belts became also appeared on the ur-continent and ur-ocean which became the second stage of volcanic activity. Further, the oceanic basin along the ur-continent became sunken from place to place and gradually filled up with sedimentary deposits, the source area of which might be naturally in the ur-continent. At that time, the geosynclinal deposits may have directly covered the ur-surface of the earth, composed of cosmic matter.

Thus, granitic crust must have been eventually formed in such geosynclinal sea in the ur-ocean one after another. This might be the beginning of the geologic age. Namely, orogenic belts must have been born from time to time in the ur-ocean, the main source area of the geosynclinal deposits for each orogenic belt might be perhaps long in the ur-continent, however.

As a result, the ur-ocean came to be finally large continent chiefly composed of granitic rocks by repeated orogenic processes, while the ur-continent became to be smaller and smaller. At the same time, the ur-crust of the ur-continent became finally very thin and then the ur-continent tended into ocean from part to part by the formation of oceanic crust caused by convective movement of the mantle below the ur-crust, while the ur-surface exposed at the bottom of the ur-ocean, on which cosmic matters were exposed, became completely covered by terrestrial crust.

Thus the large continent appeared by the end of the Lower Proterozoic in one hemisphere of the earth, which nearly perfectly replaced the ur-ocean, while the large sea appeared in another hemisphere where originally was ur-continent (fig. 9).

It is highly probable that continent may have been still standing high above sea level along the marginal belt of the present Pacific ocean at the opening of transgression either of the Huto or the dawn of the Sinian age. Certainly these continents along the western Pacific belt may have been already built by the granitic rocks of the older geologic age, instead of the remnant of the ur-crust of the ur-continent. All available data for paleogeography for the Huto and Sinian time in Asia however suggest the presence of such continent with certainty (H.Y. LIU, 1959). Existence of such continental belt of Western Pacific of the younger Proterozoic seems to accordingly suggest us the probable presence of the older continent in further east of the present Pacific ocean in the older ages, which might be nothing else but the

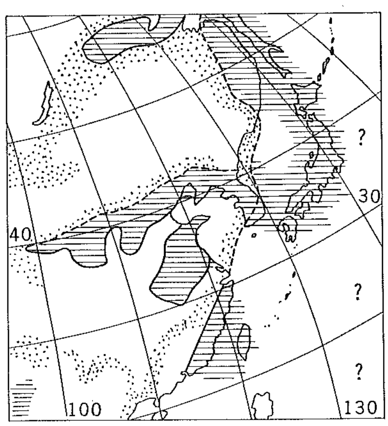


Fig. 17
Palaeogeography of late Sinian time. Shaded area—land. Dotted area—sea.

remnant of the ur-continent (fig. 17). Thus the original state of the Pacific must have been ur-continent with certainty.

The wider extension of the granitic crust before the dawn of the younger Proterozoic, which may have probably reached about three fourth of the entire surface of the earth, may be eventually doubtless by the palaeogeographical data on distribution of sea and land, throughout the entire Huto plus Sinian time. In those days, sea water however widely covered the continent composed of the granitic crust, as is suggested by extensive development of the marine deposits in nearly every cratonic, sub-cratonic and orogenic belt of the present day. Nevertheless, nearly all the sequence of the Sinian formation, for instance, shows the presence of mud cracks, ripple marks, pseudomorphs of salt crystals, rain-drop marks etc. all are the evident proofs for shallow in the environmental condition in which the younger Proterozoic sediments were deposited. Similar shallow condition of the sea in the younger Proterozoic is also well proved in the Baltic shield, Canadian shield, Indian shield and elsewhere of the cratonic and subcratonic regions in the world. Accordingly, the sea in those days must have been anyhow epicontinental in the global scale, and eventually very shallow although the deposits were reached fairly thick. Thus, the authors are now inclined to believe the sea water to have been a fairly less in volume in the Precambrian time, than the present. Namely, sea water should have been still increasing step by step since the Cambrian.

In respect to increasing of water in the ocean since the Late Precambrian time, a role of circulation from peridotite to serpentine below the ocean floor, as once held a view by H.H. HESS (fig. 7) must be appreciated to some extent. A certain amount of water must have been eventually reserved below the oceanic crust from time to time when serpentinized peridotite came to drag into the mantle by descend-

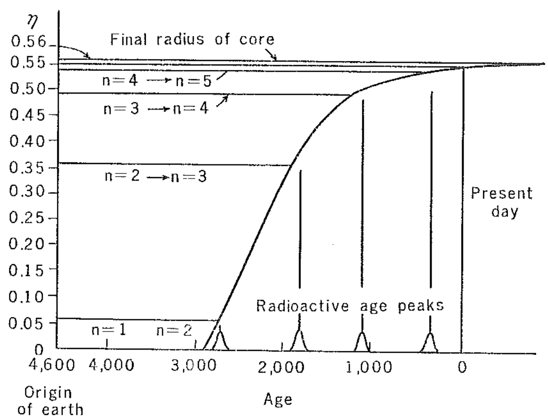


Fig. 18
Growth of the radius of the core of the earth. After S. K. RUNCORN, 1962.

ing current of mantle convection, and the reserved water may likely have been eventually carried up to the sea floor by volcanic activity of the later geologic time.

In the meantime the core has ever been growing since shortly after the time of the primary development in the interior of the earth; and the core already became as large as nearly the present state by nearly the end of the Proterozoic (S.K. RUNCORN, 1962) (fig. 18). In the course of growing of the core, cell of convective current may have ever been complex either in distribution or dimension in the mantle. In all probability the origin of ascending current seems to have also gradually approached to the surface of the earth through ages.

Principal course of evolution of the earth since the late Proterozoic

As was stated in the foregoing pages, it was the dawn of the Late Proterozoic, when the ur-ocean was perfectly replaced by the continent, chiefly composed of gneissic, migmatitic and granitic intrusives, while ur-continent became finally disappeared, and became to a new ocean which may have perhaps occupied the present Pacific. The ur-crust of the ur-continent may have become much thinner through ceaseless erosion for the long time range, even though addition of the volcanic material may have really occurred from time to time there in the Precambrian time.

Since the late Proterozoic, the geologic history opened by the reformation of the new, large, well consolidated continent, and new ocean, the floor of which may have been composed of thin remnant or the ur-crust, and oceanic crust composed of basaltic rocks.

The Baikalian, Caledonian, Variscan, older and newer Alpine orogenic belts appeared in succession on the originally extensive continent above stated. In the course of orogenic movement, this originally wide continent turned into separate blocks by shifting. Further, as a consequence of shifting, geosynclinal deposits were so greatly folded, faulted and finally very much compressed that the original basin came to be considerably reduced in width. In addition, the granitic layer and basaltic layer composed of ultra-metamorphic, and basic plutonic rocks have been more or less dragged into the mantle, the younger orogenic belt, Himalayan mobile belt as an example.

In other case, terrestrial crust may have been separated more and more into two blocks by faulting, followed by shifting towards two sides, caused by ceaseless ascending current from the depth in the mantle, the separation between the North and South America and Europe plus Africa for example may have been finally brought forth in such a way as it is currently believed.

Thus, the new ocean appeared in between, and large oceanic ridge called the Mid-Atlantic ridge has been ever growing there since some time in the Mesozoic. Nevertheless, the possibility may not be finally denied that the sialic and basaltic crust, once occupied certain area between both continents; viz. the terrestrial crust occupied between the north and south America and the Europe and Africa may have been also dragged into the mantle by convective movement below the crust, at the marginal belt of the spreading oceanic floor. Otherwise, a problem in concern to the former existence of the so-called North Atlantic continent in the geological past and its disappearance may be not finally explainable, even by plausible hypothesis on the new appearance of the Atlantic ocean in the Mesozoic and its floor spreading.

As a matter of fact, the Precambrian rocks are cropping out on surface in the western margin of the Caledonian belt of Norway and Scotland. Apparent geographical margin of the continents of the present day in both sides of the Atlantic ocean cannot be easily concluded to have never changed through the long period of time.

The Pacific ocean floor, where was once occupied, according to the present authors' view, by the ur-continent, has been also reactivated again and again, in accordance with the orogenic movements in the terrestrial crust. The great rise or ridge must have repeatedly appeared and disappeared there since the Late Precambrian time. In the course of the convective movement of the mantle below the ocean floor, sialic material derived from the continents surrounding the Pacific ocean must have been also dragged into the mantle to some extent along the descending current of convection; extent of the Pacific has been also historically changed either as being wider or narrower.

Thus, the continent and ocean of the present day have been perfectly reformed either in major topography, structure or rock constituents, since the late Precambrian. The present state of the earth's crust is the outcome through complex history of the movement of the interior of the earth in combination with geologic processes on the surface of the earth.

To imagine the uniform state of the mantle everywhere below the crust either in rock constituent, chemical composition, or structure may be accordingly concluded to be incorrect. This has been proved to some extent by various geophysical data (L. KNOSOFF, 1969). To assume the presence of unchangeable original magma in chemical composition through time and space is without doubt incorrect. The under-estimate the rôle of ur-sea water and ur-air besides effusive rocks in the lunar stage is also incorrect in consideration of the further development of the earth's crust in the ancient time. Without sediments, granitic crust could be never formed through ages.

To imagine the birth of life to have been much later than the oldest rocks found out on the terrestrial crust may be also incorrect. From the presence of water and air, the birth of life might be highly possible in still earlier days than those have been heretofore assumed in general. The oldest recorded fossil evidence is now dated as old as 3.1×10^9 ys. old, which is believed an algal substance found out in the early Precambrian Fig Tree series of South Africa (R.C. MOORE et al, 1968). Life would have been however born much earlier than this age. In all probability, the changing from organic substance to life was influenced by radiation belts through growing of core, viz. the origin of the geomagnetic field in the earth (R.J. UFFEN, 1963). No doubt, the changing of chemical composition of sea water, air and sediments of the Precambrian through ages may have been related to the birth and development of life. Therefore, the origin and development of the earth's crust may have been ever in intimate relationship with that of core and mantle. Even more, the evolution of life itself should have been much related with the changing of the earth's magnetism, through the variations of cosmic ray intensity caused by the change in the earth's radiation fields.

Before closing this part, the authors wish to briefly state on such seas as the Okhotsk sea, Japan sea, East China sea, Sulu sea, Caspian sea, Black sea and Tyrrhenian sea, as to the geologic development of their deeper basins. All the seas above listed are located along or in the belts of the younger Alpine orogenic stage. Secondly, the floor of these seas are now viewed to be composed of oceanic crust with relatively thin sedimentary cover, at least as far as the deeper basins of them are concerned. In spite of it, such seas have been believed by geologists to have been occupied by continent, perhaps composed of terrestrial crust until the Late Paleogene or by the dawn of the Neogene. This is a current view or almost well accepted conception through various geologic informations, especially, palaeogeographical data. As to the history of the Japan sea, a series of paleogeographical maps ranging from the Silurian to the recent compiled by the senior author in cooperation of his co-workers may be referred (M. MINATO et al, 1965).

Before stepping into the problem of the vanished continents in these seas in detail, the authors, however, still think, that we must wait for further informations on the so-called basaltic layer of these seas, although they are now currently viewed to be existing below the sedimentary cover, lacking granitic layer in between.

First of all, all these seas are much shallower than the eu-oceanic basin like the Pacific, even in the deepest bottom. Secondly, the p-wave velocity observed in the so-called basaltic layer of these seas seems to be generally slightly different from the basaltic crust of the eu-oceanic basin.

The basaltic layer of the seas above mentioned seems to be accordingly somewhat doubtful, whether it is as similar as the basaltic layer of the large oceanic basin in their lithologic nature.

Notwithstanding of this, if the crust of such seas were really composed of basaltic rocks in the term of petrology, cause and process of changing, either from continent to sea, or from sialic crust to simatic, should be anyhow seeked for. In such a short note, to cover various fields of geologic structure in detail is of course next to impossible. In respect to the Japan sea for instance changing from continent to sea was however without doubt occurred at the dawn of the Neogene time,

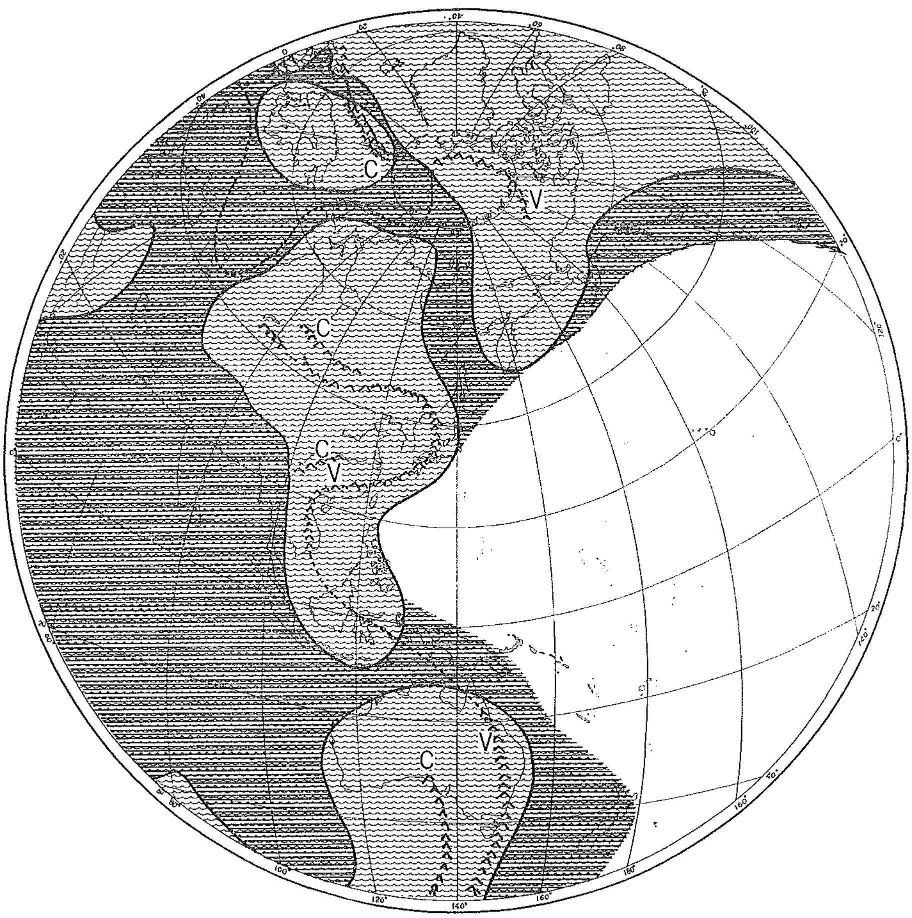


Fig. 19
Penninsula India in the Jurassic time. The distribution of the terrestrial crust of those days is shown by wave lines, while the oceanic crust by white colour. The distribution of land and sea is also diagrammatically shown in this map: continent by wave lines, while seas are shown by horizontal lines. Further, the ocean extending in the regions, where are composed of oceanic crust was also filled up with water and is shown by white colour in this figure. In the continent, distribution of the Caledonian (C) and the Variscan mountains (V) are diagrammatically shown. As to the geographical position of the India, fig. 22 may be referred.

and this geologic event has been currently discussed by Japanese geologists as having been in intimate relationship with the formation of island arc structure of the Japan arc, since the earlier works of the authors in cooperation with K. YAGI (1956). Namely, the geographical arrangement of structural unit around the Japan sea may

Fig. 20
The peninsula India in the Post Eocene and Pre-Miocene time. As to the legend, the preceding figure may be referable, except for great grabens which are shown by broad dotted lines. H : Himalayan belt, newly folded in this phase.

be enumerated as follows: (1) the continental mainland of Asia, (2) the Japan sea with relatively deeper basin, (3) the inner belt of the Japan arc, where has been a stage of intense volcanic activity since the dawn of the Neogene time, (4) the outer belt of the Japan arc without Neogene and Quaternary volcanic activity, (5) the oceanic trough, and (6) the Pacific basin. Such a geographical arrangement from (1) to (6) may be also applicable to the Okhotsk sea and the Kurile island arc, and also to the East China sea and the Ryukyu island arc. Both in the Kurile and the Ryukyu islands, the volcanic activities have been long lasting in the inner belt of the arc, since the early Miocene, where many Holocene volcanoes are actually widely distributed like in the inner belt of the Japan arc. Not only that, in all these island arcs, changing from continent to sea in the Japan, Okhotsk and East China sea, volcanic activities of the inner belt of each arc, and sinking of oceanic trough along the outer belt of the arcs seems to have been opened at nearly the same age: the early Neogene time, as was thoroughly discussed by the present authors and K. YAGI (1956). It may be accordingly natural and correct to think of mutual relationship between these geologic phenomena: change from continent to sea in the seas above stated, volcanic activity in the inner belt and sinking of trough.

Nowadays, geophysical informations either on the depth of epicenter of earthquakes, and its detailed distribution, geomagnetism, paleo-magnetism, or heat flow have become accumulated more and more around the island arcs above stated. These data are helpful to consider the cause of geologic phenomena stated in the foregoing lines.

According to the authors' view, however, this problem would be finally solved in future, when we succeed to consistently explain such geologically young phenomena in more wider space and time; namely great faults widely traced in the continent, effusion of plateau basalt, also widely developed in the continents ranging from the southern belt of the Lake Baikal, NE China, N. Korea until various regions of southern belt of Asian continent, besides island arcs and seas along the continental mainland, which are all belonging to the Neogene and Quaternary time. Further, shifting of volcanic belts in the East Asia since the Late Cretaceous instead of the Neogene to the recent must be also brought into consideration (fig. 16).

As is well known, oceanic ridges in the ocean which plunge under the terrestrial crust are now beautifully traced in global scale (B.C. HEEZEN, 1962). However, the distribution of rift valleys and oceanic ridges might be greatly different in the late Cretaceous to Paleogene and also Neogene time compared to the present.

Appearance of island arcs, which may have finally reformed the complex structures brought forth by the former orogeneses in each arc, may have eventually been caused by the movement of interior of the mantle, as the authors repeatedly stated in the present note. Shifting of crust, may have been really occurred around the island arcs in the western Pacific even in the Neogene and Quaternary time. From the view point of synchronous age of arcs and similarity of structure of each arc in the western Pacific, the principal cause for the formation of island arcs must have been in high mobilization of mantle below the oceanic crust of the Pacific. However, the authors still believe the necessity of further detailed analysis for geologic structure in wide extent of continent and ocean to know the true movement of the mantle in those days. From the view point of structural development based on geologic data, to assume too much simplified model in respect to the convective movement of the mantle, may be far from the truth. The complex nature of mantle

Fig. 21
Penninsula India in the Miocene to the recent. Wave lines : area being occupied by the terrestrial crust, most of which has been long stood above the sea level; white : oceanic crust in which extension of the Darwin rise, and oceanic ridges are shown by dotted lines, besides troughs, which is shown by black colour. In the terrestrial crust, present distribution of the Baikalian belt is shown either by combination of vertical and horizontal lines or dots ; the Caledonian by the vertical lines ; the Variscan by horizontal broad black lines and narrow white lines ; the Indosinian belts by aggregation of circles of irregular size, while the cratonic area is purposely shown by the cross.

movement may be especially the case for the young geologic age. A great number of convective cells in relatively smaller dimension may have appeared in relatively shallower mantle in the geologically young age, although there might be also perhaps less numerous larger convective cells to produce an oceanic rise or ridge of the greater scale. Thus, the relatively local shifting may have been repeatedly occurred back and forth in many regions, as is suggested by the shifting of volcanic belts or geosynclines from time to time. Also, island arc structure synchronously appeared, along the entire margin of the large oceanic basin like the Pacific. Thus the history of the earth's crust may be tabulated as below (p. 555).

In short the whole geologic history reminds the authors of the wonderful similarity which exists between the life history of an individual of any organism, namely ontogeny, and the evolutional history of a species to which it belongs, phylogeny. This is known as Ernst Haeckel's biogenetic law in general or as the theory of recapitulation; ontogeny repeats phylogeny. Likewise in any orogenic belt, the great similarity is present between their individual development starting from a geosyncline to the mountain chain and the long history of development of the earth's crust in the early geologic time. In the Japanese islands, for instance, a large continent long existed in the present Japan sea tended to a sea basin since the dawn of Miocene, as similarly in the case that the Ur-continent became to be ocean in the earlier geologic time. Changing from continent to ocean might be occurred there in a relatively short period. In the other words, the earlier history of the earth's surface was briefly repeated there in a relatively small scale. Further, in the inner belt of the Honshu, the Izu-Mariana, and the Kurile arc, orogenic movements were repeated just as in the older mobile belt in the continental mainland

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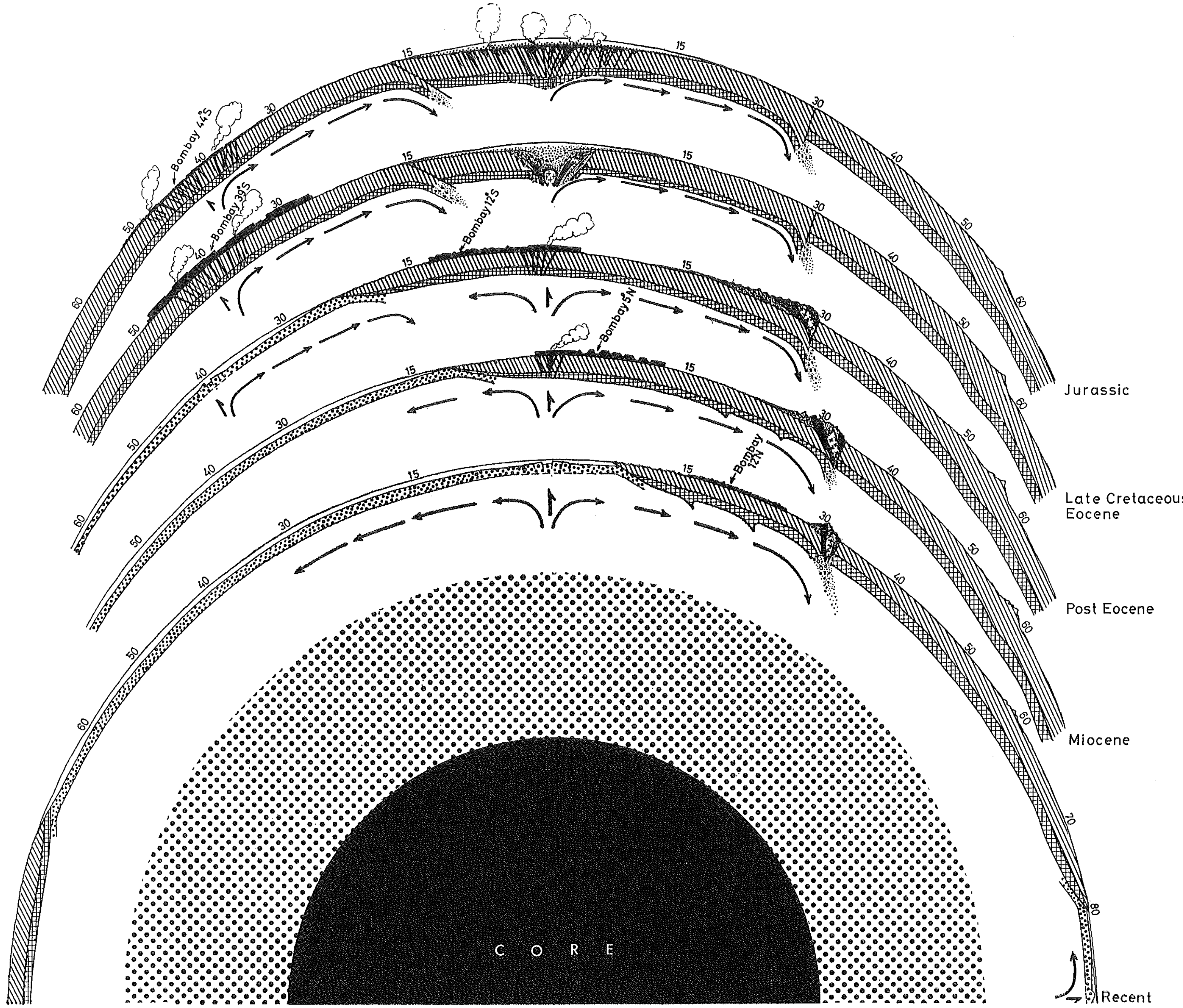
Fig. 22

Diagram explaining the drifting of Indian peninsula by convective movement in the interior of the mantle since the Jurassic to the recent based on the palaeomagnetic data. Formation of fault and effusion of basalt in the Deccan plateau through ages, birth of the Himalayan geosynclinal sea, compaction of the geosynclinal deposits by shifting of the crust, and shrinking of original basin of the geosyncline, upheaving of the Himalayan belt of the present day by thrusting and folding and building of the molasse deposits of the Siwalik formation, just above the descending current of the mantle matter below the crust are shown successively in this diagram. The geosynclinal deposits, granitic crust and so-called basaltic layer of the terrestrial crust are also diagrammatically shown in this figure to have been partly or largely dragged into the mantle by descending current of convection in the interior of the mantle.

Reformation of oceanic crust by convective movement of the mantle which caused a rise or ridge in the ocean and mutual relationship between the continental drifting and appearance of ocean are also plausibly explained in this figure. Dimension of the core, mantle and crust is not to scale in this figure.

It must be noted, that the ascending convective current brought forth different geologic phenomena on the earth's surface between the oceanic crust and terrestrial crust as is explained in detail in the text. Further, orogenic process may have been greatly progressed in the case that the drifting is so slow, like in the Himalayan belt. There, orogeny was starting by faulting followed by volcanisms like the Deccan plateau, but further advanced into geosynclinal condition accompanied by synorogenic plutonisms and upheaving of the geosynclinal belt to the mountain chains.


Jurassic
Late Cretaceous
Eocene
Post Eocene
Miocene
Recent
CORE
Bombay 44°S
Bombay 39°S
Bombay 12°S
Bombay 5°N
Bombay 12°N

History of the crust of the Earth

Stage	Absolute age	The earth's crust		Core	Mantle convection	
		Oceanic crust	Terrestrial crust			
Primary stage		non-existing	non-existing	non-existing	non-existing	
Lunar stage	4.5×10^9 yrs old	Appearance of ur-continent composed of ur-crust in one hemisphere of the earth; basaltic effusives and associated rocks were main components of the ur-crust.	Appearance of ur-ocean in the other hemisphere covered by ur-sea water. Ur-air was present throughout the surface of the earth.	non-existing	Single cell	
Geologic age	3.55×10^9 yrs old	Ur-continent became gradually replaced by sea.	Ur-ocean became gradually replaced by the continents through repeated orogeneses.	birth of core and its growing	Double cells	Birth of life
	1.5×10^9 yrs old	A large ocean appeared, and was composed of oceanic crust with the remnant of ur-crust.	A large continent composed of well consolidated terrestrial crust.	growing larger	became complex	
	0.8×10^9 yrs old Recent	Repeated reformation of the oceanic crust.	Reformation of continents into cratons, orogenic belts and oceans by— { Baikalian orogeny, Caledonian orogeny, Variscan orogeny, Alpine orogeny }		complex more and more	

of Asia. In such young structural belt, orogeny was started with faulting followed by intense volcanic activities represented by both basic and acidic volcanics in the Miocene. And the sinking area in the inner belt tended to upheave since the late Miocene when dioritic and grano-dioritic rocks intruded into the axial core of the eugeosynclinal deposits, and finally became land during the Pleistocene time.

Thus the course from the lunar stage to geologic stage, and the geologic developments in early orogenesis may be said to be simply and superficially repeated in the development of young geostructural belts. Although the reasoning for this " recapitulation " phenomenon in geologic history of the earth should be a matter to be undertaken in future, would't it be unreasonable to regard the main course as established as a " geologic law " which may be analogous to the well known law of recaptitulation in biology ?

Postscript and acknowledgement

The senior author (M. M.) has long held a hypothesis on the original state of the surface of the earth, which might be as similar as the present topography of the moon. He has reached this conclusion chiefly based on the palaeogeographical data on the Precambrian geology. Since a fairly long time ago, he has personally discussed this problem, especially on the lunar stage at the beginning of the earth, with many geologists including the junior author (M. H.) and geophysicists in Japan, although his hypothesis has been ever ignored by most of them, except for the junior author. The another single exception was Prof. S. MIYAMOTO of the Kyoto University, a leading astronomer, who kindly appreciated very much the senior author's view on the fundamental course of development of the crust of the earth, and encouraged him that this view should be published as soon as possible. It was sometime in summer 1965, when the senior author had a chance to see him at a conference held in Tokyo.

To promote his hypothesis, after the senior author met Prof. S. MIYAMOTO, the present authors have cooperated how to combine the current theories on mountain building in modern geology. In the next, how to estimate the new hypothesis on the development of oceanic crust became the authors' ploblem. The most difficult point lies in the discussion on the superficial difference observed between the oceanic rise in the oceanic crust and rift or fault in the terrestrial crust followed by volcanic activity and geosynclinal condition. Although these two features have quite different appearance they must have been caused by a similar movement of the ascending current of heat and mantle matter. All geophysicists with whom the senior author discussed on this problem, however, denied the possibility, especially on the assumption that a geosyncline appeared above the ascending current of mantle matter. At that time most geophysicists in Japan seem to have misunderstood that the formation of geosyncline as has been introduced through a similar

process as oceanic trough. Nevertheless, the authors have convinced that we should have started from firm field evidences in such a problem. There is in fact little similarity between geosynclinal sea of the past and oceanic trough of the present.

Eventually the authors published in 1968 in Japanese their view on the origin of continents and the crust of the earth, which is almost as similar as the present article.

After then the senior author went to Czechoslovakia to participate the 23rd International Geological Congress in Prague. During the session he met Prof. K. Benes, and he was informed that Prof. Benes had already published a view on the development of the earth's history, as starting from the cosmic stage, through lunar stage and geological stage in succession. Although the details of Prof. Benes's view could not be informed to him because of limited time. As a matter of fact, the senior author became acquainted with Prof. Benes since 1963 at the 6th International Carboniferous Congress in Paris, prior to the meeting in Prague. But the authors knew nothing about Prof. Benes's new idea until the senior author came over to Prague in August 1968. Anyhow the authors were greatly encouraged by the information that a similar view was already becoming current in abroad in respect to the developmental theory of the earth, as was quite independently held by the authors in Japan.

After the Congress the senior author was invited by the University of Montana, Missoula, USA for lecturing under the title of " Geologic structure of Asia." The present paper is one of summary notes of the senior author's lecture held in Missoula, although certain important part on the genesis of granitic crust and orogenic process has been thoroughly reviewed by the junior author, and the manuscript was made in cooperation. During the senior author's stay in Missoula he learned very much from discussions with the staff there. Especially he is very much obliged to Professors A. J. Silverman, J. A. Peterson, D. W. Hyndman, G. M. Crosby, D. Alt, R. W. Fields, R. M. Weidman, J. P. Wahrenberg and W. G. Melton for their fruitful discussions on the problem presented in this article.

Further, the senior author should not forget to thank for the following professor and their colleagues at each university for their kind discussions on the problems related to the present paper, when he had a chance to visit them during his short stay in the Netherlands in 1968 and USA since Sept. 1968 to April 1969: Professor H. G. Fisk, Montana College of Mineral Science and Technology, Butte; Professor C. D. Campbell, Washingtom State University, Pullman; Professor D. F. Merriam, State Geol. Surv., the University of Kansas, Lawrence; Professor P. K. Sutherland, University of Oklahoma, Professor C. L. Rowett, East Texas State University, Commerce; Professor R. B. Scott, Florida State University, Tallahassee; Professor M. Bikerman, Professor N. K. Flint, University of Pittsburgh, Pittsburgh; Professor N. D. Newell, the American Museum of Natural History, New York; Professor W. A. Berggren, Woods Hole Oceanographic Inst. Woods Hole; Professor, J. Imbrie, Brawn University, Providence in USA, and Professors J. J. Hermes, H. J. MacGillarey, T. De booy, University of Amsterdam in the Netherlands.

In the preparation of the present paper the authors have been helped by professors S. Hashimoto, M. Kato and M. Hoshino (Tokai Univ.), Drs. J. Watanabe, C. W. Kim and Y. Fujiwara, Mr. S. Kumano, Mrs. Y. Fujiwara and Mrs. C. Minato in various ways. Last but not least the authors are very much grateful to Dr. S. Ijiri (Tokyo) who first pointed out in Japan an important role of the problem about the origin of magma in geology, and he has ever been kind in discussing the concerned problem with the authors. To all the persons above mentioned the authors wish to express their heaty thanks.

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