Environmental Changes during the Last 10,000 Years in North Kyushu, West Japan with Special Reference to Shoreline Movements

北部九州における過去10,000年間の環境変遷：とくに海岸線の移動について

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[**Abstract**] The half history of the past 10,000 years opened by rapid rising of sea level in North Kyushu, West Japan. Phenomenon which shoreline came into inland by the Holocene sea level rising is called 'Jomon Transgression' in Japan. A primary small bay started in the Ariake Bay area at about 10,000 y.B.P. The sea area expanded rapidly since 10,000 y.B.P., and then the maximum sea area appeared and got into the most inland when rising sea level reached the high-peak at about 6,000 y.B.P. About 6,000 y.B.P., sea level became steady, but then sea level went down several meters during the last 5,000 years by hydro-isostatic adjustment. This phenomenon is known as 'Small regression of the Yayoi Period (ca. 2,000 y.B.P.)' in Japan.

There is wide spread tidal flat, because maximum tidal range is about 6 m in the Ariake Bay coast, it is the biggest in Japan. Big tidal range causes a special sedimentation for the transgressive process. Mass volume of sea water concentrates into river mouth at rising tide, and the tidal current digs the river bottom and make mass of suspend mud. According to the present observation of the Rokkaku River, fluid mud flows backward in the lower course of each river for several 10 km and fills the reed plain there by non-marine mud. At the transgressive stage, this phenomenon seems to appear more remarkably. As the result, wide spread lowland and two kind of clay bed, non-marine and marine clays, were formed in the Saga Plain.

Three ancient shore lines are able to restore in the Saga Plain. They are 1) shore line when is peak time of the Jomon Transgression, 2) shore line when is the maximum take off time from sea water, and 3) shore line at the beginning time of the Edo Period (ca. 300 y.B.P.). Since the Middle Age an extensive reed plain almost disappeared by cultivation in Saga Plain. Nowadays natural shore lines are almost erased by land reclamation on the Ariake Bay.

1. Introduction

A transgression in the first half of the Holocene and a regression and artificial land reclamation in the second half caused environmental changes during the last 10,000 years in North Kyushu. The Saga Plain is the largest in West Japan and contacts the innermost part of Ariake Bay (Fig. 1). The present Saga Plain is almost covered by flood paddy. Artificial irrigation, flood prevention, and reclamation works completely destroyed natural landscape. There is no clue to know the ancient environment in the Saga Plain. Information before the human alterations is however preserved below the flood paddy, and we can reconstruct the ancient landscape before the rice cultivation in

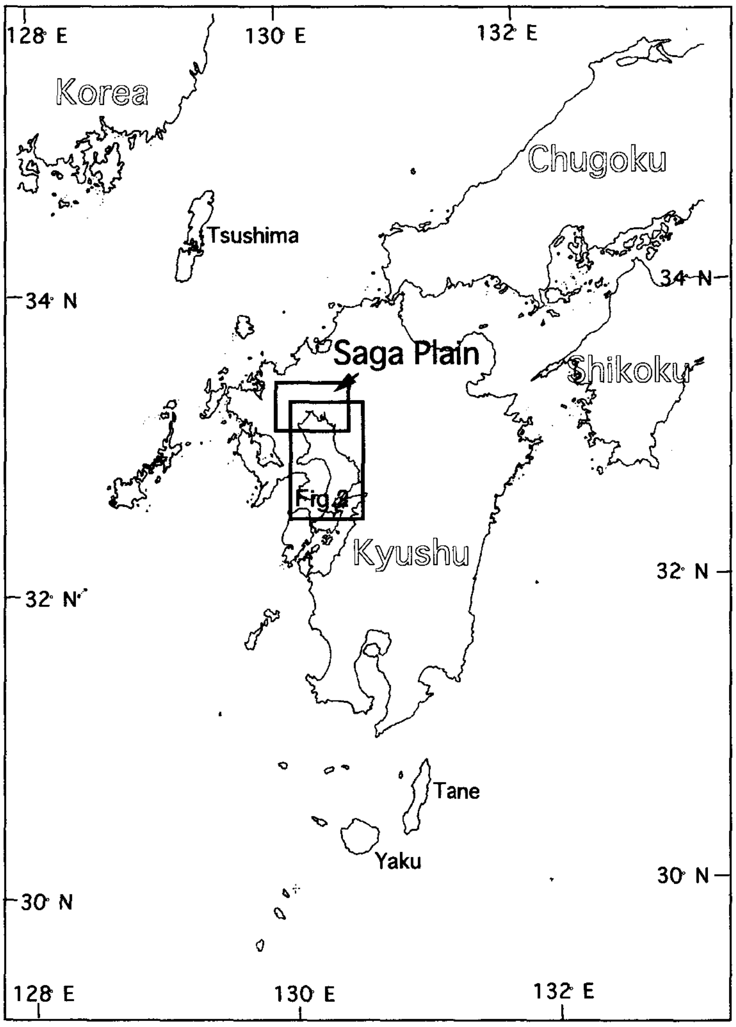

Fig. 1 Index map of Kyushu, West Japan

the Saga Plain based on such environmental information. Sediments in the present Ariake Bay will also give us a key to reconstruct ancient landscape clear.

2. Wide spread tidal and mud-fluid water sea: Ariake Bay

The Ariake Bay is a long and shallow bay in West Kyushu. The tidal range (5 to 6 m in maximum) at the innermost part is the biggest in Japan. A vast tidal flat appears at Ariake Bay coast at the spring low tide (Fig. 2). Saga low-flat land has been considered to have changed from a tidal flat into land directly. A big tide at the inner most part of Ariake Bay causes replacement of sea water in large quantities. Strong tidal streams and a big stress occur on the tidal bottom with every raising tide in the Ariake Bay, and make mud suspending water fling up bottom materials when a large quantity of sea water rushes on the tidal flat.

There are three kinds of tidal flat in the Ariake Bay: sandy-mud, sand, and mud flats (Fig. 2). Sandy flats occur in the eastern to southeastern coast in Ariake Bay. Residual sand separates from sandy-mud flats and concentrates on sand flats. The mechanism of sand flat formation is as follows. Strong tidal currents dig and fling up bottom materials, and make suspended mud and sand at the front of a tidal flat. Suspended mud is transported by a tidal current counterclockwise from the middle to the innermost part of the Ariake Bay, and then settle down at the northwestern area far away from the source. Sandy materials remain at and around the source. Sediments of both sandy and muddy flats are made up secondarily. Fluid mud diffuses in the suspention water, and mass of suspention water moves counterclockwise with a rising current from the tidal front to the inner bay (Inoue, 1980; Kamata, 1967). Mud concentrates along the innermost Ariake Bay coast, and then is deposited to make a mud flat (Fig. 2). Thus widespread mud flats fringe the northwestern part of the Ariake Bay (Picture 1 in Fig. 3). This kind of clayey sediments is marine clay. In contrast to mud, sand remains at the tidal front and forms a big sandbar in front of a tidal flat.

3. Backward flow of fluid mud and non-marine clay

Velocity of a tidal current and shear stress heighten again at the mouth of tidal rivers along Ariake Bay at the rising tide, because large salt water mass concentrates at the narrow river mouth. According to Futawatari *et al.* (1992), strong mixing occurs at the raising tide negating layering into fresh and salt water layers at the normal river mouth because of over concentration of sea water at the river mouth in the Ariake Bay. Strong surge of bottom materials makes a large quantity of high density fluid mud again at the river mouth, which goes up the river backward. River banks covered by backward flow are reclaimed by mud, and look like a mud flat (Picture 2 in Fig. 3). Front waters of the backward flow is almost fresh water, but salinity of the main flows gradually increases because of the strong mixing. There is a tradition of taking water from the backward flow for rice paddies in the Saga Plain, called "Awo Shusui". "Awo" means low salinity backward flow. According to the legend, keepers of the water gate sometimes sipped water to check its salinity, and closed the gate when he felt the water salt.

At present, the long distance backward flow is inhabited because of dams at the river mouth along the Ariake Bay except several rivers. Backward flow of fluid mud still goes up to about 30km above the river mouth in the Rokkaku River. Pore water of settled mud and the salinity of fluid mud are only 0.4‰ at the flow limit of Dainichi (Fig. 12), almost fresh water. A large amount of non-marine mud is deposited at the limit of the backward flow in the Rokkaku River (Pictures 2 and 3 in Fig.3). If we have no dike or dam, non-marine mud must have filled up the river near the limit, and the river must have overflowed. Thus, non-marine mud widely covers the surface of plain. The backward flow and deposition of the non-marine mud are the main processes in the low flat land formation of the Saga Plain, because similar clayey sediments of fluid mud deposits sometimes occupies a layer directly below paddy fields in this plain (Pictures 5 and 7 in Fig. 3).

We can find not only clay and silt particles and also diatom remains when we examine a drop of fluid mud through a microscope. Many marine diatom remains are

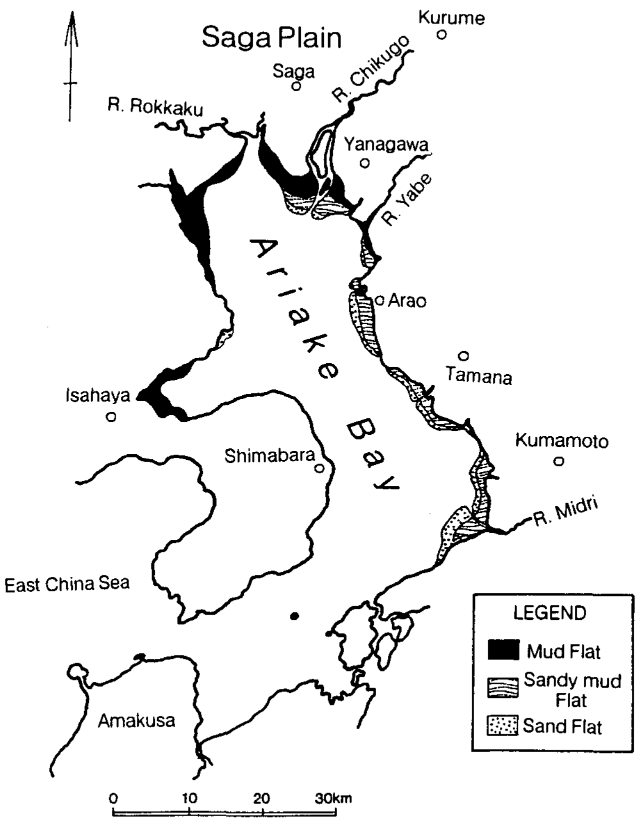

Fig. 2 Various tidal flats in Ariake Bay

also included in the fluid mud, although it is almost fresh water in the salinity at the backward flowing limit (Picture 4 in Fig. 3). Sometimes we can see black particles on the inside of diatom tests (Picture 5 in Fig. 3). These black particles are bacterial colonies and framboidal pyrites. Framboidal pyrites are product of baigenic origin under anoxic and very low pH condition. Semi-closed space in the inside of diatom tests meets this condition. Existence of marine diatom remains and framboidal pyrite strong indicates that the non-marine mud is marine origin. However, fossils of marine diatom and pyrite do not always indicate pure marine environment.

Thus there are two kinds of mud sedimentation on the Ariake Bay coast, marine and non-marine mud; the former concentrates at the northwest part in the innermost Ariake Bay, and the latter deposits in tidal rivers and the vicinities.

4. Three kinds of shoreline

The 'shoreline' at the Ariake Bay coast is problematic, because shoreline sometimes moves in a day for several kilometers. Fig. 4 shows three kinds of shoreline which we ought to consider: shorelines as 1) the mean sea level, 2) the highest high water level, and 3) the backward flow limit. The first and the third are important in considering conditions of depositional and archeological sites. The first one is a time-averaged boundary above and below the sea level through a day, and one of oxidation and reduction boundary. Therefore shoreline of the mean sea level is a kind of chemical boundary. The third one is the limit of ancestral residence.

Intertidal sediments include a large mount of pyrite on the inside of diatom remains. Pyrite generates sulfuric acid easily under the oxidic condition. Sulfuric acid will be neutralized with sea water as soon as it generates, because sea water is a little alkaline. However, acidic condition increases above the oxidic land side of the mean sea level, because of no neutralization. Shells are difficult to preserve above the mean sea level, because shells will decay slowly by sulfuric acid under the wet and oxidic condition. Rare exceptions are evaporite or a large adhered pack of shells. Therefore, existence of shells is a sign that the sediment were formed in sea area. If employed property, we can reconstruct ancient shorelines as the mean sea level, and the height of ancient shorelines can be deduced from the present bore hole data in Saga Plain.

5. Holocene trans- and re-gressions in ancient Ariake Bay area

Tidal sediments in the Holocene formation in the Saga Plain suggest that big tides appeared in the ancient Ariake Bay since about 8,000 years B.P. at the latest. The Holocene sea-level raising and the Jomon Transgression made a long bay in the western part of Kyushu. A transgression is a landward progress of a shoreline. A regression is the opposite phenomenon. The forward movement of shorelines since about 15,000 years B.P. is commonly called 'the Jomon Transgression' in Japan, because the Holocene transgression became remarkable in the Jomon Period (between ca. 10,000 and 2,200 years B.P.).

6. The largest sea area in the Saga Plain

We tried to restore the largest sea area in the Saga Plain. Distribution of marine and non-marine Holocene clayey formations was deduced from drilling data in the Saga Plain. Shimoyama *et al.* (1994) subdivided and redescribed Holocene formations into marine and non-marine formations, i.e., Ariake Clay and Hasuike Formations. Sea shells or subterranean stems of reeds in these strata is the key to identify Ariake clay or the Hasuike Formations (Pictures 5 and 6 in Fig. 3). Ariake Clay Formation mainly consists of dark grayish to bluish grey clay and silt with marine shell fragments, and is a soft marine bed. When we sieve clay from drilling cores through a 1 mm mesh, we can find far more shell fragments than we saw before. The ancient sea area and ancient shore lines during the Jomon Transgression are restored for the maximum period from fossil evidence and the bore hole data, because almost same shell species still live in the intertidal, subtidal and shallow sea water in the present Ariake Bay.

Inclusion of shell fragments in bore hole data in the Saga Plain indicates that this layer was formed in the sea area Fig.5 shows distribution and the limit line of Ariake Clay (marine) Formation in the Saga Plain. Isodepth lines indicate the shape of the basal surface and extensions of depression. Closed or open circles in Fig. 5 respectively indicate existence or absence of marine layer below the ground surface at each location. The northern limit of marine formations almost reaches Jojima Town in Chikugo, Route

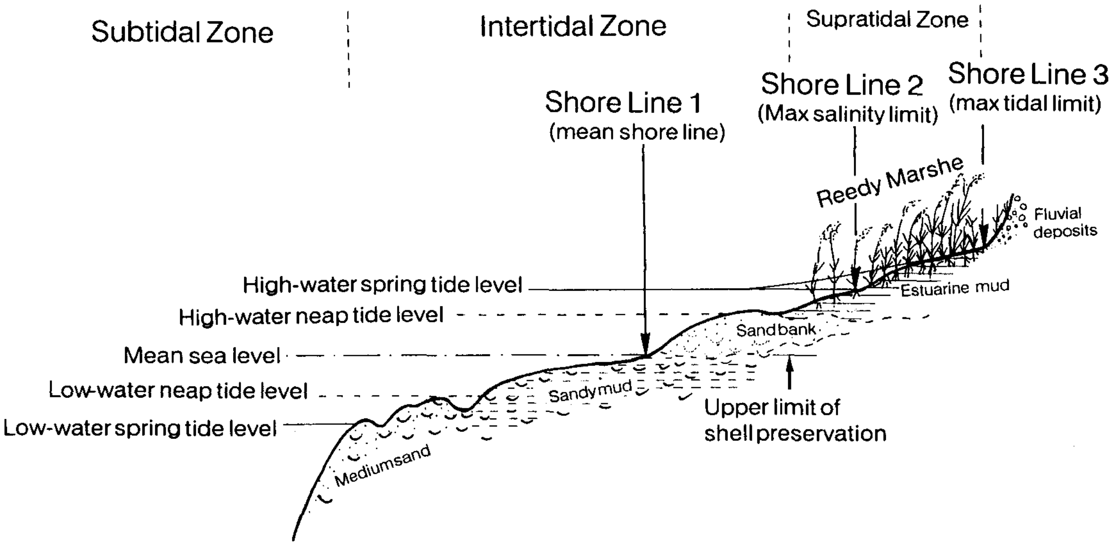

Fig. 4 Three types of shorelines
Shore Line 1 is mean shoreline, Shore Line 2 is the highest sea water line, and Shore Line 3 is limit line of mud suspended backward flow

34 in Saga City and Futamata, Takeo City (Fig. 5). The total connections of the depression look like a network of tidal creeks at a widespread tidal flat rather than a drowned valley. The bottom layer of marine formations in the center of depressions is composed of very coarse residual sediments with intertidal sea shells, and is thin lenticular in cross section. Therefore, these connections of depression probably show traces of strong erosion by rising tidal currents during the transgressive period. If this is true, the basal surface of the marine sediments should agree with a tidal ravinment surface (TR in Fig. 11).

The horizontal limit of the Ariake Clay Formation indicates the shoreline at the maximum stage of Jomon transgression.

7. Sedimentary conditions of non-marine formation in the Saga Plain

There is a homogeneous clayey layer below the basal soil of a paddy field in the eastern Saga Plain (Picture 7 in Fig. 3). This is the upper part of the Hasuike Formation (Shimoyama *et al.*, 1994). The layer contains many subterranean reed stems as a distinguishing characteristic. This suggests that the homogeneous clayey layer was formed under a very low salinity condition in a reedy marsh like the limit of the backward flow of fluid mud in a tidal river. Therefore, the upper part of the Hasuike Formation is non-marine in origin.

Pictures 5 and 6 in Fig. 3 show two kind of clays, marine Ariake clay and non-marine Hasuike Formations at the surface of the Saga Plain. The present height of the upper limit of non-marine clay at the margin of the horizontal distribution is 8 to 9m in Ogori City, but 6m in Saga and Takeo Cities (Fig. 6). This height of fluid mud sediments indicates the upper limit of the backward flow during the maximum of the Jomon

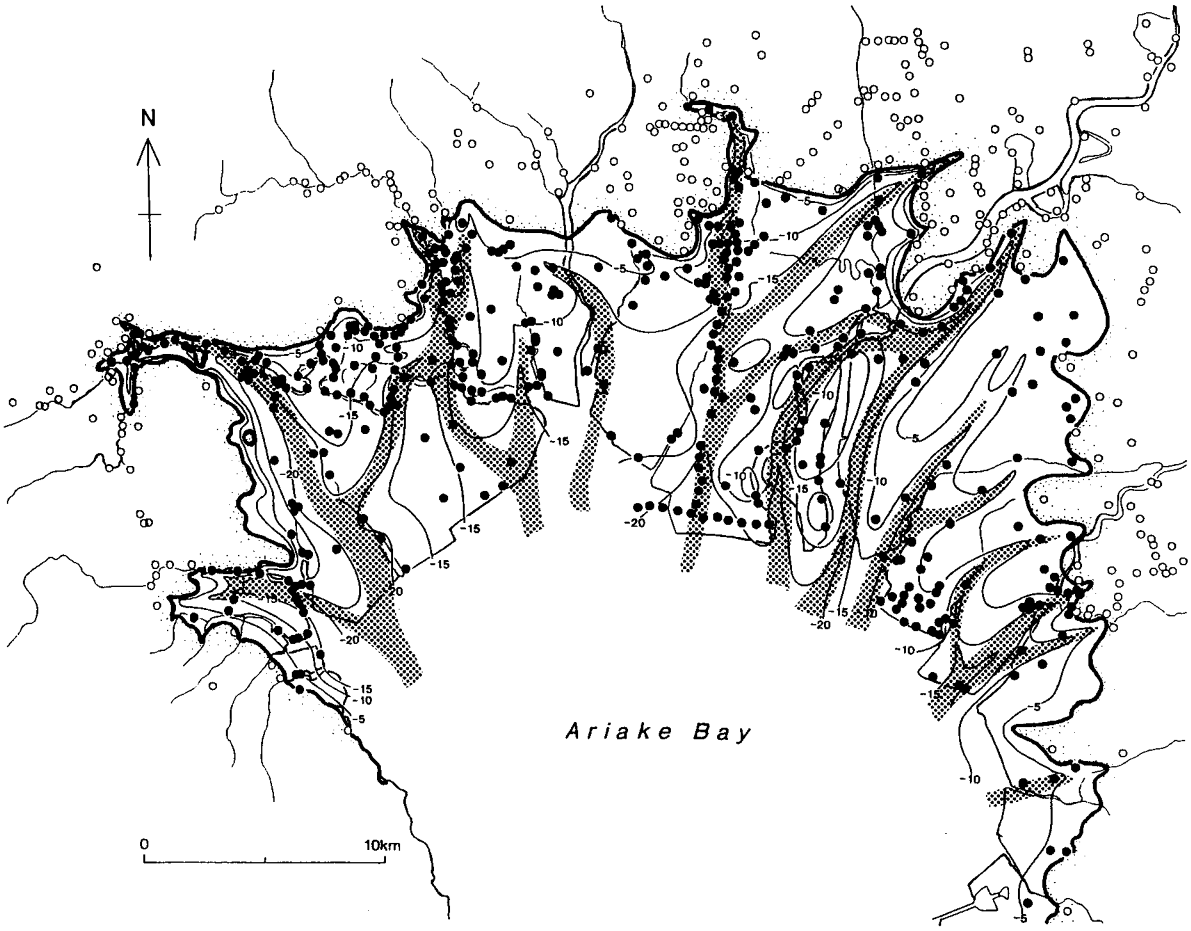

Fig. 5 Isodepth lines of the lower limit of the Holocene marine sediments (Ariake Clay Formation) in the Saga Plain
closed circles : locations where marine sediments exist below grand surface,
open circles: locations have no marine sediments below grand surface, a thick solid line represents limit of the maximum sea area through the Holocene Epoch in the Saga Plain. Hatched areas show a valley shape expressed by the basal surface of the Ariake Clay Formation

Transgression. Thick solid and fine broken lines in Fig. 6 show the maximum expansion of the Ariake Clay Formation (marine) and the upper part of Hasuike Formation (none-marine). An areal section between thick solid and fine broken lines showed progression of reedy marsh since the maximum period of Jomon Transgression. The area between fine broken and the present dike lines indicates a man-made land changed by artificial reclamation.

Fig. 7 shows distribution and thickness of non-marine clay (the upper part of the Hasuike Formation). Thick deposits of non-marine clay occur near some topological transition sites, such as the limit of backward flow or the inner outlet of tidal flow where velocity of backward flow decreases quickly and a large amount of fluid mud settles. Thick deposits more than 10 m occur in Chiyoda, Kanzaki, and the northern part of Saga City. The bottom of the non-marine clay layer juts out below the sea level,

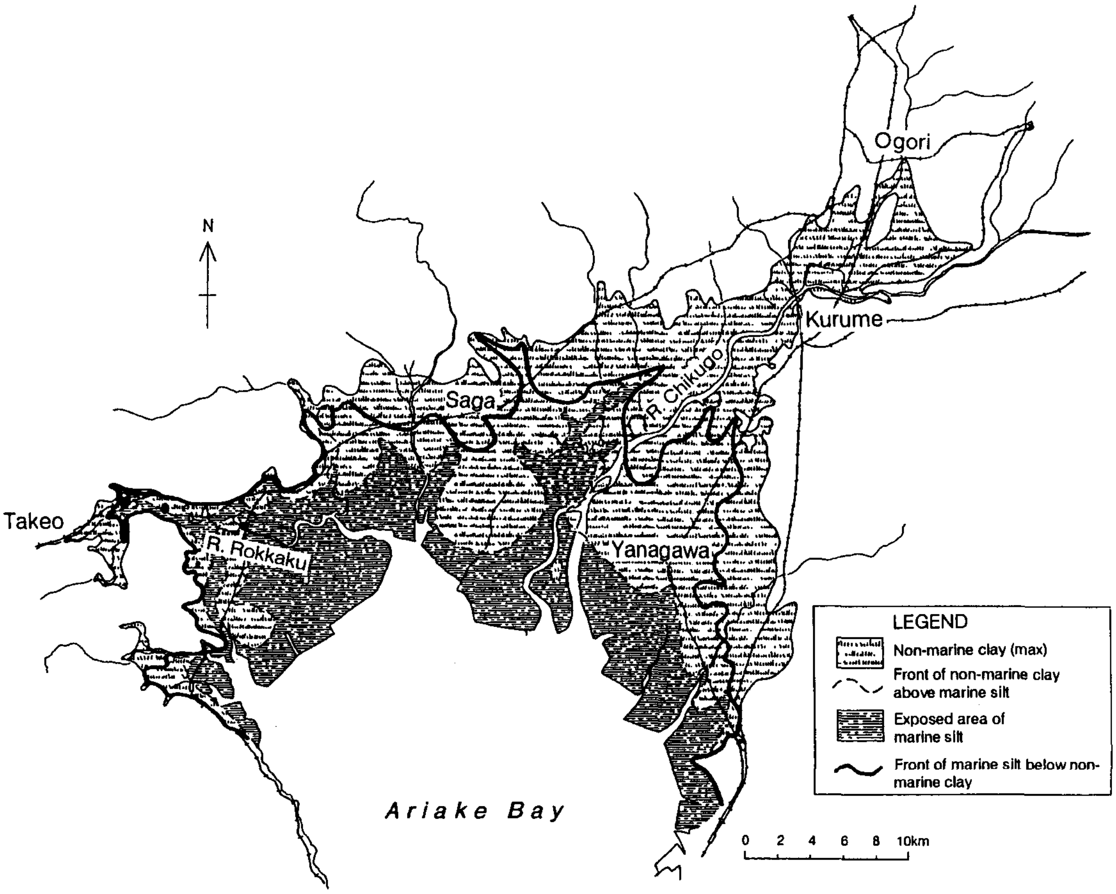

Fig. 6 Distribution of two kind of clayey soils on the surface of the Saga Plain (Shimoyama *et al.*, 1994)
Distribution of the marine silt and non-marine clay represent the living area of marine mollusks and lower saltish to fresh water area e.g. Reed plain. Exposed area of marine silt indicates man-made land in histrical ages

because the lowland surface in the Saga Plain is very flat. The shape strong suggests existence of a sedimentary trap of non-marine mud. Shimoyama *et al.* (1994) considered such a sedimentary condition as a low-salt marsh partitioned off by a sand ridge from the pure marine area.

8. Time gap between the periods of the highest sea-level and the maximum stage in the Jomon Transgression

Fig. 8 shows an outline of the sea level curve during the past 10,000 years in the Saga Plain. Most Japanese sea level curves are characterized by a highest period at about 6,000 to 5,000 years B.P. during the Holocene sea-level changes (Ota *et al.*, 1982). The highest period of about 6,000 to 5,000 years B.P. in the Holocene sea-level changes usually matches with the maximum stage of the Holocene transgression (Jomon Transgression). However, the former was about 1,000 years or more later than the latter in the Saga plain. Stratigraphy of the Kikai-Akahoya tephra (K-Ah) and two archeological

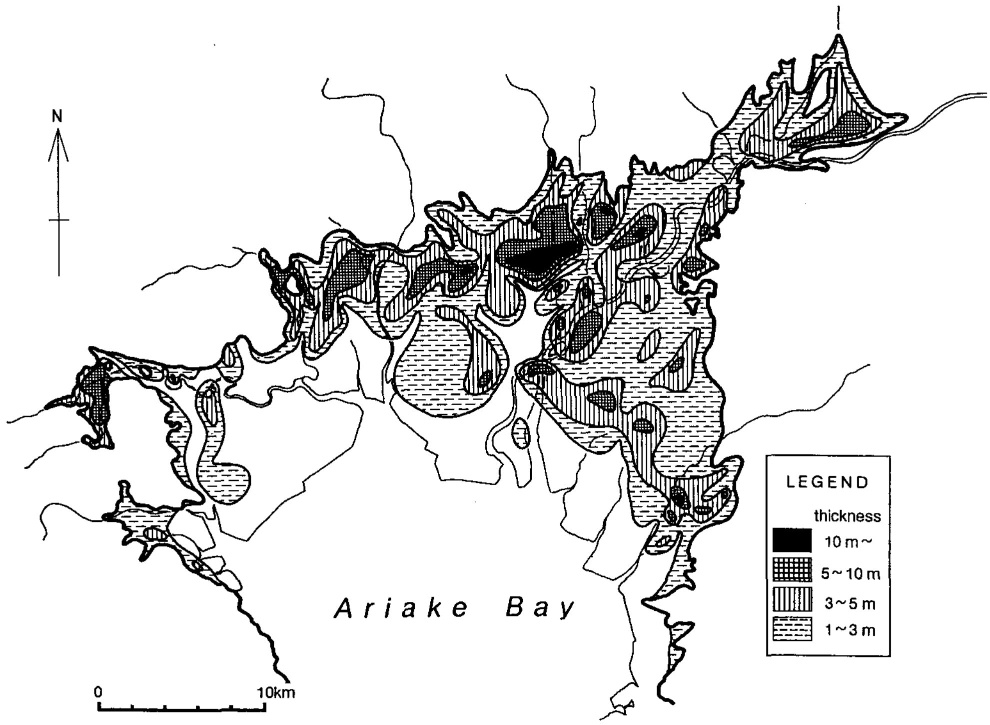

Fig. 7 Distribution and the iso-thickness lines of non-marine clayey (muddy) sediments (Shimoyama, 1996)

sites in the Saga Plain provides important evidences. Fig. 9 shows a north-south geological section in the Saga plain. When K-Ah tephra fell as volcanic ash at about 6,300 years B.P. (Machida and Arai, 1992), the Saga Plain was already in a regression stage, because depositional location of the upper part of the Hasuike Formation (non-marine clay) already backed seaward considerably.

The Higashimyou archeological site at the northern part of Saga City was excavated by the Department of Buried Cultural Properties, Board of Education of Saga City, in 1993-96. The cultural layer of ca. 7,000 years B.P. boiling stones and oven of round stones, animal bones as catches, a lot of arrowheads, Senokan-type potteries, and eight bodies of human bones in crouched burial (Pictures 1 to 8 in Fig. 10). The cultural layer occured below the K-Ah tephra (ca. 6,300 years B.P.) between upper and lower non-marine clay layers (fluid mud sediments). The circumstantial evidence shows that this site was a stable land at about 7,000 years B.P. (the end of the Earliest Jomon Period), and was contiguous with ancient shorelines, because marine shells and ^{14}C dates of 7,000 years B.P. were obtained from the adjoined drilling cores.

An archeological site of about 2,000 years B.P. (the middle stage of Yayoi Period) was exposed on a non-marine clay layer (fluid mud sediments) at 3.2m above the present sea level in an outcrop of a construction site at Kawaramachi, the eastern Saga City (Pictures 7 and 8 in Fig. 10). Marine clay (Ariake Clay Formation) occured below non-marine clay layer at 1.6m below the present sea level. ^{14}C age of the Ariake clay

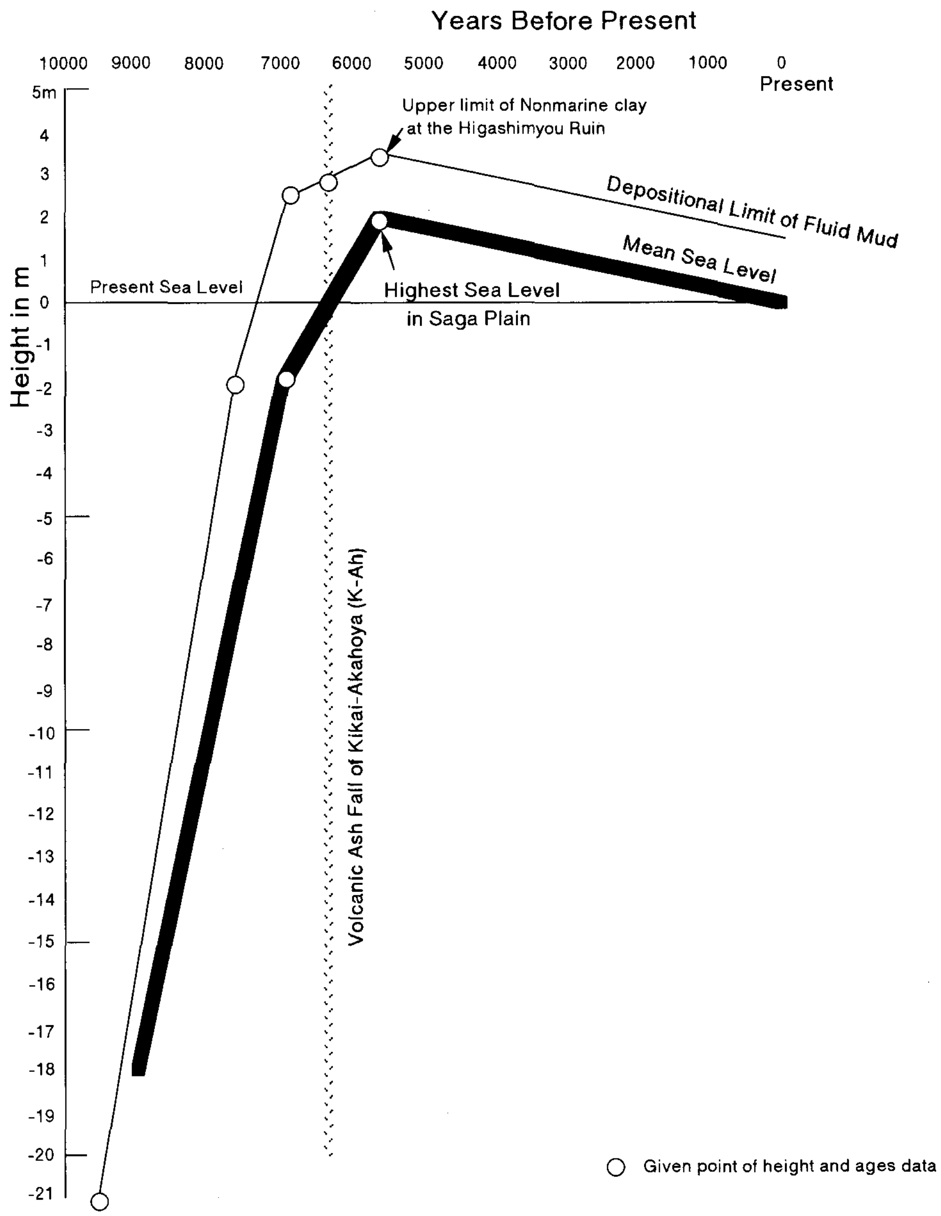

Fig. 8 Outline of the sea level changes during the last 10,000 years in the Saga Plain

formation is about 6,600 years B.P. Thus, the regression in the northern Saga plain started at about 7,000 years B.P. and continued to the Yayoi Period at least.

Although the Holocene sea level curve in the whole Saga Plain (Fig. 8) almost agrees with most Japanese sea level curves, the regression started 1,000 years earlier here. Quick deposition of a large amount of non-marine mud (fluid mud) behind the shoreline resulted in the premature regression in the northern Saga Plain as a considerable cause (Figs. 6 and 7).

Fig. 11 shows a depositional model and the mechanism of fluid mud formation along the Ariake bay coast and shows relationship between the development of Holocene

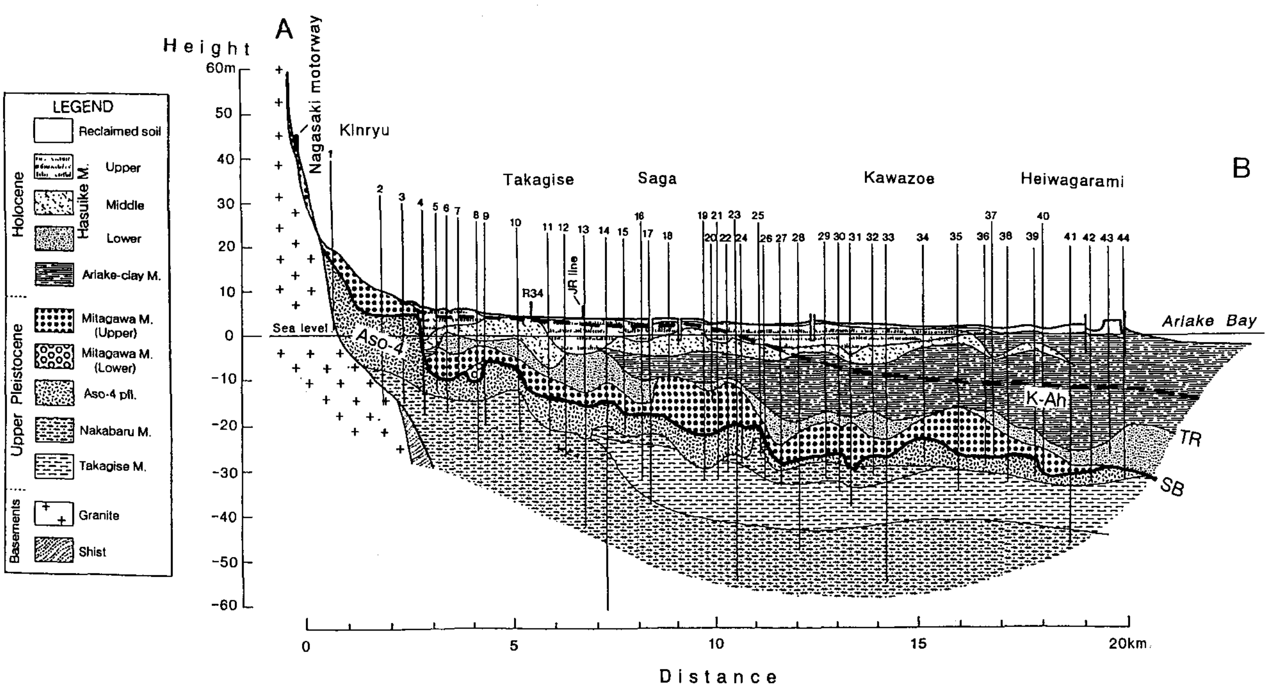

Fig. 9 Geological cross-section of line from A to B in Fig. 12 (revised from Shimoyama *et al.*, 1994)
K-Ah : Kikai-Akahoya volcanic ash fall layer (ca. 6,300 y.B.P.), SB : Sequence boundary,
TR : tidal ravinment surface, Aso-4 : Aso-4 pyroclastic flow deposits (ca. 90,000 y.B.P.)

strata in the Saga Plain and separated deposition by tidal erosion. A big tide in the Ariake Bay appeared at about 8,000 years B.P. in the Saga Plain, considered from fluid mud deposits from drilling cores of the same age. A rapid transgression caused strong tidal erosion and made a large amount of fluid mud, and then filled lowland behind the shorelines with thick non-marine mud. The transgression already turned to a regression at the highest period of the sea level at about 6,000 to 5,000 years B.P. (period of mfs) in the Saga Plain, because non-marine clay filled up the lawland far and above the high tide level.

9. Changes of shorelines and coastal environments during the past 10,000 years in the Saga Plain

The depositional center of clayey sediments moved northward with the progression of shoreline during the Jomon transgression, and then turned back southward since about 7,000-6,000 years B.P. in the Saga Plain. Thus, shoreline changes for the past 10,000 years were the immediate cause of terrestrial environmental changes.

Three positions of reconstructed ancient shorelines are shown in Fig. 12. They are shorelines at 1) the maximum period of the Jomon transgression (ca. 7,000-6,000 years B.P.- solid line), 2) the late stage of Yayoi Period (ca. 2,000-1,800 years B.P.- broken line), and 3) the beginning of Edo period (ca. 400 years B.P.- barbed line). The solid line expressing the limit of the maximum sea area is deduced from a lot of bore hole data in the whole Saga Plain. The broken line assumed as the shoreline of the Yayoi Period,

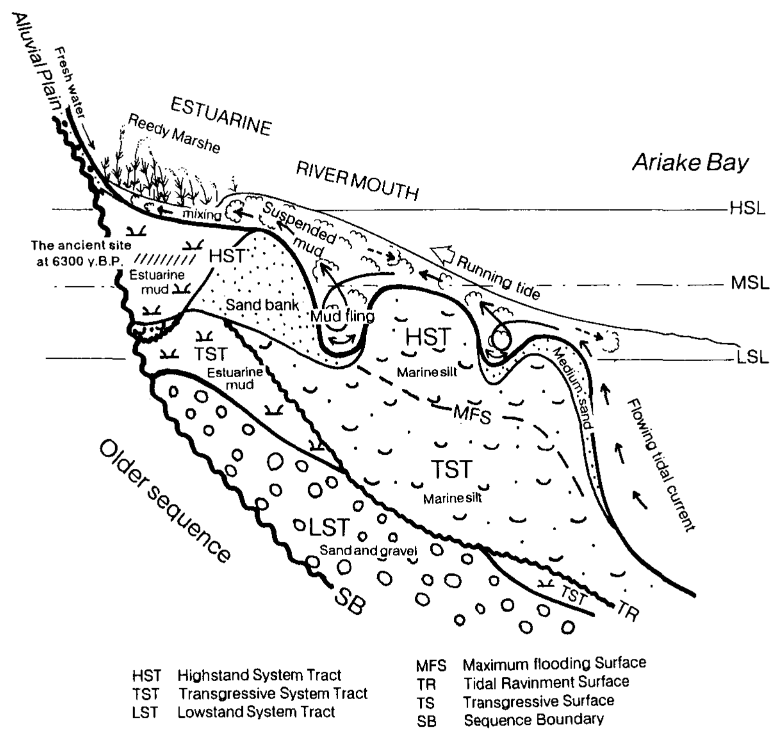

Fig. 11 Schematic stratigraphic and facies model of suspended mud transport system in a tidal river on the Ariake Bay coast

but actually the southern margin of natural reclaimed land area by non-marine clay before organized artificial reclamation. This line has less support than the solid line. However, an old document suggests that an organized artificial reclamation was carried out near Saga City in the Kamakura Period. Thus, the oldest artificial reclamation may started at an earlier period, the Tumulus Period (4-5 century) practically. The broken line shows that an estuary remains near the northern Kanzaki Town and Morotomi Town, and an island appears in the area from Shiraishi Town to Ariake Town (Figs. 6 and 12). Most of the broken line runs inside the barbed line, except for remarkablie a overstepping at Higashiyoga Town (the southward of Saga City). The area south of the broken line is equivalent to an artificial reclaimed land on the tidal flat.

According to Noma (1985), many documents since Kamakura Period prove promotion of land reclamation by human activity, making creek networks or cultivated lands from reed marshes. Then, these local networks of creeks were united, and big coastal dikes were built in domains of Saga and Yanagawa at the beginning of Edo Period (ca. 400 years B.P.). These dike lines are called 'Matsudoi' and 'Hondoi'. This line is the oldest shoreline that we can trace from historical documents (barbed line in Fig. 12).

These three shorelines indicate lines of the mean sea level at each period. Most of the present shorelines are artificial ones. Comparison between the oldest topographical map of the Meiji Period (1900) and the present one shows that the shoreline along the Ariake Bay progressed seaward about 3 km for the last 100 years, and the extensive tidal flats

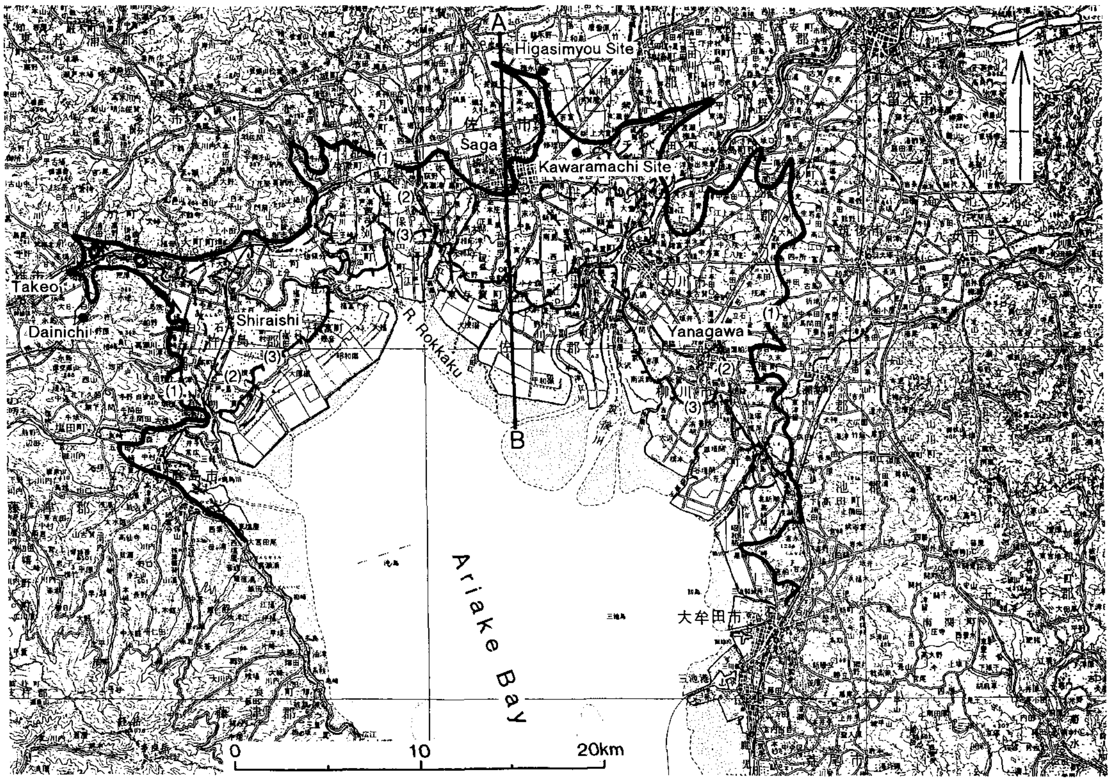

Fig. 12 Changes of anchient shoreline situations for the past 7,000 years in the Saga Plain. 1 : Early stage of Jomon Period (ca. 7,000-5,000y.B.P.) as the maximum sea area, 2 : End of Yayoi Period (ca. 2,000-1,800y.B.P.), and 3 : Beginning of Edo Period (ca. 400y.B.P.) (revised from Noma, 1985)

were changed into cultivated fields during the past 1,000 years.

Man nervously utilized natural reclaimed land at the first, but as time went on, man began to make artificial reclaimed land positively. When we look at extensive paddy fields on reclaimed land, it is an illusion to think that man conquered Nature at last. However, nature lies under paddy fields with a possibility of land subsidence by drawing water from a well, liquefied layer, salt damage, and strong acid soil, and so on.

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北部九州における過去10,000年間の環境変遷：とくに海岸線の移動について

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有明海の湾奥での潮位差は最大５～６ｍに達し，全国最大である。大きな満干差は少なくとも約8,000年前から生じている。海進とは海面が上昇して海岸線が陸側に向かって前進する現象をいう。日本では約1.5万年前からの海進を縄文海進と呼んでいる。

縄文海進がピーク付近に達すると，潮位差が最大になり，有明海沿岸の低地では強い潮流による海底の堆積物の巻き上げが卓越するようになった。各河川では海域の泥が大量に河口部を逆流してリーチングを受けながら運搬され，逆流限界付近で堆積したので，海岸線の背後に広大な低平地が形成されたと考えられる。佐賀平野では7,000年前に海進最盛期に達し，海域が最大になった。この時期は完新世の最高海面期よりも1,000年も早い。7,000年前以降は海退期となった。海退に伴って，浮泥の堆積領域（アシ原）も南下した。このような浮泥の堆積領域の南下は低地での人類生活圏の拡大にとって重要であった。

浮泥の堆積領域の移動は海岸線の移動とリンクしている。浮泥の堆積領域は海進期は北上し，海進ピーク時期には標高８ｍのラインまで達した。海進ピーク時期以後海岸線は南下したが，淡水粘土の堆積した場所は水はけの悪い湿地として残された。

弥生時代になると，湿地帯の中の部分的な高まり，特に砂州の上に生活地が現れた。しかし湿地帯そのものの開拓は組織的に行う必要があった。平安時代には開発失敗の記録が残っている。さらに海域に近い湿地帯の開拓には水害や塩害への対策が必要なので，中世以降のクリーク網の整備とあお取水が耕地化の切り札となった。

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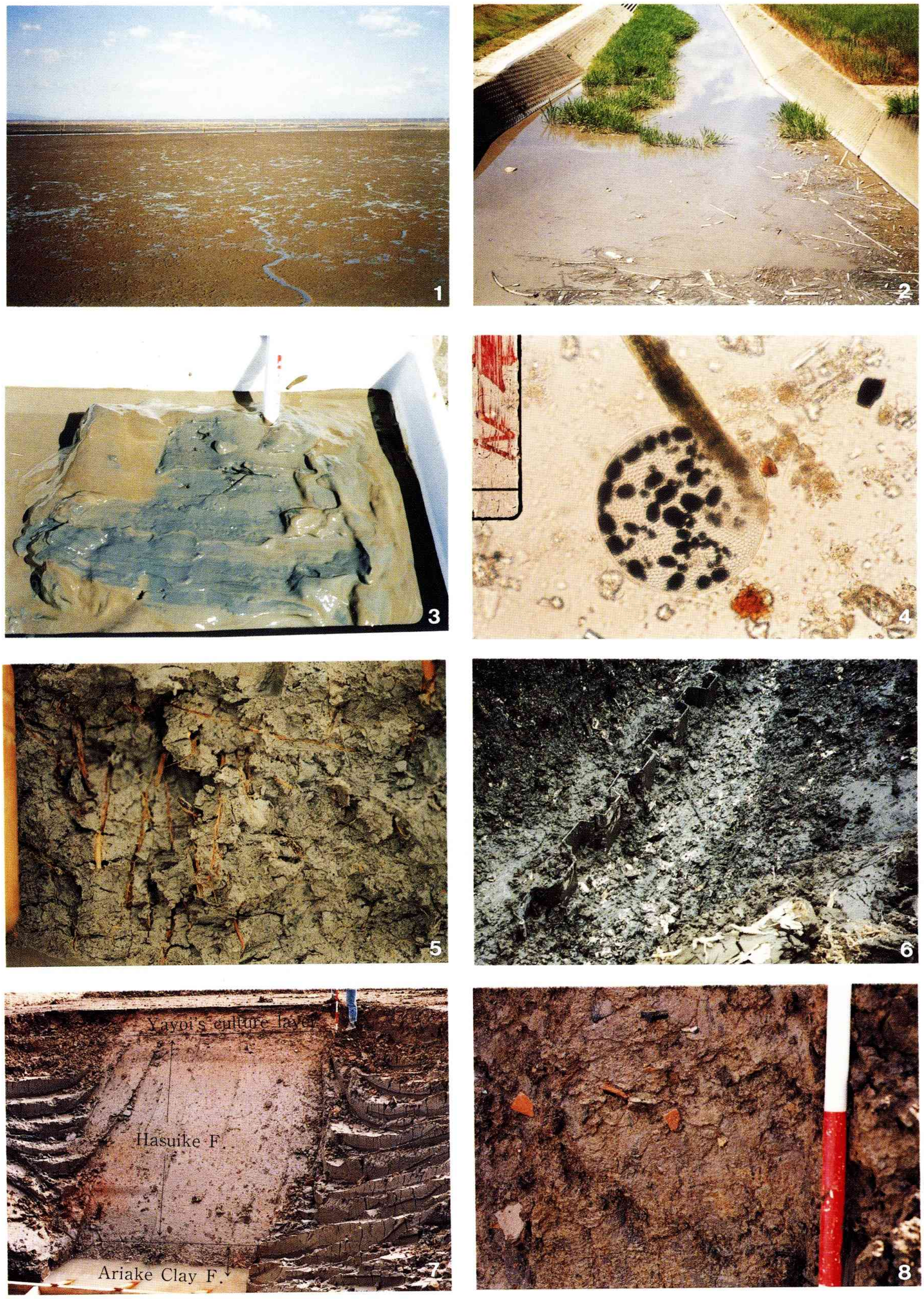

Fig. 3 1 : Widespread mud flat at off Kashima City. 2 : Fluid mud and drift wood derived from sea at about 30km site from the river mouth of the Rokkaku River, in the Saga Plain. 3 and 4 : Soft mud deposited at about 30km site from the river mouth of the Rokkaku River, and a marine diatom remain (*Thalassiosira bramaptrae*, diameter of diatom is 0.2mm) with clay minerals in the soft mud. 5 and 6 : Non-marine and marine muddy sediments at dug outcrops. They are the upper clay of the Hasuike and the Ariake Clay Formations. Laces in the non-marine sediments in picture 5 are subterranean stems of reed (hight of the picture is about 10cm). White matters in picture 6 are oyster's shells in marine sediments. 7 and 8 : Marine (base) and non-marine (most middle) layers at the archeological site at Kawaramachi Site, Saga City. 8 is the expansion of the culture layer included the late Yayoi-type potteries. One unit of scale bar is 20cm.

Fig. 10 Monuments and relics in Higashimyou Site, the northern Saga City
1 : a bird's-eye view of Higashimyou Site, the northern Saga City, 2 : Senokan-type potteries, 3 and 5 : stone boiling and oven made of round stones, 4 : arrowheads made of stones, 6 : the lower jawbones of deer and wild boars, 7 and 8 : human bones with crouched burial.