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Origins of the Japanese Islands: The New "Big Picture"

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Archaeologists and historians working on topics such as agricultural technology, resource distribution, settlement patterns, raw materials procurement, artifact analysis and natural disasters are automatically involved in geological questions. The geologic history of the Japanese Islands is, therefore, of basic importance to our enquiries, but those interests are poorly served by the current literature available. It is difficult to find an overview that is up to date and whose contents are both comprehensive and understandable to lay readers who are not geologists. Some texts of recent publication still subscribe, in whole or in part, to the discarded paradigm of Geosyncline Theory rather than the current Global (Plate) Tectonics Theory. Even Japanese school texts of the 1990s still used a hodge-podge of geosyncline and plate tectonics theory. The time lag in adopting the framework of plate tectonics can perhaps be laid at the feet of Confucian-style scholarship, but it has not served Japanese geology well. Nevertheless, persistent scholarship by the progressive plate tectonicists and their protégés—the group of young geophysicists calling themselves the "geokids"—have now revolutionized views on the formation of the Japanese landmass. This article attempts to put Japanese Studies researchers in touch with these exciting new developments, paving the way for an increased understanding of the nature of Japanese geology and how it has affected lifestyles throughout the ages.

Keywords: JAPANESE GEOLOGY, PLATE TECTONICS, ACCRETIONARY PRISMS, JAPANESE ISLANDS

> "All parts of the surface of the Earth are moving and changing...think of the view of the Earth that we acquire during our short lifetime as like a single frame from a continuously running sequence."[1]

INTRODUCTION

Tectonic plate movement in the Pacific is known today to be responsible for the considerable earthquake and volcanic activity, in what is popularly called the Pacific "Ring of Fire,"[2] having caused the 1995 Kobe earthquake, the 1883 eruption of Krakatau in Indonesia,[3] the San Andreas fault and recent earthquakes in California, and the 1980 eruption of Mount St. Helens in Washington state.[4] Since the formulation of the concept of plate tectonics in the mid-1960s, research on plate movement has revolutionized understanding of the evolution of the world's surfaces—including the formation of the Japanese Islands themselves.

Plate tectonics are acknowledged responsible not only for the volcanic eruptions and earthquakes that periodically interrupt Japanese life, but also for the shape and contents of the Japanese archipelago itself, including its mountainous nature, its system of north-south faults causing basin-and-range formation, and the fact that more than half of Japan's rocks are sedimentary—not volcanic as we might expect. However, the biggest difference plate tectonics has made in understanding Japan's past rests on the fact that for 97% of its existence,[5] the Japanese landmass was NOT an island chain. This is in direct contrast to the previous geological paradigm, geosyncline theory,[6] which until recently has been very influential and encouraged the assumption that Japan has ALWAYS comprised a chain of islands.

Before the development of plate tectonics in 1968, geosyncline theory existed in several versions depending on the area of the world in which researchers were developing their ideas.[7] KOBAYASHI Teiichi was the foremost proponent of this theory in Japan, with his seminal work in 1941 giving rise to the University of Tokyo school of geosynclinists.[8] These researchers held that the major movement of a landmass was essentially vertical, in which mountain chains were formed by undulations or foldings of the surface. This often caused sideways slippage of materials, so that horizontal movement could not totally be ruled out; however, movement of materials on the scale proposed by plate tectonics—thousands of miles across the Pacific Basin to finally become incorporated into the Japanese landmass—could not be envisioned within the framework of geosyncline theory. This theory has been especially powerful in Japan and still lingers in geological writings long after its demise in other parts of the world.

Plate tectonics as applied to Japan began to be introduced in the early 1970s by such researchers as UYEDA (UEDA) Seiya in Japan,[9] and MIYASHIRO Akiho in Albany, New York,[10] whose writings have fostered the current "geokids."[11] It must be said that for two decades, such plate tectonicists were battling an entrenched school of interpretation in Japanese geology and their work was often disregarded in favor of the established view of geosynclinists. ISOZAKI Yukio, one of the "geokids" and now a professor at the University of Tokyo himself, has written a brief historical review of the four stages in the conversion from geosyncline theory to plate tectonics—"a long winding road with many arguments" between the groups of scholars.[12] The greatest strides, he writes, came in stage four after the introduction of plate tectonics: in the 1980s, the refinements in biostratigraphy based on microfossils and an acceptance of the concept of linked subduction and accretion; and in the 1990s, refinements in dating weakly metamorphosed strata.[13] Another important factor, though earlier, was the development of palaeomagnetism in the 1960s as a measure of geographical location,[14] and its application in the 1980s to the rotation of the Japanese landmasses to form the current archipelago.[15]

Western geologists have been kept abreast of developments in plate tectonics as applied to and illuminated by the Japanese case study through field trips,[16] symposia,[17] and specialist publications in geological journals.[18] However, Japanologists on the whole have been exposed to little more than geosynclinist publications of the University of Tokyo publications in English. Using these University of Tokyo texts unwittingly, particularly the double issue of the *Geology of Japan*,[19] causes much confusion, particularly in terms of understanding the topography of the Japanese landmass through past geological eons.

Until 15 million years ago, Japan was not an independent geographical entity; whatever strata that formed up to that time were merely part of the continental edge of Eurasia. The mid-1980s palaeomagnetic data clearly showed that the Japanese landmasses had occupied positions parallel to the continental edge and had only rotated outwards into their current positions between 19 and 15 million years ago. This finding has undermined all discussion and writing of Japanese landmass origins cast in a geosynclinal framework, which assumed that Japan has always been an island chain—giving a false sense of topography for discussing and understanding the early time periods of stratigraphic formation.

It has taken a long and still yet to be completed time for the full incorporation of plate tectonics theory into Japanese society. It was only added to school textbooks in the 1990s, and these remain a jumble of new and old, geosynclinal thinking with plate tectonics overlay. This is undoubtedly due to the influence of the Tōdai[20] geosynclinists who are finally being superseded in Japan by the geokids. Even in the latter's research, however, it has only been since 1993 by their own admission, when the dating method for low-pressure metamorphic rocks was refined, that the "big picture" of the compositional process of the Japanese landmass came to be rewritten.[21] This new understanding of the origins of Japan based on plate tectonics is summarized below, as published in two series. The first constitutes two thematic sections of the journal, *The Island Arc*,[22] entitled "Geology and Orogeny of the Japanese Islands" (vol. 5.3, Sept. 1996) and "Orogeny of the Japanese Islands" (vol. 6.1, Mar. 1997). These should be consulted for the reams of new data concerning Japanese orogeny and for the color plate reconstruction sequences of the continental clusterings,[23] which could not be reproduced here but are especially enlightening. The second is the new multi-volume series on Quaternary geology, *Nihon no chikei* 日本の地形 *(Japanese Landforms*) published sequentially by the University of Tokyo Press from 2000; the first volume *Sōsetsu* 総説 (*General Introduction*)[24] is especially useful for reviewing neotectonic processes, and the descriptions of individual regions in different volumes are the latest interpretations of the lay of the land. Taira has also published an overview entitled "Tectonic evolution of the Japanese island arc system" (2001) for the geological community, accompanied by very informative color plates.

In the following sections, some aspects of plate tectonics especially crucial to the understanding of the Japanese situation will first be introduced, and then a chronological presentation of the development of the Japanese landmass is given up to the point of archipelagic formation. In closing four points will be reviewed, emphasizing the important lessons gleaned from the new "big picture."

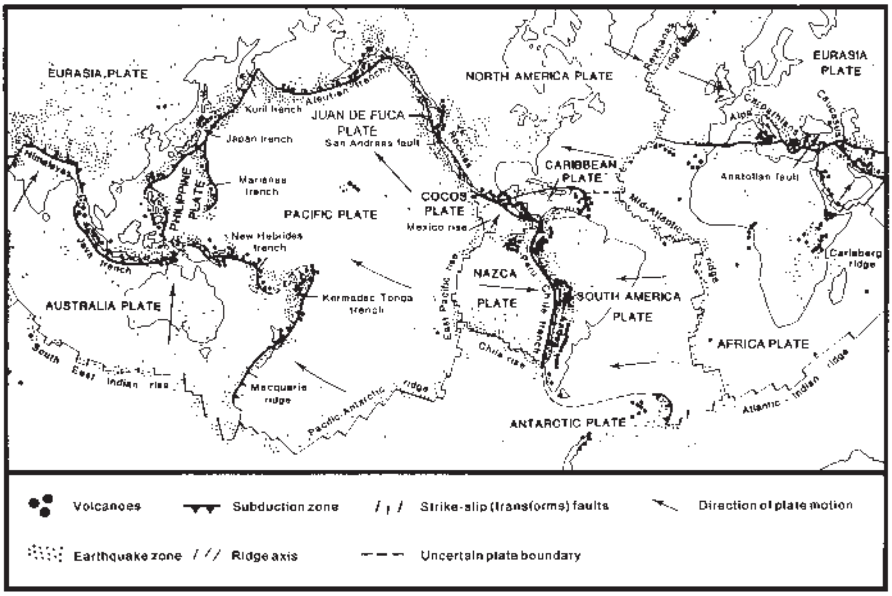


Figure 1 Major plate divisions of the earth's crust. Note that the finer plate divisions surrounding the Japanese Islands are not fully represented here but can be seen instead in Figure 4 (modified and reproduced with permission from Chester 1993, p. 28, fig. a).

Principles of plate tectonics as applied to Japan

Plates and their construction

The world is divided into continental and oceanic plates (Figure 1), which follow differ-

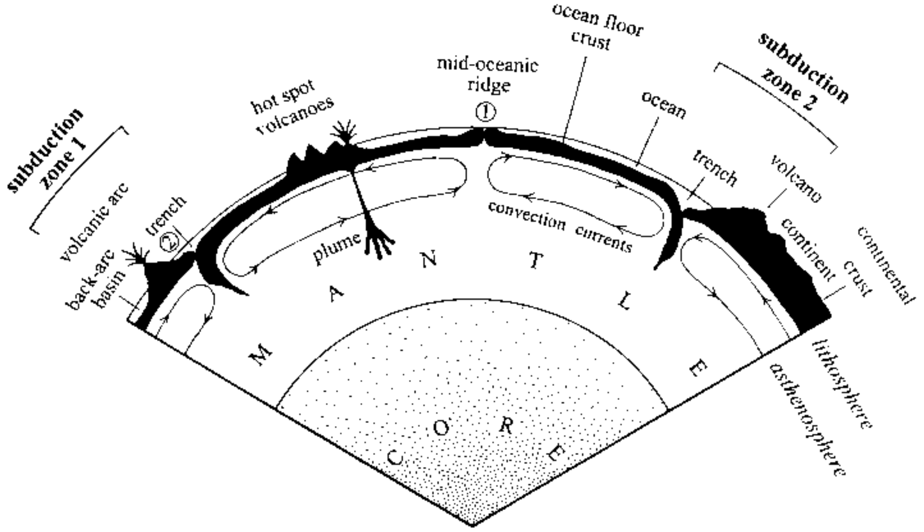


Figure 2 Cross-section of the earth showing layered composition of core (solid), mantle (solid), asthenosphere (viscuous) and lithosphere (solid but mobile), with convection currents in asthenosphere highly exaggerated (after Chester 1993, fig. 2.1b; and Taira 1990, fig. 1-4a). See expanded version of subduction zone 1 in Figure 3.

ent rules of operation depending on whether they are rotating or moving directionally, whether they are separating, colliding or moving past each other, and whether the edges in contact are similar (e.g. continental to continental) or different (oceanic to continental). The plates are composed of an upper solid crust (the lithosphere) resting on a viscous upper layer (the asthenosphere) of the earth’s mantle (Figure 2; see the Glossary for definition of terms such as these). In general, ocean floor crust is thin, several kilometers in depth, while continental crust is thick, tens of kilometers in depth. However, these types of crust do not occur exclusively on the different types of plates: continental plates may include today’s continents as well as substantial areas of thin ocean floor, and oceanic plates often support thick-rooted volcanoes, seamounts, and plateaus, some formed by hot spot plumes.

These plates ride on the earth’s viscous mantle, and convection currents within the mantle—caused primarily by radioactive heat[25]—move the plates across the earth’s surface. Horizontal movement is accompanied by two kinds of vertical movement of materials: 1) the creation of new ocean floor at mid-oceanic ridges (rises), where mantle upwells and spreads out—increasing the surface area of the ocean floor (Figure 2-①); and 2) the consumption of old ocean floor through subduction (dragging down) at oceanic plate margins, where the oceanic crust is sinking down into the mantle (Figure 2-②). Because the earth is finite in size, the production of new crust is always associated with the consumption of older crust somewhere else on the planet. A crude analogy would be to think of an oceanic plate as the surface of a conveyor belt, continuously generated upwards from one spot, moving horizontally across a long distance, and disappearing downwards at the terminus of movement.

The current Pacific Plate is being continuously added to from the East Pacific Rise in the southern Pacific oceanic basin and being subducted under the different plates in the northwest (Figure 1). The subduction zone (e.g. Figure 2: zone 1) is marked by deep sea trenches off the eastern coast of the Japanese, Kurile and Aleutian archipelagos—all currently active volcanic island arcs. Because of differential rates of crust generation in the Atlantic and the Pacific, however, one may eventually expand at the expense of the other. This has already happened several times with oceans in world prehistory, as evidenced by the opening of the Atlantic, which split the continents of North and South America from Europe and Africa, and the closing of the extinct Iapetus Sea, which brought together the land areas of England and Scotland—once on opposite shores of the intervening sea.[26] Based on this so-called "life-cycle" of an ocean basin,[27] it has been estimated that the Pacific Ocean will disappear in another 300 million years if the present processes continue undeflected![28]

Subduction processes

The present-day Japanese Islands sit at the juncture of four major plates: the Pacific and Philippine oceanic plates and the Eurasian and North American continental. Scholarly opinion is divided on the extent and boundaries of more possible plates, for example, the North Japan Microplate and an Okhotsk subdivision of the North American plate (Figure 3) or a division of the Eurasian plate to form an Amur plate.[29] However, the principles of subduction at the northwestern edge of the Pacific remain the same. The creation of Japan by subduction of the oceanic plates under the continental plates appears to be a textbook case of modern island arc formation (Figure 4).[30] As the oceanic crust is subducted, it dehydrates, giving off water vapor into the overlying mantle; this vapor lowers the melting temperature of the rock-forming minerals in the mantle, leading to the production of magma.[31] The magma rises to the surface, extruding itself through volcanic ducts and craters as lava and various forms of volcanic ash (tephra), or crystallizing on the interior as granitic rock. Such volcanic activity on the continental side of the trench creates a chain of mountains often of arc formation. The volcanic chain usually forms behind a nominal line called the Volcanic Front at a uniform distance (usually between 110-200 km)[32] from the deep sea trench doing the subducting. The forearc area between the trench and the Volcanic Front lacks volcanoes, but it is subject to heavy earthquake activity from the friction of one plate being dragged down underneath another. The current Japanese archipelago is considered a mature island arc composed of the results of several generations of subducting plates;[33] approximately 15,000 km of oceanic floor have passed under the Japanese area in the last 450 million years, with most being fully subducted.[34]

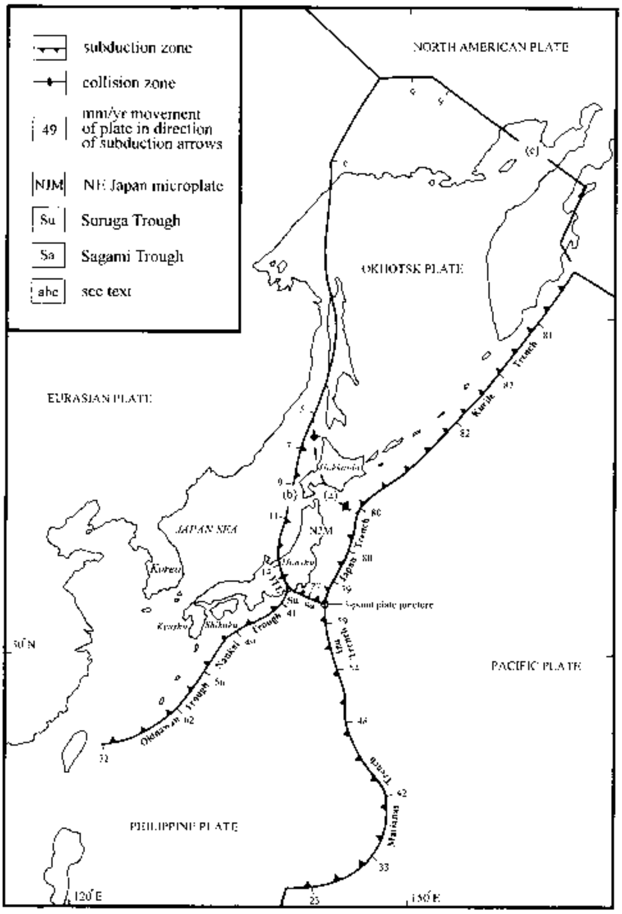


Figure 3 Evolution of scholarship on the four plates of Japan; not included is the recent discussion of an Amur Plate division of the Eurasian Plate (caption text after Seno 1995, pp. 148-149; illustration compiled from Seno 1995, figs. 5.1.1-2, 5.2.1; Katsudansō Kenkyūkai 1991, map II; Nakamura 1989, p. 244; and Okamura et al. 1995, p. 168).

The 1970s view of the four-plate construction did not recognize the existence of the Okhotsk Plate or the Northeast Japan microplate, and the boundary of the North American Plate (a) was drawn through southern Hokkaido; most of Japan was thought to be located on the Eurasian Plate.

The 1980s view: earthquakes along the eastern edge of the Japan Sea resulted in the North American plate boundary being extended west of Tōhoku (b) and passing through central Honshu on the Itoigawa-Shizuoka Tectonic Line (ITL).

The 1990s view: research on slip-vectors of the northern plate determined the independence of the Okhotsk Plate from the North American Plate (c).

The current controversy over the existence of a Northeast Japan microplate, reinstating a plate boundary passing through Hokkaido (a).

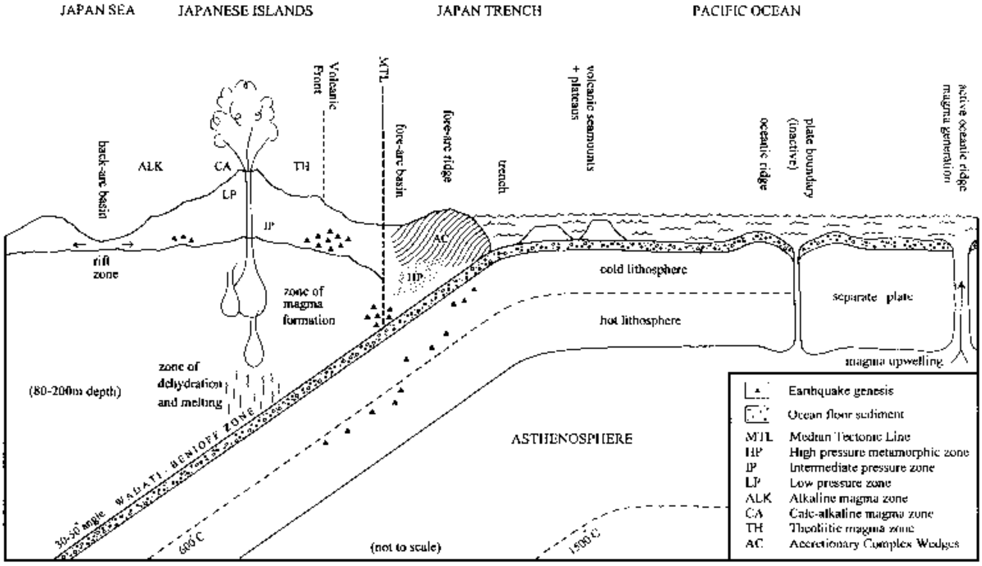


Figure 4 Major activities and areas of the subduction zone where the Pacific Plate is being dragged under the continental plate at whose edge the Japanese Islands have recently formed as a volcanic arc (after Taira 1990, fig. 1-4b; Chester 1993, figs. 2.8-9; and Kearey & Vine 1996, fig. 8.21).

Subduction processes, however, do not necessarily result in the entire consumption of the oceanic plates. One of the more interesting aspects of Japanese geology is the thrusting up of oceanic components on the continental edge instead of their being dragged under. Three examples of this beaching effect are noted in the hard-rock geology of Japan today: the detachment of coral reef from a supporting volcanic seamount being subducted in the deep sea trenches and the riding up of the coral formation into the edge of the continental plate;[35] the bulldozing up of some ocean floor and other trench sediments onto the continental edge as the oceanic plate is dragged under;[36] and the collision of volcanic plateaus or mountains riding on a thin-crusted oceanic plate, ploughing into the continental plate without being subducted.[37] Moreover, subduction does not always entail interaction between continental and oceanic plates but can occur between two oceanic plates. Currently, the Pacific Plate, while drawn under the continental Okhotsk (North American) Plate in the north, is also being subducted under the oceanic Philippine Plate in the west. We will see clear examples of all the above processes in the shaping of the Japanese Islands in below. However, the addition of sediments and oceanic features to a continental plate through accretion is probably a process unfamiliar to most and therefore needs slightly more amplification here.

Accretionary processes [38]

The term “accretion” simply means “to add to,” and it has been used in a variety of ways in the geological literature: to explain the formation of planet earth itself,[39] to describe the growth of continental crust, even when the source was igneous;[40] to characterize a type of passive continental margin;[41] and to refer to the addition of material from the subduction trench to the continental edge.[42] For Japan, the last-named context is most important, and there “accretion tectonics” refers directly to the process of adding trench sediments and fragments of the subducting oceanic plate to the overriding continental edge in an active margin.[43] In the last fifteen years it has become apparent that the major crustal component of the Japanese area has been formed by accretion tectonics acting in an episodic fashion.[44]

This directly refutes the earlier proposition that “major volumes of continental erosion are not involved in subduction and recycling.”[45] Great volumes of eroded sediments from the Eurasian continent were periodically washed into the off-shore subduction trenches, but instead of being subducted themselves, they were and still are bulldozed back onto the continental shelf together with debris off-scraped from the ocean floor as it is dragged under. These materials are accreted to the continental edge in the form of an accretionary wedge (or “prism,” so-called because of its shape), which itself is made up of a series of overlapping strata likened to a pile of linen table napkins (nappe) (Figure 4). It is estimated that these accretionary processes have contributed to the growth of the Eurasian continent in the area in which Japan developed by ca. 400 km oceanwards in the last 450 million years.[46] Once such accretionary wedges, formed submarinely at the edge of the continental shelf, are incorporated into the dry-land continental landmass, the geological units are called “accretionary complexes” (sometimes abbreviated to “AC”).

In accretion, two facts are important:

1) The ocean floor has two chronological dimensions: a) it is stratified vertically from oldest below (generally greenstone of volcanic origin, then bedded chert) to the deep-sea (pelagic) and shallow-sea (hemipelagic) sediments accumulated on top during the plate’s journey across the ocean basin; and b) the farther away the lower strata are positioned from the origination point of the ocean floor itself (the oceanic ridge), the older they are going to be and the younger the overlying sediments will be.

2) The accreted wedges seem to form a finite size so that successive wedges form underneath each other; this results in the counter-intuitive situation where the earlier wedges are pushed farthest inland and occur stratigraphically on top of the younger wedges added later.[47] Nevertheless, different accretionary complexes are separable because of long temporal gaps between them. These gaps result from the episodic decrease in accretion rate and volume that occurred especially during tectonic quiet times after oceanic ridges are subducted into trenches. Ridge subduction happens periodically when a ridge (marking the boundary between oceanic plates) becomes becomes separated from the magmatic fissure of new crust formation and is pushed along with its old plate as a new plate forms behind it from a new oceanic ridge. At least five plates and four ridges are known

to have passed under the East Asian continental edge throughout geological history.

Increased rates of accretion during ridge subduction are not due to the incorporation of ocean floor so much as to the sudden availability of eroded sediments from the landmass itself. It is theorized that the subduction of oceanic ridges tends to cause uplift of the continental landmass and volcanic activity as the ridge passes into the trench and under the continental edge. The increased height of the landmass is due not only to the raised height of the inter-plate ridge passing underneath but also to the buoyancy of relatively hot, young oceanic crust at the ridge; the corresponding uplift stimulates magma production and the formation of granitic intrusions.[48] Uplift also increases erosion processes, by which much terrestrial material of granitic origin is washed into the ocean.[49] The subduction trench tends to serve as a sump for these sediments eroded off the landmass, which are then bulldozed back up onto the continental shelf through accretionary processes dubbed "semi-autocannibalistic-material recycling."[50] Not all subduction zones, however, experience accretion—such as the current Pacific coastal zone of Tōhoku 東北 where subduction is eroding the continental mass instead of adding to it.

The integral relationship among ridge subduction, continental edge uplift, subsequent erosion, and increased accretion has just recently been fully recognized, resulting in the understanding that in times of uplift, the continental edge will grow proportionally to the amount of inland erosion. This recycling of terrestrial materials accounts for a large proportion of the accretionary complexes, and by implication, it makes for an extremely complicated geology. In Japan, the oceanic components (reef limestone, basaltic/gabbroic greenstones, bedded chert) make up only an estimated 30% of an accretionary complex,[51] with the majority comprised of eroded sediments from terrestrial sources thrown back up on land and intruded by later granites. Moreover, it is known that once an accretionary complex is in place, it can be deformed and reformed so that up to 70% of the materials in such a complex may be chaotically organized rather than representing even the primary accreted stratigraphy.[52]

The importance of accretion tectonics cannot be overstated, for these views totally overturn previous theories of the formation of the Japanese Islands. Although alien blocks of land (smaller than the usual "exotic terranes")[53] such as ocean floor volcanic seamounts and plateaus have been incorporated into the Japanese landmass, they are by far a minor component of the geological setting. However, a distinction must be made between accretion tectonics as the means of forming the dominant geological belts that comprise the Japanese Islands and the chain of causation that allowed accretion processes to occur. For accretion to take place, the subducting trench must have a sufficient amount of eroded sediments from the landmass itself to be bulldozed up again into the accretionary wedge. Uplift of the continental mass from subduction processes is not enough in and of itself to cause sufficient erosion—instead, it is postulated that subducting a plate ridge provides sufficient uplift. It is also argued that uplift stimulates magmatic movement, which creates more continental crust through granitic and volcanic emplacement; these new igneous materials, primarily granite, are then eroded and fed to the trench.[54] Thus, the Japanese landmass is neither a pure volcanic island chain implying only the presence of volcanic rocks, nor has it always been an island chain. The formation of the Japanese landmass required considerable igneous activity to provide erosionable materials and then required the accretion of those materials back onto the continental edge as sedimentary AC.

Exhumation processes

Another little-known process of subduction tectonics is the exhumation of slabs of rock from deep inside the lithosphere to the surface. This process is best described by referring to the structure of successive accretionary wedges (cf. Figure 4). Instead of lying flat, they are slanted parallel to the subducting slab, with their leading edges tilted downwards into the lithosphere. The deeper they are dragged down, the more the crustal pressure increases, so that portions of the deeply buried wedge undergo high-pressure metamorphism. The resulting slab of metamorphic rock, which is harder and less pliable, is liable to be popped back up to the surface when the underlying angle of subduction of the oceanic plate changes to a shallower angle[55]—somewhat like squeezing a pip or seed out of a piece of soft fruit. The stippling around the "HP" in Figure 4 indicates a high-pressure metamorphosed block of rock that may be exhumed to protrude at surface level later.

Exhumations both of high-pressure[56] metamorphic slabs and of bodies of deeply seated igneous rocks have been documented in Japan. Such high-pressure slabs of metamorphic rock commonly come to rest in an accretionary "sandwich" where the surrounding belts have undergone very low, or weak or no metamorphic change.[57]

Seismic processes

It is important to mention the phenomenon of earthquakes. Subduction zones are only one of four active plate boundaries that can cause earthquakes, the others being ocean ridges, transform faults (such as the San Andreas fault) and collision zones (such as the Himalayas).[58] Subduction zones give rise to considerable earthquakes through 1) the cracking of the oceanic crust and bending of the underlying asthenosphere as the oceanic plate is forced under the continental plate, 2) compression of the continental crust as the oceanic plate is thrust against it, and 3) deformation of the oceanic crust as it penetrates deep into the mantle.[59] In particular, earthquakes are generated in a well-defined focal plane in the upper surface of the descending slab (called the Wadati-Benioff zone, cf. Figure 4). Earthquake hypocenters generated in this focal plane may occur from the surface up to ca. 700 km in depth as the slab is subducted; beyond that depth, the mantle is viscous so movement does not produce earthquake shock waves.[60]

In addition to subduction zone earthquakes, Japan is also subject to earthquakes generated in crustal fault zones. In contrast to the "deep" earthquakes generated in the Wadati-Benioff zone, fault-zone earthquakes are "shallow," with their hypocenters usually located only 10-15 km deep, or at most 30 km at the base of the brittle area of the continental crust.[61] Such shallow earthquakes often result in the propagation, through brittle rock failure, of cracks or "faults" in the earth's surface along which blocks of rock move against each other. Once such faults are formed, they provide a focus for further movement and hence are considered "Active Faults"; the Katsudansō Kenkyūkai 活断層研究会 (Research Group for Active Faults) in Japan has recently mapped hundreds of Active Faults across the archipelago and on the continental shelf surrounding it.[62] Crustal fault-zone earthquakes in Japan are caused by various stresses from the interaction, including subduction, of the four or five plates on which modern Japan rests.

Finally, earthquakes in Japan may also be generated around volcanoes as magmatic chambers are emptied of magma, gas and rock during eruptions. Since magma formation and eruption are secondary phenomena over subduction zones, these kinds of earthquakes may also be explained by Japan bordering an active subduction margin. Because subduction processes are ongoing with active plate movement, it stands to reason that as long as the oceanic plates of the Pacific Ocean continue to move northwestwards, accretionary, volcanic and earthquake activity will continue in Japan.

Collision tectonics

The more spectacular forms of continental collision temporally follow subduction, when the oceanic plate between two continental landmasses has been consumed and the continents brought into crushing contact with each other. Such large-scale collisions typically cause mountain uplift—witness the Himalayas as the Indian subcontinent smashes into Eurasia. Although most geological processes in Japan are due to subduction tectonics, there are several small-scale examples of collision tectonics within the landmass. It is unclear as yet whether these also followed subduction sequences or whether they resulted from movement along fault lines. Nevertheless, Japan as a whole is not the product of collision tectonics, as suggested in the general Japanology literature.[63]

The two oldest geological belts in Japan, discussed below under the Precambrian, are composed of remnants of a collision between two ancient continental blocks, called cratons, in the Triassic (see Table 1 for geological time divisions). Much more recently, in the Miocene, the island of Hokkaido was compiled through collision with a microplate moving southwestwards.[64] In the Pleistocene, it may be argued that the elevation of the Hida 飛騨 Range is due in part to the collision between southwestern and northeastern Japan along the Itoigawa-Shizuoka 糸魚川一静岡 Tectonic Line.[65] And taking place today is the collision of the Izu 伊豆 Arc with central Honshu.[66] These are minor parts of the overall picture, which is subduction-driven, but they are interesting in their own right and described more in detail in the sections below which take us through the sequential development of the Japanese landmass.

Shaping the Japanese Islands

The eighth-century chronicles state that the male and female gods Izanagi and Izanami:

> stood on the floating bridge of Heaven, and held counsel together, saying: “Is there not a country beneath?” Thereupon they thrust down the jewel-spear of Heaven, and groping about therewith found the ocean. The brine which dripped from the point of the spear coagulated and became an island....[67]

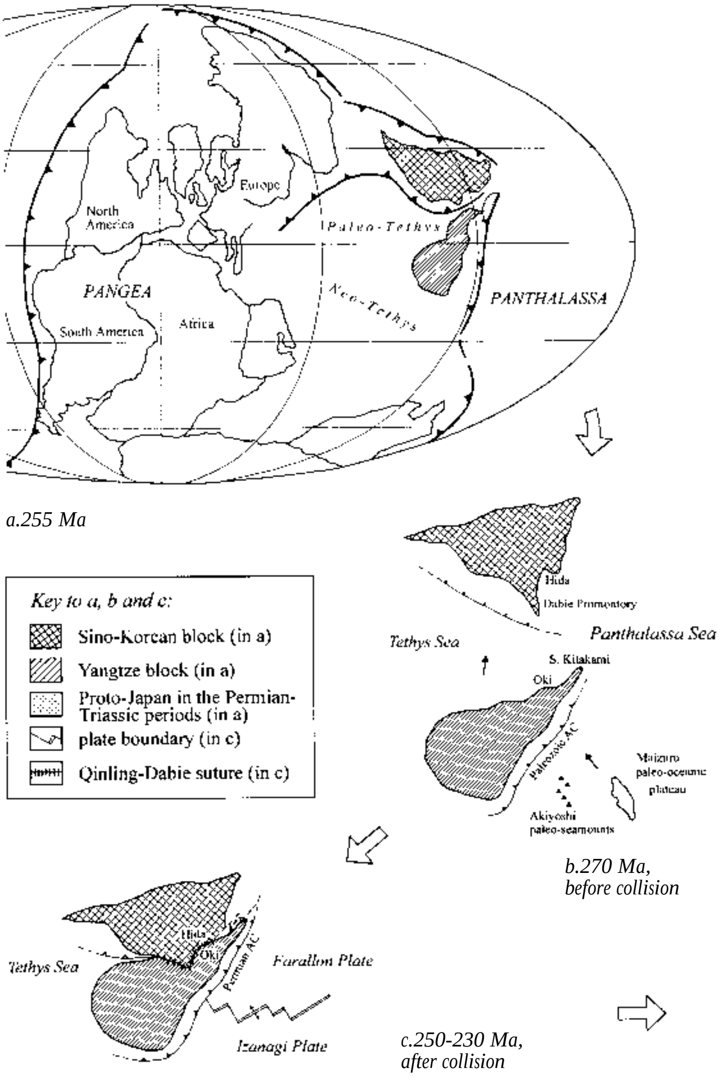
In such a manner were the eight major islands formed, according to the Japanese creation myths. It is significant in this context that one of the early tectonic plates recognized as having a role in the formation of the Japanese Islands has been dubbed the Izanagi Plate by Japanese researchers. This plate, conjointly known as the Kula Plate, existed between 220 and 75 million years ago and was the forerunner of the Pacific Plate, now the largest player in the Ring of Fire.

However, the earliest physical evidence—including heat generation, igneous rocks, metamorphism, and palaeomagnetism—for worldwide plate tectonics can be dated far earlier than Izanagi to over 2500 million years ago (Ma)[68] at the beginning of the Proterozoic (see Table 1).[69] Geophysicists have identified several phases of continental clustering and oceanic formation since then during the evolution of the earth’s surface,[70] and specific plates have been continuously generated and consumed during the successive grouping and breaking up of the world’s continents. It is logical that in all this movement over such an enormous amount of time, Japan did not always have the shape it possesses today—in contrast to the assumption of geosyncline theorists that it was always an island arc off Eurasia. Nevertheless, how dramatically it has changed through the successive geological eras has just recently come to light. The time periods of the major transformations of the Japanese landmass are selected for discussion in the following subsections and can be correlated with strict hierarchical ordering of geological periods and the broader evolutionary events in Table 1.

PRECAMBRIAN TO EARLY PALAEOZOIC: RODINIA’S BEQUEST

It is now clear that we cannot even speak of the Japanese Islands before 15 million years ago, when the Japanese landmass achieved full separation from the Eurasian continent and became an independent archipelago. However, this does not mean that the islands do not have older material bequeathed to them. The oldest rocks in Japan are low- to medium-pressure metamorphics and can be traced to the Precambrian.[71] But these rocks were not then part of a recognizable “Japan”; instead they probably belonged to one of the several supercontinents before the formation of Rodinia—which came into existence in the Late Proterozoic, between 1300 and 1000 Ma.[72]

The story of the geographical consolidation of the Japanese area ostensibly begins with the breakup of the supercontinent Rodinia by the Pacific superplume ca. 750-600 Ma, when the proto-Pacific Basin was formed by superplume upwelling, and the continental blocks (cratons) of Sino-Korea (North China) and Yangtze (South China) were liberated from Rodinia.[73] Around 500 Ma, the edges of these blocks changed from pas-



a.255 Ma

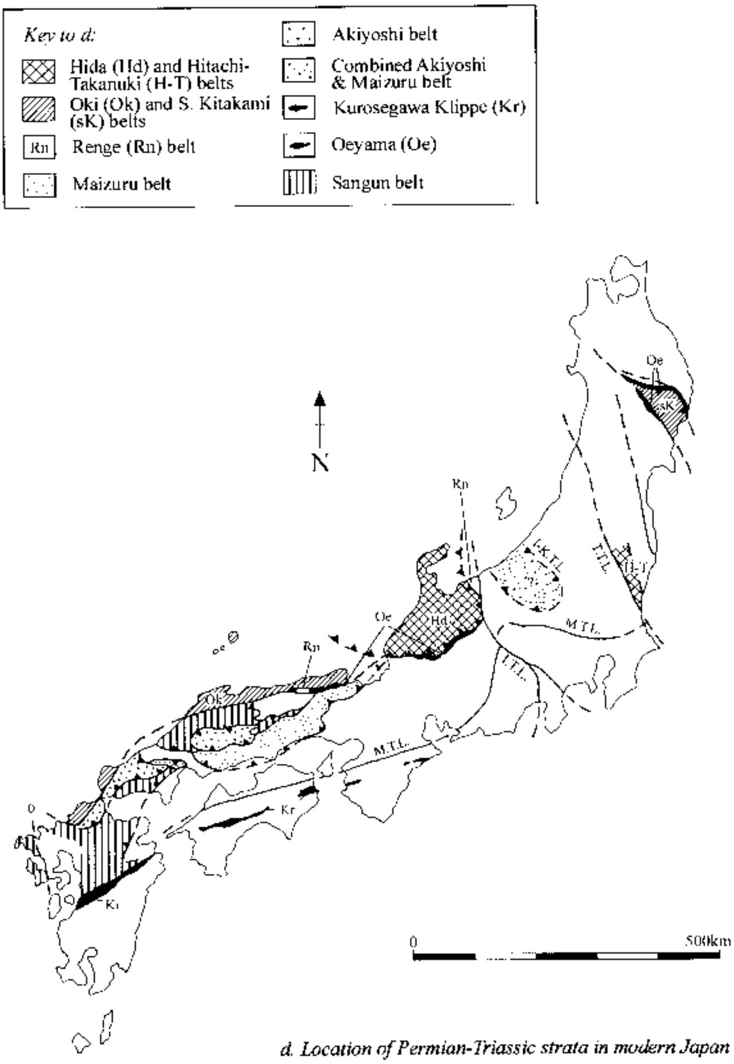
b.270 Ma, before collision

c.250-230 Ma, after collision

Figure 5 Permian and Triassic formation of Japanese geological belts (ca. 286-213 million years ago, abbreviated Ma). Sub-figures b and c are time progressive; note that Japan did not exist at this time but its rocks were in the making and their modern positions are shown in Sub-figure d.

a. The supercontinent Pangea surrounded by the superocean Panthalassa (ca. 255 Ma). The area of proto-Japan is located at the edge of the Yangtze continental block (after Isozaki 1997a, fig. 1).

b. The prior subduction at ca. 270 Ma of the Farallon Plate in the Palaeozoic trench system off the Yangtze craton and the approaching seamounts and plateau created by the Panthalassa superplume, ready for subducting (after Isozaki 1997a, fig. 16a). Note that the Yangtze block



d. Location of Permian-Triassic strata in modern Japan

plate is being subducted under the Sino-Korean block to the north. The black arrows indicate direction of plate movement.

c. The collision of the Sino-Korean and Yangtze cratons between 250-230 Ma, resulting in the Qinling-Dabie suture zone on the China Mainland and its extension in the Hida and Oki belts in the Japanese region (after Isozaki 1997a: fig. 16b). Note the Izanagi Plate approaching the area of proto-Japan below the Farallon Plate.

d. Locations of Permian accretionary complexes and the Triassic metamorphosed belts in modern Japan (after Isozaki 1996: fig. 3, 1997a: fig. 2).

sive rift margins to active subduction margins; and the subduction processes which gave rise to the Japanese landmass began around 450 Ma, when both blocks were still located in the southern hemisphere as separate plates at the edge of Rodinia's successor supercontinent of Gondwana which assembled between 750 and 550 Ma.[74]

Between 300 and 200 Ma, the formation of a cold superplume attracted several continental blocks including the Sino-Korean and Yangtze cratons to amalgamate into a new composite continent called Laurasia, which joined with others, including Gondwana, by ca 250 Ma to form the new supercontinental cluster called Pangea (Figure 5-a).[75] Here, the proto-Japanese area developed as the eastern continental margin of the Yangtze block facing the Panthalassa Sea.

In the following subsections, we will trace the evolution of the Japanese landmass and formation of the islands at this eastern continental margin in relation to subduction tectonics, as the area encountered successive oceanic plates on their journeys to the northwest. Fifteen major geological "belts,"[76] now usually running parallel to the continental margin (i.e. NE-SW), are identified as having been formed mostly by accretionary and igneous processes during these successive cycles of subduction.[77] The oldest belts in Japan, however, are the metamorphosed #1 Hida 飛騨 and #2 Oki 隠岐 Belts (numbered according to Isosaki's scheme; see Figure 9)[78] which are fragments of these old cratons of Rodinia; Hida belonged to the Sino-Korean craton in the north, and Oki belonged to the Yangtze craton in the south. However, it was only many million years later, when they were pulled apart from their original blocks during separation of the Eurasian coast to become the Japanese Islands, that these fragments became part of Japan's geological structure.

CARBONIFEROUS: SWALLOWING THE FIRST OCEANIC RIDGE

Soon after the subduction history of Japan began at ca. 450 Ma off the coasts of the Sino-Korean and Yangtze cratons, one of the most extreme events possible occurred: the subduction of the ridge between two oceanic plates into the off-shore trench. This caused the formation of igneous basements from the superheated magma below, and the first of several high-pressure metamorphosed accretionary complexes was exhumed to eventually become the modern #4 Renge 蓮華 Belt of schists, formed at ca. 300 Ma. It is the third oldest geological belt in Japan and no other rock types of this period survive in the modern archipelago. However, the new plate that succeeded the subducted ridge was the Farallon Plate, a portion of which is thought to still exist in the form of the Juan de Fuca Plate facing the northwestern coast of modern-day Canada (cf. Figure 1).

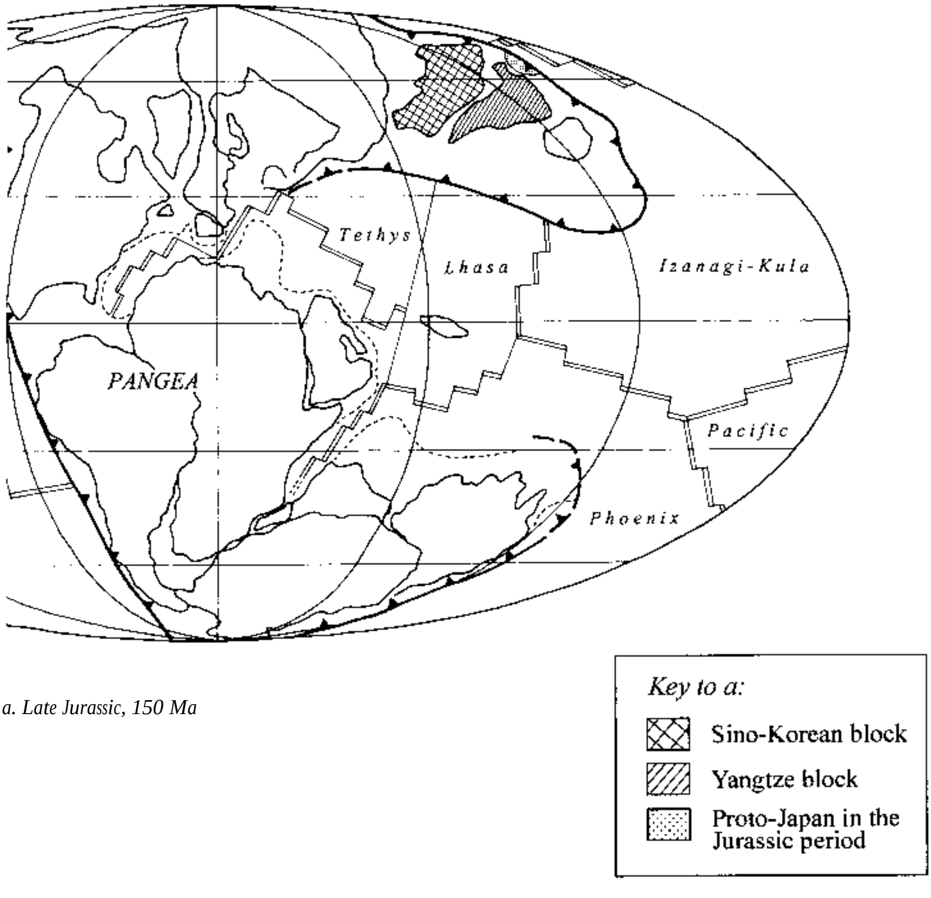
PERMIAN: FARALLON PLATE ACCRETION

The Permian period (ca. 286-248 Ma) in which Pangea assembled witnessed the active subduction of the Farallon Plate under the Yangtze craton (Figure 5-b).[79] Such subduction activity resulted in three sequences of bulldozed oceanic sediments onto the continental margin, now identified as the #5 Akiyoshi 秋吉, #6 Maizuru 舞鶴 and #7 Sangun 三郡 Belts. These belts currently traverse western Japan on the north side (Figure 5-d), but at the time of their formation, they were merely accretions to the edge of the Yangtze craton. Two aspects of their contents are exotic: the Akiyoshi Belt contains limestone inclusions from pebble size up to a ca. 3 x 5 km block, which originally formed the coral reef caps on the Akiyoshi-Sawadani 秋吉一沢谷 palaeo-seamount chain;[80] and the Maizuru Belt contains remnants of a palaeo-oceanic plateau.[81] Both the seamount and plateau are thought to be volcanic features originating from a superplume in the Panthalassa Sea near the Australian continent,[82] much like the Hawaiian and Emperor Seamount chains emanating from the hot spot on the current Pacific Plate. With the movement of the Farallon Plate to the northwest, these oceanic features eventually collided with the Yangtze continental margin, but instead of being drawn down into the trench and subducted, their upper portions were scraped off and added to the accretionary wedge of the continent. It follows that they are much older, estimated to be Silurian (438-408 Ma),[83] than the date at which they became part of the continental margin—allowing for travel time across the proto-Pacific basin.

TRIASSIC: CRATONIC COLLISION

At the beginning of the Triassic (248-213 Ma), the two cratons of Sino-Korea and Yangtze collided with each other in a north-south direction (Figure 5-c), closing the paleo-Tethys seaway.[84] The suture line of the collision is represented on the China Mainland by the Qinling-Dabie 秦嶺一大別 mountainous zone, and it is thought that the #1 Hida and Hitachi-Takanuki 日立一竹貫 Belts in the current Japanese Islands are exhumed metamorphic belts which formed at the eastern extension of this collision suture (Figure 5-d).[85] The cold-water fauna of the Hida Belt suggest a northerly position (on the Sino-Korea side), whereas another set of contemporaneous metamorphic belts, the #2 Oki and Southern Kitakami 北上, are related to the southerly Yangtze craton. All four of these belts currently located in central and western Japan were originally composed of Middle-Late Paleozoic continental shelf sediments that underwent metamorphism during collision of the cratons (Table 2).[86]

At the end of the Triassic, the oceanic ridge between the Farallon and Izanagi Plates, which ran perpendicular to the continental shoreline, moved northwards with the plates, causing exhumation of the #6 Sangun metamorphic belt and generating more granitic basements in its wake.[87]

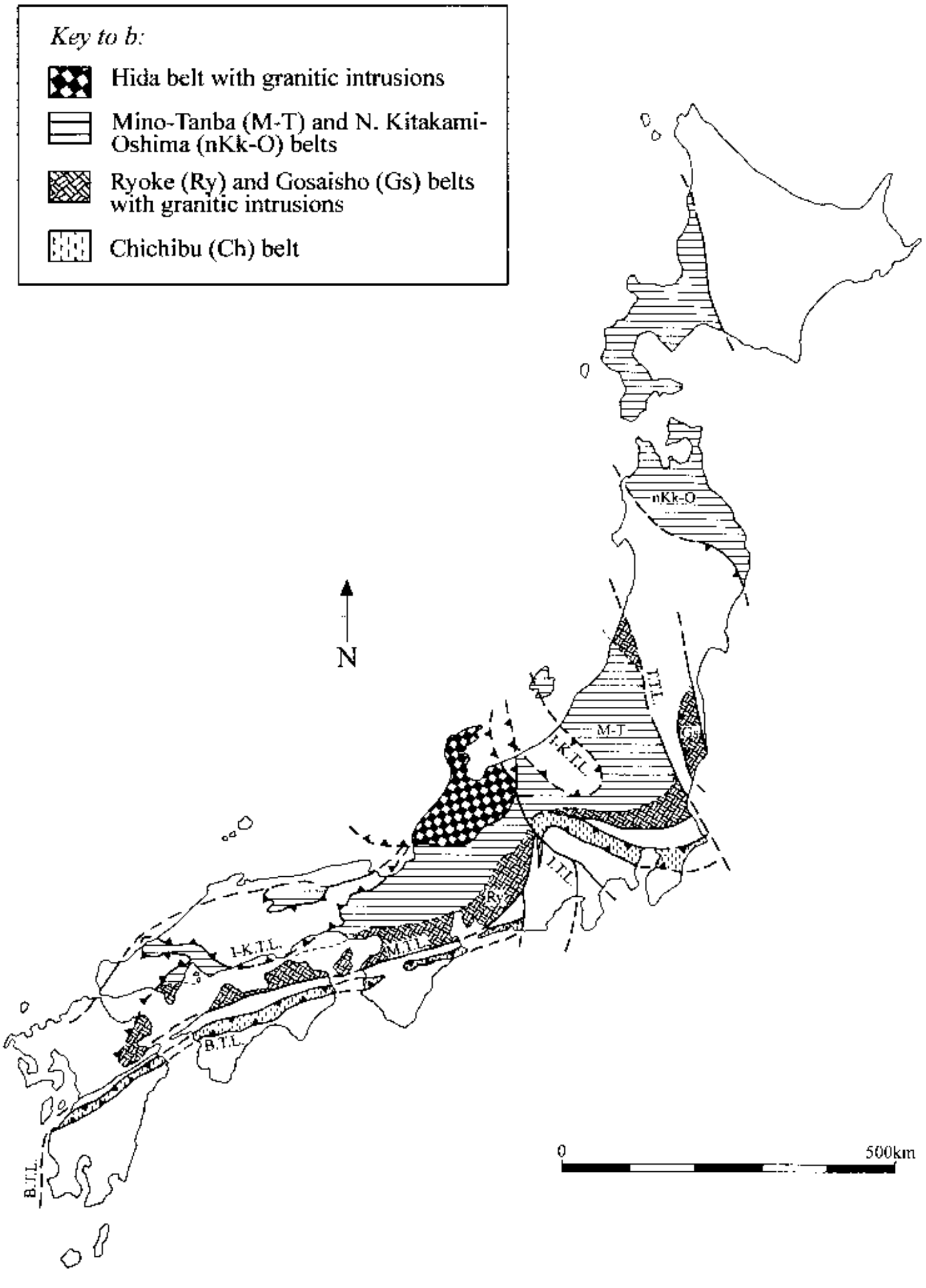


a. Late Jurassic, 150 Ma

Figure 6 Jurassic formation of the geological belts of Japan (ca. 213-144 Ma).

a. The breaking-up of Pangea into Laurasia in the north and Gondwana in the south ca. 180-150 Ma (after Isozaki 1997b, fig. 1).

b. Jurassic arc (granite) and trench (Accretionary Complex) belts (after Isozaki 1997b, fig. 2).



b. Location of Jurassic strata in modern Japan

JURASSIC: MEETING IZANAGI

There are several views as to when Pangea began to break up—ranging from 300-180 Ma (the majority view) to as late as 120-80 Ma.[88] The extension of the Tethys Sea ridge to the west caused Pangea eventually to separate into a northern continental mass (Laurasia) and the southern continental mass (Gondwana again) (Figure 6-a). At 150 Ma, the eastern edge of incipient Laurasia—consisting of the now consolidated Sino-Korean and Yangtze cratons and other continental landmasses—had seen the passing of the Farallon Plate[89] and was now receiving the Izanagi Plate into its subduction trenches, which ran along the continental edge for 6000 km.[90] The area of proto-Japan, at the inner edge of the trench, again experienced the accreting of bulldozed oceanic floor sediments and volcanic features—the latter being the Akasaka-Kuzū 赤坂一葛生 seamount cluster of Permian date.[91] The Jurassic accretionary complexes (the #8 Mino-Tanba 美濃一丹波, #9 Ryōke 領家, #11/13 Chichibu 秩父 and N. Kitakami-Ōshima 北上一大島 Belts) (Figure 6-b) account for nearly 50% of the current archipelagic basement (Table 3).[92] They are paralleled by a contemporaneous granitic belt once situated along the edge of the Laurasian continent.

CRETACEOUS: EPISODIC GROWTH

In the Early Cretaceous,[93] another series of oceanic plateaus was incorporated into the proto-Japanese landmass at the edge of Laurasia: the Mikabu 御荷鉾 plateau of Late Jurassic date and the Sorachi 空知 plateau. These might once have been part of a single plateau that was split up during its journey across the proto-Pacific Basin; the parts now form the Mikabu Greenstone belt in the Seto 瀬戸 area and the Sorachi Greenstone belt in Hokkaido (Figure 7-b).

At ca. 120 Ma, the Izanagi Plate changed directions to move more northerly, slipping along the Laurasian landmass—presumably along a transform fault—rather than directly into it. It is postulated by some researchers that this movement brought parts of the Jurassic AC located far to the south into line with modern Japan's position on the continental edge.[94] This sideways movement along the continental shelf also halted the accretionary and igneous processes on land. Such tectonic quiescence lasted until 90 Ma when the Izanagi Plate changed directions again, generating much igneous activity in the #9 Ryōke Belt and accelerating the cycle of uplift, erosion, and increased accretionary activity to form the northern #14 Shimanto 四万十 Belt. Between 90 and 60 Ma, the #10 Sanbagawa 三波側 Belt of high-pressure schists was exhumed gradually from south to north in the wake of the passing of the oceanic ridge between Izanagi/Kula and the new Pacific Plate (Figure 7-a). These belts, together with the Cretaceous accretionary complexes, are assumed to have been continuous along the continental margin; however, due to the bending of the later island arc, the Shimanto Belt is discontinuous between western Japan and Hokkaido. Presumably the intervening continental shelf off the coast of Tōhoku hosts some of these missing geological strata or they might have already been eroded into the trench by the subducting Pacific Plate—forming one example of erosion rather than accretion along a subducting plate margin.

Concurrently, a new plate was forming off the northern edge of the Laurasian continent through "trench jumping"—the relocation of the subduction trench to the oceanward side of a block of oceanic plateau called the Okhotsk Block (Figure 7-a). This new plate contained the landmasses that would eventually become the Kamchatka Peninsula, the northern tip of Sakhalin Island, the Kurile Arc, and the eastern tip of Hokkaido Island.

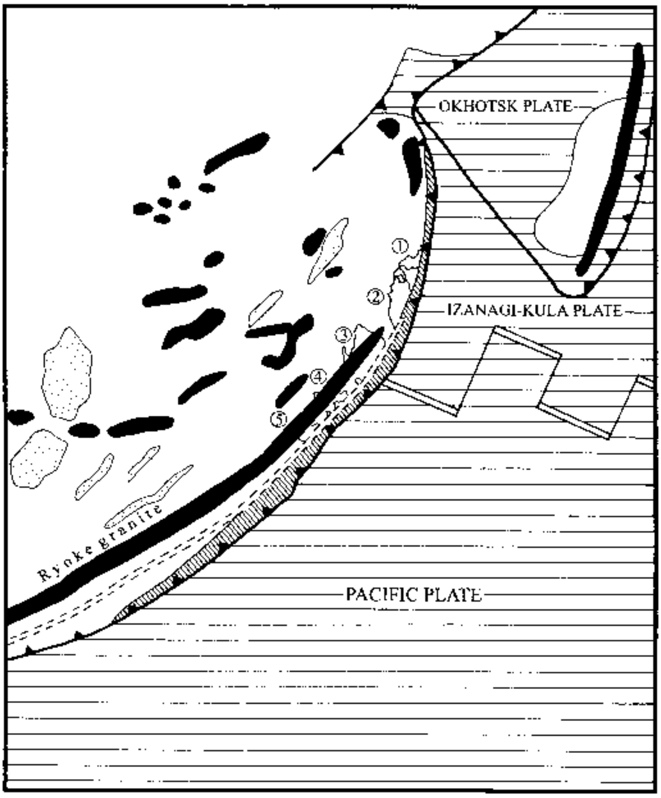
TERTIARY: STRUCTURAL REALIGNMENTS

The Tertiary[95] witnessed several important structural modifications to the Eurasian coastline, giving rise to the island arc topography that characterizes this area today. The developments included the definition of a new oceanic Philippine Plate and formation of a new volcanic island chain along its edge, the Izu Arc. From the Eocene, the Eurasian coastal region was subjected to superplume activity, causing the Baikal rift and the opening of several basins along the coast, pushing out the volcanic shoreline into a series of volcanic island arcs. This marked the formal shaping of Japan and the formation of the Japan Sea and Okhotsk Sea in what are called "back-arc basins" because they occur behind volcanic arcs. The significant events are detailed below.

In the Eocene at ca. 40 Ma, a new trench, plate and arc system formed at the western edge of the Pacific Plate, perpendicular to the continental shoreline. The new trench developed from a pre-existing fault line in the Pacific Plate, carving a new plate, the Philippine Plate, out of the western Pacific. Subsequent subduction of the Pacific Plate into this new Izu Trench (extending to the south as the Marianas Trench) caused the Miocene formation of a very young volcanic chain along the eastern edge of the Philippine Plate, the Izu Arc (Figure 8-a).[96]

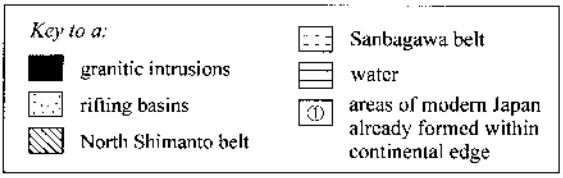
In the early Miocene, the superplume upwelling under the eastern Eurasian continent first caused rifts in the continental crust, such as that now filled with Lake Baikal, and later, the opening of some of these rifts into continental basins, such as the Bohai 渤海 Basin (Figure 8-a). In the cases of the Japan and Kurile Sea basins, the continental crust split apart and the basin floor flooded with magma, creating oceanic-type crust. The spreading of the latter two basin floors pushed the accretionary and igneous belts that had developed at the continent's edge into detached island arcs, the Japanese and Kurile archipelagos. Palaeomagnetic data have revealed that during basin opening, the area of proto-Japan along the continental edge was split in the middle and rotated outwards to form two archipelagic segments (Figure 8-b). The southwestern portion of Japan rotated clockwise from a notional axis (a Euler pole) close to present-day Tsushima 対馬 Island through 45°,[97] moving 21 cm/yr in 1.8 million years from its position along the continental margin and coming to rest in its present position at ca. 15 Ma.[98] Northeastern Japan rotated counterclockwise ca. 40°,[99] from another notional axis off the eastern point of present-day Hokkaido, and came to rest in its present position but having more than 50% of its land surface submerged (Figure 8-c).[100]

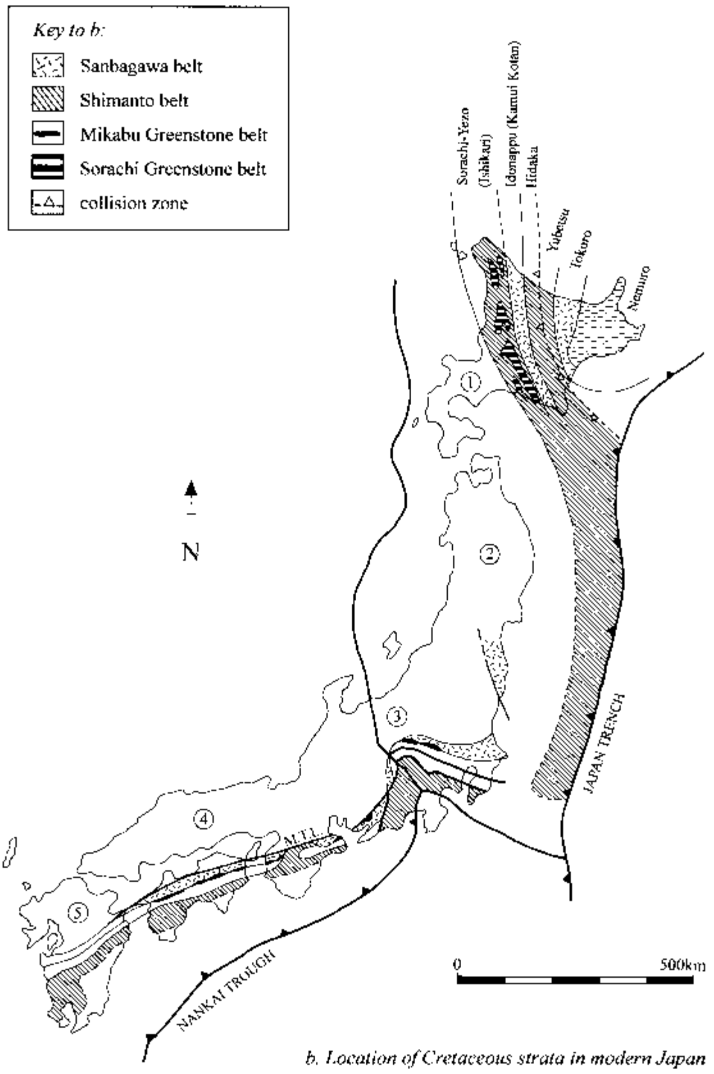
During this so-called "double door" opening of the Japan Sea Basin between 19 and 15 Ma, some fragments of the original Yangtze and Sino-Korean cratons were detached and carried with the island masses. These now form the earliest dated and westernmost



a. Late Cretaceous, 90 Ma

Figure 7





b. Location of Cretaceous strata in modern Japan

Figure 7 Late Cretaceous formation of the geological belts of Japan (ca. 90-65 Ma).

a. Formation of the Ryōke granite belt and exhumation of the Sanbagawa high-pressure schist belt along the Eurasian coastline (opposite page)(after Maruyama et al. 1997, fig. 14).

b. The Cretaceous belt systems (after Kimura G. 1997, fig. 1)

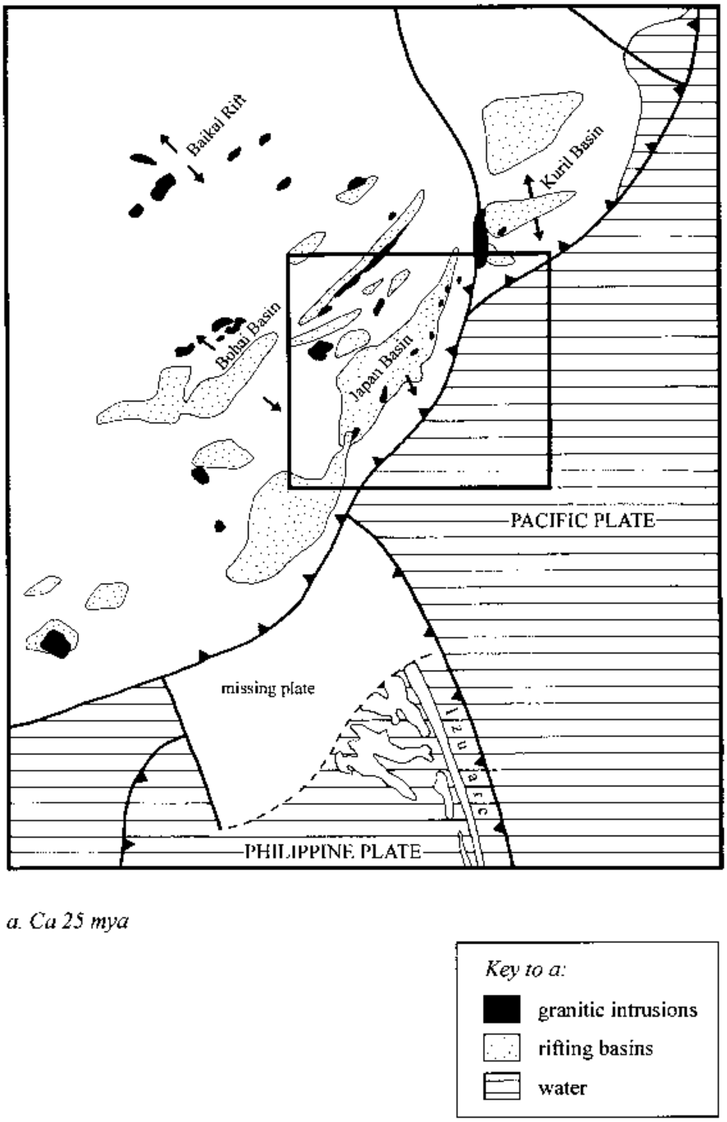
① Position of the western tail of Hokkaido in the Late Cretaceous (a) and now (b)

② Position of the northern tip of Tōhoku in the Late Cretaceous (a) and now (b)

③ Position of the Hokuriku district in the Late Cretaceous (a) and now (b)

④ Position of western Honshu in the Late Cretaceous (a) and now (b)

⑤ Position of northern Kyushu in the Late Cretaceous (a) and now (b)



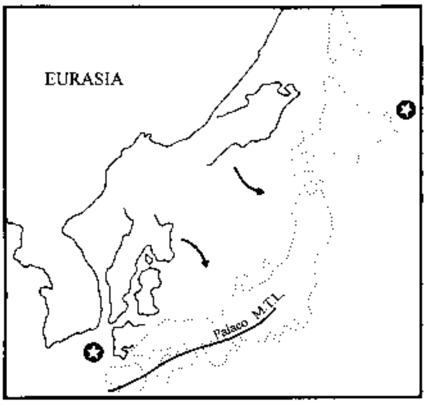
a. Ca 25 mya

Figure 8 Eocene-Miocene structural changes in plate and basin (ca. 40-15 Ma).

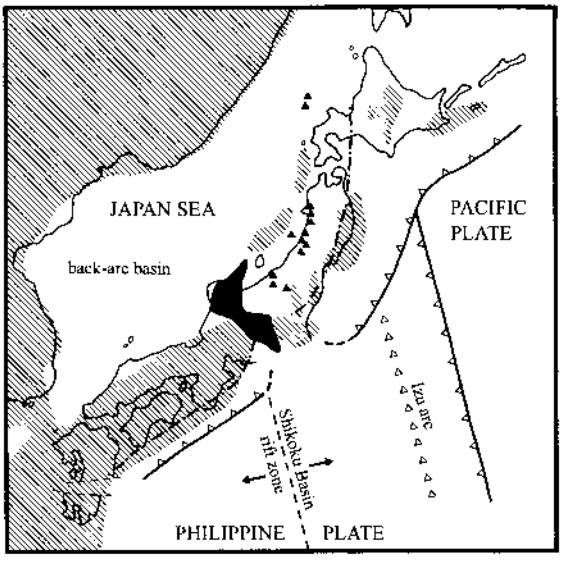
a. Formation of the Philippine Plate and beginning subduction of the Pacific Plate underneath it, giving rise to the Izu Arc (after Maruyama et al. 1997, fig. 17). The missing part of the Philippine Plate has today already been subducted under the continental edge so that we do not know what the upper portion of the Izu Arc consisted of at that time. Inset=Fig8.b,c

Key to b and c:

- ✪ Euler pole
- ▨ dry land
- ⬚ modern Japan
- ⋰ volcanic front
- ▲ back-arc basin basalt
- ■ missing continental crust



b. Ca 19 Ma



c. Ca 15 Ma

b. Position of northern and southwestern Japan at the continent’s edge before the opening of the Japan Sea Basin and rotation of the landmasses outwards (after Otofuji 1996, fig. 5a). Note the missing central parts of today’s Honshu.

c. Japan at 15 Ma after initial opening of Japan Sea Basin (after Ōtsuki 1991, fig. 4; superimposed with 11 Ma coastline (from Yonekura et al. 2001, p. 308, fig. 10.1.6).

geological belts of the Japanese Islands: the #1 Hida and the #2 Oki, consisting of portions of the metamorphosed suture rocks resulting from the cratonic collision in the Triassic. Also tagging along at the edges of these metamorphic belts were rock segments forming the #3 Oeyama 大江山 Belt, which consists of ophiolites dating to 580 Ma[101] that were trapped in a previous forearc zone.[102]

Two important constructional fault lines also originated with the back-basin opening: the Median Tectonic Line (MTL) and the Tanakura 棚倉 Tectonic Line (TTL), which currently run respectively east-west through southwestern Japan and north-south through northeastern Japan (cf. Figure 5-d).[103] The northeastern district experienced faulting parallel to the TTL, thus splitting previous geological belts and rearranging them spatially. Fragments of the Hida and Oki Belts were possibly moved into the Tōhoku region along fault lines at this time, accounting for the current positioning of Hitachi-Takanuki Belt (a Hida fragment) and the Southern Kitakami Belt (an Oki fragment) isolated in eastern Tōhoku. Faulting along the MTL also juxtaposed geological belts of accretionary and tectonic origin that originally formed 100-200 km from each other.[104]

The final alignment of the fragments of Hokkaido also took place ca. 15 Ma. The current island of Hokkaido is divisible into three parts: the southwestern tail, which is geologically continuous with northern Honshu; the eastern point, which is the intrusive head of the Kurile Arc descending into position from the northeast; and the central section consisting of Cretaceous accretionary complexes which are contemporaneous, and possibly continuous, with the Shimanto Belt in southwestern Japan (Figures 3 and 7-b).

It is thought that the southwestern and northeastern portions of Japan, rotating outwards during the Japan Sea opening, might have stopped from opening further due to encountering the new Izu Arc at the edge of the new Philippine Plate.[105] The Izu Arc was also affected by back-basin formation at ca. 15 Ma, as a rift developed behind the arc,[106] separating it from the Kyushu-Palau Ridge to form the Shikoku Basin (Figure 8-c). Continued rifting action caused the fore-edge of the Philippine Plate to move eastwards during the Miocene along the continental coastline, bringing the Izu Arc eastwards into its present position perpendicular to central Honshu, where the advancing arc of the newly formed archipelago collided with it. Thus was brought into existence the triple junction of the three plates in its modern position (cf. Figure 3). Northeastern Japan, still mostly underwater, became directly subject to subduction of the Pacific Plate, while southwestern Japan was uplifted by the action of the Philippine Plate and became dry land reconnected to the continent.[107]

The collision of the Izu Arc with Honshu is one of the more spectacular processes in Japanese tectonic history. Beginning with their meeting upon the opening of the Japan Sea Basin, the Izu Arc has continued to plough into Honshu without subducting with the rest of the Philippine Plate. Its buoyancy is due to its youth and oceanic origin,[108] and it follows in the footsteps of many previous oceanic fragments being incorporated into the Japanese landmass. Initially, the collision took place underwater, when northeastern

Japan was still in the main submerged; the resultant intensive volcanic activity created much basaltic lava and pyroclastic deposition in the collision zone. By 11 Ma, the Izu Arc had intruded far enough to bend the pre-existing geological belts into their present shape (cf. Figures 6-b, 7-b).[109] However, the uplift of the area to dry land only began in the Quaternary, forming the Izu Peninsula of Honshu. This peninsula is thus actually situated on the Philippine Plate, which is still in the process of carrying the rest of the Izu chain into Honshu.

Discussion

In reciting the formation and shaping of Japan, we have touched on four very important topics: the relative importance of magmatic and accretion tectonics in creating the Japanese landmass, the episodic nature of the formation of that landmass, its transformation from continental margin to island arc, and the current belted structure of Japanese geology. Summaries of these four points follow.

The relative importance of magmatic and accretion tectonics

Japan has long been characterized as a volcanic island chain—with the emphasis on "volcanic," implying that its major constituents are igneous rocks. Now, with the majority of rocks classified as sedimentary and with accretionary complexes recognized as the main components of Japanese geology, it seems the pendulum has swung the opposite way. However, one cannot have sedimentary rocks without sediments; and in the case of Japan, the majority of sediments are erosional products of former igneous rocks. The records of former magmatic processes have thus been erased by erosion, and the importance of those processes is hidden in the new sedimentary complexes. It is now clear that both magmatism and accretion are equally important in Japanese landmass formation, and they both result from subduction and are linked by erosion.

Episodic formation of the Japanese landmass

Another lesson of the new accretion tectonics is that accretionary processes were not gradual and ongoing but intermittent and drastic in nature. They decreased primarily during times of oblique subduction of an oceanic plate; and they increased particularly during times of uplift and erosion, caused by the subduction of an oceanic ridge or very young oceanic crust or the exhumation of a metamorphic slab. Uplift exacerbated erosional processes, making available more terrestrial sediments to the subduction trench to be bulldozed back up on land. An extraordinary example of this cycle is the case of the exhumation of the ultra high-pressure metamorphic slab formed during the collision of the Sino-Korean and Yangtze continental blocks at ca. 250 Ma. It is estimated that the subsequent exhumation of this metamorphic slab from the "diamond-level" of deep crust metamorphism displaced three million cubic kilometers of terrestrial materials from the suture zone. These were then washed into the offshore subduction trench, only to be subsequently accreted as the Jurassic AC; the volume of eroded materials was equivalent to a land area of ca. 144 km (90 miles) cubed! [110]

Based on these cycles of uplift, igneous activity, erosion and accretion, four episodes of crust-building in the Japanese area have been proposed:[111] the Abean 阿部 Orogeny at 450 Ma,[112] an unnamed orogeny at 320 Ma,[113] the Akiyoshi 秋吉 Orogeny at 250-180 Ma,[114] and the Sakawa 佐川 Orogeny at 100 Ma.[115] It thus appears that a plate ridge is subducted every 100 million years or so, accounting for the climax of orogenic processes; and the cycle begins again as a new plate starts its subduction. Though these orogenic names have been given here for correlation with the existing literature, there is a shift among Japanese geologists not to use these old names since they are associated with outdated concepts of geosyncline theory—but the dates remain important! And even within worldwide physical geology, there is increasing recognition that the main feature of some named orogenies (like the Sakawa above) is not mountain-building per se. Thus, there is a tendency of late to speak of Events rather than Orogenies.

The shaping of Japan

The most fascinating part of Japan's recent geological history is the larger scale magmatic processes that led to the detachment of the Japanese landmass from the continent to form the current island arc. Japan was not originally an island arc but part of the continental coastline of Eurasia throughout most of its accretionary history. Only from 19 Ma was part of this coastline detached and shoved out in an arc-like formation due to the development of an ocean-floored back-basin behind it. The full extension of the archipelago was achieved by 15 Ma. Only from that time can we say that Japan existed as a separate geographical entity. Then, from 5 Ma, the collision of the Izu Arc with central Honshu has been a major contributor to the modern Japanese landscape, not only through the formation of the Fuji and Hakone volcanoes but also in its role of isolating southwestern Japan from the active subduction of the Pacific Plate—resulting in a higher level of present-day volcanic activity in northeastern than in southwestern Japan.

The islands as first detached from the Eurasian continent and the islands of today bear little resemblance to each other. Major physical changes—the "sculpting" of the landscape—have been wrought by tectonic uplift and collision tectonics beginning at the end of the Miocene to form the major non-volcanic mountain ranges (Hida, Echigo 越後 and Hidaka 日高 chains); and in the Quaternary, new volcanic activity gave rise to the archipelago's current active volcanic character, and faulting (in the form of the Rokkō 六甲 Movements) formed the major inland basins where much of the current population resides. Because these large-scale tectonic processes are ongoing, we shall continue to see more "shaping" and "sculpting" of Japan in the near future.

For those interested in the distant future, the Japan Sea is already in the process of closing up again,[116] and Japan will eventually rejoin the Eurasian continent. In 50 million years the Australian continent—which is moving northwards—is expected to arrive on

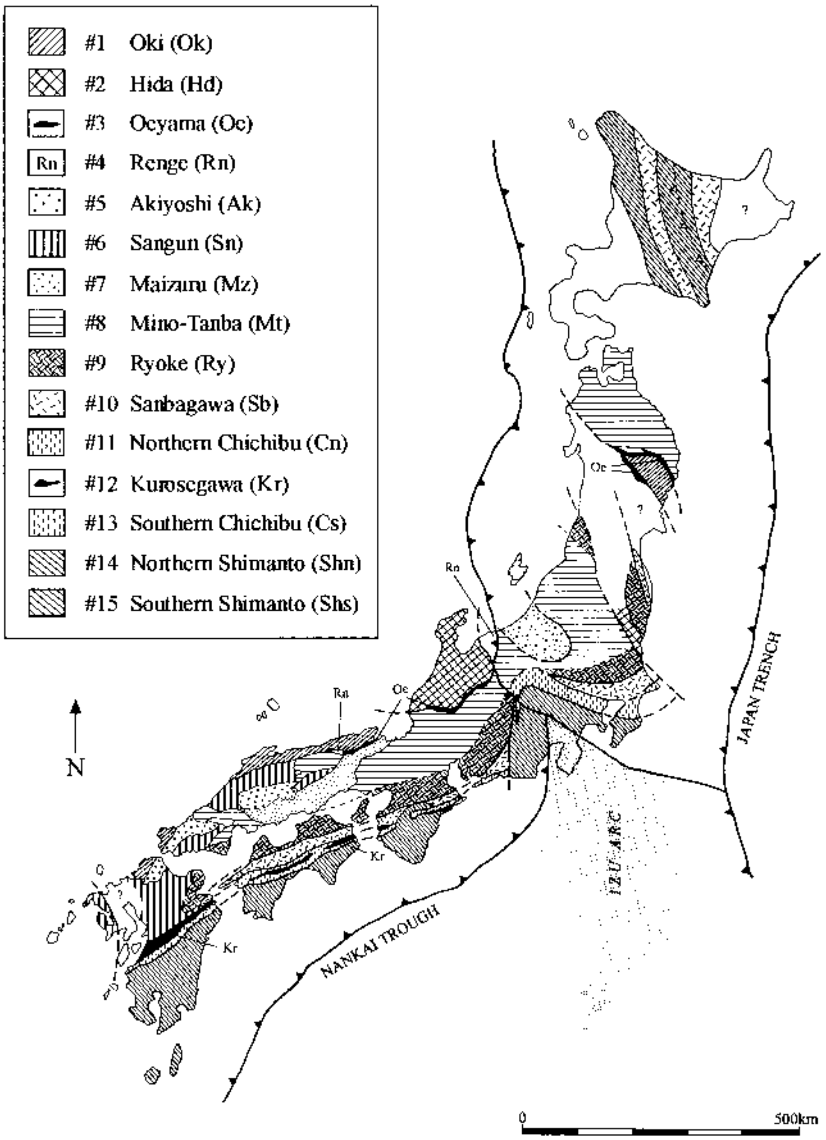


Figure 9 The major tectonic belts composing the Japanese landmass (after Isozaki 1996: figs. 3, 5; Maruyama 1997: fig. 2a; Kimura G. 1997, fig. 1). Numbers indicate the 15 most important geotectonic divisions as ascertained by Isozaki (1996). Note that several question marks remain, and this scheme will undoubtedly change with future research or according to different classificatory needs. North and South members of the Chichibu and Shimanto Belts have not been distinguished here by legend though they have different belt numbers.

Japan's doorstep.[117] However, there are differing views on the future of the Pacific Ocean; one scenario has the North American continent closing onto the eastern edge of newly positioned Australia, leaving the Pacific Ocean trapped 250 million years into the future as a small sea in the northwest below the present-day Bering Straits;[118] another scenario has the Atlantic Ocean closing instead, with the reconstitution of a supercontinent with the Japanese archipelago attached to the far eastern edge as it was with Pangea.[119]

The major geological belts of Japan

Accretionary processes account for the basic belted structure of tectonic units in Japan (Figure 9), generally running parallel to the plate edge or continental coastline and piled diagonally against each other with the oldest to the west. These tectonic belts account for a full 80% of the current archipelagic basement,[120] with the remaining basement consisting of later granitic intrusives from different periods. Over this basement lie more recent rocks and sediments of volcanic and sedimentary origin which have accumulated since the mid-Tertiary period—another story altogether.

In lay terms, the tectonic belts might be thought of as Japan's building blocks, but they are neither homogeneous in content nor coherent in structure. The original portions are most likely divided up and distributed across the landscape through successive faulting and block movement, as for example the isolated fragments of the #1 Hida and #3 Oki Belts of southwestern Japan appearing in eastern Tōhoku. Such subsequent dislocations and transformations through metamorphism, igneous intrusion, erosion and faulting, in addition to the original heterogeneity of contents, makes for an extremely complicated geology. Nevertheless, plate tectonics allows for a processual grasp of why and how such complicated structures arose, and in doing so, it provides the tools for greater understanding of Japanese geology than allowed by either the picture generated by geosyncline theory or the standard descriptions of stratigraphic groups, formations and rock types occurring in different areas.

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NOTES

[1] Butler and Bell 1988: 5.

[2] According to Chester (1993, p. 40), this is an out-dated term, the zone preferably being termed the "orogenic volcanic series."

[3] See case study in Heiken and Wohletz 1985, pp. 156-161; Simkin and Fiske 1983.

[4] See Lipman and Mullineaux 1981 for the full report; Heiken and Wohletz 1985, pp. 204-5.

[5] Between 450 and 15 million years ago.

[6] Propounded in Japan by T. Kobayashi in his seminal article of 1941, forming the dominant paradigm in Japanese geology until the early 1990s.

[7] See, for example, Dietz 1972; Mitchell and Reading 1986.

[8] Kobayashi 1941.

[9] Ueda 1971, Uyeda 1978, Uyeda and Miyashiro 1974, Sugimura and Uyeda 1973.

[10] Miyashiro 1973, 1994.

[11] See Isozaki, et al. 1997.

[12] Isozaki 1996; see his Appendix to this article, entitled “Historical review on studies of orogeny and geotectonic subdivisions of the Japanese Islands.”

[13] Isozaki 1996: 320.

[14] Sugimura and Uyeda 1973: 73.

[15] See Otofuji 1996 and his bibliography. Hashimoto 1991 is a half-way house between the two theories; the English version, published in 1991, is a translation of a Japanese text published in 1980. Chapter 10, the “Geotectonic history of the Japanese Islands” incorporates plate tectonics, but most of the other chapters are cast in geosyncline terminology. Although Chapter 10 acknowledges the opening of the Japan Sea Basin late in geological history, it does not yet acknowledge the intrusion of the Izu Arc into Honshu as the cause of the reverse syntaxis structure in central Japan and cites as a cause Kobayashi’s 1941 thesis of the rotation of northeast Japan eastwards (p. 236)

[16] Smith 1986.

[17] Whitaker 1982; Greensmith and Whitaker 1982.

[18] E.g. Uyeda and Miyashiro 1974, in addition to multitudes of research papers published in such journals as *Tectonophysics, Tectonics, Geology, Modern Geology, and Journal of Geophysical Research,* to name but a few.

[19] See *The Geology of Japan* by Takai et al. 1963, which was “compiled on the occasion of the sixtieth birthday of Professor Teiichi Kobayashi” as stated on the title page, and its successor volume of the same title but different authors, Kimura, T. et al. 1991. Despite the late publication date of the latter, the text is still based on geosyncline theory.

[20] A colloquial abbreviation for Tokyo Daigaku (i.e. University of Tokyo).

[21] Nakajima 1997, p. 69-70.

[22] *The Island Arc* is the official journal of the Geological Society of Japan in association with the Japan Association for Quaternary Research, the Japanese Association of Mineralogists, Petrologists and Economic Geologists, the Palaeontological Society of Japan and the Society of Resource Geology, published in English by Blackwell Science, Carlton, Vic. Australia (ISSN 1038-4871).

[23] Maruyama et al. 1997, pp. 121-42.

[24] Yonekura et al. 2001.

[25] Davidson et al. 2001, p. 45.

[26] Kearey and Vine 1996, p. 160.

[27] Miyashiro et al. 1979, p. 76.

[28] Kearey and Vine 1996, p. 80.

[29] Taira 2001, fig. 1-c.

[30] Kearey and Vine 1996, p. 163.

[31] Middlemost 1985, p. 12.

[32] Isozaki 1997a, p. 17.

[33] Kearey and Vine 1996, pp. 160-1.

[34] Maruyama 1997, p. 114.

[35] Taira 1990, pp. 41-74.

[36] Taira 1990, p. 193. The term "bulldozing" is used in its transliterated English form by Taira, providing an especially evocative image of the processes involved. It is used here to incorporate three processes as described in Maruyama (1997, p. 103): shallow offscraping of trench sediments, medium-depth accretion of sediments and oceanic floor, and underplating with sediments and oceanic floor at considerable depth. These bulldozed sediments are formally termed "accretionary prisms," and the edge of the prism is termed the "accretionary wedge."

[37] Seno 1995, p. 147.

[38] This section is based on Isozaki 1996 unless otherwise noted; the original material for Isozaki 1996 can be found in Isozaki and Maruyama 1991.

[39] Richardson, S. n.d.

[40] E.g. Brown 1979, p. 107; Keary and Vine 1996, p. 280.

[41] Best 1982, p. 27.

[42] Best 1982; Keary and Vine 1996, p. 198.

[43] See Hashimoto and Uyeda 1983; Smith 1986; Taira et al. 1997.

[44] Nasu et al. 1986; Isozaki 1996, p. 289.

[45] Quoted from Brown 1979, p. 111.

[46] Maruyama 1997, p. 114.

[47] Termed "downward-younging polarity" (Isozaki 1996, p. 307).

[48] Maruyama 1997, p. 91.

[49] Maruyama 1997, p. 91.

[50] Isozaki 1997a, p. 19.

[51] Isozaki 1997a, p. 16.

[52] As known in the Jurassic AC belts (Isozaki 1997b, p. 43).

[53] Terranes are "fault-bounded crustal blocks which have distinct lithologic and stratigraphic successions and which have geologic histories different from neighbouring terranes" (Condie 1997, p. 62).

[54] Maruyama 1997.

[55] Maruyama 1997, p. 98; see also Yardley 1989, pp. 202-4, esp. fig. 7.8.

[56] "High-pressure" is shorthand for "high-pressure, low-temperature" metamorphism, often written as high-P/T.

[57] Maruyama 1997, p. 97.

[58] Condie 1997: 8.

[59] Kearey and Vine 1996: 141.

[60] Condie 1997: 8.

[61] Scholz 1990, pp. 125, 132; Condie 1997, p. 53.

[62] See Katsudansō Kenkyūkai 1992.

[63] Totman 2000, p. 13.

[64] E.g. Okada 1982; Taira 2001.

[65] Taira 2001.

[66] Kimura G. et al., 1983; Kimura, G. 1996.

[67] Aston 1972, p. 12.

[68] The scientific notation for "million years ago" is Ma, in parallel with Ga,"billion years ago."

[69] Kearey and Vine 1996, p. 269-85. Also measured as 2.5 Ga.

[70] Kearey and Vine 1996, p. 269-85.

[71] These are the schists of Kamiaso in Gifu Prefecture (Kimura, T. et al. 1991, p. 15), dated to 2.0 Ga (National Science Museum display, Nov. 2000), and the Proterozoic gneiss complex, dated ca. 1.9 Ga (Maruyama 1997, p. 94). They can be compared to 4.5 Ga, when the solar system originated, or the formation of the earth's crust at 4.3 Ga, or evidence for life and photosynthesis in rocks dating to 4.0 Ga (Uhlig 2001).

[72] Kearey and Vine 1996, pp. 270-1; Condie 1997, p. 29; Chester (1993, p. 33) summarizes the "Wilson cycle" in which supercontinents are thought to aggregate and disperse in cycles of ca. 500 million years.

[73] Isozaki 1997a, p. 2; Maruyama et al. 1997, pp. 121, 123. Both blocks consist of Precambrian rocks including an Archaean core which originally made up the supercontinent of Rodinia (Isozaki 1997a, p. 3).

[74] Isozaki 1996, p. 289; Maruyama et al. 1997, pp. 121-2; Condie 1997, p. 30-31.

[75] Maruyama et al. 1997, p. 124.

[76] The geological belts are numbered according to Isozaki 1996. See Figure 9.

[77] Isozaki 1996.

[78] Ibid.

[79] This section is summarized from Isozaki 1997a unless otherwise stated.

[80] Maruyama et al. 1997, fig. 8; the limestones thus date originally to the Carboniferous-Permian (Isozaki 1997a, p. 6).

[81] Fragments of oceanic crust such as seamounts and plateaus are called "ophiolites," and the plateau fragments trapped in the Maizuru Belt are referred to as the Yakuno ophiolites.

[82] Isozaki 1997a, p. 20; Taira 1990, p. 192.

[83] Taira 1990, p. 192.

[84] Summarized from Maruyama et al. 1997 and Isozaki 1997a unless otherwise stated.

[85] See "Principles" section above for explanation of the exhumation process.

[86] Isozaki 1997a: 13-14.

[87] Maruyama et al. 1997, p. 130.

[88] Kearey and Vine 1996, p. 48, 90.

[89] A corner of this plate still exists off the American northwestern coast; it is currently referred to as the Juan de Fuca Plate (see Figure 1), although in the original publication of Figure 1 (Chester 1993) it is named the Gorda Plate.

[90] Isozaki 1997b, p. 42.

[91] Maruyama et al. 1997, pp. 130-131; figs. 10-12.

[92] I.e. five-eighths of all the accretionary complexes in Japan; Isozaki 1997b, p. 28.

[93] This section is based on Kimura G. 1997 and Maruyama et al. 1997 unless otherwise noted.

[94] Taira 1990, 2001. He hypothesizes that the bits of modern Japan located southeast of the Median

Tectonic Line (i.e. southern Kyushu and Shikoku) and north of the Tanakura Tectonic Line (i.e. northern Tōhoku and western Hokkaido) were originally located in the area the Ryūkyū Arc occupies today and were moved northwards almost a 1000 km between 130-70 Ma.

[95] This section is based on Maruyama et al. 1997 unless otherwise stated.

[96] Also referred to as the Izu-Ogasawara, Izu-Bonin, Izu-Marianas, Shichito-Marianas, and Tanzawa-Izu Arc; here, Izu Arc will be used for short.

[97] Yonekura et al. 2001, p. 299.

[98] Otofuji 1996, p. 238.

[99] Yonekura et al. 2001, p. 299.

[100] Maruyama 1997, p. 101; Nihon Rettō 1996, p. 50.

[101] Maruyama 1997, p. 98.

[102] Cf. Figure 4 for definition of volcanic arc zones.

[103] Maruyama 1997, p. 94.

[104] The Sanbagawa metamorphic belt and the Ryōke granitic belt.

[105] Yonekura et al. 2001, p. 304.

[106] I.e. on the opposite side of the arc from the subducting trench.

[107] Yonekura et al. 2001, p. 302.

[108] It has an exceptionally buoyant volcanic composition (Taira et al. 1997, p. 473).

[109] Yonekura et al. 2001, p. 303.

[110] Isozaki 1997b, p. 46.

[111] Maruyama 1997, p. 112.

[112] Named after an early historic clan, the Abe, in the Tōhoku district (Chigakudantai Kenkyūkai 1996, p. 39; see also Minato, M. et al. 1979).

[113] Maruyama 1997, p. 112.

[114] Identified by Kobayashi and linked with the incorporation of the Akiyoshi limestones, but rejected today as a single process (Chigakudantai Kenkyūkai 1996, p. 13; Kobayashi 1941).

[115] Named by T. Kobayashi in his 1941 publication (Chigakudantai Kenkyūkai 1996, p. 485; Kobayashi 1941).

[116] Maruyama 1997, p. 108.

[117] Maruyama 1997, p. 105.

[118] Maruyama 1997, p. 105.

[119] See the animated projections of continental movement into the future at www.scotese.com/futanima.htm.

[120] Taira et al. 1997, p. 468.

GLOSSARY

Cross-references are in ALL CAPS.
Citations, with relevant page numbers noted, are keyed to the text References:
* = Jackson 1997

¤ = Richardson, S. n.d.
§ = Condie 1997
† = Best 1982
‡ = Maruyama 1997

accretion tectonics The growth of a continental PLATE through accretion to its edge of TRENCH and ocean floor sediments and oceanic TERRANES such as OPHIOLITES, island arcs and OCEAN PLATEAUS; mountains built of such processes are called ‘accretionary orogens.’

accretionary complex (AC) “A tectonic mélange or mixture of rock types derived from both oceanic and continental PLATES…, including slices of dismembered ancient oceanic LITHOSPHERE, called OPHIOLITE, and high-P low-T METAMORPHIC ROCKS, called blueschists” †:28. Such a mixture is emplaced through ACCRETION TECTONICS as a prism or wedge at the edge of the overriding continental plate in a SUBDUCTION ZONE.

accretionary prism, see ACCRETIONARY COMPLEX.

accretionary wedge, see ACCRETIONARY COMPLEX.

active plate margin = convergent plate boundary = active subduction margin “A boundary between two plates that are moving toward each other.”*

arc-trench system The classic formation of a SUBDUCTION TRENCH and volcanic arc at an ACTIVE PLATE MARGIN.

asthenosphere The “soft, weak MANTLE material” that lies between the Earth’s CRUST and the “more rigid lower mantle” †:26. “It lies 70 to 100 km below the surface and may extend to a depth of 400 km. Corresponds to the SEISMIC low-velocity zone.”¤

back-arc basin “The region between an island arc and the continental mainland, commonly with at least some oceanic CRUST on its floor.”¤

basalt “A dark colored extrusive IGNEOUS ROCK composed chiefly of [the minerals] calcium plagioclase and pyroxene. Extrusive equivalent of GABBRO, underlies the ocean basins and comprises oceanic CRUST.”¤

basement The CRUST of the Earth underneath the surface cover of sedimentary deposits. Mainly composed of IGNEOUS or METAMORPHIC ROCK but includes ACCRETIONARY COMPLEXES, which are sedimentary constructions.

bedded chert Thick deposits of successive 3-5 cm layers of chert on the ocean floor, thought to be produced through crystallization of the discarded shell casings of radiolaria and diatoms.*

biostratigraphy “The organization of strata into units on the basis of their contained fossils.”*

core “Innermost zone of Earth. Consists of two parts, an outer liquid section and an inner solid section, both chiefly of iron and nickel with about 10 percent lighter elements. It is surrounded by the MANTLE.”¤

craton The original continental fragments of RODINIA. “The stable portions of the continents that have escaped OROGENIC activity for the last 2 billion years. Made predominantly of granite and METAMORPHIC ROCKS."¤

crust (crustal) The upper solid surface of the LITHOSPHERE whose base is defined by the MOHO discontinuity. **continental** ~ Deep-rooted, between 25-75 km thick, areas of the Earth's surface comprising the continents and the continental shelves.* **oceanic** ~ Thin areas of the Earth's submarine surface, 5-10 km thick, underlying ocean basins.*

downward younging polarity A term used to describe the counterintuitive assessment of age of ACCRETIONARY WEDGES which become younger the lower the stratigraphic position.

emplacement A term used in geology to indicate the active positioning of a rock body in the landscape, i.e. the intrusion of MAGMA which crystallizes as a granitic PLUTON or the bulldozing up of an ACCRETIONARY WEDGE.

Euler pole The point which remains stationary and around which any piece of the Earth's CRUST will rotate if dislocated, following Euler's theorem that "any displacement of a spherical surface over itself leaves one point fixed."*

exhumation "The uncovering or exposure by erosion of a pre-existing surface, landscape, or feature that had been buried."*

fault (faulting) "The surface of rock rupture along which there has been differential movement of the rock on either side."¤

fore-arc "The region between a SUBDUCTION-related TRENCH and a VOLCANIC ARC."*

gabbro "A coarse-grained IGNEOUS rock, chemically equivalent to a BASALT."¤

geological belts Zones which are distinguished by their structure.

geosyncline "A downwarping of the Earth's CRUST, either elongate or basin-like, measured in scores of kilometers, in which sedimentary and volcanic rocks accumulate to thicknesses of thousands of meters. Not in current use since the development of PLATE TECTONIC theory."¤

geotectonic, see MEGATECTONICS

global tectonics "Processes related to very large-scale movement of material within the Earth."*

Gondwana One of several SUPERCONTINENTS in Earth's history, formed 750-550 Ma out of RODINIA CRATONS; later was incorporated into PANGEA, and became independent again upon Pangea's breakup. Now mainly accounts for the southern hemisphere continents of South America, Africa, India, Australia and Antarctica. The name means the 'Land of the Gonds', a people in India.

granite "Light colored, coarse grained, intrusive IGNEOUS ROCK characterized by the minerals orthoclase and quartz with lesser amounts of plagioclase feldspar and iron-magnesium minerals. Underlies large sections of the continents."¤

hemipelagic Pertaining to the shallow sea or continental shelf regions.

hominid Pre-human, designating the ancestral species to modern humans.

hot spot The upwelling of hot MAGMA through the MANTLE to the surface outside of a SUBDUCTION ZONE.

igneous: ~ processes The creation, movement and solidification of MAGMA and their resulting structures. ~ **rock** “A rock that has crystallized from a molten state.”¤

island arc A VOLCANIC ARC which exists as an island chain, usually arcuate in shape (e.g. the Kuriles, Japan, the Ryūkyūs).

klippe Any isolated rock mass such as an erosional remnant or outlier of a NAPPE.*

Laurasia The northern half of the SUPERCONTINENT PANGEA, mainly consisting of the RODINIA CRATONs of Laurentia and Siberia.

lithology (lithologic) The description of rocks, now synonymous with petrography.*

lithosphere The relatively thin, rigid surface of the Earth, “encompassing the uppermost MANTLE and all of the CRUST” †:26. See also ASTHENOSPHERE.

magma “Molten rock, containing dissolved gases and suspended solid particles. At the Earth’s surface, magma is known as lava.”¤

mantle The middle section of the Earth’s structure between the CRUST and the CORE, bounded by the MOHO and the 660-km deep SEISMIC discontinuites §:4.

megatectonics “The tectonics of the very large structural features of the Earth, or of the whole Earth.”*

metamorphism “The processes of recrystallization, textural and mineralogical change that take place in the solid state under conditions” of pressure and/or temperature change.¤

metamorphic rock “A rock changed from its original form and/or composition by heat, pressure, or chemically active fluids, or some combination of them.”¤

microplate “A small lithospheric plate.”*

mid-oceanic ridge “A continuous, SEISMIC, median mountain range extending through the North and South Atlantic, the Indian Ocean, and the South Pacific Ocean…[it] is the source of new CRUSTAL material.”*

mid-oceanic rise, see MID-OCEANIC RIDGE.

Moho (Mohorovicic discontinuity) “The sharp SEISMIC velocity discontinuity that separates the CRUST and the MANTLE.”¤

nappe “A sheet of rock that has moved over a large horizontal distance by thrust FAULTING, recumbent folding, or both, so that it lies on rocks of markedly different age or LITHOLOGIC character.”¤

neotectonics “The study of the post-Miocene structures and structural history of the Earth’s CRUST.”*

ocean: ~ plateau A flat-topped submarine feature formed by volcanic activity. ~ **seamount** An extinct submarine volcano which may have a coral reef rim.

ophiolite Segments of oceanic CRUST, such as fragments of OCEAN PLATEAUS or OCEAN SEAMOUNTS, that have been broken off in the SUBDUCTION ZONE and trapped within an ACCRETIONARY COMPLEX † :187-91.

orogeny (orogenic, orogenesis) Often limited to mean the process of "mountain-building," but it "is a complex concept that refers not only to mountain building but also to the formation of continental CRUST, the recrystallization of previously-formed OROGENS, the formation of major orogenic structures, and sedimentation related to mountain building" ‡:92.

orogen "Linear to arcuate in plan, intensely deformed CRUSTAL belt associated with mountain building. Compare CRATON."¤

palaeomagnetism "Study of the Earth's past magnetism as it is recorded in the rocks."

Pangea A SUPERCONTINENT which completely formed by 250 Ma and began to break up around 160 Ma §:31-2.

passive margin = divergent plate boundary "A continental boundary formed by RIFTING and continental rupture."*

pelagic Pertaining to the deep sea.

plate "A rigid segment of the Earth's LITHOSPHERE that moves horizontally and adjoins other plates along zones of SEISMIC activity. PLATES may include portions of both continents and ocean basins."¤

plate tectonics "A theory of GLOBAL TECTONICS according to which the LITHOSPHERE is divided into mobile PLATES. The entire lithosphere is in motion, not simply those segments composed of continental material"¤; see also TECTONICS.

plume A localized body of MAGMA moving from through MANTLE between CRUST and CORE. **hot ~** An upwelling of magma rising to the surface outside of a SUBDUCTION ZONE, causing HOT SPOT volcanoes. **cold ~** A downwelling of magma which tends to draw crustal blocks together, causing continental aggregation. **super~** A very large upwelling of magma causing rearrangement of crustal features.

pluton "An igneous intrusion."¤

P/T Notation for Pressure/Temperature in METAMORPHISM.

pyroclastic "Pertaining to clastic [fragmental] material formed by volcanic explosion or aerial expulsion from a volcanic vent."¤

reverse syntaxis The sharp bending of an OROGENIC belt causing compression of materials.

rift (rifting, graben) "A valley caused by extension of the Earth's CRUST. Its floor forms as a portion of the crust moves downward along normal FAULTS."¤

Rodinia A former SUPERCONTINENT which existed between ca. 1.3 Ga and 600 Ma.

seismic Having to do with earthquakes.

subduction "The process of one LITHOSPHERIC PLATE descending below another."*

subduction zone "A narrow, elongate region in which one LITHOSPHERIC plate descends relative to another."¤

supercontinent The ammalgamation of all the currently existing continents into one large continent.

superplume, see PLUME.

syntaxis “The sharp bending in an OROGENIC belt, accompanied by a fraying into several strands.”*

tectonics “A branch of geology dealing with the broad architecture of the outer part of the Earth.”*

tectonic line “An older term for a major regional FAULT zone in an OROGEN.”*

tephra “A general term for all PYROCLASTIC material.”¤

terranes “FAULT-bounded CRUSTAL blocks which have distinct LITHOLOGIC and stratigraphic successions and which have geologic histories different from neighbouring TERRANES” §:62. Although most terranes have been sutured to continents through collision, fragments of terranes such as ISLAND ARCS, OCEAN PLATEAUS, etc. can be incorporated through ACCRETION TECTONICS. Sometimes equivalent to a MICROPLATE.¤

trench “Along, narrow, steep-walled, often arcuate depression in the ocean floor, much deeper than the adjacent ocean and associated with a SUBDUCTION ZONE.”¤ ~ jumping The phenomenon whereby a FAULT in a PLATE becomes a new TRENCH in a SUBDUCTION ZONE parallel to the former trench.

volcanic arc The zone over a SUBDUCTION slab where volcanoes form, usually in an arcuate or linear pattern pattern paralleling the TRENCH.

Volcanic Front A notional line paralleling the subduction TRENCH but occuring several tens of kilometers inland from the trench; marks the border between the FORE-ARC region and the occurrence of active volcanoes in an VOLCANIC ARC regime.

Watadi-Benioff zone An inclined zone of earthquake foci which marks the position of the descending PLATE in a SUBDUCTION regime † :27.

Wilson cycle the lifecycle of an ocean beginning with its opening as a RIFT system, development of SUBDUCTION systems at its edge(s), and closure of the ocean through PLATE consumption §:12.

Table 1 GEOLOGICAL TIME DIVISIONS AND EVENTS RELATING TO JAPAN
Ma = million years ago; Ka = thousand years ago

DIVISIONS	DATES	EVENTS [FIGURES]	LIFE FORMS
PRECAMBRIAN	4600-590 Ma		
Archaean	4000-2500 Ma		
Proterozoic	2500-590 Ma	· 2500-590 Ma Proterozoic supercontinent "Rodinia"	
		· 2000-1900 Ma earliest rocks in Japan, belonging to Rodinia	ALGAE
		· 750-700 Ma breakup of Rodinia;	SPONGES

		formation of proto-Pacific (Panthalassa Sea); liberation of Yangtze and Sino-Korean cratons	First multicelled organisms
		· >590 Ma beginning of Japan's metamorphic rock sequence (Hida, Oki)	
PALAEOZOIC	590-248 Ma		
lower:			
Cambrian	590-505 Ma	· first fossils from Japan	Multicelled organisms diversify
		· 570 Ma beginning of Japan's plutonic rock sequence	SNAILS, BRACHIOPODS, TRILOBITES
Ordovician	505-438 Ma	· 500 Ma shift from passive rift to active subduction margin on Yangtze and Sino-Korean cratons	First primitive fishes JAWLESS FISHES, STARFISH
		450 Ma Abean Orogeny	SNAILS, CLAMS, CORALS
		· 450 Ma subduction begins under proto-Japan continental edge	
Silurian	438-408 Ma	· 439 Ma beginning of Japan's sedimentary rock sequence	SHARKS, AMMONITES
upper:			Early land plants
Devonian	408-360 Ma	· ca. 385 Ma beginning of Japan's accretionary complex sequence	First forests (evergreens)
Carboniferous	360-286 Ma	320 Ma unnamed orogeny	
		· 300 Ma ridge subduction and exhumation of Renge metamorphic belt; beginning of Farallon Plate subduction	First reptiles, amphibians Variety of insects
Permian	286-248 Ma	250-180 Ma Akiyoshi Orogeny	Coal-forming forests
		· 250 Ma formation of Pangea [Figure 5a]	
		· accretion of Akiyoshi-Sawadani palaeo-seamount chain	
MESOZOIC	248-65 Ma		
Triassic	248-213 Ma	· exhumation of Sangun metamorphic belt with passing of Farallon ridge	First dinosaurs
		· collision of Yangtze and Sino-Korean cratons to form Eurasia [Figure 5c]	Early birds, mammals
Jurassic	213-144 Ma	· by 180 Ma break-up of Pangea [Figure 6a]	PLEISIOSAURS, PTEROSAURS
		· 150 Ma finish Farallon and begin Izanagi/Kula subduction	TOOTHED BIRDS, flying reptiles
		· accretion of Akasaka-Kuzū seamount cluster	Early flowering plants
		· 146 Ma beginning of Japan's volcanic rock sequence	
Cretaceous	144-65 Ma	· accretion of Mikabu-Sorachi ocean	TURTLES, DINOSAURS

		plateaus · 120-90 Ma tectonic quiescence with oblique plate subduction	
		100 Ma Sakawa Orogeny	
		· 90-60 Ryōke igneous activity; exhumation of Sanbagawa Belt [Figure 7a]	Placental mammals
		· formation of Okhotsk Plate through trench jumping [Figure 8a]	Extinction of dinosaurs
CENOZOIC	65Ma-present		
Tertiary	65-2 Ma		
Palaeogene	65-24 Ma		
Palaeocene	65-55 Ma	· consumption of Kula plate; begin subduction of Pacific Plate	INSECTIVORES, CROCODILES
Eocene	55-38 Ma	· 40 Ma change of direction of Pacific Plate, NNW > WNW	BIRDS, MONKEYS, MARSUPIALS
		· 40 Ma formation of Philippine Plate and Izu Arc [Figure 8a]	BATS, CARNIVORES HORSES, CAMELS, ELEPHANTS
Oligocene	38-24 Ma		
Neogene	24-2 Ma		
Miocene	24-5 Ma	· early Miocene continental rifting · subsidence of Tōhoku region and submarine volcanism · 19-15 Ma Japan Sea Basin, Japan & Kurile Arc formation [Figure 8b] · Median Tectonic Line & Tanakura Tectonic Line formation · 15 Ma back basin formation behind Izu Arc [Figure 8c] · 15 Ma alignment of Hokkaido parts; intrusion of Kurile Arc · 13-5 Ma tectonic basin formation · 13 Ma shift from extensional to compressional stress in NE Japan · by 11 Ma Izu Arc collision · 8 Ma emergence of Tōhoku as dry land · uplift of Hida, Echigo & Hidaka ranges	
		· 6-4 Ma extensional depression forming Palaeo-Inland Sea	PRIMATES
Pliocene	5-2 Ma		HOMINIDS, WHALES
Quaternary	2 Ma-present		
Pleistocene	2 Ma-10 Ka		HUMANS
Early Quaternary			Homo erectus
	2 Ma-700 Ka	· formation of Fossa Magna & growth of Mt Fuji and Mt Hakone · formation of Okinawa Trough · 1 Ma northward tilting of SW Japan	Large carnivores
Middle Quaternary			
	700-13 Ka	· 700 Ka beginning of Quaternary volcanics	

		· 300-200 Ka Rokkō movements, basin & range formation	
Late Quaternary			
	13 Ka to present		Extinction of large mammals and birds
Holocene	10 K to present		

要旨

日本列島の起源　ー新しい概論ー

ジーナ・バーンズ

考古学者や歴史学者による農耕技術・資源分配・集落分布・原資源の発掘・出土品の分析・自然災害などの研究は、自動的に地質学の問題に取り込まれることが多い。本研究は地理学的な日本列島の形成の歴史に焦点を当てる。日本研究者向けの日本地質についての欧文文献は非常に貧弱である。地質学者でない者に、新しい概念を分かりやすく説明している文献を探すのは困難を極める。最近の出版物の中でもプレートテクトニクス（plate tectonics）ではなく、いまだに古風な地向斜論（geosyncline theory）をもとにして解釈を行う本もある。1990年代の日本の教科書にさえその二つの対論を折衷した理論が紹介されている。日本の社会がプレートテクトニクス論を受け入れることが遅れたのは孔子の学問スタイルの所為かもしれないが、それは日本の地理学研究の発展には寄与しなかった。しかしながら、先駆的なプレートテクトニクス論を信奉するジオキッズ（geokids）と呼ばれる若手の研究者達が日本列島形成理論の革新を行った。ここでは日本研究者に、日本地質学の性格と、日本列島の地質的な形成が時代の流れの中で住民の生活様式にどう影響したかを理解するための新しい観点を紹介したい。