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DEACON LABORATORY

Natural Environment Research Council

RRS CHARLES DARWIN

CRUISE 35/88

13 OCTOBER – 17 NOVEMBER, 1988

GLORIA STUDY OF THE EASTER MICROPLATE, EAST PACIFIC RISE

CRUISE REPORT NO. 211

1989

INSTITUTE OF OCEANOGRAPHIC SCIENCES

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CRUISE REPORT NO. 211

RRS CHARLES DARWIN
Cruise 35
Tahiti - Valparaiso
13 October - 17 November 1988

GLORIA Study of the Easter Microplate, East Pacific Rise

Principal Scientist
R. C. Searle

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ABSTRACT

Underway geophysical data, consisting of GLORIA sidescan imagery, magnetic and gravity profiles were collected on passage from Tahiti to the Easter Microplate and covering the whole of the Microplate and adjacent areas. The principal aim was to image and assess the present structure of the microplate and to deduct its evolution since its inception. Additional objectives included combination of GLORIA digital images with SeaBeam and SeaMARC II data and to improve knowledge of the distribution of fracture zones and volcanic chains between Tahiti and the Easter microplate.

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ITINERARY

Departed Tahiti, French Polynesia:	1988 October 13 (day 287)
Arrived Valparaiso, Chile:	1988 November 17 (day 322)

OBJECTIVES

1. To run GLORIA over a well-defined microplate, imaging as much of the plate as possible.

2. Thus to completely determine the position and nature of the present microplate boundaries.

3. To determine as far as possible the tectonic history of the microplate from its inception to the present.

4. To digitally combine GLORIA, SeaBeam and SeaMARC II data to provide for the first time a combined topographic and sidescan image of a tectonic plate.

5. On passage to the microplate, to obtain GLORIA and other data relevant to the tectonic history of the region, and particularly to improve knowledge of the distribution of fracture zones and volcanic chains between Tahiti and the Easter microplate.

6. On passage from the microplate, to obtain GLORIA and other data relevant to the tectonic history of the region; particularly to determine the precise position and azimuth of the Chile transform fault, and thus to improve the precision of the Nazca-Antarctic rotation pole.

Objectives 1-2 and 5 were met in full during the cruise, and we fully expect 3 and 4 to be met by subsequent shore-based work. During the course of the cruise it was decided to abandon objective 6, in order to give more time to the study of the microplate.

NARRATIVE

Monday October 10th

The Principal Scientist and several of the scientific party visited the Geophysical Laboratory in Papeete, and were kindly shown around by its Director, Dr. J. Talandier. As well as examining his equipment (seismographs of the French Polynesian network and the French global Geoscope network), we held fruitful discussions on the local geology, particularly the recent seismic activity associated with the Tahiti Hot Spot near Teahetia Seamount, some 100 km SE of Tahiti.

October 11th-12th

RRS Charles Darwin was visited by members of the French hydrographic service (SHOM) stationed in Tahiti, and in return the Principal Scientist and Master were entertained on board one of their ships. A gravity base-tie was made in Papeete.

Thursday October 13th (Julian day 287, All times GMT; refer to Fig. 1 for track)

RRS Charles Darwin departed Papeete at 1930 GMT (0930 local time). At 2200 we deployed the gear in perfect weather. PES, 3.5 kHz, GLORIA and magnetometer were launched; the gravimeter was also run. We then turned onto a southeasterly course to examine the active hotspot in the region of Teahitia Seamount and Mehetia Island.

October 14th - 18th

At 288/1237 GMT we had passed Mehetia, and turned onto a course of 109°, en route for Oeno Atoll. During the next four days we overcame several initial problems in the instrumentation, (mainly in the GLORIA logging and replay systems), and settled into a data processing routine.

A gravimeter gyro was replaced on 291/1855.

October 18th - 21st

We rounded Oeno at 292/1803, and altered course to 096°. This took us along the line of the "Fracture Zone 2" hypothesized by Okal & Cazenave (1985) to be the forerunner of the Easter microplate's southern boundary.

October 21st - 23rd

At 295/1926 we left the Fracture Zone 2 line (without having seen the proposed fracture zone) and turned southeast along the southern trace of the microplate boundary. A single line (with a small initial zigzag) allowed us to image the whole of this trace with GLORIA and took us to the vicinity of the southern triple junction where the microplate abuts the East Pacific Rise (EPR).

On day 296 we lost about two hours of computer logging from 0222 GMT, when the Cambridge Ring failed.

October 23rd - 24th

From 297/0250 to 298/0655 we investigated the southern triple junction and adjacent Overlapping Spreading Centre with a small box survey.

October 24th - 25th

At 298/0704 we turned westward onto line 8. This was to be the first of ten long E-W lines covering most of the microplate interior and its eastern and western boundaries. Because we felt the southern part of the microplate interior was reasonably well understood from earlier work, lines 8 and 9 were relatively widely spaced, to allow time for a fuller coverage to the north.

October 26th-27th

Line 10, at 25°07'S, began at 300/0815. From here on, almost all lines were spaced 10 miles or less, giving nearly 100% GLORIA coverage. Towards the west end of line 10 we made a small V-shaped diversion (301/0728 - 301/1127) to investigate further some enigmatic structures glimpsed at the end of line 8. These turned out to be associated with a previously unknown propagating rift on the western microplate boundary - the first of several propagators that we discovered there.

October 27th - November 3rd

We continued following E-W survey lines, gradually working our way up the microplate and revealing both the precise location of its boundaries and the detailed structure of its interior.

November 3rd - 4th

At 308/1230 we began the first of two adjacent lines designed to view Pito Deep at the northeast corner of the microplate. At almost 6000m this is thought to be the deepest point on a Pacific spreading centre. We did not attempt 100% GLORIA coverage of this region, however, because it had been well surveyed by Hey and others using Sea MARC II.

November 4th - 5th

We ran the last long E-W line along what had been considered the northern boundary of the microplate, passing the northern triple junction at 309/0510. At 309/1930 we turned onto a SW-NE line, commencing a survey of a possible northern extension of the microplate.

November 5th - 7th

The microplate extension survey continued, employing NE-SW tracks since the predominant tectonic fabric here was N-S, with subsidiary E-W trends. This area is characterised by significant seismicity, and reconnaissance Sea MARC II swaths had shown some major E-W fault blocks in this area. GLORIA showed that they are in fact common here.

November 7th - 9th

The extension survey ended at 313/0845, after running a final W-E line just to the north of the existing Sea MARC II coverage around the Pito Rift area. We then turned south until we picked up the trace of the initial outer pseudofault (which marks the path of the developing East Rift of the microplate). It was hypothesised that it might extend as far as Easter Island, indicating that the microplate could have come into being there 3 Ma ago. We actually followed the pseudofault to a point close to the Island, then on day 314 steamed round the west and south sides of the island to see if it extended further south. At 314/2300 we began slowing to recover GLORIA and the 3.5 kHz.

November 10th - 17th

At 314/2348 we had recovered GLORIA and the 3.5kHz fish, and restreamed the magnetometer. We then set course for Valparaiso at full speed (about 11.5 knots in direct drive). The PES and magnetometer were recovered at 321/1236, and at 1700 that day an e/m log calibration was carried out. Darwin docked in Valparaiso at 322/1250.

RCS

PROJECT REPORTS

Passage to Easter Microplate

Teahitia hot spot

Following our visit to the Geophysical Laboratory in Tahiti and a request from our colleagues in Paris, we launched GLORIA immediately on leaving Tahiti, in order to survey the extent of the Teahetia-Mehetia hot spot while on passage to the microplate. The hotspot is thought to mark the current position of the mantle plume that has produced the Society Islands chain. The easternmost island in the chain is the 435-m-high Mehetia at 17°53'S 148°03'W, but recent seismic activity has been concentrated around both it and Teahitia seamount at 17°33'S 148°49'W, and fresh lavas have been recovered from both (Cheminee et al., 1988).

Relatively young lava flows can be distinguished on GLORIA images by their high acoustic backscatter (Holcombe et al., 1988). Our GLORIA swath shows extensive recent lavas and small (<2-5km diameter) cones in the Teahitia area between 17°20'S 149°05'W and 17°45'S 148°40'W, We recorded a -900 nT magnetic anomaly over the southwestern flank of Teahetia at 17°35'S 148°50'W, possibly indicating that the seamount contains undifferentiated, high Fe-Ti basalts. Apart from a small flow at 17°55'S 148°22'W on the west flank, we saw no very recent-looking lavas around Mehetia.

No lineated seafloor spreading fabric was seen between Tahiti and 148°00'W suggesting that the original fabric has been completely buried by lavas and/or sediments. Subdued fabric, oriented about 345°, was seen between 148°00'W and 147°20'W, with some small cones and older-looking (partially sedimented) lava flows, whose outlines are partly controlled by fault scarps of this fabric. A large (15km diameter) seamount was passed at 18°45'S 147°10'W. East of that there is a 200-km-long section of very well developed spreading fabric which extends to 145°30'W. The western boundary of this fabric may indicate the eastern limit of Mehetia hot spot activity, although even here (and episodically eastwards to the microplate) we see some moderately recent looking lava flows and clusters of small seamounts.

Mehetia to Austral Fracture Zone

Except for two gaps of 120 and 190km, we could see tectonic spreading fabric, with varying degrees of exposure but consistently trending 340-349°, from 18°20'S 148°00'W to the northern edge of Austral Fracture Zone at 21°20'S 139°30'W. The western of the two gaps, from 143°20'W to 142°10'W, is characterized by tens of small (1-3km diameter) volcanic cones surrounded by recent lavas; the eastern one has hundreds of very small (1-2km) cones surrounded by a highly backscattering field which probably represents recent lavas, although typical lobate flow edges were not seen there. Some moderately recent lava flows were seen even between these two volcanic fields; their flow directions were clearly controlled by the spreading fabric, but they were not sufficiently voluminous to completely obscure the fabric.

No major fracture zones were seen between Tahiti and 139°30'W, though some partially obscured and discontinuous 067-077° lineaments between 142°30'W and 143°30'W may indicate one or two minor fracture zones there.

Magnetic anomaly 30 was recognised at 148°30'W, with a complete sequence to anomaly 21 at 141°W, just west of the Austral fracture zone (Fig. 2). The best fit for the average half spreading rate over this interval, projected E-W, is 46 mm a^{-1}.

Austral Fracture Zone

We crossed a major fracture zone, which we believe is the Austral Fracture Zone, between 21°20'S 139°30'W and 21°45'S 138°00'W. Like other major fracture zones formed at medium to high spreading rates, it displays several distinct fossil transform traces. In this case there are five in a 90 km-wide zone, trending between 070° and 077°, associated with a series of ridges and valleys having a total relief of 1500m.

The fracture zone controls the northern margin of the volcanic plateau that culminates in Mururoa Atoll. It is colinear with the fracture zone that passes between Tubai and Raivavae islands near 23°30'S, 148°00'W, and which shows up clearly on the SeaSat gravity map (Haxby, 1987). However, it is offset from the projection of the Austral Fracture Zone as mapped east of the Tuamotus on General Bathymetric Chart of the Oceans (GEBCO) chart 5.11, and is north of the position indicated for the Austral Fracture Zone on the American Association of Petroleum Geologists (AAPG) Tectonic Map of the Southeast Pacific (Corvelan et al., 1981), which runs between Fangataufu (south of Mururoa) and Gambier islands. These mapped traces do not show up on the SeaSat gravity. Since we did not cross any other major fracture zone on the whole passage, we are confident that the five-strand feature we crossed must be the Austral. We did cross a single 082° lineament at 136°30'W which would correspond with the AAPG position for the Austral Fracture Zone. However, this lineament is not very clear west of our track, where it is crossed by spreading fabric striking 342-005°; we think it is at most a minor fracture zone.

The continuous sequence of magnetic anomalies is broken at our preferred position of the Austral Fracture Zone: the next clearly recognizable anomaly eastwards is number 13 at 137°30'W, at the beginning of a sequence fitted by a different spreading rate (see below and Fig. 2).

Austral Fracture Zone to Henderson Island

As we approached the end of the southernmost chain of the Tuamotus, GLORIA showed their massifs to the north. They have typically constructional volcanic (lobate) margins, though possibly with some structural control from the spreading fabric and orthogonal trends. Recent lavas were seen just east of Austral Fracture Zone, at 135°35'W, and then almost continuously eastwards from 133°40'W to 125°30'W. From the Austral Fracture Zone to 132°45'W, the tectonic spreading fabric continues trending consistently 347-349°, with the exception of two small patches of N-S fabric near 136°50'W and 134°00'W.

A significant change occurs near 132°30'W. The spreading fabric changes trend from 337° to 021° in the space of 50 km, and then becomes largely obscured by volcanic terrain until about

123°30'W. Magnetic anomaly 8 is recognised at 132°30'W, at the east end of a continuous sequence, fitted by 60 mm a^{-1} half spreading rate, which extended from anomaly 13 (Fig. 2). To the east it is harder to recognise the anomalies, though we think anomaly 7 is missing from our profile and anomaly 6 is probably at 128°30'W.

A small fracture zone trending 079° probably crosses our track at 132°00'W, and may account for the abruptness of some of these changes. What little spreading fabric can be seen between 132°20'W and 128°10'W is confused. Occasional trends of 001-005° are interspersed with variable trends in the range 300-350°. Possible trends of minor fracture zones (orthogonal to spreading fabric) are 054° and 082°. The 082° fracture zone appears to pass through Henderson Island (24°21'S, 128°20'W). We suggest that this region of confused trends (128° to 132°30'W) may indicate the passage of one or more propagating rifts, possibly at the time (~18.5 Ma) when the present East Pacific Rise was taking over from the Roggeveen Rise (Mammerickx et al., 1980). Similar disturbed trends were seen by GLORIA in the Bauer Basin (Nazca Plate) at the time of the corresponding change from Galapagos Rise to East Pacific Rise (Searle et al., 1981).

Henderson to Easter Microplate

Magnetic anomalies 4 and 5 were probably seen at 118°30'W and 121°W, respectively, giving an average spreading rate from anomaly 4 to 6 of 70 mm a^{-1} (Fig. 2). Recent lava flows remain common from 128°10'W to 125°40'W, and a few recent-looking flows were seen east of there, mostly associated with ENE-trending ridges (see below). Sediment chutes or debris flows were seen north of Ducie island and the neighbouring Acie seamount (24°40'S 125°05'W). There are many volcanic cones in this region, including quite large (2-7 km diameter) ones from 124°30'W to 126°00'W. A +750 nT magnetic anomaly occurs at 124°00'W. Six en echelon ENE-trending volcanic ridges occur between 123°30'W and 118°30'W, and are described in the next section. Finally, at 118°10'W, the spreading fabric (still trending 342°) suddenly becomes much clearer, apparently marking the western boundary of structures related to the Easter microplate. We traced this boundary to the southeast into what is clearly an initial rifting structure (pseudofault) where the microplate West rift appears to have propagated along a pre-existing fracture zone; and between 25°56'S and 26°15'S, and perhaps also at 26°32'S, we see the earlier traces of this fracture zone, trending 079-090°, intersecting the initial rifting structure.

Linear volcanic ridges

A remarkable feature of the eastern end of our passage is the occurrence, between 123°30'W and 118°30'W, of six en echelon ENE-trending ridges. They range from 60 to over 120 km long, 500 to 2500 m high, and 10 to 25 km wide. They are clearly of volcanic construction, comprising many coalesced cones 1-3 km in diameter, and occasionally having more amorphous, knobbly and strongly backscattering material in their flanks. The tops of the individual cones are poorly backscattering, suggesting that they have a moderate sediment cover and are relatively old. However, most of the ridges have relatively recent lava flows associated with them. The ridges all have quite sharp, linear crests, as attested by their acoustic shadows. These crests all strike consistently 065-076°. Although this is parallel to the nearest fracture zones, and perpendicular to most of the spreading fabric observed farther west, the local spreading fabric is not constant and departs considerably from being orthogonal to the ridges: it trends 330-353° from 123°30'W to 121°15'W, 012-028° from 121°15'W to 119°25'W, and 342-359° from 119°20'W to at least 117°30'W. The detailed morphology of these ridges and their consistent strike (irrespective of local spreading fabric) suggest to us that they are not primarily associated with fracture zones, but are ridges of the 'en-echelon cross-grain' type described by Winterer and Sandwell (1987) or the Hawaiian north arch type of Holmes et al. (1988, 1989). However, there are differences. The mantle gravity lineations (the 'cross-grain' fabric) strike about 105° both in our area and Winterer & Sandwell's, and about 110° at Hawaii; however the ridges strike on average 070° in our area, 090° in Winterer and Sandwell's, and 080° on the Hawaiian arch. Because of their clearly linear volcanic origin, we agree with Winterer and Sandwell that such ridges are related to lithospheric tension; but because the angles between the cross-grain gravity anomalies and the ridges vary, we do not think the origin of this tension is necessarily in longitudinal convection rolls alone. Thermal contraction normal to the spreading direction could also be important (Collette, 1974; Turcotte, 1974), as could more local effects, such as lithospheric flexure in the Hawaiian arch.

RCS, JH

Investigation of a Magnetic Profile across the Central Pacific

During the cruise the total magnetic field intensity was measured at intervals of 6 secs by a towed proton magnetometer. These data were transformed into magnetic field and anomaly at two minute intervals by the routine PROMAG using the IGRF1985.

In order to identify geomagnetic reversals, and thus to gain information about the evolution of the Pacific plate, the magnetic anomalies measured on the passage Tahiti-Easter Microplate were further analysed. They were plotted along the ship's track and free air gravity anomaly and the bathymetry were added. This should enable us to compare the geophysical profiles with the GLORIA sonographs and detect features due to late volcanism such as seamounts or lavafields or steps of the gravity or the bathymetry due to fracture zones (FZ).

Corresponding magnetic anomaly models were calculated using the program MAGIC which was slightly modified to create files in the required format for the plotting routine ASCPLOT. The geomagnetic time scales used were those of Labrecque et al. (1977) and Larson & Hilde (1975).

The input parameters were:
Average field=34500nT; Present dip=-35°; Present declination=0; Present strike=0; Palaeolatitude=-20°; Palaeostrike=0; Magnetisation=8Am^{-1}; Top of magnetic blocks at 3Km depth; bottom at 4Km.

Comparing the data and the model profiles the half-spreading rate SPR was adjusted and offsets were included to match both profiles.

The best fit and the anomaly identification are shown in Figure 2. In the western part the smooth bathymetry allows good correlations. East of 132°W, however, relatively young volcanism inhibits obvious identifications. Nevertheless three subsequent models were found having decreasing spreading rates with age and being separated by two FZs (Figure 2). These offsets also coincide with lineations on the GLORIA sonographs: the western one is the Austral FZ and is recorded as four linear features between 21.3°S 139.5°W and 21.6°S 138.5°W with azimuths between 070° and 077°. The age gap across is about 9 Ma. The second FZ is marked as a 079° orientated feature at 132°W marking a sudden change from 160° trending spreading fabric in the west to volcanic dominated patterns in the east. It is also the beginning of strongly disturbed bathymetry associated with high gravity anomalies towards the east. The offset requires an age gap of 1Ma and has the same sense as the Austral FZ. i.e. the older seafloor lies to the northwest.

For the eastern part of the profile the IGRF did not prove to be accurate enough as the magnetic anomaly shows a negative offset of about 200nT. We suggest taking an averaged field value as a reference field in such a case to enhance the identification of normal and reversely polarized crust.

The profiles were also investigated with respect to Okal's proposed evolution of the east-central Pacific based on SEASAT data (Okal & Cazenave 1985). Our data do not show indications of his FZ2, which we were supposed to cross. Neither lineations paralled to FZ2, steps in the bathymetry or the gravity anomaly, nor a change from younger crust north of FZ2 to older south of it could be found. This, however, might be due to our quite parallel track relative to FZ2.

The predicted ages of the plate on which the islands Hao, Aceton, Marutea, Oeno, Henderson, Ducie and Crough Seamount sit are very well in agreement with our anomaly identifications and thus confirm our correlation especially in the eastern part of our profile which may be contaminated by seamounts.

According to our profile the evolution of the central Pacific seems to be more continuous than other models (e.g. Okal's proposed model) suggest. Our data only require two transform faults and an increasing spreading rate, from Paleocene and Eocene (42mm/yr) through Oligocene (60mm/yr) to Miocene (70mm/yr).

The incorporation of all other available data, including SEABEAM and side scan sonars of the whole Pacific, however should yield better constraints on the evolution and reorganisation of the Pacific plates.

JH

Easter Microplate

The following are our main conclusions:

Microplate boundary

1. Both the east and west rifts propagate.
2. The west rift has three propagators propagating south; the east has four propagating north.
3. On both rifts, new spreading centres propagate on the interior, or microplate, side of old ones. This leads to very asymmetric accretion. It has the effect of minimising the total length of microplate boundary.
4. The west rift may be propagating south through the previous southern boundary of the microplate. By contrast the east rift appears to be stalled in the northeast corner, but compressional and shear deformation seem to be taking place in the Nazca plate to the north.
5. There are no transforms on the east rift, but three on the west rift. The northern two have clear principal transform displacement zones, and their strikes suggest a recent clockwise change of motion, or possibly the existence of an additional microplate or microblock.

Microplate interior

1. The interior consists of several domains characterized by different tectonic fabrics and different apparent ages.

2. The oldest domain appears to be in the west; the rest of the microplate has accreted round this. By contrast with the acoustic backscattering level on the surrounding Pacific and Nazca plates, this domain seems to be at least several million years old.

3. The most recent (0-3Ma?) accretion has occurred by relatively simple rift propagation and rotation (fanning) about the east and west rifts, leading to two opposed fans of lineated fabric.

4. The pseudofaults bounding these fans mark strong contrasts with the rest of the (presumably older) microplate interior. These are what used to be called the 'initial' pseudofaults, but we think we can see older ones in the microplate interior.

5. East-west fabric in the northeast corner of the microplate is similar to north-south PAC/NAZ fabric just to the north. The latter appears to be being incorporated into the microplate across the northern boundary zone.

Microplate history

1. The present microplate may have been initiated at a fracture zone near its present southern boundary; as the microplate rotated, the west rift propagated east along this fracture zone, but may now be beginning to break through it to the south.

2. The 'initial' pseudofaults follow curves similar, but not identical, to those predicted by the Schouten et al. (1988) 'ball bearing' model.

3. The initial east rift outer pseudofault does not trend east as predicted by the Schouten et al. model, but was traced from near Easter Island to northeast of Pito Deep, with an average trend of about 330°. The initial eastern propagating rift appears to have stalled northeast of Pito Deep, and has subsequently jumped repeatedly westwards towards the Deep.

4. Deformation structures (probably thrusts) are presently forming on the Nazca plate north of the northern microplate 'boundary'. They (and the surrounding N-S Pacific/Nazca spreading fabric) appear to be being incorporated into the microplate interior, accompanied by a 90° rotation.

<u>Note added in proof</u>: Some of these conclusions have been modified by subsequent shore-based work; for a more up-to-date account the reader is referred to the paper by Searle et al; Nature, <u>341</u>, 701-705.

RCS

SCIENTIFIC EQUIPMENT

GLORIA Instrumentation

At the start of the cruise several problems had to be investigated. The first was to try and reduce the interference on the compass lines caused by the transmit (TX) pulse, by incorporating two balanced filters in the compass clock and data lines at the input to the Yaw Filter control card, and to modify the output circuit of the opto-coupler on that card allowing the mark space ratio of the signal to be adjusted, and set to 1:1. When the vehicle had been launched and the transmission switched on, the data and clock signals were checked on an oscilloscope. During transmission the clock signal barely moved and the data had a slight jitter. The modification seems to have produced some improvements.

The next problem was to check the time varying gain (TVG) amplifiers for noise and signal levels. During the last cruise some of the records had discrete steps in the signal level and so particular attention was paid to finding a possible cause. No such steps were noticed, and the increase in gain across the record was smooth in all amplifiers.

On switching on the Sonar Amplifiers rack, the 5 volt supply failed to operate. This was caused by supply bus-bar pins at the rear of the rack shorting together. Once operational, I checked through the various signal stages and because the output DC levels of the amplifiers in the Log Rec modules were out, adjusted them to read zero for zero input signal.

Prior to launching the vehicle, the Transmission Control module was suspected of having a fault. The clock was jumping several hours at a time. The spare was tried, but because of a wiring error the (TX) pulse failed to work. Once repaired, the spare was tried again. Seven hours after logging started, it was noticed that the hour marks on the EPC recorder were 28 minutes slow. Logging was terminated and the original module used. Later during the cruise, the Inhibit Delay times of the spare module were checked. All were found to be way out of specification. In particular, the "30 second" rate with a 2 second pulse was 32 seconds instead of the 29.2 specified.

As soon as the vehicle had been launched, we took the opportunity of checking all the Pulse Power Amplifiers (PPAs). Several of the protection boards failed to operate and were replaced. These and the spare protection boards were tested, and where necessary repaired or adjusted. This doesn't necessarily mean they will work in the PPAs; it does however help to repair the more 'fatal' faults.

At 0224/289, 19 hours after logging started, the Direct Memory Access (DMA) alarm tripped. The Cosmac Control card was suspected and changed. This appeared to cure the problem and logging recommenced. At 0011/294, the DMA alarm tripped again. This time it was preceded by the TM70 keyboard throwing up odd messages and symbols. As the DMA cycle is controlled by the state of the SC0-P and SC1-P lines from the Cosmac 601 computer microboard this was suspected and finally replaced, but not before trying the 641 Uart which interfaces the keyboard and the 643 A-D board. Both these boards are on the Cosmac interface bus and it was just possible that they may have been loading the two control lines. They were not, and the fault did lie in the 601 board. It was a useful exercise as the spare 643 A-D board didn't work at all. Checking the board showed the supply links wired in the Cosmac development kit position C-D, instead of the microboard position A-B. I have rewired them in the A-B positions.

It is worth mentioning here that when the DMA cycle failed, there were dropouts on the record which looked like problems with the Yaw Filter. If the DMA alarm had not been connected, we might initially have suspected the wrong unit, since the vehicle was yawing as much as 5 degrees at the time. It is also worth mentioning that since the Cosmac Control and CPU 601 cards have been changed, the Transmission Control clock has stopped its random time jumps.

When the Laser Filmwriter was used for the first time, it was noticed on the oscilloscope that the 'grey scale' was severely distorted (non-monotonic increase) and had noise spikes. Although this showed up on the strip at the end of the prints the actual data looked all right. The fault was traced to the 0 volts (earth line) on the rear of the Acoustic-Optic Modulator (AOM) module connector having been disconnected. Apparently, this may have been done as far back as May 1987. It is interesting that although quite the wrong signal levels were being transferred to film, the prints still looked 'normal'. Clearly the grey scale is a very useful check.

The first film to be developed was noticeably devoid of any data, the data having been compressed into a single line down one edge of the negative. The scanning mirror had jammed due to a corrosive growth between the base and the mirror holder. Once this was removed we were back in business, but not for long. Shortly after, the clutch started slipping and had to be adjusted.

The first of several software faults occurred when we tried to transfer data from the cartridges to the hard disk using program T2D. Although the Tandberg would accept commands from the IBM, it was unable to send data back. It was due to Jon Campbell's latest Replay floppy which had been copied on to the hard disk prior to sailing. It had all the system set-up files (COMMAND.COM, AUTOEXEC.BAT, etc.), which, when loaded, were put into the wrong area of memory. Martin Beney solved this problem by relocating these files and generating separate directories. Because the tape driver TAPE-MT0.SYS was also in the wrong area of memory the IBM would not boot properly. This was also to manifest itself as yet another fault later in the cruise.

The next fault was detected when we began to mosaic the prints. It was found that the prints were 15% too wide. Printing out the RATDEP program revealed the value of 'Filmwidth' to be 20.6769. This value is used on the Farnella Laser Filmwriter and we should have been using 21.45. To change this parameter, RATDEP had to be recompiled and linked. In order to produce an object file from PROFOR.ASM we needed to find a floppy with a macro assembler before linking the two object codes together. Eventually we found one and were able to change the value of Filmwidth to 21.45. When the prints were checked, the width had only changed from 14 to 13.4mm. We eventually homed in by 'trial and error' and reached a value of 24.05. It seems that the scanning mirror was changed prior to cruise 33 and hadn't been calibrated. The prints on that cruise were also 15% too wide.

The tape driver program rears its ugly head again. When we tried to transfer pass 48 (File 16) from the 9-track to hard disk it somehow lost a data line during the transfer and came up with 719 lines instead of 720, added to which file 2 was missing.The data on the 9-track tapes were rechecked using FDUMP and found to be all right, suggesting that the problem lay in the software. It's worth mentioning here that when using FDUMP the files are numbered 0 to 15, and NOT 1 to 16 as used on the RAWPS files. We loaded the new MAGT and TAPE-MT0 files from the Sept '88 Replay floppy. This cured the missing file 2 but not the 719 line file. Further investigation revealed that if a block of files was transferred, the first file of that block was always 719 lines long, the rest 720. The exception to this was when all 16 files were transferred. The problem seems to lie in the use of the first line of a file, other than file 1, for identification, and its subsequent loss.

Tim Le Bas has incorporated several extra routines into the Replay system (see next section for details). The most useful in terms of improving the quality of the data is his FILTER program. This effectively filters out any drop-outs and produces an exceptionally clean record. It is achieved by using a 71 x 9 pixel window to perform an averaging or low pass filter, and a 71 x 1 pixel window to perform the high pass filtering. Tim Le Bas has also introduced shading and reversal functions into a new program called UTILITY. This allows LASPS files to be shaded, filtered, reversed, or any combination of all three. Reversed will produce prints which are 'black-on white', and Roger Searle has used the reversed/shaded version to produce his mosaic. As Ruth Rusby has used the normal LASPS prints it will be an interesting exercise to compare the two mosaics. Finally, D2L has been modified to accept these new files along with the standard LASPS, some of which are REVER, FILTR, LASHD, RVSH2 and RVSH3.

Although the Laser Filmwriter has managed to produce the negatives, it has sometimes been a struggle. On several occasions the clutch has had to be adjusted to cure random black lines across the negatives, caused by a 'sticking' film advance. A new problem, which we haven't seen before this cruise, has been the appearance of light bands across the negatives caused by what looks like a sudden reduction in intensity level. All the negatives on this film had the same fault. At the time, we thought the problem may have been caused by replacing the temporary earth on the Acoustic-Optic Modulator (AOM) module by its permanent lead on the rear connector, prior to running the film through the Laser. However, running a new film through produced clean negatives. Was the cause of the light banding a bad connection affected by the ship's rolling? At the time, the ship movement was sometimes 'jerky'.

DB

GLORIA Shipboard Image Processing

As part of the suite of programs available during replay and back-up of GLORIA data certain image processing techniques were used and some new ones implemented.

The replay processing system is based on an IBM AT Personal Computer. The raw data are read off data tape cartridges creating data files named RAWPSnnn.DAT, where nnn is the pass number, on the IBM hard disk. These are then merged with the navigation data and together are used to produce slant-range-corrected and anamorphosed data files, and are written to file LASPSnnn.DAT. At this point further image processing is possible as the data file represents a printable 2D geometrically correct image.

Following previous IOSDL cruises on MV Farnella and RRS Charles Darwin a shipboard 'shading' capability was already available, to be performed if required. The purpose of this technique is to remove the range-dependant system response. This response is due to the directivity pattern of the GLORIA transducer array and any spreading and attenuation losses of sonar energy in the water column. This is partially corrected by a time varying gain (TVG) function which is applied before recording. However it is still possible to see a range dependant variation and thus a 'shading' correction was introduced to uniformly illuminate the image. Programs AVSCAN and PLOT were used to estimate and display the system response during the initial data passes 1 to 5. The resulting plots of average and maximum response levels for each range pixel were overlaid, and an average response envelope determined. From this envelope, correction factors were calculated to give an equal intensity across the range. This was tried several times with different sets of 6-hour passes and finally two correction curves were accepted; one for deeper water (SHAD2.DAT, >3500m) mainly off the Easter microplate; and one for shallower water (SHAD3.DAT, <3500m) for the interior and ridge system of the Easter microplate.

After initial (hand) mosaicing, we attempted to make comparisons of GLORIA data with SeaMARC II data of the same area. It was found to be quite difficult because SeaMARC II data uses the reverse polarity of grey scales to GLORIA. Thus a strong reflection in SeaMARC II data would appear black and a weak return white. It was therefore suggested that GLORIA reverse its usual polarity to complement the SeaMARC II mosaic already available; this was done with program REVERSE. The first experimentation simply used 255 - z, where z is the 8-bit GLORIA grey level. The results from this were considerably too white, with little or no definition of all the intermediate grey-levels. This was due to the non-linear curve of density levels characteristic of the film. Thus a reverse logarithmic curve was used. This contrast stretch created more grey levels of lower values for the film thus matching the non-linear curve. The equation finally used was:

$$\text{Reverse} = 255-(\ln(z+1)*46)$$

This produced most satisfactory results which in places appeared to show more geological detail then the normal polarity images, especially in areas of relatively low return. In areas of high return the reverse polarity images were slightly too dark in places and there normal polarity was preferred. It was therefore decided to create two mosaics - one of normal polarity and one in reverse polarity. At this point it must be stated that the natural logarithmic scale was only an estimate of the characteristic response curve of the film, and further research may improve this equation.

The third and most commonly used image processing technique was the use of low- and high-pass box-car filters. Raw GLORIA images can be divided into 2 frequency spectra; a low frequency spectrum for regional effects such as varying geologic fields and range dependant variation, and a high frequency spectrum consisting of detailed topological changes, geological differences and system noise (especially data drop-outs - where GLORIA misses the return pulses due to incorrect orientation of the vehicle's receivers). The filtering technique (Chavez, 1986) attempts to separate these two frequency spectra. It smooths the low frequency spectrum and removes unwanted high frequency elements such as drop-outs and system electrical noise. The low frequency spectrum is extracted by a box-car function, using 71 pixels across track by 9 pixels along track. This equates to an area approximately 3000 m by 1400 m. All the pixels are summed and the average calculated. The central pixel is given this value and then the box-car function moves to the next pixel and the process is repeated. Once each pixel has been recalculated the resultant new image can be said to be a low-pass filtered image. The high frequency spectrum is extracted in a similar way by a box-car function of size 71 pixels wide (across track) but only 1 pixel long along track. Again the pixels in the box-car are summed and an average obtained, but now the original central pixel is replaced by the difference between it and the average. The values of 71 by 9 for the low pass filter and 71 by 1 for the high pass filter are the numbers commonly used by the Mini Image Processing System (MIPS) and are the result of much experimentation on other GLORIA data.

When each pixel has a value for the result of low and high pass filtering, the two values for corresponding pixel locations are recombined . Thus adding the two separated spectra together will make a fully filtered image of all frequencies, but without the high frequency noise. Thus the final equation for each pixel is:

$$\sum_{i=x-35}^{x+35} - \sum_{j=y-4}^{y+4} \frac{d_{ij}}{639} + \left(d_{xy} - \sum_{i=x-35}^{x+35} \frac{d_{iy}}{71} \right) \Rightarrow\!> d_{xy}$$

where dxy is the density level at pixel location x,y.

Results from this processing technique were extremely good. The most obvious improvement was that all drop-outs and write errors were removed, being replaced by invisible interpolations between adjacent lines. The amount of system noise was also reduced though only across track. Near-nadir signals were not affected, these being improved by the shading technique.

Four programs are now available for image processing: SHADE, REVERSE, FILTER, and UTILITY. All the programs read the LASPSnnn.DAT files, calculate the new pixels and output the new data image to a new file:

SHADE produces a LASHDnnn.DAT file;

REVERSE produces a REVERnnn.DAT file;

FILTER produces a FILTRnnn.DAT file;

UTILITY combines the other 3 programs:

it can produce any combination of the above image processing techniques and can also write more than one combination of output to file, though the more combinations calculated the slower the running speed. It produces a file with similar 5 character name as above but user defined (e.g. one might choose REVSF099 for reversed, shaded and filtered output of pass 99).

All image processing was done on the IBM AT personal computer. This machine is not designed for such work-intensive usage and it was commonly producing a 2 hour delay before the film processing; especially when filtering was involved. With a more powerful computer this could be considerably reduced. Any replacement computer should have a graphics capability so that images could be displayed on screen, allowing the results of processing (or even original data quality) to be assessed without a lengthy wait for photographic processing. It is also suggested that the filtering technique be incorporated into program GPROC (which produces the LASPSnn.DAT files) since filtering was requested for every image.

TLB

Shipboard Computing System

The shipborne Level ABC system was used to log and process navigation from Emlog and Doppler Log with Gyro, together with Transit satellite and GPS, Magnetics, Gravity and Bathymetry. Daily DXFMT formatted tapes were produced for subsequent use in the GLORIA processing together with daily plots and Anamorphic ratio listings.

Prior to the cruise an offset was made in the Gyro Level A to cater for the difference between the ship's gyro and the scientific gyro. During the cruise the ship's gyro was changed over and another offset allowed for. Comparisons between the emlog and doppler indicated that the emlog was reading high and this too was allowed for in the emlog Level A. At this time the Emlog was uncalibrated as the new head had been fitted previously. In addition it was found that the athwartships reading was predominantly to port and varied with speed. This was put down to the fact that the Emlog was misaligned probably by as much as 2 to 3 degrees in a clockwise direction. As the speed for the cruise was 10 knots a fixed offset was applied to the athwarthship component of the Emlog of +0.4 knots. Investigation of the Emlog head assembly has shown that with the present arrangement it is impossible to turn the log any more in an anti-clockwise direction to correct it.

Although the computing system was not without its difficulties, there was no substantial loss of data. Within a few days of sailing, there were a lot of errors reported on the Data Winchester drive associated with Level C. This was reformatted and the data read back down from the Level B. A week later the ring carrying the data from the plot to the computer room failed. This was re-routed and about 2 hours of data was lost. The majority was recovered by manual entry from paper records. Another week on and the Data Winchester drive was playing up as before. This time a new board cured the problem. From then on it was plain sailing.

During the cruise we received over the Marinet communication system a Fortran source program that originated from Cambridge. This had been sent to RVS at Barry via the electronic mail and appended on to the daily messages which are transmitted to the ship. We also made direct connection into the PAD by calling up IOS Wormley and getting routed through to Cambridge. The program 'Kermit' was used to convert the PC to a terminal emulator and to handle the error correction and handshaking for the few messages that were passed across. My thanks to Roy Livermore for initiating the trial and Jeff Baker (RO) for putting up with us. On a previous cruise a similar trial had taken place but there was so much corruption of data that it was abandoned. For our trial we benefited by having a direct satellite link with the UK rather than the tortuous route to Singapore and thence by landline.

Use was also made of the computing system by members of the scientific staff. Fortran sources were compiled and data plotted from them without too much problem. Much of the credit for this goes to a document produced by Tim Le Bas (1989) after a previous cruise, in which he experienced problems.

MGB

10 kHZ Precision Echosounder

A loosely secured helix trigger disc on the helix shaft extension caused the timing lines to shift after a blade change. Apart from this the P.E.S. worked well throughout.

CP

Electro-Magnetic Log

Large fluctuations in readings on both components was traced to a disconnected Sea Earth. Despite this most problems were confined to the Hydraulic ram and ball valve circuitry. A new electric motor to drive the hydraulic pump was installed in Suva along with a replacement set of ball valve micr switches. Failure to drive the ram down was traced to a faulty solenoid valve and was adjusted to prevent the pump "running on" after the log was fully recovered and to enable remote Bridge operation.

CP

Lacoste and Romberg Gravimeter S.40

A faulty gyro caused large fluctuations in the Long Axis accelerometer trace and eventual degradation of gravity data quality.The gyro was replaced with consequent good results.The final Free Air Anomaly was averaged using an 8 minute moving window and referenced to IGSN.1971.

CP

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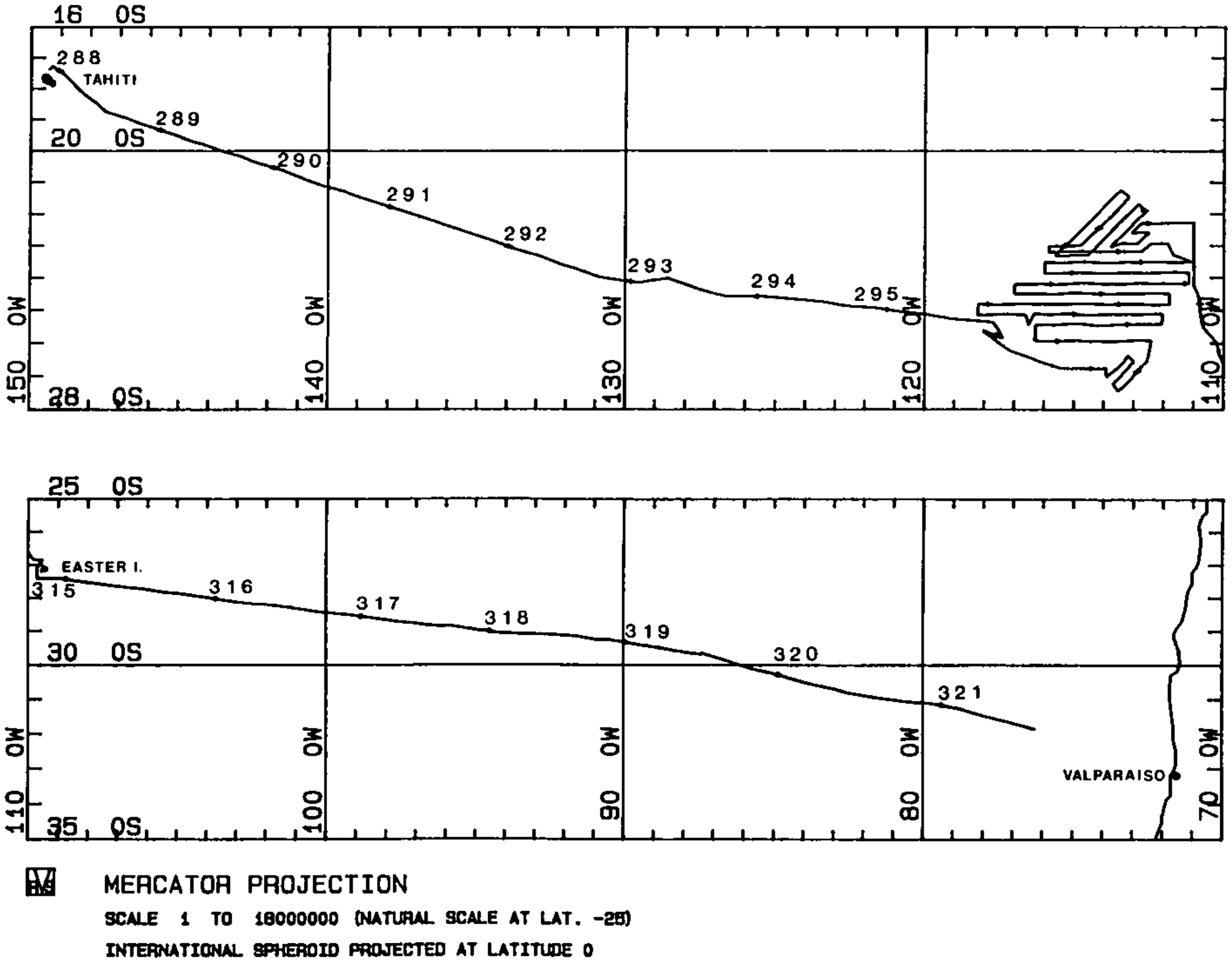

Figure 1 Track chart for Charles Darwin Cruise 35, 13 October - 17 November 1988. Top: Tahiti to Easter Microplate; bottom: Easter Island to Valparaiso. Ticks and day numbers at 0000GMT.

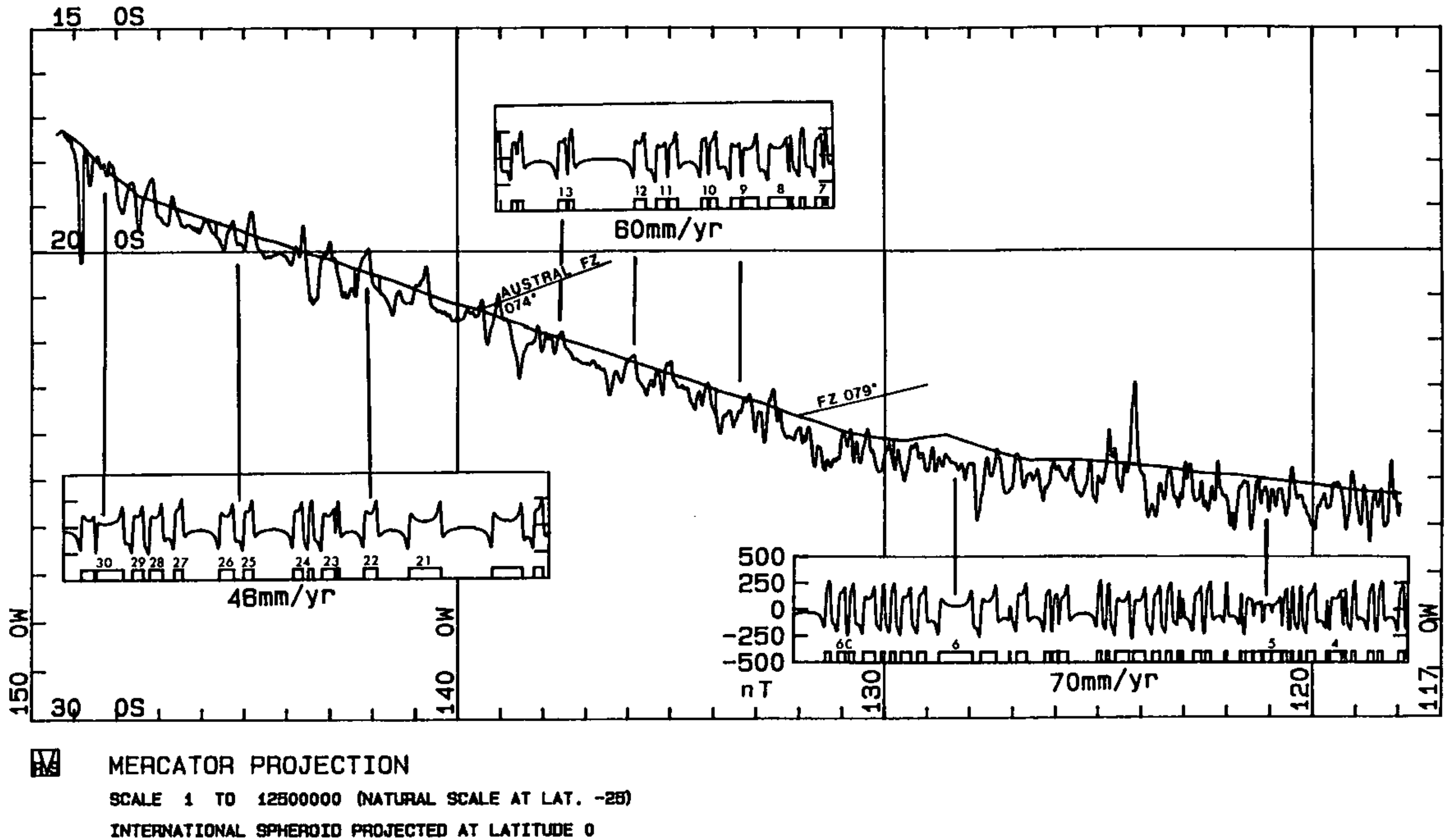

Figure 2 Profile of magnetic anomaly along the Tahiti - Easter passage track. Insets show computed anomalies following the model described in the text. Two fracture zones are also indicated.