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XI. MAGNETIC SUSCEPTIBILITY ANISOTROPY AND REMANENCE OF SOME DEEP-SEA SEDIMENTS OF THE TOKAI BASIN

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Introduction

A growing number of deep sea drilling studies have recently been focused on the sediments of the Nankai Trough (Kagami et al., 1986; Taira *et al.*, 1991). Anisotropy of Magnetic Susceptibility (AMS) has particularly been a useful tool in clarifying the provenance and sedimentation mechanism in this trough (Taira and Niitsuma, 1986; Pickering *et al.*, 1992; Owens, 1993). In our study, nine gravity cores from further east and northeast have been examined using paleomagnetic and magnetic fabric techniques aiming to clarify the provenance and mode of deposition. These cores were obtained from the off-Tokai area and the Sagami Trough during the GH97 cruise of the R/V Hakurei-Maru at water depths of 545 m to 2420 m. Site GH97-301 (core length: 285 cm) was located east of the Izu Peninsula and site GH97-302 (core length: 371 cm) off Fuji river mouth together with site GH97-314 (core length: 57.5 cm) along the axis of the Suruga Trough. Sites GH97-306 (core length: 156 cm), GH97-310 (core length: 274 cm) and GH97-311 (core length: 270 cm) were located in trench slope basins at the northeastern tip of the Nankai Trough, sites GH97-308 (core length: 199 cm) and GH97-309 (core length: 235.5 cm) west of the Tenryu Canyon off Atsumi Peninsula, and finally site GH97-307 (core length: 371 cm) at the mouth of the Kumano Basin (Fig. XI-1).

Sampling and Measurements

A total number of 891 discrete samples were obtained through continuous sub-sampling by pressing Kyoto-type 7 cm^3 plastic cubes into the split working half of each core. Initial low field magnetic susceptibility and its anisotropy were first measured using a KappaBridge KLY-3S susceptibility meter. Remanent magnetization was then measured and demagnetized using a three-axis 2G-Enterprises cryogenic magnetometer with in-line AF demagnetizer with a peak field strength of 80 mT.

Results and analysis

Lithology

Visual observations indicate that most of the present sediments compose olive black silty clay-clayey silt to very fine sand intercalated with numerous turbidite beds composed of very fine sand to coarse silt. Two ash layers were identified at site GH97-301 and another layer near the bottom of the core at site GH97-307. The latter has

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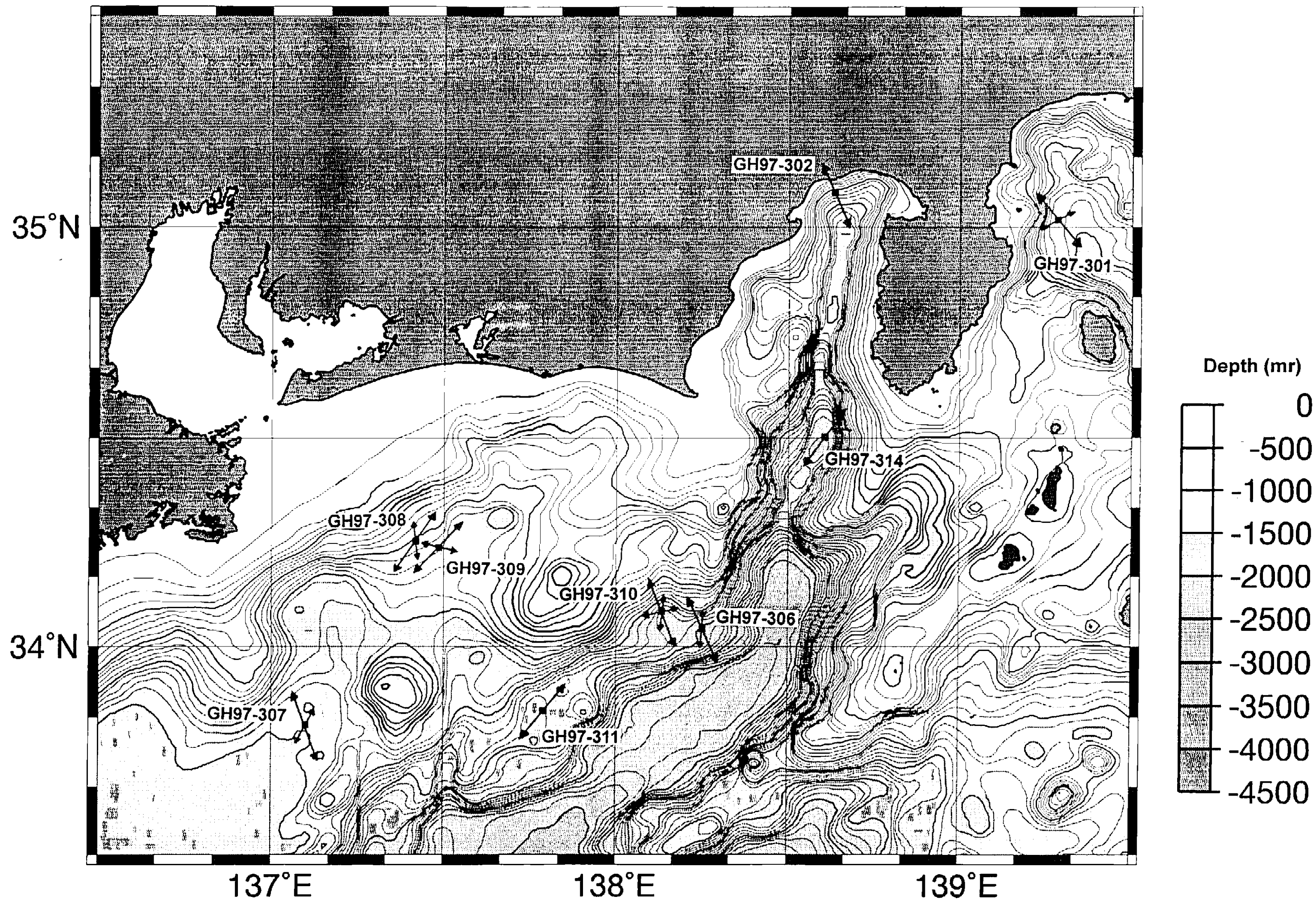

Fig. XI-1 Bathymetric map of the off-Tokai area with site locations and paleocurrent directions inferred from AMS measurements.

been identified as the wide-spread Kikai-Akahoya Ash layer that has recently been re-dated to ca. 7300 yr. BP (Kitagawa *et al.*, 1995). Detailed lithological description of each core is shown in Ikehara *et al.* (this volume).

Remanence

About half of the entire sample collection was first subjected to 17 incremental AF demagnetization steps up to 80 mT. After the first few steps, most samples exhibited a single component that heads toward the origin of the orthogonal plot (Fig. XI-2). AF demagnetization at 20 mT was found sufficient to remove the soft viscous remanence and isolate the stable characteristic component. North directions at each sample level were calculated from a linear/polynomial fitting of declination on depth and were used for reorientation of the AMS axes to their geographic coordinates. Declinations were also adjusted by a constant factor around the 0° (to study the paleosecular variation pattern. Fig. XI-3 shows the plots of declination and inclination records at each site. A reasonable agreement can be seen among most records reflecting the fidelity of the present sediments in recording geomagnetic variations. A comparison between the paleosecular variation record from core at site GH97-307 that intercalates the Kikai-Akahoya Ash layer near its bottom with other records suggests younger ages for sediments at all other sites. This is consistent with the fact that the Kikai-Akahoya Ash layer could not be identified at any of those sites.

Anisotropy of magnetic susceptibility

Following the recommendations of Ellwood *et al.* (1988) and Tarling & Hrouda (1993), we have used the following parameters to define the magnetic fabric characteristics:

$K = (K_1 + K_2 + K_3)/3$ (Mean susceptibility, Nagata, 1961)

$Pj = \exp\sqrt{\{2[(n_1 - n_m)^2 + (n_2 - n_m)^2 + (n_3 - n_m)^2]\}}$

where $n_1 = \ln K_1$; $n_2 = \ln K_2$; $n_3 = \ln K_3$; $n_m = (n_1 + n_2 + n_3)/3$

(Anisotropy degree, Jelinek, 1981)

$L = K_1/K_2$ (Magnetic lineation, Balsley & Buddington, 1960)

$F = K_2/K_3$ (Magnetic foliation, Stacey *et al.*, 1960)

$q = (K_1 - K_2)/\{[K_1 + K_2]/2 - K_3\}$ (Shape parameter, Granar, 1958)

In the present study, q values <0.67 together with K_3 directions lying within 25° of the vertical were considered indicative of a primary fabric credible for providing information on paleocurrent direction and depositional conditions (Hamilton and Rees, 1970; Hrouda, 1982; Tarling and Hrouda, 1993).

Fig. XI-4 shows down-hole plots of the mean magnetic susceptibility, K_3 inclinations and the key anisotropy parameters q, P_j, F and L for each of the nine sites. Magnetic susceptibility values vary in sediments from one site to another and range from low to relatively high. Sediments from cores at sites GH97-301, GH97-302 and GH97-306 exhibit the highest values while those from cores at sites GH97-307 and GH97-309 having the lowest values (Table XI-1). Downhole variations also exist

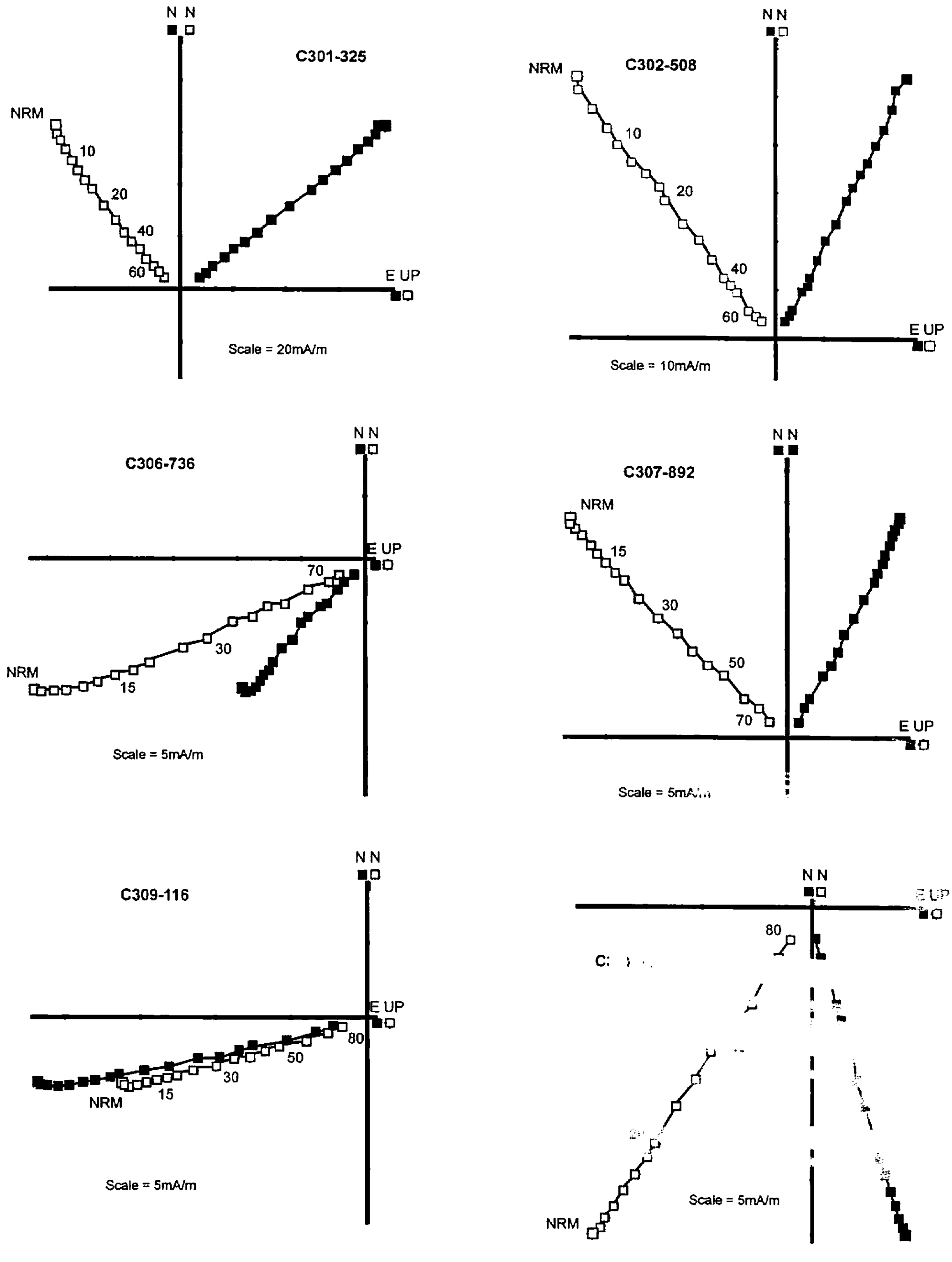

Fig. XI-2 Typical examples of orthogonal Zijderveld plots of stepwise AF demagnetization data of representative samples from the off-Tokai cores. Closed (open) squares are projections on horizontal (vertical) planes. Sample name is labeled according to core number. Scale unit is fixed for both vertical and horizontal axes.

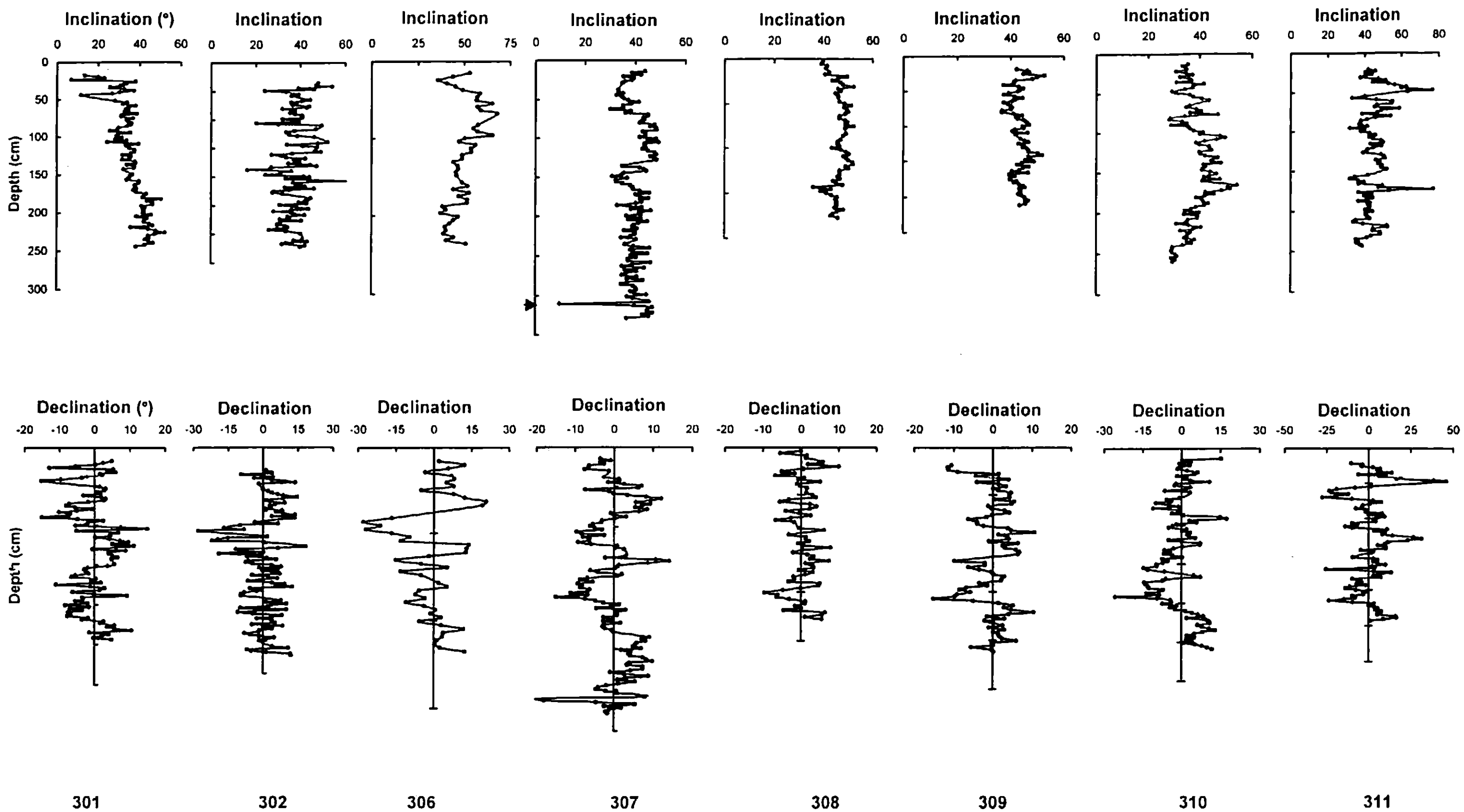

Fig. XI-3 Directional paleosecular variation records for the off-Tokai cores. The pointing arrow at the inclination plot of site GH97-307 shows the location of the Kikai-Akahoya Ash layer. In all plots, each vertical scale unit equals 50 cm.

Table XI-1 Mean and standard deviation of magnetic susceptibility and AMS parameters for the off-Tokai cores. N is the total number of samples measured.

Core No.	N	K x 10^{-6}	Pj	q	L	F
301	113	2004 ± 1151	1.068 ± 0.03	0.134 ± 0.12	1.006 ± 0.00	1.055 ± 0.03
302	150	2350 ± 512	1.080 ± 0.02	0.251 ± 0.15	1.014 ± 0.01	1.059 ± 0.02
306	55	1136 ± 285	1.045 ± 0.02	0.223 ± 0.14	1.007 ± 0.00	1.035 ± 0.01
307	147	246 ± 70	1.052 ± 0.01	0.158 ± 0.12	1.006 ± 0.00	1.042 ± 0.01
308	78	381 ± 49	1.040 ± 0.01	0.217 ± 0.14	1.007 ± 0.00	1.030 ± 0.01
309	96	280 ± 47	1.064 ± 0.01	0.092 ± 0.06	1.004 ± 0.00	1.052 ± 0.01
310	113	490 ± 97	1.070 ± 0.02	0.115 ± .08	1.006 ± 0.00	1.057 ± 0.01
311	115	728 ± 181	1.075 ± 0.02	0.166 ± 0.09	1.009 ± 0.00	1.059 ± 0.02
314	25	576 ± 910	1.036 ±0.02	0.263 ± 0.18	1.006 ± 0.00	1.027 ± 0.02

within sediments in each core (Fig. XI-4) reflecting changes in concentration or grain size of magnetic minerals or both. Sediments at site GH97-314 show a remarkable downhole increase in susceptibility values marking the lithological transition of diatom ooze to turbidite. The downhole array of K_3 inclinations and q values indicate a clear predominance of a well-preserved primary depositional fabric that is marked by very steep K_3 axes and q values falling well within ranges known for primary depositional fabrics (see also average values of L , F and q in Table XI-1). Only few samples, mostly from the top parts of the cores, seem to have developed a secondary fabric marked by prolate ellipsoids ($q > 0.67$) and K_3 axes well away from vertical (Fig. XI-4). The latter has long been attributed to coring and sub-sampling disturbances commonly reported from top soft parts of deep-sea sediments (Rees and Fredrick, 1974; Kent and Lowrie, 1975).

Down-hole plots of the P_j and F parameters show a clear similarity in their pattern and a general tendency of increase down each of the seven cores. This is most probably due to compaction effect. This is confirmed by the observation that no such correlation can be seen between P_j and L (Fig. XI-4). The down-hole changes in magnetic susceptibility seem to correspond very closely with changes in the q and P_j parameters for sediments from all sites (Fig. XI-4). A close inspection of these variations indicates that they are lithologically controlled and generally tend to increase in correspondence with the presence of turbidite layers down some of the cores (Fig. XI-4). Since these parameters are sensitive to changes in depositional conditions they tend to rise in response to the increase of input of influx materials. It is, therefore, believed that these variations mark the episodic changes in flux and composition of supplied materials mostly related to occasional gigantic earthquakes known to have occurred in the Tokai region. Future studies should allow full assessment of such correlation between AMS parameters and episodes of turbidite influx.

Paleocurrent analysis

Equal-area stereographic projections of the paleomagnetically oriented K_1 and K_3 susceptibility axes for samples satisfying the criteria for a primary fabric in each site are shown in Fig. XI-5. A fairly good cluster of K_1 axes, marking a reasonably well-defined magnetic lineation is also evident at all sites. No preferred imbrication direction could be identified in most cases. The magnetic lineation trend in each core is brought out more clearly in the rose diagrams (Fig. XI-5) and is plotted on the present-day bathymetric map in Fig. XI-1.

At site GH97-301, although the orientation of the K_1 axes extends over a wide range of azimuths, the highest concentration occurs along the NW-SE. This is apparent in the rose diagram, which also shows a subordinate trend toward NE-SW (Fig. XI-5). On the bathymetric map, the principal NW-SE trend corresponds closely to a down-slope long-grain alignment that is parallel to the axial trend of the Sagami Trough (Fig. XI-1). This is consistent with the view that sediments at this site were deposited through currents that flowed down the continental slopes with sediment influx essentially carried by the Sakawa River. Intermittent turbidity currents occurred in relation to earthquakes or river floods may have deposited the turbidite layers identified at this site. The subordinate NE-SW magnetic lineation trend may reflect a flow normal rolling of some coarse grain materials down the slope. At site GH97-302, down-slope deposition is also evident with a well-developed long-grain alignment running NNW-SSE (Fig. XI-1). This trend is generally parallel to the axial trend of the Suruga Trough but also seems to be slightly affected by local morphology of the slope. Such trend is in favor of the assumption that sediments at this site were derived by the Fuji River and deposited through a relatively strong current deep into the water as indicated by the many fine-grained turbidite layers encountered down along the core from this site. Likewise, at site GH97-314, a slope parallel depositional system that generally runs along the axis of the Suruga Trough has been identified (Fig. XI-1). This direction seems to be slightly deflected toward the trend of local small channels (canyons) on the eastern slope of the main Suruga Trough (Fig. XI-1). Sediments at this site may have probably come from the same source of those at site GH97-302.

At sites GH97-306 and GH97-310, the inferred transport direction is principally running NNW-SSE down the slope (Fig. XI-1). These two sites are located in an area of small isolated basins and the most probable source for their sediments, is the steep slope bounding the northern side of the basins (Fig. XI-1). Earthquakes related to the active faults located near these sites are probably the driving forces for turbidite deposition. Similarly, site GH97-311 is located near the steep slope bounding the isolated basins to the north, however the inferred transport direction is contour-parallel and runs NE-SW parallel to the steep slope trend. This trend may reflect a change of the current direction from slope-parallel to contour-parallel. This dramatic change in the hydrodynamic regime could be attributed to variations of the local bottom topography that is also considered as the possible source for sediments at this site. A similar setting is also observed at sites GH97-308 and GH97-309 where the inferred NE-SW magnetic lineation trend (Fig. XI-1) may reflect the change of current direction from slope parallel at the small canyons to the north to slope normal at these sites. The most likely cause for this current shift is also the steep slope located immediately north to these sites. A subordinate transport direction that generally runs parallel to the slope can also be observed at the two sites (Fig. XI-1). Finally at site GH97-307, the inferred transport direction is principally slope-parallel running NNW-SSE. This direction, although difficult to explain fully, seems to follow the main axis of the sub-bottom relief. A subordinate direction running NNE-SSW, parallel to the axial trend of the Kumano Trough, also exists. The likely source for sediments at this site is the Anoriguchi Canyon.

Summary and Conclusions

A magnetic fabric analysis has been carried out on a total of 891 cubes obtained from nine gravity cores collected from the deep-sea sediments off the Tokai region. Magnetic remanence was also measured and used for both reorientation of the cores to their geographic coordinates and examination of the directional paleosecular variations. From the present results the following conclusions can be drawn:

1) The recent deep-sea sediments off Tokai region carry a stable remanent magnetization with rather consistent paleosecular variation records across the sampled area.

2) The off Tokai sediments retain their original depositional fabric in most parts. This is clearly demonstrated by the exhibition of a well-developed near-horizontal magnetic foliation, reflecting the original bedding surface, and minimum susceptibility axes that are normal to it. Down-core irregularities of magnetic susceptibility and some other AMS parameters, particularly q and Pj, correspond closely to turbidite layers and may, therefore, serve as good indicators for episodic influx changes mostly related to paleoseismicity.

3) The present results confirm the presence of preferred alignments of grain-long axes at all sites. The inferred transport directions are mostly consistent with a down-slope flow during deposition. Exceptions are sediments at sites GH97-308, GH97-309 and GH97-311 where long-grain alignment seems to follow local settings, e.g., basin shape and bottom topography. The overall transport pattern suggests that most of the coarse-grained sediments in the Suruga and Sagami Troughs were derived from the mouths of the Fuji and Sakawa Rivers while those at other sites were mostly from the steep slopes bounding the northern edge of the local basins.

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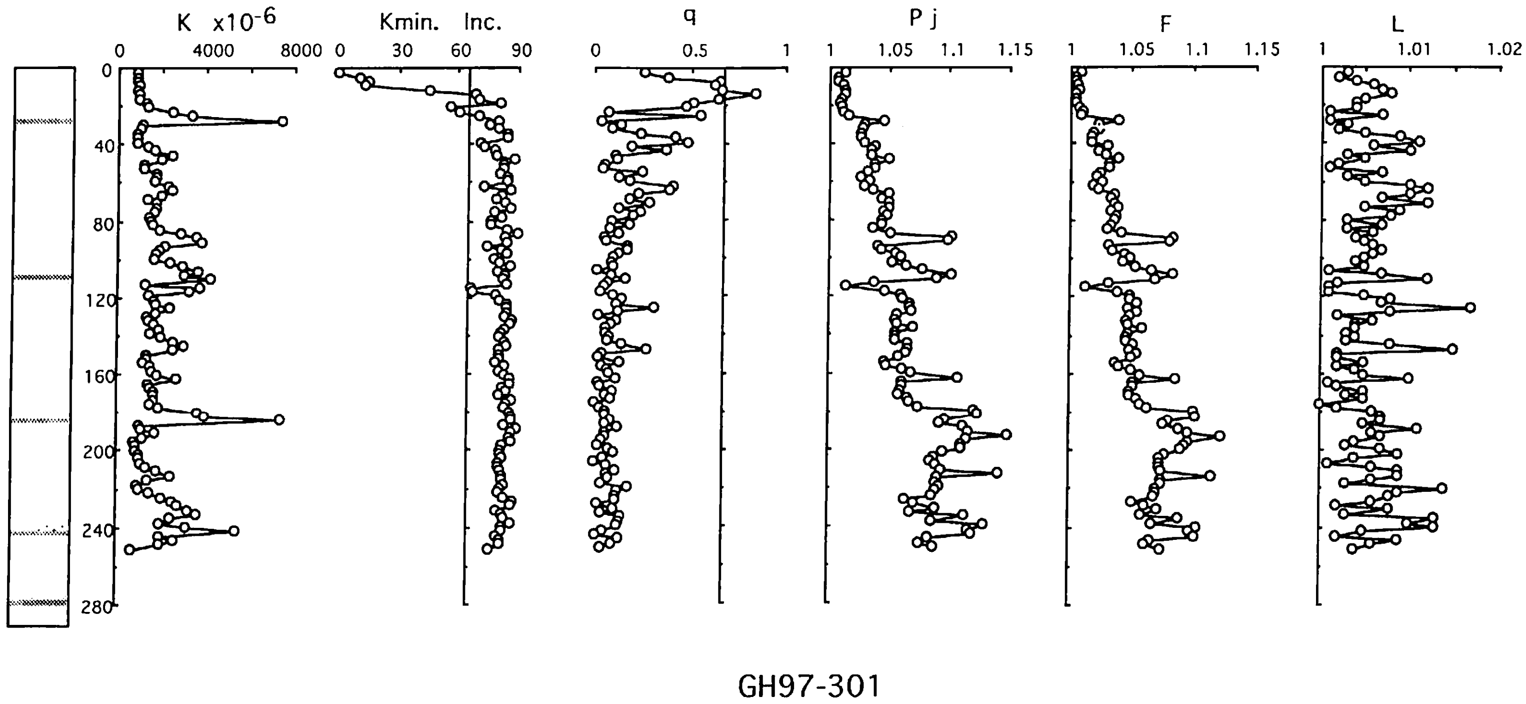
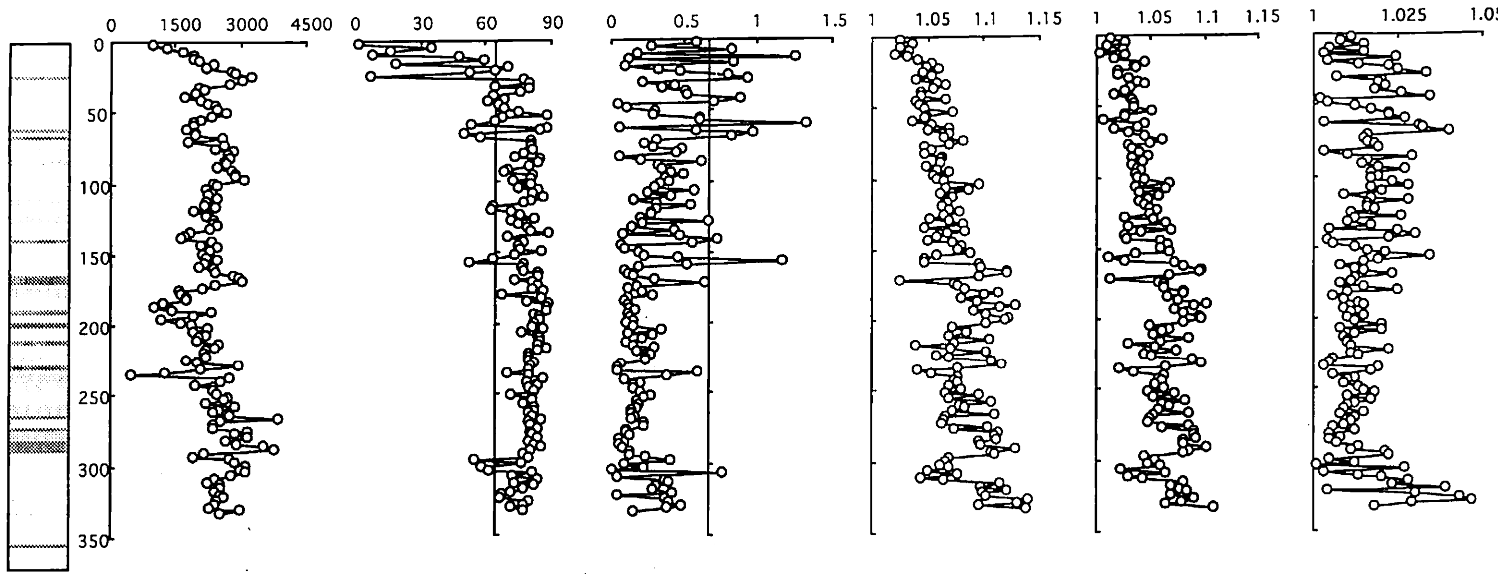
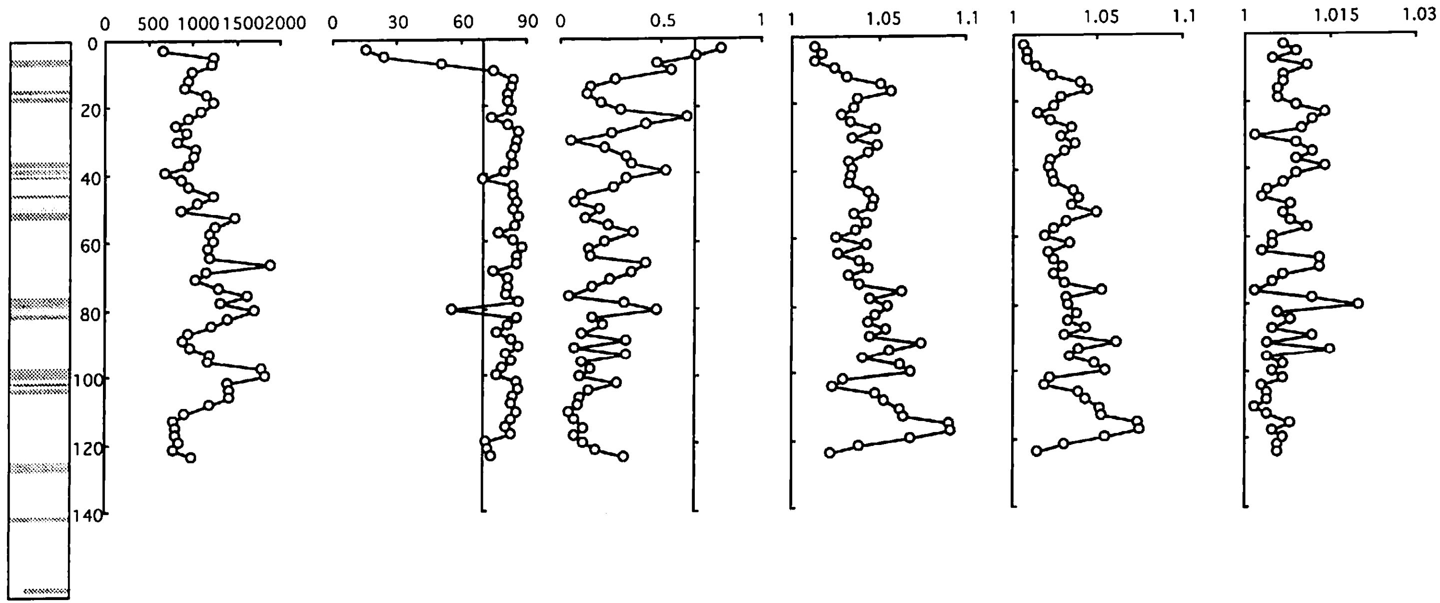


Fig. XI-4 Down-hole variations of mean magnetic susceptibility, K_3 inclination, q, Pj, F and L for the off-Tokai cores. Simplified lithologic columns with locations of turbidite layers (shaded areas) are also shown (for detailed lithological description of each core, please refer to Ikehara *et al.*, this volume). Depths are in cm below sea floor.



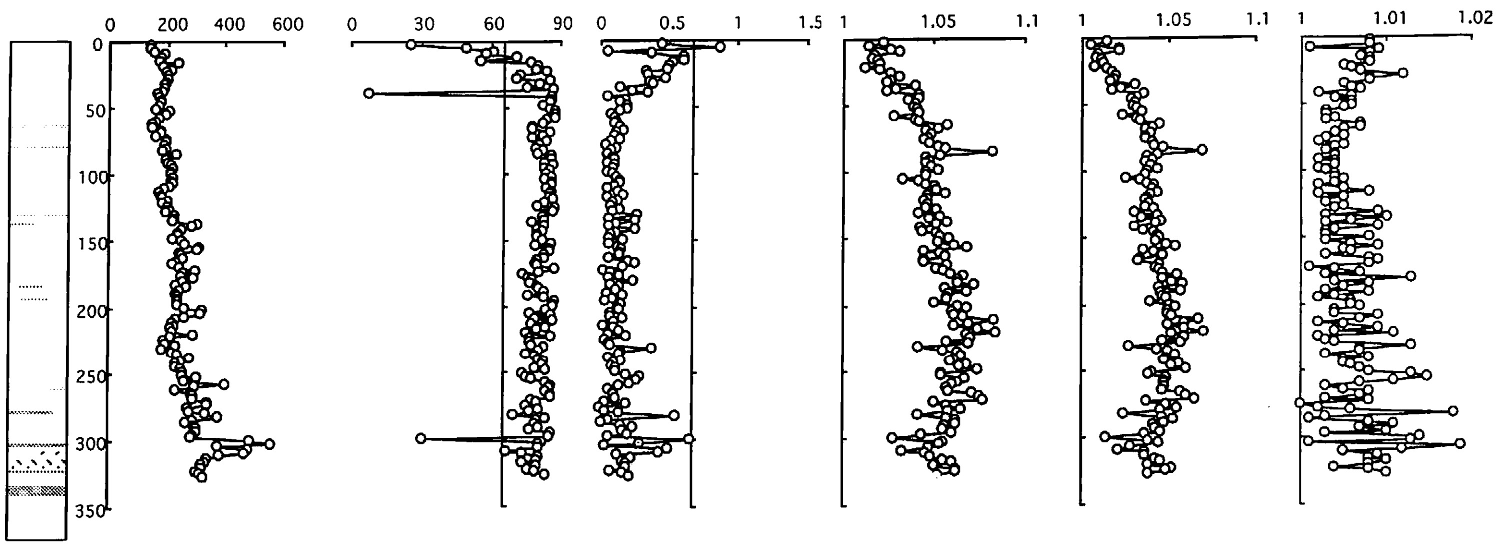
GH97-302

Fig. XI-4 (continued)



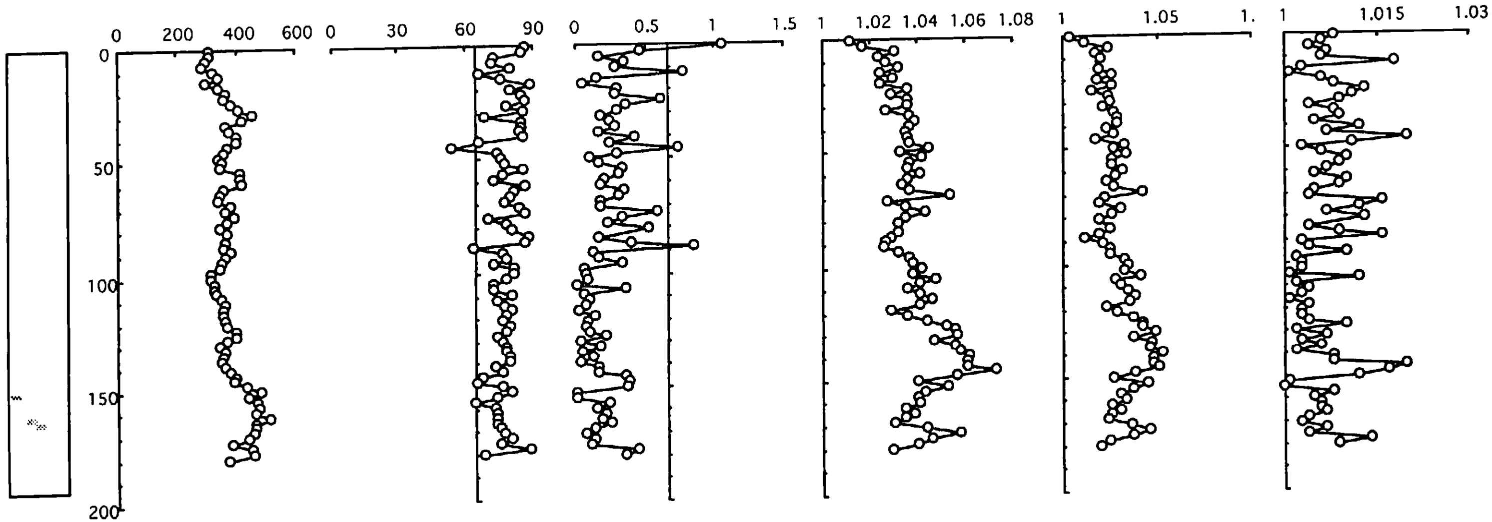
GH97-306

Fig. XI-4 (continued)



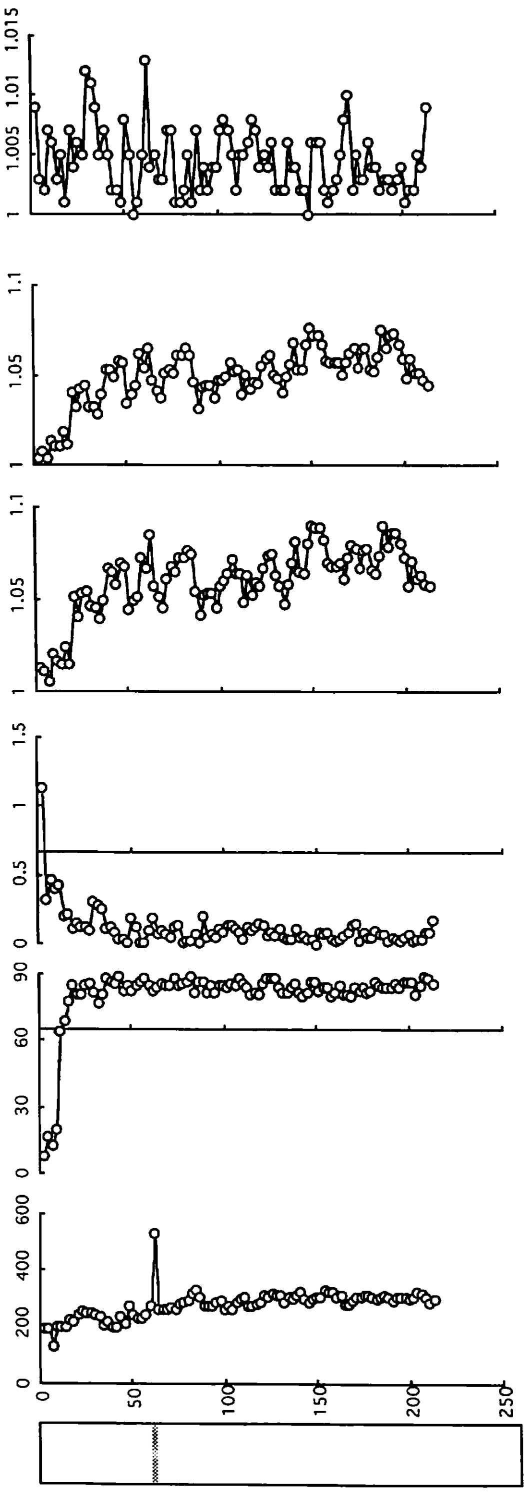
GH97-307

Fig. XI-4 (continued)



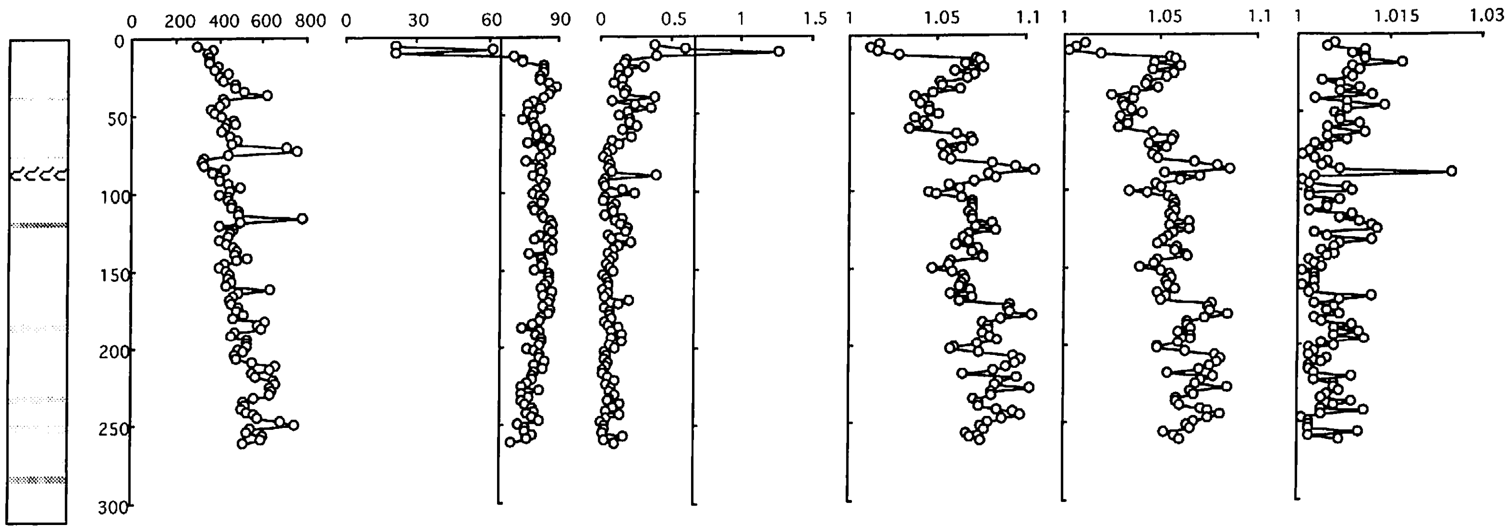
GH97-308

Fig. XI-4 (continued)



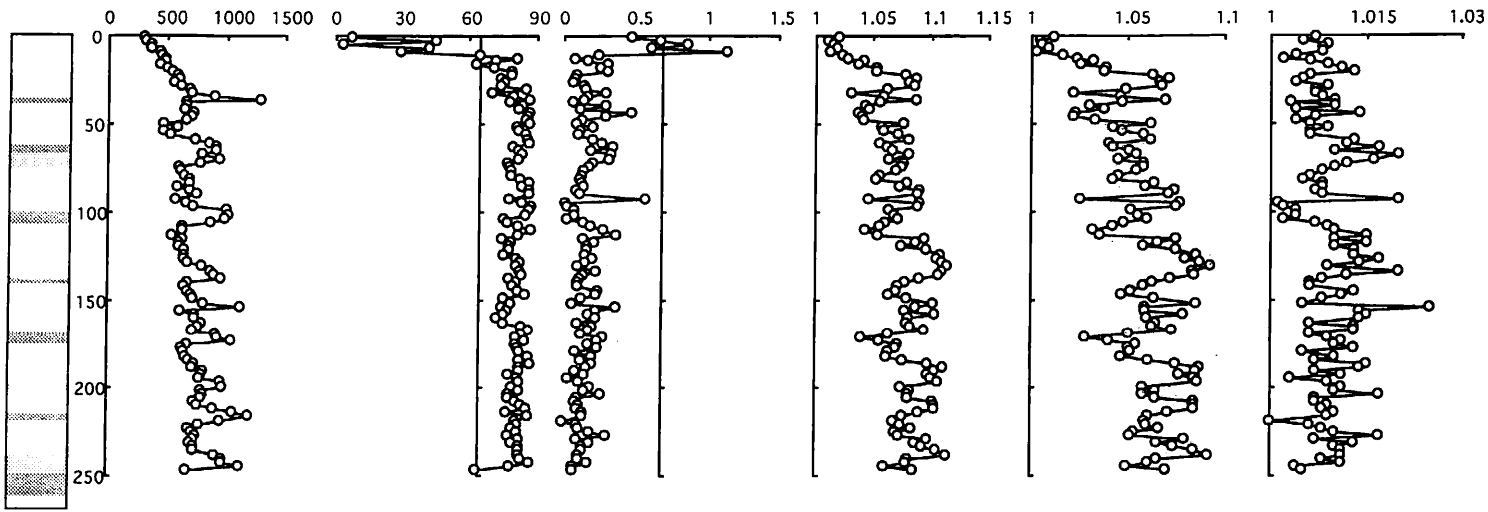
GH97-309

Fig. XI-4 (continued)



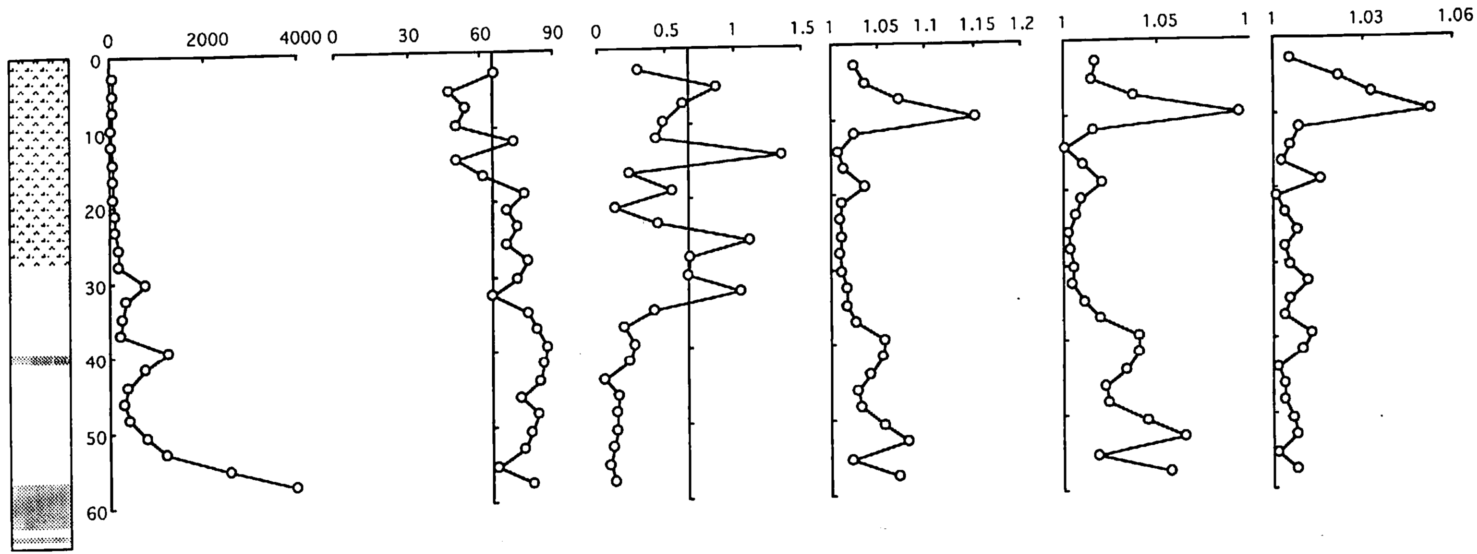
GH97-310

Fig. XI-4 (continued)



GH97-311

Fig. XI-4 (continued)



GH97-314

Fig. XI-4 (continued)

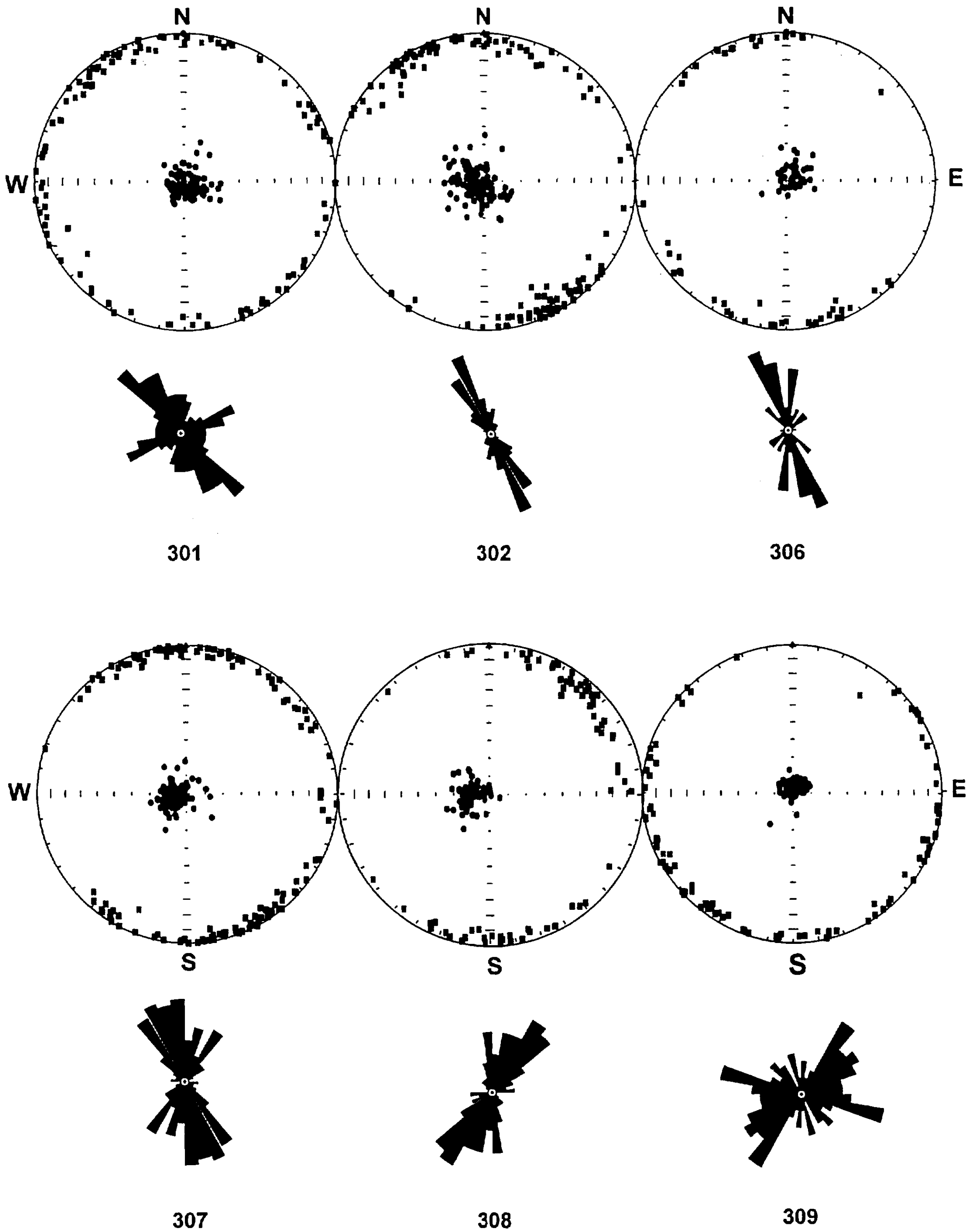


Fig. XI-5 Equal-area stereographic projections (lower hemisphere) of K_1 (squares) and K_3 (circles) and rose diagrams showing azimuthal distribution of K_1 axes for the off-Tokai cores.

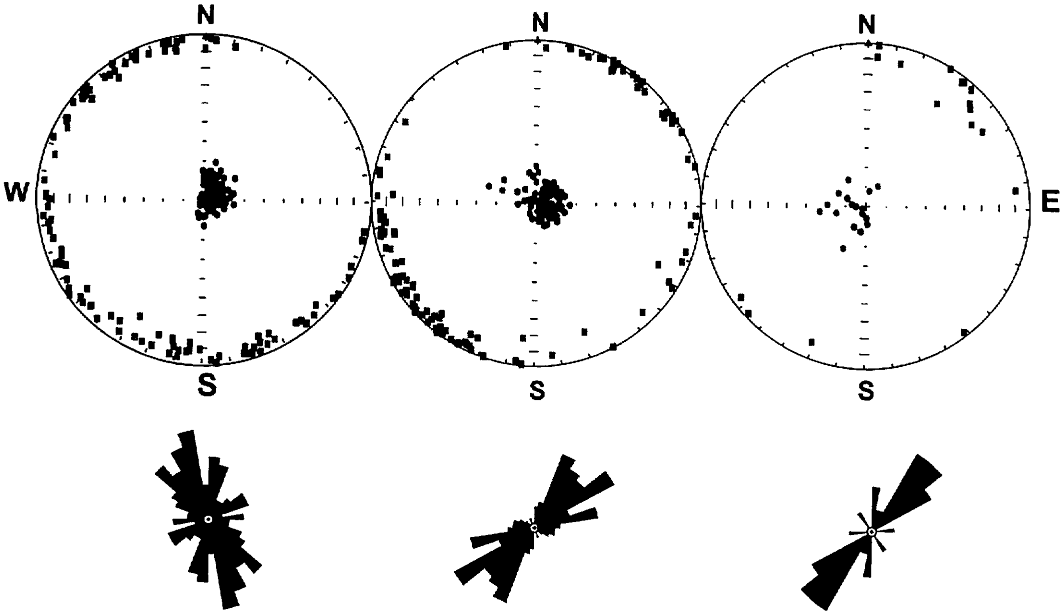


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Fig. XI-5 (continued)