Marine sedimentation and volcanic activity in the Tabar-Lihir-Tanga-Feni Island region, New Ireland Basin, Papua Neu Guinea

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Abstract

Sediments raised during the EDISON I nd II Expeditions in the Tabar-to-Feni Island Chain area of the eastern New Ireland Basin, Papua New Guinea were studied to quantify the marine depositional conditions and volcanic activity during the Late Quaternary and the Holocene. δ^{18}O-values of the planktic foraminifera *Globigerinoides ruber* (white) showed that the cores on the slopes penetrated down to over 75,000 years BP, while cores at the distal end reached sediments that were 330,000 years BP, Interpolation between δ^{18}O-event marks allowed the identification and correlation of the major depositional phases in this region.

Volcanic activity and related submarine slides were particularly intensive in the whole island chain at around 75 to 73 ka BP, implying a significant contribution to global coolimg from these eruptions to cause the cool δ^{18}O-Stage 4. The Tanga area was continuously active to around 31 ka and then sporadically to Recent, with two major phases at round 18 ka and 3 ka. The Tabar group was quiescent during δ^{18}O-Stage 4 but became more active from about 48 ka to the Present.

Introduction

The New Ireland Basin of Papua New Guinea occupies a fore-arc position of the dormant Manus-Kilinailau arc-trench system, with a number of Pliocene to Recent volcanoes on a rifted Miocene sedimentary basement. During the EDISON I nd II Expeditions (Epithermal Deposits Southwestern Pacific Ocean) with the R.V. Sonne (cruise #94 in 1994 and #133 in 1998) in the marine areas surrounding the active Tabar-to-Feni volcanoes of the eastern New Ireland Basin, a large number of sediment cores were raised from the nearshore slopes down to the distal ends of the submarine valleys. Both biogenic production as well as tephra are deposited, with a considerable reworked portion of volcanic/biogenic debris from submarine slides especially during periods of intense volcanic activity and earthquakes.

Geological setting

The Tabar-to-Feni Island Chain area is located at the southeastern end of the arcuate New Ireland Basin behind the Manus-Kilinailau trench in the northeast of Papua New Guinea. Its formation was due to the westward subduction of the Pacific Plate under the Indo-Australian Continent in early Tertiary to Eocene. The collision of the Ontong Java plateau with the Manus-Kilinailau subduction zone at about 15 Ma blocked further subduction of the Pacific plate (Coleman and Kroenke, 1981). The resulting plate rotation and stress relocation caused a subduction reversal and the formation of the presently active north-northeast-facing New Britain Trench. It has over 5,000 m of mainly Oligocene and younger sedimentary fill (Exon et al. 1986; Marlow et al. 1988; Exon and Marlow 1990; Rogerson and McKee 1990; Herzig et al. 1994, 1998).

Post-collisional volcanism in the region which began about 3.5 Ma ago at Tabar are characteristically high-K, SiO_2-undersaturated magmas dominated by alkali-olivine basalts, olivine nephelinite, basanite, tephrite, ankaramite, trachybasalts, trachyandesites, tephritic phonolite, and phonolitic trachyte (Wallace et al. 1983; Steward and Sandy, 1988; Kennedy et al. 1990). It migrated southeastward to the Feni Island Group in recent times with recorded eruptions about 2,300 years ago, and submarine eruptions on the flanks of Lihir Island (Wallace et al. 1983; Licence et al. 1987; Rytuba et al. 1993).

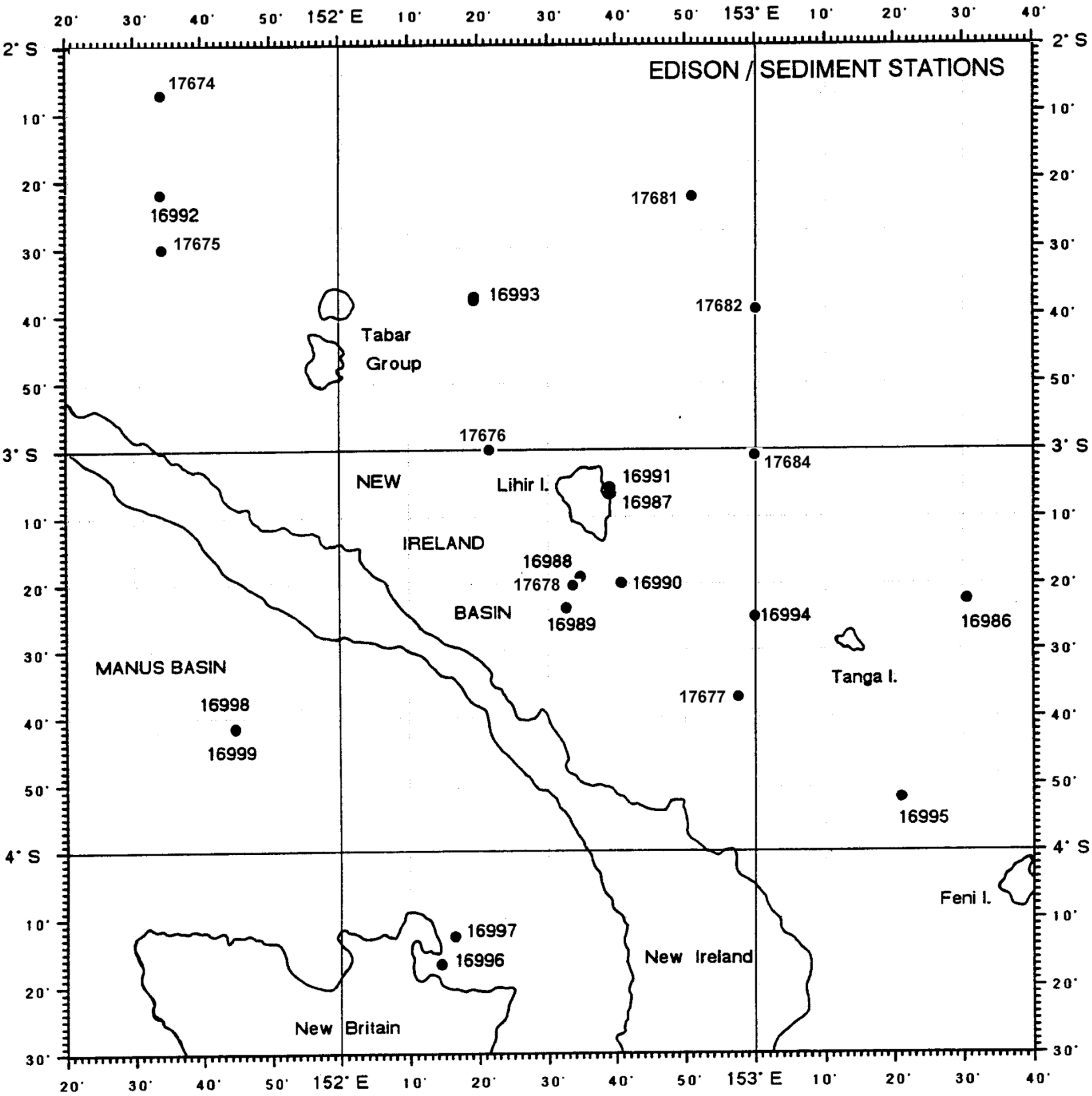


Fig. 1: Locations of GIK cores: SO 94 nos. 16986-16999, SO 133 nos. 17674-17684

Coring Operations

The core sites (fig. 1) were chosen after the study of sediment reflectors and sea floor morphology on various acoustic records from shipboard instruments. Parasound and hydrosweep surveys supplied the major information, and were sometimes supplemented by single channel seismic profiles. A constant sound velocity of 1500 m/s was applied for the water column, which is the standard setting on German research ships. Considering the high tropical surface water temperatures and local salinity variations, this setting was too high, with the result that the water depths from the parasound and hydrosweep deviated considerably from those of the wireline, especially at shallow water stations. Sound velocity measurements in sediment made on selected cores after the cruise in Geomar/GTG Kiel (Jian/ Angermann), showed that the velocities in clayey sediments lay between 1500-1550 m/s, and ranged in thick ash layers from 1650 to 1700 m/s at 20°C laboratory temperature.

The big box corer (GKG, 50 cm x 50 cm x 65 cm) was set out first in order to gain a first impression of the surface sediment, and to obtain an undisturbed surface layer and topmost decimeters of sediment. This was generally successful, with the exception of areas where the surface was impregnated with volcanic debris of gravel to boulder size.

A gravity corer (SL) and/or a piston corer (KOL), with a liner having 12 cm diameter, was set out depending upon the sediments brought up by the box core, and the nature of the sediment reflections from the acoustic records. The numerous ash layers below decimeter thickness proved to be a problem since their thicknesses usually lie below the resolution of the parasound. The gravity corer released through the trigger weight from a piston corer (SLS), together with an acoustic sender (pinger) on the wireline, resolved the problem of deviating water depths, and improved the penetration in sediment.

Sediment succession

The shallowest cores raised off Luise Harbour/Lihir Island showed an enrichment in their upper 30 cm especially of fine grained magnetite, generally in thin ash and debris layers. A 65 cm unconsolidated layer of angular basalt fragments with more pumice in its upper part was also encountered overlain by 50 cm of Recent sediment.

The deeper water cores were taken between Feni and Lihir Islands, between Lihir Island and New Ireland, and at the northwestern margin of the New Ireland Basin northwest of Simberi Island of the Tabar Group. A 125 cm thick volcanic ash layer underlying about 150 cm pelagic sediments was cored 30 km from Tanga Island, representing a major eruptive phase in the area (GIK 16986). Numerous thick, peppery, grey and brown volcanic ash layers from the sediment basin between the Feni-Tanga-Tabar Islands attested to past sporadic huge outbreaks from at least two major sources. The locations also included a small crater, only 180 m across, to observe the sedimentary sequence with reduced influence from submarine slumps and turbidites (GIK 16990). Only the upper 30 to 35 cm of the cores showed brown colors indicating higher oxidisation rates. The lower section of the sequence was composed mainly of grey and olive grey colors. Previous geochemical investigations (e.g. in the Atlantic Ocean off NW Africa, and in the equatorial Pacific) have revealed that these grey hues were indicative of reducing conditions within the core profiles caused by diagenetic decay of organic matter. The sediment surfaces in the box cores generally show a dearth of living organisms, and bioturbated segments (mainly through Zoophycos) were observed in only a few cores (see core descriptions). The alternating darker and lighter colors typical of glacial-interglacial cycles (a reflection of the carbonate content in the sediments) observed in most Atlantic and some Pacific cores was not present in our cores. The thick volcanoclastic beds in the sedimentary sequence representing episodic eruptive events of short geologic duration, coupled with the high sedimentation rates (e.g. over 20 cm/ka in the neighbouring Manus Basin), and nearness to land, may mean that most of our cores did not quite penetrate to sediments of the Last Glacial. In the Manus Basin, the big box corer (GIK 16998-1) brought up evidence of ongoing hydrothermal activity (thin surfacial Mn-rich layer), as well as four similar major episodes in the young geologic past. Two thin volcanic ash layers were also observed. Turbidity in the near bottom water column at 3¯42.115'S, 151¯41.937'E, 1767 m water depth in the side scan sonar records of profile SO-94 92-SSS a few kilometers to the west of our core locations may be due to active venting. This was also supported by the near bottom acoustically transparent layer in the parasound records.

During the EDISON II (SO 133) cruise, extremely gas rich sediments populated with clams were discovered at a fracture zone south of Lihir Island. Here, the variable reflectors in the Parasound records turned out to be concretionary crusts that were lithified through calcareous cement forming “hardgrounds”. The core recovery was moderate (GIK-17678). A box core (GIK-17680) had a sinuous opening representing the path of gas escape to the sediment surface measuring 2.5 cm in diameter. Numerous other holes are all less than 1 cm in diameter.

Magnetic susceptibilities were measured onboard on whole core sections with a portable instrument und reported in µ cgs (centimeter gram second) units. They enabled not only the local core to core correlation (core fit), but also helped in the identification/characterisation of ash layers with high ferrous content. The calibration of these onboard values were carried out through magnetic susceptibility measurements on archive liners of the box cores with a larger laboratory instrument at GEOMAR/GTG (Jian/Anger- mann) in Kiel. Replicate measurements made on the archive halves of cores GIK 16986-2 and GIK 16993-2, and on whole cores of GIK 16994-2 and 16995-2 substantiated the onboard profiles. The curves were shown on the same scale as the core logs to enable a direct overlay and correlation of the sedimentary sequence with the magnetic susceptibility profiles.

Description of cores

The sediment succession with composite depths are given here, by which the depths in the gravity and piston cores were corrected for surface sediment loss after the core fit. All available sedimentological, acoustical and magnetic data were correlated in such a core fit. Where high sediment loss did not allow a core fit, the sedimentary sequence was reconstructed in conjunction with the acoustic records.

SO 94-12 GKG GIK 16986-1; -13 KOL GIK 16986-2

This core station was sited in a small sediment basin situated to the north of Feni Island and east of Tanga Island. It was located on a promontory lying about 40 m higher than the base of a narrow valley running down eastwards north of Tanga. The parasound records showed a series of reflectors that paralleled the bottom morphology in the uppermost 12 meters of the sediment (fig. …). The stronger reflectors were over 1 m in thickness and were fairly consistent over kilometers. A correlation with the cored succession (fig. …) indicated that the two thick and strong shallow reflections were caused by an upper thick ash deposit (> 1.25 m), and by a lower series of thin ash layers. Due to the presence of this thick loose ash layer in the piston core, the sediments above it were lost during the coring operations (the top 40 cm of this core was muddy ash resettled in the core liner). A continuous sequence could not be established. The magnetic susceptibility measurements on archive halves (fig. …) showed that the thicker ash layers have values above 600 µ cgs. The clayey intercalations ranged from 120-180 µ cgs, reflecting the admixture of volcanoclastic material. An interesting feature observed for some thin ash layers was an offset of the magnetic peak, generally core-downwards, signifying higher magnetic susceptibilities from ash-filled borings and pockets (through bioturbation) in the underlying sediment section.

SO 94-16 GKG GIK 16987-1; -17 SL GIK 16987-2

The gravity core was located in the Luise Harbour area of Lihir Island. Probably as a result of the shallow water depth, bottom roughness, and thin soft sediment cover with hard acoustic underground, the parasound recorded poor reflections only. The box core came up empty due to a malfunction of the equipment. The sediment sequence from the gravity core consisted mainly of volcanic ash, and was illustrated and described in figure …..

SO 94-30 GKG GIK 16988-.1

This station was selected after OFOS surveys and was located in the crater of the newly discovered Edison Seamount south of Lihir Island. A few large living clams (related to Calyptogena sp.), some small living brachiopods (specimens with the Canadian Geological Survey), and numerous large shells (> 15 cm long axis), some filled with grey, soft, fine to medium grained volcanic material with a rotten smell was brought up. The shells from both living and dead clams were brittle and break easily. These giant clams far below the euphotic zone were clear indicators of active hydrothermal venting. The ship drifted during the coring and the sample was probably from the side of the crater, where numerous fields of large clams were observed by the OFOS.

SO 94-31 GKG GIK 16989-1; -32 SL GIK 16989-2

The cores were taken approximately 100 m high on the flanks of a channel between New Ireland and Lihir Islands. The base of the channel showed no sediment (fig. …) in contrast to over 25 m of sediment with thin reflectors on the flanks. The box and gravity cores brought up clays with thin volcanic ash layers (fig. ….). The high very fine silt sized volcanic glass content of these ``clays" is reflected in their high magnetic susceptibilities (fig. …). Due to the fineness of the grains, these volcanoclastic enriched layers were very difficult to detect visually during the course of a normal core description, but were apparent in the susceptibility profile and through smear slides.

SO 94-35 GKG GIK 16990-1; -36 SL GIK 16990-2

The cores were raised from a small crater (180 m diameter) on the southern slope of Lihir Island. The crater rim should protect the area from adulteration with sediment (at least the coarser fraction) from submarine slumps. Through exact navigation on the part of the ship's crew, the sediment in the inside of the crater could be cored. A correction of +4 cm had been made to the depths in the gravity core after a core fit with the big box core, to compensate for sediment loss at the top of the gravity core.

The parasound records (fig. …) showed large lateral thickness variations of the sediment layers. This was supported by the numerous erosional unit boundaries observed in the sediment succession of the cores (fig. …). The magnetic susceptibility values (fig. …) increased gradually towards the base of the core. Only the ash layers below 3 m depth were resolved by the 3 cm interval applied for these measurements.

SO 94-37 GKG GIK 16991-1; 38 SLS GIK 16991-2

These cores were also located in the Luise Harbour area of Lihir Island. The gravity corer with trigger weight was bent during the operation. A 65 cm thick debris layer with loose, angular, black basaltic fragments (with no fine sediment matrix), and more pumice in its upper part was cored through (fig. …). The magnetic susceptibility measurements showed values over 800 µ cgs for the basalts and between 100-150 µ cgs for the clayey layers (fig. …).

SO 94-46 GKG GIK 16992.2, -47 KOL GIK 16992-2; 48 SL GIK 16992-3

These cores were raised from the New Ireland Basin northwest of Simbiri Island off its foot. The 12 m piston corer was bent and the nails stripped from the core catcher, resulting in only 1.7 m of sediment. The gravity corer also brought in 2.2 m of sediment only. Apparently the strong reflections in the parasound records which showed very strong lateral variations (fig. …), parasound record ``on station") were too thick and hard here for the corers to penetrate through. A good correlation could be made between the cores, allowing the construction of a composite succession (fig. …) through magnetic susceptibility measurements (fig. …) substantiated by onboard core descriptions.

SO 94-54 GKG GIK 16993-1; -55 SLS GIK-16993-2

These cores were located in the middle of a local sediment basin situated to the east of the Tabar Group of islands. The parasound records indicated over 33 meters of sediment (fig.), with numerous strong reflectors in the upper 16 m. The gravity corer with trigger weight won 674 cm of sediment. A core fit based on sediment physical and lithological characteristics suggested that about 12 cm of surface sediment was missing in the gravity core. The succession included 15 major and minor ash and turbidite/ash layers (fig.). Magnetic susceptibilities (fig. …) in the upper segment of the core generally correlated well with the ash layers. In the core section below 3 m, the ash layers appeared to be well hidden in the clayey parts, and the fine silty ash layers encountered were full of transparent glass shards.

SO 94-74 GKG GIK 16994-1; -75 SLS GIK 16994-2

These stations were located between the Tanga and Lihir Islands. Parasound records were not available for this station. The gravity corer with trigger weight raised 450 cm of sediment. The cores have abundant volcanoclastics with intercalated clays (fig. …). The magnetic susceptibility measurements (fig. …) showed peaks corresponding to the numerous major and minor volcanic ash layers. They also indicated that the top 9 cm of sediment were missing in the gravity core.

SO 94-77 GKG GIK 16995-1 -78 SLS GIK 16995-2

These cores were located south of Tanga Island between it and Feni Island. Parasound records showed a strong surficial reflector over a partially transparent intermediate layer with reflections. A strong basal reflection was present at about 7 m depth (fig. …). The gravity corer with trigger weight brought up 209 cm of sediment only, and could not penetrate through the major ash layer (traces in the core catcher) at around 2.5 m depth (fig. …). The magnetic susceptibility profile (fig. …) showed a good correspondence of the clay and ash layers with the low and high levels in the record respectively. The core fit indicated that 16 cm were missing from the top of the gravity core.

SO 94-81 GKG GIK 16996-1;
SO 94-82 SLS GIK 16997-1

These request core stations of our Papua New Guinea hosts were positioned off Rabaul Harbour at its outer periphery, with the objective to monitor the past eruptive events of the Rabaul volcanoes. Unfortunately, the uppermost volcanic rocks-pumice debris (up to

15x18x14 cm blocks observed in the box core), also prevented core recovery with the gravity corer at a second site located even further offshore. The corer was damaged during this operation. The parasound records (fig. …) showed acoustically hard surfaces with irregular internal reflections.

SO 94-94 GKG GIK 16998-1; -96 SLS GIK-16998-2
SO 94-97 SL GIK 16999-1

These stations were located in a local sediment depression parallel to the southeastern flank of the Pual Ridge in the SW-NE trending main ridge complex of the Manus Basin. Parasound profiles in the vicinity showed subcrops of slightly dipping, acoustically very hard volcanics with a transparent (cloudy) cover reaching over 15 m above it (fig. …). Appparently, there was enough difference in acoustic impedance at the boundary layer to produce this reflection. We speculate that temperature and salinity differences caused by hydrothermal venting could account for changes in the densities and sound velocities in the near bottom water mass to produce this phenomena, which should be further investigated in future cruises.

Attempts were made to raise cores from “sediment ponds" in this patchy hard volcanic cover (fig …). The big box corer was overfilled with sediment. The surface sediment, a mm thick black layer, was only partially preserved. Core liners thrust into the box core contained over 70 cm of very soft sediment (fig. …) . Both gravity cores (the second was raised in the vicinity after the ship left the station after GIK 16998-2) were damaged, and the sediment section partially or fully lost. The magnetic susceptibility profiles of the box and gravity cores, shown in fig. … with actual depths, clearly illustrated the loss of sediment over the basalt layer.

SO 133/2 -1 GKG GIK-17674-1; -2 SL GIK-17674-2
SO 133/2 -3 GKG GIK-17675-1; -4 SL GIK-17675-2

These core stations are located on slopes to the north and south of the broad flat basinal area of EDISON I station GIK-16992 (fig. 1). Parasound and magnetic susceptibility profiles (fig. …) showed that the base of the GIK-17674 and GIK-17675 reached down to around 25 ka and 30+ ka respectively. The sandy nature of the sediments (see core descriptions fig. …,) did not allow deeper penetration than in core GIK-16992 of the previous EDISON I cruise.

SO 133/2 - 8 GKG GIK-17676-1; -9 SL GIK-17676-2

This core station is located between GIK-16989 and GIK-16993 of the former cruise (fig. 1). Pelagic foraminiferal oozes and numerous ash layers typical for this area were also penetrated in this core (fig. …). Core recovery of under 3 m is much less than in the EDISON I cores. The magnetic susceptibility measurements (fig. …), however, indicated that the age at the base of the present core is comparable to the neighbouring cores (δ^{18}O Stage 4, 65 ka). The thick ash layer at the base of GIK-16993 was not reached.

SO 133/2 - 37 GKG GIK-17677-1; -38 SL GIK-17677-2

This core is located to the SW of Tanga Island and penetrated five black ash layers.(fig. …). Parasound records showed that the reflectors were lensing out towards the core station, with an accumulation of several reflectors in the upper meters of sediment.. The numerous ash layers in the upper meter of the core as indicated by the magnetic susceptibility measurements (fig. …), and confirmed as ash layers (fig. …) means that in spite of its short length, this core probably penetrated much older sediments than GIK-16994.

SO 133/2 - 57 GKG GIK-17678-1; -58 SL GIK-17678-2
SO 133/2 - 59 GKG GIK-17679-1
SO 133/2 - 60 GKG GIK-17680-1

This set of stations was located in the vicinity of the new clam beds from the newly discovered gas rich sediment area south of Lihir Island (see also CTD report, Schmidt/ Thiessen). GIK-17678 was located directly at the sites of the clam beds on the slope. GIK-17680 came from the valley area close by.

As GIK-17678 was raised up, a strong smell of rotten eggs (H_2S) was noted when the corer neared the sea surface, and upon opening the core onboard in the laboratory. On deck, a odourless gas escape was also observed. Four major concretionary “hardgrounds” each about 10 cm in thickness were encountered between 1 and 2 m depth in sediment. Calcareous concretions were also present in the sandy beds between the hard layers. Below 2 m (fig. …), the sediment was clayey and concretions were not observed.

The large grab became entangled in its own wire during station GIK-17679, fell on its side, and there was no sediment recovery.

In GIK-17680 (fig. …), a large sinuous open hole 2.5 cm in diameter was observed almost reaching the surface. Smaller openings (< 0.8 mm) in a cluster were also observed. No correlation through magnetic susceptibility profiles with the neighbouring cores GIK-16989 and GIK-16990 was possible.

SO 133/2 - 63 GKG GIK-17681-1; -64 SLS GIK-17681-2
SO 133/2 - 65 GKG GIK-17682-1; -66 SLS GIK-17682-2
SO 133/2 - 69 GKG GIK-17683-1; -70 SLS GIK-17684-1

These stations form part of a profile extending the coring northwards of the first expedition’s GIK-16994 core. The ash layers are expected to be less dominant, in numbers as well as in thickness, accompanied by a corresponding increase of normal deep sea sediments.

Core recovery was very good at the first two locations. Most of the sediment, estimated to be about 5m, slipped out again from the last core barrel due to a damaged core catcher (GIK-17684). The last big box corer (GIK-17683) at this site also had no penetration in sediment and brought back some pieces of brown and black coated pumice.

A tentative correlation between the above three cores with the previous (anchor) locations GIK-16993 and GIK-16994 showed that the outermost core GIK-17681 recovered the sediment sequence extending down beyond (δ^{18}O- Stage 4).

Conclusions and recommendations

The box, gravity and piston cores from the New Ireland Basin showed evidence of numerous eruptive events from at least two different sources in the young geologic past. The intercalation of volcanic ashes in the sedimentary sequence offered ideal reflection horizons in the parasound records, being consistent over tens of kilometers. Combined with sedimentological, chronological, geochemical, and petrological studies of selected horizons in the sediment cores, it may be possible to identify and map the deposits of major volcanic eruptive events over large areas, and thus also gain an insight into the paleoceanographical and paleometeorological conditions in the area.

The living Calyptogena fields offered evidence of ongoing hydrothermal venting. The sedimentary sequence from a crater further downslope presented an opportunity to study the sedimentological and petrological aspects with reduced adulteration from allochthonous material.

The thin black fluid mm-thick top layer in cores from the Manus Basin signified that the present hydrothermal activity was short lived. Numerous thicker black layers in the cores confined to limited horizons indicated that the venting was episodic with long periods of quiescence or reduced activity.

The ``cloudy" bottom layer observed in the parasound records near the Pual Ridge in the Manus Basin provided a unique chance to follow and identify the sources of these phenomena. Combined with side scan surveys, it should be possible to chart the hydrothermal vents.

SO 94-54 GKG GIK 16993-1 Latitude: 2°38.00′S Longitude: 152° 19.47′E
Date raised: 27.03.1994 Water depth: 2216 m Core length: 48 cm

SO 94-55 SLS GIK 16993-2 Latitude: 2°37.88′S Longitude: 152° 19.42′E
Date raised: 27.03.1994 Water depth: 2215 m Core length: 674 cm

This core station with a large box core and a gravity core with trigger weight was located in the middle of a local sediment basin situated to the east of the Tabar Group of volcanic islands. The parasound records indicated over 33 meters of sediment, with numerous strong reflectors in the upper 16 m (fig. 16993a). The peaks with high magnetic susceptibility values (fig. 16993b, table 16993a) in the upper segment of the core generally correlated well with the ash deposits in the core. In the lower part of the core, the ash layers were not prominent and appeared to be well hidden in the clayey layers. The fine silty ash layers encountered were full of transparent glass shards (volcanic ash).

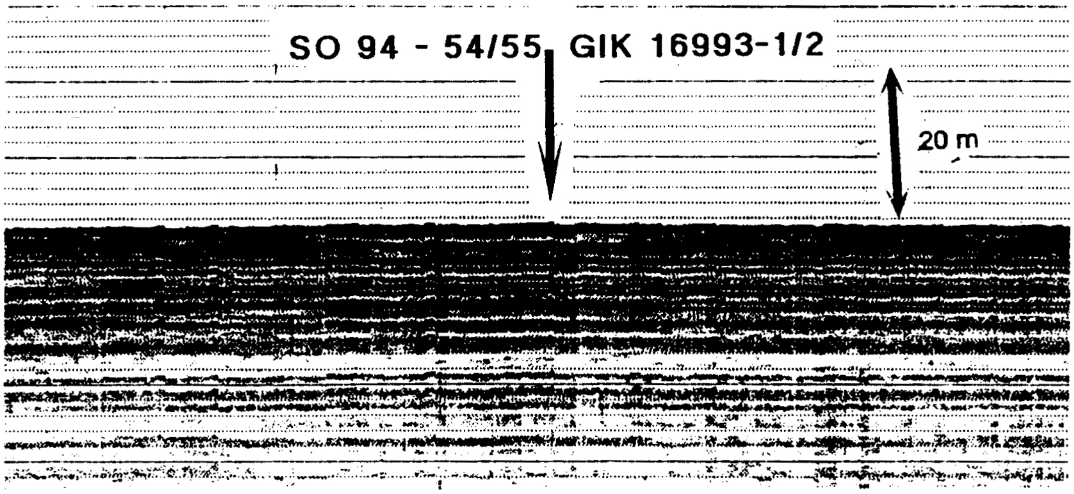


Fig. 16993a: Parasound records at core station SO 94 –54/55. Cores GIK 16993-1 and –2.

The surface of the box core was almost devoid of living organisms. Small fragments of basaltic lava having less than 1 mm in diameter either on the surface or covered by a thin film of yellowish brown mud were observed (see the following photograph of the undisturbed sediment surface of the 16993 box core). Darker bands in the box core showed phases of partially anoxic conditions in the area.

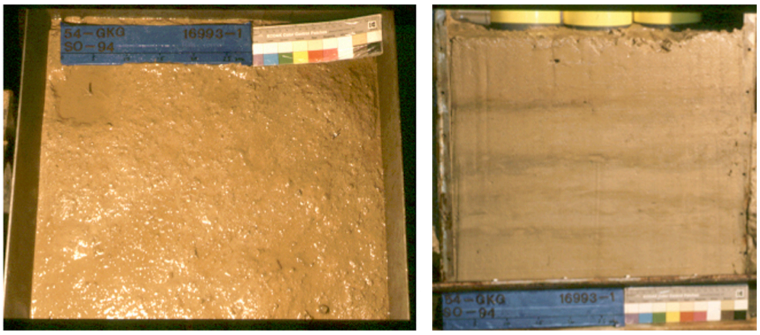


Plate 16993a: Left: Surface of box core 16993-1
Right: Vertical section with dark bands

Photographs of the gravity core are presented below (plates 16993b, c). The brownish coloured oxygenated layer extended down to about 35 cm (=46 cm composite depth) in the gravity core. The numerous irregular basal boundaries, and current and graded beddings of the coarser grained sediment layers illustrated the high dynamics that prevailed in the area, with sediment flows and reworking of older deposits. The δ^{18}O-Stage 4/5 boundary at 4.85 m was underlain by a thick ash layer. A series of clays and ashes were further penetrated down to the base of the core.

Plate 16993b: Upper section of the gravity core

Plate 16993c: Lower section of the gravity core

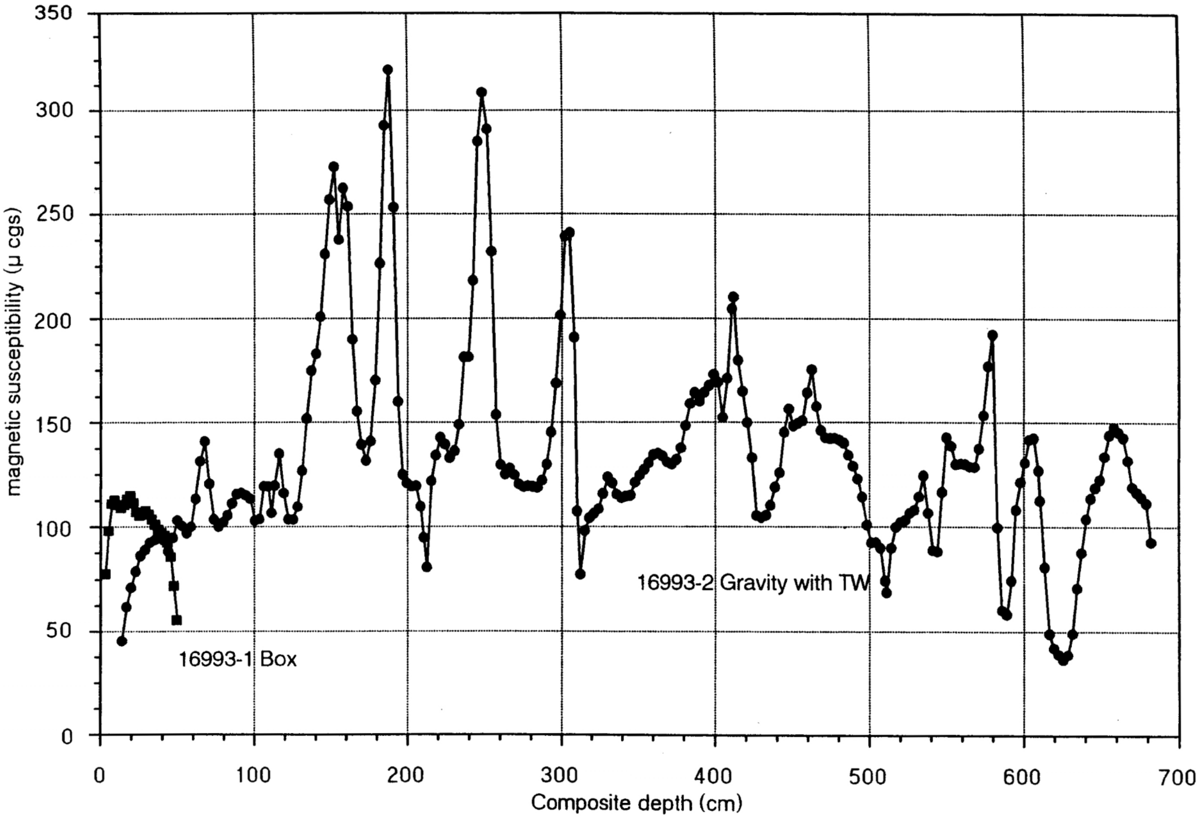


Fig. 16993 b: Magnetic susceptibility measurements of cores GIK 16993-1 and –2.

A core fit based on magnetic susceptibility measurements and lithological succession/ characteristics suggested that about 11 cm of surface sediment was missing in the gravity core. This was confirmed by the core fit made with $\delta^{18}O$-analyses on *Globigerinoides ruber* (white). A lithological description of the cores is presented in fig. 16993c.

Sediment physical properties such as water content, dry bulk density, and percentage of the sieved fraction >63 µm, as well as observations on the presence of volcanic materials in this fraction > 40 µm were presented in Table 16993b.

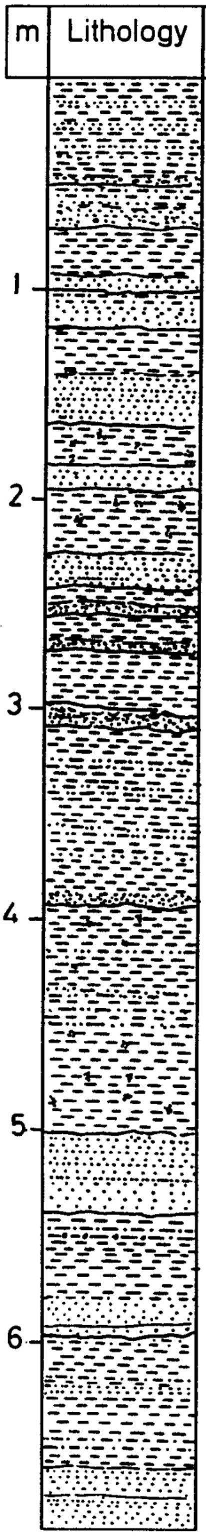
$\delta^{18}O$-analyses on *Globigerinoides ruber* (white) carried out in the then ^{14}C-Laboratory (now Leibniz Laboratory) of the Kiel University were presented in table 16993c, together with the $\delta^{18}O$-stratigraphy, calculated ages of the layers and sedimentation rates. The latter rates were calculated leaving out the tephra layers.

Two AMS ^{14}C- age measurements were carried at the above mentioned Leibniz Laboratory gave the following results:-

Core no.	Depth	Comp. Depth	No. of *G. ruber*	*AMS ^{14}C-Age*	*$d^{13}C$ (‰)*
16993-2	460 cm	471 cm	900	52 010+5210/-3140	-3,16±0,21
und as an ^{14}C aktivity sample					
16993-2	475	486	900	48 920+3250/-2310	-5,33±0,20

Ship : **SONNE - 94** Station: **SO 94- 54 GKG, -55 SLS**

GIK No.: **16993-1/2** Tabar-Lihir Area, Papua Neu Guinea



Color	Depth	Lithological Description
10YR 5/4 2.5Y 4/3	0- 46 cm	yellowish brown, plastic clay with light olive, silt size volcanoclastics at 10-12, 22-24, 29-32, 34-35 and 45-48 cm. Speckled white with larger foraminifera below 35 cm. Occasional coarser pumice fragments.
5Y 4/2 5Y 6/2 5Y 5/2	46- 118 cm	olive grey, fine to medium grained, volcanic ash, silty at 62-65 cm, graded units at 90-100 and 100-118 cm, with uneven basal contacts, salt and pepper texture from white larger foraminifera and coarse grained, black magnetites and pyroxenes, with intercalated olive grey clays with greenish-hue, larger foraminifera at 52-58 and 70-90 cm.
5Y 5/2	118- 138 cm	olive grey, plastic clays with greenish streaks.
5Y 6/2 5Y 4/1 5Y 3/1 5Y 5/2	138- 238 cm	light olive grey, silty to fine grained, volcanic ash, 1-3 mm bands with darkminerals (pyroxenes, magnetites, some amphiboles, biotites). Nonlaminated 182-193 cm. Irregular contacts with interbedded olive grey, plastic clays at 165-182 and 193-225 cm (bioturbate, zoophycos), greenish streaks at 204-207 cm, salty texture from larger foraminifera.
5Y 5/2 5Y 4/1	238- 297 cm	olive grey, plastic clays with greenish streaks. Light and very dark grey, silty to coarse grained, volcanic ash layers at 245-254 and 265-270 cm.
5Y 4/1	297- 308 cm	Volcanic ash as above, cross-bedded at 297-303 cm.
5Y 5/1	308- 384 cm	Olive grey, fairly hard, plastic clays. Greenish flecks/ spots at 325-329, 340-343, 356-357, and 369-370 cm.
2.5Y 4/3 5Y 4/1 5Y 5/1	384- 406 cm	olive brown, silty to fine grained ash with light and dark grey laminations at 384-394 cm, wood 1 cm ϕ at 402-403 cm, bioturbate with ash fillings in worm tubes.
5Y 4/1	406- 500 cm	olive grey, plastic clays, white speckled with larger foraminifera, with 2 to 8 mm olive grey-green layers at 414, 434, 442-443, 449 and 450 cm. Patches of bioturbation (zoophycos) more frequent below 450 cm, filled with silt sized volcanic ash between 460 and 468 cm. Irregular boundary with
10YR 4/1	500- 539 cm	dark grey, silty, volcanic ash with thin 2 and 1 mm darker layers at 506 cm and 508 cm respectively. The laminations faded out with increase in grain size from silt to fine grain below 509 cm.
5Y 4/1	539- 578 cm	olive grey, plastic clays with very fine grained volcanic ash layer at 544-551 cm having medium sized black grains towards the base.
10YR 4/1	578- 597 cm	dark grey, very fine silty to very fine grained, volcanic ash. Distinct boundarywith lower ash at 592 cm. Irregular basal boundary at 597 cm.
10YR 3/2 5Y 4/2	597- 659 cm	olive grey, plastic clays with foraminifera. Greenish grey streaks at 599, 614-615, 645-646 and 648-649 cm, and dark greyish brown, fine silty ash at 620-623 cm.
2.5Y 4/2 5Y 4/2	659- 686 cm	Dark greyish brown, silty to fine grained, volcanic ash with light and dark layering.

Fig. 16993c: Lithological description of composite core 16993. 11 cm in core 16993-1 = 0 cm (surface) in 16992-2.

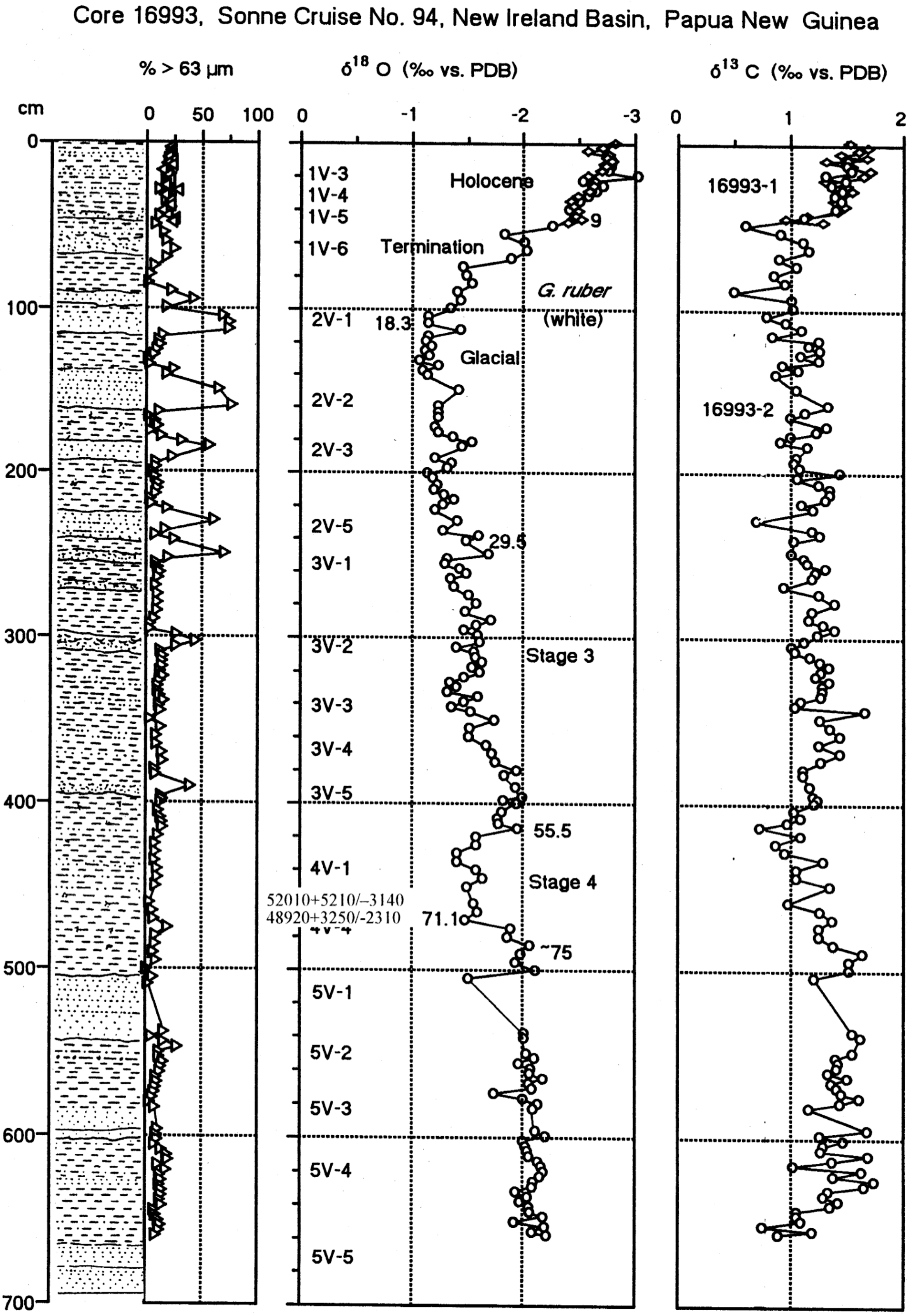


Fig. 16993e: Lithology, grain size >63 µm, δ18O and δ13C with ages in 1000 calendar years and volcanic events in composite core GIK 16993. AMS 14C-ages are conventional.