Proc. NIPR Symp. Antarct. Geosci., 8, 230-238, 1995

ESR AND TL DATING OF QUATERNARY SEDIMENTS IN THE LÜTZOW-HOLM BAY REGION, EAST ANTARCTICA

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Abstract: Fossil shells and marine sediments in the Lützow-Holm Bay region, East Antarctica, were dated by electron spin resonance (ESR) and thermoluminescence (TL), respectively. The ESR and TL dates obtained in this study could be correlated with the postglacial ^{14}C age group around Lützow-Holm Bay. The sample of shells was taken from the emerged marine sediments in Langhovde which also contain another sample of quartz, and there is a small discrepancy between the two dates. Probably it is due to uncertainties in the estimates of the internal dose for the fossil shells and of the paleodose for the quartz sample.

1. Introduction

Dating of raised beach and emerged marine deposits is an important clue to reconstruct sea level, ice advance and environmental changes in the polar regions. In the Lützow-Holm Bay region, East Antarctica, there have been obtained many radiocarbon dates of fossil organic materials from raised beaches (*e.g.* MEGURO *et al.*, 1964; OMOTO, 1977; YOSHIDA and MORIWAKI, 1979; YOSHIDA, 1983; HAYASHI and YOSHIDA, 1994; IGARASHI *et al.*, 1995a, b). Though radiocarbon dates are useful for interpreting the regional geohistory, those for marine fossils around Antarctica are problematic because of the reservoir effect (RAFTER, 1961; OMOTO, 1983; ADAMSON and PICKARD, 1983; STUIVER and BRAZIUMAS, 1985). Furthermore, radiocarbon dates around Lützow-Holm Bay can be classified into those in the postglacial age between 1000 and 10000 yr BP and those between 22000 and 34000 yr BP or more (YOSHIDA and MORIWAKI, 1979). The altitude of occurrence of the older age group is not necessarily higher than that of the younger group even if the respective sites are close together (HAYASHI and YOSHIDA, 1994). Therefore, ages obtained by other dating methods would be of great help in interpreting these data. For

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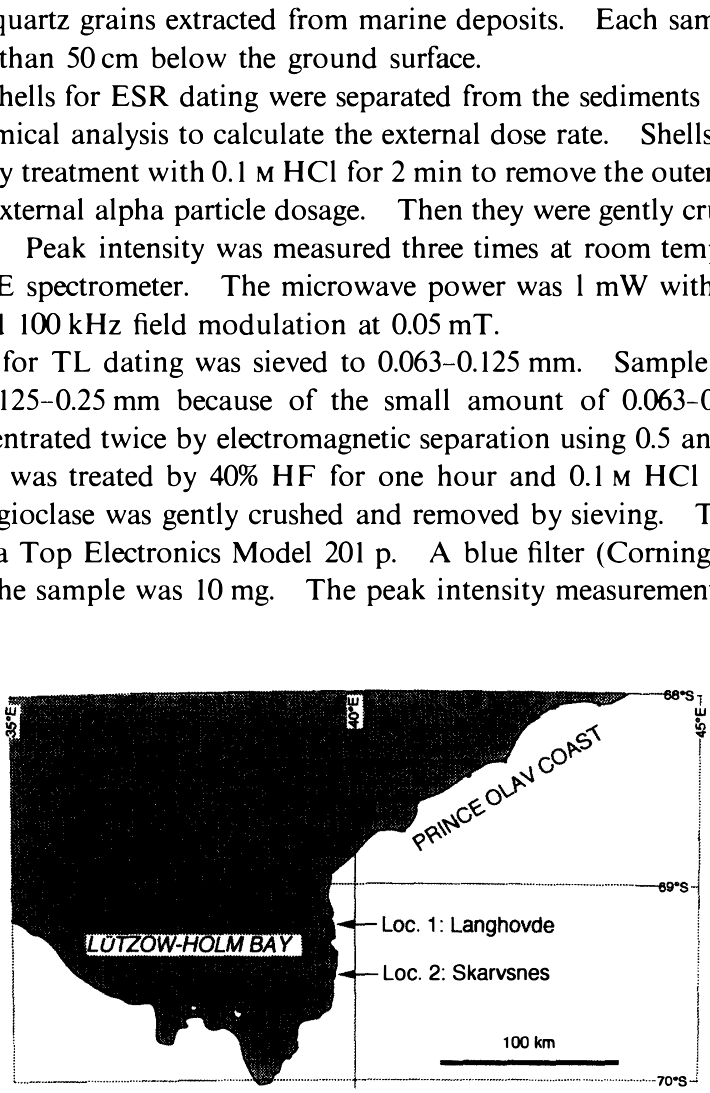
this reason we report on ESR dating of aragonitic shells and TL dating of quartz grains in marine deposits.

2. Samples and Experiments

Samples were collected from the emerged marine deposits at Loc. 1 in Langhovde and Loc. 2 in Skarvsnes (Fig. 1). Sample No. 1 of Loc. 1 for ESR dating was aragonitic molluscan shells (*Laternula elliptica*). Samples No. 2 of Loc. 1 and No. 3 of Loc. 2 for TL dating were quartz grains extracted from marine deposits. Each sampling point was at a depth more than 50 cm below the ground surface.

Aragonitic shells for ESR dating were separated from the sediments and the remnant was used for chemical analysis to calculate the external dose rate. Shells were washed in water, followed by treatment with 0.1 M HCl for 2 min to remove the outer layer which has a component of external alpha particle dosage. Then they were gently crushed and sieved to 0.5–0.125 mm. Peak intensity was measured three times at room temperature with an X-band JEOL FE spectrometer. The microwave power was 1 mW with a scan speed of 1.25 mT/min and 100 kHz field modulation at 0.05 mT.

The sample for TL dating was sieved to 0.063–0.125 mm. Sample No. 2, however, was sieved to 0.125–0.25 mm because of the small amount of 0.063–0.125 mm grains. Quartz was concentrated twice by electromagnetic separation using 0.5 and 1.5 A currents. Then the sample was treated by 40% HF for one hour and 0.1 M HCl for 2 min. The altered white plagioclase was gently crushed and removed by sieving. TL measurements were made with a Top Electronics Model 201 p. A blue filter (Corning 5–60) was used. The amount of the sample was 10 mg. The peak intensity measurement was repeated 4



Sample Number	Locality	Region	Altitude (m a.s.l.)	Material	Dating method
No. 1	Loc. 1	Langhovde	0.95	Shell (*Laternula elliptica*)	ESR
No. 2	Loc. 1	Langhovde	0.95	Marine sand (quartz)	TL
No. 3	Loc. 2	Skarvsnes	ca. 5	Marine sand (quartz)	TL

Fig. 1. Location map of sampling sites.

times. Glow curves were recorded in an ambient nitrogen atmosphere at a heating rate of 4.25°C/s. In all sample preparations for thermoluminescence dating, the procedures were carried out in subdued red light to avoid bleaching effects. An HID sunlamp (Toshiba-Raitekku, DR125/TL), kept 15 cm from samples, was used for the bleaching test. The sunlamp spectrum is similar to that of natural sunlight.

Artificial gamma irradiation was carried out with a ^{137}Cs source. All the samples for ESR and TL dating were irradiated in 4 steps to calculate an equivalent dose (ED) or a paleodose (PD). The concentration of K was determined by atomic absorption spectrometry;those of U and Th were obtained by inductively coupled plasma mass spectrometry (IMAI, 1990).

3. Results and Discussion

There is only a very weak signal of radiation induced radicals, when shells less than a few thousand years old are studied. However, results for shells from a number of places (IKEYA, 1993; NAKAJIMA *et al.*, 1993; BAFFA and MASCARENHAS, 1985) indicate that ESR is a useful technique for young shells using signal C. Therefore, in order to determine the ED of Sample No. 1, we used the ESR signal C (g=2.0008) (Fig. 2), which is considered to be related to the relative age as shown by IKEYA and OHMURA (1981). The intensity of this signal was normalized by that of the external Mn^{2+} marker and this ratio was plotted as a function of the radiation dose. Figure 3 shows the growth of the signal amplitude with artificial irradiation. The equivalent dose (ED) was obtained by linear fitting (straight line) and extrapolation to the intersection with the x axis.

Figure 4 shows a typical TL glow curve obtained from Sample No. 3. It has a plateau region of 250–270°C. Therefore, integrated TL intensities between 250 and 270°C were used for dating.

The observed natural TL (I_{nat}) in the sample comprises the unbleachable TL that was already present in the sample at the time of deposition (I_0), and the TL acquired by the sample since deposition as a buried sediment (I_{d}) (SINGHVI *et al.*, 1982).

$$I_{\mathrm{nat}} = I_0 + I_{\mathrm{d}}.$$

Thus the estimation of I_{d} requires determination of I_0 and I_{nat}. Figure 5 shows the fraction of the TL for the Sample No. 3 evaluated between 250 and 270°C remaining after sunlamp exposure against exposure time. The experiment was performed on a set of natural samples which were not irradiated artificially. The bleaching curve quickly approaches an asymptotic value. This indicates that TL cannot be bleached beyond a finite residual value by any length of Sun/sunlamp exposure. Subtracting this residual TL level from natural and artificial irradiated TL intensities, we obtained the net TL intensities. These net TL intensities were plotted as a function of the radiation dose. Figure 6 (lower) shows the growth of integrated net TL intensities with artificial irradiation for Sample No. 3. The paleodose was obtained by linear fitting (straight line) and extrapolation to the intersection with the x axis.

The residual TL intensity of Sample No. 2 integrated between 250 and 270°C, where a plateau region occurred, was 52% of the natural intensity. Figure 6 (upper) shows the net TL growth of Sample No. 2 upon an additive radiation dose. Because this sample

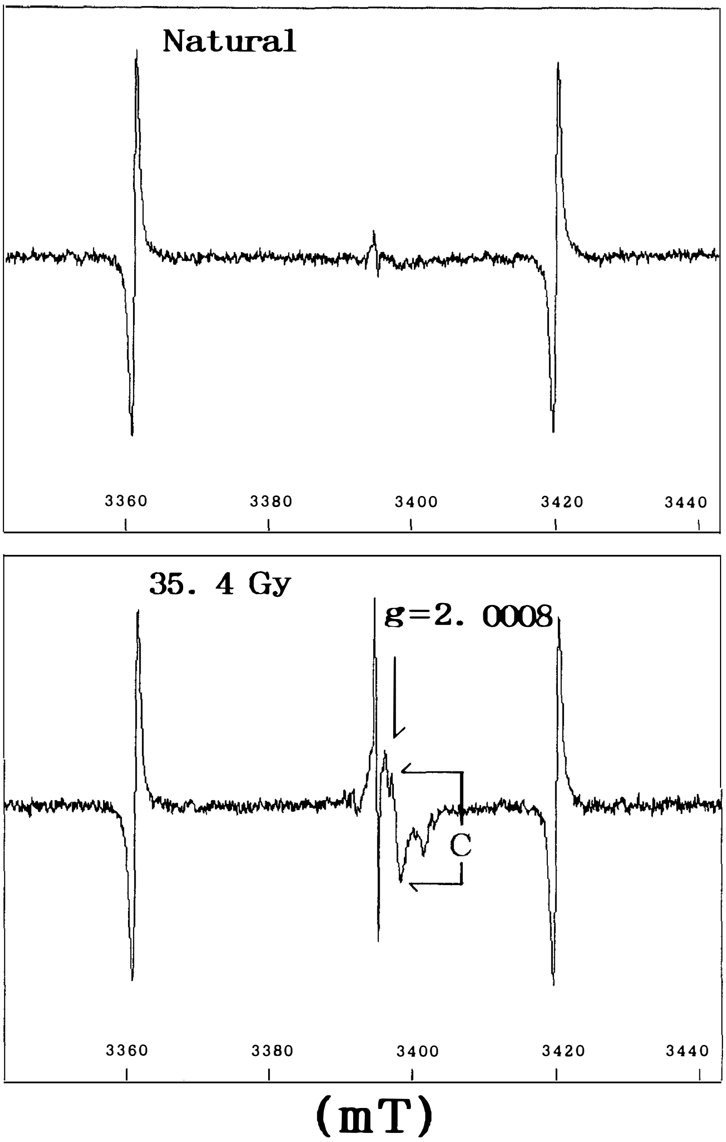


Fig. 2. ESR spectra of aragonitic shells (upper) and that after artificial gamma irradiation of 35.4 Gy (lower) in Sample No. 1. The microwave power was 1 mW with a scan speed of 1.25 mT/min and 100 kHz field modulation at 0.05 mT. The measurements were made at room temperature. "C" indicates the ESR signal C (g = 2.0008).

shows strong saturation in the growth curve, the paleodose was obtained by fitting to the reciprocal exponential function $(-\ln(1-I/I_{max}))$, where I and I_{max} are the TL intensity and that of saturation level, respectively.

The ESR and TL ages are obtained from the equivalent dose or paleodose (the total amount of radiation damage accumulated in the past) divided by the annual dose (AITKEN, 1985). Table 1 lists the analytical results of U, Th and K, and the annual dose. The annual dose was calculated from U, Th and K_2O for beta and gamma doses using BELL's data (BELL, 1979), assuming secular equilibrium. The contribution of the external alpha dose was neglected because the outer layer of shells and quartz was removed by etching

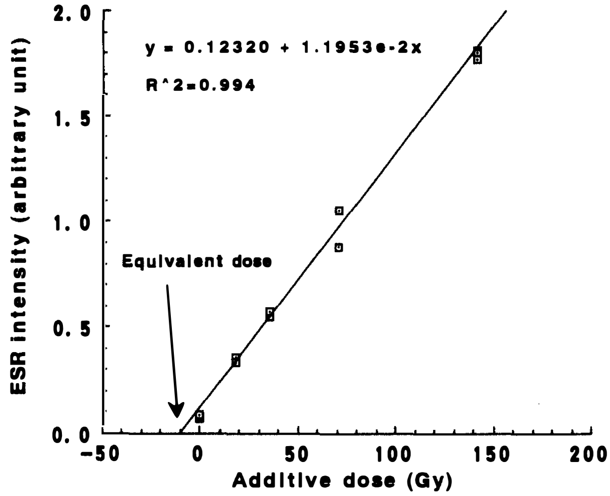


Fig. 3. *The growth of the ESR "C" signal as a function of radiation dose.*

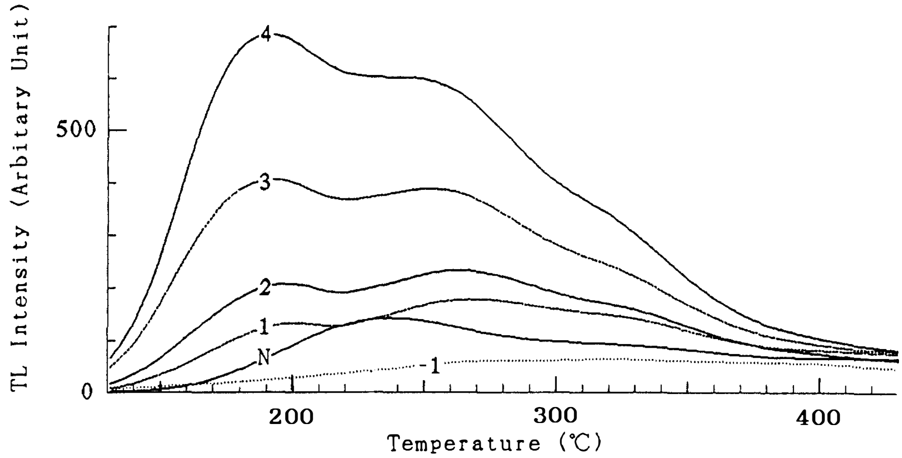


Fig. 4. *Typical TL glow curves for quartz extracted from marine deposits of Sample No. 3. (N: natural TL; 1, 2, 3, 4: TL after 17.3, 34.6, 69.2 and 138.4 Gy artificial irradiation; -1: TL after 56 hour exposure to a sunlamp.)*

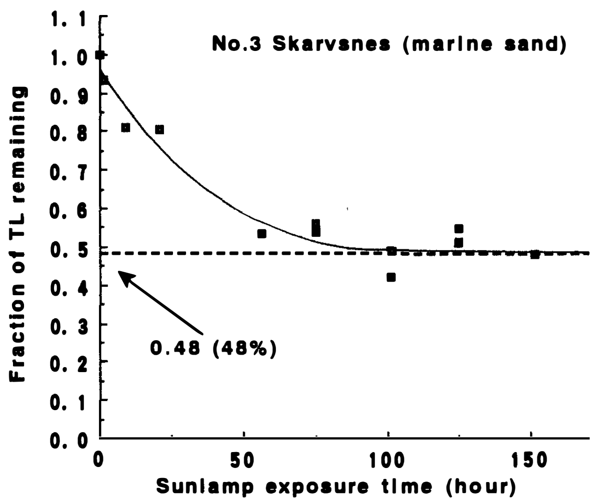


Fig. 5. *The fraction of the TL for Sample No. 3 evaluated at a glow-curve temperature between 250 and 270°C remaining after a sunlamp exposure against exposure time.*

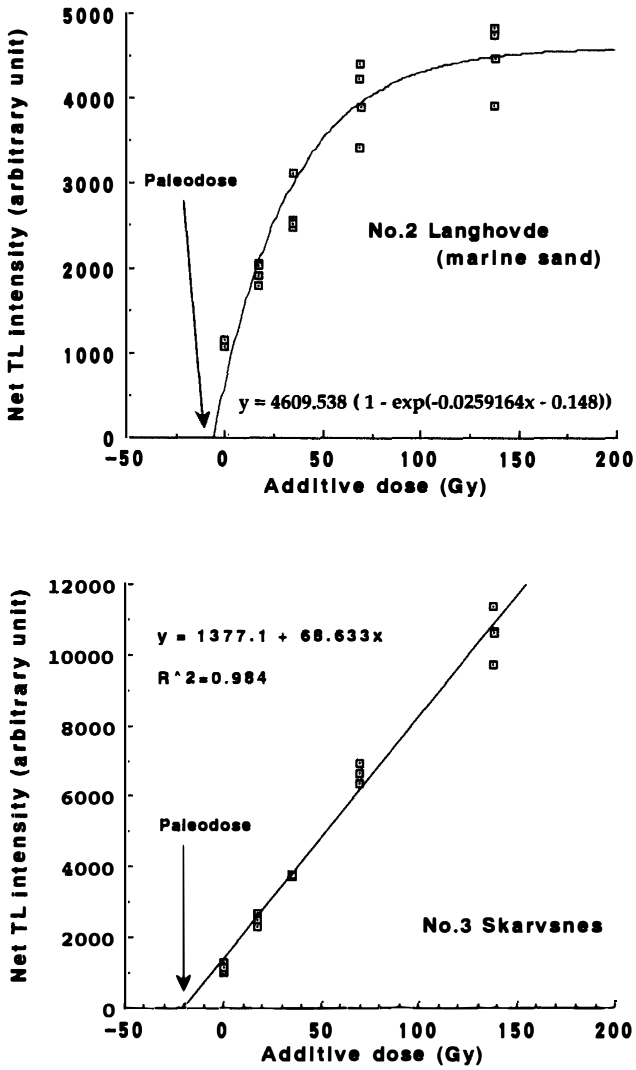


Fig. 6. The growth of TL intensity of quartz for Samples No. 2 and No. 3 as a function of radiation dose.

with HCl or HF. For the internal dose of Sample No. 1, the average of the annual dose in the past was calculated on the assumption that the fossil shells had taken up U, Th and K linearly with time. Three corrections of annual dose for beta-ray attenuation, water effect and cosmic rays were considered (MEJDAHL 1979; AITKEN, 1985). The values of external dose are rather high because gneissose or granitic rocks rich in K_2O are exposed in the surrounding area (NATIONAL INSTITUTE OF POLAR RESEARCH, 1986) where the marine sediments come from.

For ESR, the ED value of Sample No. 1 was 10±2.5 Gy and the date was 3.5±0.9 ka. For TL, the paleodoses of Samples No. 2 and No. 3 were 5.7±2.4 Gy and 20±2.7 Gy, giving the dates of 2.1±0.9 ka and 7.9±1.1 ka, respectively (Table 2).

Figure 7 shows the relationship between the dates and altitudes of the samples in Langhovde and Skarvsnes for ESR and TL dating in this study as well as for ^{14}C dating in other studies. The ESR age for the shells of Sample No. 1 indicates the time when they were living in the sea. The TL ages in this study indicate the time when marine sands

Table 1. Analytical results of U, Th and K, and annual dose.

Sample No.	Region	Dating method	Annual dose evaluation	U (ppm)	Th (ppm)	K_2O (%)	Water content (%)	*1 Size (mm)	*2 α (mGy/y)	*2 β (mGy/y)	*2 γ (mGy/y)	Annual*3 dose (mGy/y)
No. 1	Langhovde	ESR	Internal dose*4	1.3	0.1	0.13	—	0.25	3.69	0.28	0.37	0.42
			External dose	1.1	6.6	2.83	5.1	0.25	7.34	2.16	1.19	2.52
No. 2	Langhovde	TL	External dose	1.1	6.6	2.83	5.1	0.19	7.37	2.16	1.19	2.67
No. 3	Skarvsnes	TL	External dose	0.9	4.4	2.84	13.2	0.09	4.81	1.55	1.00	2.55

*1: The average thickness of shells or diameter of grains.
*2: Assuming secular equilibrium.
*3: Including cosmic rays (=0.19 mGy/y). Two corrections of annual dose for beta-ray attenuation and water effect were considered.
*4: Assuming linear uptake of U, Th and K_2O and 0.15 of k-value.

Table 2. Annual dose, equivalent dose or paleodose, and ESR or TL ages.

Sample No.	Region	Dating method	Material	Annual dose evaluation	Plateau region (°C)	Residual TL Intensity (%)	Annual dose (mGy/y)	Equivalent dose or paleodose (Gy)	ESR or TL age (ka)
No. 1	Langhovde	ESR	Aragonitic shell	Internal & external dose	—	—	2.94	10.3±2.53	3.5±0.9
No. 2	Langhovde	TL	Quartz	External dose	250–270	48	2.67	5.7±2.4	2.1±0.9
No. 3	Skarvsnes	TL	Quartz	External dose	250–270	52	2.55	20.1±2.70	7.9±1.1

were being churned by sea waves and exposed to sunlight. Therefore the actual high tide level at each time indicated by the ESR and TL dates is assumed to have been higher at least than each sampling altitude. From the above viewpoint, the ESR and TL dates are consistent with the ^{14}C ages in Langhovde and Skarvsnes and could be correlated with the postglacial ^{14}C age group (HAYASHI and YOSHIDA, 1994).

The shells of Sample No. 1 were extracted from the marine sediments of Sample No. 2. Therefore the dates for Samples No. 1 and No. 2 should be almost the same. There is, however, a small discrepancy between these dates. Probably it is partially due to an uncertainty in the internal dose value for Sample No. 1 calculated on the assumption that the fossil shells had been taken up U, Th and K linearly with time. Moreover, since net TL intensities for Sample No. 2 are rather dispersed at higher additive doses (Fig. 6), there is a possibility that Sample No. 2 may contain a variety of quartz grains which are different in origin and have experienced various bleaching histories. From this it may be inferred that the discrepancy is also due to uncertainties in the estimate of the paleodose for Sample No. 2.

Acknowledgments

We thank Dr. N. IMAI and Dr. K. SHIMOKAWA of the Geological Survey of Japan for their kind cooperation in providing experimental facilities for this work. Thanks are also

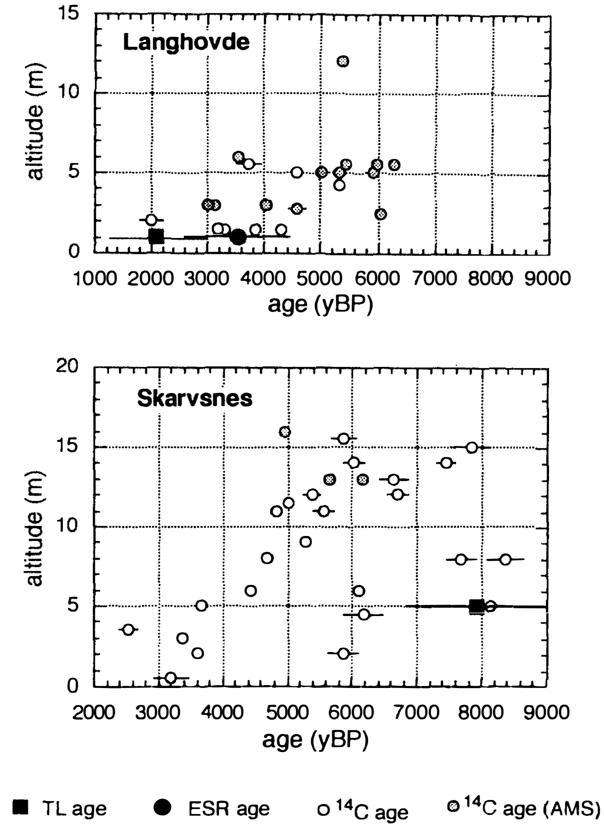


Fig. 7. The relationship between the ages and altitudes of Holocene marine sediments in Langhovde and Skarvsnes. The ESR and TL ages have been obtained in this study. The data on ^{14}C ages, which are shown without reservoir correction, were taken from HAYASHI and YOSHIDA (1994) and IGARASHI et al. (1995a).

due to Prof. N. YONEKURA and Dr. H. EGUCHI of the University of Tokyo for their help and discussions.

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(Received April 7, 1995; Revised manuscript received May 9, 1995)