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Detailed Carbonate Stratigraphy of the Japan Sea Sediments During Last Glaciation-Holocene

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ABSTRACT

Cores J-3-RGA, J-11-RGA (south and central part of the Japan Sea) were studied for $\delta^{18}O$, palynological analyses, determination of carbonate and organic carbon content in sediments and dating by AMS methods. New AMS data on the J-11 core helped to identify the age of A-Tn volcanic ash as 25 thousand years. The Synthesis of the obtained data and the data provided by other cores taken in the Japan Sea reveal the detailed carbonate stratigraphy of the Japan Sea sediments for the last 25 Ky formed in the course of the paleoceonographic evolution of the basin. The carbonate horizons (CH) 1, 2, 3, are the result of the last glaciation event; they are related to the sea level regression and the semireduction condition of the bottom. The CH 4 and CH 5 horizons were formed during the transition period, and probably correlate with the cold events of Oldest and Younger Dryas. The CH 6 and CH 7 were accumulated in Holocene sediments, and they are related to insufficient changes in the Japan Sea environment.

(Key words: Carbonate stratigraphy, Japan Sea, Sediment)

1. INTRODUCTION

The Paleoenvironment dynamics of the Japan Sea is a natural model of regional climatic changes in the past. To understand the development of the regional climatic system, scientists have been paying much attention to the study of the marine paleoenvironment (Oba *et al.*, 1991, Gorbarenko, 1987). Of particular interest are the paleoceanographic changes of the basin in the past 25,000 years by virtue of the fact that this period of time covers different climatic epochs and the dynamics of the transitional process from the glacial condition to an interglacial one. The study of several cores covering a major part of the sea area have

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resulted in $\delta^{18}O$ foraminifera records, carbonate and organic carbon and opal contents in the sediments. All these date have shown similar trends in the paleoenvironment development of the basin over the past 30,000 years. Hence, the characteristic feature of the paleoceanology of the basin is the desalination of surface waters by 5-6$^o/_{oo}$(and the decrease of $\delta^{18}O$ planktonic formainifera by 2.5-3$^o/_{oo}$) during the maximum of the last glaciation (Oba *et al.* 1980, Gorbarenko 1983). Many scientists have noted the weakening of the vertical water circulation of the basin and the decrease in the O_2 content in bottom waters. The sharp enhancement of the reducing processes in the surface layer of sediments resulted in the occurrence of reduced sulphur (bramboidal pyrite) and the improved preservation of carbonate shells. Given enough data, it should be possible to mark out two horizons enriched with calcium carbonate in sediments of the Japan Sea during the last glaciation in the Holocene. The low horizon approximately complies with the maximum of the last glaciation and the upper one fits the completion of the glaciation and changes to the Holocene (Gorbarenko, 1987).

The study of sediment cores from Cruise of *R/V "Akademik Aleksander Vinogradov"* provided the possibility for a more comprehensive stratigraphic classification of the sediments of the Japan Sea at that time. This study also served as the basis for more detailed paleoceanologic reconstruction. Thus, the data from the J-3 RGA and J-11 RGA cores correlated with those obtained earlier and made it possible to distinguish of 3 carbonate horizons in the sediments of the last glaciation, 2 horizons of the transition period and 2 horizons of the Holocene. The different carbonate contents of the sediments characterize the changes in water productivity, bottom ventilation and chemical properties of bottom waters which had an influence on the preservation of carbonate shells at the bottom. Consequently, the detailed reconstruction of carbonate content changes in the sediments is one of the most important criterion in the study of the paleoenvironment of the basin. Radiocarbon dates obtained by the Accelerated Mass-spectrometry (AMS) method from core J-11 helped to solve the A-Tn layer age problem and to determine the age of some specified carbonate horizons.

2. MATERIAL AND METHODS

Core J-3 RGA is drawn in the south part of the Tsushima Basin from the depth of 1400 m (35°53.8'N, 130°14.9'E), while Core J-11 RGA is taken from the north slope of Yamato Rise from the depth of 1150 m (40°07.1'N, 133°59.7'E) (Figure 1). Core J-3 RGA consists of homogeneous silty clay. A pumice layer previously attributed to the U-Oki eruption is observed on the horizon 489-441 cm. The J-11 RGA core sediments consist of clayey silt at intervals 0-23 and 84-131 and silty clay at interval 23-84 cm. There is the addition of volcanogenic material at the interval 144-146 cm.

Carbonate and organic carbon contents in the sediments were determined by the coulonometric titration method using an AN-7529 analyzer. Total and carbonate carbons were released by roasting samples at 1100°C and dissolving diluted hydrochloric acid. The organic carbon content was calculated from the difference between total and carbonate carbon. The $\delta^{18}O$ foraminiferal analyses of the J-11 core was carried out on a three-collectors mass spectrometer VG using the conventional technique in Dr. Lloyd D. Keigwin's laboratory (Woods Hole Oceanographic Institute, USA). Planktonic foraminiferal shells *Neogloboquadrina pachyderma* sin for isotopic analysis were picked up from the sediment fraction 125-250 μm. Then they were dissolved in 100% orthophosphorous acid at a temperature of

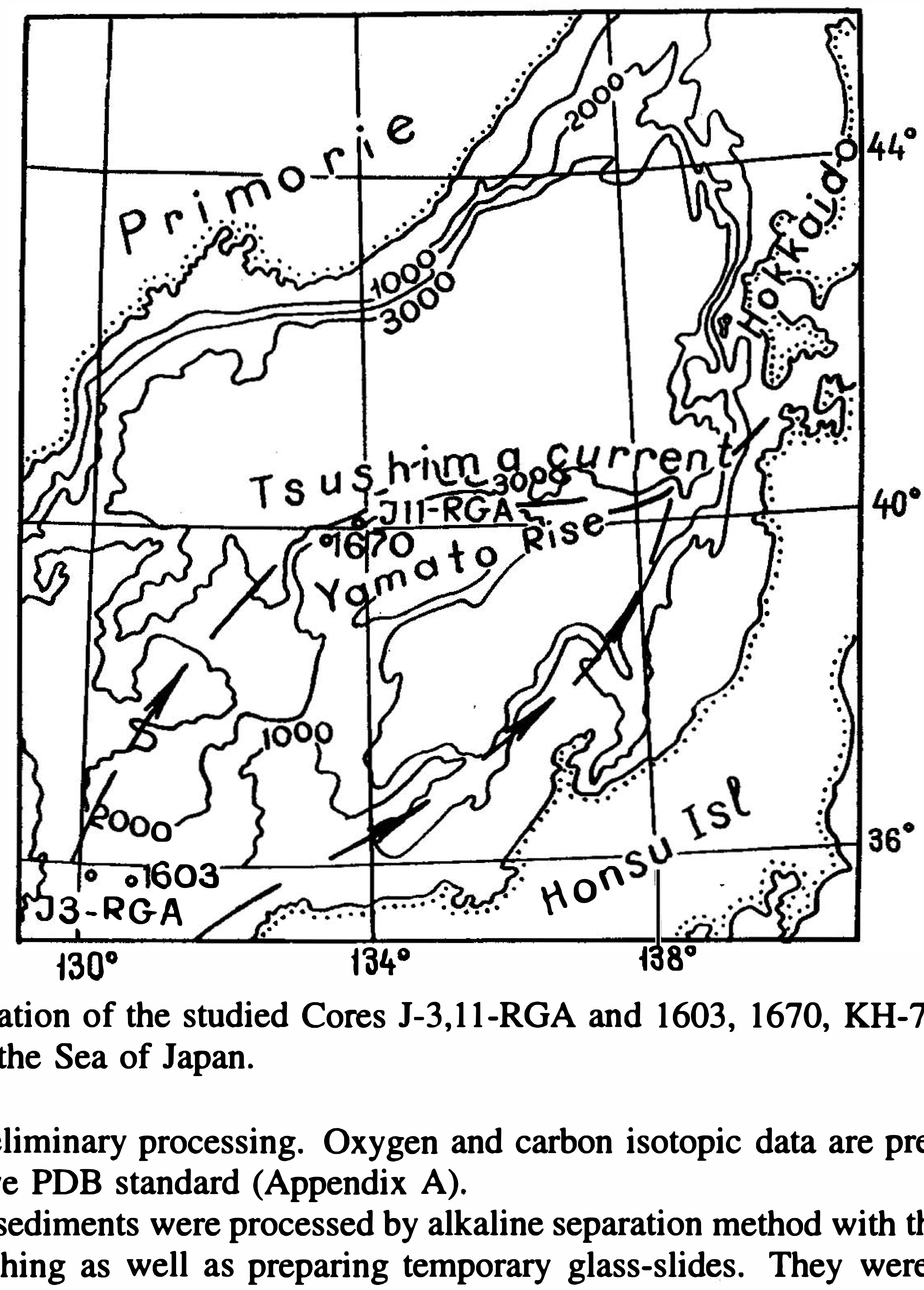

Fig. 1. Location of the studied Cores J-3,11-RGA and 1603, 1670, KH-79-3, C-3 in the Sea of Japan.

70°C without preliminary processing. Oxygen and carbon isotopic data are presented in the permillage relative PDB standard (Appendix A).

Samples of sediments were processed by alkaline separation method with the subsequent acetolis, and washing as well as preparing temporary glass-slides. They were investigated mainly using the Amplival microscope at × 600. At least two slides of each sample were scanned to reveal all spore/pollen taxa. At least 300 microfossils for each sample were counted. The percentages of the three main groups (spores, arboreal and nonarboreal pollen) were calculated; the percentage of each taxon within a corresponding group is calculated too. If any of the groups was small, it was counted up to a hundred separately. After scanning, the microfossils were washed out with alcohol into a test-glass and preserve there.

3. TIMING FRAME

As the basis for the correlation of sediments , the isotope-oxygen curves of the planktonic foraminifera, AMS dates, position of the dated layers of volcanic ashes, general climatic tendencies obtained by the micropaleonotological method and the detailed variations in the carbonate content in sediments were used. The ages of the volcanogenic ashes Ah, U-Oki, A-Tn were considered to be estimated thousand years; 9.3 thousand years and 21-22 thousand years respectively (Mashida and Arai, 1981). Tephra K-Ah, U-Oki and A-Tn are represented mainly by bubble walled shard (refractive index 1.508-1.514), pumiceous shard (1.514-1.124) and again bubble walled shard (1.498-1.501) respectively following procedures by Mashida and Arai (1981). The authors express a great gratitude to Dr. Igor V. Utkin (Pacific Oceanological Institute) for helping in the identification of the ash layers. The Volcanogenic layer A-Tn lies at the basis of the last glacial sediments. Because of its key stratigraphic position, its age was verified by the radiocarbon dates of the Nara Basin sediments (south-east part of Honsu Island). The A-Tn age equals 24 thousand or more years (Azuma *et al.*, 1983). Based on paleogeographic data correlation and keeping in mind the climatic changes of the surrounding area and the paleoceanology of the Japan Sea, the age of A-Tn was considered to be 25 thousand years (Gorbarenko, 1987). Kato (1984) estimated the age of A-Tn ashes at 26 thousand years by radiocarbon dates of the core taken from the East China Sea.

The following peculiar characteristics of the $\delta^{18}O$ curves of the Japan Sea planktonic foraminifera were used for sediment correlation: the decrease in the $\delta^{18}O$ values above the A-Tn layer resulting from the last sea regression and freshening of surface waters; the minimal value of $\delta^{18}O$ during the maximum of the last temperature fall and the lowest position of sea level; the increase in $\delta^{18}O$ at the beginning of transgression during the late glaciation; and the $\delta^{18}O$ decrease in the transition to the Holocene deposits (the boundary between the 1-st and the 2-nd isotopic stages) (Gorbarenko, 1987). The Core J-11 RGA was studied for diatoms and radiolaria (Drs. I. B. Tsoy and V. V. Shchastina Pacific Oceanological Institute). Unfortunately only the upper 8 cm and 30 cm of the sediments in the core have a sufficient quantity of diatomic and radiolarian fossils to enable micropaleontological analyses. I. B. Tsoy and V. V. Shchastina conclude that the upper 30 cm of the sediment were accumulated during the Holocene period. To analyze the cores 1603 and J-11, Verkhovskaya *et al.*, (1992) used palynological data also. The greatest content of the organic carbon in the sediments on the boundary between late the glaciation and Holocene is a good stratigraphic indicator of the sediments as well (Gorbarenko, 1987).

4. DISCUSSION OF RESULTS

Due to the different rate of sedimentation in the cores and different details in the sampling, not all carbonate peaks are pronounced in each core. Figures 2, 3 show a generalized scheme of the carbonate-content changes in sediments and the obtained data from Cores J-3 and J-11 which are compared to those of 1603 (Verkhovskaya *et al.*, 1992) and KH-79-3, C-3 (Oba *et al.*, 1991). For the correlation of the sediments and the subsequent paleoceanological reconstructions, the isotopic geochemical and micropaleontological data of other cores from the Japan Sea were taken into account (Gorbarenko 1987, 1993, Oba *et al.*, 1991, Keigwin and Gorbarenko, 1992). Radiocarbon dates as stated by the AMS method for the shells of foraminifera *Neogloboquadrina pachyderma* sin., (Appendix B) measured in Core J-11 helped to determine the age of the volcanic layer A-Tn. It is evident that the age of A-Tn ash is greater than the one established ealier, i.e. 25 thousand years ago. This important fact suggests the associaton of paleoanographic changes in the Japan Sea with the temperature fall which occurred in the surrounding area about 25-23 thousand years ago (Yasuda, 1983, Ooi, 1992).

The spore/pollen spectra from 271-60 cm are characterized by the prevalence of herb pollen which is mostly *Artemisia. Ephedra, Sparganium, Polygonum sect. Bistorta, P. sect. Aconogonon, Thalictrum Sanguisorba, Valeriana* and families *Ericaceae, Poaceae, Cyperaceae, Li liaceae, Ranunculaceae, Chenopodiaceae, Caryophyllaceae,*

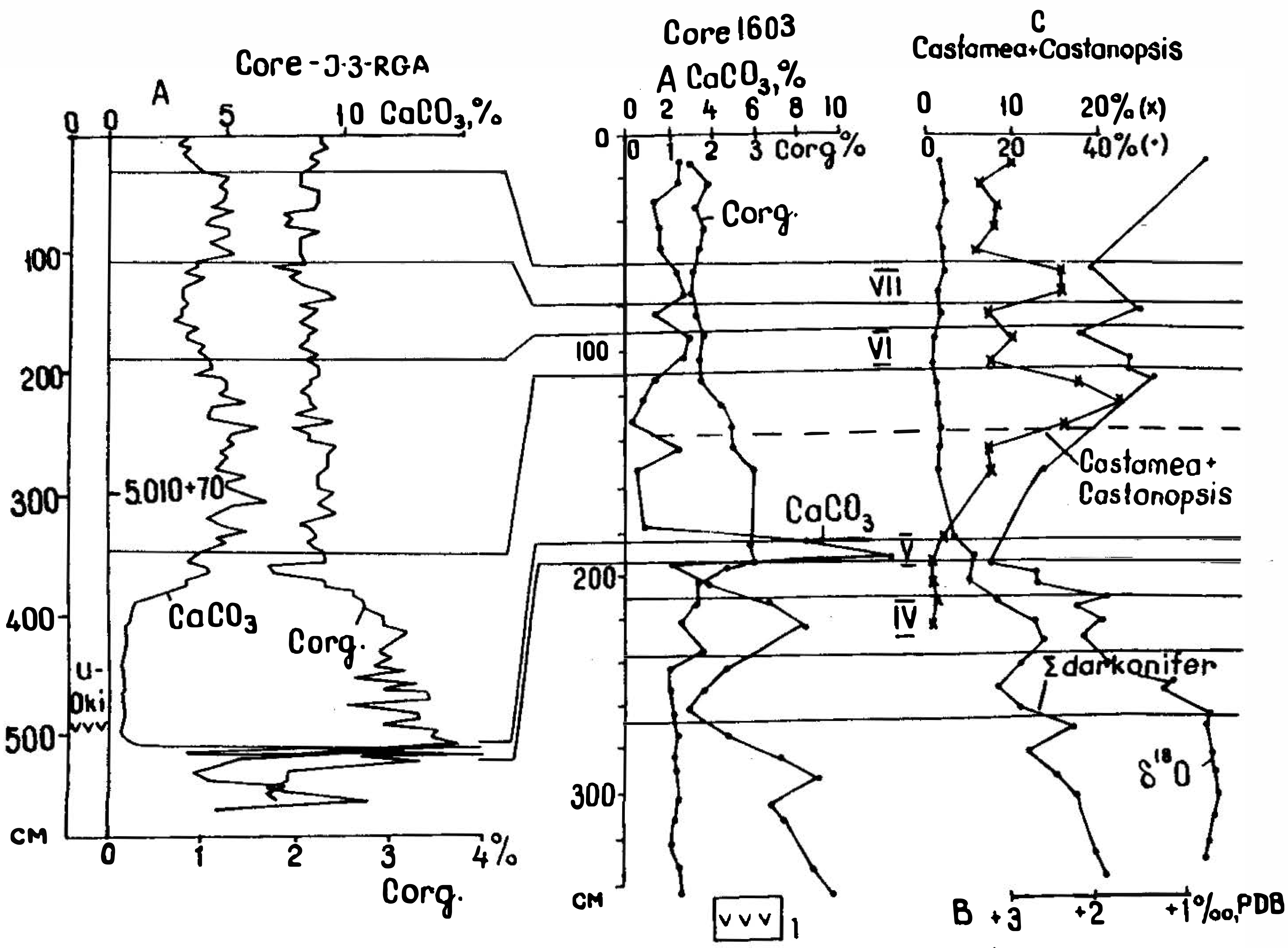

Fig. 2. Core J-3-RGA; A - Carbonate and organic contents in sediment (in % per 1g of dry bulk sediment). Core 1603; A -Carbonate and organic carbon content; B - $\delta^{18}O$ planktonic foraminifera Neogloboquadrina pachidenna sin, per mile to PDB standard; C- Content of wann pollen grains (Castamea plus Castanopsis) and cold (sum of dakrconifer) in % accordingly (Verkhovskaya *et al.*, 1992). On the left marginal AMS dates: 1-volcanic ash; I, II, III, IV, V, VI, VII - number of carbonate horizons CH-1, 2, 3, 4, 5, 6, 7, respectively.

Rosaceae, Lamiaceae, Fabaceae, Brassicaceae, Apiaceae, Dipsacaceae, Cannabaceae, Polemoniaceae, Cichoriaceae, and *Asteraceae* are presented by a minor number of pollen grains or by single ones. There is a predominance of dark conifer pollen (Picea, Abies, Tsuga), *Pinus s.g. Haploxylon* and *Betula* within the arboreal group. The pollen of broad-leaved plants is rather varied and belongs to *Ulmus, Quercus, Fagus, Castanea, Carpinus, Fraxinus, Juglans, Tilia, Corylus, Acer, Aralia.* However, its distribution within the core is not uniform. The Pollen portion of *Quercus* from 232-169 cm makes up 7.3-10.3%, and *Ulmus* 4,5-9,2%. The number of thermophilous taxa reaches 8-10.

From 160 to 70 cm only single pollen grains of broad-leaved trees occur, and their composition becomes meager (the taxa numbers are reduced to 4-5). Spores belong to *Polypodiaceae* mainly and *Bryalesand Lycopodium* to a lesser extent. In core interval between 70 and 55 cm the spore/pollen spectra are changed significantly (Figure 3). Above 55 cm, the pollen of trees and shrubs decreases rapidly. The *Quercus* pollen begins to play the main role, the variety of broad-leaved plants increases to 9-11 taxa. In the core top the pollen of conifers predominate again but at the expense of *Pinus.* It should be noted that both *P. s.g. Haploxylon* and *P. s.g. Diploxylon* are presented here in a rather

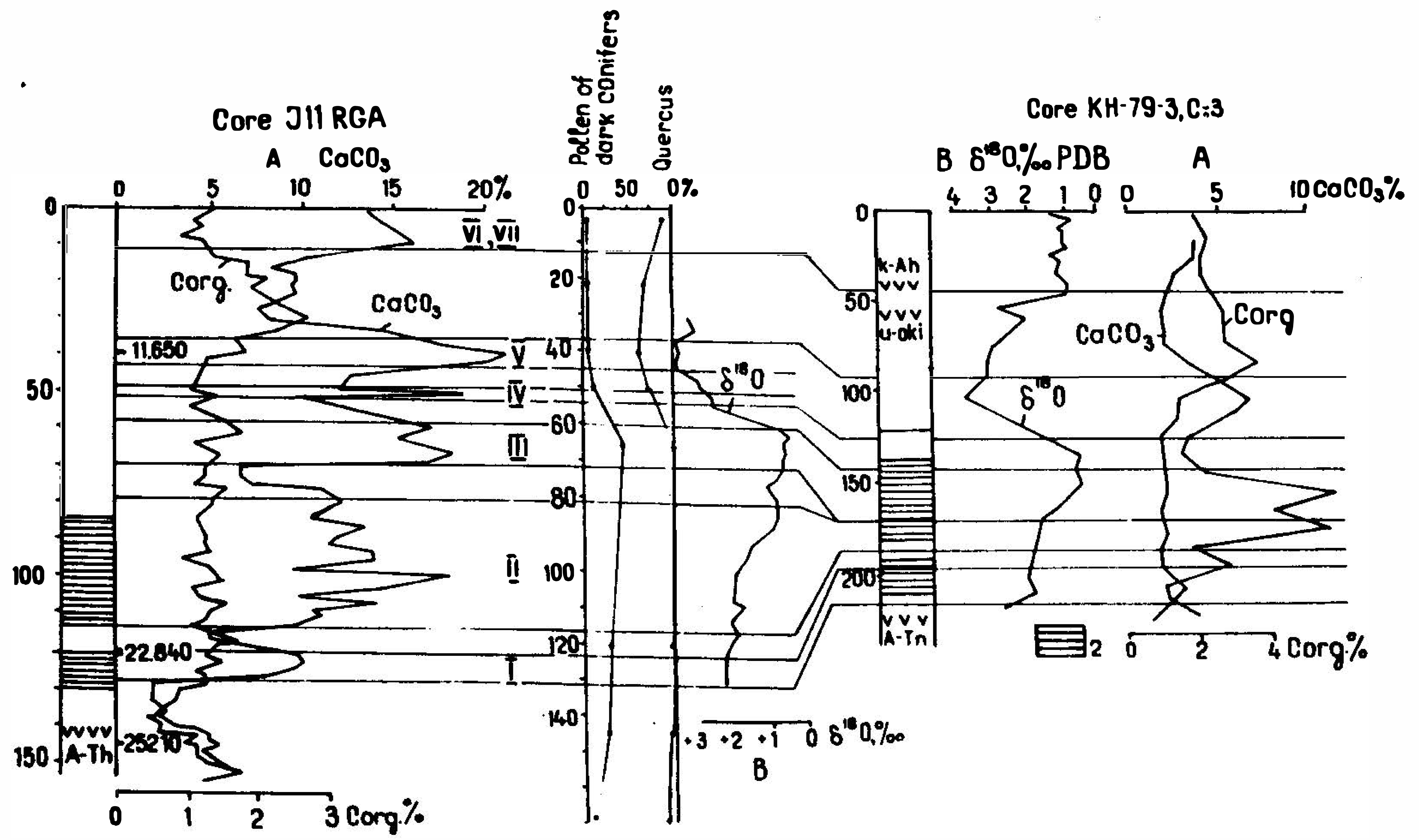

Fig. 3. Core J-11-RGA; A - Carbonate and organic content in sediments; B - $\delta^{18}O$ N. pachidenna sin.; C - Pollen content of dark conifers and *Quercus* in %; A - Carbonate and organic content is sediment of core KH-79-3,C- 3 (Oba *et al.*, 1991); B- $\delta^{18}O$ planktonic foraminifera; 2 - thin laminated sediments.

great quantity. The herb group is predominated by *Artemisia* as lower but the taxa variety decreases perceptibly.

According to the information of American, Japanese and Chinese researchers, dark conifer forests were replaced by broad-leaved ones during a transition phase between the Pleistocene and Holocene, which is about 12,000-10,000 years BP (Heusser and Morley, 1990; Tsukada, 1986; 1988; Sakaguchi, 1989; Sun *et al.*, 1991). However this change took place at different latitudes non-simultaneously. The percentage of the *Quercus* pollen in the spectra increases rapidly in profiles of South Japan areas in the period of about 12,000-11,000 years BP. (Tsukada, 1986). A similar distribution of this pollen was described from the deep sea cores taken east off the Japan Archipelago. The maximum of *Quercus* pollen curve from the core KH79-3-C6 was dated to 10,700-9,700 years BP (Heusser and Morley, 1990) in contradistinction to the more northern areas where the oak forests expansion only began at this time interval.

The latitude of the Yamato Submarine Ridge within which the J-11 core has been taken is closer to the latitude of North Japan. However, the Yamato area was influenced by the Tsushima branch of the Kuroshio warm current. Probably, the changes of the spore/pollen spectra above 55 cm have reflected a sharply intensified inflow of the warm water of this current into the Japan Sea resulting from the transgression that began in the period of about 15,000-14,000 years BP (Gohara, 1976). The authors believe the significant increase in pollen produced by the vegetation of the more southern territories is connected exactly to this event. Consequently, the Pleistocene/Holocene boundary in the core corresponds to the *Quercus* pollen maximum, which is located within the core interval from 39 to 25 cm.

Carbonate horizons CH 1, 2 and 3 were fonned during the last glaciation. The Micropaleontologic data on the cores J-11 (with interval 160-60 cm), 1670, 1682 (Gorbarenko, 1987) show that sediments above the A-Tn with light values of $\delta^{18}O$ were accumulated during the last glaciation. The regression of the sea level brought about the decreasing water exchange with the Pacific Ocean and a strengthening of the fresh water influence upon the water balance in the Japan Sea. During this period, the atmospheric precipitation and river runoff were greater than the evaporation. The Characteristic property of the given latitude at glaciation in particular caused the freshening of surface waters and the decreasing of $\delta^{18}O$ of waters and planktonic foraminifera.

Carbonate horizon 1 (CHl) just over the A-Tn layer was formed at the beginning of the sea regression and corresponding lightening of $\delta^{18}O$ In many cores of the Japan Sea, CHl, the maximum of which accounts for 22.5 thousand years, is represented by thin laminated sediments. Their accumulation is likely to correlate with weakening of the vertical circulation of waters and decrease in the oxygen-content in bottom waters. The deficit of O_2 in bottom waters is also confinned by the inhibition of benthonic foraminiferal fauna in the deposits embracing carbonate peaks 1-3. In the above lying sediments, the CH1 thin stratified structure was replaced by a massive texture, while the $CaCO_3$ content decreased. It is conceivable that at that time sea regression slowed down or even changed for minor transgression.

CH2 and CH3 accumulation took place with the further drop in sea level and the increasing isolation of the basin. The strongest freshening of the basin's surface waters (the lowest value of $\delta^{18}O$) was observed in the second part of CH2 and in CH3. Possibly, these deposits correlate with the late glaciation and the lowest level of the sea. The CH-2 and CH-3 in the Core J-11 are separated by a minor thickness of sediments with the lower carbonate content. Unfortunately, the rare sampling for palynological analysis does not permit the correlation of carbonate variations with climatic changes in this core. The possibility that this interval of minor carbonate deposits resulted from insufficient rise in temperature and changes in the sea level cannot be excluded. Sediments of CH-2 in the of Core J-11 and in the Core KH-79-3 CH2 and CH3 also have thin laminated texture compatible accumulation of deposits at weak aeration of bottom waters.

The CH-4 and CH-5 fall at the completion of the late glaciation period and at the beginning of the transgression of the sea. The inflow of the Pacific waters into the Japan Sea increased and the salinity of surface waters also gradually grew as is obvious from the production of heavy $\delta^{18}O$. According to 1603 core records, an increase was noticed in the carbonate content of the sediments correlated with the slight fall in temperature on spore-pollen evidence and the inhibition in $\delta^{18}O$ increase. This is why it is believed that CH-4 formation fell with the Oldest Dryas decrease in temperature of the transition period (14-13 thousand years ago) (Berger, 1990)..

CH-5 is situated immediately under the volcanogenic layer U-Oki (9300 years ago,) and according to AMS dating it can be dated at 11,150 years ago. On diatom and polynological analyses of the core 1603 (Verkhovskaya *et al.*, 1992) the fall in the temperature of surface waters and the inhibition of the rise in atmospheric temperature were also observed during CH-5 accumulation. It is likely that the time of CH-5 accumulation is synchronous with the short-time fall in temperature (Younger Dryas) and attendant decrease in aeration of bottom waters and better preservation of shell foraminiferas in the sediment. At this time, the sea level reached mark minus 65 meters (Fairbanks, 1989), and the water exchange with the Pacific Ocean had increased significantly while the salinity of the surface waters had been normalized ($\delta^{18}O$ equal to $+3\sim+3.5^{o}/_{oo}$).

The next time lapse up to the volcanic layer K-Ah (6300 years ago) was characterized by the rise in temperature of surface waters and the atmosphere. By 6 thousand years, the sea level was -10~-15 m, and the $\delta^{18}O$ value decreased up to $+1^{o}/_{oo}$. This value is typical of the isotope-oxygen background of the World Ocean in the interglacial period. Usually, the carbonate content in Holocene deposits was lower than that in glacial and transition sediments owing to the intensive vertical circulation of waters. The strong aeration of bottom waters at the increased productivity of surface waters resulted in an intensive release of CO_2 and a high corrosion of carbonate shells in the surface layer of sediments. The traces of the solution of planktonic foraminiferal shells were seen under microscope. The strongest solution of carbonate shells, and the lowest $CaCO_3$ content are characteristic of sediments accumulated from 9 to 6.5 thousand years ago. At this time and at CH5 (10-11 thousand years ago), the deposits of the Japan Sea in all analyzed cores had the highest organic carbon content (up to 3-4% per dry weight of sediment). It is possible that the productivity of the Japan Sea at that time was maximal. Oceanographic parameters, similar to those of the present time, were set in the Japan Sea some 7 thousand years ago. Two less pronounced carbonate content rises (CH6, CH7) were noted in Holocene deposits. The last of them, CH-7, correlates well with the time if insufficient temperature rise in surface waters and atmosphere established by the micropaleontological method in the Core 1603 (Verkhovskaya *et al.*, 1992). The CH-6 lying slightly above the volcanogenic layer K-Ah was formed from the data of the Core 1603 at the end of the early Holocene rise in temperature, approximately 5,000 years ago, according to AMS dating. It is still elusive if the changes in planktonic foraminifera productivity or their preservation in bottom sediments are the reasons for the formation of CH-6 and CH-7 in the Japan Sea.

5. CONCLUSION

Using radiocarbon dates of planktonic foraminiferal shells, *N. pachyderma*, it was determined that the age of the widely spread A-Tn volcanic layer in the region was equal to 25 thousand years. Using a detailed complex analysis of several cores of the Japan Sea sediments corresponding to the period of the late glaciation, the transition period and Holocene, the authors established seven horizons with the increased calcium carbonate content (CH) and made an attempt to determine their paleoceanologic causes. The formation of CH1, CH2 and CH3 in sediments during the late glaciation is related to sea level regression, moderation of ventilation of bottom waters and the improvement in the preservation of planktonic foraminiferal shells. The CH4 and CH5 of the transient period is probably correlated with cold events (Oldest Dryas and Younger Dryas). In the Holocene deposits, the carbonate content is low and those CH6 and CH7 rises formed after 6 thousand years are connected with insufficient changes in surface water temperature and paleoceanology.

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regret that due to the absence of representatives of the diatoms and radiolaria complexes in the late Pleistocene deposits of this core, they failed to do a full micropaleonological analysis.

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APPENDIX A

Analytic results on $\delta^{18}O$ planktonic foraminifera *Neogloboquadrina pachyderma* (sinistral) Japan Sea core J11-RGA.

$\delta^{18}O$ units are ‰ PDB. Values are given in form X+S, where X=mean, S=1 sigma.

Depth (cm)	$\delta^{18}O$	Depth (cm)	$\delta^{18}O$
30-31	3.275+0.018	76-77	1.096+0.008
33-34	3.107+0.022	79-80	0.683+0.012
36-37	3.689+0.007	81-82	0.799+0.007
38-40	3.498+0.006	84-85	0.875+0.010
40-42	3.612+0.017	86-87	0.937+0.003
43-44	3.500+0.008	89-90	1.276+0.006
46-47	2.984+0.019	91-92	1.488+0.020
49-50	2.876+0.012	93-94	1.588+0.008
52-53	2.578+0.012	97-98	1.826+0.013
54-55	2.539+0.010	99-100	1.936+0.006
56-57	1.759+0.006	101-102	2.008+0.005
59-60	1.755+0.005	103-104	2.025+0.006
59-60	0.916+0.004	105-106	2.135+0.016
60	0.863+0.004	107-108	1.769+0.013
62-63	0.398+0.009	109-110	1.891+0.006
64-65	0.604+0.006	111-112	2.097+0.011
66-67	0.603+0.019	115-116	1.937+0.006
66-67	0.646+0.014	119-120	2.089+0.005
68-69	0.687+0.010	121-122	2.213+0.010
70-71	0.693+0.006	123-124	2.356+0.011
73-74	0.905+0.008	125-126	2.308+0.011
75-76	1.114+0.006	127-128	2.326+0.012

APPENDIX B

AMS radiocarbon results at J-3-RGA and J-11-RGA cores.

Core	Depth (cm)	Accession number	Species foram. measured	Age, yrs measured	Age, yrs corrected [a]
J-3 RGA	295-300	10547	*Neogloboquadrina-pachyderma dextral*	5010±70	4610±70
J-11 RGA	39-40	10125	*N.pachyderma sinistral*	11650±90	11150±90
	121-122	10122		22840±280	22440±280
	146-147	10546		25210±550	24810±550

[a] - Radiocarbon ages were corrected by -400yrs to account for surface Japan Sea reservoir effects.