Normal faulting of the Daiichi-Kashima Seamount in the Japan Trench revealed by the Kaiko I cruise, Leg 3

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A detailed topographic and geophysical survey of the Daiichi-Kashima Seamount area in the southern Japan Trench, northwestern Pacific margin, clearly defines a high-angle normal fault which splits the seamount into two halves. A fan-shaped zone was investigated along 2-4 km spaced, 100 km long subparallel tracks using narrow multi-beam (Seabeam) echo-sounder with simultaneous measurements of gravity, magnetic total field and single-channel seismic reflection records. Vertical displacement of the inboard half was clearly mapped and its normal fault origin was supported. The northern and southern extensions of the normal fault beyond the flank of the seamount were delineated. Materials on the landward trench slope are displaced upward and to sideways away from the colliding seamount. Canyons observed in the upper landward slope terminate at the mid-slope terrace which has been uplifted since start of subduction of the seamount. Most of the landward slope except for the landward walls aside the seamount comprises only a landslide topography in a manner similar to the northern Japan Trench wall. This survey was conducted on R/V “Jean Charcot” as a part of the Kaiko I cruise, Leg 3, in July-August 1984 under the auspices of the French-Japanese scientific cooperative program.

1. Introduction

1.1. Principal objectives

During Leg 3 of the Kaiko I cruise aboard the R/V “Jean Charcot”, we mapped the Daiichi-Kashima Seamount (Fig. 1) to test a hypothesis that the seamount and subducted oceanic lithosphere were dislocated here by a high-angle normal fault. Gross bathymetry, showing that the seamount is divided into a relatively high-standing outboard half and a relatively low-standing inboard half by a scarp paralleling the trench, was the basis for this hypothesis. The Daiichi-Kashima Seamount is situated in the axial zone of the southernmost portion of the Japan Trench, about 150 km east off Cape Inubo, northeastern Honshu, Japan.

Detailed survey of the northern sector of the
Japan Trench in later part of the same Kaiko I cruise (Leg 3) of "Jean Charcot" [1] has shown that the oceanward slope of the trench is marked by a number of normal faults trending parallel to the trench axis. The most prominent scarp found 20–40 km east of the trench axis south of 40° N in latitude has a length greater than 60 km and shows a vertical displacement of 300 m, creating a 12° slope facing the trench axis. It has been suggested that these normal faults are created under the horizontal extensional stress perpendicular to the trench axis caused by the downward bending of the oceanic lithosphere on the ocean side of the trench. With precise topographic and geophysical data, we hope to shed light on the tectonic evolution of the Daiichi-Kashima Seamount probably associated with the normal faults in the oceanward slope of the Japan Trench.

The lower part of the landward slope of the Japan Trench is uplifted in front of the Daiichi-Kashima Seamount, probably by the collision and the partial subduction of the seamount. A detailed survey of disrupted canyons, associated terraces and folding in the uplifted impact area of the landward slope may yield a clue to the time of initial collision and uplift.

1.2. Seabeam operation

The survey tracks of the "Jean Charcot" were planned to fully cover the crest and flank of the Daiichi-Kashima Seamount together with the axial zone of the Japan Trench and the uplifted portion of the landward slope adjacent to the subducted part of the seamount. The ship followed twenty subparallel tracks with spacings of about 4 km on the oceanward side and 2 km on the landward ends (Fig. 2). Such a fan-shaped track pattern was the most efficient to map the bottom topography, because the Seabeam coverage is wider in the deep oceanic waters and narrower on the shallower

Fig. 1. Location of the surveyed area during Kaiko I, Leg 3. Depth contours in meters.
Fig. 2. Survey tracks of R/V "Jean Charcot" during Kaiko I, Leg 3 in July 13-17, 1984 for the Daiichi-Kashima Seamount and its vicinity. Numbers 6-26 beside the track lines denote profile numbers. Numbers beside the dots indicate time every three hours in GMT.

A swath of bathymetry was continuously mapped onboard the ship. Map 3 of Plate IIA is a redrawn topographic map of the seamount area at a contour interval of 50 m. During the return transit from Hakodate to Tokyo after completion of Leg 3, a line parallel to the trench axis and on the oceanward side of the seamount was surveyed. Data obtained in transit were added to the present study.

1.3. Seismic profiling and other geophysical measurements

Seismic profiles were recorded throughout the survey using two water-guns activated by compressed air at 150 atm pressure, each having a displacement of 80 cubic inches and fired every 15 seconds. Signals from the hydrophone streamer towed 300–400 m behind the ship, were recorded in single-channel analog and digital tape format. Interpreted profiles are schematically illustrated with bathymetry along the closely-spaced survey tracks (Fig. 3). Two of the reprocessed records are shown here, one across the crest of the Daiichi-Kashima Seamount (Fig. 4a) and the other across the deepest part of the Japan Trench north of the seamount (Fig. 4b). Gravity and total field magnetic measurements were made along all tracks.

2. Previous studies

Mogi and Nishizawa [2] first found the scarp separating Daiichi-Kashima Seamount into two blocks based upon their compilation of bathymetric data obtained by the Hydrographic Department, Maritime Safety Agency of Japan. They proposed a normal fault origin of the scarp. Oshima et al. [3] conducted a comprehensive survey of this seamount with the S/V "Takuyo" equipped with a Seabeam sounder and other geophysical tools in December, 1983. A multichannel reflection seismic profile was reported by Hydrographic Department of Japan [4]. Nasaka et al. [5] also investigated the Daiichi-Kashima Seamount along one east-west multichannel seismic profile which they obtained with the R/V "Tansei-Maru" of the Ocean Research Institute, University of Tokyo.

Magnetic anomalies over the seamount, analysed by Ueda [6,7] show a non-magnetic cap on both halves of the seamount and reflect the downward vertical offset of the western half. Tomoda et al. [8] compiled gravity data in the Daiichi-Kashima Seamount region and discussed the gravitational consequences of the subduction of seamounts.

The Research Group for Daiichi-Kashima Seamount (Tokai University) [9–11] argued that the present topography of the seamount was originally formed in early Cretaceous and was not due to down-faulting. Based upon their paleontological study of some dredge samples, they adopted the "fixist" argument that a reefoidal limestone from the western half is of Barremian age which is older than an Albian limestone collected from the eastern half, and that the coral was formed when sea level was much lower than at present [12].

3. Seaward slope of the Japan Trench

The seaward slope of the trench is dissected by several normal faults to form horsts and grabens. In the Seabeam map, the faults are continuous
4. Daiichi-Kashima Seamount and the trench axis

A continuous, nearly straight, 100 km long scarp defines the normal fault. Trending N30°E, it cuts the Daiichi-Kashima Seamount in half in a remarkable fashion. The greatest vertical displacement along the fault plane at the crest of the seamount is 1600 m; displacement gradually decreases towards the ends of the fault. The inclination of the fault plane is about 35° at the crestal zone.

The diameter of the exposed body of the seamount is 30 km, but the fault extends as long as 100 km along the axial zone of the Japan Trench. At the northern extension of the fault is the deepest portion of the Japan Trench (7938 m deep). A seismic reflection record traversing this portion (Fig. 4b) indicates an offset of the ocean...
Fig. 4. Seismic reflection profiles reprocessed from the digital records on board “Jean Charcot”. (a) Profile 14 across the crest of Daiichi-Kashima Seamount. (b) Profile 22 across the deepest axis of the Japan Trench north of the Daiichi-Kashima seamount.
crust by the normal fault covered by thin horizontal trench-fill deposits similar to the uppermost (fourth) unit in the seaward slope. Occurrence of the sediment cover suggests that the fault motion is not very recent, at least in this portion.

The crestal areas of the two halves of the Daiichi-Kashima Seamount body have quite similar features in topography and acoustic characters; both are capped by a partially laminated but generally disturbed layer with about 400 m thick (Fig. 4a). Surface of the oceanward margin of the outboard (eastern) crest is particularly rough. Subbottom reflector on the outboard crest is nearly horizontal, whereas both surface and subbottom reflector of the inboard (western) crest are inclined 2.6° northwest. Erosion of the surface of the outboard crest is clear.

A small graben elongated parallel to the fault at the base of the scarp is very flat and filled by stratified sediments. The strata are nearly horizontal and quite laminated, suggesting layers of turbidites. These characteristics show that the sediments filling the graben have completely different origin to those capping the inboard and outboard crests. There is a fault boundary between the inboard seamount body and the graben, marked by a linear east-facing scarp with secondary irregularities.

Careful examination of topography of the lower crest and the fault scarp provides evidences showing that debris deposits observed on the downthrown crest were derived from the upper crest through the fault scarp. There exist many horseshoe-shaped valleys and ridges along the fault scarp which appear to have been formed by landslides. Ridges are particularly prominent along the 5200 m contour at the base of the fault scarp. Upstanding ridges between the landslides areas provide good outcrops of the upper part of the seamount.

5. Landward slope facing the seamount

5.1. Tectonic boundary between the trench axis and the landward slope

The toe of the landward slope is well defined by topography and in seismic records. The landward slope between 7000 and 4000 m shows neither clear reflectors nor faulted structures. This is in part a function of the limit of resolution of the seismic system, but may also indicate deposits with irregular bedding such as slumps, landslides and debris flows.

The junction between the trench axis and the landward slope is, on the other hand, a sharp boundary. It appears to be a thrust between the oceanic plate and the landward mass. The seismic profiler record shown in Fig. 4a indicates that the western margin of the 400 m thick layer capping the downthrown half has already been subducted beneath the landward slope at the crestal region of the seamount. A contact plane between the oceanic plate and the landward mass is clear in this profile as well as in the other records.

As shown in Fig. 5, the thrust bends oceanward on both northeast and southwest sides of the seamount and takes a form of indentation due to the collision of the Daiichi-Kashima Seamount. In the northern part of the surveyed area, the front of the landward wall diverges into several scarps. These scarps may possibly be a morphological expression of several thrusts in the lower part of the slope. This morphology might suggest possible accretionary processes at the toe of the landward wall. Such a topography has not been found in the other portions of the surveyed area.

Trajectory of the contact plane on the seafloor outside of the seamount zone has a general trend of N30°E, parallel to many normal faults on the oceanward side including the main fault. Nevertheless, this line must correspond to a thrust rather than a simple vertical fault, as its general shape is sinuous with some sharp changes in direction around the seamount. In the seismic records thrust and normal faults have a distinctly different appearance. The former can be traced beneath the landward slope, whereas the latter is truncated abruptly, especially in migrated record.

5.2. Sedimentary structures of the landward slope

Three sedimentary units are distinguished on the landward slope. The first (lowest) is a sedimentary infilling of basins on the upper slope that is up to 1 second thick (about 1 km deep). Several different facies can be observed in this unit. The second unit is represented by layered reflectors with a high frequency nature. It is concentrated on the upper slope, particularly below landslide scars. The third is an infilling of basins which is discordant with the layered sediments. It is only re-
cognized in the lower slope between the mid-slope terrace and the trench axis.

The reflectors on the upper slope are either horizontal or dip oceanward. Between the upper and the lower slopes is the mid-slope terrace marked by a depression filled with stratified sediments. The shape of the lower slope changes in front of the seamount and the base of the slope rises about 500 m over the subducted seamount. The mid-slope terrace between the upper and lower slopes is situated further towards the continent opposite this point of lower slope uplift.

5.3. Canyons in the landward slope

Several canyons are seen on the landward slope above the 4000 m contour. Fig. 5 shows distribution of these canyons. The principal characteristics of the canyons are as follows:

(1) Well developed with levees occur on the upper slope. Their general directions are NNW-SSE to WNW-ES except in the north where E-W to WSW-ENE directions prevail.

(2) Canyons in the upper slope terminate at the mid-slope terrace where they are buried by sediments and form small basins. One small canyon drains in the reverse direction flowing landward from the outer topographic high.

(3) Sediments transported through these canyons are deposited on the landward bulge (mid-slope terrace) below the 4000 m contour but do rarely reach the trench axis.

(4) One canyon with many tributaries is seen in the northern part of the surveyed area. Its average direction is WNW-ESE. It is traceable to the trench axis.

Distribution of most of these canyons is consistent with recent and probably continuing uplift of the local outer topographic high above the subducting Daiichi-Kashima Seamount. Old canyons were truncated by the outer high and sediments were deposited landward of the high in the new depressions dammed by the uplift of the slope.

6. Gravity and magnetism

The tracks of the vessel are close enough to one another that it is easy to correlate the values of both free air gravity and total geomagnetic field anomalies from one track to the next with ease.

![Fig. 5. Distribution of sedimentary facies in an area surrounding the Daiichi-Kashima Seamount. Canyon's paths are represented on the Japan Trench landward slope.](image-url)
The accuracy is better than ±2 mgal and ±1 nT, so it is possible to draw precise isoonomalous lines and, because of the good navigation (±100 m), to correlate Seabeam bathymetry, gravity, geomagnetism and seismic profiles.

The absolute minimum of the free air gravity anomaly (FAA) is -198 mgal (Fig. 6) corresponding to the deepest point of the trench and the relative absolute maximum is -17 mgal over the highest point of the Daiichi-Kashima Seamount at a depth of 3560 m. The average value above the abyssal seafloor along a line parallel with the trench axis crossing the top of the seamount is about -150 mgal. That means that when the seamount was situated on the abyssal plain before approaching the subduction zone, the maximum FAA above the Daiichi-Kashima Seamount was about -17 - (-150) = 133 mgal (as the abyssal plain is isostatically equilibrated. FAA = 0 approximately). This relative positive value above the seamount is in good agreement with values generally observed on most of the Pacific seamounts. The present observations confirm that the Daiichi-Kashima Seamount (at least its upper half) is still supported by a sinking rigid lithospheric plate as modelled by an elastic bar.

The map of the total geomagnetic field (Fig. 7) shows long amplitudes from -727 nT, minimum, to +480 nT, maximum. It is superimposed on anomalies corresponding to the magnetic lineations of the Pacific plate which general trend is about N75° E. These magnetic lineations are still visible under the landward slope. The observed coincidence between the magnetization of the seamount and the lineations of the plate implies that it was placed close to the accretionary ridge some 120–140 Ma B.P. This magnetic age is confirmed by recent identification of microfossils Orbitolina contained in limestone samples collected on the seamount during dives 55 and 57 [15]. Some discrepancy between the magnetic age (120–140) and fossil age (Albian: 100 Ma) may be due to off-ridge eruption of the seamount rocks and later subsidence of the crest to the sea-level forming the coral reefs.
7. Conclusions and discussion

Topographic and seismic reflection results obtained during the present survey provide definitive evidences for the splitting of the Daiichi-Kashima Seamount by a young normal fault. It is notable that the fault displacement was traced nearly 100 km, and that the deepest spot of the Japan Trench occurs along it. Such normal faults are observed across the oceanward slope of the Japan Trench but not east of the marginal swell about 100 km from the trench axis in the abyssal basin of the Pacific Ocean [14].

The present fault is not a relict of normal faults formed at the spreading axis, because it is oblique to the magnetic lineations in this region. It is likely that the Daiichi-Kashima Seamount was a round-shaped seamount with flat limestone cap that was split into two halves after it rode into the zone of downward flexure that forms the seaward slope of the Japan Trench. Obviously, the fault was not one continuous scarp but a stepwise sequence of cliffs and terraces resulted from an accumulation of many repeated displacements.

Seismic reflection profiles and topography indicate that the downthrown half of the Daiichi-Kashima Seamount is now being subducted beneath the landward slope of the Japan Trench. As the western edge of its crestal (possibly limestone and mudstone) cap is now situated just beneath the landward toe, initiation of subduction of the western (basaltic) flank of the downthrown half is estimated to be approximately 100,000 years based upon the known convergence rate. This date seems consistent to the time of start of uplift on the landward slope facing the seamount. Several canyons in the upper slope terminate at the mid-slope terrace which has been uplifted under the influence of the subduction of the Daiichi-Kashima Seamount.
References


