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Quaternary Sea-Level Fluctuations on the Northwestern Shelf of the Japan Sea[1]

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ABSTRACT

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Paleogeographic reconstructions for the northwestern margin of the Japan Sea suggest that the 2 to 4-meter fall of sea level below present datum coincides with cold transitions between the Atlantic-Subboreal and Subboreal-Subatlantic episodes. Quaternary oscillations of the Japan Sea, which were glacio-eustatic in nature, resulted in the formation of lower marine and lagoonal terraces that were separated from one another by well-defined erosional features. Late Pleistocene — Holocene transgressions had greater impact on the geomorphic and sedimentary framework than did tectonic proceses which occured throughout these glacio-eustatic oscillations. The lack of marine terraces above the highest levels of the Quaternary transgressions (8 to 10 m above MSL) indicates a relatively stable or slowly subsiding northwestern shelf of the Japan Sea during the Pleistocene. Geological, geophysical, geomorphological, and absolute dating of marine deposits permitted division of a well-known marine bench previously believed to have resulted from the Riss-Würm (Kazantsevo) transgression. This nearly equidimensional bench level is now recognized as two separate terraces, each corresponding to a Riss-Würm transgression.

ADDITIONAL INDEX WORDS: *Abrasion platform, drowned/submerged shoreline, Dzeman terrace, Flandrian transgression, Kazantservo transgression, Peat-Igarlsan cold episode, raised shoreline, Spokoynaya Bay.*

INTRODUCTION

Analytical studies of geological information and paleogeographical reconstructions for the northwestern shelf of the Japan Sea suggest the existence of several key problems and offer different methods for approaching their solution (KOUDYAKOV *et al.*, 1972; KULAKOV, 1973; KRAPIVNER and DANILINA, 1978; MARKOV *et al.*, 1980; MECHETIN, 1981). Points of particular interest involve the following considerations: (1) delineation of criteria for the recognition of ancient shorelines, (2) the number of Quaternary transgressions and estimates for amplitude of sea-level oscillation, (3) the relative roles of glacio-eustatic and tectonic factors in the formation of ancient shorelines, and (4) the relationship between sea-level oscillations and climatic changes.

Until fairly recently, most investigators devoted attention chiefly to the problem of raised and drowned shorelines. This effort was considered essential to the determination of the magnitude of sea-level oscillations and to a more complete understanding of the role of tectonic factors in the formation of coastal zone and shelf relief. The possible existence of raised shorelines in the continental coastal zone along the Japan Sea proved to be a rather controversial subject. Confusion resulted not so much from the limited information on the area as from the state of preservation of the abandoned shorelines and the presence of continental landforms that morphologically resembled marine terraces. Different views concerning the origin of these landforms and the number of marine terraces occurring in the area are extensively discussed in the literature (*e.g.* KHUDYAKOV *et al.*, 1972; KULAKOV, 1973; KRAPIVNER

[1] *[Editorial Note: We are pleased to publish the English version of papers presented at the 1982* **INQUA** *Symposium (Shorelines Commission) held in Moscow. Russian versions were previously published in collection by "Nauka" and Moscow State University publishers but this is the second installment in a series of reports that will appear in subsequent issues of the journal.]* *Received 15 January 1984.*

and DANILINA, 1978; KOROTKII *et al.*, 1980). The present paper focuses, however, only on those landforms for which a marine origin has been established within definable bounds and accepted by most researchers investigating the region.

IDENTIFICATION OF MARINE TERRACES

On the continental coast of the Japan Sea, in addition to Holocene shorelines (up to 4 m in height) there are older marine terraces that lie between 6 to 10 m in height. In contrast to the younger marine terraces, they are commonly overlain by a thick cover of slope and proluvial deposits. During the first stage of investigations these terraces were thought to be a unique 6 to 10 m bench level corresponding to the Riss-Würm (Kazantsevo) transgression (KOROTKII, 1976; KOROTKII, *et al.*, 1980; MECHETIN, 1981).

Subsequent investigations conducted primarily in the central and northern Sikhote-Aline established that these benches, originally believed to be of one level, are in fact different both in height and age. The subdivision of these practically equidimensional terraces was suggested, first of all, by the results of thermal-luminescence (TL) and paleomagnetic analyses, secondly, by the differences in the composition of the spore-pollen and diatom assemblages, and thirdly, by differences in the height of abrasion platforms.

Thermal-Luminescence (TL) Age Determination

The thermal-luminescence age determination of the 8 to 10 meter terrace at Cape Medvezhii (eastern Sikhote-Aline) indicates that the marine deposits encountered here are older than the suspected age ($220\pm35 \times 10^3$ years). Residual magnitization (RM) studies of the covering deposits, *i.e.* those that overlie the marine terraces, indicate the presence of rocks with reverse magnetization. The TL age determinations and RM data suggest that the 10-meter marine terrace is Middle Pleistocene in age. Seemingly, this terrace can be correlated with the global transgressions during the Odintsovo Interglacial period (KAPLIN, 1977).

Climatic Factors and Paleoenvironments

The marine beds comprising the 6 to 10 meter bench, assigned to the Riss-Würm interval, differ not only in their elevations but also in their paleoclimatic characteristics. Part of the sequence, based on the composition of the diatom assemblages, the presence of brackish fauna and other purely lithological features seems to represent typical coastal-marine deposits that are characterized by heat-loving spore-pollen assemblages (TL-datings: $110\pm30 \times 10^3$ years). In other places the 6 to 10 meter terrace is comprised predominantly of lagoonal sediments that contain sublittoral and marine cold-loving diatom species, mollusk shells and foraminifera. These evidently accumulated under cold climatic conditions [presumably at the end of the Riss-Würm, (*i.e.* at the beginning of the Würmian]. The ^{14}C dates obtained for the lagoonal sediments are, unfortunately, near the limits of the radiocarbon method (KOROTKII, 1976).

No valid interpretations of the results can yet be offered because the described sections have not been adequately studied and are widely scattered along the coast. It is believed, however, that they may correspond to two Riss-Würm transgressions, one of which continued up to the beginning of Early Würm. Such considerations do not preclude the possibility that the "cold" lagoonal sediments accumulated in isolated lagoons. These sequences are preserved within the coastal plain at a considerable distance from the Japan Sea that, at this time, underwent concurrent regression.

Positions of Paleo Sea Levels

The lagoonal sediments and abrasion platforms occur within the 6 to 10 meter range for marine terraces at heights between 4 to 5 m and 8 to 10 m. These figures agree with other data used to establish the position of mean sea level during the Sangamon Interglacial period (*e.g.* CURRAY, 1968; JAMES *et al.*, 1974; KAPLIN, 1977; MILLIMAN and EMERY, 1968).

DISCUSSION

Early Würmian Regressions

Compared to present MSL (mean sea level), lowering of the level of the Japan Sea, which corresponds in time to early Würmian climatic cooling and calculated according to the slope of estuarine thalwegs, was on the order of 90 to 100 m. Marine deposits that mark the shoreline of the Japan Sea during the late Pleistocene, according to MECHETIN's (1981) data, form outcrops along the shelf within the isobathic contour line of 115 to 120 m. According to seismic-acoustic profiling (SAP) data, this depth marks the facies change from deposits of

breaking waves and estuaries to continental associations. There is a discordance in estimates of the magnitude of the early Würmian regression in the Japan Sea region. Japanese investigators (*e.g.* MINATO, 1966; GOHARA, 1976) suggest that the regression was on the order of 60 to 80 m whereas MECHETIN (1981) proposes an even greater fall of about 140 m. These differences are resolved to a certain extent by difficulties in the subdivision of deposits of various ages in coastal marine deposits that lie at depths below 100 m where traces of several large transgressions have been recorded. If we take into account the low stand (down to 130 m), then it is easy to understand why difficulties arise in the distinction of various ages for marine deposits that were formed under similar climatic and geomorphic conditions. The spore-pollen assemblages, which MECHETIN (1981) identified as the Zyryanskiye "cold" assemblages, are identical to the Sartan assemblages. The SAP data, obtained for the zone of mosaic sediment distribution, can hardly by regarded as reliable proof for subdivision of various ages of coastal-marine deposits on the outer shelf. Therefore, our estimate of the magnitude of the early Würmian regression is placed in the more moderate range between 90 to 100 m (see Figure 1). This estimate, as a first approximation, corresponds to the conjectured lowering of mean sea level during the early Wisconsinan regression (BROECKER and VAN DONK, 1974; HOPKINS, 1976).

Middle Würmian Transgression

The middle Würmian (Karginsky) transgression is marked on the Japan Sea shelf by coastal shallow-water marine facies, which were encountered at depths ranging from 14 to 75 m. KOROTKII and KARAULOVA, 1975; VNUCHKOV *et al.*, 1976; KAPLIN, 1977; MARKOV *et al.*, 1979; KOROTKII *et al.*, 1980; MECHETIN, 1981). Among them, lagoonal sediments form covers that extend over large areas. According to the position of the top (upper) surface of the lagoonal sediments on the shelf, it is thus conceivable that during the middle Würmian transgression the Japan Sea level rose to about -15 to -20 m.

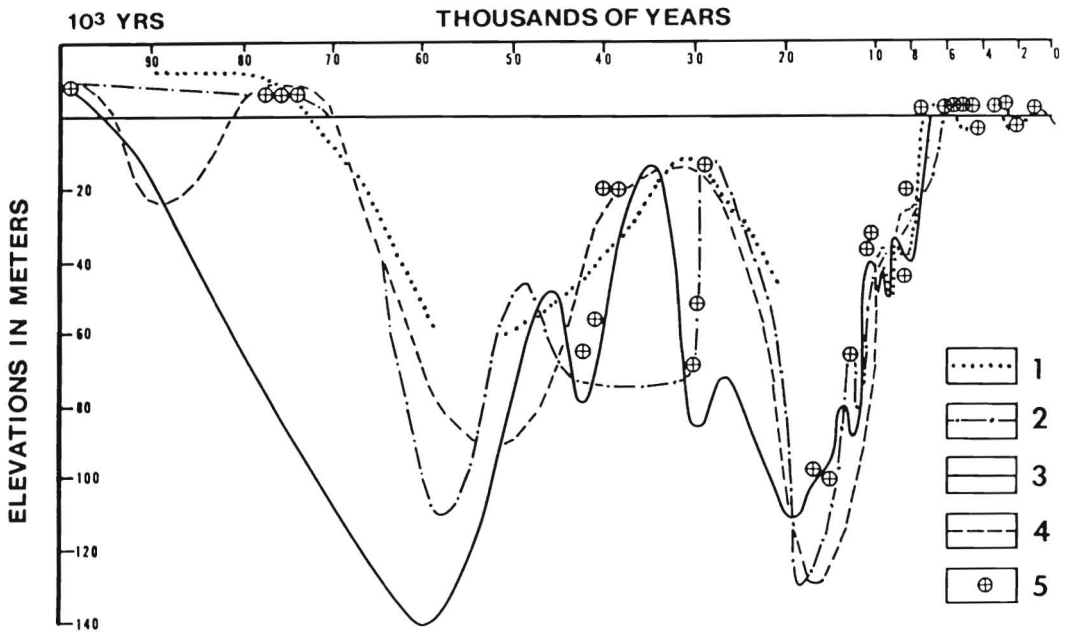
In respect to middle Würmian oscillations of MSL in the Japan Sea, special attention is directed to the order of their magnitude as evidenced from drill-core data from the Gulf of Peter the Great (MARKOV *et al.*, 1979). The rise of MSL predicted for the time-interval of 30,500 to 29,000 BP (60 m during 1,500 years) is over-estimated compared to other areas of the World Ocean. The conclusion is based on the fact that the coastal-marine deposits, which were encountered on the shelf of the Japan Sea at depths between 50 to 80 m and which show radiocarbon dates that correspond to the middle Würm, may correspond to older shorelines of the late Pleistocene (KAPLIN, 1977; KOROTKII *et al.*, 1980). If the ^{14}C dates are treated as maximum values that exceed the practical limits of the radiocarbon method, then the oscillatory curve of the Japan Sea level will be much smoother and similar to that for other areas of the World Ocean (see Figure 1). The rather high hypsometrical position (-26 to -16 m) of the coastal-marine deposits that correspond to the middle Würmian climatic optimum does not contradict this supposition.

Late Würmian Regression and Transgression

The controlling factor in the development of relief and sedimentation in the coastal zone and shelf area of the Japan Sea was the large late Würmian regression. The lowering of sea level, compared to the maximum level during the middle Würm, was on the order of 95 to 115 m. The shoreline corresponding to the complete regressive cycle according to data presented by different authors (*e.g.* ISEKI, 1971; SHIBASAKI *et al.*, 1971; KHUDYAKOV *et al.*, 1972; KOROTKII *et al.*, 1980; MECHETIN, 1981) was at altitudes between -110 and -130 m. This position of the shoreline can be satisfactorily correlated with deposits in the continental and coastal-marine belt that are defined by late Würmian spore-pollen assemblages. The diatoms identified in these deposits are typical freshwater assemblages, or rich mixed assemblages of freshwater, brackish and marine types. The maximum depth at which this mixed diatom assemblage was encountered lies at 130 m (PUSHKAR, 1979). On the northwestern shelf of the Japan Sea, in about the same depth-range, a band of coarse-clastic sediments is regarded by MECHETIN and RYAZANTSEV (1978) as the abandoned shoreline of the maximal regression. These deposits are gradational upward along the slope into alluvial and lagoonal deposits (^{14}C dates: at 101 m depth, 14,000±120 BP; at 67 m depth, 13,900±130 BP)†.

During the second half of the Late Glacial Period the rise in sea level was concomitant with the

† It is believed that these dates sooner apply to beds that accumulated during the glacio-eustatic transgression, which can be inferred from their position on the oscillation curve of the Japan Sea level.



Fiugure 1. Pleistocene sea-level curves for the Japan Sea. [Curve of sea-level fluctuations as given by (1) PUSHKAR (1979), (2) MARKOV *et al.* (1979), and (3) MECHETIN (1981). Curve 5 is based on absolute age determinations.]

progressive shifting of the zone of coastal-marine accumulation upward along the shelf. Traces of this shift can be found in the abandoned shorelines occurring in various parts of the northwestern shelf. The data available from shallow wells does not give adequate evidence for interpretation of variations in the level of the Japan Sea and its correlation with trends in climatic change. Therefore, those variations in the sea-level curve (MECHETIN, 1981) that strictly follow late Würmian climatic change where the oscillatory amplitude reaches 8 to 12 m at the transition from one climatic phase to another, we regard to be the result of the formal approach to the interpretation of the spore-pollen data. At present there is reason to believe that short-term sea-level stands during the late Würmian cold-climatic phases led to the formation of drowned shorelines (at depths of: 110 to 120 m, 80 to 90 m, 52 to 60 m, and 42 to 48 m).

Holocene Sea Levels

The Holocene oscillation curves of the Japan Sea, plotted for different marginal sectors of the water body, cannot be unambiguously interpreted and correlated with trends for the World Ocean level. Although difficulties associated with interpretation of available data were summarized by KOROTKII *et al.* (1980), it is noted here that discrepancies in sea level cannot be explained by mere reference to tectonic factors. To us they seem to be due to the isolation of the Japan Sea from the World Ocean during the late Würmian and to different chronologic manifestations of hydro-isostasy.

The early Holocene sediments, corresponding in time to the invasion of sea waters into the river valleys, were penetrated in the depth-range of 43 to 48 m. The facies boundary between the late Pleistocene continental deposits and the Holocene coastal-marine deposits was encountered at depths of 42.9 m in the Gulf of Amur and at 47.2 m on the shelf of Spokoynaya Bay (KOROTKII *et al.*, 1980). According to MECHETIN (1981), on the shelf of the Gulf of Peter the Great, lower Holocene coastal-marine deposits occur at depths between 33 and 35 m. It is believed that the rise of the Japan Sea level during the Holocene was irregular, just like the global transgression trend. According to KIND (1974), the retardation in the rate of transgression that led to the formation of distinctly reflected shorelines, was coincident with climatic cold-spans. For the northwestern shelf of the Japan Sea, MECHETIN (1981)

reported a lag in the transgressive phases compared to the warm-climatic phases at the end of the Late Glacial — beginning of the Holocene. This lag effect corresponds to a lowering of the level of the Japan Sea from -40 to -42 m (Late Dryas) to -48 m at the beginning of the Preboreal. Climatic cooling at the end of the Preboreal led to a lowering of sea level of -50 to -55 m.

Due to the lack of radiocarbon dates for this Holcene interval, it is difficult to interpret lower Holocene spore-pollen assemblages that are recovered from various parts of the shelf in the Gulf of Peter the Great. Inferences concerning sharp oscillations of sea level (up to 13 m in amplitude) thus seem unwarranted. Examination of the section in borehole N 510 (shelf of Spokoynaya Bay) at any rate does not confirm a sharp decline of sea level during the Peat-Igarkan cold episode. Taking into account the rate of organogenic accumulation (the formation of the lowland peats that correspond in time to this climatic phase) dates of approximately 400 to 500 years are obtained. According to MECHETIN's (1981) constructions for this time-span, sea level fell 13 m and then was followed by a rise to a depth of -55 to -44 m. The fluctuation rate in this case averages 4 cm/yr but this rate of change seems exaggerated.

Consideration of the position of the shorelines (at 47 to 28 m depth) and also the thickness of the lagoonal sediments in the Hasan well suggests that the general rise of the Japan Sea during the early Holocene was about 19 or 20 m. This mean annual rate of rise averages about 0.8 cm/yr and agrees satisfactorily with other data available for fluctuations in mean sea level in temperate latitudes.

During the Holocene Atlantic phase, sea level continued to rise as rapidly as it did during the Boreal. At the end of this climatic phase the transgression reached its maximum with sea level rising about 2 to 5 m above present datum. The well known geomorphic system along the Japan Sea coast composed of a "low marine terrace (+4 to +8 m)," is regarded as representing the mean Holocene shoreline. This shoreline corresponds to the Dzemon terrace and its analogues on the Japan Islands (FUFII and MOGI, 1970; GOHARA, 1976; OHSHIMA, 1971) and is correlated with the peak of the Flandrian transgression.

CONCLUSION

Oscillations of the Japan Sea were, in our opinion, galcio-eustatic in nature, of generally low-amplitude, and resulted in the formation of lower marine and lagoonal terraces that were separated from one another by well developed erosional landforms. The information available indicates that the general fall of the mean sea level of the Japan Sea during the last 5 x 10^3 yrs was rhythmic in nature. The drop of sea level below present datum (by 2 to 4 m) is superficially coincident with cold-spans that occur at transitions between the Atlantic-Subboreal and Subboreal-Subatlantic episodes. During the late Holocene transgressions, the rate of sea level rise was more rapid (up to 3 mm/yr) than the present rate (1 mm/yr). These figures are probably somewhat inflated because the amplitudes of the late Holocene transgressions were calculated from data for depths of small erosional downcuts observed in the estuaries of the Japan Sea river basin.

Analytical studies of sedimentary deposits indicate less ambiguously that the development of glacio-eustatic transgressions during the late Pleistocene-Holocene periods had considerably greater impact on the geomorphic and sedimentary framework than did tectonic processes which occurred throughout these oscillations. The absence of raised marine terraces, exceeding in height the maximal levels of the Quaternary transgressions (+8 to +10 m) supports our hypothesis of a relatively stable or slowly sinking northwestern shelf of the Japan Sea during the Pleistocene.

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Editorial Note:

Traditional Soviet bibliographic style includes only the journal volume and issue number. We have made no effort to complete citations as most of them refer to work in the Russian language. The MECHETIN (1981) reference was omitted from the translation of the original Russian text.