Holocene Sea-Level Changes and Coastal Evolution in Japan¹⁾

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Recent progress in Holocene sea-level studies and studies on coastal evolution in Japan are reviewed. Several studies recorded either a slight fall or slow rise of sea-level in the early Holocene, and some studies recognized minor regressions after the culmination of rapid postglacial transgression. Coastal landforms have changed remarkably during the Holocene. Many drowned valleys were formed in the middle Holocene, and the coast lines in Japan were very rugged at the time. Various types of coastal evolution have been reported in numerous studies. Some of the studies were carried out as cooperative research using a variety of research techniques.

I. Introduction

The Japanese Islands are located along the boundaries of the Eurasian, Pacific Ocean and Philippine Sea Plates, and the landforms of the islands have been strongly influenced by the plates movements. Coastal landforms of Japan during the late Quaternary have also changed and developed under the influence of both tectonic and eustatic movements. Regional differences and variations can be found in the processes of evolution of the coastal landforms, and relative sea-level curves have been clarified in various locations of Japan.

Many studies of sea-level changes, coastal landform evolution, and coastal environments during the Holocene have been made, and various sea-level curves have been produced. Some of these studies were based on stratigraphic and microfossil analyses and ¹⁴C dating of the sediments. In some cases, uncontaminated soil samples collected with peat corers were used for the studies.

Symposia were held on the Late Quaternary sea-level changes and special issues were published by the ASSOCIATION OF JAPANESE GEOGRAPHERS (1978) and the JAPAN ASSOCIATION FOR QUATERNARY RESEARCH (1982).

Recently, several review papers on Holocene coastal evolution and sea-level changes were

published by OTA *et al.* (1982, 1990), YONEKURA and OTA (1986), OTA and MACHIDA (1987) and ISEKI (1987). Recent studies on sea-level changes in Japan were compiled in the “*Atlas of Holocene Sea Level Records in Japan*” (OTA *et al.*, 1981) and the “*Atlas of Late Quaternary Sea Level Records in Japan, vol. I*” (OTA *et al.*, 1987a). The coastal environments in the Late Quaternary and the Holocene were illustrated in the “*Quaternary Maps of Japan*” (JAPAN ASSOCIATION FOR QUATERNARY RESEARCH ed., 1987) and the “*Middle Holocene Shoreline Map of Japan*” (OTA *et al.*, 1987b). An “*Inventory of Quaternary Shorelines*” was also compiled by YOSHIKAWA (1987).

In this article, sea-level changes and coastal evolution in Japan during the Holocene are reviewed according to the recent studies and publications.

II. Holocene sea-level changes

The sea-level has risen rapidly with some oscillations, from the lowest sea-stand in the last glacial maximum towards the present level. This postglacial transgression in Japan is called the “Jomon transgression”, being named after the prehistoric Jomon culture of Japan. The postglacial transgression is considered to have started c. 20,000 ~ 18,000 BP, and several oscillations during the transgression have been reported. One of the major sea-level drops was in

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the period of 11,000 BP to 10,000 BP. That sea-level drops can be seen in a common occurrence, and the coarse sediments of this period called "HBG (Holocene Basal Gravel Bed)" can often be seen in the middle horizon of the "Chuseki-so" formation which has been deposited since the last glacial maximum, in and on the buried valleys under the coastal lowlands. This temporary sea-level regression is considered to correspond with the cold climate episode in the latest stage of the last glacial epoch.

The Holocene sea-level rise started after this temporary regression, from a sea-level estimated c. -40 m. During the early stage of the Holocene, between c. 10,000 and 8,000 BP, the sea-level rise seems to have been slow and accompanied by a slight sea-level drop in some places. ENDO *et al.* (1982) recognized a slight sea-level drop around c. 8,300~8,000 BP in the Paleo-Oshikiri and Paleo-Isumi Bays in the Kanto District, eastern Japan. A slow sea-level rise during the early Holocene is also reported for the Oku-Tokyo Bay and the Tama River delta, around Tokyo Bay (ENDO *et al.*, 1989; MATSUSHIMA *et al.*, 1987). MAEDA (1980), UMITSU (1979) and ISEKI *et al.* (1982) also reported temporary regressions or slow sea-level rise in the early stage of the Holocene in both the Osaka Bay coast area and the Nobi Plain, of western and central Japan respectively. The temporary regressions or slow sea-level rises of the early Holocene, however, have not been well clarified in other areas of Japan, and whether the phenomena took place as general or as local occurrences has not been proven yet.

From the early to middle Holocene, during c. 8,000~6,500 BP, the rate of sea-level rise was very rapid, attaining 1.5~2.0 cm/yr. The lower part of coastal lowlands and valley plains in this period were drowned, and many drowned valleys were formed along the coasts of Japan.

Most of the relative sea-level curves in Japan show their maxima during the period of c. 6,500~5,000 BP. OTA *et al.* (1982) pointed out that the age of the maximum level of the Jomon transgression exhibited regional variations. Some regions which are characterized by a high rate of uplift had a maximum at c. 6,500 BP, and

in contrast, other stable or subsiding regions had it at or after c. 5,000 BP.

The southern Boso Peninsula in eastern Japan is one of the most notable uplift areas in Japan, and the maximum sea-level in the Jomon transgression was 23~26 m above sea level (c. 6,700~6,200 BP) (NAKATA *et al.*, 1979, 1980; FRYDLE, 1982). The sea-level at the maximum of the transgression, in the coastal areas of Sagami Bay, east of the Izu Peninsula, along the extension of the Sagami Trough, was reported as 21~22 m (6,300~6,200 BP) by ENDO *et al.* (1982) and MATSUSHIMA (1982). The highest shoreline during the Holocene along Kagoshima Bay in southern Kyushu was reported as 15 m (6,300~6,000 BP) by MORIWAKI *et al.* (1986), and that of the Kikai Island was reported as c. 10 m (6,500~6,000 BP) and 9~13 m (6,800~6,000 BP) by NAKATA *et al.* (1978) and OTA *et al.* (1978), respectively.

Most of the highest sea-levels during the Holocene in relatively stable or subsiding regions were between 0~5 m a.s.l. In the Okhotsk coast of Hokkaido, northern Japan, the maximum sea-level was 3~4 m a.s.l. at 6,000~5,500 BP (MAEDA, 1984; SAKAGUCHI *et al.*, 1985; HIRAI, 1987). Similar heights and ages for the maxima of postglacial transgressions were reported for other regions such as, the Tsugaru Plain in northern Japan (UMITSU, 1976), the Tama River delta in eastern Japan (MATSUSHIMA, 1987), the Toyama Bay region on the Japan Sea coast of central Japan (FUJI and FUJII, 1982), Osaka Bay (MAEDA, 1980), the Harimanada coast of the Inland Sea (NARUSE *et al.*, 1984, 1985) and the San'in coast of western Japan (TOYOSHIMA, 1978).

There are some places where sea-levels during the Holocene did not reach their maxima between c. 6,500~5,500 BP. Some of them had maximum sea-level from the middle to late Holocene or in the late Holocene, including the present time.

In the southern part of the Izu Peninsula, which is situated at the northern tip of the Philippine Sea Plate, the highest sea-level was recorded in the period of 3,000~2,000 BP with a height of 2~3 m a.s.l. (OTA *et al.*, 1986). OTA *et al.* (1986) mentioned that the study area subsided

Fig. 1 Various types of relative sea-level curve in Japan

from about 6,000 BP until uplift began at 3,200~2,000 BP, and they suggested that the emergence of the area may have been due to coseismic uplift. The Holocene sea-level maximum in the Ryukyu Islands, southwestern Japan, also occurred in the period of 3,500~1,700 BP and was less than 1.0 m a.s.l. (Koba *et al.*, 1982).

Sea-level curves determined for the Shonai Plain by Ariga (1984), and the Sendai Plain by Omoto *et al.* (1978) show maxima in the period of c. 2,000 BP to the present. The sea-level curve for the Sendai Plain presented by Omoto *et al.* (1978) had a maximum at c. 1,000 BP. The curve, however, was based on data from a single out crop in the plain, and Matsumoto (1981) has presented a different sea-level curve in the plain. The maximum Holocene sea-level in his curve was at c. 5,000 BP, with a slight regression following in the period between c. 3,000~2,000 BP.

Since the culmination of the Holocene transgression in the period c. 6,500~5,500 BP, the sea-level in several regions has

shown minor oscillations. Minor sea-level drops after that period have been recognized, in c. 5,000~4,000 BP and c. 3,000~2,000 BP. The former is called the "Middle Jomon minor regression" and the latter is called the "Yayoi regression". The "Middle Jomon minor regression" was discovered in the Boso Peninsula (Yokota, 1978), the San'in coast in western Japan (Toyoshima, 1978) and Kikai Island of the northern Ryukyus (Ota *et al.*, 1978) and was named by Ota *et al.* (1982). The regression of that period has also been recognized in other places such as the Okhotsk coast in northern Hokkaido (Maeda, 1984; Sakaguchi *et al.*, 1985; Hirai, 1987), the Chita Peninsula in central Japan (Maeda *et al.*, 1983), the Osaka Bay coast (Maeda, 1980) and the Harimanada (Naruse *et al.*, 1984, 1985). Sakaguchi and Tanimura (1987) also found the regression in the Tokyo Bay region and called it the "Kemigawa regression".

The "Yayoi regression" was named by the Ariake Bay Research Group (1965) for the Ariake Bay region in northern Kyushu, and this minor regression has been reported in many places in

Fig. 2 Middle Holocene shorelines in central Japan

1. middle Holocene shoreline, 2. present shoreline, 3. boundary of mountains and plain, 4. selected height (m) and radiocarbon age (years BP) indicating the middle Holocene shoreline, 5. shell, 6. peat (close above marine sediments), 7. geomorphologically estimated former shoreline, 8. upper limit of marine sediments.

(based on OTA *et al.*, 1987b)

Japan. Evidence of this regression has been found in a buried forest in and around the Toyama Bay region, central Japan (FUJII and FUJI, 1967; FUJII and FUJI, 1982), buried shallow valleys in and around the Nobi Plain (ISEKI, 1974), peat layers in the Nobi Plain (FURUKAWA, 1972), lost sand dunes in the Hokuriku District (FUJI, 1975), sandy (beach) ridges in the Kujukuri coastal plain in the northeast of Boso Peninsula (MORIWAKI, 1979), the Sendai Plain (MATSUMOTO, 1981, 1984), and archaeological sites on the San'in coast (ONO, 1975; TOYOSHIMA, 1978).

Further sea-level fluctuations have been reported after the "Yayoi regression". In the Okhotsk coast of Hokkaido, SAKAGUCHI *et al.* (1985)

reported a slight rising and a falling of sea-level at +0.8 m (1,200 BP) and -0.3 m (400 BP), respectively. HIRAI (1987) also reported sea-levels of +2.2 m (1,000 BP) and -0.2 m (200 BP) in the region. Similar sea-level rises at c. 1,200 BP were also reported by MAEDA *et al.* (1983) in the Chita Peninsula near Nagoya and by NARUSE *et al.* (1984, 1985) in the Harimanada of the Inland Sea, western Japan.

The relationship between the sea-level and climatic changes during the Holocene has often been discussed in Japan (*e.g.* FUJII, 1966; FUJII and FUJI, 1967; ISEKI, 1977). Many reports on the Holocene climatic fluctuations in Japan, based on pollen analyses, have shown a warm stage in the

middle Holocene and a cool stage in the late Holocene. The high sea-stand during the middle Holocene (the maximum of the "Jomon transgression"), and the slight regression of the sea-level in the late Holocene (the "Yayoi regression") seem to correlate to the warm and cool stages shown by the pollen data. Furthermore, SAKAGUCHI (1983) recognized a temporary cool stage named the "middle/late Jomon cold stage" in the period c. 4,400~4,200 BP on the basis of pollen data from central Japan, and this may correlate to the "Middle Jomon minor regression".

MATSUSHIMA and OSHIMA (1974) pointed out that the water temperature suggested by the molluscan assemblages in northern Hokkaido during the Climatic Optimum (6,000~5,000 BP) was about 5°C higher than at present. The warm water species in the molluscan assemblages began to disappear between 5,000 and 4,000 BP in the Kanto District, eastern Japan (MATSUSHIMA, 1979), and MATSUSHIMA (1979) pointed out that a slight regression following the maximum was recorded at c. 4,500 BP. CHINZEI *et al.* (1984) also found a slight decline in water temperature for the periods c. 5,000~4,000 BP and c. 2,500 and 2,000 BP recorded in littoral molluscan and micro fossil assemblages along the Japanese coast. These changes in the littoral water temperature also seem to coincide with sea-level changes in the Holocene.

Furthermore, based on the fluctuation pattern of $\delta^{13}\text{C}$, C/N ratio and FeS_2 , NAKAI *et al.* (1982) found evidence for a low sea-level and cold climate at c. 9,000~8,800 BP, and the maximum sea-level at c. 6,700~6,000 BP. A low sea-level and cold climate interval which corresponds to the "Yayoi regression" and a gradual rising of sea-level after 1,000 BP were also recognized in this study.

III. Studies of the Latest Quaternary sediments and coastal evolution in Japan

Some pioneering studies of the latest Pleistocene and Holocene sediments called "Chuseki-so" (Recent Formation, Recent Alluvium) and the evolution of coastal lowlands were done in

the first half of the 20th century, and the following important studies started in the 1960's. For example, ISEKI (1962) subdivided the "Chuseki-so" into five beds: basal gravel, lower sand and mud, middle mud, upper sand, and top terrestrial beds, sequentially from bottom to top, and discussed their formation in relation to the sea-level changes. Regional characteristics of the sedimentary facies of the "Chuseki-so" along the route of the "Shinkansen" (new Tokaido line) in central Japan were illustrated by IKEDA (1964), and a model of the formation of the "Chuseki-so" in relation to the sea-level changes and depositional environments was presented.

Special issues including important papers on the "Chuseki-so" and the evolution of coastal lowlands were also published (JAPAN ASSOCIATION FOR QUATERNARY RESEARCH, 1966; GEOLOGICAL SOCIETY OF JAPAN, 1972).

Further studies of the "Chuseki-so" and the evolution of coastal lowlands were done on several coastal lowlands and deltas in Japan (*e.g.* KAIZUKA and MORIYAMA, 1969; MORIYAMA and OZAWA, 1972; KAJIYAMA and ITHARA, 1972; UMITSU, 1976; KAIZUKA *et al.*, 1977). Most of these studies were based on detailed analyses of boring log columnar which were obtained in conjunction with the construction of roads, bridges and large buildings. Radiocarbon ages of the sediments also played an important role in the studies. In addition to the sedimentary facies of the "Chuseki-so", the evolution of deltas and paleo-coastlines during the Holocene was clarified for the Osaka Plain (KAJIYAMA and ITHARA, 1972) and the Tsugaru Plain (UMITSU, 1976), and paleogeographic maps of the plains at several stages of the Holocene were also presented.

Paleogeographical maps of the coastal lowlands in and around Tokyo Bay during the past 30,000 years were also shown by KAIZUKA *et al.* (1977). The coastline during the middle Holocene (c. 6,000~5,000 BP), as shown in the maps, was very rugged, and Oku-Tokyo Bay was formed towards the north of the present Tokyo Bay. Further studies of the coastline of Oku-Tokyo Bay were done by ANDO (1986), ANDO *et al.* (1987), ENDO *et al.* (1987, 1989) and KOSUGI (1989).

Most of these studies have discussed the paleo-environmental changes of the region, based on diatom analyses. For example, KOSUGI (1989) explained in detail the evolution of the region. He divided the coastal evolution of Oku-Tokyo Bay into three stages: the transgressional stage (10,000~6,500 BP), maximum stage of transgression (6,500~5,300 BP) and regressional stage (5,300 BP~present). He also illustrated the features of the coast, such as the complicated features of the transgressional stage, deeply invaded features of the maximum transgressional stage and the simple features of the regressional stage.

Latest Quaternary sediments and embayments formed during the period of the "Jomon transgression" were also studied on the Tama River delta (UMITSU, 1978; MATSUSHIMA, 1979), the Nobi Plain (UMITSU, 1979; FUJI *et al.*, 1982) and the Hiroshima Plain (SHIRAGAMI, 1985). UMITSU (1978, 1979) reconstructed the paleogeography of these regions, based on the sedimentary facies of the "Chuseki-so" and its basal topography. MATSUSHIMA (1979) reconstructed the paleo-sedimentary environments on the basis of the characteristics of molluscan assemblages. He also reconstructed the sedimentary environments of the paleoembayments in some small valleys of the southern Kanto District and the Osaka Plain (MATSUSHIMA and OSHIMA, 1974) using the similar method. SHIRAGAMI (1985) discussed the sedimentary structure and evolution of the Ota River delta in the Hiroshima Plain, western Japan. He clarified the movements of the coastline of the delta on the basis of the amounts of FeS₂ in the sediments.

The Holocene coastline evolution and the paleogeography of the coastal lowlands, with their rows of barriers or former beach ridges, were described by MORIWAKI (1979), and MATSUMOTO (1981, 1984) for the Kujukuri coastal plain and the Sendai Plain, respectively. Most of the Kujukuri coastal plain was drowned in the period of c. 6,000~5,500 BP due to the post-glacial transgression, and the rows of sandy ridges were formed, around c. 5,000 BP, 3,000 BP and 1,000 BP (MORIWAKI, 1979). The rows on the Sendai Plain were formed during the

periods ?~4,500 (4,300) BP, (3,100~3,000) BP, 2,800 (2,500)~1,700 BP and 1,000 (700)~present (MATSUMOTO, 1984). ARIGA (1984) discussed the sediments and geomorphic development of the Shonai Plain, northern Japan, and described the remarkable evolution of lagoons in the plain.

Evolution of the coastal lowlands along Suruga Bay, central Japan, was studied by MATSUBARA (1984, 1988, 1989) on the basis of fossil foraminiferal analysis. She classified the coastal barriers in the region as "primary" and "secondary" ones, and also explained that the primary barrier was formed during the marine transgression of the early Holocene, migrating landward with the rising sea-level. The secondary barrier was formed in the periods c. 5,000~4,000 BP and c. 3,000~2,000 BP after the primary barrier reached its innermost position. The secondary barrier gradually developed as a series of beach ridges.

Some detailed studies of the latest Quaternary sediments in the coastal small valleys have been done as cooperative investigations. Small drowned valleys are suitable for reconstructing sea-level changes, and most of the studies were done by self-excavation using convenient peat cores.

OTA *et al.* (1985, 1990) described the Holocene environmental changes of the valleys in the Choshi Peninsula, eastern Japan. The study involved analyses of the sedimentary facies, radio carbon dating, and analyses of some biological assemblages. The upper limit of marine deposit determined by different indices is 3.3 m a.s.l. by facies observation, 2.3 m by molluscan assemblages, 1.8 m by ostracods and 3.3 m by diatoms. The landform evolution of the region during the Holocene was also discussed in the article.

Detailed study of Holocene sedimentary environments in the Matsuzaki lowland, situated in the southern part of the Izu Peninsula, central Japan, was done by MATSUBARA *et al.* (1986). They did all-cored borings and made observations about the sediments, obtained radiocarbon dates, analysed volcanic ash, and did paleontological analyses of molluscs, foraminifera, ostracods and diatoms from the collected

samples. The environmental changes and landform evolution of the lowland during the Holocene were described, and paleogeographic maps of the region were also presented in the study. Further studies were done in several small coastal valleys and in and around lagoons such as Lake Hamana and Lake Kasumigaura (ex. IKEYA *et al.*, 1990 ; SAITO *et al.*, 1990). They clarified the characteristics of the sediments and the environmental changes in the region during the Holocene.

Geomorphological features of some maritime coastal lakes in Japan were studied by HIRAI (1983, 1987, 1989). He discussed the late Holocene sea-level changes on the basis of analyses of littoral landforms, and distinguished three low sea-level in the periods c. 4,500 BP, 3,000~2,000 BP and 16~17 th centuries.

In addition to these articles, UMITSU (1981) discussed the evolution of coastal lowlands and their regional characteristics since the latest Pleistocene, and arranged the evolution of the lowlands into six types. MATSUSHIMA (1984) discussed the evolution of shallow marine molluscan assemblages in Japan during the postglacial period. He focused on their historical and geographical changes induced by the postglacial environmental changes.

IV. Concluding remarks

Many studies have been done on Holocene sea-level changes and coastal evolution in Japan. Regional differences in sea-levels and landform evolution have also been discussed, and detailed sea-level changes and regional characteristics of the coastal evolution were described for various places in Japan.

There are, however, several subjects left for further investigation. One of these is to accurately determine the characteristics of the sea-level changes and coastal evolution by collecting more detailed data in regions where the studies were not well done. Minor fluctuation of the sea-level during the Holocene may also be examined in detail, and global, regional and local phenomena may be distinguished in further studies. In order to clarify the mechanisms of formation of the latest

Quaternary sediments called the "Chuseki-so", landform evolution in the coastal lowlands should be considered, in relation to the environmental changes in whole river basins and submarine regions. The effects of climatic changes on formation of the latest Quaternary sediments and coastal evolution should also be considered.

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