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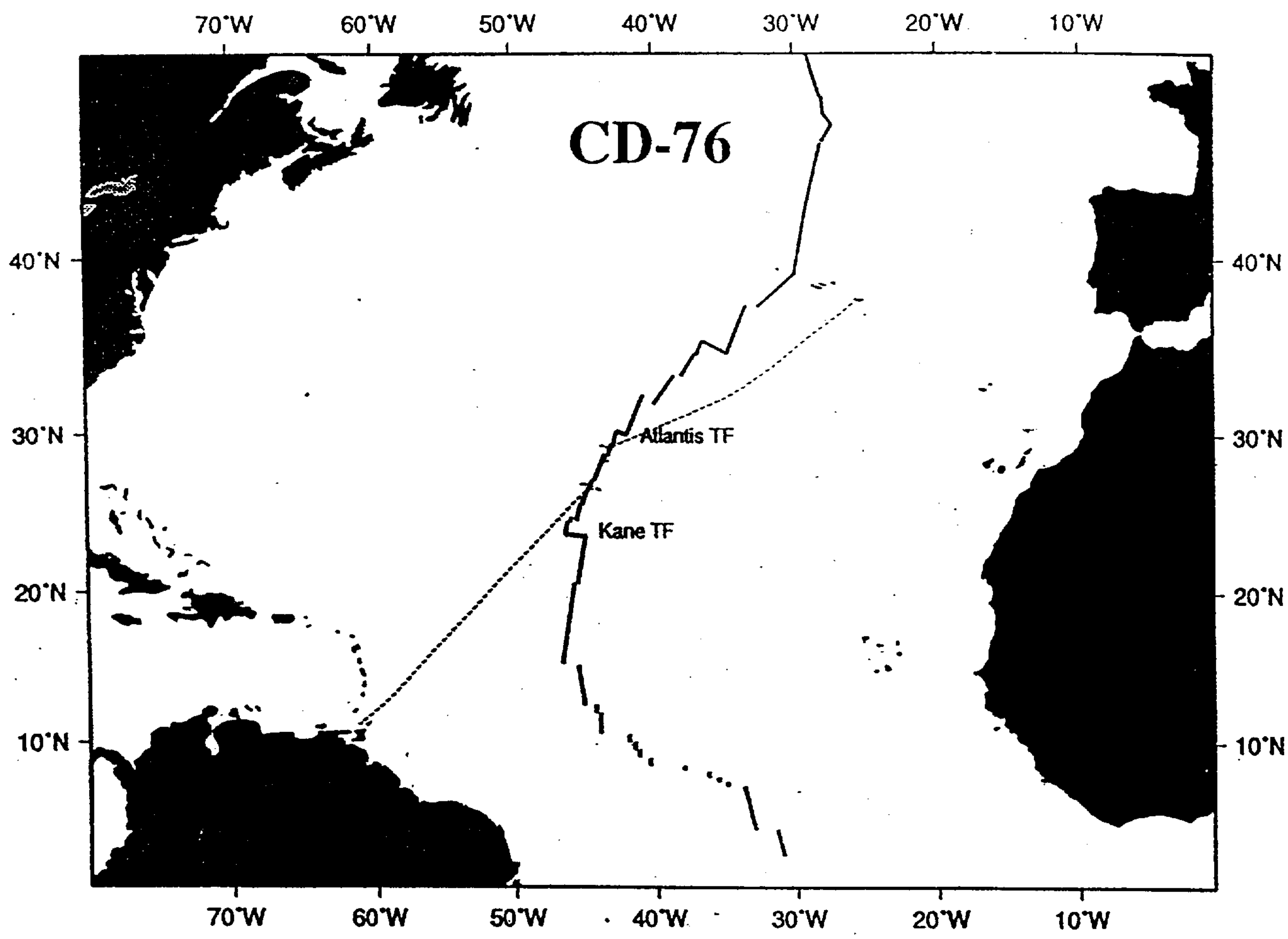
RRS *Charles Darwin* Cruise 76

04 Feb - 11 Mar 1993

Geological and geochemical investigation between 27°N and 30°N of the Kane-Atlantis segment; the Mid-Atlantic Ridge

Cruise Report No 236 1993



Natural Environment Reseach Council

INSTITUTE OF OCEANOGRAPHIC SCIENCES

DEACON LABORATORY

CRUISE REPORT NO. 236

RRS *CHARLES DARWIN* CRUISE 76
04 FEB - 11 MAR 1993

Geological and geochemical investigation between 27°N and 30°N of the Kane-Atlantis segment; the Mid-Atlantic Ridge

Principal Scientist
B J Murton

1993

RESTRICTED CIRCULATION

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Signed: ....

Dr B.J.Murton

Eggshell seamount, at 27°15'N, 43°35'W on the eastern side of the axial valley of the Mid-Atlantic Ridge. The seamount is approximately 1 km in diameter. It was imaged from the starboard side of IOSDL's TOBI deep towed sidescan sonar during the recent RRS *Charles Darwin* cruise (CD 76)

DOCUMENT DATA SHEET

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ABSTRACT

A survey during February and March 1993 along the slow spreading Mid Atlantic Ridge between 27-30°N assessed the regional extent of hydrothermal activity. The IOSDL Towed Ocean Bottom Instrument (TOBI) was used as the platform for sidescan sonar imagery, water column properties and real time submarine chemical analysis. The most dominant signals for high-temperature hydrothermal activity were found at 29°N, and were examined in detail using Dr. Gary Klinkhammer's Zero Angle Photo Spectrometer (ZAPS) sledge and IOSDL's Wide Angle Submarine Photograhy sledge (WASP). Both water column and bottom observations confirmed the presence of a high-temperature vent field, named here as the Broken Spur Vent Field.

KEYWORDS

BROKEN SPUR VENT FIELD
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EGGSHELL SEAMOUNT
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MID-ATLANTIC RIDGE
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ZAPS SLED
ZERO ANGLE PHOTON SPECTROMETER

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1 KASP: THE KANE TO ATLANTIS SUPERSEGMENT PROJECT RRS CHARLES DARWIN CD76 CRUISE REPORT

(By Bramley J Murton)

Port of Spain, Trinidad - Ponta Delgada, Azores
4th February 1993 - 11th March 1993

1.1 Introduction

Hydrothermal activity on the worlds mid ocean ridge system plays a unique role in the physical, chemical and biological development of young oceanic crust. Hydrothermal vents make a major contribution to the geothermal and geochemical flux from the lithosphere to the global ocean;cooling the newly formed volcanic crust, affecting chemical exchange between the seafloor and water column, and often forming massive metalliferous sulphide deposits. They also support aphotic life forms that are uniquely associated with high-temperature hydrothermal activity (e.g. Corliss *et al.*, 1979; Macdonald *et al.*, 1980; Cann & Strens, 1982; Rona *et al.*, 1983; Cann *et al.*, 1985; Grassle, 1986; Tunnicliffe, 1991).

Unlike fast- to medium-spreading rate mid-ocean ridges, such as the East Pacific Rise where hydrothermal venting is relatively common (Haymon *et al.*, 1991), on slow spreading ridges it remains more elusive. According to Klinkhammer et al (1985) and Charlou et al (1991) water column measurments taken from the axial region of the MAR between 11°N and 30°N have shown either Mn and/or CH_4 enrichment, indicating that high-temperature hydrothermal activity is pervasive. However, until recently only three active vent sites on the have been verified: TAG (Trans-Atlantic Geotraverse) at 26°08'N (Rona *et al.*, 1984, 1986), Snake Pit at 23°22'N (Detrick & Honnorez *et al.*, 1986), and Lucky Strike at 37°17'N (Klinkhammer *et al*, 1992). The Broken Spur Vent Field, at 29°22'N, is only the fourth and most recent hydrothermal vent system to be located on the Mid Atlantic Ridge, discovered on the 4th of March this year during cruise CD76 of the RRS *Charles Darwin*..

Cruise CD76 of project KASP aimed to assess the extent of high-temperature hydrothermal activity along 300 km of the Kane to Atlantis Supersegment of the MAR. The work began with a systematic study of 4000^2 km of the axial valley, between 27°N and 30°N, using the IOSDL Towed Ocean Bottom Instrument (TOBI). This was used to assess the extent of chemical and physical effects of plume activity in the water column above the ridge crest, while imaging the tectonic and volcanic character of the axial valley. We then targetted the strongest plumes with deep-towed sledges carrying water physics sensors, chemical sensors and cameras in order to locate the active vent sites. Final work involved geological sampling in the vicinity of the vent site by dredging.

This was the first time that a combined systematic and real-time geophysics, geochemical and geological survey for hydrothermal activity has been made along the MAR. This integrated approach was an essential aspect of our experimental technique which aimed to collect data on the chemistry and physical distribution of plumes, and the volcanic and structural environment in which hydrothermal venting is active.

The scientific party on cruise CD76 comprised a multinational team from the UK, USA, Germany, France and Japan. In addition the work depended entirely on the expertise and superb seamanship of the officers and crew of the RRS *Charles Darwin*, from the Master to the Stewards. Their ability in maintaining an excellent working platform, and manouvering the vessel in unseasonally poor weather conditions over stations that required location precision to within a few tens of metres can not be overstated. And finally, but by no means least, the work could not have been attempted without the tenaceous persistence of the engeneering personnel of Research Vessel Services, Barry, who not only overcame many unforseen technical difficulties, but also cheerfully built and modified pieces of equipment at short notice.

Methodology

Unlike previous deployments of TOBI, when the vehicle has been towed at 500-800 m above the seafloor, during cruise CD76 we towed at an altitude of between 200m and 300 m. This was to attempt to pass through, sense and map the distribution of particulates and total concentration of dissolved manganese within hydrothermal plumes which elsewhere on the MAR and the EPR typically develop neutral buoyancy at 200 m to 400 m above their sources (Nelson and Forde 1991, Baker et al. 1985, Baker and Massoth 1987). Two survey tracks were made along the axial valley, a northerly pass over the western side and a southerly pass over the eastern side (Fig. 1.1) The base bathymetry charts used to navigate TOBI close to the bottom were 1:50,000 scale raw SeaBeam data from Purdy *et al.* (1990) contoured at a 25 m interval. Although low altitude towing exaggerated the acoustic shadowing effect of rugged topography on the sidescan sonographs, the vehicle survey lines were navigated so that the inner axial valley wall faults were at the edge of the 3 km swath range. Because the axial valley between the Kane and Atlantis fracture zones is on average only 9 km wide, we were able to image 4000 km^2 of the valley floor and inner valley walls including typically a 40% central overlap, while passing within a three to four kilometre range of any axial vents.

The second phase of the study involved station work with the ZAPS sledge concentrating on a 14 km length of the axial valley that coincided with the strongest plume signals observed during the TOBI survey. Stations were selected over elevated neovolcanic areas of the ridge that lay 200 m to 300 m below the base of the strongest plumes. Several seafloor sites were identified which proved to have strong transmissometer, nephelometer and total oxidisable manganese signals in the overlying water column. We spent several days homing in on the vent site by bracketing the search area and assessing the plume structure from up-, down- and towed- casts through the water column.

After locating the source of the strongest plume to within an area of 1 km^2, and deploying an Oceano acoustic transponder net of four beacons enclosing an area of 25 km^2, a near bottom (<10 m altitude) search strategy was adopted during which we sought temperature anomalies of several hundredths of a degree centigrade above an ambient background of 2.3 °C. Once these were found, an upcast through the water column was made with the ZAPS sledge to examine the plume structure and hence confirm the close proximity of the vent.

Having identified an area of a few hundred square metres within which the active vent was located, phase three of the study involved deploying the WASP at an altitude of between 8-15m above the bottom. This was followed by nine dredge deployments aimed at geologically sampling the vent and its vicinity.

1.2 Results

Regional extent of hydrothermal plumes

At least three areas along the Kane to Atlantis Supersegment near 27°N, 29°N, and 30°N, identified from the TOBI suvey, revealed transmissometer and/or ZAPS indications of plumes within 400 m of the bottom. Two plumes, near 27°N and 29°N, are located above axial neovolcanic ridges aligned along the western margin of the axial valley. They are not evident 4 km away on the eastern side of the valley at the same latitude, suggesting that the plumes are restricted to the western valley wall, probably by axial bottom currents. The plume at 30°N, principally defined by an increase in the concentration of total oxidisable manganese, is also located over a neovolcanic ridge that extends into the nodal deep basin at the western end of the Atlantis Transform Fault.

The strongest TOBI transmissometer and ZAPS indications among the three plume areas were found along a 14 km section of of the Mid-Atlantic Ridge. This 14 km section, along the crest of a second order ridge segment centred on 27°05'N and aligned parallel to the western axial valley wall, contains several distinct hydrothermal plumes at depths of between 2650 to 2750 m (Fig 1.2). Within this section, the maximum plume intensity observed by the TOBI transmissometer corresponded to 0.2% light attenuation and was the first indication of what was later to become known as the Broken Spur Vent Field (BSVF).

Plume Structure at 29°N; the Broken Spur Vent Field

A total of 14 vertical up and down casts with the ZAPS sledge, in an area of 30 km^2 centred on 29°N, revealed a complex vertical and horizontal plume structure (Fig. 1.3). Although the plumes are vertically stable with time, remaining within 5% of the water depth, their strength is variable. For example, at station 1 (6 km from the BSVF) the plume caused about 0.03% attenuation of light transmission when first measured but it had decreased to 0.005% attenuation of light transmission by 30 hours later. Elsewhere, we observed the reverse, with an increase in plume strength over a similar time period. From the shape of the hydrothermal plume, 10 km long 3 km wide and elongated parallel to the axial valley we infer the presence of diurnal bidirectional bottom currents probably flowing parallel to the ridge axis. We attribute these currents to a tidal origin.

The Broken Spur site contains a composite vertical plume structure comprising both relatively thick (>100 m) and thin (<50 m) plumes. Two ~50 m thick plumes, with sharp nephel maxima, occur at 2700 m and 2825 m. Their nephel profiles are closely matched by their transmissometer profiles. A thicker plume occurs between 2810 m and 2975 m and has a broad and symmetric nephelometry profile, with a sharp decrease in nephels at the base. In contrast, its transmissometry profile is asymetric with a sharp maximum in attenuation and rapid increase in transmission at the base. The temperature profile through the depth range enclosing the three plumes is almost isothermal suggesting that this near bottom water mass is well mixed.

These data are evidence of several neutrally buoyant plumes that emerged from the seafloor with different potential temperatures which suggests the presence of more than one active vent. The two thin plumes with sharp nephel and transmissomter profiles are probably advected features from a distal source. The thicker plume with its broad nephel and transmissometer profile is probably a convected feature from a proximal source. This interpretation is supported by the increase in the nephelometer to transmissometer signal ratio for the base of the thicker plume indicating an increase in the particle diameter. Larger diameter particles, from Stokes Law, will settle faster than smaller diameter ones and are thus likely to be found at the base of a young non-turbulent neutrally-buoyant plume and absent altogether from an old non-turbulent neutrally-buoyant plume. If the plume was bouyant then it is likely that turbulent mixing would prevent settling of the particulate load.

Following the location of the strongest plume, at a depth of 2700 m, the ZAPS sledge was deployed in a near bottom mode to search for perturbations in potential temperature caused by high-temperature venting. Several traverses of 1-2 km long were made along the crest of an axial volcanic ridge at an altitude of 8-10 m and a depth of 3050 m. A number of positive temperature anomalies of up to 0.3° C were encountered over a horizontal distance of 200 m. An upcast through the water column was made at the location of the temperature anomalies, and high nephel counts were encountered at 50 m above the bottom, at a depth of 3000 m. This is the deepest level at which a plume had been encountered, and we believe it to represent a buoyant column located within several tens of metres from an active vent.

During subsequent photography in the area of the temperature anomalies with the WASP sledge, towed at an altitude of 10-15 m above the seafloor and a depth of 3035 m, the buoyant plume column was again observed. Shortly afterwards the WASP sledge ran in to a sulphide chimney, recovering fragments of material which were subsequently collected on the vehicle's return to the surface. The best position of this active vent in the Broken Spur Vent Field, determined from the acoustic navigation net, is 29°10.15'N, 43°10.28W.

Geological setting

The Broken Spur Vent Field lies within the neovolcanic zone of a second order segment at the northern end of the first order supersegment between the Kane and Atlantis fracture zones on the Mid Atlantic Ridge. This second order segment is one of the bathymetrically shallowest in the supersegment, and has a periclinal shape (Purdy *et al*, 1990) with a marked mantle Bouguer gravity low at its centre (Lin *et al*, 1990).

Variations in the acoustic texture and backscatter intensity of the TOBI sidescan sonar images allowed us to map the extent of the neovolcanic and neotectonic zones within the axial valley, as well as distinguishing variations in the volcanology. On TOBI images the neovolcanic zone is defined as strongly backscattering hummocky sediment free terrain that is essentially devoid of faults and fissures resolvable by the sonar. At 29°N the neovolcanic zone lies adjacent to the western valley wall where it forms an elevated axial-parallel volcanic ridge up to 20 km long, 5 km wide and 200 m high (Fig. 1.4). This asymetric position of the neovolcanic zone is common in the Kane to Atlantis Supersegment, which also has an asymetric rift valley structure with the highest fault scarps forming the western valley walls. The neotectonic zone, defined on TOBI images as densely fissured and faulted terrain with fissures or gjas up to 30 m deep and areas of smooth low backscatter intensity indicating patchy sediment cover, forms the eastern valley floor at 29°N, as generally elsewhere along the Kane to Atlantis Supersegment.

Both TOBI and WASP imagery show that the Broken Spur Vent Field is located at the crest of an axial volcanic ridge, adjacent to an axial summit caldera (Fig. 1.5). The axial summit caldera is a graben-like structure, 1.2 km long and 35-60 m wide. Acoustic altimetry data from WASP indicate that the axial summit caldera , where it is adjacent to the Broken Spur Vent Field, is 30 m deep by 30 m wide. The axial summit caldera has a single vertical wall on its western side, and a stepped wall on its eastern side.

Although relatively common on the fast spreading East Pacific Rise (Lonsdale,1977; Haymon, *et al.* 1991), axial summit caldera have not been reported from the Mid Atlantic Ridge before now. On the East Pacific Rise, where they are associated with the most volcanically active parts of the ridge crest and ascribed to subsidence of shallow magma chambers, hydrothermalism occurs within 20 m of the caldera margins (Haymon *op cit.*). Therefore, it is perhaps not surprising that there should be hydrothermal activity adjacent to an axial summit caldera at the Broken Spur site. By comparison with the EPR, the presence of the axial summit caldera adjacent to the Broken Spur site suggests that the axial volcanic ridge at this location currently hosts, or has recently been host to a shallow magma chamber.

This interpretation is supported by photographs of sediment free pillow and sheet-flow lavas and the recovery of unaltered glassy basalt from the site. Dredge deployments at the vent site recovered a diverse range of basalt compositions. These include some fresh, unsedimented glassy aphyric basaltic sheet-flows that are young (probably less than several hundred years), as well as plagioclase phyric (~30% by volume) glassy basaltic pillow lavas. The presence of fresh neovolcanic sheet flows indicates recent eruptive activity and the 30% plagioclase phyric basalts demonstrates that there is, or recently has been, a magma chamber capable of supporting fractional crystallisation in the vicinity of the vent.

Sulphide samples recovered from the Broken Spur Vent Field have been analysed by X-Ray diffraction, X-Ray fluorescence, reflected light microscopy and scanning electron microscopy. Results reveal the samples comprise mainly sphalerite, pyrite, chalcopyrite, marcasite, phyrrotite and wurtzite, indicative of precipitation temperatures of 250-300 °C. The coexistence of both phyrrotite and marcasite, which together are readily oxidised on the seafloor (Haymon et al. 1991), is evidence that the vent site is very young and almost certainly active when we sampled it.

WASP photographs of the ocean floor from within 25 m of the vent reveal brecciated angular rubble, probably of weathered iron and copper sulphides, pillow lavas and a dusting of iron and manganese oxide and hydroxide sediment from the vent. Photographs also reveal abundant particulate material in the water column over the vent itself.

Biological Activity

Several photographs, that coincide in time with the encounter with the buoyant plume column and chimney, reveal abundant biota including what appears to be a vent ecosystem containing a number of individual worm- like creatures (probably semi-recumbent *polychetea* , Paul Dando *pers. comm.*) attached to a substrait of talus which is covered in places with a mat of fibrous material of possibly the bacterial origin. Also photographed were white squat lobsters (*Munidopsis*, Tony Rice, *pers. comm.*), large bottom grazing fish and some anemones. The vent ecosystem imaged resembles the biology found at the periphery of the other Mid Atlantic Ridge vents such as. the TAG hydrothermal field (Grassle 1986, Tunnicliffe 1991).

1.3 Discussion and Conclusions

The success of using real-time geophysics, geochemical and water- column physics sensors in regional surveys of mid-ocean ridges for hydrothermal plumes has been demonstrated by the discovery of the Broken Spur Vent Field at 29°N on the Mid-Atlantic Ridge. However, it remains to be verified whether the other plumes observed at 27°N and 30°N are also of hydrothermal origin.

The regional extent of the plume at 29°N, being over 14 km long, and at least 3 km wide, and its vertical and horizontal complexity indicate that the area hosts a vent field rather than just a single active vent site. The vent that was sampled at 29°10.15'N, 43°10.28W is probably just one of a number of vents, each exhaling fluids with different potential temperatures. The two thin plumes at the Broken Spur site with sharp nephel and transmissometer profiles are probably advected features from a distal source. The thicker plume with its broad nephel and transmissometer profile is probably a convected feature from a proximal source. This interpretation is supported by the increase in the nephelometer to transmissometer signal ratio at the base of the thicker plume, indicating an increase in the partical diameter. Because larger diameter particles settle faster than smaller diameter ones, they are likely to be present at the base of a young non-turbulent neutrally-buoyant plume and absent from an old non-turbulent neutrally-buoyant plume. If the plume was bouyant then turbulent mixing would prevent settling of the particulate load.

We suggest the diurnal fluctuations in the plume strength and its ridge-axis parallel structure are caused by tidal sloshing parallel to the trend of the axial valley of the near-bottom water mass.

The geological structure of the ridge axis along the Kane to Atlantis Supersegment influences the location and dispersion of the hydrothermal plumes. At 29°N the Mid-Atlantic Ridge is assymmetric with the highest axial valley walls on its western side, at the base of which is a neovolcanic ridge. The hydrothermal plume from the Broken Spur Vent Field is localised in the vicinity of a neovolcanic ridge where it rises 200-300 m above the seafloor is elongated parallel to the western axial valley wall.

Fresh unsedimented glassy lavas, porphyritic lavas and an axial summit caldera along the crest of the volcanic ridge are evidence of recent eruptions and a shallow magma chamber. We suggest that the latent heat of crystallisation and the residual heat of the magma body drive the hydrothermal circulation at Broken Spur. We also note the periclinal shape, shallow depth and negative Bouger gravity anomaly at the centre of the second order ridge segment in which the Broken Spur Vent Field is located, and suggest that this is probably the most magmatically active part of the Kane to Atlantis Supersegment, fed by a prominant upwelling asthenospheric plume, and hence has the highest energy flux.

The Kane to Atlantis Supersegment is subdivided into closed basins (Purdy et al., 1990) which contrast with the crestal shape of the East Pacific Rise. Unlike hydrothermal plumes, which easily disperse on the East Pacific Rise, it is likely that the basins along the Supersegment trap the plumes and restrict their chemical and biological dispersal.

Figure Captions

Fig. 1.1 Ship's track showing the TOBI survey along the Mid Atlantic Ridge between 27°N and 30°N.

Fig. 1.2 TOBI transmissometer (heavy line) and depth data (thin line) for approximately 14 km along the western side of the axis of the MAR, centred on 29°05'N. The plume signals from the Broken Spur Hydrothermal Field give the largest shifts in light attenuation at around 29°08'N and a depth of about 2600 m. Other transmissometer signals at 29°02'N and 29°05'N, indicate that hydrothermal activity is widespread at the Broken Spur Vent Field.

Fig. 1.3 Contoured nephel density map of the extent of the Broken Spur plume from a combination of ZAPS sledge and TOBI vertical and towed profiles through the water column. Contours are in Formazin Turbidity Units (FTU x 10^4), TOBI transmissometer data for the eastern side of the area gave background values (equivalent to 40 FTUs).

Fig. 1.4 Gridded bathymetry of the Broken Spur Ridge from *HYDROSWEEP* multi-narrow beam sonar system (courtesy of J-Christophe Sempere).

Fig. 1.5 TOBI sidesscan sonar image, 2 km x 2 km, of the Broken Spur Vent Field. The image is similar to a monochrome photograph with bright areas being strong echos and dark areas being weak echoes and shadows. Broken Spur Vent Site (BSVS) lies at the top of an axial volcanic ridge and adjacent to an axial summit graben (ASC) running along the length of the ridge.

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CD-76 TOBI's Track

Fig 1.1

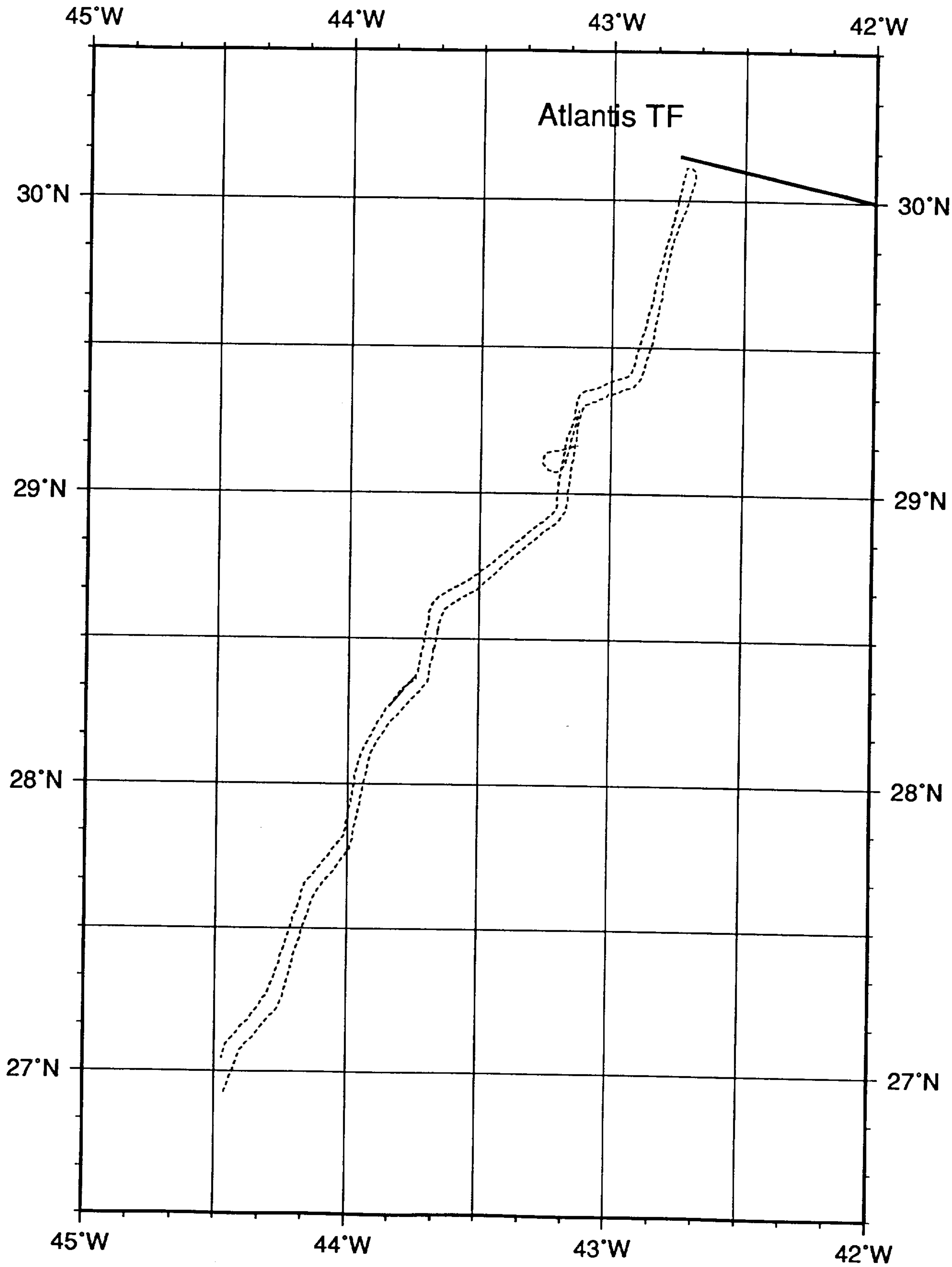
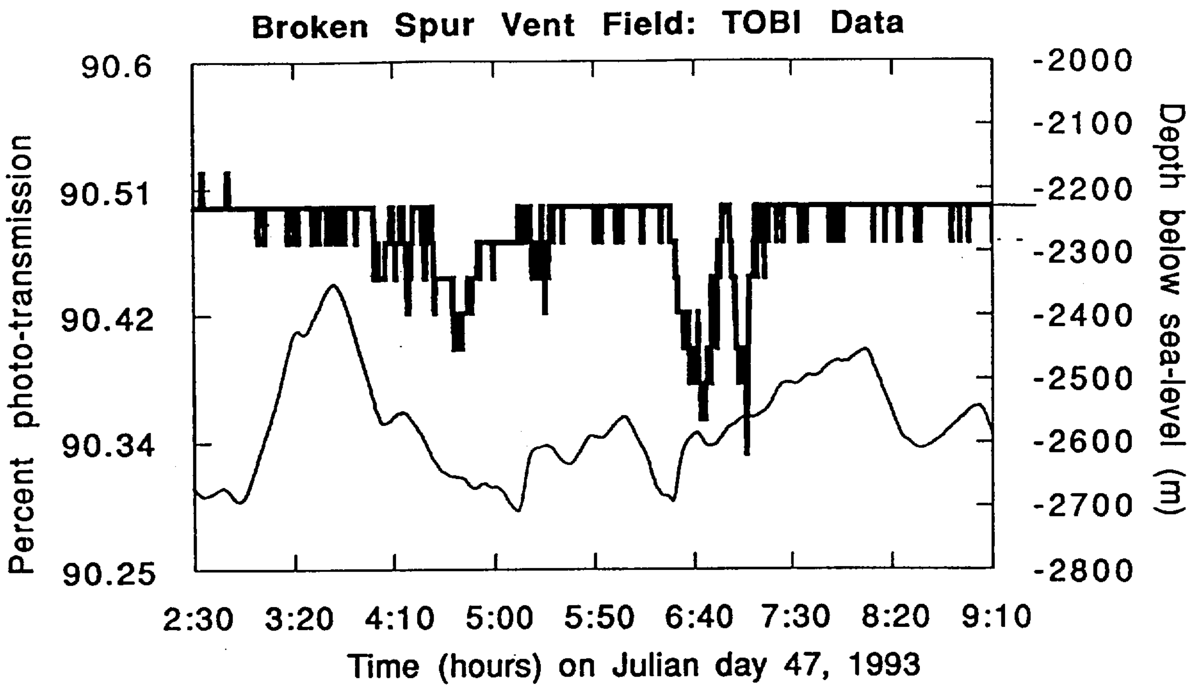


Fig 1.2



Broken Spur Vent Field: TOBI Data
Percent photo-transmission
90.6
90.51
90.42
90.34
90.25
Depth below sea-level (m)
-2000
-2100
-2200
-2300
-2400
-2500
-2600
-2700
-2800
2:30
3:20
4:10
5:00
5:50
6:40
7:30
8:20
9:10
Time (hours) on Julian day 47, 1993

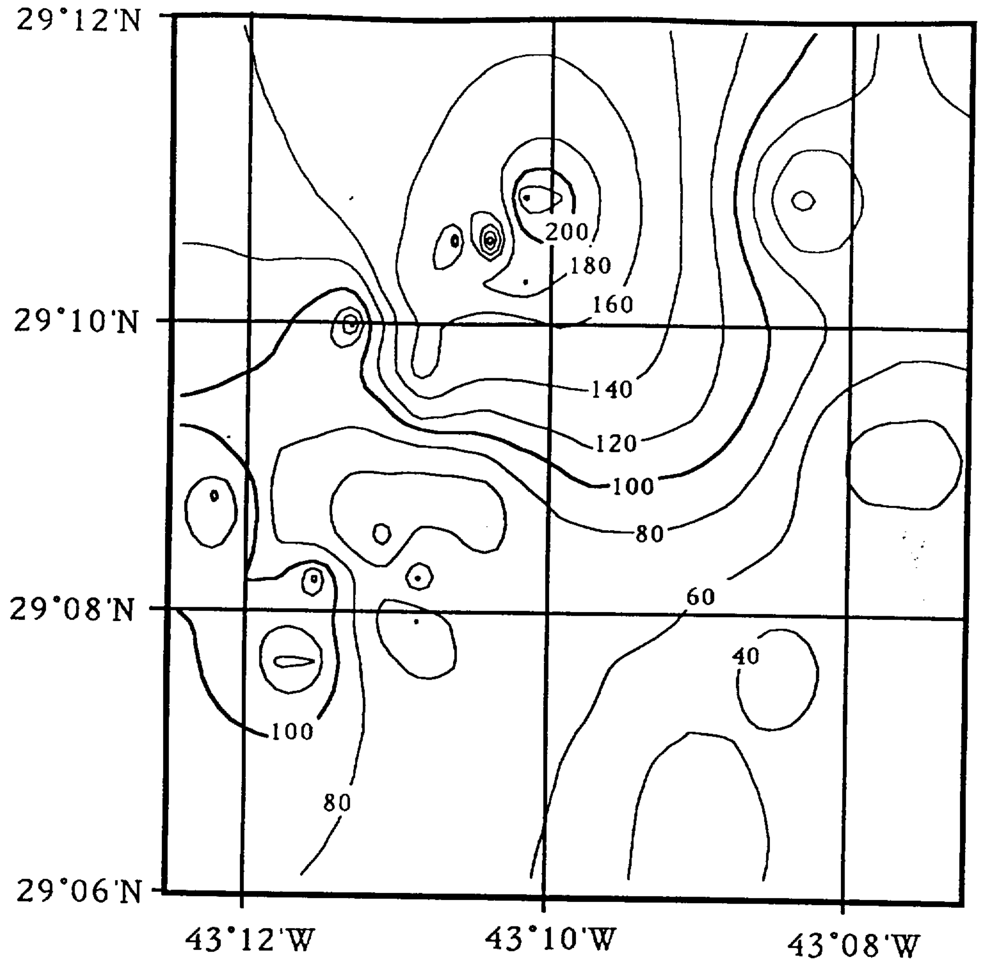

29°12'N
29°10'N
29°08'N
29°06'N
43°12'W
43°10'W
43°08'W
200
180
160
140
120
100
80
60
40
100
80

Fig 1.3

Gridded Bathymetry of the Broken Spur Ridge

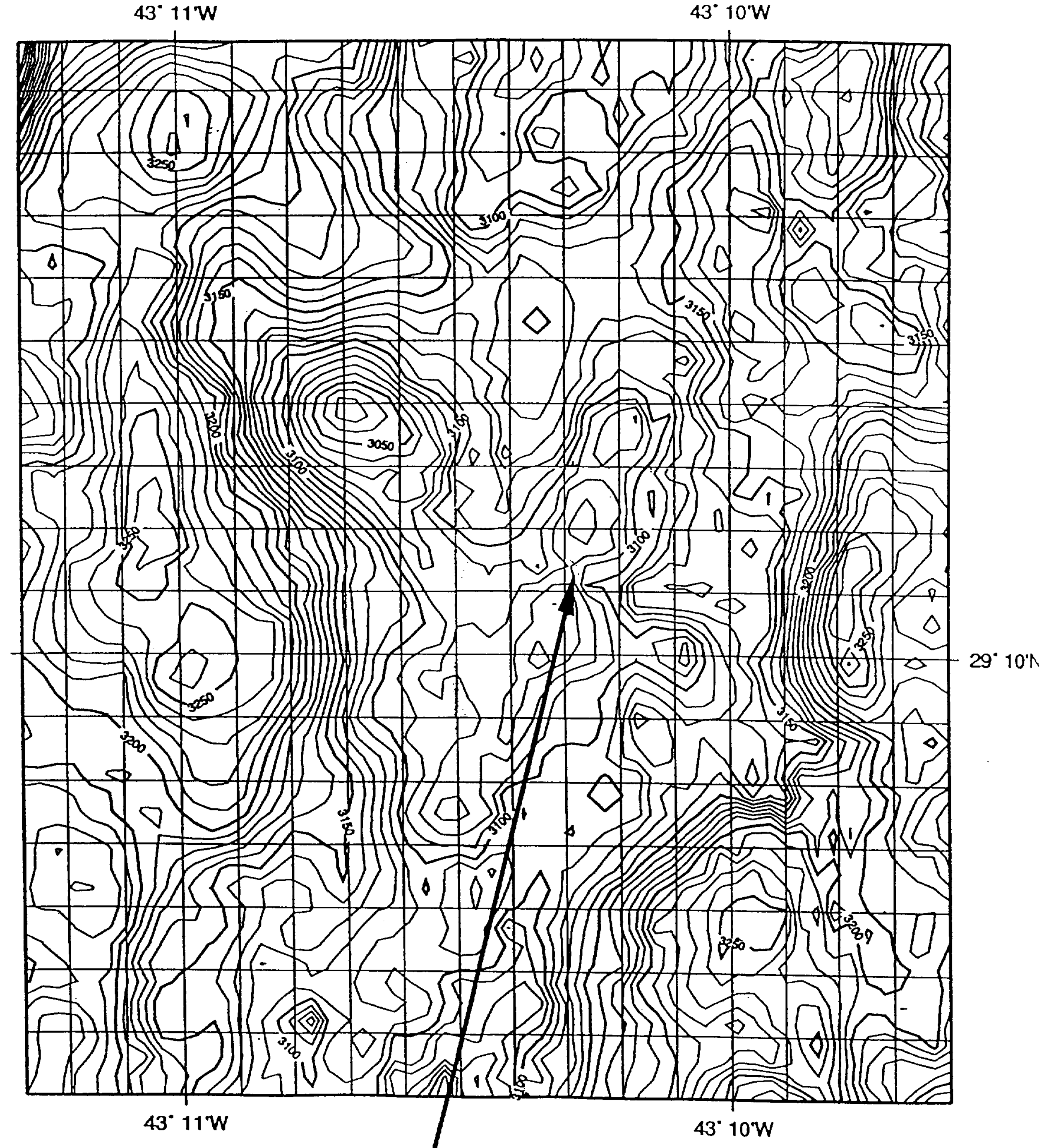


Fig 1.4 **Broken Spur Vent Field(29°10.15N ; 43°10.28W)**

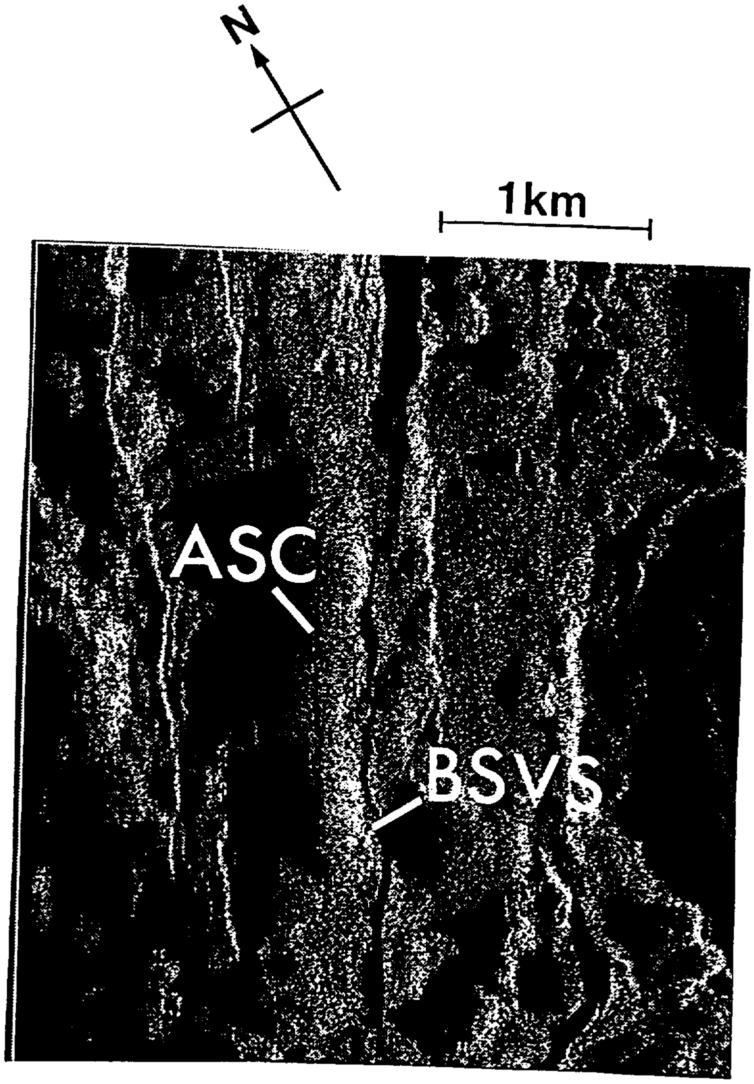


Fig 1.5

2 CRUISE CD76 INSTRUMENTATION REPORTS

2.1 TOBI Instrumentation

(by Nick Millard and Ian Rouse)

2.1.1 Narrative

The main objective for the TOBI system was to provide a sidescan survey of the MAR axis between 27°N and 30°N. The vehicle was to be "flown" at a low altitude (where possible below 300 metres) to give the plume detecting sensors the best chance to see a signal. In addition to the usual thermistor probe and transmissometer, there were two sensors fitted especially for the cruise. These were a nephelometer configured to measure backscatter and the ZAPS probe to measure disolved manganese. The plan was to make one run of about 10 days, running first north up the eastern side of the ridge axis followed by an overlapping southerly line down the western side.

In the event the survey was completed with three separate runs. The first took three attempts to get under way due to instrument problems and lasted two days before recovery to repair a short circuit down the towing cable. The second run provided most of the data, lasting 7 days, and being recovered at the southern end of the survey at 27°N. The third, 18 hour, run was deemed necessary to fully image the Broken Spur Vent Field (Fig. 1.5).

Day 041, the first day of TOBI operations, was warm and calm during which a number of launch and recovery operations took place. After 11 hours the ZAPS instrument was removed from the vehicle for repairs. The weather remained good for Day 042 when TOBI (with ZAPS) was again launched. Although ZAPS failed again, the systems were lowered to the seafloor to establish the seriousness of the acoustic interference, which had become evident on the sidescan records, from both the nephelometer and ZAPS. Both these instruments produce an electronic 'click' when their xenon flash tubes fire which was picked up by the sonar transducers. The 5.5Hz. signal from the nephelometer proved much more of a problem than the 25Hz. ZAPS noise. It was decided that the nephelometer had to be removed from TOBI to achieve acceptable sidescan data and the vehicle was thus recovered.

In the early hours of day 043 TOBI was again launched for Run 1, which lasted for 2 days. This was despite the fact that 12 hours after launching, with the vehicle flying at 350 metres, a pinnacle of rock, seen neither on the Simrad precision echosounder nor on the swath bathymetry charts, rose more than 350 metres in less than 8 minutes. Hitting it was inevitable but luckily the collision must have been close to its peak as contact time was short. All instruments on the vehicle continued working and no excessive loads were observed on the wire and so the survey resumed. thirty-six hours later the system failed with a short circuit appearing on the cable. On recovery, this was traced to a damaged umbilical cable which had to be replaced. During this run the pressure gauge first gave erratic readings and eventually failed. It was found to have leaked and also had to be replaced. The chemical cartridge on ZAPS was recharged during this time. Damage caused by the collision was observed in the form of scores on the depressor weight and swivel unit. There was also slight damage to (and a small rock sample embedded in) the lower bumper of TOBI.

Day 046 saw the launch for Run 2 which went smoothly with all systems apparently working. Persistently strong winds made life difficult for the officers on the bridge and the low altitude flying continued to tax the TOBI watchkeepers. This part of the Mid Atlantic Ridge was found to have many pinnacles which did not show on echosoundings made from the surface. This run continued for 7 days until the end of the planned survey.

The short 18 hour TOBI Run 3 commenced on Day 063. ZAPS was not fitted on this occasion and a higher altitude (400-500 m) survey of the vent field was carried out. The area was insonified from two directions. An acoustic navigation beacon was attached to the vehicle for this run but proved to be of little use as both the ship and TOBI were not inside the network at the same time.

During TOBI Run 2 there were inexplicable variations in the gain observed on the starboard sidescan during both lowering and recovery. At depth the gain settled to a value only a little less than that of the port side. It was also felt that the resolution on this starboard side was also not as good as it should have been and a faulty sonar array section was suspected. Before Run 3 started an open circuit connector was replaced on the centre section of the starboard array. This action restored the full resolution and gain at depth but there is still a pressure dependent problem affecting the starboard gain that has to be resolved.

During TOBI deployments the vehicle position was estimated from a knowledge of its depth, the amount of wire paid out and its altitude. These positions were used to produce replays of the sidescan data at a scale of 1:50,000, corrected for the vehicle speed over the ground and for geometric slant range. A recently developed bend correcting routine was also used to produce curved track replays for a total of 21 bends so that more accurate mosaics could be produced. Selected areas were replayed at a large scale in which every data point in each sweep was displayed. Although not corrected for ship speed these images gave impressive results with a great improvement in the observable detail.

The TOBI data for the cruise is contained on 10 magneto-opical discs making a total of about 5.6 G bytes of data.

2.1.2 TOBI Instrumentation Configuration

TOBI is IOSDL's deep-towed instrumented sonar platform. The system consists of a neutrally buoyant underwater vehicle towed from the ship on a 10km long conducting cable via a 600kg depressor weight and a 200m umbilical. The shipboard system consists of data logging and display, system control and data reply. The vehicle's main scientific instruments are a double-sided 30kHz sidescan sonar with a swath width of 6km and a 7.5kHz sub-bottom profiler capable of penetrating up to 60m of sediment. Other scientific instruments used on the cruise were a tri-axis flux-gate magnetometer, temperature probe, transmissometer, ZAPS manganese sniffer and a nephelometer.

The vehicle is designed to be operated at depths of up to 6000m. On this trip the profiler was used mainly as an altimeter for the vehicle as there was little or no sedimentation in the area under study. The data logging/display system uses an IBM PS/2 model 80 computer and stores the sonar and instrument data on 600 M byte magneto-optical disks. After formatting, the disks are capable of storing 800 minutes of data on each side. Sidescan data were displayed on a video monitor corrected for slant range distortion in real time and printed out using a Raytheon TDU650 thermal recorder. Profiler data were displayed on an EPC 3200 line scan recorder. Two channels of instrument data (ZAPS and transmissometer) were displayed on a chart recorder. The replay system uses a similar IBM computer and produces scaled and corrected sidescan, profiler and instrument data.

2.1.3 TOBI System Specifications (CD76)

Sonar Instruments

Sonar system	Transducer Frequency	Beam Angles	Range
Port Sidescan: Ceramic stack motors driving face plate.	32.15kHz	0.80 x 40°	3km
Stbd Sidescan: Ditto	30.37kHz	0.80 x 40°	3km
Profiler : 7 x ceramic rings.	7.5kHz	25° cone 60m	2km

Other Scientific Sensors:

Instrument	Output	Range	Digitization
Tri-axis fluxgate	+/- 5V	+/- 40960n Tesla	3 x 12bit +polarity magnetometer
Temperature +polarity probe	+/- 5V	1 - 22 °C	12bit
Transmissometer	0 - 5V	0 - 100%	12bit
ZAPS	0 - 5V		12bit
Nephelometer	0 - 5V		8bit

Vehicle Instruments:

Pitch	0 - 5V	+/- 20 degrees	8bit
Roll	0 - 5V	+/- 20 degrees	8bit
Depth (Pressure)	1Hz/m	≤6000m	16bit
Compass	Gray code	360 degrees	10bit
Impeller log (Speed)	0 - 5V	0 - 2. 5knts	8bit

2.1.4 Major Computer Programmes Used

Programme Name and description:

TOBILOG. EXE
Logs all TOBI data, displays sidescan data on video monitor and thermal printer hard copy and outputs analogue signals to chart recorder.

ERASDISC. EXE
Reads TOBI sidescan data from magneto-optical discs and produces a scaled and slant range corrected file on hard disc.

DISSCRAY. EXE
Reads scaled and slant range corrected sidescan files and outputs data to Raytheon thermal recorder.

BEND. EXE
Reads selected TOBI sidescan data from magneto-optical discs and scales, corrects and fits data to a predetermined curve storing the result on hard disc.

DISCBRAY. EXE
Reads scaled, corrected and curve fitted sidescan files and outputs data to Raytheon thermal recorder.

REPTST76. EXE
Reads instrument data from magneto-optical disc and displays on video monitor in numerical form.

2.2 ZAPS Instrument Deployments and ZAPS Sled Operations
(by Gary Klinkhammer)

2.2.1 Introduction

Venting of hot, chemically-rich, buoyant fluids from mid-ocean ridge spreading centres produces hydrothermal plumes with thermal, physical, and chemical signatures quite different from background deep sea water. These plumes rise several hundred meters above the sea floor where they reach neutral buoyancy and begin to spread laterally. The marine geochemistry group at Oregon State University has designed and constructed an instrument package, the ZAPS sled, that carries state-of-the-art, *in situ* sensors capable of detecting such plumes. This vehicle was used as a survey tool in the search for hydrothermal activity, in an active segment of the Mid Atlantic Ridge, identified during the TOBI long-line survey. This work led to the identification of an active hydrothermal vent field within this segment.

2.2.2 The ZAPS Sled Frame

The ZAPS Sled towed vehicle (Fig. 2.1) is an open framework of 5 cm Type 316 SS pipe. The ZAPS Sled stands 90 cm wide, 90 cm tall, and is 210 cm long with a tapered bow 86 cm wide. This frame hangs from a standard conducting cable by an adjustable 3-point chain bridle to ensure that the sled attains a forward facing, level attitude in the water. The two vertical sides of the sled aft section have 0.95 cm thick polycarbonate panels attached to serve as rudder vanes and give structural hydrodynamic stability while being towed at 1-2 knots through the water. On Cruise CD76 the sled was deployed from the starboard hydrographic A-frame both vertically and during slow "drift" surveys. The weight of the sled in air is about 350 kg.

2.2.3 ZAPS Sled Instrumentation

The central instrument on board the ZAPS Sled is a Sea-Bird 9/11 *plus* CTD sampling at 24 Hz, fitted with modular temperature and conductivity sensors and a Paroscientific Digiquartz Pressure Sensor. Four analog instruments are interfaced through the Sea-Bird underwater unit. These include:

(1) A SeaTech Transmissometer to measure 660 nm wavelength beam transmission through a 25 cm path length.

(2) A Chelsea Aquatracka Mk III Fluorometer operating as a nephelometer at a wavelength of 420 nm to measure scattered light at 90 degrees to the incident light beam.

(3) A Zero Angle Photon Spectrophotometer (ZAPS) that uses solid-state chemistry with analog fluorescence to measure the concentration of total oxidizable manganese (TOM).

(4) A SIMRAD Mesotech Systems Model 807 Echo Sounder / Altimeter to determine the height of the sled off the bottom within a 500 meter range.

The ZAPS Sled also carries a General Oceanics Rosette array interfaced to the CTD and capable of holding 12 5-litre Niskin sample bottles for collecting sea water samples for laboratory measurements of such parameters as methane, helium, and trace metals. The bottles are tripped by signals from the CTD deck unit at any time without interrupting the data steam.

In addition the sled can be fitted with an acoustic transponder that is interrogated with a transducer at the surface to determine the direct slant range and computed horizontal range to the sled. On CD Cruise 76 a pinger was fit to the sled to aid in near bottom surveys and a relay transponder was used to position the sled within an Oceano transponder net.

2.2.4 CTD Data Acquisition and SLED Navigational System

The ZAPS sled is powered through a Sea-Bird deck unit that also receives frequencies from the underwater unit and sends converted data via an RS232 port to a Silicon Valley 486 computer that supports an Introl optical disk. Raw CTD data files are stored on the optical disk and echoed to a second, identical computer. This second, navigational computer also receives ship positions from a Garmin MRN 100 GPS Satellite Receiver and imports this data into a proprietary SLED navigational programme developed at Oregon State University. This navigational programme plots in real time the ship's position and trackline and the computed horizontal range and position of the sled as projected onto the trackline of the ship. The SLED navigational programme also shows a diagrammatic cross-sectional view of the ship, the towed vehicle, and a calculated "bottom depth" derived from the sum of the CTD pressure data and the concurrent altimeter data (height above bottom) from the package. This calculated bottom depth beneath the sled can then be compared to the depth records and/or bathymetric maps of the area to help in locating the sled with respect to bottom features or obstacles. The ZAPS Sled was not used for towing during CD76. Much of the positioning of the package was accomplished by monitoring the trace from the IOS pinger using the "waterfall display".

2.2.5 Field Performance

ZAPS on TOBI

ZAPS was on the TOBI vehicle during four deployments. The instrument failed to respond during the first deployment. It turned out that in the process of closing up the pressure case after calibration the wire supplying trigger voltage to the flash tube was pulled loose from its connector. ZAPS signals during the second lowering were erratic and eventually died. Upon recovery it was discovered that there was a problem with the main wiring harness on the signal board. Unfortunately the signal board was exposed to sea water while attempting to repair the instrument on the deck. The instrument was then removed from TOBI and the backup signal board installed. After the faulty connector was resoldered the instrument seemed to respond normally. Reasonable signals were transmitted from the ZAPS instrument during the first successful run but the umbilical cable for the vehicle failed and the run was aborted after 2 days.

ZAPS was deployed with TOBI during the second run without further electronic modification but the chemical cartridge was recharged during this time. The second and longest TOBI run lasted from 16:30 (local time) on the 14th of Feb. until 18:30 on 22 Feb. Transmissometer data from this tow were used to identify the hydrothermally active area that was explored with the ZAPS Sled, WASP Sled and dredges in the second part of the cruise.

ZAPS data from this second TOBI run was affected by an apparent artifact produced by moving the vehicle rapidly through the water column. The exact nature and extent of this problem will require a further analysis of the data set. Discounting this artifact there was not a general correlation between the signal from ZAPS and readings from the tansmissometer although anomalies from these instruments did sometimes overlap. This result is expected since ZAPS measures dissolved manganese and light transmission indicates particulates in the water column. Alternatively, if one discounts any part of the ZAPS record that may have been affected by the motion of the vehicle then two deep water features remain: a large signal near the Western Atlantis Ridge Transform Intersection and a gradual, systematic, decrease of the signal during the tow. Unfortunately time did not allow for a further investigation of the Western RTI ZAPS anomaly. The background deep water signal decreased from about 1.9 V at the beginning of the tow to about 1.6 V at the end. At least some of this decrease resulted from reagent bleed from the cartridge with time. In a way this was a reassuring result as it suggests that the probe was active during the entire deployment. It was possible to verify this result at the end of the tow when the ZAPS signal produced the TOM (total oxidizable manganese) profile shown in Fig 2.2. This profile is consistent with the structure of the water column in this area and our general understanding of the geochemistry of manganese in the oceans.

ZAPS on the ZAPS Sled

After the second TOBI run, ZAPS was recalibrated and we began a detailed investigation of the Broken Spur Vent Field. This work began with ZAPS being deployed on the ZAPS Sled but it was obvious from the first lowering that there were serious problems with the instrument. The signal was noisy and erratic; eventually the probe stopped working altogether. It was then determined that the second electronics board had been damaged beyond repair by water penetration during the process of recalibration. It was not possible to use the ZAPS probe for the remainder of the leg.

Altogether the ZAPS Sled was deployed 14 times in an area 5.5 km along strike and 3.7 km across strike. The hydrothermally active ridge was identified during the 12th of these lowerings. The downcast designations and their locations before drifting are indicated in the following table.

CD76SD01	29° 08.20' N; 43° 10.80' W	CD76SD08	29° 09.30' N; 43° 10.91' W
CD76SD02	29° 08.15' N; 43° 11.52' W	CD76SD09	29° 08.15' N; 43° 11.25' W
CD76SD03	29° 08.58' N; 43° 12.30' W	CD76SD10	29° 08.60' N; 43° 10.75' W
CD76SD04	29° 09.50' N; 43° 10.90' W	CD76SD11	29° 07.80' N; 43° 11.00' W
CD76SD05	29° 10.33' N; 43° 11.00' W	CD76SD12	29° 10.30' N; 43° 10.40' W
CD76SD06	29° 08.40' N; 43° 11.20' W	CD76SD13	29° 10.65' N; 43° 10.16' W
CD76SD07	29° 09.02' N; 43° 10.91' W	CD76SD14	29° 10.21' N; 43° 10.32' W

Except for the ZAPS probe, the equipment on the sled worked flawlessly during these deployments. Fig. 2.3 is an example of the light transmission and nephel profiles that were used to locate the hydrothermal site discovered during CD76.

2.2.6 ZAPS Navigational System

The graphical display of the ship's position and track presented by the SLED Program turned out to be a valuable resource during all CD76 operations. Positions from this display were used for scientific logs during underway watches and TOBI tows. The Garmin antenna and receiver proved to be extremely reliable and offered accurate positions 98% of the time. The capability of accurately recording ship's positions and the locations of events during ZAPS Sled lowerings, WASP deployments, and dredges proved to be a valuable compliment to navigational information logged on the bridge. Fig. 2.4 is a screen dump from WASP 04, the deployment that encountered a hydrothermal chimney. This information helped us pinpoint the location of at least one vent site and gave us a better chance of sampling sulfides during subsequent dredging operations.

2.3 The WASP System

(by David Edge)

2.3.1 Narrative

Despite the late funding for the development of this system the WASP vehicle was deployed on 5 occasions resulting in over 1000 seabed photographs.

A deployment early in the cruise was essential to test the system, since the anticipated 11 day TOBI survey would allow time to correct any problems before the WASP system was needed operationally. On Julian Day 039 the WASP system was tested resulting in 32 seabed photographs. Problems with the acoustic telemeter were corrected and subsequent 2nd, 3rd and 4th deployments were successful.

Before the 3rd WASP survey, a transmissometer was interfaced to the telemeter to assist in locating an active hydrothermal vent. To ensure a change in transmissometer output could be positively detected, the acoustic telemeter was configured to transmit an expanded scale of between 4 and 5V. During the 3rd WASP survey, the transmissometer signal remained steady.

During the 4th WASP survey a strong transmissometer signal indicated a particulate plume near the seafloor. The computer waterfall display of acoustic telemetry data showed a transmissometer signal variation of at least 0.5 V (i.e. a 20% reduction in light transmission). This information was correlated with the sonar altimeter which revealed a seabed feature some 15m high and adjacent to a graben 30m deep and approx 30m wide. On recovery the vehicle was found to have sulphide deposits encrusted on its frame. Approx 400 seabed photographs were recorded during this survey. During the 5th WASP survey, the transmissometer reading remained steady.

2.3.2 WASP Developments

Several key components were used on WASP for the first time during cruise CD76. The IOSDL acoustic telemeter had been redeveloped to include a microprocessor for programming of control and data logging functions and to simplify sensor interfacing. Communication to the unit to set time, enter calibration coefficients, set camera interval and down-load logged data has been achieved via an RS232 deck cable connected to a PC.

A Mesotech 200kHz acoustic altimeter was interfaced to the acoustic telemeter via an RS232 link, and provided accurate seabed detection from a range of up to 200m above the seafloor.

The IOSDL oil filled pressure balanced battery packs, used for the first time to power the WASP instrument, were designed to take advantage of relatively low-cost, gel-type automobile batteries. These worked well and compare favourably both in performance and price with the alternative commercially available electrical sources.

During the cruise, software was written to utilise the telemeter processor card facilities. The IOSDL pulse position acoustic transmission technique can now be accomplished using the processor card timers. This makes redundant a counter/timer card resulting in a significant power saving of 2 watts. Software was also written for the PC to improve set-up and data acquisition facilities. The telemeter-logged information can now be down-loaded directly into a Microsoft Excel spreadsheet.

2.3.3 Photographic Processing

Processing of film was limited to topping, tailing and developing of negatives. The remaining film had to be processed and printed at IOSDL.

2.3.4 Waterfall Display

Once again, this cruise proved that the IOSDL computer "waterfall display" was better than the Simrad Echo Sounder for monitoring deployed instrumentation. It was often used for monitoring the altitude of the rock dredge and ZAPS sled in addition to WASP.

2.3.5 Recommendations

Operating the WASP system in areas of rough topography, trying to image specific hydrothermal targets, and processing photographic film indicated requirements for:-

(a) Improved vehicle framework to withstand impacts and protect instrumentation from seabed collisions.

(b) Addition of a sensor suite to include transmissometer, CTD, compass, roll, yaw and pitch

(c) Real time video

(d) Altimeter controlled camera aperture setting

(e) Shipborne image processing system.

(f) 35mm Photographic film digitiser

(g) High resolution electronic printer

(h) Acoustic navigation - To aid repeated, accurate location of specific sites, an expendable transponder attached to the WASP vehicle could be deposited on command.

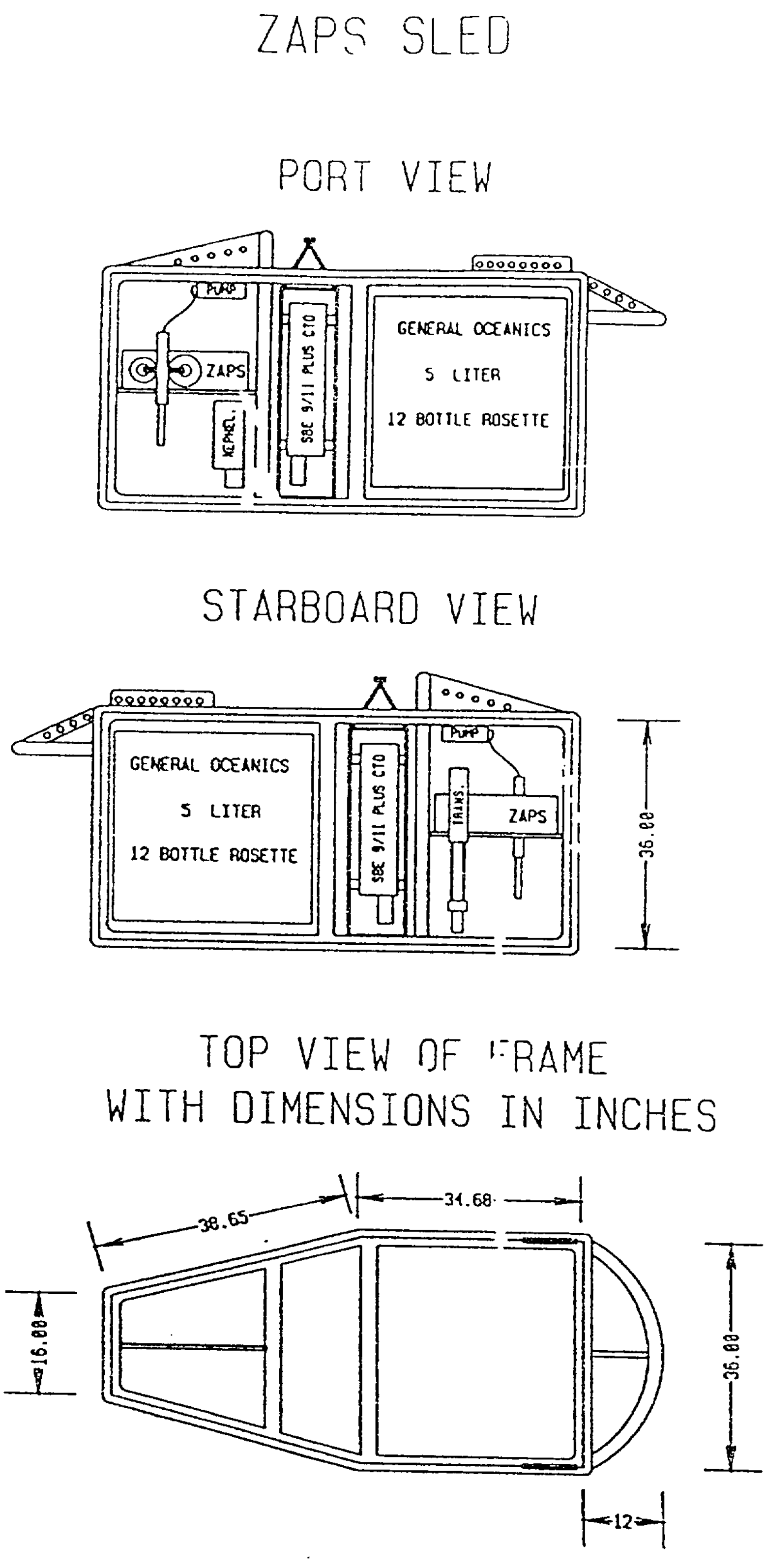

ZAPS SLED
PORT VIEW
PUMP
ZAPS
NEPHEL.
SBE 9/11 PLUS CTD
GENERAL OCEANICS
5 LITER
12 BOTTLE ROSETTE
STARBOARD VIEW
GENERAL OCEANICS
5 LITER
12 BOTTLE ROSETTE
SBE 9/11 PLUS CTD
PUMP
TRANS.
ZAPS
36.00
TOP VIEW OF FRAME
WITH DIMENSIONS IN INCHES
38.65
34.68
16.00
36.00
12

Fig 2.1

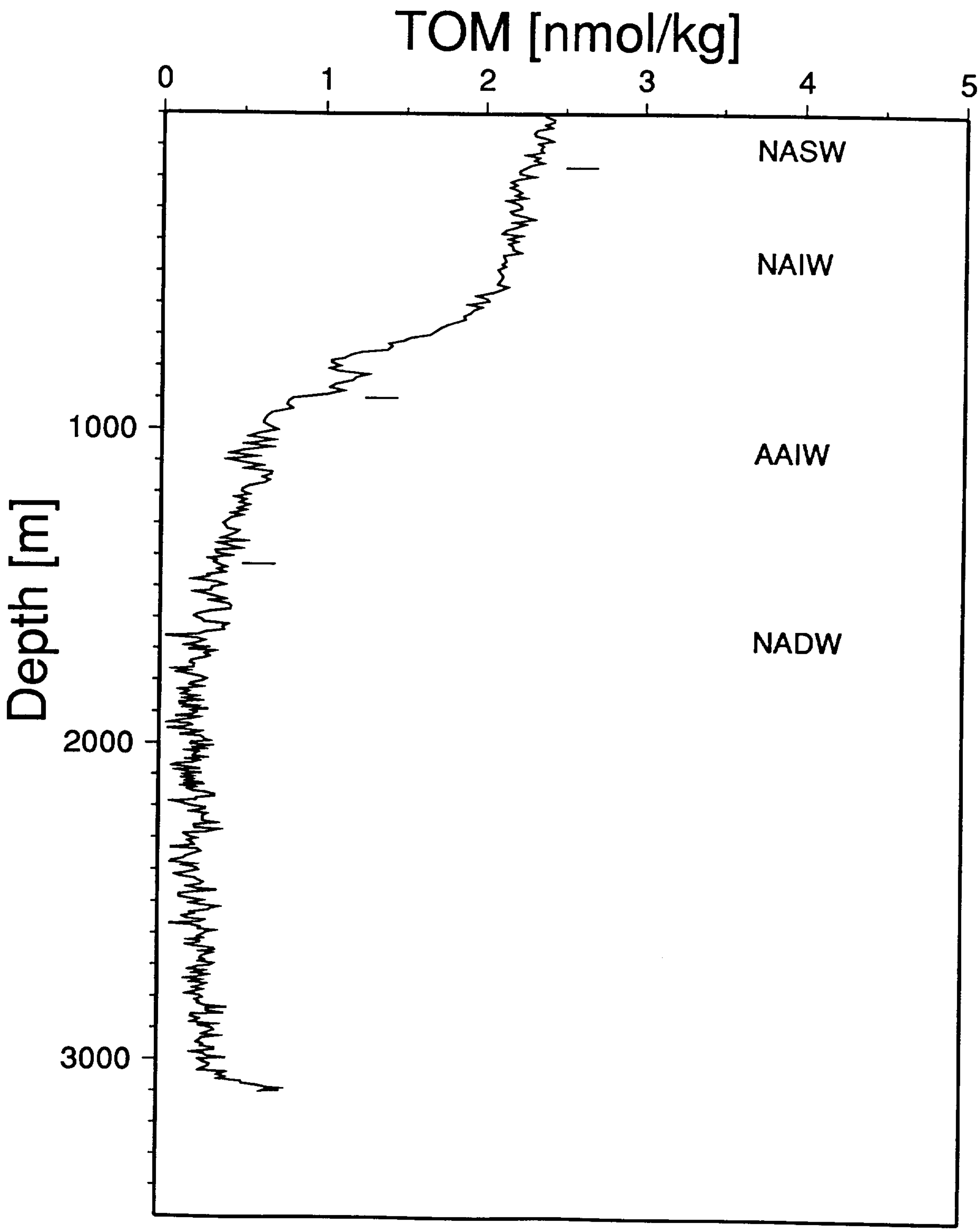


Fig 2.2 ZAPS Profile 053/16:01 - 18:25
26° 52.05' N 44° 29.38' W

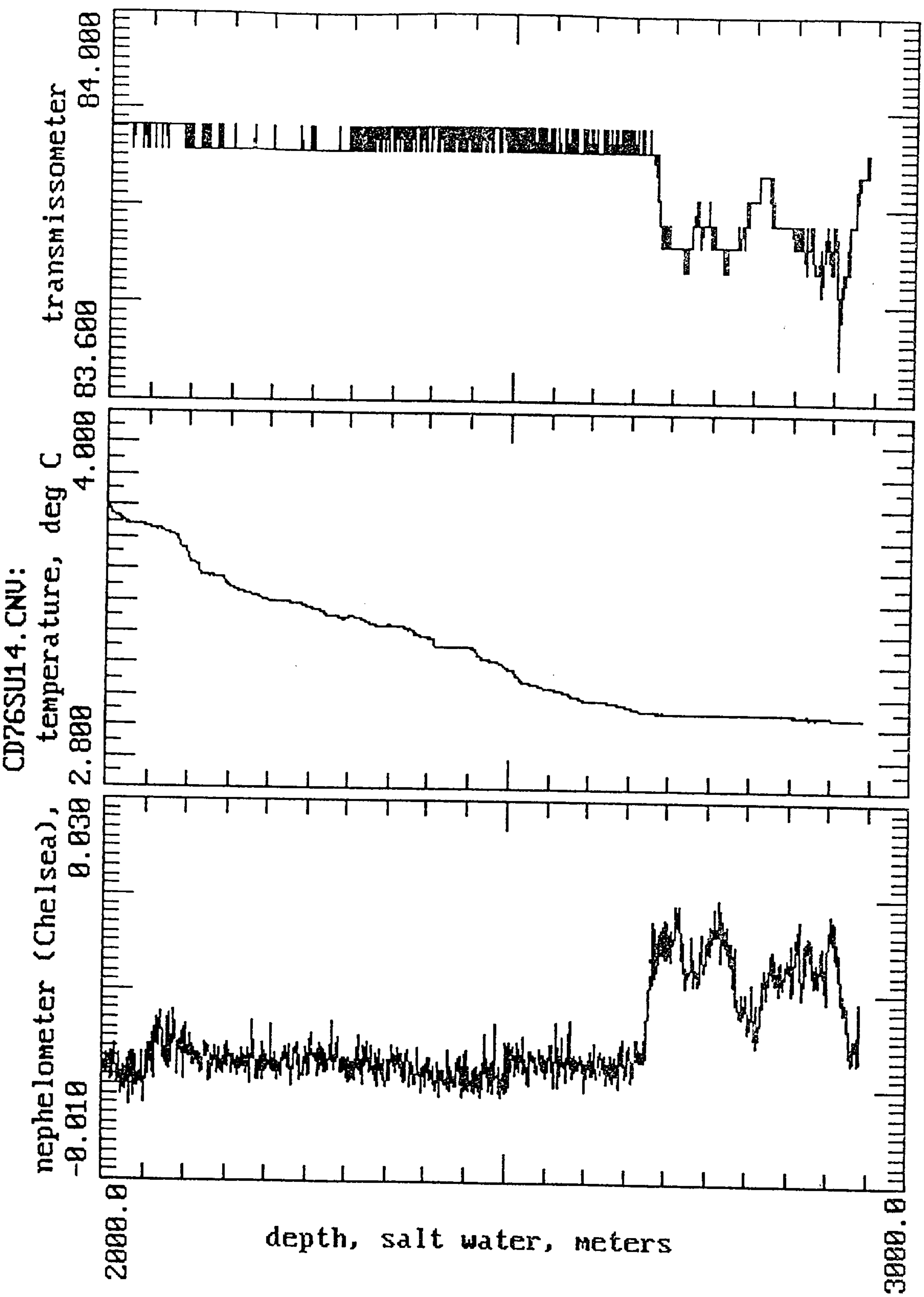
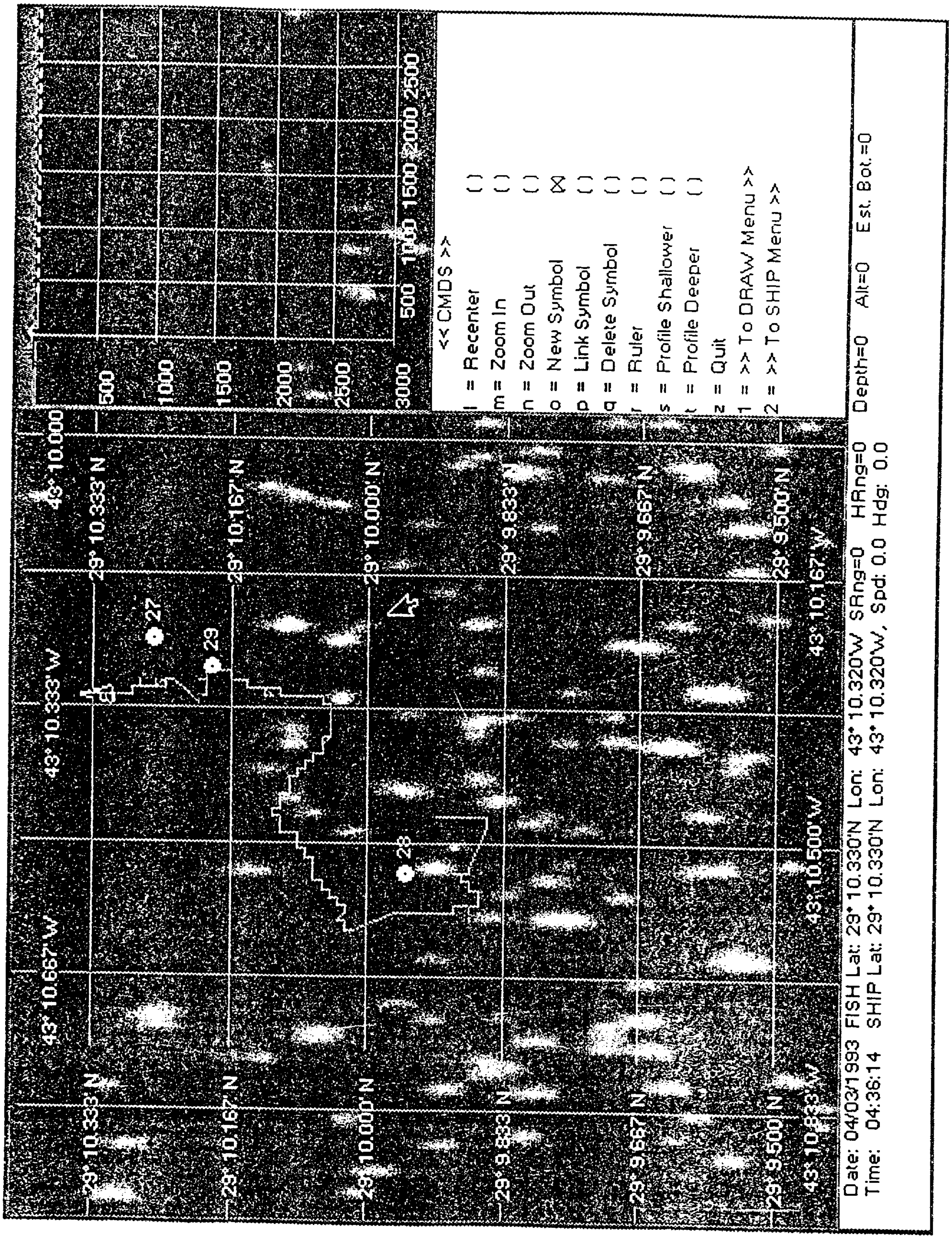

CD76SU14.CNV:
transmissometer
84.000
83.600
temperature, deg C
4.000
2.800
nephelometer (Chelsea),
0.030
-0.010
depth, salt water, meters
2000.0
3000.0

Fig 2.3



WASP 04 first pass

29° 10.157 43° 10.254

Fig 2.4

2.4 Measurement of Vector Geomagnetic Field By STCM
(by Keizo Sayanagi)

2.4.1 Introduction

Vector data of the geomagnetic field were collected with the Shipboard Three Component Magnetometer (STCM) during this cruise except when the ZAPS, WASP, and dredging surveys were conducted over the Broken Spur Vent Site. The vector magnetic data provide more detailed information than total intensity data to understand the magnetic structure of oceanic crust, because the amplitude of vector magnetic anomalies is not affected by the direction of the ambient geomagnetic field or the strike of magnetic lineations. The STCM system has been developed and improved since 1977 (Isezaki et al., 1981; Isezaki, 1986; Seama et al., 1990). It has been used in many oceanic regions to successfully measure the geomagnetic field vector (e.g. Seama and Isezaki, 1990; Nogi et al., 1990; Seama et al., 1993). The geomagnetic field observed by the STCM are superimposed on the magnetic field produced by the induced and permanent magnetic moments of the ship. The ambient geomagnetic field vector are calculated by reducing those artificial magnetic fields. For this calibration, we ran the ship along a track in a figure "8" at 4 sites and in a circle at one site.

2.4.2 Principle of Measurement

The observed geomagnetic field is superimposed on the magnetic field produced by the induced and permanent magnetic moments of the ship.

$$\mathbf{H}_{ob} = \mathbf{F} + \mathbf{H}_i + \mathbf{H}_p \quad (1)$$

where $\mathbf{H}_{ob}$ and $\mathbf{F}$ are the observed and ambient geomagnetic fields. $\mathbf{H}_i$ and $\mathbf{H}_p$ are the magnetic fields produced by the induced and permanent magnetic moments of the ship. The induced magnetic field $\mathbf{H}_i$ is proportional to $\mathbf{F}$, since $\mathbf{F}$ is a weak field. Therefore equation (1) can be rewritten as;

$$\mathbf{H}_{ob} = \mathbf{F} + \mathbf{AF} + \mathbf{H}_p \quad (2)$$

where $\mathbf{A}$ is a 3x3 matrix which depends on the magnetic susceptibility of the ship, the shape of the ship and the position of the sensor. Because the sensor is fixed to the ship, the equations must be written in the ship's coordinate system. $\mathbf{F}$ is transformed into the ship's coordinate system from the geomagnetic coordinate system (Fig. 2.5). The expression is $\mathbf{(RPY)F}$ where $\mathbf{R}$, $\mathbf{P}$ and $\mathbf{Y}$ are coordinate transform matrices due to the roll, pitch and yaw of the ship. The ship's coordinate system axes are along the heading, starboard and downward direction, respectively.

$$\mathbf{H'}_{ob} = \mathbf{(RPY)(1 + A)F} + \mathbf{H'}_p \quad (3)$$

where $\mathbf{H'}_{ob} = \mathbf{(RPY)H}_{ob}$, and $\mathbf{H'}_p = \mathbf{(RPY)H}_p$. From equation (3)

$$\mathbf{F} = ((\mathbf{RPY})(\mathbf{1} + \mathbf{A}))^{-1}(\mathbf{H'}_{ob} - \mathbf{H'}_p) \quad (4)$$

$\mathbf{F}$ is a linear function of $\mathbf{H'}_{ob}$. Therefore, $\mathbf{F}$ can be obtained from the observed magnetic field.

The transform matrix $\mathbf{A} = (A_{ij})$ and $\mathbf{H'}_p = (H'_{ph}, H'_{ps}, H'_{pv})$ can be defined where the data $\mathbf{H'}$ob are obtained in all ship directions. In practice the data for determining the transform matrix are collected while the ship sails along a track forming a figure "8". There are 12 unknown values (9 in $\mathbf{A}$, 3 in $\mathbf{H'}_p$) that are determined by the least squares method. The heading angle varies from 0° to 360° while the pitch and roll -5° to 5° during calibration. Therefore $\mathbf{A}_{i1}$ and $\mathbf{A}_{i2}$ are determined better than $\mathbf{A}_{i3}$ and $\mathbf{H'}_p$. To avoid this defect several figure "8" rotations are needed at places with varying downward components of the geomagnetic field. The STCM calibration sites and 12 constants are shown in Tables 1 and 2.

2.4.3 Instrument and Data Acquisition

STCM consists of a flux-gate magnetometer, two gyro-compasses and a personal computer (Fig. 2.6). The sensors of magnetometer consist of three-axial flux-gate coils. The sensor package was rigidly mounted on the "Monkey Island" with a wooden board and ropes. All of the other instruments were installed in the Plotting Room. The flux-gate magnetometer measures individual x, y, z component of the magnetic field with accuracy of about 0.5 nT. The gyro-compasses obtain the ship's yaw, pitch and roll data. The personal computer collects the magnetic (x, y, z) data and the yaw data through a PIO (Parallel I/O) board, and the pitch and roll data via a RS-232C interface. Those data are sampled every second. The data are stored on a hard disk in binary code. Header information of Cruise ID, Date, and Time is attached to the binary records every minute. These STCM data are also stored on a 5 inch floppy disk in ASCII code to check the collected data.

In this cruise, the STCM was not linked to the ship's navigation and geophysical data acquisition system, which provides the ship's position, speed and yaw data, water depth data and magnetic total intensity data obtained by the proton precession magnetometer. We combined those data with the STCM data as follows:

(1) STCM data in binary code are translated into the data in ASCII code and are saved on a 5 inch floppy disk. The data are edited if there are some irregular data.
(2) The ASCII data are copied from an IBM personal computer to the ship-board SUN workstation. The copied data are checked for the format and number of records.
(3) The ship's navigation and geophysical data every 30 seconds, except for the yaw data, are added to header information of the STCM data. The yaw data are appended to a STCM data record every second.
(4) The completed STCM data set is stored on a 150 Mbyte cartridge tape by "tar" command.

The above processing was conducted for the STCM data obtained between 6 Feb and 27 Feb, while the vent surveys of Station 1 were carried out. The other STCM data were not processed because the STCM system was running until arrival at Azores.

2.4.4 Sample Data

Figure 2.7 shows a sample of STCM data on 14 Feb, obtained along a magnetic survey line almost perpendicular to the direction of magnetic lineations. X, Y, Z indicate the northward, eastward and downward component of the vector geomagnetic anomalies, respectively. Tp indicates total intensity anomalies obtained by proton magnetometer. The vector magnetic data were calculated by using 12 constants from R1 STCM calibration data. The vector and total intensity magnetic anomalies were calculated by subtracting IGRF 90 from the observed magnetic field. X component anomalies have relatively smaller amplitude than Y and Z components. Y and Z component anomalies have similar variations. Their phases are, however, different by a quarter period.

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Figure Captions

Fig. 2.5 The geographic coordinate system (x,y,z) and the ship's coordinate system (h,s,v). a_1, a_2 and a_3 are heading, roll and pitch angles, respectively.

Fig. 2.6 Block diagram of the system of STCM

Fig. 2.7 A part of vector and total intensity magnetic anomaly profiles on 14 Feb 1993. This magnetic survey line was almost perpendicular to the direction of magnetic lineations. X, Y, Z indicate the northward, eastward and downward components of the ambient geomagnetic field, respectively. Tp indicates total intensity magnetic anomalies obtained by proton magnetometer.

Table 1. STCM Calibration Sites

R1
06 Feb. 93, 14:15 -> (Right turn) -> 14:42 -> (Left turn) -> 15:04
16°35.66'N, 55°21.31'W
Ship speed = 7.9 ~ 10.7kts (av. 9.1kts), Water depth = 5816.6 ~ 5791m (av. 5795.4m)

R2
10 Feb. 93, 04:26 -> (Left turn) -> 04:50 -> (Right turn) -> 05:16
26°31.41'N, 43°35.27'W
Ship speed = 8.4 ~11.3kts (av. 9.4kts), Water depth = 3060.0 ~ 3791.0m (av. 3277.1m)

R3
14 Feb 93, 09:38 -> (Right turn) -> 09:42 -> (Left turn) -> 09:47
28°15.97'N, 42°58.07'W
Ship speed = 2.4 ~ 7.9kts (av. 5.0kts), Water depth = 3683.2 ~ 3728.7m (av. 3706.6m)

R4
14 Feb. 93, 09:51 -> (Right turn) -> 10:06, no Left turn
28°15.71'N, 42°59.31'W
Ship speed = 5.0 ~ 10.3kts (av. 7.5kts), Water depth = 3387.8 ~ 3824.1m (av. 3620.6m)

R5
08 Feb. 93, 10:00 -> (Right turn) -> 10:21 -> (Left turn) -> 10:41
32°00.51'N, 35°16.99'W
Ship speed = 7.0 ~ 11.5kts (av. 9.0kts), Water depth = 3687.2 ~ 3713.0m (av. 3700.7m)

Table 2. List of '12 Constants'

R1

$$(1 + \mathbf{A}) = \begin{matrix} 1.4261 & -0.0759 & -0.0373 \\ 0.0529 & 1.5893 & -0.0795 \\ 0.0632 & 0.2452 & 0.7363 \end{matrix} \qquad \mathbf{H}'\mathrm{p} = \begin{matrix} -9609 \\ -16925 \\ -5506 \end{matrix}$$

R2

$$(1 + \mathbf{A}) = \begin{matrix} 1.4216 & -0.1479 & -0.2261 \\ 0.0598 & 1.5183 & -0.2690 \\ 0.0623 & 0.1994 & 0.6285 \end{matrix} \qquad \mathbf{H}'\mathrm{p} = \begin{matrix} -964 \\ -7754 \\ 223 \end{matrix}$$

R3

$$(1 + \mathbf{A}) = \begin{matrix} 1.4415 & -0.0570 & -0.0353 \\ 0.0369 & 1.5984 & -0.0382 \\ 0.0452 & 0.2321 & 0.7064 \end{matrix} \qquad \mathbf{H}'\mathrm{p} = \begin{matrix} -9371 \\ -18036 \\ -2920 \end{matrix}$$

R4

$$(1 + \mathbf{A}) = \begin{matrix} 1.4401 & -0.0784 & 0.0307 \\ 0.0767 & 1.6077 & 0.0011 \\ 0.0751 & 0.2747 & 0.8921 \end{matrix} \qquad \mathbf{H}'\mathrm{p} = \begin{matrix} -12095 \\ -19918 \\ -11290 \end{matrix}$$

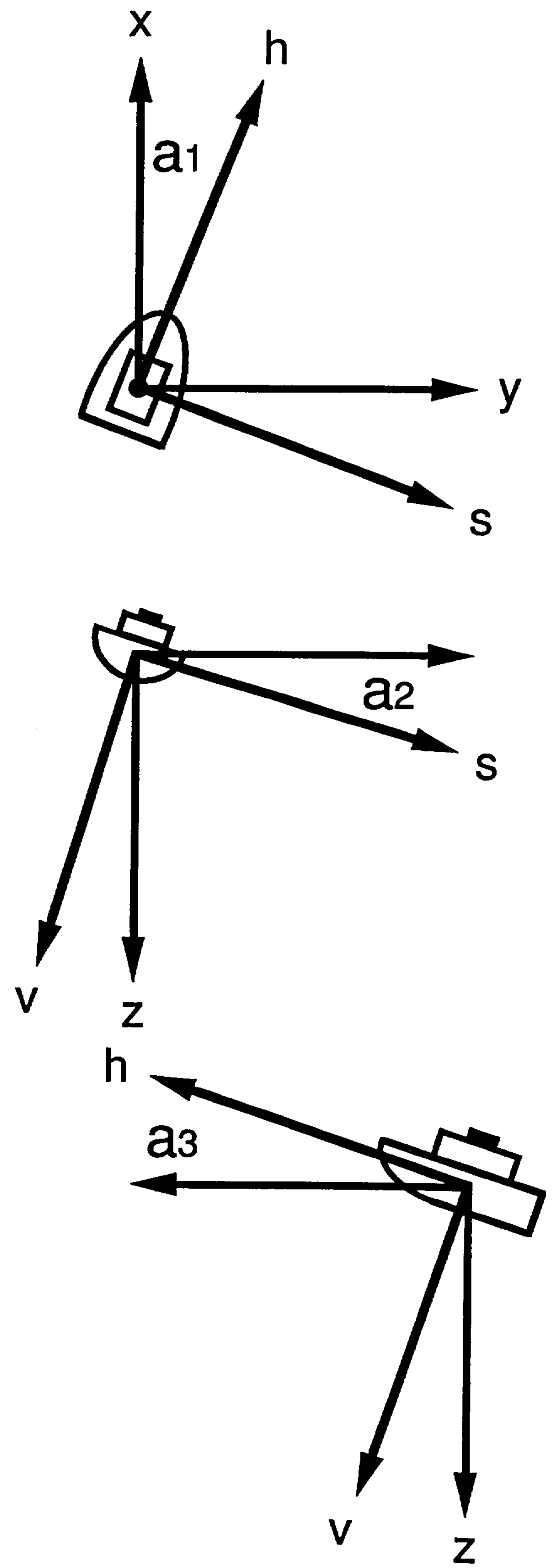

Fig 2.5

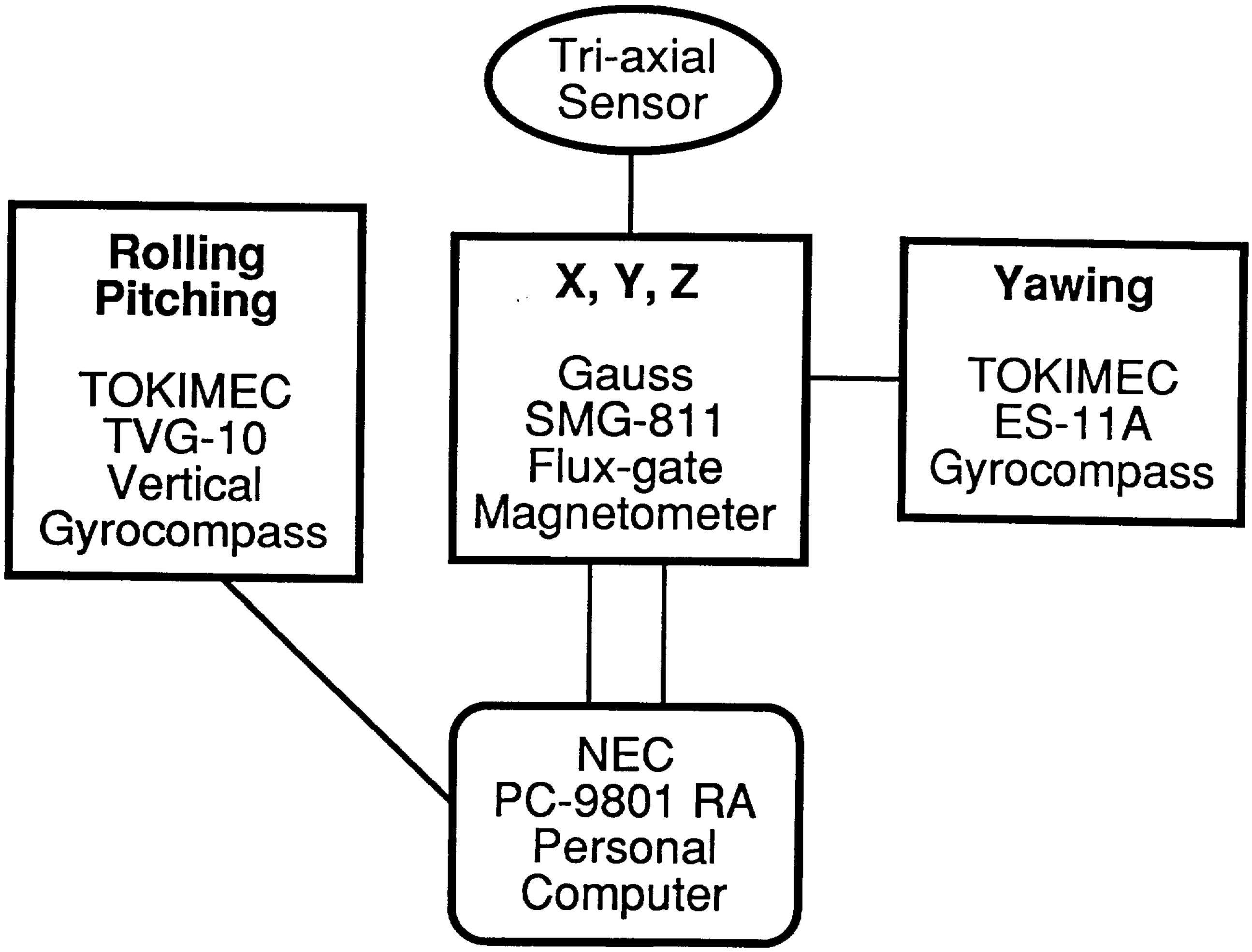
Tri-axial
Sensor
Rolling
Pitching
TOKIMEC
TVG-10
Vertical
Gyrocompass
X, Y, Z
Gauss
SMG-811
Flux-gate
Magnetometer
Yawing
TOKIMEC
ES-11A
Gyrocompass
NEC
PC-9801 RA
Personal
Computer

Fig 2.6

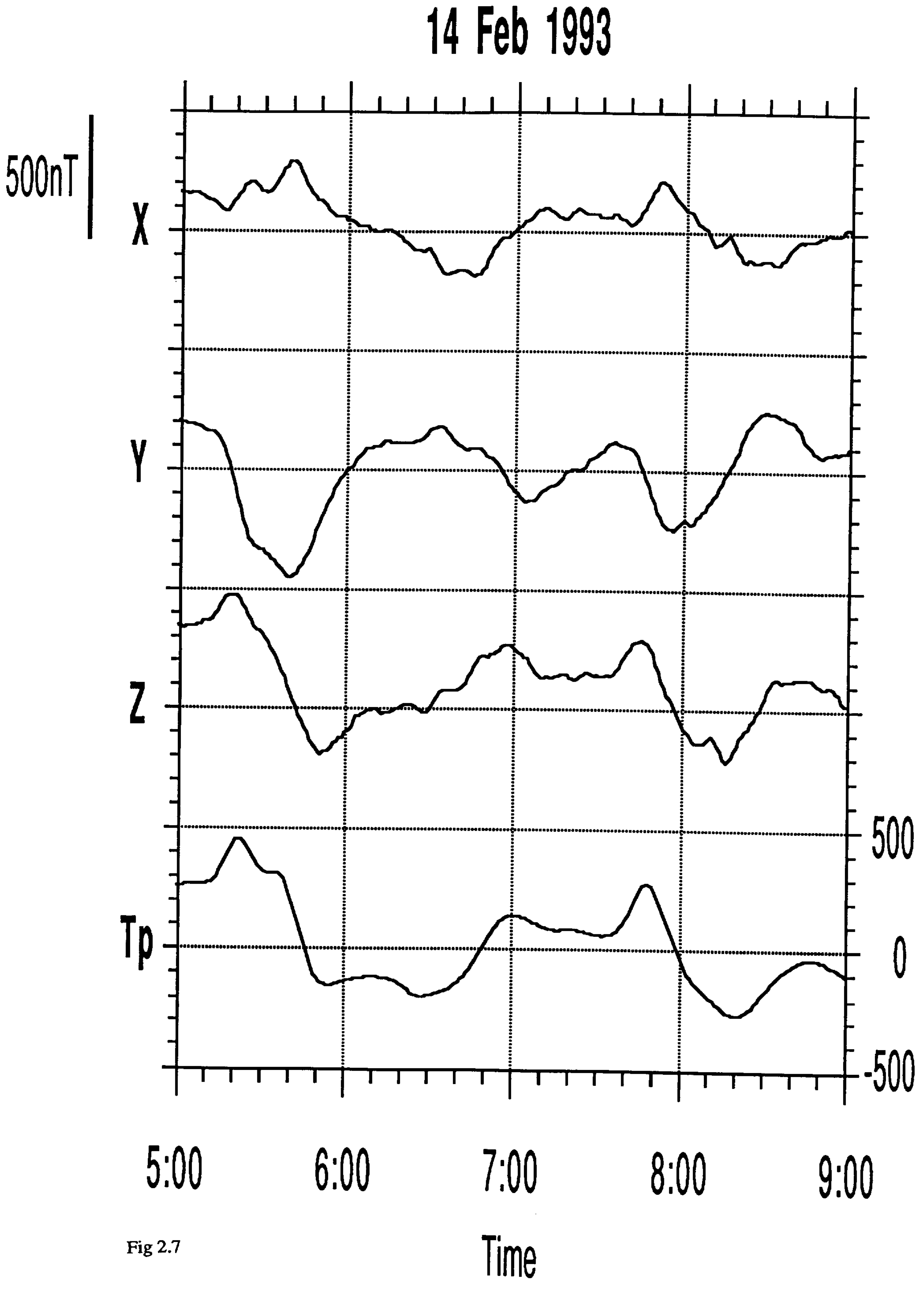

Fig 2.7

2.5 ^{222}Rn- ^{226}Ra Analysis of Water Samples
(by Mark Rudnicki)

2.5.1 Introduction

Although not originally intended until cruise CD77, water samples were collected during ZAPS sledge run S14. Four 5 litre Niskin bottles were tripped within the neutrally buoyant plume at a depth of 2700m, and a further two above the plume at 2500m. On recovery, it was found that bottles 6 and 10 had misfired, resulting in the collection of one 10 litre sample R1 at 2700m and two five litre samples, R2 and R3, at 2700m and 2500m.

The three samples were analysed by the method of Mathieu *et al.* (1988). The radon gas is stripped from the sample and retained on activated charcoal at -70°C by bubbling and recirculating He carrier gas. The charcoal is then heated to 450°C to drive off the ^{222}Rn gas into an evacuated plexiglass cell coated with an activated ZnS phosphor for alpha scintillation counting. Although it is standard practise to collect 15-20 litres of sea water for analysis, smaller volumes such as those collected here can be measured with greater signal to noise ratios and correspondingly greater errors. After stripping once for ^{222}Rn, the samples were resealed and ^{222}Rn allowed to ingrow due to decay of natural ^{226}Ra. A repeat of the ^{222}Rn analysis procedure after 7 or more days ingrowth allows measurement of the parent ^{226}Ra activity. The difference between the measured ^{222}Rn activity and the parent ^{226}Ra activity, the 'unsupported ^{222}Rn' (i.e. over and above that naturally produced in the water column) can be due to either ^{222}Rn diffusion from sediment, from a hydrothermal source, or conversely due to particle scavenging removal of ^{226}Ra. In the sparsely sedimented axial valley of the Mid-Atlantic Ridge, the presence of unsupported ^{222}Rn is assigned to hydrothermal activity.

2.5.2 Results

Results of ^{222}Rn and ^{226}Ra analysis are presented in the table. The units are dpm/100kg- disintegrations per minute per 100kg of sea water

Sample	Depth (m)	Volume (litres)	^{222}Rn dpm/100kg	^{226}Ra dpm/100kg
R1	2700	11.0	26.3	33.6
R2	2700	5.5	31.9	55.7
R3	2500	5.5	40.8	53.6

The ^{222}Rn and ^{226}Ra backgrounds of sea water in the axial valley of the Mid-Atlantic Ridge are known from 26°N (Rudnicki and Elderfield, 1992) and are: ^{222}Rn= 33.5 dpm/100kg, ^{226}Ra= 36.4 dpm/100kg. Thus, the ^{222}Rn analyses lie within error (10%) of background sea water, providing a good test of new equipment for CD77.

References

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2.6 Standard RVS Vessel Instrumentation and Underway Geophysics Gear
(by Dave Teare)

2.6.1 Gravity Meter

The Platform used with this system was a non-RVS (Research Vessel Services) unit and, as such, we had no history of its previous performance. An initial problem, due to a gyro change in Trinidad, caused the platform to oscillate. The original gyro was refitted and the system appeared to function properly.

2.6.2 Gravity Results

The gravity field at the survey area was observed on the RRS Charles Darwin by a S110 gravimeter with digital logging on loan from LaCoste and Romberg. This was in place of the usual meter which was being repaired. During the transit leg to the survey area one of the gyros in the stability platform caused serious problems and had to be replaced leaving little data from this section of the cruise. The gravimeter output continued to be noisier than perhaps expected and it was felt that this was partly due to a minor problem in the gyro and partly due to the nature of the cruise.

Raw gravity data was sampled every 10 seconds and and filtered in the gravimeter using a 5 minute running mean filter. This was then recorded both with a paper recorder and on the RVS computers (ABC system), before being processed with the navigation data by RVS Senior technician Gareth Knight.

The gravity was firstly averaged to 30 second values in order to be standard with the navigation and depth data. This 30 second interval gravity was then reduced to give Free Air Anomaly (FAA) using a correction for latitude and the EOTVOS correction for reducing the artificial gravity effects caused by variations in the ships course and speed.

Eotvos Correction (Worzel 1959)

$$dg = 7.487 \times S \times \sin(C) \times \cos(lat \times N) + S^2 / 240.8$$

S = speed made good (in knots), C = course made good

International gravity formula (Jacobs et al 1959)

$$g(lat) = 9.78031.8 \times (1 + 0.0053024 \times (\sin(lat)^2) + 0.0000059 \times (\sin(2 \times lat))^2)$$

The EOTVOS corrections depend on good satellite coverage, which was generally available during CD76. Corrections can be made for all but the abrupt course changes. The gravimeter itself required 10 - 15 minutes for the gyros to stabilise after any major course changes. This results in local spikes (30 mgal) in the FAA which needed to be edited manually before any further work can be done. Part of the overall noisiness of the data may be explained by the nature of the cruise. Deep towed vehicles require slow ship speeds and frequent minor course corrections which is not ideal for gravity surveys. It is not coincidental that the quality of data improved on the transit leg to the Azores when the ship was moving faster and with fewer course alterations.

Drift in the gravimeter was monitored using a number of crossovers (fig. 2.8) which seem to indicate little instrument drift.

2.6.3 Underway Magnetics
(by Anne Briais and Heather Sloan)

Magnetic data were collected using a surface towed proton precession magnetometer during the transits from a point northeast of Trinidad (out of the 200 nm Trinidad EEZ) to the survey area and from the survey area to a point southwest of the Azores (out of the 200 nm Azores EEZ), as well as during eight off-axis runs along lines approximately parallel to the local tectonic flowlines or plate-spreading direction. The times and positions of these routes are listed below. The raw magnetic data exist as field measurements every six seconds in a file called magnet. The processed magnetic data exist in a file named promag90 which contains values every 30 seconds for the total magnetic field and the magnetic anomaly (using the 1990 IGRF) merged with the corrected GPS navigation.

The magnetic anomaly values were plotted as profiles along the shiptracks using the GMT mapping software (Wessel and Smith, 1991). Anomaly identifications and correlation were made using a model calculated by Sloan and Patriat (1992) with a constant spreading rate of 12.5 km/Ma and a magnetized layer thickness of 400m. Anomalies 0, 2, 3, 3a, 4, 4a and 5 correspond to ages 0, 1.89, 3.85, 5.69, 7.01, 8.69, and 10.10 Ma, respectively.

Profile	Start			End		
	time	lat N	long W	time	lat N	long W
M1 - M2	040 2240	26° 38.89'	44° 42.34'	041 0415	26° 32.49'	43° 36.19'
M3 - M4	041 0530	26° 32.08'	43° 37.78'	041 0930	26° 46.19'	44° 27.30'
M5 - M6	041 2309	26° 53.31'	44° 33.19'	042 0405	27° 05.46'	45° 31.03'
M7 - M8	042 0500	26° 59.70'	45° 29.93'	042 0930	26° 47.48'	44° 32.23'
M9 - M10	045 0450	28° 29.62'	43° 39.00'	045 0900	28° 21.10'	42° 57.65'
M11 - M12	045 1023	28° 15.47'	42° 59.91'	045 1440	28° 25.08'	43° 42.51'
M13 - M14	058 0130	29° 14.46'	43° 08.41'	058 0530	29° 22.67'	43° 45.88'
M15 - M16	058 0612	29° 17.37'	43° 47.75'	058 0930	29° 10.93'	43° 10.44'

2.6.4 Simrad Echo Sounder

Two faults occurred on this system, both of which affected the printer. One was the printer itself not operating correctly and the other was caused by the Simrad stopping the printer. The first problem cleared itself after the printer was partially stripped down and cleaned, the second problem cleared after switching the Simrad 'off' and 'on' again.

2.6.5 3.5 kHz Echo Sounder

This system was not used because the bottom topography was so rough as to render it useless.

2.6.6 D.M.W. Clock

The year '2' digit was lost on the output signal thus giving a 1991 output; no spare board in the spares kit and no suitable I.C. found on board. Spares coming out from Barry to the Azores.

2.6.7 Winch Monitoring

For the Corel Dredge, wire-out rate and load cell sensors both had faults. These were traced to a faulty backplane connector and faulty chart recorder respectively.

2.6.8 General Observations/Recommendations

No major breakdowns in the standard RVS underway geophysical gear deployed during CD76 occurred, but the level of spares carried leaves something to be desired. The present winch monitoring system should be replaced with the type fitted to Discovery and Challenger.

2.7 The Oceano Acoustic Navigation System

(by Gary White and Andy Hill)

The Oceano Transponder net was deployed using four transponders in an average water depth of 3000 metres. A relay transponder was fitted to various towed vehicles and interrogated with the "V-fin" fish on a new 19-way tow cable. The usual relative calibration, iteration and absolute calibration of the 5 km square net was carried out during good weather.

The "V-fin" fish had several deployment problems: there was no proper arm to keep the fish clear of the side of the ship. This limits the manoeuvrability of the ship, making turns to port almost impossible. The basic shape of the "V-fin" fish should create a downforce to keep it level in the water. However, it tends to yaw violently in the water and sometimes comes dangerously close to the ship's propeller. This, coupled with the new thicker tow cable which has a very tight turn in the cable as it enters the fish, eventually resulted in the electrical cable to fail after one day's use. The failure, at the wire locked termination, had to be cut off, remade and repotted with wire lock. This took 36 hours in all. There is no safety specification sheet or usage instructions on board for the wire lock moulding medium.

We recommend that the wire lock termination trailing arms need to be longer so that a less torturous route for the electrical cable can be used; the fish body shape needs to be reviewed and a more solid design adopted.

Otherwise the survey collected good data, although long TOBI runs were only navigated correctly by the Oceano System when both the ship and TOBI were within the net together.

The Oceano System still causes the GPS navigation to lock up occasionally but did not cause any problems on this cruise. Overall the system worked within specification but the excessive time required to deploy and calibrate the system is a major drawback, especially as time on these cruises is at a premium. We believe that the system is too slow with its present computer hardware to be used satisfactorily in modern scientific research.

2.8 Dredge Summaries

All dredges were collected using the standard RVS basket plus pipe dredge, attached to the main dredge warp and towing winch.

Dredge 1

Target	29° 10.25'N, 43° 10.25'W

Dredge 1 was aborted due incorrect ship positioning, no samples were recovered.

Dredge 2	29° 10.17'N, 43° 10.43'W - 29° 10.54'N, 43° 9.86'W
Target	29° 10.25'N, 43° 10.25'W

Dredge 2 recovered 7 rocks, and 1 kg of assorted fragments, largely glass.

Dredge 3	29° 10.22'N, 43° 10.33'W - 29° 10.45'N, 43° 10.00'W
Target	29° 10.25'N, 43° 10.25'W

Dredge 3 recovered approx. 0.5kg of basalt fragments (~25% plagioclase phenocrysts)/ shards of glass

Dredge 4 29° 9.8'N, 43° 11.17'W - 29° 10.03'N, 43° 8.55'W
Target 29° 10.25'N, 43° 10.25'W

Dredge 4 recovered approximately 2kg ofglassy plagioclase sheet flow pillow lavas material.

Dredge 5 29° 9.96'N, 43° 10.29'W - 29° 10.76'N, 43° 8.87'W
Target 29° 10.25'N, 43° 10.25'W

Bag 1: Five pieces of 40 to 70cm size pillow basalt extrusions. Medium to dark grey basalt, showing some cores with vesicles of <1mm. Yellow/ brown alteration/ staining, internal layering. Glassy rinds. ≈10% light cream white plagioclase phenocrysts up to 2mm diametre.

Bags 2 and 3: Lighter grey flow basalts, not as fresh, more weathering/ alteration. Hyaloclastic outer surfaces, included sediment is cream coloured. Two 20cm pieces in bag 2; 13 smaller pieces <5cm in bag 3.

Bag 4: Basaltic lava flow. Top surfaces of these are weathered orange- brown- black with finely spaced parallel striations.

Bag 5: Small bag of most fresh, black hard glasses from approx. 5kg mass collected.

Dredge 6 29° 10.6'N, 43° 11.63'W - 29° 10.4'N, 43° 10.45'W
Target 29° 10.25'N, 43° 10.25'W

Bag 1: Approx. 8kg of glass fragments and chippings of basalts from bucket dredge of which one small bag of best samples was preserved.

Bags 2 and 3 : 2 half filled nylon sacks of medium sized 10-20cm diameter chunks of largely pillow basalts (70%), some with chilled glassy rinds and occasional plagioclase <2cm megacrysts. Sheeted lava flow basalts (30%) with some showing layer interaction features such as tubes, drips, concave and convex surfaces. The best examples have been preserved.

Samples retained:

Bag 1: Glass shards from pipe dredge.

Bag 2: Glass shards from main dredge.

Bag 3 Three samples of plagiocloase phyric sheet flow, ~20cm thick with ~10mm plagioclase megacrysts.

Bag 4, 5: Plagioclase phyric pillow. (1+ ~8 samples)

Bag 6: Lava buds with vesicular cores.

Bags 7 and 8: Aphyric pillow basalt fragments.

Bag 9: Aphyric 10cm sheet flow basalt.

Also : pure glass fragments.

Dredge 7 29° 10.11'N, 43° 10.22W - 29° 9.8'N, 43° 9.8'W
Target 29° 10.25'N, 43° 10.25'W
acoustically navigated dredge deployment

Bags 1 and 2 Decimetre sized frseh aphyric- plagioclase phyric glassy pillow basalt from micro-pillows.

Bag 3: 4 pieces of slightly palagonitised glassy pillow selvedges.

Dredge 8 29° 10.99'N, 43° 10.20'W -
Target 29° 10.99'N, 43° 10.20'W (acoustic navigated)
acoustically navigated dredge deployment

(Weak link failed, dredge choked with small catch)
Bag 1: Glassy pillow rinds. Black glass approx. 0.5cm thick, with one surface showing rust coloured weathering in places, easily fractured.

Bag 2: ~10cm basalt pillow fragments with glassy rinds and 0.5cm plagioclase phenocrysts.

Bag 3: ~10cm pillow fragments with glassy rinds, with smaller more numeroous plagioclase phenocrysts (1 by 2 mm)

Dredge 9 29° 10.1'N, 43° 8.2'W - 29° 10.33'N, 43° 10.55'W
Target 29°10.25', 43°10.25'W

Hand specimens:

Bags 1 and 2: Small fragments <2 cm black basaltic glass with palagonite surface weathering. Some with small millimetre size plagioclase phenocrysts.

Bag 3 and 5: Large fragments >3 cm in size of black basaltic glass with palagonite surface weathering showing millimetre scale plagioclase phenocrysts (<2%).

Bag 4: Biology- small shell fragments.

Bag 6: Non-glassy dark grey basalt approx. 10% plagioclase phyric. Sample shows tube like/ flow feature morphology.

Bag 7: Black fine very fresh glass shards.

Bag 8: Two pieces of basaltic sheet flow approx. 10% plagioclase phyric (1 by 2 mm), with palagonitised glassy top surface. Bottom surface appears bulbous as if formed in a cavity.

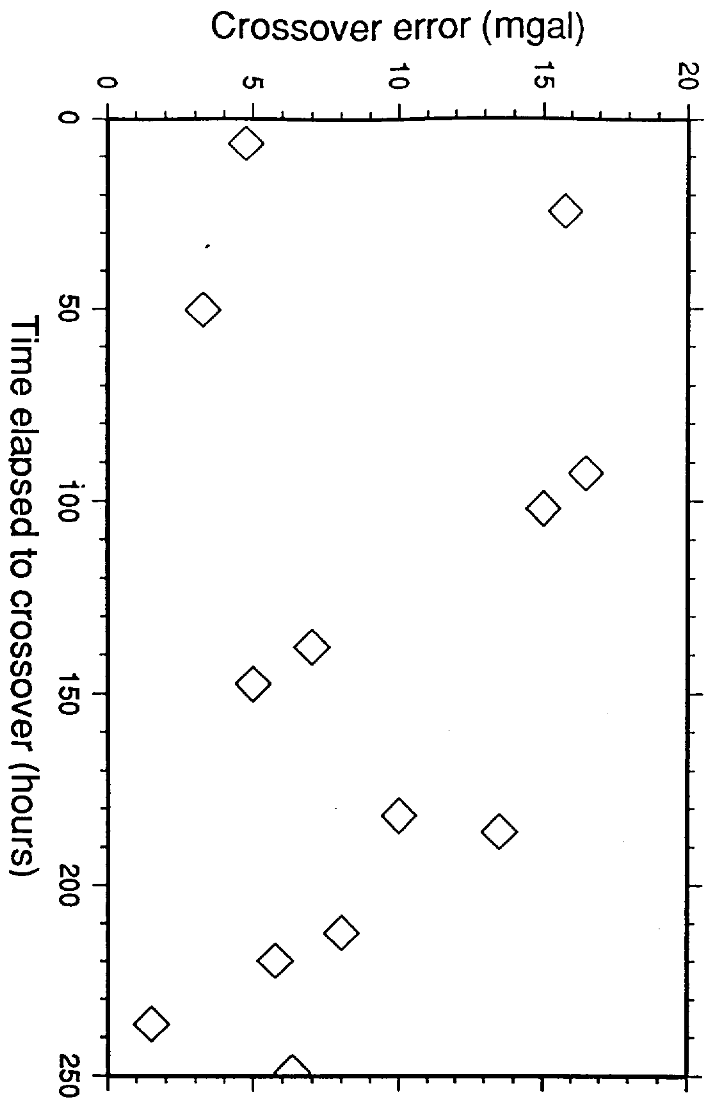

Crossover error (mgal)
0
5
10
15
20
0
50
100
150
200
250
Time elapsed to crossover (hours)

Fig 2.8

3 COMPUTING AND PROCESSING

3.1 Level A-B-C Computers
(by Gareth Knight)

During cruise CD76 the ABC computing network was used for both the processing of directly logged data and the transfer of TOBI image and instrumentation data. Data was sampled at six seconds for raw magnetic field, ten seconds for gravity meter data and thirty seconds for echo sounder depth. Navigation for the cruise was corrected to GPS position fixing the receiver output being at its maximum data rate of every two seconds. Acoustic navigation when available was recorded every twenty seconds. Data was processed to a final navigation interval of thirty seconds and subsequent calculations of magnetic anomaly, corrected depth and gravity anomaly were made also at a thirty second interval. Magnetic anomaly was calculated using the 1990 IGRF and echo sounder data corrected with Carter Area sound velocity corrections.

The gravity meter on loan from Lacoste-Romberg produced data which was far noisier than normally seen. It was felt that the stability of the servo mechanism for the meter was poor and that this was the root cause of the noise. The overall recording of low frequency gravity trends was however satisfactory and when gravity crossover points were taken these also appeared to be reasonable and free from meter drift.

For the first time a spare TOBI optical disk drive was successfully attached to one of the ships work stations. This enabled the logged image disks to be read onto a unix platform. Reduced resolution images were then stored onto back-up optical media after some initial processing. Previous attempts to install this device failed due to conflicts between its logical unit number and that of a standard SUN hard disk device sd3. On this occasion the drive was installed using the custom installation procedure to a diskless client workstation. This proved to be most useful as the drive was often moved between the Sun workstation and the TOBI replay system as the drive was the only device on the workstation this could easily be done. The public domain package GMT was installed for use on CD76. This took some time to achieve as the compilation from source relied upon a number of Makefile structures which were not correct. Eventually however the package was successfully installed.

The public domain image processing package PBMPLUS was also installed for use on CD76. The passage time to and from the working area was a great assistance in allowing the changes to the system to be made and the distributing of the very large amount of TOBI data transferred to the processing system.

Towards the end of the cruise three relatively small TOBI images of 300Kb were produced in Sun Raster image form and transferred to RVS using the satellite communication system. The images were loaded onto the communication system using the addmsg -b function which allows transfer of binary data. These images were then enlarged to A4 sized raster images back at RVS and dispatched by courier for the live interview given by the PSO on BBC television's Tomorrows World programme.

3.2 TOBI Image Processing
(by Nick Hayward)

The primary recording system for the TOBI is the IBM PS/2 used during deployment for immediate processing. The records generated are then stored in MS-DOS format on magneto-optical (MO) discs. For distribution purposes the raw TOBI data on MO disc was read, processed and stored as UNIX files using the RVS SUN workstations.

The data processing system was based primarily on the software written on CD65 by Scott Garland of Boise State University. The minor modifications necessary were due to the addition of the geochemical sensors to TOBI. In addition a byte swapping routine needed to be added in order to transfer data from IBM MS-DOS to SUN UNIX format.

The processing operation consisted of the following stages (*programme name*):

reading the data from disc (*rtd2*)
performing the byte swap (*dd*)
processing the TOBI records (*ptd2*)
writing image files (*ptd2*)
conversion of images to pbm format (*side2pgm*)
extracting magnetics and geochemical data (*ptd2*)
image processing (*pbmplus*)
image display (*alv*)
convert binary magnetics data to ascii for underway geophysics (*rmag3*)

RTD2

Rtd2 is based almost entirely on *rtd* , the programme written for CD65, modified only to take account of the new data in the data stream. It reads the MO disc and finds each 4 second TOBI record by matching a user supplied string to that heading each record. The string is usually the ship name (6 characters), in this case Charle. Since one MO disc holds about 12000 records (approx 13 hours), an amount too great to process in a single run, the processing is split into 3 sections of about 4000 records each. This is done using *rtd2* by specifying the byte offset to start reading the disc, and the number of records to be read. Each 4 second record takes the form:

unit	offset:	
char heading[48]	00000	
int version	00048	
int time	00050	
int date	00052	
struct position approx	00054	
int magx[8]	00066	
int magy[8]	00082	
int magz[8]	00098	
int roll[8]	00114	
int pitch[8]	00130	
int speed[8]	00146	
int nephelometer[8]	00162	-not used this cruise, ie empty
int compass[8]	00178	
int press[8]	00194	
int altitude	00210	
int water_path	00212	
int temp[8]	00214	
int trans[8]	00230	
int zaps[8]	00246	
byte empty[314]	00262	
int port_sonar[4000]	00576	
int starboard_sonar[4000]	08576	
int profiler[4000]	16576	
	24576	-total 4 second stream

PTD2

The data is then piped into a standard UNIX data processing routine, *dd*, which performs the byte swapping, before it is piped into *ptd2.*, again based on a CD65 programme. *Ptd2* reads the 4000 record file in the same manner as *rtd2* (the header string is now hCrael), extracts the data from the geophysical and geochemical sensors into a binary file, slant range corrects the side scan sonar data and pipes this into an image conversion programme.

SIDE2PGM

Side2pgm converts the sonar data into a more portable image format called PGM (portable grey map). The PGM format is a simple two dimensional array of binary (8-bit) pixels and a small header containing the dimensions of the image. This simple format allows for easy manipulation and conversion and is recognised by many display packages. A limitation of this conversion process is that although the original side scan data is in 12 bit format the PGM library, *PBMPlus* , can only handle up to 8 bit precision - although most workstations can only display 8 bit samples. This loss in precision results in a 'darker' image, which can be corrected for by applying a histogram correction with the PGM software.

MKIMAGES2

The processing stream discussed above is held in a UNIX shell script, *mkimages2*, which processes a MO disc in 3 sections and also passes the finished PGM image on to short pipeline of *PBMPlus* applications in order to produce a small normalised image from a full TOBI PGM file, suitable for viewing on screen or printing for reference. Each 4000 records of TOBI data results in three files of output with the following name convention:

filetype_starttime_discid_surveyarea.extension giving
big_starttime_discid_cd76[ns][abc].pgm :the full tobi image file
small_starttime_discid_cd76[ns][abc].pgm :the condensed image file
mag_starttime_discid_cd76[ns][abc].dat :the binary magnetics file
[ns] indicates north or south bound tobi tracks in this survey
[abc] indicates 1st, 2nd or 3rd section of a disc

Occasionally other suffix characters are added at later stages and indicate a slightly different file. For example, in some parts of certain discs, problems were encountered in processing the 4000 records in one go and so it would be split in two - such as a1 and a2. In this case the full image file would be a concatenation of the 2 files with a white buffer in between to represent missing records, the added labels are m for the buffer and x for the combined file. The suffix .ras indicates a raster file used for display purposes (see *PBMPlus*). The prefix med indicates an image which is physically large but has been desampled for viewing and thus not suitable as a source file for further image files.

PBMPLUS

This is a public domain image processing package written by Jef Poskanzer. It was designed to allow easy manipulation of a portable image format as well as conversion routines to convert between different formats. All the *PBMPlus* routines are easily pipelined to allow multiple operations before producing a final image and shell scripts were used for many of the most common pipelines, including those for cutting (*pnmcat*), rescaling (*pnmscale*) and contrast stretching the images (which was subsequently broadcast on BBC TV's 'Tomorrows World' programme). The routine *pnmtorast* was used to convert all completed images into raster files for transfer to the display package *Alv*. For more information on *PBMPlus* consult the manual pages on the CD76 data exabyte tape.

ALV

The *Alv* package is another public domain image processing package and uses standard Sun raster format image files as storage. Since the images were in PGM format this package was only used for display purposes and of the 47 programmes in *Alv* only a few were used. These include programmes to display images on screen, interactively adjust contrast, brightness and magnification, and to print to a laserwriter.

Note: An alternative to *Alv* as the display package is *xloadimage*, a programme which takes as input PGM format images. This was not used since it requires the *xwindows* environment, which was unavailable on the RVS SUN workstations, but is included on the CD76 exabyte for completeness.

RMAG3 & RMAG2

These programmes required the most changes from the CD65 versions in order to cope with the added data produced by TOBI. *Rmag3* is a command line based C programme which reads a binary TOBI magnetics file and converts the requested fields into ascii format. It includes all of the calibrations used on CD76 and hence gives the output (mostly) in SI units. Several of the calibrations were changed mid-cruise and the variations are held in the source code for *rmag3* , and should be altered there. The calibrations for temperature and pressure were to be checked at the end of the cruise, and so *rmag2* (with no calibrations in) has been included in the exabyte for completeness and as a basis for applying any new calibrations. The input from *ptd2* for both *rmag3* and *rmag2* is of the form:

```
short   time
short   date
short   magx[8]
short   magy[8]
short   magz[8]
short   roll[8]
short   pitch[8]
short   compass[8]
short   pressure[8]
short   altitude
short   temp[8]
short   trans[8]
short   zaps[8]
```

TOBI Exabyte

An exabyte tape was produced on board to distribute the SUN processed data to those cruise participants requiring digital images or the binary magnetics data, and includes all of the above software with the exception of *Alv*, as well as manual pages for almost everything.

The data on tape is the result of multiple tar backups which was necessary as there was insufficient disk storage on the RVS SUN system to do it any other way. Each tar archive was made with the command :-

```
tar cvf /dev/nrstl .
```

In order to restore the files on another system, the tape needs to be positioned using the mt command and the non rewind device (which may not be nrstl on the IOS system), before reading each archive other than the first one. For example :-

```
mt -f /dev/nrstl fsf 3
```

will position the tape after the third archive so you can recover data from archive four.

The file pbmplus.tar.Z is a compressed tar archive of the original PGM distribution software. To extract this software the following commands should be executed before compilation:

```
mkdir pbmplus
cd pbmplus
zcat pbmplus.tar.Z | tar xvf -
```

Compilation should be done after reading the ReadMe notes in *PBMPlus* , and using the instructions therein. Before accessing files with the Z suffix, these also need uncompressing using the *uncompress* filename command.

Listing of CD76 TAR Tapes

TAR1
big_043.0946_201_cd76na.pgm.Z
big_043.0946_201_cd76nb.pgm.Z
big_043.0946_201_cd76nc.pgm.Z
big_043.2305_202_cd76na.pgm.Z
big_043.2305_202_cd76nb.pgm.Z
big_043.2305_202_cd76nc.pgm.Z
big_044.1225_203_cd76na.pgm.Z
big_044.1225_203_cd76nb.pgm.Z
big_044.1225_203_cd76nc.pgm.Z
small_043.0946_201_cd76na.pgm
small_043.0946_201_cd76na.ras
small_043.0946_201_cd76nb.pgm
small_043.0946_201_cd76nb.ras
small_043.0946_201_cd76nc.pgm
small_043.0946_201_cd76nc.ras
small_043.2305_202_cd76na.pgm
small_043.2305_202_cd76na.ras
small_043.2305_202_cd76nb.pgm
small_043.2305_202_cd76nb.ras
small_043.2305_202_cd76nc.pgm
small_043.2305_202_cd76nc.ras
small_044.1225_203_cd76na.pgm
small_044.1225_203_cd76na.ras
small_044.1225_203_cd76nb.pgm
small_044.1225_203_cd76nb.ras
small_044.1225_203_cd76nc.pgm
small_044.1225_203_cd76nc.ras
TAR2
big_046_1153_205_cd76na.pgm.Z
big_046_1153_205_cd76nb.pgm.Z
big_046_1153_205_cd76nc.pgm.Z
big_047.0112_206_cd76na1.pgm.Z
big_047.0112_206_cd76na2.pgm.Z
big_047.0112_206_cd76nam.pbm.Z
big_047.0112_206_cd76nax.pgm.Z
big_047.0112_206_cd76nb.pgm.Z
big_047.0112_206_cd76nc.pgm.Z
big_047.1431_207_cd76na.pgm.Z
big_047.1431_207_cd76nb.pgm.Z
big_047.1431_207_cd76nc.pgm.Z
small_046.1153_205_cd76na.pgm
small_046.1153_205_cd76na.ras
small_046.1153_205_cd76nb.pgm
small_046.1153_205_cd76nb.ras
small_046.1153_205_cd76nc.pgm
small_046.1153_205_cd76nc.ras
small_047.0112_206_cd76na.pgm
small_047.0112_206_cd76na.ras
small_047.0112_206_cd76nax.pgm
small_047.0112_206_cd76nax.ras
small_047.0112_206_cd76nb.pgm
small_047.0112_206_cd76nb.ras
small_047.0112_206_cd76nc.pgm
small_047.0112_206_cd76nc.ras
small_047.1431_207_cd76na.pgm
small_047.1431_207_cd76na.ras
small_047.1431_207_cd76nb.pgm
small_047.1431_207_cd76nb.ras
small_047.1431_207_cd76nc.pgm
small_047.1431_207_cd76nc.ras
TAR3
big_048.0350_208_cd76na.pgm.Z
big_048.0350_208_cd76nb.pgm.Z
big_048.0350_208_cd76nc.pgm.Z
big_048.1708_209_cd76sa.pgm.Z
big_048.1708_209_cd76sb.pgm.Z

big_048.1708_209_cd76sc.pgm.Z
big_049.0628_210_cd76sa.pgm.Z
big_049.0628_210_cd76sb.pgm.Z
big_049.0628_210_cd76sc.pgm.Z
small_048.0350_208_cd76na.pgm
small_048.0350_208_cd76na.ras
small_048.0350_208_cd76nb.pgm
small_048.0350_208_cd76nb.ras
small_048.0350_208_cd76nc.pgm
small_048.0350_208_cd76nc.ras
small_048.1708_209_cd76sa.pgm
small_048.1708_209_cd76sa.ras
small_048.1708_209_cd76sb.pgm
small_048.1708_209_cd76sb.ras
small_048.1708_209_cd76sc.pgm
small_048.1708_209_cd76sc.ras
small_049.0628_210_cd76sa.pgm
small_049.0628_210_cd76sa.ras
small_049.0628_210_cd76sb.pgm
small_049.0628_210_cd76sb.ras
small_049.0628_210_cd76sc.pgm
small_049.0628_210_cd76sc.ras
TAR4
big_049.1930_211_cd76sa.pgm.Z
big_049.1930_211_cd76sb.pgm.Z
big_049.1930_211_cd76sc.pgm.Z
big_050.0922_212_cd76sa.pgm.Z
big_050.0922_212_cd76sb.pgm.Z
big_050.0922_212_cd76sc.pgm.Z
big_050.2240_213_cd76sa.pgm.Z
big_050.2240_213_cd76sb.pgm.Z
big_050.2240_213_cd76sc.pgm.Z
small_049.1930_211_cd76sa.pgm
small_049.1930_211_cd76sa.ras
small_049.1930_211_cd76sb.pgm
small_049.1930_211_cd76sb.ras
small_049.1930_211_cd76sc.pgm
small_049.1930_211_cd76sc.ras
small_050.0922_212_cd76sa.pgm
small_050.0922_212_cd76sa.ras
small_050.0922_212_cd76sb.pgm
small_050.0922_212_cd76sb.ras
small_050.0922_212_cd76sc.pgm
small_050.0922_212_cd76sc.ras
small_050.2240_213_cd76sa.pgm
small_050.2240_213_cd76sa.ras
small_050.2240_213_cd76sb.pgm
small_050.2240_213_cd76sb.ras
small_050.2240_213_cd76sc.pgm
small_050.2240_213_cd76sc.ras
TAR5
big_051.1158_214_cd76sa.pgm.Z
big_051.1158_214_cd76sb.pgm.Z
big_051.1158_214_cd76sc.pgm.Z
big_052.0117_215_cd76sa.pgm.Z
big_052.0117_215_cd76sb.pgm.Z
big_052.0117_215_cd76sc.pgm.Z
big_052.1438_216_cd76sa.pgm.Z
big_052.1438_216_cd76sb.pgm.Z
big_052.1438_216_cd76sc.pgm.Z
small_051.1158_214_cd76sa.pgm
small_051.1158_214_cd76sa.ras
small_051.1158_214_cd76sb.pgm
small_051.1158_214_cd76sb.ras
small_051.1158_214_cd76sc.pgm
small_051.1158_214_cd76sc.ras
small_052.0117_215_cd76sa.pgm
small_052.0117_215_cd76sa.ras
small_052.0117_215_cd76sb.pgm

small_052.0117_215_cd76sb.ras
small_052.0117_215_cd76sc.pgm
small_052.0117_215_cd76sc.ras
small_052.1438_216_cd76sa.pgm
small_052.1438_216_cd76sa.ras
small_052.1438_216_cd76sb.pgm
small_052.1438_216_cd76sb.ras
small_052.1438_216_cd76sc.pgm
small_052.1438_216_cd76sc.ras
TAR6
big_043.0038_200_cd76na.pgm.Z
big_043.0038_200_cd76nb.pgm.Z
big_043.0038_200_cd76nc.pgm.Z
big_045.2234_204_cd76na.pgm.Z
big_045.2234_204_cd76nb.pgm.Z
big_045.2234_204_cd76nc1.pgm.Z
big_045.2234_204_cd76nc2.pgm.Z
big_045.2234_204_cd76ncm.pbm.Z
big_045.2234_204_cd76ncx.pgm.Z
big_053.0400_217_cd76sa.pgm.Z
big_053.0400_217_cd76sb.pgm.Z
big_053.0400_217_cd76sc.pgm.Z
small_043.0038_200_cd76na.pgm
small_043.0038_200_cd76na.ras
small_043.0038_200_cd76nb.pgm
small_043.0038_200_cd76nb.ras
small_043.0038_200_cd76nc.pgm
small_043.0038_200_cd76nc.ras
small_045.2234_204_cd76na.pgm
small_045.2234_204_cd76na.ras
small_045.2234_204_cd76nb.pgm
small_045.2234_204_cd76nb.ras
small_045.2234_204_cd76nc.pgm
small_045.2234_204_cd76nc.ras
small_045.2234_204_cd76ncx.pgm
small_045.2234_204_cd76ncx.ras
small_053.0400_217_cd76sa.pgm
small_053.0400_217_cd76sa.ras
small_053.0400_217_cd76sb.pgm
small_053.0400_217_cd76sb.ras
small_053.0400_217_cd76sc.pgm
small_053.0400_217_cd76sc.ras
TAR7
big_053.1720_218_cd76hsa1.pgm.Z
big_053.1720_218_cd76hsa2.pgm.Z
big_053.1720_218_cd76hsam.pbm.Z
big_053.1720_218_cd76hsax.pgm.Z
big_053.1720_218_cd76hsb.pgm.Z
big_053.1720_218_cd76hsc.pgm.Z
big_064.2350_219_cd76hsa.pgm.Z
big_064.2350_219_cd76hsb.pgm.Z
small_053.1720_218_cd76hsax.pgm
small_053.1720_218_cd76hsax.ras
small_053.1720_218_cd76hsb.pgm
small_053.1720_218_cd76hsb.ras
small_053.1720_218_cd76hsc.pgm
small_053.1720_218_cd76hsc.ras
small_064.2350_219_cd76hsa.pgm
small_064.2350_219_cd76hsa.ras
small_064.2350_219_cd76hsb.pgm
small_064.2350_219_cd76hsb.ras
in directory CD76:
Enlargments
Magnetics
Small.pgm
Small.ras
in directory CD76/Enlargments:
big_213b_caldera1.pgm.Z
med_213b_caldera1a.ras.Z

med_213b_caldera1b.ras.Z
med_213b_caldera1c.ras.Z
in directory CD76/Magnetics:
mag_043.0038_200_cd76na.dat
mag_043.0038_200_cd76nb.dat
mag_043.0038_200_cd76nc.dat
mag_043.0946_201_cd76na.dat
mag_043.0946_201_cd76nb.dat
mag_043.0946_201_cd76nc.dat
mag_043.2305_202_cd76na.dat
mag_043.2305_202_cd76nb.dat
mag_043.2305_202_cd76nc.dat
mag_044.1225_203_cd76na.dat
mag_044.1225_203_cd76nb.dat
mag_044.1225_203_cd76nc.dat
mag_045.2234_204_cd76na.dat
mag_045.2234_204_cd76nb.dat
mag_045.2234_204_cd76nc1.dat
mag_045.2234_204_cd76nc2.dat
mag_046.1153_205_cd76na.dat
mag_046.1153_205_cd76nb.dat
mag_046.1153_205_cd76nc.dat
mag_047.0112_206_cd76na1.dat
mag_047.0112_206_cd76na2.dat
mag_047.0112_206_cd76nb.dat
mag_047.0112_206_cd76nc.dat
mag_047.1431_207_cd76na.dat
mag_047.1431_207_cd76nb.dat
mag_047.1431_207_cd76nc.dat
mag_048.0350_208_cd76na.dat
mag_048.0350_208_cd76nb.dat
mag_048.0350_208_cd76nc.dat
mag_048.1708_209_cd76sa.dat
mag_048.1708_209_cd76sb.dat
mag_048.1708_209_cd76sc.dat
mag_049.0628_210_cd76sa.dat
mag_049.0628_210_cd76sb.dat
mag_049.0628_210_cd76sc.dat
mag_049.1930_211_cd76sa.dat
mag_049.1930_211_cd76sb.dat
mag_049.1930_211_cd76sc.dat
mag_050.0922_212_cd76sa.dat
mag_050.0922_212_cd76sb.dat
mag_050.0922_212_cd76sc.dat
mag_050.2240_213_cd76sa.dat
mag_050.2240_213_cd76sb.dat
mag_050.2240_213_cd76sc.dat
mag_051.1158_214_cd76sa.dat
mag_051.1158_214_cd76sb.dat
mag_051.1158_214_cd76sc.dat
mag_052.0117_215_cd76sa.dat
mag_052.0117_215_cd76sb.dat
mag_052.0117_215_cd76sc.dat
mag_052.1438_216_cd76sa.dat
mag_052.1438_216_cd76sb.dat
mag_052.1438_216_cd76sc.dat
mag_053.0400_217_cd76sa.dat
mag_053.0400_217_cd76sb.dat
mag_053.0400_217_cd76sc.dat
mag_053.1720_218_cd76hsa1.dat
mag_053.1720_218_cd76hsa2.dat
mag_053.1720_218_cd76hsb.dat
mag_053.1720_218_cd76hsc.dat
mag_064.2350_219_cd76hsa.dat
mag_064.2350_219_cd76hsb.dat
in directory CD76/Small.pgm:
-duplicates of the small.pgm files in TAR 1-6
in directory CD76/Small.ras:
-duplicates of the small.ras files in TAR 1-6

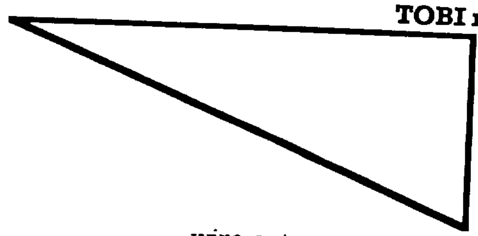
in directory darwin:
bin
man
in directory darwin/bin:
Makefile2 - a makefile for tobi processing programmes
itd2.c - an indexing programme for tobi data, not used on this cruise
mkimages2
pbmplus.tar.Z
pgmmag - a shellscript for producing enlargements, and viewing in Alv
pgmvu2 - a shellscript for viewing tobi images using Alv
ptd2
ptd2.c
rmag2
rmag2.c
rmag3
rmag3.c
rtd2
rtd2.c
side2pgm
side2pgm.c
xloadimage
in directory darwin/man:
man1
man2
man3
man5
in directory darwin/man/man1:
-all PBMPlus process manual pages
in directory darwin/man/man2:
itd2.2
mkimages2.2
ptd2.2
rmag2.2
rmag3.2
rtd2.2
side2pgm.2
in directory darwin/man/man3:
-all PBMPlus library manual pages
in directory darwin/man/man5:
-all PBMPlus image format manual pages

4 TOBI MOSAICING AND NAVIGATION

4.1 TOBI MOSAIC

First stage:

TOBI position relative to the ship's position was estimated every 15 min by a range calculation involving a simple trigonometric relation between the length of the wire out and the depth to the vehicle.



Each ship postion and subsequently each TOBI position were plotted on a 1:50000 Sea Beam bathymetry map from the C2912 survey (Sempéré et al., 1990), TOBI positions being estimated by using the calculated range and the water depth measured from the vehicle's altitude and depth meter and cross-referencing this with the depth given on the bathymetry chart.

Mosaic base charts were prepared by tracing straight synthetic TOBI track lines to fit as many plotted TOBI positions as possible and projecting these position on to the lines at every half hour. The distance between the projected half hour positions was measured and then used in production/replay of TOBI images at a scale of 1:50000. Using these measured distances the speed over the ground along a straight line was calculated and the sidescan images anamorphosed to convert from a time to a distance plot. Taking the half hour time marks as a first guide the images were matched as closely as possible to the bathymetry, cutting the swaths to accommodate course changes where necessary. Where the swaths overlap, images were spliced by trimming away the "shadowed" portions at the edge of the swaths. Wherever substantial gaps or overlaps occured along track, the distance between half hour time marks was re-measured.

Second stage:

The side scan images were replayed correcting for the re-measured distance portions of the swaths. The turns were separately anamorphosed by expanding the outside of the turn and compressing the inside. Fitting the side scan images with the bathymetry was then accomplished and a more complete image achieved.

Digital mosaic:

Digital mosaicing can be completed at IOS using MIPS/WHIPS packages. Merging of some of the images with the bathymetry will then be possible.

Appendix 1: Cruise Log

Date	Julian Day	Time (GMT)	Event
4-Feb	035	10:00	Depart Port of Spain, Trinidad In transit to waypoint W1
5-Feb	036	23:50	Magnetometer, 3.5kHz and Simrad PES (10.25kHz) echosounders deployed
6-Feb	037	13:05	Gravimeter down, platform stability problems: Switched off and under repair
		15:00	1st Figure 8 manoeuvre for 3-component magnetometer calibration
		18:30	GPS data unstable
		19:30	PES no printed display, under repair
		23:00	PES link back up, poor signal
7-Feb	038	03:00	PES down
		18:30	Gravimeter repaired and working
		21:30	PES link down, not pinging- under repair
8-Feb	039	07:30	PES back up
9-Feb	040	14:30	Gravimeter down
		17:30	Gravimeter back up
		18:30	Magnetometer and echosounders on deck
		19:15	WASP test deployment, sledge in water- run 1
		22:30	WASP sledge on deck, after successful test run
		22:37	Magnetometer and Echosounders back in water Off-axis magnetics run M1-M2-M3-M4 including 2nd Figure 8 maneouvre for 3-component magnetometer calibration
10-Feb	041	10:04	Arriving at TOBI deployment site, T1 Magnetometer on deck
		10:54	TOBI in water
		11:25	Cable test passed, Depressor weight in water
		12:34	ZAPS sensor failure, TOBI to be recovered
		13:30	TOBI on deck, ship turning and returning to T1
		14:15	Off-axis magnetics run M5-M6-M7-M8, whilst ZAPS is tested and repaired
		15:22	TOBI and ZAPS ready, magnetics run cut short, return to T1
		16:15	Magnetometer on deck
		16:30	TOBI in water, continued problems with ZAPS Many resulting test deployments fail to remedy the problematic ZAPS sensor for the next day
		23:09	Magnetometer in water for off-axis magnetics run M9-M10-M11-M12
11-Feb	042	09:25	Arrival at T1, magnetometer being recovered
		11:20	TOBI in water
		12:20	TOBI logging started
		14:00	Interference on TOBI images, 5.5Hz related to nephelometer flash light TOBI pressure gauge malfunctioning
		15:35	TOBI at 300m altitude

		16:00	Hauling TOBI back up to remedy pressure gauge and interference problems
		18:34	TOBI on deck
12-Feb	043	00:06	TOBI in water at T1, temperature sensor not connected
		00:37	TOBI logging restarted, aim to fly TOBI at around 300m
		05:42	T2 waypoint reached
		07:30	T3 waypoint reached
		12:25	TOBI scrapes bottom, 300m pinnacle not on charts
		13:00	T4 waypoint reached
13-Feb	044	00:13	T5 waypoint reached
		06:15	T6 waypoint reached
		15:15	T7 waypoint reached
		19:40	T8 waypoint reached
		23:12	T9 waypoint reached
		23:45	Noise on TOBI images, variable speed and pitch consistent with 1kt tail current
14-Feb	045	00:07	TOBI transmitter turned on/off in an attempt to remedy noise problems
		00:11	Everything off, cable/power short circuit?
		00:22	TOBI logging stopped, TOBI being recovered
		04:09	TOBI on deck
		04:30	Off-axis magnetics run M13-M14-M15-M16, magnetometer in water includes 3rd Figure 8 for 3-component magnetometer calibration
		15:00	Magnetometer on deck
		16:00	TOBI umbilical cable replaced, temperature sensor replaced and connected
		18:57	TOBI deployed at waypoint T8, retracing path of previous day's poor imagery ZAPS recharged and recalibrated during time spent repairing TOBI
15-Feb	046	00:32	T9 waypoint reached on the 2nd pass
		08:45	T10 waypoint reached
		14:30	T11 waypoint reached
		20:15	Magnetometer in water
16-Feb	047	06:00	T12 waypoint reached
		07:45	T13 waypoint reached
		13:15	T14 waypoint reached
		18:55	T15 waypoint reached
17-Feb	048	19:30	T16 waypoint reached
		22:00	T17 waypoint reached
18-Feb	049	05:15	T18 waypoint reached
		14:30	T19 waypoint reached
		19:15	T20 waypoint reached
19-Feb	050	01:35	T21 waypoint reached
		12:15	T22 waypoint reached
		22:45	T23 waypoint reached
20-Feb	051	06:00	T24 waypoint reached
		13:15	T25 waypoint reached
		18:50	T26 waypoint reached
		23:40	T27 waypoint reached

21-Feb	052	10:30	T28 waypoint reached
		16:30	T29 waypoint reached
		20:30	T30 waypoint reached
22-Feb	053	05:15	T31 waypoint reached
		11:15	T32 waypoint reached
		16:30	Magnetometer off and being recovered in preparation for TOBI recovery
		19:01	TOBI on deck, end of scheduled survey
		19:05	Magnetometer in water
			Analysis of TOBI physical data suggests location of a possible hydrothermal plume around Station 1
			Resulting transit to Station 1 follows, via gravimetry way points T33, G1-G7, S1
23-Feb	054	15:00	Arrived at station S1
		16:00	Magnetometer on deck
		16:46	ZAPS sledge deployment
		22:17	ZAPS sledge on deck
		22:37	Arrived on station S2
		22:50	ZAPS sledge in water
24-Feb	055	01:00	Positive signals from ZAPS/ transmissometer/ nephelometer indicating plume at about 2390m
		01:40	In vicinity of hydrothermal plume.
		04:43	ZAPS sledge on deck
		05:13	ZAPS sledge deployment at S3
		08:12	Recovery of ZAPS sledge
		10:53	Arrived at station S4
		11:20	ZAPS sledge deployment
		17:58	ZAPS sledge on deck
		18:17	Arrived at station S5
		18:22	ZAPS sledge deployment
		23:40	ZAPS sledge on deck
25-Feb	056	00:10	Arrived at station S6
		00:20	ZAPS sledge deployment
		02:31	ZAPS sledge on deck
		03:40	ZAPS sledge deployment
		07:00	Drifting with ZAPS sledge to station S7
		08:43	ZAPS sledge on deck
		08:49	ZAPS sledge deployment at S7
		12:30	Drifting with ZAPS sledge to station S8
		14:00	Drifting with ZAPS sledge to station S9
		16:30	ZAPS sledge on deck
		17:05	ZAPS sledge deployment at S9
		20:30	Problems with ZAPS
		21:30	Simrad 10.25kHz off to check interferences with ZAPS sledge signals
		21:45	Simrad back on
		22:20	ZAPS blown out
		23:10	ZAPS sledge on deck
26-Feb	057	00:05	Traversing from S9 to S10: watching Simrad topography to locate ridge crest
		00:35	Station S10 located at 29° 08.6'N, 43° 10.75'W
		00:46	ZAPS sledge deployment at S10 (without ZAPS sensor)
		08:30	ZAPS sledge on deck
		08:33	Arrived at S11

		08:33	ZAPS sledge deployment
		12:30	ZAPS sledge on deck
		13:05	Arrived at S12
		13:05	ZAPS sledge deployment
		20:30	ZAPS sledge on deck
			Sledge operations suspended due to bad weather
27-Feb	058	00:30	Start of magnetics run
		09:10	Last magnetics waypoint
		09:52	Magnetometer on deck
		10:10	Steaming to S13
		10:26	ZAPS sledge deployment at S13
		18:01	Bottom temperature anomaly found at 29° 10.25'N, 43° 10.25'W
		23:00	ZAPS sledge on deck
28-Feb	059	00:00	Start of dredging: dredge D1 abandoned due to ship overshooting target
		00:31	Dredge D2 deployed target 29° 10.25'N, 43° 10.25'W
		08:00	Dredge on board
		08:20	Dredge D3 deployed target as D2
		11:07	Dredge D3 off bottom and being recovered
		14:15	Dredge D4 deployed
		16:26	Dredge D4 on deck
			Dredge D5 deployed- target is line running NNE to 29° 10.25'N, 43° 10.25'W
		20:50	Dredge D5 on deck
1-Mar	060	00:10	Acoustic net deployment:
			Deployment of transponder 1 [29° 09.25'N, 43° 11.70'W, water depth 3150m]
		01:15	Deployment of transponder 2 [29° 11.50'N, 43° 10.90'W, water depth 3075m]
		02:30	Deployment of transponder 3 [29° 10.40'N, 43° 08.70'W, water depth 3275m]
		03:36	Deployment of transponder 4 [29° 08.50'N, 43° 10.70'W, water depth 3025m]
			Start of acoustic navigation GPS tie lines
		10:50	End of acoustic navigation GPS tie lines
		11:03	Dredge D6 deployed
		13:59	Dredge D6 off bottom
			Restart of acoustic navigation GPS tie lines
		22:30	Finished acoustic navigation GPS tie lines
2-Mar	061	01:36	ZAPS sledge deployment at S14
		08:00	Sledge cannot see transponder net when near bottom
		09:31	Firing 5 litre Niskin bottles Nos. 1,2,4,6 at 2700m
		09:39	Firing 5 litre Niskin bottles Nos. 8,10 at 2500m
		11:09	ZAPS sledge on deck- water sampled for radon analysis
		12:38	WASP sledge deployment with transponder 200m up cable- run 2
		17:25	WASP on deck
		18:45	Dredge D7 deployed with pinger 200m up on cable
		23:45	Dredge D7 on deck

3-Mar	062	02:45	WASP deployed- run 3
		11:23	WASP on deck
		11:30	Weather worsening
		19:45	Dredge D8 deployed
		23:52	Dredge D8 on deck
4-Mar	063	01:40	WASP deployed- run 4
		11:10	WASP on deck
		13:10	WASP deployed- run 5
		17:30	WASP on deck- sulfides discovered on top of WASP frame, thought to be related to large transmissometer spike during run 4, 063-04:17 (demolition of chimney?)
		19:30	Trial dip of JBP (Jason's birthday plunger) at 29° 10.156'N, 43° 10.263'W
		22:32	Recovery of JBP- watchkeeper notes 'Thing on deck- nothing'
5-Mar	064	00:20	Dredge D9 deployed
		02:00	Dredge D9 on deck- cancelled due to bad weather
		11:20	TOBI deployed, attempting to image hydrothermal vent field
		12:50	TOBI logging started
		14:30	Chaos watch starts TOBI position logging
		18:10	TOBI images area of hydrothermal activity
6-Mar	065	01:40	Start of TOBI vehicle recovery
		02:53	TOBI wire not laying properly: wire out= 3000m
		05:59	TOBI on deck, wire problem not resolved
		06:30	Start acoustic net recovery
		12:40	Acoustic net recovery completed
		13:58	Dredge 9 in the water
		18:32	Dredge 9 on deck
		19:25	Magnetometer in water
			Transit to the Azores
7-Mar	066		
8-Mar	067		Conducting cable payed out and respooled
9-Mar	068		
10-Mar	069		
11-Mar	070		

Appendix 2: CD76 Waypoints

Way Point		Position Latitude N	Position Longitude W
W1	WASP-Test	26° 40.00'	44° 43.20'
M1	Magnetics	26° 38.89'	44° 42.34'
M2		26° 32.49'	43° 36.19'
M3		26° 32.08'	43° 37.78'
M4		26° 46.19'	44° 27.30'
M5		26° 53.31'	44° 33.19'
M6		27° 05.46'	45° 31.03'
M7		26° 59.70'	45° 29.93'
M8		26° 47.48'	44° 32.23'
M9		28° 29.62'	43° 39.00'
M10		28° 21.10'	42° 57.65'
M11		28° 15.47'	42° 59.91'
M12		28° 25.08'	43° 42.51'
M13		29° 14.46'	43° 08.41'
M14		29° 22.67'	43° 45.88'
M15		29° 17.37'	43° 47.75'
M16		29° 10.93'	43° 10.44'
T1	1st TOBI track	26° 48.00'	44° 34.00'
T2		27° 00.00'	44° 29.10'
T3		27° 05.70'	44° 27.50'
T4		27° 15.20'	44° 18.30'
T5		27° 39.40'	44° 09.50'
T6		27° 49.30'	44° 00.90'
T7		28° 06.80'	43° 57.00'
T8		28° 15.00'	43° 51.10'
T9		28° 22.90'	43° 44.20'
T10		28° 37.85'	43° 40.50'
T11		28° 43.75'	43° 29.70'
T12		28° 55.90'	43° 13.40'
T13		29° 10.65'	43° 10.40'
T14		29° 20.70'	43° 06.90'
T15		29° 24.60'	42° 55.30'
T16	End 1st track	30° 06.00'	42° 43.60'
T17	Start 2nd track	30° 05.40'	42° 40.80'
T18		29° 51.10'	42° 46.60'
T19		29° 30.85'	42° 51.15'
T20		29° 22.40'	42° 53.75'
T21		29° 17.80'	43° 07.25'
T22		28° 55.95'	43° 10.35'
T23		28° 41.30'	43° 29.25'
T24		28° 35.82'	43° 38.50'
T25		28° 21.40'	43° 41.60'
T26		28° 13.85'	43° 48.95'
T27		28° 06.25'	43° 55.00'
T28		27° 46.75'	43° 59.35'
T29		27° 37.80'	44° 07.10'
T30		27° 29.95'	44° 10.25'
T31		27° 14.00'	44° 15.35'
T32		27° 04.30'	44° 24.60'
T33	End 2nd track	26° 46.00'	44° 31.50'

G1	Gravimetry	27°	16.00'	44°	03.00'
G2		27°	26.00'	44°	20.00'
G3		27°	56.00'	44°	10.00'
G4		27°	58.00'	43°	50.00'
G5		28°	39.00'	43°	16.00'
G6		28°	57.00'	43°	22.00'
G7		29°	01.00'	43°	06.00'
S1	ZAPS sledge	29°	08.20'	43°	11.05'
S2		29°	08.40'	43°	12.06'
S3		29°	08.58'	43°	12.30'
S4		29°	09.45'	43°	10.90'
S5		29°	10.35'	43°	11.00'
S6		29°	08.40'	43°	11.20'
S7		29°	09.02'	43°	10.91'
S8		29°	09.30'	43°	11.30'
S9		29°	08.15'	43°	11.25'
S10		29°	08.60'	43°	10.75'
S11		29°	07.80'	43°	11.00'
S12		29°	10.40'	43°	10.40'
S13		29°	10.65'	43°	10.15'
S14		29°	10.25'	43°	10.25'

Appendix 3: TOBI Navigation Log

Juln. Day (dd	Time GMT hh:mm)	TOBI Lat. N (deg.	min.)	TOBI Lon. W (deg.	min.)	Water Depth (m)	TOBI Altitude (m)	TOBI Depth (m)
43	4:30	20	0.00	44	29.56	3503	451	3954
43	5:00	27	0.70	44	29.50	3412	504	3916
43	5:30	27	2.70	44	28.80	3320	601	3921
43	6:00	27	2.75	44	28.38	3263	395	3658
43	6:30	27	3.55	44	28.12	3326	345	3671
43	7:00	27	4.65	44	27.82	3387	259	3646
43	7:30	27	5.66	44	27.47	3465	235	3700
43	8:00	27	6.56	44	26.65	255		
43	8:30	27	7.40	44	25.82	333		
43	9:00	27	8.25	44	25.00	3271	301	3572
43	9:30	27	9.20	44	24.30	3160	263	3423
43	10:00	27	10.00	44	23.64	3068	405	3473
43	10:30	27	10.80	44	22.50	3114	233	3347
43	11:00	27	11.75	44	21.85	3025	314	3339
43	11:30	27	12.52	44	21.31	3252	324	3576
43	12:00	27	13.26	44	20.54	3469	208	3677
43	12:35	27	14.48	44	19.64	3360	455	3815
43	13:00	27	15.15	44	19.53	3531	311	3842
43	13:30	27	16.00	44	18.32	3574	370	3944
43	14:00	27	16.64	44	18.12	3559	453	4012
43	14:15	27	17.23	44	17.90	3606	519	4125
43	14:45	27	18.14	44	17.52	3444	582	4026
43	15:00	27	18.72	44	17.18	3456	549	4005
43	15:15	27	19.20	44	16.90	3475	608	4083
43	15:30	27	19.90	44	16.70	3516	703	4219
43	15:45	27	20.40	44	16.40	3487	500	3987
43	16:00	27	20.90	44	16.20	3413	504	3917
43	16:15	27	21.00	44	16.30	3350	586	3936
43	16:30	27	22.30	44	15.80	3310	514	3824
43	16:45	27	22.80	44	15.45	3289	378	3667
43	17:00	27	23.55	44	15.45	3317	394	3711
43	17:10	27	23.80	44	15.40	3323	251	3574
43	17:15	27	24.00	44	15.30	3321	214	3535
43	17:30	27	24.90	44	14.95	3217	200	3417
43	17:45	27	25.70	44	14.50	3127	311	3438
43	18:00	27	26.25	44	14.30	3094	303	3397
43	18:15	27	27.00	44	14.10	3085	267	3352
43	18:30	27	27.62	44	13.92	3048	166	3214
43	18:45	27	28.15	44	13.62	2984	322	3306
43	19:00	27	28.90	44	13.40	2987	336	3323
43	19:15	27	29.35	44	13.20	3060	329	3389
43	19:30	27	29.90	44	13.15	3070	356	3426
43	19:45	27	30.45	44	12.85	3084	311	3395
43	20:00	27	31.00	44	12.75	3087	314	3401
43	20:15	27	31.50	44	12.50	3083	227	3310
43	20:30	27	32.15	44	12.40	2991	252	3243
43	20:45	27	32.60	44	12.10	3029	315	3344
43	21:00	27	33.20	44	11.95	3129	260	3389
43	21:15	27	33.60	44	11.60	3215	43	3558
43	21:30	27	34.10	44	11.45	3221	356	3577
43	21:45	27	34.70	44	11.25	3272	318	3590

43	21:45	27	34.70	44	11.25	3272	318	3590
43	22:00	27	35.00	44	11.10	3293	279	3572
43	22:15	27	35.50	44	10.85	3323	230	3553
43	22:30	27	35.90	44	10.80	3294	309	3603
43	22:45	27	36.60	44	10.60	3350	340	3690
43	23:00	27	37.00	44	10.45	3338	385	3723
43	23:15	27	37.50	44	10.40	3378	286	3664
43	23:30	27	38.00	44	10.25	3469	270	3739
44	23:45	27	38.35	44	9.97	3448	251	3699
44	0:00	27	39.00	44	9.82	3501	245	3746
44	0:15	27	39.32	44	9.75	3532	275	3807
44	0:30	27	39.66	44	9.42	3566	170	3736
44	0:45	27	40.13	44	9.05	3581	204	3785
44	1:00	27	40.42	44	8.75	3592	260	3852
44	1:15	27	40.80	44	8.15	3632	262	3894
44	1:30	27	41.28	44	7.77	3534	367	3901
44	1:45	27	41.63	44	7.50	3461	383	3844
44	2:00	27	42.03	44	7.15	3444	265	3709
44	2:15	27	42.62	44	6.80	3270	326	3596
44	2:30	27	42.93	44	6.35	3181	512	3693
44	2:45	27	43.33	44	6.05	3133	518	3651
44	3:00	27	43.82	44	5.75	3102	371	3473
44	3:15	27	44.20	44	5.30	3184	251	3435
44	3:30	27	44.60	44	5.00	3199	285	3484
44	3:45	27	44.90	44	4.70	3245	391	3636
44	4:00	27	45.20	44	4.30	3344	392	3736
44	4:15	27	45.60	44	4.10	3452	333	3785
44	4:30	27	46.10	44	3.70	3506	315	3821
44	4:45	27	46.50	44	3.40	3444	380	3824
44	5:00	27	46.80	44	3.10	3381	514	3895
44	5:15	27	47.20	44	2.50	3353	553	3906
44	5:30	27	47.80	44	2.20	3371	437	3808
44	5:45	27	48.20	44	1.70	3261	234	3495
44	6:00	27	48.50	44	1.50	3111	410	3521
44	6:15	27	49.30	44	0.90	3014	400	3414
44	6:30	27	50.00	44	0.80	2887	367	3254
44	6:45	27	50.60	44	0.60	2757	340	3097
44	7:00	27	51.10	44	0.50	2734	528	3262
44	7:15	27	51.70	44	0.40	2755	483	3238
44	7:30	27	52.25	44	0.30	2785	271	3056
44	7:45	27	52.70	44	0.25	2798	270	3068
44	8:00	27	53.30	44	0.05	2810	341	3151
44	8:15	27	53.80	44	0.05	2869	205	3074
44	8:30	27	54.50	44	0.00	2904	196	3100
44	8:45	27	55.00	43	59.70	2855	164	3019
44	9:00	27	55.60	43	59.60	2789	379	3168
44	9:15	27	56.15	43	59.20	2832	360	3192
44	9:30	27	56.60	43	59.30	2887	325	3212
44	9:45	27	57.01	43	59.30	2930	319	3249
44	10:00	27	57.45	43	59.15	2965	308	3273
44	10:15	27	57.88	43	59.05	3089	228	3317
44	10:30	27	58.32	43	58.97	3103	239	3342
44	10:45	27	58.84	43	58.85	3107	239	3346
44	11:00	27	59.28	43	58.80	3167	315	3482
44	11:15	27	59.70	43	58.71	3225	254	3479
44	11:30	28	0.22	43	58.59	3295	180	3475
44	11:45	28	0.58	43	58.48	3278	230	3508
44	12:00	28	0.98	43	58.49	3336	165	3501

44	12:15	28	1.62	43	58.50	3297	253	3550
44	12:30	28	2.12	43	58.28	3173	379	3552
44	12:50	28	2.65	43	58.08	3117	486	3603
44	13:00	28	2.85	43	58.00	3078	575	3653
44	13:15	28	3.35	43	57.86	3085	494	3579
44	13:30	28	3.78	43	57.75	3105	509	3614
44	13:45	28	4.27	43	57.65	3072	622	3694
44	14:00	28	4.62	43	57.50	3181	350	3531
44	14:15	28	5.02	43	57.40	3239	318	3557
44	14:30	28	5.48	43	57.15	3264	365	3629
44	14:45	28	5.87	43	57.08	3409	290	3699
44	15:00	28	6.17	43	57.00	3519	202	3721
44	15:15	28	6.70	43	56.70	3458	160	3618
44	15:30	28	7.20	43	56.40	3433	299	3732
44	15:45	28	7.60	43	56.30	3352	333	3685
44	16:00	28	8.00	43	56.00	3309	373	3682
44	16:15	28	8.30	43	55.70	3379	325	3704
44	16:30	28	8.80	43	55.50	3385	329	3714
44	16:45	28	9.30	43	55.20	3285	366	3651
44	17:00	28	10.00	43	54.60	3214	325	3539
44	17:15	28	10.20	43	54.50	3245	321	3566
44	17:30	28	10.80	43	54.30	3278	272	3550
44	17:45	28	11.20	43	53.90	3250	236	3486
44	18:00	28	11.70	43	53.70	3204	315	3519
44	18:15	28	12.30	43	53.30	3180	245	3425
44	18:30	28	12.70	43	53.10	3101	225	3326
44	18:45	28	13.20	43	52.45	2933	323	3256
44	19:00	28	13.80	43	52.20	2904	320	3224
44	19:15	28	14.20	43	52.00	2877	330	3207
44	19:30	28	14.65	43	51.60	2916	311	3227
44	19:45	28	15.15	43	51.40	2935	367	3302
44	20:00	28	15.70	43	51.00	2938	257	3195
44	20:15	28	16.10	43	50.53	2868	336	3204
44	20:30	28	16.40	43	50.15	2881	367	3248
44	20:45	28	16.80	43	49.80	2887	373	3260
44	21:00	28	17.25	43	49.60	2992	379	3371
44	21:15	28	17.55	43	49.30	3055	328	3383
44	21:30	28	18.00	43	48.90	3092	224	3316
44	21:45	28	18.40	43	48.55	3035	327	3362
44	22:00	28	18.75	43	48.35	3043	44	3387
44	22:15	28	19.20	43	47.95	3156	218	3374
44	22:30	28	19.48	43	47.56	3060	207	3267
44	22:45	28	19.97	43	46.98		435	
44	23:00	28	20.40	43	46.50		374	
44	23:15	28	21.10	43	45.22		388	
44	23:30	28	21.65	43	44.45		420	
45	0:00	28	22.40	43	44.45		665	
45	21:00	28	15.85	43	50.50	1600	1660	3260
45	21:30	28	16.40	43	50.00	1949	849	2798
45	21:45	28	16.55	43	49.95	2165	849	3014
45	22:00	28	16.72	43	49.65	2400	700	3100
45	22:15	28	17.10	43	49.35	2588	700	3288
45	22:30	28	17.40	43	49.05	2714	645	3359
45	22:45	28	17.75	43	48.90	2792	600	3392
45	23:00	28	18.03	43	48.60	2922	467	3389
45	23:15	28	18.28	43	48.36	3084	383	3467
45	23:30	28	18.44	43	48.00	3045	313	3358
45	23:45	28	18.99	43	47.74	2954	297	3251

46	0:00	28	19.74	43	47.30	2793	454	3247
46	0:15	28	20.14	43	46.73	2849	434	3283
46	0:30	28	20.64	43	46.28	2961	230	3191
46	0:45	28	21.17	43	45.70	2719	382	3101
46	1:00	28	21.62	43	45.25	2756	419	3175
46	1:15	28	22.00	43	44.83	2890	490	3380
46	1:30	28	22.52	43	44.43	2883	399	3282
46	1:45	28	23.20	43	44.03	2846	336	3182
46	2:00	28	23.60	43	43.95	2873	362	3235
46	2:15	28	24.10	43	43.80	2897	354	3251
46	2:30	28	24.68	43	43.78	2839	270	3109
46	2:45	28	25.20	43	43.70	2865	349	3214
46	3:00	28	25.69	43	43.60	2958	268	3226
46	3:15	28	26.25	43	43.45	2909	256	3165
46	3:30	28	26.70	43	43.40	2878	288	3166
46	3:45	28	27.30	43	43.20	2858	310	3168
46	4:00	28	27.80	43	43.10	2875	340	3215
46	4:15	28	28.30	43	42.90	2912	256	3168
46	4:30	28	28.70	43	42.90	2878	343	3221
46	4:45	28	29.20	43	42.70	2940	304	3244
46	5:00	28	29.90	43	42.80	2847	357	3204
46	5:15	28	30.50	43	42.60	2864	259	3123
46	5:30	28	31.00	43	42.50	2861	327	3188
46	5:45	28	31.60	43	42.30	2882	420	3302
46	6:00	28	32.10	43	42.20	2976	330	3306
46	6:15	28	32.50	43	42.00	3048	308	3356
46	6:30	28	33.15	43	41.85	2956	334	3290
46	6:45	28	33.60	43	41.80	2912	391	3303
46	7:00	28	33.90	43	41.70	2909	357	3266
46	7:15	28	34.75	43	41.66	2959	395	3354
46	7:30	28	35.25	43	41.67	2999	390	3389
46	7:45	28	35.75	43	41.53	3072	319	3391
46	8:00	28	36.30	43	41.25	3011	262	3273
46	8:15	28	36.60	43	41.10	2907	291	3198
46	8:30	28	37.40	43	40.70	2885	219	3104
46	8:45	28	37.75	43	40.40	2790	438	3228
46	9:00	28	38.15	43	39.90	2782	446	3228
46	9:15	28	38.60	43	39.45	2760	434	3194
46	9:30	28	38.75	43	39.00	2675	320	2995
46	9:45	28	39.05	43	38.50	2679	448	3127
46	10:00	28	39.35	43	38.00	2740	290	3030
46	10:15	28	39.50	43	37.60	2818	256	3074
46	10:30	28	39.90	43	37.20	2931	405	3336
46	10:45	28	40.10	43	36.75	3047	340	3387
46	11:00	28	40.23	43	36.25	3145	302	3447
46	11:15	28	40.52	43	35.73	3043	240	3283
46	11:30	28	40.78	43	35.12	2902	325	3227
46	11:45	28	41.05	43	34.68	2891	351	3242
46	12:00	28	41.16	43	34.24	2857	308	3165
46	12:15	28	41.40	43	33.84	2880	211	3091
46	12:30	28	41.80	43	33.10	2765	296	3061
46	12:45	28	42.08	43	32.68	2840	336	3176
46	13:00	28	42.27	43	32.23	2921	394	3315
46	13:15	28	42.45	43	31.97	3038	388	3426
46	13:30	28	42.68	43	31.66	3110	346	3456
46	13:45	28	43.00	43	31.24	3180	433	3613
46	14:00	28	43.15	43	30.90	3161	518	3679
46	14:15	28	43.45	43	30.30	3104	446	3550

46	14:30	28	43.78	43	29.82	3073	437	3510
46	14:45	28	44.05	43	29.62	3111	307	3418
46	15:00	28	44.28	43	29.25	3088	371	3459
46	15:15	28	44.50	43	28.80	3116	455	3571
46	15:30	28	44.70	43	28.40	3136	383	3519
46	15:45	28	45.10	43	27.95	3179	414	3593
46	16:00	28	45.40	43	27.50	3118	276	3394
46	16:15	28	45.70	43	27.10	3124	307	3431
46	16:30	28	45.90	43	26.80	3203	259	3462
46	16:45	28	46.20	43	26.45	3242	391	3633
46	17:00	28	46.50	43	26.05	3302	307	3609
46	17:15	28	46.70	43	25.80	3402	247	3649
46	17:30	28	47.10	43	25.30	3434	344	3778
46	17:45	28	47.40	43	24.80	3418	362	3780
46	18:00	28	47.60	43	24.50	3423	285	3708
46	18:15	28	48.10	43	23.90	3365	337	3702
46	18:30	28	48.45	43	23.40	3268	348	3616
46	18:45	28	48.80	43	23.00	3107	410	3517
46	19:00	28	49.20	43	22.70	3232	349	3581
46	19:15	28	49.50	43	22.20	3245	207	3452
46	19:30	28	49.90	43	21.85	3188	318	3506
46	19:45	28	50.20	43	21.30	3218	272	3490
46	20:00	28	50.60	43	20.70	3158	327	3485
46	20:15	28	50.80	43	20.30	3119	180	3299
46	20:30	28	51.25	43	19.80	2976	271	3247
46	20:45	28	51.60	43	19.40	2957	321	3278
46	21:00	28	51.90	43	18.90	3004	344	3348
46	21:15	28	52.34	43	18.50	3006	414	3420
46	21:30	28	52.65	43	18.05	3062	590	3652
46	21:45	28	52.85	43	17.70	3201	541	3742
46	22:00	28	53.20	43	17.15	3392	356	3748
46	22:15	28	53.50	43	16.75	3449	402	3851
46	22:30	28	54.00	43	15.95	3288	591	3879
46	22:45	28	54.10	43	15.70	3261	591	3852
46	23:00	28	54.65	43	15.05	3142	580	3722
46	23:25	28	55.05	43	14.56	2883	583	3466
46	23:35	28	55.28	43	14.28	2933	389	3322
46	23:45	28	55.53	43	13.90	2865	434	3299
47	0:00	28	55.80	43	13.45	2780	638	3418
47	0:15	28	56.20	43	13.06	2779	598	3377
47	0:30	28	56.57	43	12.80	2911	435	3346
47	0:45	28	56.95	43	12.55	2963	444	3407
47	1:00	28	57.40	43	12.46	3013	289	3302
47	1:15	28	58.00	43	12.36	2889	385	3274
47	1:30	28	58.57	43	12.40	2704	588	3292
47	1:45	28	59.05	43	12.42	2729	524	3253
47	2:00	28	59.53	43	12.32	2776	587	3363
47	2:30	29	0.37	43	12.28	2809	501	3310
47	2:45	29	0.65	43	12.25	2834	364	3198
47	3:00	29	1.25	43	12.20	2800	370	3170
47	3:15	29	1.70	43	12.10	2632	511	3143
47	3:30	29	2.22	43	12.12	2548	476	3024
47	3:45	29	2.64	43	12.05	2524	486	3010
47	4:00	29	2.90	43	12.00	2680	359	3039
47	4:15	29	3.45	43	11.90	2698	400	3098
47	4:30	29	3.85	43	11.75	2773	327	3100
47	4:45	29	4.40	43	11.80	2803	322	3125
47	5:00	29	4.95	43	11.65	2814	281	3095

47	5:15	29	5.52	43	11.47	2819	188	3007
47	5:30	29	5.92	43	11.42	2754	278	3032
47	5:45	29	6.45	43	11.25	2752	352	3104
47	6:00	29	6.93	43	11.13	2720	376	3096
47	6:15	29	7.45	43	11.04	2759	391	3150
47	6:30	29	8.00	43	10.96	2828	137	2965
47	6:45	29	8.42	43	10.75	2741	296	3037
47	7:00	29	8.85	43	10.75	2719	293	3012
47	7:15	29	9.30	43	10.70	2695	325	3020
47	7:30	29	9.90	43	10.65	2654	342	2996
47	7:45	29	10.55	43	10.40	2630	433	3063
47	8:00	29	11.05	43	10.35	2610	402	3012
47	8:15	29	11.54	43	10.35	2665	399	3064
47	8:30	29	11.85	43	10.05	2755	333	3088
47	8:45	29	12.30	43	9.90	2733	370	3103
47	9:00	29	12.83	43	9.65	2693	434	3127
47	9:15	29	13.10	43	9.60	2789	376	3165
47	9:30	29	13.60	43	9.30	2790	320	3110
47	9:45	29	14.00	43	9.20	2900	270	3170
47	10:00	29	14.55	43	8.90	2942	271	3213
47	10:15	29	14.95	43	8.90	2903	325	3228
47	10:30	29	15.50	43	8.70	2922	343	3265
47	10:45	29	15.83	43	8.30	2914	238	3152
47	11:00	29	16.39	43	8.50	2861	433	3294
47	11:15	29	16.78	43	8.58	2993	384	3377
47	11:30	29	17.13	43	8.45	3027	289	3316
47	11:45	29	17.68	43	8.30	3036	406	3442
47	12:00	29	18.16	43	8.24	2999	406	3405
47	12:15	29	18.61	43	8.10	2981	398	3379
47	12:30	29	19.18	43	7.95	2944	386	3330
47	12:45	29	19.64	43	7.80	2844	521	3365
47	13:00	29	20.25	43	7.60	2860	612	3472
47	13:15	29	20.65	43	7.00	2801	444	3245
47	13:30	29	20.90	43	6.60	2841	482	3323
47	13:45	29	21.15	43	5.95	2878	525	3403
47	14:00	29	21.15	43	5.30	2938	512	3450
47	14:15	29	21.35	43	4.66			
47	14:30	29	21.50	43	4.15	2818	689	3507
47	14:45	29	21.67	43	3.50	2596	950	3546
47	15:00	29	21.90	43	2.90	2372	1200	3572
47	15:15	29	22.30	43	2.01	2157	892	3049
47	15:30	29	22.54	43	1.40	2006	627	2633
47	15:45	29	22.85	43	0.74	1970	553	2523
47	16:00	29	23.00	43	0.26	2026	511	2537
47	16:15	29	23.15	42	59.83	2087	532	2619
47	16:30	29	23.29	42	59.46	2229	497	2726
47	16:45	29	23.40	42	59.12	2419	638	3057
47	17:00	29	23.48	42	58.80	2653	515	3168
47	17:15	29	23.60	42	58.30	2878	441	3319
47	17:30	29	23.70	42	57.93	3004	394	3398
47	17:45	29	23.80	42	57.53	3163	275	3438
47	18:00	29	23.91	42	57.10	3166	319	3485
47	18:30	29	24.25	42	56.25	3317	418	3735
47	18:45	29	24.48	42	55.80	3384	240	3624
47	19:00	29	24.96	42	55.42	3263	314	3577
47	19:15	29	25.45	42	55.20	3120	614	3734
47	19:30	29	25.80	42	55.10	3213	502	3715
47	19:45	29	26.20	42	54.90	3347	305	3652

47	20:00	29	26.55	42	54.80	3382	268	3650
47	20:15	29	27.10	42	54.70	3387	314	3701
47	20:30	29	27.45	42	54.60	3298	336	3634
47	20:45	29	27.90	42	54.50	3400	304	3704
47	21:00	29	28.40	42	54.40	3421	216	3637
47	21:15	29	28.80	42	54.25	3365	275	3640
47	21:30	29	29.35	42	54.15	3359	267	3626
47	21:45	29	29.80	42	53.90	3227	428	3655
47	22:00	29	30.20	42	53.85	2967	503	3470
47	22:15	29	30.75	42	53.70	2847	529	3376
47	22:30	29	31.25	42	53.40	2725	531	3256
47	22:45	29	31.95	42	53.25	2765	471	3236
47	23:00	29	32.30	42	53.20	2748	461	3209
47	23:15	29	32.56	42	53.15	2742	462	3204
47	23:30	29	32.94	42	52.82	2693	478	3171
48	23:45	29	33.32	42	52.78	2746	412	3158
48	0:00	29	33.71	42	52.60	2855	331	3186
48	0:15	29	34.20	42	52.49	2810	298	3108
48	0:30	29	34.55	42	52.28	2792	393	3185
48	0:45	29	34.95	42	52.25	2806	336	3142
48	1:00	29	35.39	42	52.08	2860	292	3152
48	1:15	29	35.85	42	52.10	2845	351	3196
48	1:30	29	36.00	42	52.00	2851	370	3221
48	1:45	29	36.55	42	51.95	2845	364	3209
48	2:00	29	37.05	42	51.75	2838	311	3149
48	2:15	29	37.42	42	51.65	2839	320	3159
48	2:30	29	37.75	42	51.50	2837	253	3090
48	2:45	29	38.12	42	51.33	2837	379	3216
48	3:00	29	38.52	42	51.21	2848	273	3121
48	3:15	29	38.75	42	51.17	2876	247	3123
48	3:30	29	39.20	42	51.05	2801	300	3101
48	3:45	29	39.65	42	50.92	2794	419	3213
48	4:00	29	40.00	42	50.80	2757	423	3180
48	4:15	29	40.25	42	50.80	2792	434	3226
48	4:30	29	40.72	42	50.70	2825	368	3193
48	4:45	29	41.15	42	50.64	2885	271	3156
48	5:00	29	41.58	42	50.55	2891	282	3173
48	5:15	29	42.08	42	50.50	2871	275	3146
48	5:30	29	42.49	42	50.45	2860	311	3171
48	5:45	29	42.90	42	50.30	2787	304	3091
48	6:00	29	43.27	42	50.20	2763	388	3151
48	6:15	29	43.80	42	50.00	2748	410	3158
48	6:30	29	44.32	42	49.95	2720	421	3141
48	6:45	29	44.65	42	49.90	2732	346	3078
48	7:00	29	47.10	42	49.71	2700	294	2994
48	7:15	29	45.55	42	49.50	2782	332	3114
48	7:30	29	46.10	42	49.30	2741	397	3138
48	7:45	29	46.55	42	49.15	2673	454	3127
48	8:00	29	47.10	42	49.05	2589	520	3109
48	8:15	29	47.60	42	48.80	2567	540	3107
48	8:30	29	48.10	42	48.75	2564	426	2990
48	8:45	29	48.50	42	48.65	2533	449	2982
48	9:00	29	48.95	42	48.50	2520	422	2942
48	9:15	29	49.65	42	48.30	2537	402	2939
48	9:30	29	50.00	42	48.20	2588	385	2973
48	9:45	29	50.60	42	48.05	2570	272	2842
48	10:00	29	50.90	42	47.90	2569	331	2900
48	10:15	29	51.40	42	47.85	2630	275	2905

48	10:30	29	51.80	42	47.70	2662	227	2889
48	10:45	29	52.20	42	47.45	2600	239	2839
48	11:00	29	52.70	42	47.45	2737	273	3010
48	11:15	29	53.08	42	47.15	2788	342	3130
48	11:30	29	53.47	42	47.02	2851	250	3101
48	11:45	29	53.93	42	47.00	2881	271	3152
48	12:00	29	54.36	42	46.90	2934	245	3179
48	12:15	29	54.78	42	46.80	2962	322	3284
48	12:30	29	55.20	42	46.60	2988	385	3373
48	12:45	29	55.53	42	46.63	3019	360	3379
48	13:00	29	55.80	42	46.45	3093	403	3496
48	13:15	29	56.15	42	46.26	3236	330	3566
48	13:30	29	56.35	42	46.25	3297	294	3591
48	13:45	29	57.86	42	46.05	3283	390	3673
48	14:00	29	57.15	42	45.98	3305	316	3621
48	14:15	29	57.50	42	45.87	3318	358	3676
48	14:30	29	57.88	42	45.78	3353	374	3727
48	14:45	29	58.22	42	45.58	3412	350	3762
48	15:00	29	58.54	42	45.50	3407	299	3706
48	15:15	29	59.00	42	45.41	3321	324	3645
48	15:30	29	59.40	42	45.40	3362	329	3691
48	15:45	29	59.72	42	45.28	3381	316	3697
48	16:00	30	0.15	42	45.15	3354	396	3750
48	16:15	30	0.47	42	45.17	3375	365	3740
48	16:30	30	0.80	42	45.05	3398	450	3848
48	16:45	30	1.10	42	45.00	3462	423	3885
48	17:00	30	1.40	42	44.90	3629	293	3922
48	17:15	30	1.80	42	44.80	3645	334	3979
48	17:30	30	2.32	42	44.70	3560	430	3990
48	17:45	30	2.90	42	44.45	3175	746	3921
48	18:00	30	3.35	42	44.45	2977	976	3953
48	18:15	30	3.70	42	44.33	2961	976	3937
48	18:30	30	3.90	42	44.30	2963	1100	4063
48	18:45	30	4.45	42	44.15	2925	1100	4025
48	19:00	30	4.95	42	44.00	2742	1100	3842
48	19:30	30	5.80	42	43.70	2684	1400	4084
48	20:00	30	6.70	42	43.50	2682	1400	4082
48	20:30	30	6.80	42	42.50	2517	1700	4217
48	21:00	30	6.80	42	42.50	2614	2000	4614
48	21:30	30	6.00	42	41.40	2715	1950	4665
48	22:00	30	5.64	42	41.42	3071	1300	4371
48	22:30	30	4.92	42	41.32	3474	1200	4674
48	22:45	30	4.45	42	41.35	3535	1100	4635
48	23:00	30	4.15	42	41.45	3611	950	4561
48	23:15	30	3.70	42	41.55	3658	950	4608
48	23:30	30	3.37	42	41.80	3643	950	4593
48	23:45	30	3.03	42	41.82	3679	850	4529
49	0:00	30	2.60	42	41.97	3579	980	4559
49	0:15	30	1.61	42	42.29	3618	450	4068
49	0:30	30	1.05	42	42.50	3643	447	4090
49	0:45	30	0.86	42	42.65	3794	453	4247
49	1:00	30	0.32	42	42.82	3870	404	4274
49	1:15	29	59.97	42	42.95	3896	524	4420
49	1:45	29	59.00	42	43.23	3905	503	4408
49	2:00	29	58.54	42	43.40	3857	343	4200
49	2:15	29	58.12	42	43.57	3834	392	4226
49	2:30	29	57.51	42	43.90	3724	519	4243
49	2:45	29	56.92	42	44.20	3605	600	4205

49	3:00	29	56.42	42	44.39	3488	750	4238
49	3:15	29	55.80	42	44.68	3258	630	3888
49	3:30	29	55.40	42	45.00	3118	538	3656
49	3:45	29	54.75	42	45.20	2960	540	3500
49	4:00	29	54.15	42	45.40	2848	445	3293
49	4:15	29	53.45	42	45.68	2747	369	3116
49	4:30	29	52.90	42	45.91	2682	461	3143
49	4:45	29	52.25	42	46.20	2662	490	3152
49	5:00	29	51.72	42	46.40	2692	411	3103
49	5:15	29	51.20	42	46.60	2605	415	3020
49	5:30	29	50.45	42	46.80	2461	345	2806
49	5:45	29	49.65	42	47.10	2388	399	2787
49	6:00	29	49.10	42	47.12	2399	412	2811
49	6:15	29	48.60	42	47.30	2449	460	2909
49	6:30	29	48.15	42	47.30	2526	418	2944
49	6:45	29	47.45	42	47.50	2588	320	2908
49	7:00	29	46.90	42	47.60	2602	317	2919
49	7:15	29	46.15	42	47.75	2697	349	3046
49	7:30	29	45.70	42	47.90	2711	389	3100
49	7:45	29	45.10	42	48.00	2717	446	3163
49	8:00	29	44.65	42	48.10	2744	439	3183
49	8:15	29	44.10	42	48.20	2771	347	3118
49	8:30	29	43.50	42	48.40	2765	243	3008
49	8:45	29	42.65	42	48.60	2751	444	3195
49	9:00	29	42.45	42	48.65	2806	353	3159
49	9:15	29	41.85	42	48.75	2879	441	3320
49	9:30	29	41.20	42	48.90	2928	415	3343
49	9:45	29	40.73	42	48.90	2969	319	3288
49	10:00	29	40.10	42	48.90	3010	284	3294
49	10:15	29	39.45	42	49.25	3021	326	3347
49	10:30	29	38.85	42	49.40	2996	316	3312
49	10:45	29	38.20	42	49.55	2926	372	3298
49	11:00	29	37.70	42	49.70	2979	307	3286
49	11:15	29	37.15	42	49.70	2985	300	3285
49	11:30	29	36.55	42	49.89	2992	318	3310
49	11:45	29	36.11	42	49.94	3055	403	3458
49	12:00	29	35.65	42	50.05	3120	415	3535
49	12:15	29	35.12	42	50.17	3146	362	3508
49	12:30	29	34.70	42	50.23	3188	379	3567
49	12:45	29	34.20	42	50.29	3220	397	3617
49	13:00	29	33.80	42	50.40	3285	338	3623
49	13:15	29	33.27	42	50.54	3326	235	3561
49	13:30	29	32.68	42	50.62	3294	273	3567
49	13:45	29	32.20	42	50.60	3274	333	3607
49	14:00	29	31.80	42	50.89	3241	345	3586
49	14:15	29	31.26	42	50.90	3280	310	3590
49	14:30	29	30.80	42	50.99	3306	337	3643
49	14:45	29	30.35	42	51.17	3364	320	3684
49	15:00	29	29.90	42	51.30	3374	265	3639
49	15:15	29	29.35	42	51.60	3117	371	3488
49	15:30	29	28.85	42	51.70	3178	253	3431
49	15:45	29	28.42	42	51.80	3238	216	3454
49	16:00	29	28.12	42	52.00	3291	445	3736
49	16:15	29	27.55	42	52.20	3374	300	3674
49	16:30	29	27.15	42	52.25	3429	242	3671
49	16:45	29	26.63	42	52.41	3430	297	3727
49	17:00	29	26.20	42	52.57	3397	243	3640
49	17:15	29	25.70	42	52.75	3366	337	3703

49	17:30	29	25.28	42	52.75	3400	405	3805
49	17:45	29	24.70	42	53.05	3462	220	3682
49	18:00	29	24.28	42	53.25	3309	210	3519
49	18:15	29	23.90	42	53.35	3273	347	3620
49	18:30	29	23.50	42	53.61	3249	466	3715
49	18:45	29	23.25	42	53.80	3240	431	3671
49	19:00	29	22.85	42	54.15	3269	460	3729
49	19:15	29	22.50	42	54.60	3231	625	3856
49	19:30	29	22.00	42	55.05	3025	820	3845
49	19:45	29	21.80	42	55.45	2983	880	3863
49	20:00	29	21.70	42	56.00	2833	650	3483
49	20:15	29	21.55	42	56.65	2612	700	3312
49	20:30	29	21.35	42	57.30	2409	700	3109
49	20:45	29	21.10	42	57.90	2267	691	2958
49	21:00	29	20.95	42	58.20	2248	552	2800
49	21:15	29	20.75	42	58.85	2228	451	2679
49	21:30	29	20.65	42	59.30	2294	500	2794
49	21:45	29	20.45	42	59.90	2374	310	2684
49	22:00	29	20.30	43	0.35	2423	447	2870
49	22:15	29	20.50	43	0.75	2464	365	2829
49	22:30	29	19.90	43	1.25	2359	455	2814
49	22:45	29	19.80	43	1.60	2499	332	2831
49	23:00	29	19.60	43	2.00	2646	194	2840
49	23:15	29	19.50	43	2.44	2696	274	2970
49	23:30	29	19.30	43	3.20	2692	326	3018
50	23:45	29	19.00	43	3.65	2694	400	3094
50	0:00	29	18.92	43	4.10	2790	455	3245
50	0:15	29	18.88	43	4.50	2855	616	3471
50	0:30	29	18.83	43	4.80	2902	530	3432
50	0:45	29	18.60	43	5.10	3009	550	3559
50	1:00	29	18.35	43	5.70	3042	367	3409
50	1:15	29	18.20	43	6.30	2986	291	3277
50	1:30	29	17.83	43	6.50	2950	390	3340
50	1:45	29	17.52	43	6.80	2483	408	2891
50	2:00	29	17.10	43	6.94	2942	378	3320
50	2:15	29	16.61	43	7.10	2990	279	3269
50	2:30	29	16.10	43	7.26	2982	298	3280
50	2:45	29	15.59	43	7.40	2969	275	3244
50	3:00	29	15.30	43	7.50	2850	291	3141
50	3:30	29	15.30	43	7.60	2873	294	3167
50	4:00	29	13.30	43	8.00	2869	270	3139
50	4:30	29	12.10	43	8.00	2788	467	3255
50	5:00	29	11.10	43	8.10	2867	309	3176
50	5:30	29	10.05	43	8.39	2703	326	3029
50	6:00	29	8.98	43	8.56	2713	283	2996
50	6:30	29	7.85	43	8.70	2728	366	3094
50	7:00	29	7.00	43	8.83	2806	315	3121
50	7:15	29	6.30	43	9.10	2887	359	3246
50	7:30	29	5.90	43	9.20	2918	354	3272
50	7:45	29	5.15	43	9.25	2943	313	3256
50	8:00	29	4.75	43	9.40	2901	321	3222
50	8:15	29	4.50	43	9.40	2838	268	3106
50	8:30	29	3.45	43	9.50	2788	338	3126
50	8:45	29	3.00	43	9.50	2815	222	3037
50	9:00	29	2.50	43	9.60	2778	314	3092
50	9:15	29	1.90	43	9.65	2703	350	3053
50	9:30	29	1.45	43	9.80	2692	319	3011
50	9:45	29	0.85	43	9.85	2701	356	3057

50	10:00	29	0.40	43	9.95	2716	331	3047
50	10:15	28	59.95	43	9.95	2757	380	3137
50	10:30	28	59.50	43	10.00	2866	296	3162
50	10:45	28	58.90	43	10.05	2870	276	3146
50	11:00	28	58.30	43	10.10	2836	263	3099
50	11:15	28	57.60	43	10.25	2784	303	3087
50	11:30	28	57.22	43	10.28	2808	307	3115
50	11:45	28	56.92	43	10.33	2843	306	3149
50	12:00	28	56.38	43	10.43	2833	407	3240
50	12:15	28	56.08	43	10.70	2789	399	3188
50	12:30	28	55.67	43	11.10	2850	435	3285
50	12:45	28	55.38	43	11.45	2899	512	3411
50	13:00	28	54.86	43	11.72	3028	607	3635
50	13:15	28	54.49	43	12.05	3208	532	3740
50	13:30	28	54.22	43	12.25	3354	410	3764
50	13:45	28	53.80	43	12.72	3356	329	3685
50	14:00	28	53.50	43	13.13	3382	310	3692
50	14:15	28	53.13	43	13.67	3400	275	3675
50	14:30	28	52.80	43	14.27	3279	514	3793
50	14:45	28	52.47	43	14.80	3320	377	3697
50	15:00	28	52.22	43	15.28	3164	547	3711
50	15:15	28	51.72	43	15.87	3122	620	3742
50	15:30	28	51.46	43	16.25	3180	529	3709
50	15:45	28	51.15	43	16.70	3116	409	3525
50	16:10	28	50.45	43	17.52	3212	211	3423
50	16:15	28	50.25	43	17.80	3107	267	3374
50	16:30	28	49.85	43	18.30	3108	260	3368
50	16:45	28	49.45	43	18.95	3014	293	3307
50	17:00	28	49.12	43	19.40	2940	390	3330
50	17:15	28	48.60	43	20.00	2880	498	3378
50	17:30	28	48.22	43	20.52	2885	275	3160
50	17:45	28	47.98	43	20.82	2883	314	3197
50	18:00	28	47.75	43	21.20	2961	424	3385
50	18:15	28	47.35	43	21.65	3046	397	3443
50	18:30	28	47.00	43	22.10	3091	338	3429
50	18:45	28	46.80	43	22.52	3161	253	3414
50	19:00	28	46.50	43	22.80	3232	330	3562
50	19:15	28	46.10	43	23.40	3420	193	3613
50	19:30	28	45.65	43	23.85	3385	285	3670
50	19:45	28	45.35	43	24.25	3352	246	3598
50	20:00	28	45.05	43	24.65	3310	319	3629
50	20:15	28	44.70	43	25.10	3298	393	3691
50	20:30	28	44.30	43	25.60	3214	355	3569
50	20:45	28	43.90	43	26.00	3128	531	3659
50	21:00	28	43.60	43	26.30	3081	400	3481
50	21:15	28	43.20	43	26.80	2918	440	3358
50	21:30	28	42.90	43	27.35	2732	596	3328
50	21:45	28	42.55	43	27.65	2663	544	3207
50	22:00	28	42.15	43	28.15	2708	403	3111
50	22:15	28	41.95	43	28.40	2575	733	3308
50	22:30	28	41.70	43	28.75	2766	621	3387
50	22:45	28	41.50	43	28.90	2985	447	3432
50	23:00	28	41.30	43	29.20	3100	182	3282
50	23:15	28	41.00	43	29.50	3063	320	3383
50	23:30	28	40.65	43	29.90	3011	286	3297
50	23:45	28	40.40	43	30.30	2943	293	3236

51	0:00	28	40.12	43	30.68	2892	384	3276
51	0:15	28	39.95	43	30.97	2892	417	3309
51	0:30	28	39.83	43	31.42	2908	265	3173
51	0:45	28	39.63	43	31.72	2903	242	3145
51	1:00	28	39.45	43	31.98	2891	375	3266
51	1:15	28	39.25	43	32.42	2878	275	3153
51	1:30	28	39.17	43	32.75	2749	299	3048
51	1:45	28	39.05	43	33.00	2840	314	3154
51	2:00	28	38.75	43	33.27	2978	289	3267
51	2:15	28	38.66	43	33.52	3030	359	3389
51	2:30	28	38.48	43	33.92	3190	170	3360
51	2:45	28	38.30	43	34.25	2954	427	3381
51	3:00	28	38.22	43	34.50	2975	497	3472
51	3:15	28	38.05	43	34.72	2957	290	3247
51	3:30	28	37.95	43	34.90	2987	377	3364
51	3:45	28	37.75	43	35.30	2975	465	3440
51	4:00	28	37.60	43	35.52	3027	400	3427
51	4:15	28	37.40	43	35.80	3079	271	3350
51	4:30	28	37.15	43	36.20	3026	231	3257
51	4:45	28	36.90	43	36.58	2986	385	3371
51	5:00	28	36.72	43	36.82	3003	449	3452
51	5:15	28	36.50	43	37.18	3024	563	3587
51	5:30	28	36.40	43	37.55	3044	455	3499
51	5:45	28	36.08	43	37.95	3052	520	3572
51	6:00	28	35.72	43	38.15	3047	498	3545
51	6:15	28	35.50	43	38.32	3068	454	3522
51	6:30	28	35.20	43	38.47	3188	331	3519
51	6:45	28	34.70	43	38.70	3162	362	3524
51	7:00	28	34.30	43	38.90	3131	356	3487
51	7:15	28	33.80	43	39.00	3143	447	3590
51	7:30	28	33.30	43	39.25	3065	492	3557
51	7:45	28	32.70	43	39.40	2990	535	3525
51	8:00	28	32.20	43	39.50	2945	501	3446
51	8:15	28	31.55	43	39.60	2945	477	3422
51	8:30	28	31.90	43	39.60	2929	496	3425
51	8:45	28	30.50	43	39.80	2912	214	3126
51	9:00	28	30.20	43	39.85	2932	379	3311
51	9:15	28	30.15	43	39.95	2952	322	3274
51	9:30	28	29.20	43	40.05	2976	279	3255
51	9:45	28	28.65	43	40.20	2822	376	3198
51	10:00	28	28.05	43	40.30	2862	412	3274
51	10:15	28	27.65	43	40.40	2854	340	3194
51	10:30	28	27.20	43	40.60	2811	365	3176
51	10:45	28	27.65	43	40.65	2741	351	3092
51	11:00	28	25.95	43	40.80	2666	440	3106
51	11:15	28	25.43	43	41.05	2656	373	3029
51	11:30	28	25.00	43	41.21	2713	346	3059
51	11:45	28	24.58	43	41.30	2764	336	3100
51	12:00	28	23.95	43	41.35	2815	21	2836
51	12:15	28	23.52	43	41.45	2766	297	3063
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51	12:45	28	22.52	43	41.58	2656	447	3103
51	13:00	28	22.00	43	41.60	2647	454	3101
51	13:15	28	21.55	43	41.73	2700	460	3160
51	13:30	28	21.05	43	41.85	2718	426	3144
51	13:45	28	20.56	43	42.32	2734	248	2982
51	14:00	28	20.38	43	42.60	2633	408	3041
51	14:15	28	19.95	43	43.00	2670	586	3256

51	14:30	28	19.58	43	43.26	2765	488	3253
51	14:45	28	19.31	43	43.52	2878	410	3288
51	15:00	28	18.92	43	43.80	2923	237	3160
51	15:15	28	18.65	43	44.18	2794	486	3280
51	15:30	28	18.48	43	44.32	2984	397	3381
51	15:45	28	18.05	43	44.78	3096	380	3476
51	16:00	28	17.75	43	45.13	3087	367	3454
51	16:15	28	17.50	43	45.42	3131	321	3452
51	16:30	28	17.05	43	45.85	3159	278	3437
51	16:45	28	16.70	43	46.15	3141	366	3507
51	17:00	28	16.40	43	46.40	3243	305	3548
51	17:15	28	16.05	43	46.78	3349	269	3618
51	17:30	28	15.70	43	47.13	3354	350	3704
51	17:45	28	15.27	43	47.55	3305	433	3738
51	18:00	28	14.99	43	47.80	3348	339	3687
51	18:15	28	14.73	43	48.12	3442	310	3752
51	18:30	28	14.30	43	48.47	3469	251	3720
51	18:45	28	14.00	43	48.80	3336	413	3749
51	19:00	28	13.63	43	49.13	3409	412	3821
51	19:15	28	13.20	43	49.70	3513	370	3883
51	19:30	28	12.70	43	50.25	3287	534	3821
51	19:45	28	12.30	43	50.50	3194	800	3994
51	20:00	28	11.91	43	50.90	3235	593	3828
51	20:15	28	11.55	43	51.10	3270	280	3550
51	20:30	28	10.90	43	51.45	3178	322	3500
51	20:45	28	10.50	43	51.85	3175	438	3613
51	21:00	28	10.20	43	51.97	3278	341	3619
51	21:15	28	9.95	43	52.20	3325	227	3552
51	21:30	28	9.45	43	52.65	3199	417	3616
51	21:45	28	9.20	43	52.90	3290	331	3621
51	22:00	28	8.75	43	53.20	3324	379	3703
51	22:15	28	8.40	43	53.40	3363	344	3707
51	22:30	28	8.00	43	53.65	3436	401	3837
51	22:45	28	7.65	43	53.90	3454	430	3884
51	23:00	28	7.30	43	54.15	3458	487	3945
51	23:15	28	6.72	43	54.40	3288	860	4148
51	23:30	28	6.40	43	54.62	3085	950	4035
51	23:45	28	6.08	43	54.78	3028	900	3928
52	0:00	28	5.55	43	54.92	2987	649	3636
52	0:15	28	5.18	43	55.05	3037	617	3654
52	0:30	28	4.85	43	55.15	3211	603	3814
52	0:45	28	4.45	43	55.25	3241	542	3783
52	1:00	28	4.00	43	55.40	3220	505	3725
52	1:15	28	3.65	43	55.50	3328	419	3747
52	1:30	28	3.27	43	55.60	3296	357	3653
52	1:45	28	2.32	43	55.70	3217	398	3615
52	2:00	28	2.23	43	55.78	3141	368	3509
52	2:15	28	1.70	43	55.90	3093	426	3519
52	2:30	28	1.28	43	56.00	3100	261	3361
52	2:45	28	0.63	43	56.20	2970	243	3213
52	3:00	28	0.17	43	56.35	2938	300	3238
52	3:15	27	59.75	43	56.42	2912	181	3093
52	3:30	27	59.05	43	56.60	2770	330	3100
52	3:45	27	58.65	43	56.65	2735	396	3131
52	4:00	27	58.20	43	56.80	2728	319	3047
52	4:15	27	57.78	43	56.92	2711	362	3073
52	4:30	27	57.25	43	57.10	2688	404	3092
52	4:45	27	56.70	43	57.00	2659	329	2988

52	5:00	27	56.27	43	57.13	2642	409	3051
52	5:15	27	55.60	43	57.31	2623	206	2829
52	5:30	27	55.10	43	57.45	2470	310	2780
52	5:45	27	54.65	43	57.62	2484	383	2867
52	6:00	27	54.17	43	57.70	2557	408	2965
52	6:15	27	53.90	43	57.80	2642	379	3021
52	6:30	27	53.42	43	57.90	2683	329	3012
52	6:45	27	53.00	43	58.00	2702	300	3002
52	7:00	27	52.55	43	58.12	2756	301	3057
52	7:15	27	52.00	43	58.20	2901	341	3242
52	7:30	27	51.60	43	58.35	2906	382	3288
52	7:45	27	51.20	43	58.50	2918	421	3339
52	8:00	27	50.85	43	58.65	2888	447	3335
52	8:15	27	50.45	43	58.65	2867	491	3358
52	8:30	27	49.95	43	58.80	2853	566	3419
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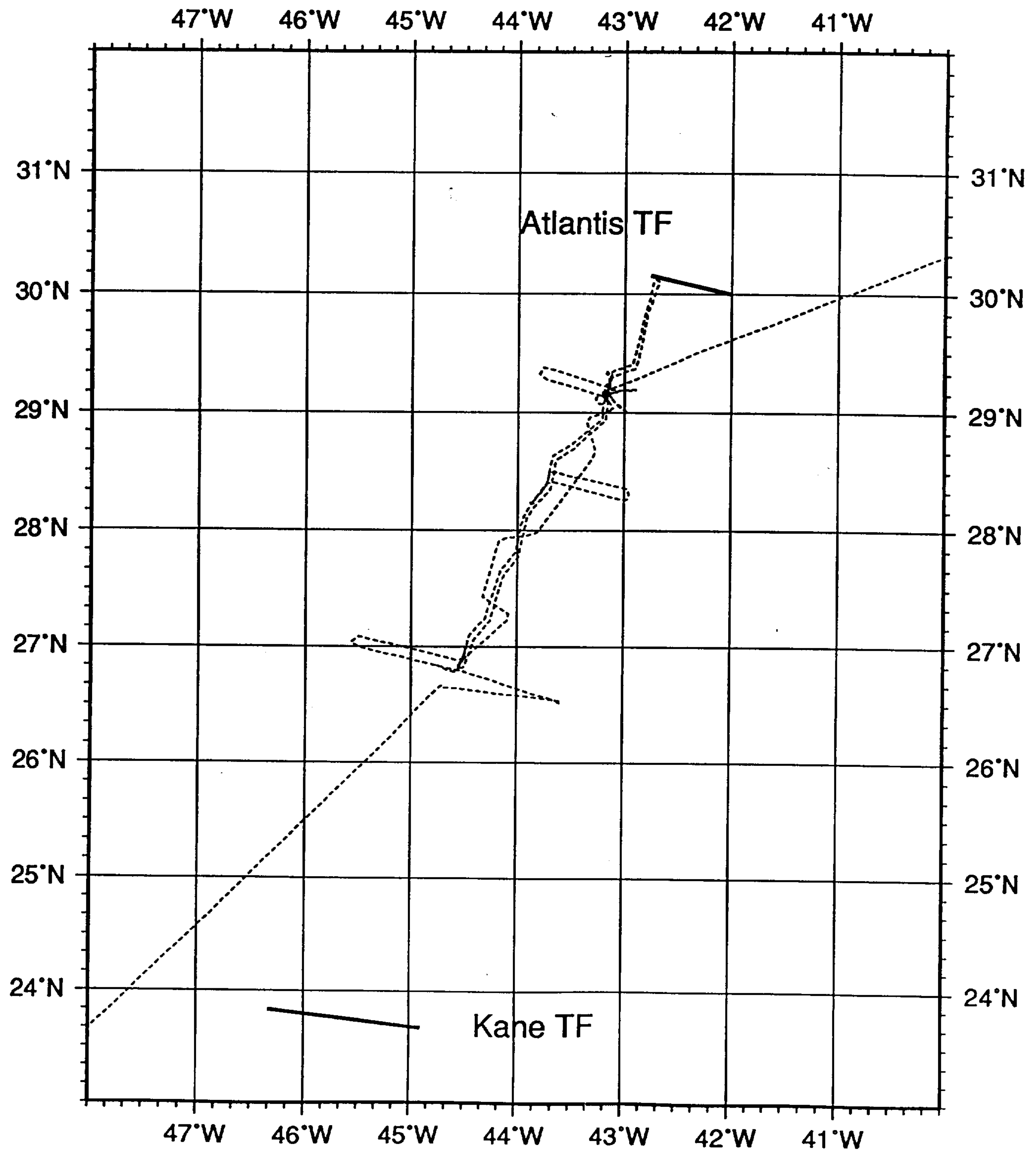
52	9:00	27	49.10	43	58.85	2825	631	3456
52	9:15	27	48.65	43	58.90	2946	419	3365
52	9:30	27	48.30	43	59.00	3072	441	3513
52	9:45	27	48.15	43	59.11	3171	390	3561
52	10:00	27	47.75	43	59.25	3252	356	3608
52	10:15	27	47.45	43	59.40	3311	301	3612
52	10:30	27	46.90	43	59.50	3344	281	3625
52	10:45	27	46.45	43	59.60	3328	306	3634
52	11:00	27	46.20	44	0.00	3292	251	3543
52	11:15	27	45.62	44	0.35	3181	322	3503
52	11:30	27	45.38	44	0.58	3165	437	3602
52	11:45	27	45.00	44	0.90	3173	429	3602
52	12:00	27	44.67	44	1.23	3037	455	3492
52	12:15	27	44.22	44	1.45	3106	511	3617
52	12:30	27	43.85	44	1.86	3087	439	3526
52	12:45	27	43.43	44	2.08	3127	631	3758
52	13:00	27	42.97	44	2.44	3088	730	3818
52	13:15	27	42.48	44	2.85	3058	594	3652
52	13:30	27	41.95	44	3.10	3140	504	3644
52	13:45	27	41.75	44	3.35	3159	456	3615
52	14:00	27	41.45	44	3.70	3139	550	3689
52	14:15	27	41.15	44	4.00	3285	367	3652
52	14:30	27	40.85	44	4.30	3394	211	3605
52	14:45	27	40.55	44	4.80	3336	392	3728
52	15:00	27	40.10	44	5.05	3425	595	4020
52	15:15	27	39.55	44	5.50	3941	315	4256
52	15:30	27	39.35	44	5.75	3526	425	3951
52	15:45	27	39.05	44	5.92	3544	433	3977
52	16:00	27	38.65	44	6.32	3593	249	3842
52	16:15	27	38.20	44	6.70	3543	256	3799
52	16:30	27	37.83	44	6.93	3430	348	3778
52	16:45	27	37.30	44	7.28	3324	637	3961
52	17:00	27	36.72	44	7.60	3300	322	3622
52	17:15	27	36.29	44	7.90	3155	566	3721
52	17:30	27	35.82	44	8.10	3063	393	3456
52	17:45	27	35.28	44	8.27	2923	603	3526
52	18:00	27	34.72	44	8.50	2877	638	3515
52	18:15	27	34.22	44	8.65	2838	509	3347
52	18:30	27	33.72	44	8.80	2806	464	3270
52	18:45	27	33.40	44	8.94	2820	530	3350
52	19:00	27	32.78	44	9.10	2842	466	3308
52	19:15	27	32.25	44	9.30	2963	403	3366

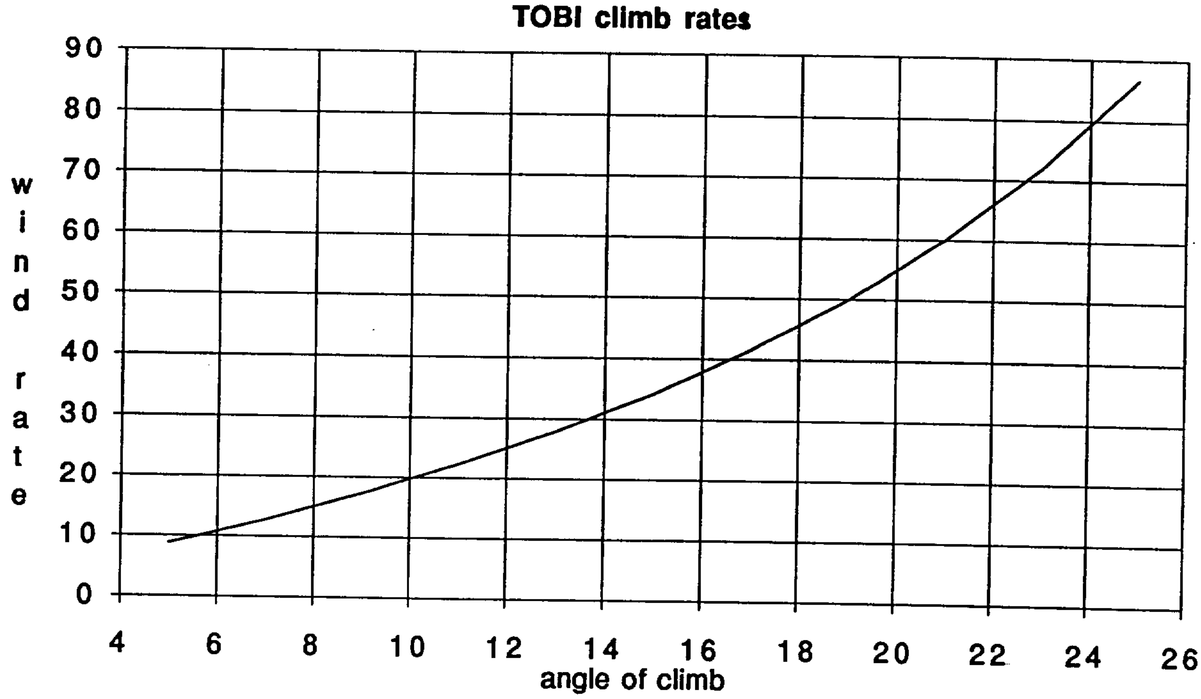
52	19:35	27	31.55	44	9.62	2974	304	3278
52	19:45	27	31.30	44	9.70	3033	385	3418
52	20:00	27	30.90	44	9.90	3050	366	3416
52	20:15	27	30.40	44	10.10	3015	341	3356
52	20:30	27	30.00	44	10.35	2955	375	3330
52	20:45	27	29.60	44	10.50	2851	425	3276
52	21:00	27	28.75	44	10.60	2710	431	3141
52	21:15	27	28.25	44	10.60	2705	490	3195
52	21:30	27	27.85	44	10.75	2697	700	3397
52	21:45	27	27.46	44	11.00	2678	700	3378
52	22:00	27	27.00	44	11.20	2725	700	3425
52	22:15	27	26.55	44	11.35	2713	612	3325
52	22:30	27	26.25	44	11.50	2762	629	3391
52	22:45	27	25.85	44	11.70	2951	388	3339
52	23:00	27	25.45	44	11.80	3064	320	3384
52	23:15	27	25.00	44	12.00	3109	319	3428
52	23:30	27	24.60	44	12.10	3073	368	3441
52	23:45	27	24.15	44	12.28	3042	445	3487
53	0:00	27	23.80	44	12.32	3028	375	3403
53	0:15	27	23.30	44	12.43	3012	488	3500
53	0:30	27	22.82	44	12.60	2999	519	3518
53	0:45	27	22.32	44	12.65	2983	503	3486
53	1:00	27	21.82	44	12.82	2997	531	3528
53	1:15	27	21.97	44	12.93	3019	565	3584
53	1:30	27	20.97	44	13.08	3044	608	3652
53	1:45	27	20.50	44	13.23	3148	535	3683
53	2:00	27	20.05	44	13.35	3151	514	3665
53	2:15	27	19.60	44	13.52	3155	486	3641
53	2:30	27	19.17	44	13.70	3177	422	3599
53	2:45	27	18.68	44	13.77	3185	410	3595
53	3:00	27	18.20	44	13.90	3172	428	3600
53	3:15	27	17.65	44	14.08	3060	490	3550
53	3:30	27	17.30	44	14.23	3074	360	3434
53	3:45	27	16.72	44	14.50	3107	507	3614
53	4:00	27	16.32	44	14.55	3138	512	3650
53	4:15	27	15.85	44	14.60	3225	448	3673
53	4:30	27	15.42	44	14.80	3278	360	3638
53	4:45	27	14.92	44	15.00	3273	463	3736
53	5:00	27	14.31	44	15.35	3246	289	3535
53	5:15	27	13.87	44	15.54	3242	403	3645
53	5:30	27	13.52	44	15.64	3242	406	3648
53	5:45	27	13.10	44	15.95	3298	421	3719
53	6:00	27	12.73	44	16.30	3397	376	3773
53	6:15	27	12.36	44	16.80	3440	330	3770
53	6:30	27	12.05	44	16.99	3467	334	3801
53	6:45	27	11.75	44	17.50	3490	373	3863
53	7:00	27	11.30	44	17.90	3491	343	3834
53	7:15	27	10.75	44	18.40	3509	388	3897
53	7:30	27	10.20	44	18.80	3442	349	3791
53	7:45	27	9.85	44	19.20	3293	389	3682
53	8:00	27	9.35	44	19.65	3161	530	3691
53	8:15	27	8.75	44	20.20	2988	438	3426
53	8:30	27	8.30	44	20.55	2875	442	3317
53	8:45	27	7.90	44	20.85	2871	751	3622
53	9:00	27	7.40	44	21.15	2904	745	3649
53	9:15	27	7.10	44	21.55	2967	850	3817
53	9:30	27	6.70	44	22.00	3068	700	3768
53	9:45	27	6.40	44	22.30	3151	538	3689

53	10:00	27	6.15	44	22.70	3239	419	3658
53	10:15	27	5.75	44	23.10	3367	540	3907
53	10:30	27	5.25	44	23.50	3433	580	4013
53	10:45	27	4.90	44	23.75	3466	404	3870
53	11:00	27	4.65	44	24.20	3427	333	3760
53	11:15	27	4.12	44	24.42	3441	372	3813
53	11:30	27	3.64	44	24.60	3486	356	3842
53	11:45	27	3.20	44	24.78	3430	392	3822
53	12:00	27	2.71	44	24.93	3338	426	3764
53	12:15	27	2.13	44	25.15	3426	540	3966
53	12:30	27	1.76	44	25.31	3476	558	4034
53	12:45	27	1.30	44	25.50	3486	444	3930
53	13:00	27	0.85	44	25.68	3503	480	3983
53	13:15	27	0.46	44	25.79	3553	343	3896
53	13:30	26	59.85	44	26.00	3495	369	3864
53	13:45	26	59.35	44	26.25	3480	394	3874
53	14:00	26	58.90	44	26.60	3499	397	3896
53	14:15	26	58.50	44	26.70	3511	482	3993
53	14:30	26	58.00	44	26.80	3518	417	3935
53	14:45	26	57.50	44	26.95	3532	443	3975
53	15:00	26	56.95	44	27.20	3530	443	3973
53	15:15	26	56.45	44	27.50	3332	521	3853
53	15:30	26	55.90	44	27.70	3244	587	3831
53	15:45	26	55.45	44	27.80	3256	684	3940
53	16:00	26	55.00	44	28.00	3282	589	3871
64	14:30	29	17.15	43	7.60	2845	536	3381
64	15:00	29	—	43	0.00	2640	535	3175
64	15:15	29	15.40	43	8.05	2639	413	3052
64	15:30	29	15.00	43	8.25	2673	491	3164
64	15:45	29	14.70	43	8.25	2709	378	3087
64	16:00	29	14.16	43	8.35	2760	504	3264
64	16:15	29	13.55	43	8.55	2749	439	3188
64	16:30	29	13.25	43	8.76	2729	479	3208
64	16:45	29	12.72	43	8.80	2670	480	3150
64	17:00	29	12.18	43	9.00	2610	450	3060
64	17:15	29	11.67	43	9.20	2637	435	3072
64	17:30	29	11.13	43	9.30	2645	490	3135
64	17:45	29	10.70	43	9.42	2664	437	3101
64	18:00	29	10.20	43	9.50	2848	498	3346
64	18:15	29	9.70	43	9.70	2794	439	3233
64	18:30	29	9.16	43	9.80	2745	323	3068
64	18:45	29	8.80	43	9.90	2773	408	3181
64	19:00	29	8.46	43	10.00	2790	392	3182
64	19:15	29	7.60	43	10.25	2580	557	3137
64	19:30	29	7.15	43	10.40	2309	816	3125
64	19:45	29	6.65	43	10.60	2151	1075	3226
64	20:00	29	6.20	43	10.60	2173	919	3092
64	20:15	29	5.85	43	10.95	2276	950	3226
64	20:30	29	5.40	43	11.25	2283	910	3193
64	20:45	29	4.90	43	11.70	2187	951	3138
64	21:00	29	4.50	43	12.35	2178	1030	3208
64	21:15	29	4.46	43	13.00	1990	1200	3190
64	21:30	29	4.68	43	13.60	1900	885	2785
64	21:45	29	4.80	43	14.45	1805	872	2677
64	22:00	29	5.40	43	14.90	1695	868	2563
64	22:15	29	6.10	43	14.80	1652	874	2526
64	22:30	29	6.40	43	14.80	1714	890	2604
64	22:45	29	7.00	43	14.65	1809	872	2681

64	23:00	29	7.75	43	15.45	1782	912	2694
64	23:15	29	8.42	43	14.80	1690	916	2606
64	23:30	29	8.65	43	14.05	1850	870	2720
64	23:45	29	8.70	43	13.45	2070	621	2691
65	0:00	29	8.78	43	13.00	2278	499	2777
65	0:15	29	8.86	43	12.39	2383	422	2805
65	0:30	29	9.96	43	11.82	2520	690	3210
65	0:45	29	10.05	43	11.30	2692	520	3212
65	1:00	29	10.20	43	10.77	2735	426	3161
65	1:15	29	10.33	43	10.18	2740	390	3130
65	1:30	29	10.53	43	9.60	2788	420	3208
65	1:45	29	10.75	43	8.78	2570	695	3265
65	2:00	29	10.90	43	7.94	2270	617	2887

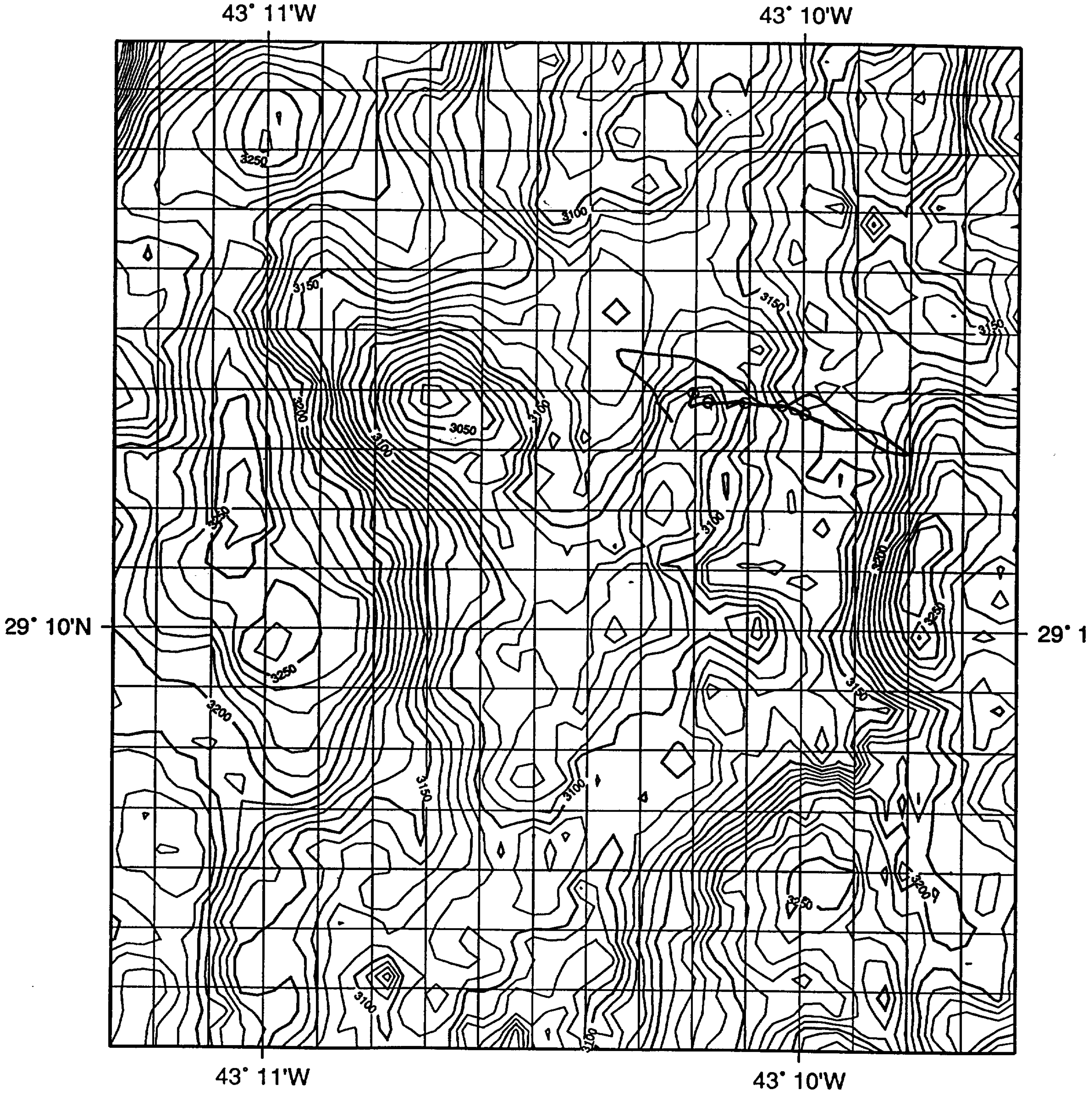
CD-76 Ship's Track





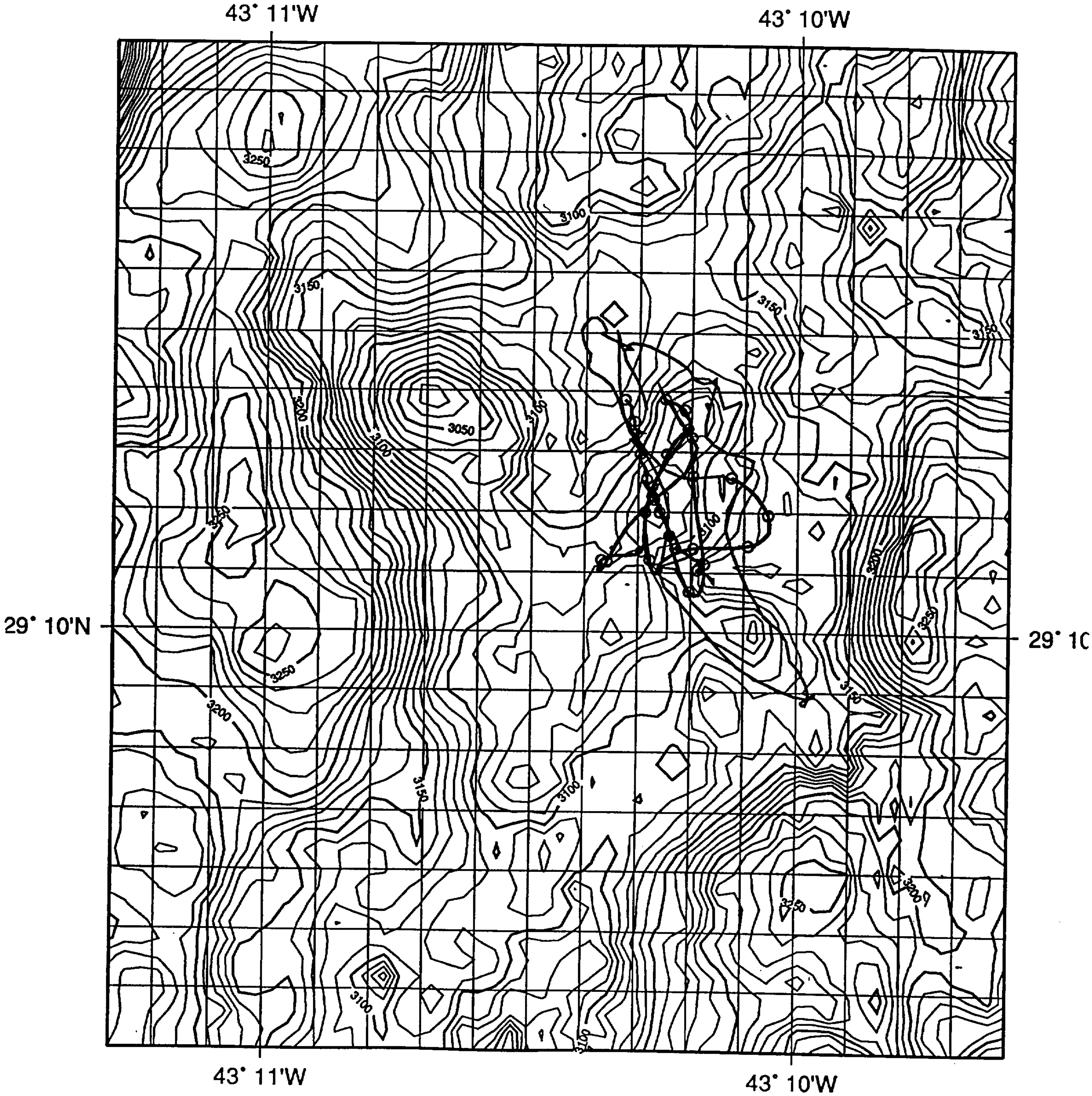
TOBI climb rates
wind rate
angle of climb
90
80
70
60
50
40
30
20
10
0
4
6
8
10
12
14
16
18
20
22
24
26

Track of Wasp No.2



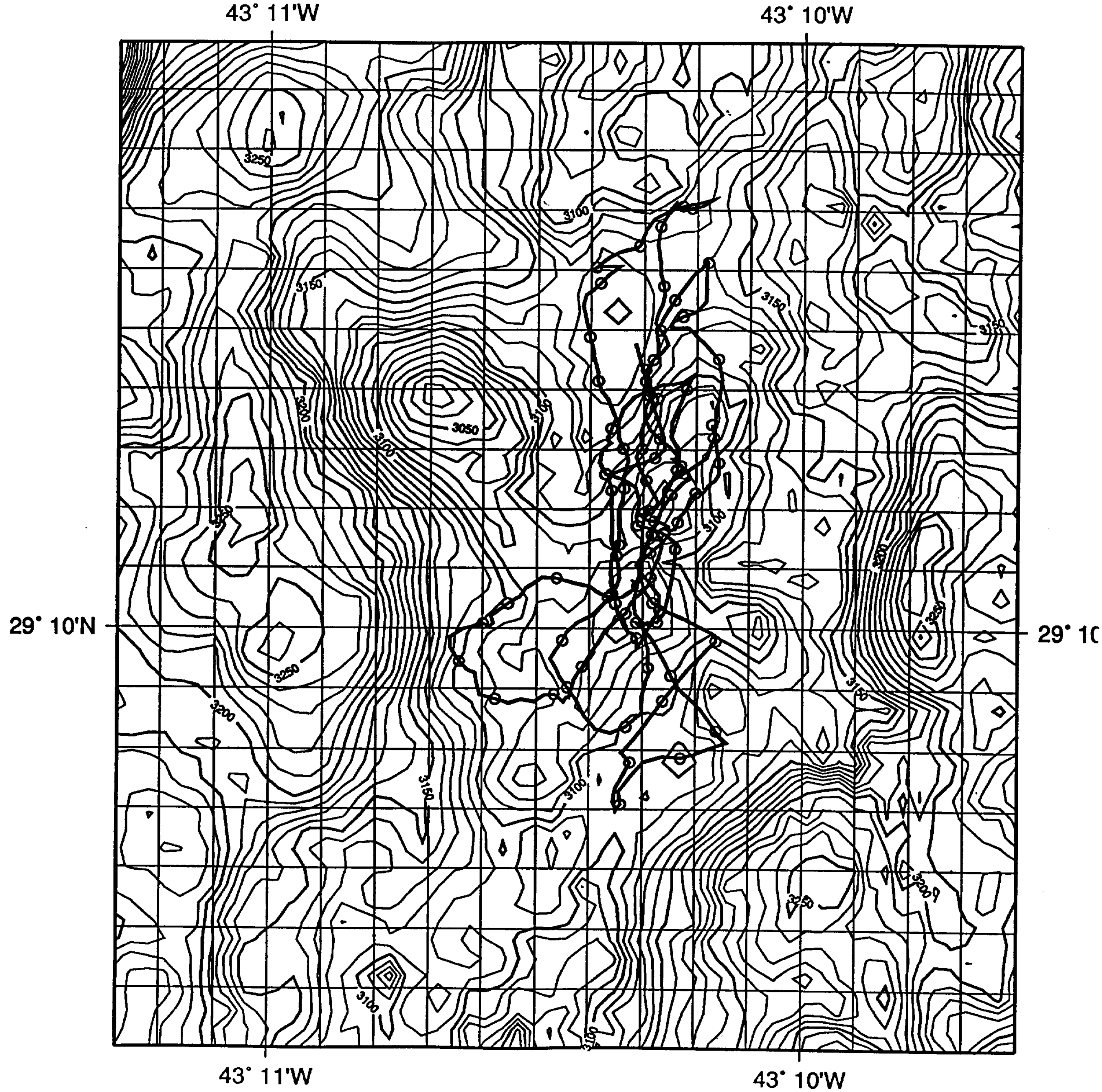
oooo ships track during bottom time 061/15:53 - 16:16

Track of Wasp No.3



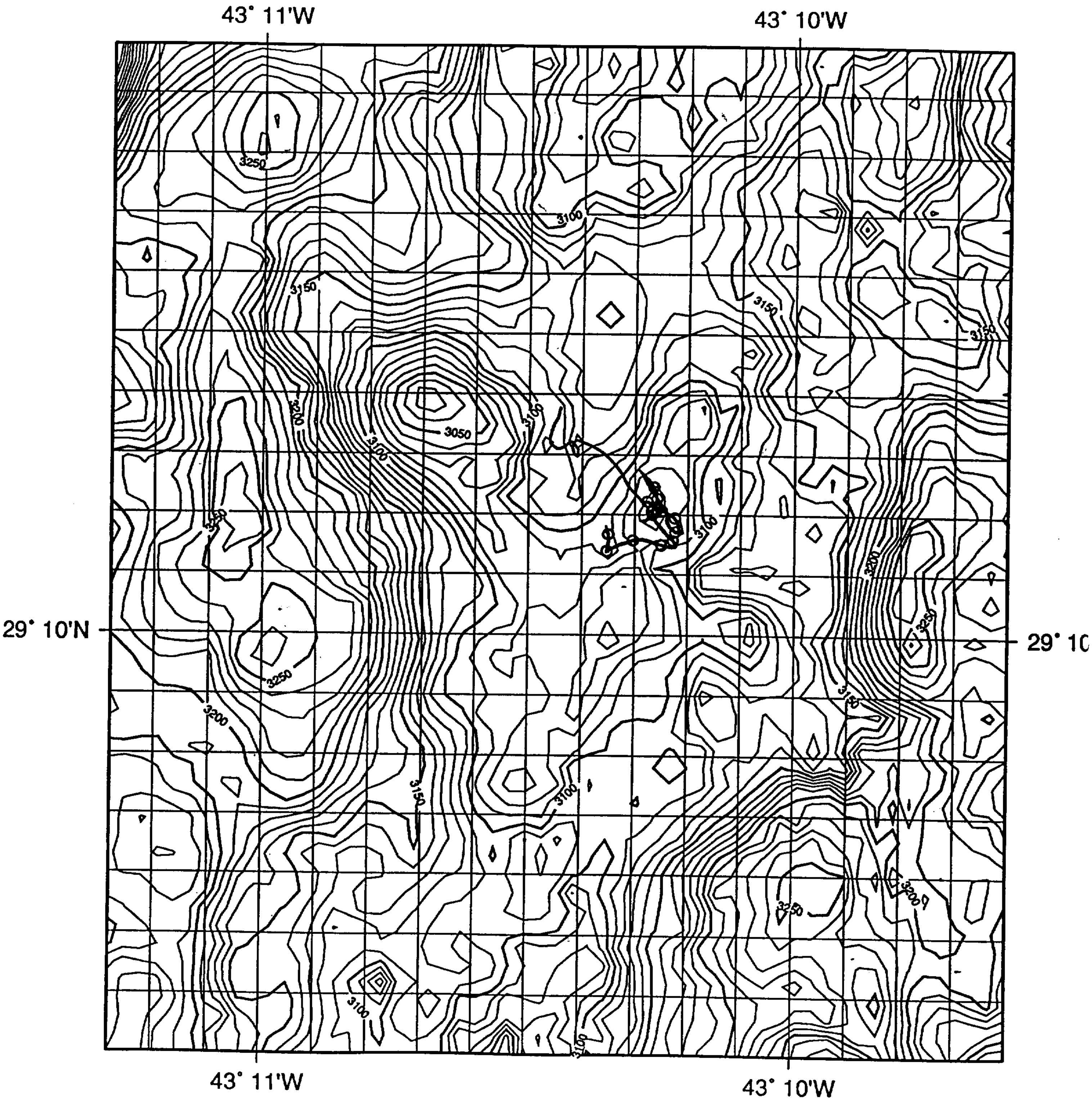
oooo bottom time 062/04:45 - 05:18 (acoustic navigation) and 062/07:15 - 09:02 (ships track)

Track of Wasp No.4



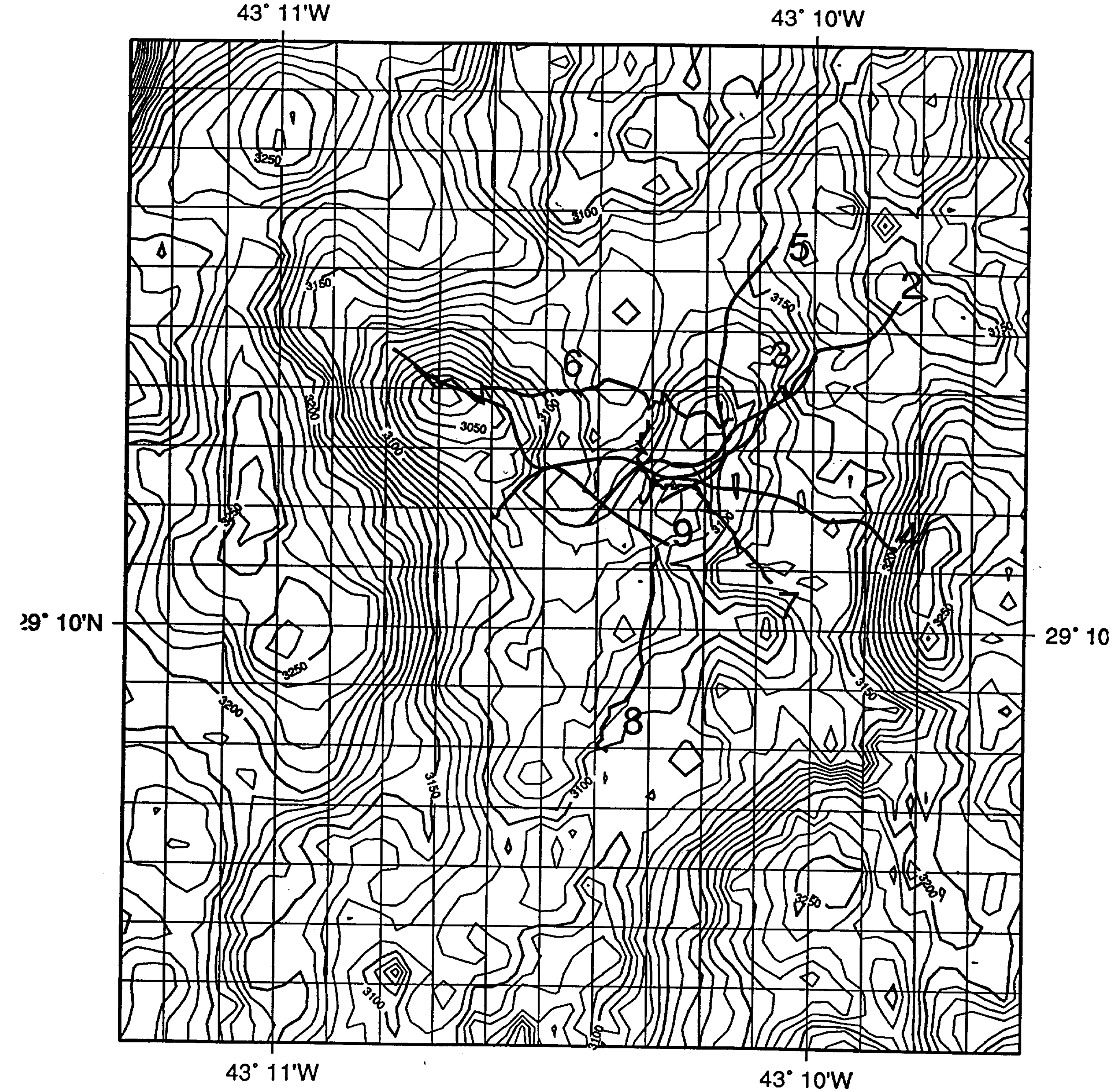
oooo ships track during bottom time 063/03:00 - 09:28

Track of Wasp No.5

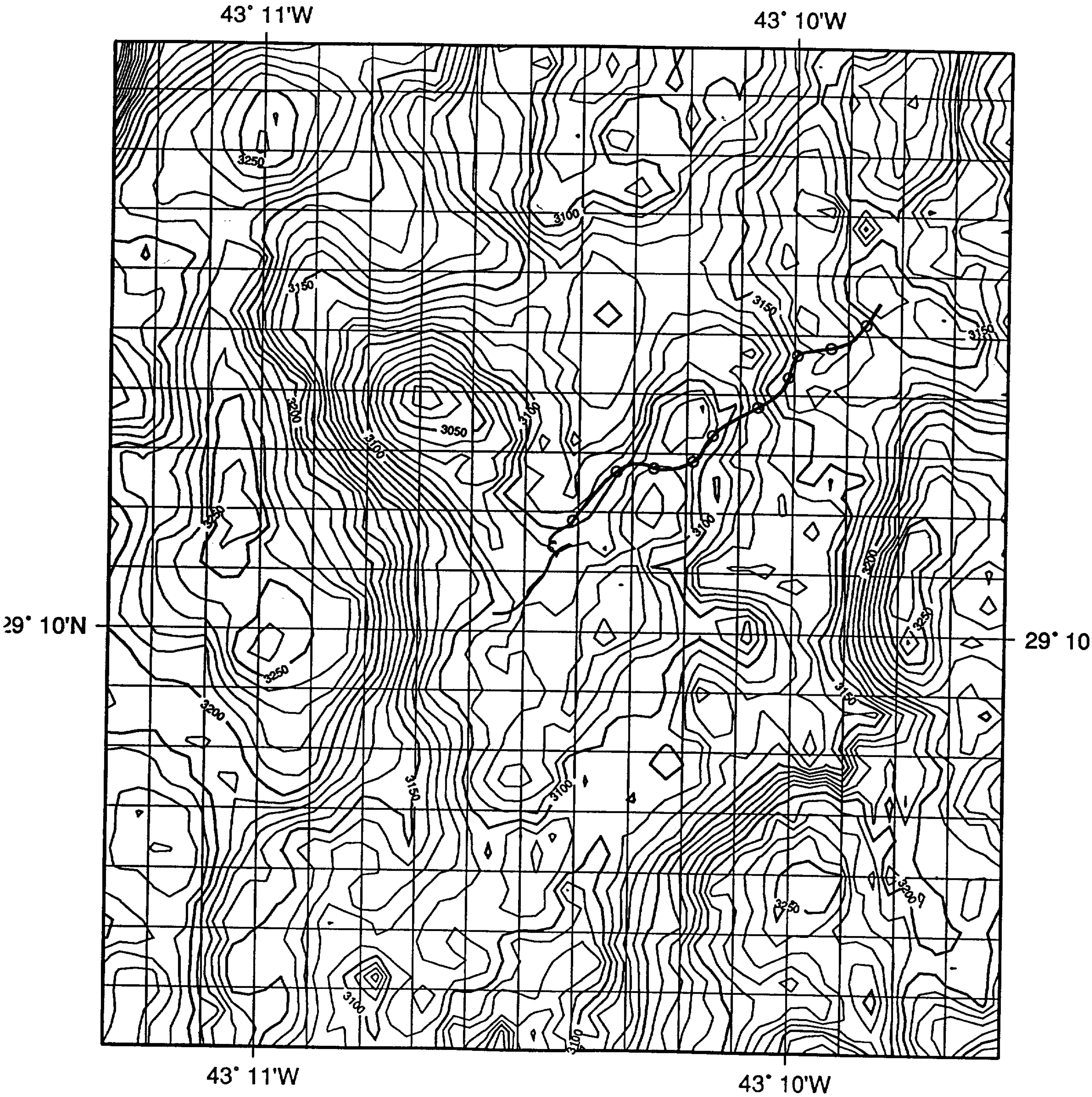


OOOO ships track during bottom time 063/14:40 - 15:48

CD-76 Dredge-Tracks

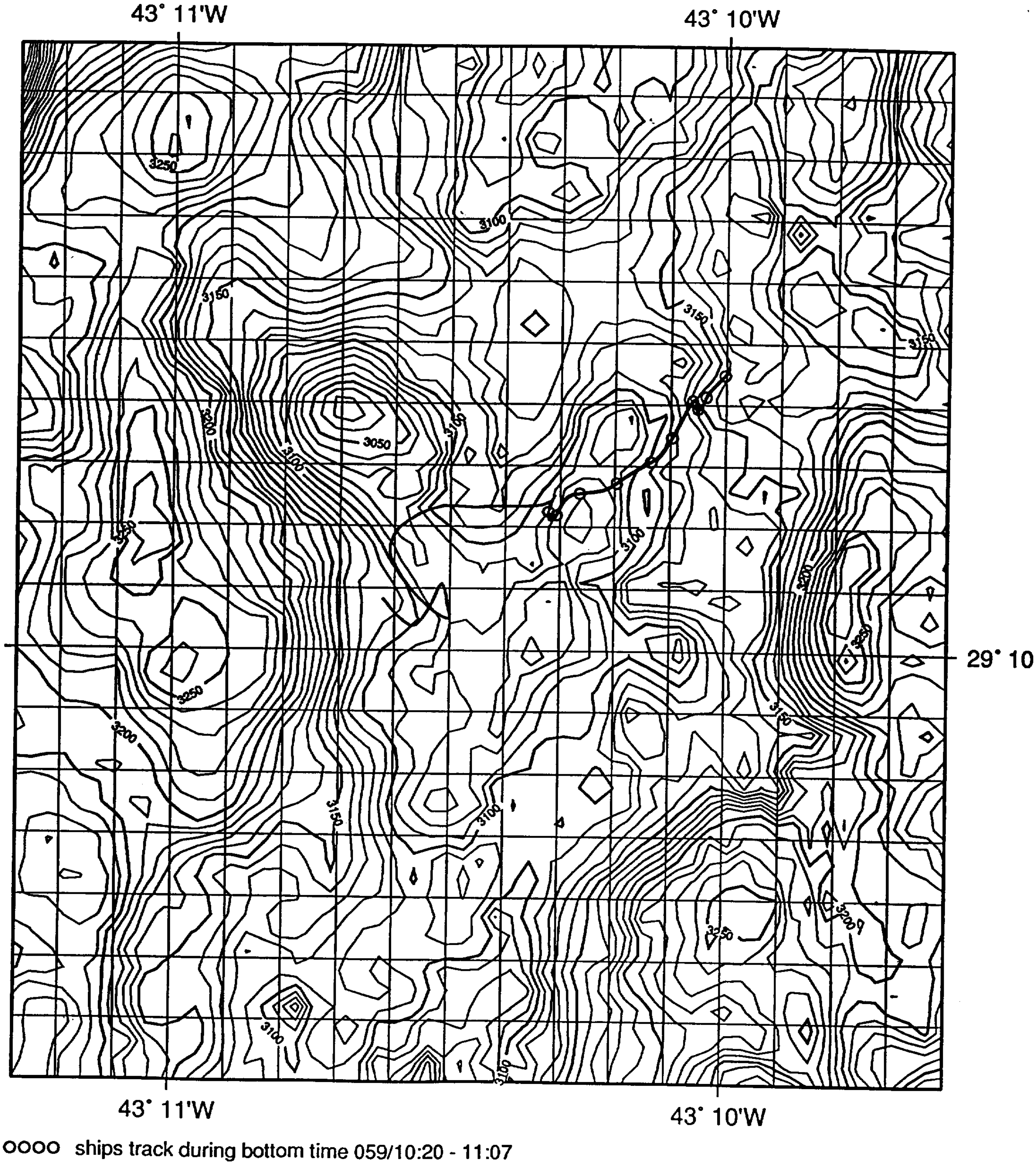


Track of Dredge No.2



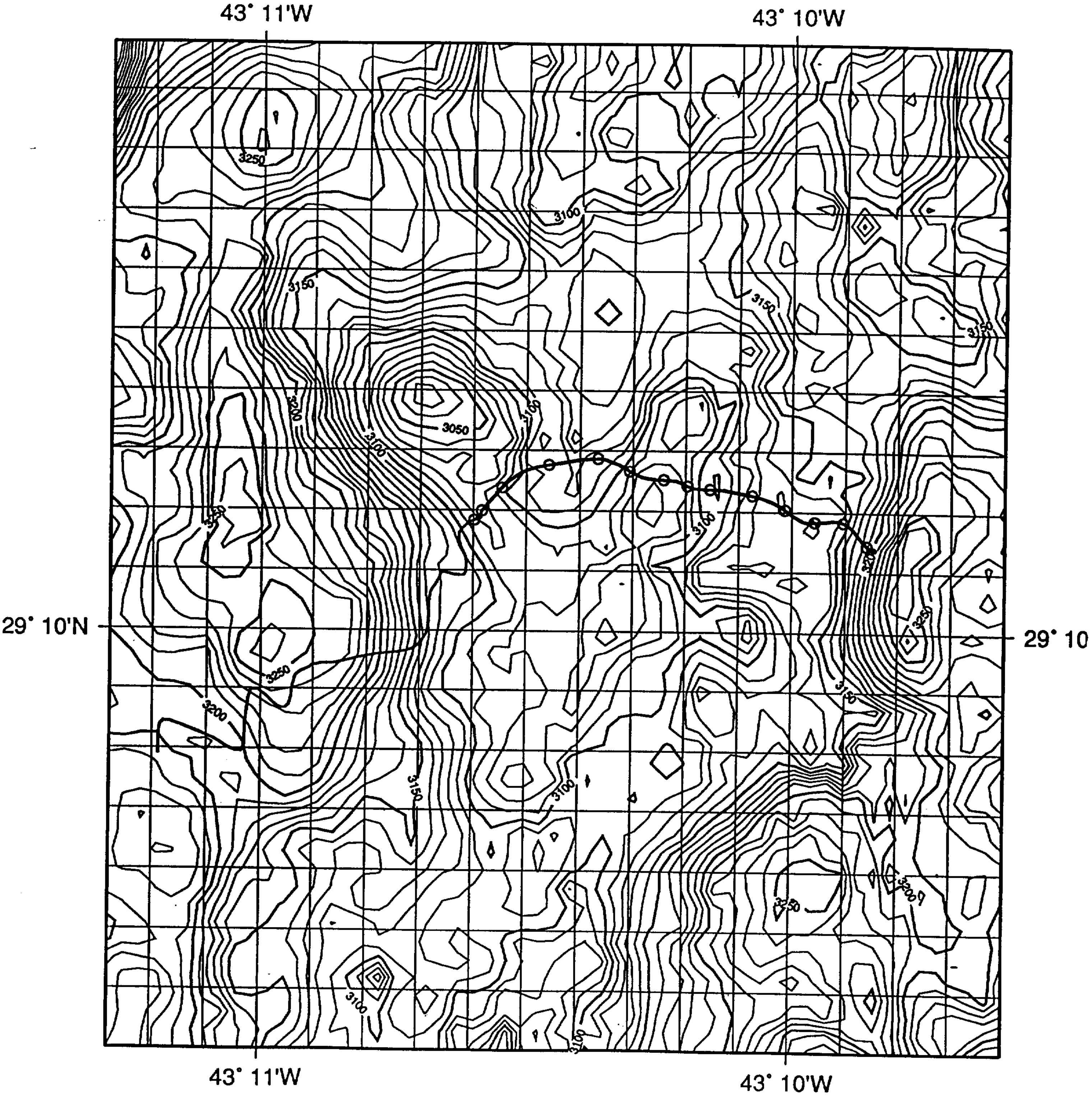
oooo ships track during bottom time 059/05:32 - 06:23

Track of Dredge No.3



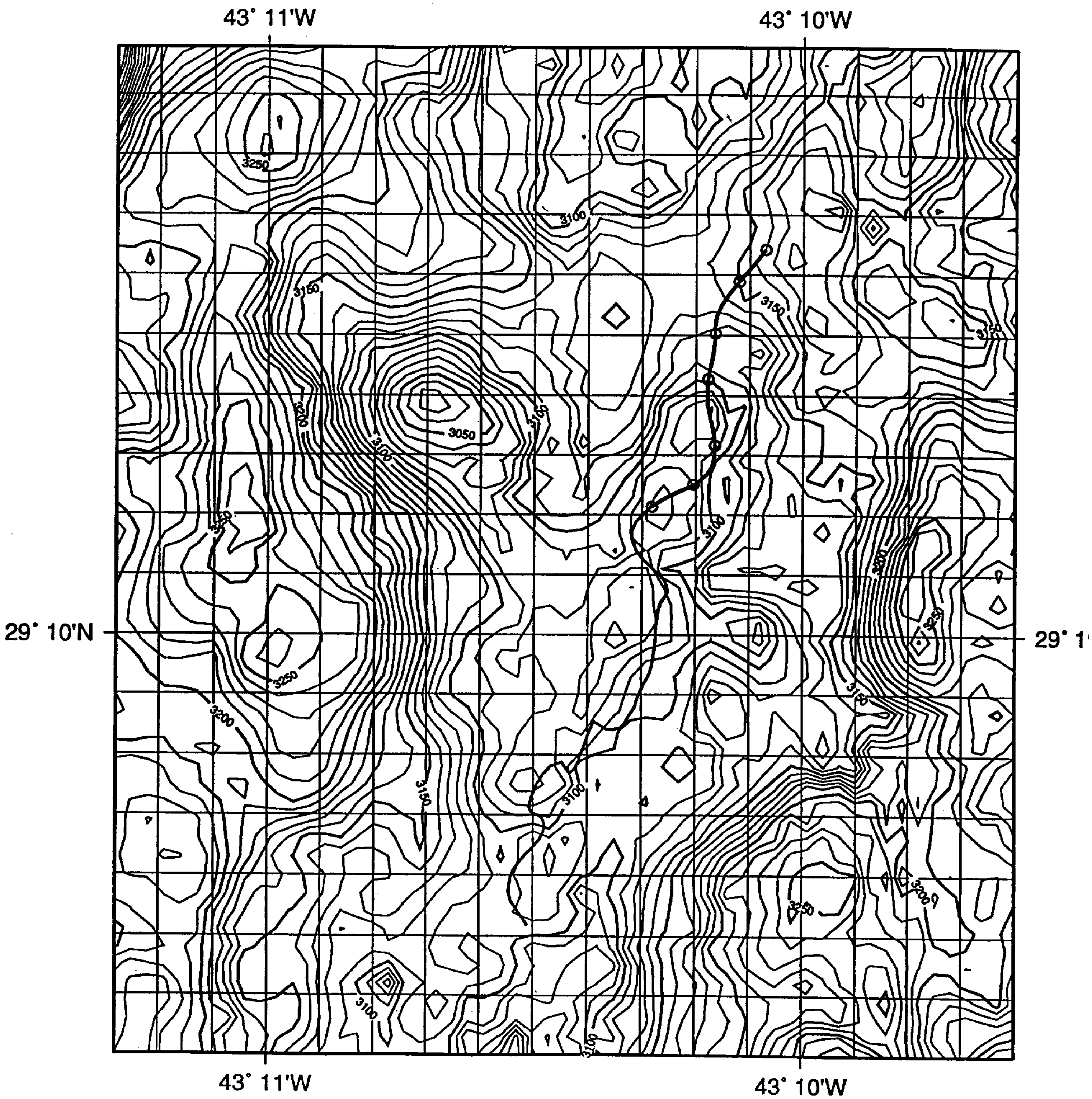
oooo ships track during bottom time 059/10:20 - 11:07

Track of Dredge No.4



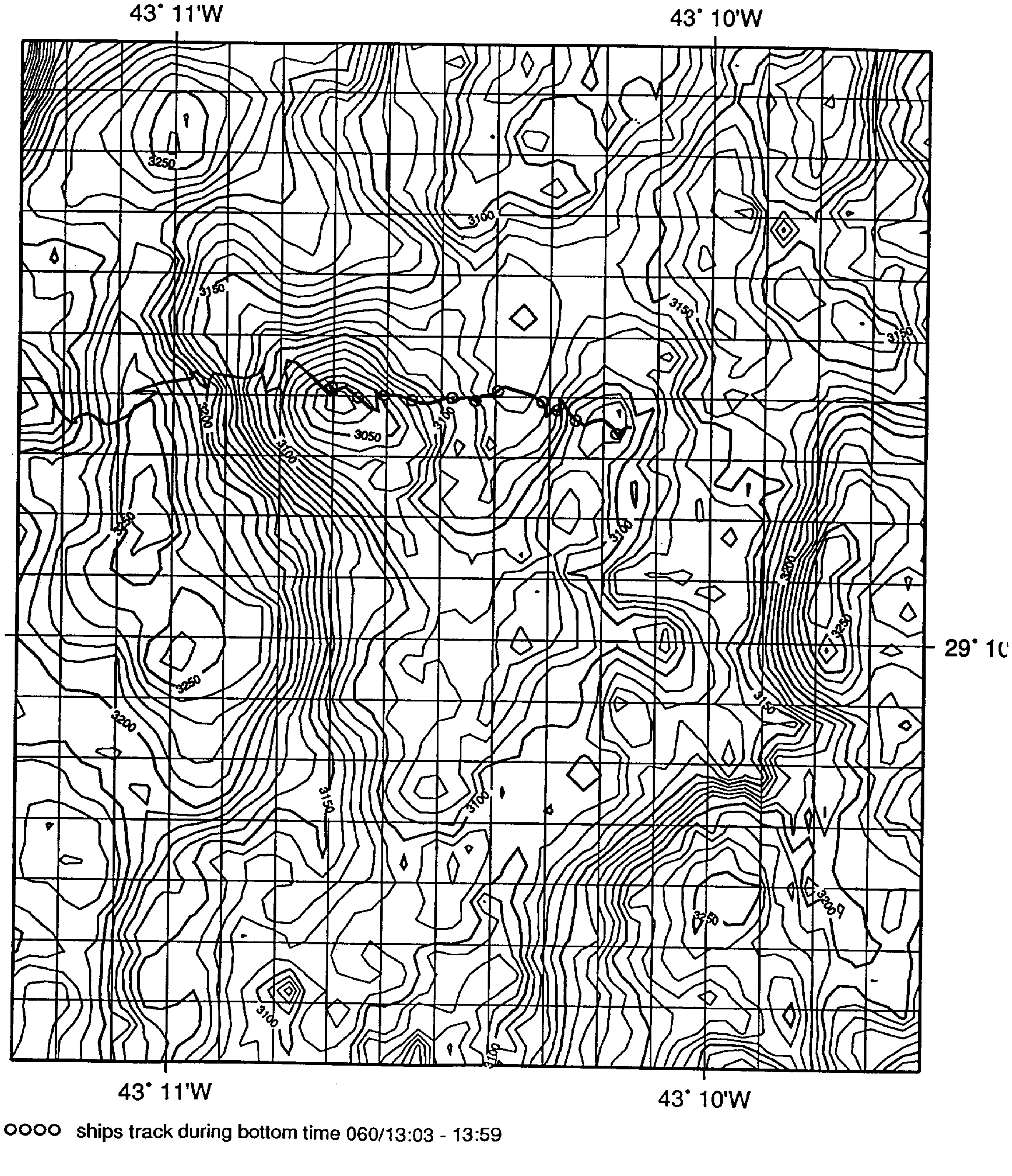
oooo ships track during bottom time 059/14:05 - 15:12

Track of Dredge No.5



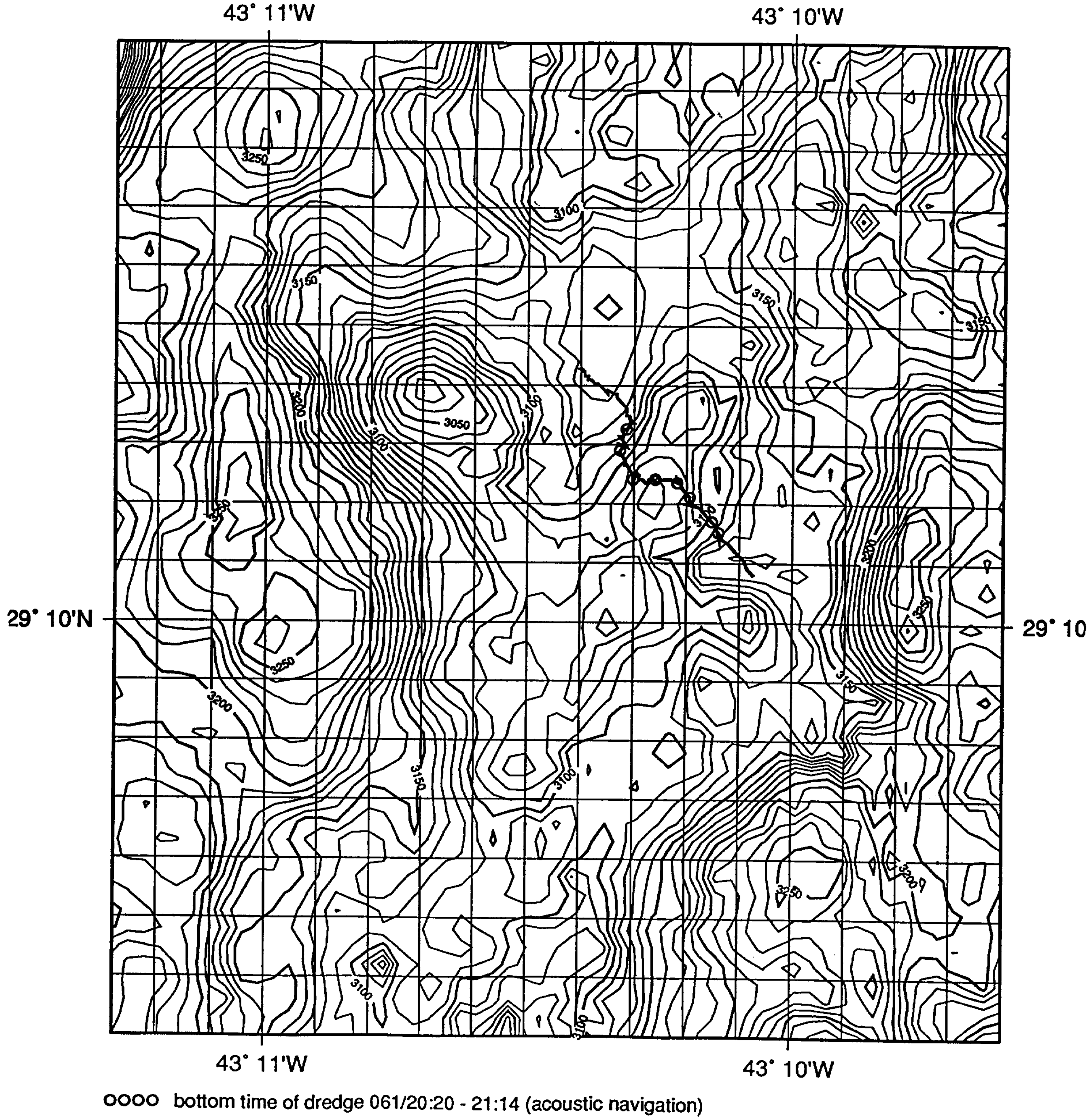
oooo ships track during bottom time 059/19:00 - 19:30

Track of Dredge No.6



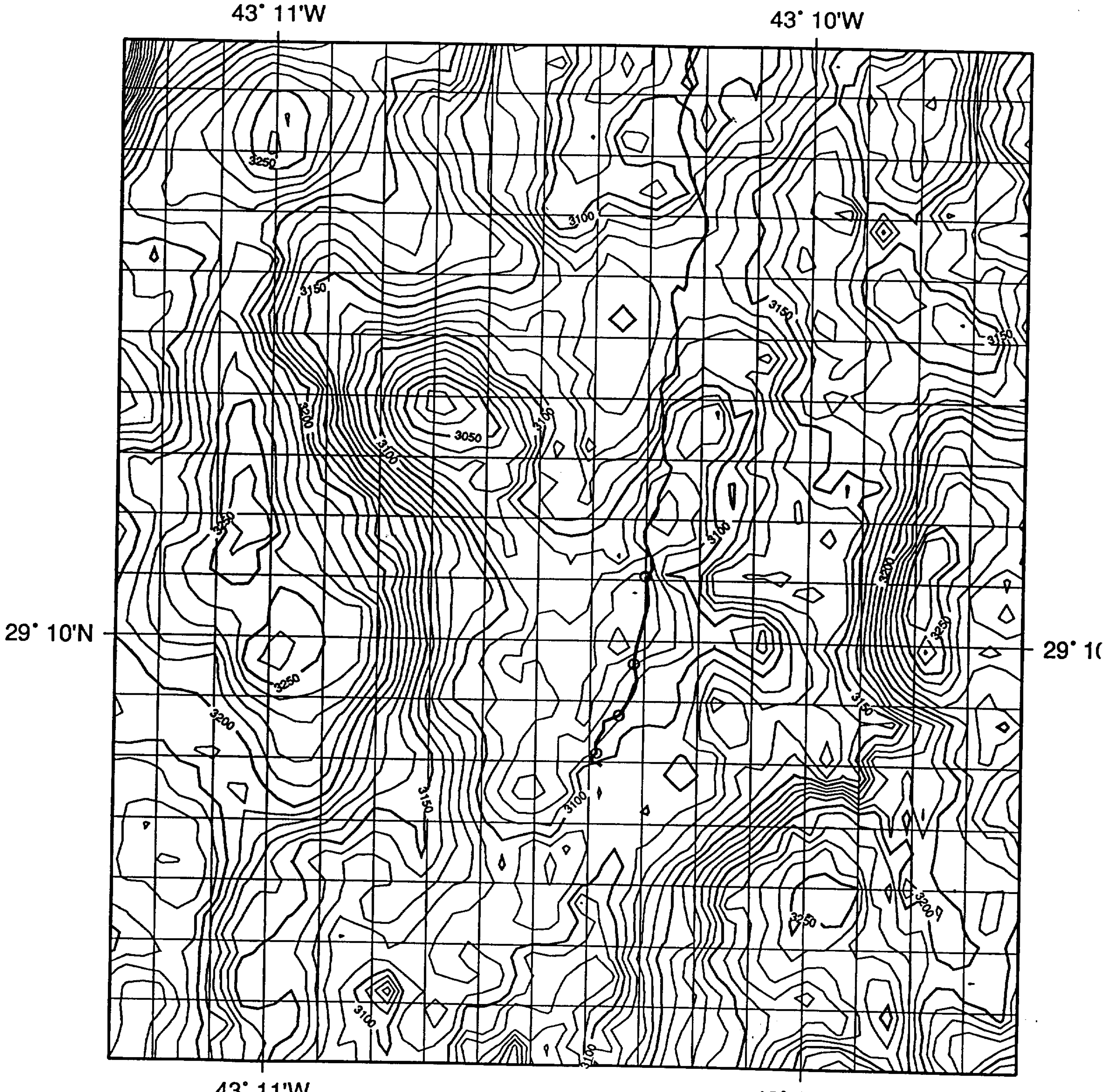
oooo ships track during bottom time 060/13:03 - 13:59

Track of Dredge No.7



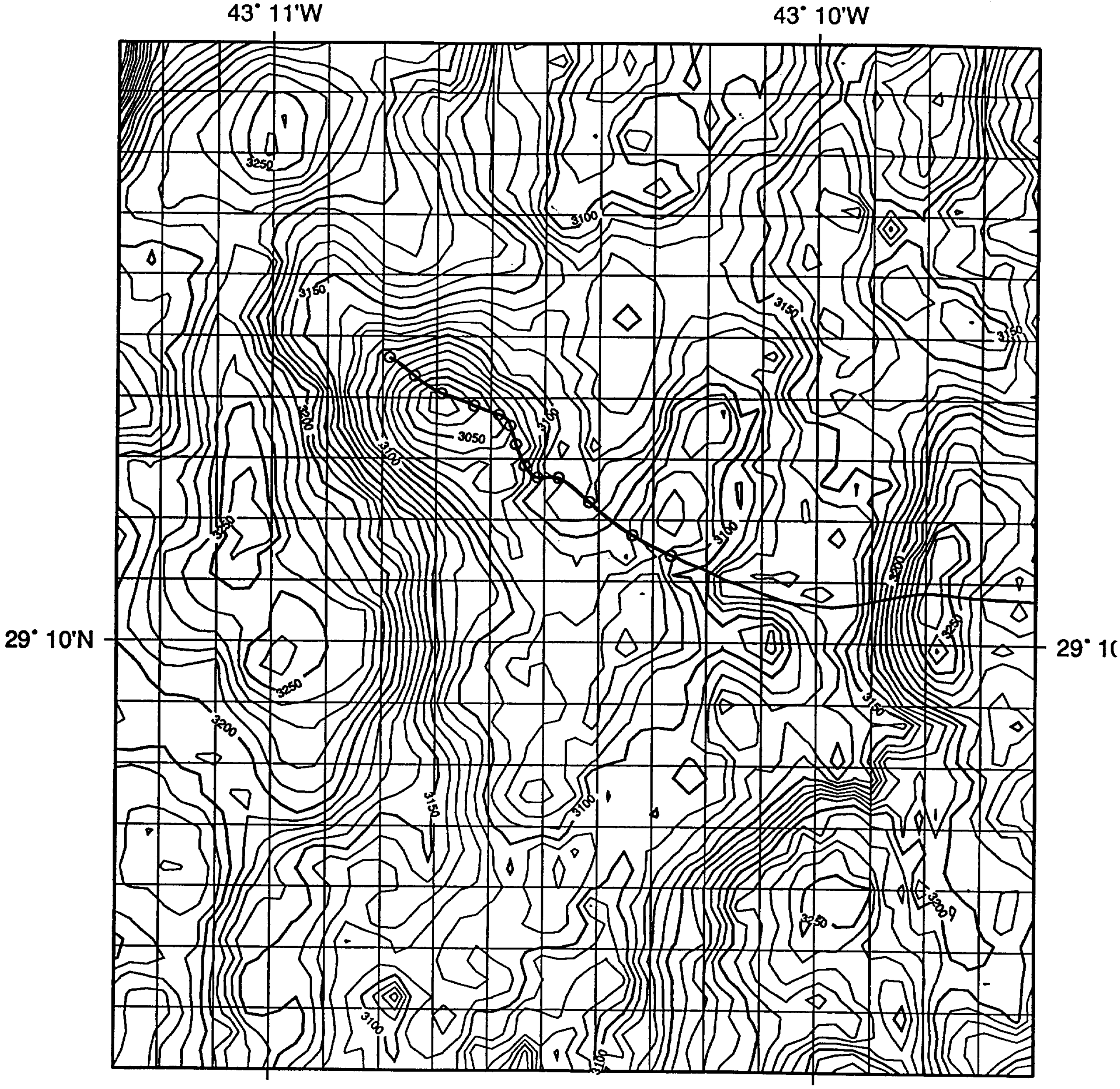
oooo bottom time of dredge 061/20:20 - 21:14 (acoustic navigation)

Track of Dredge No.8



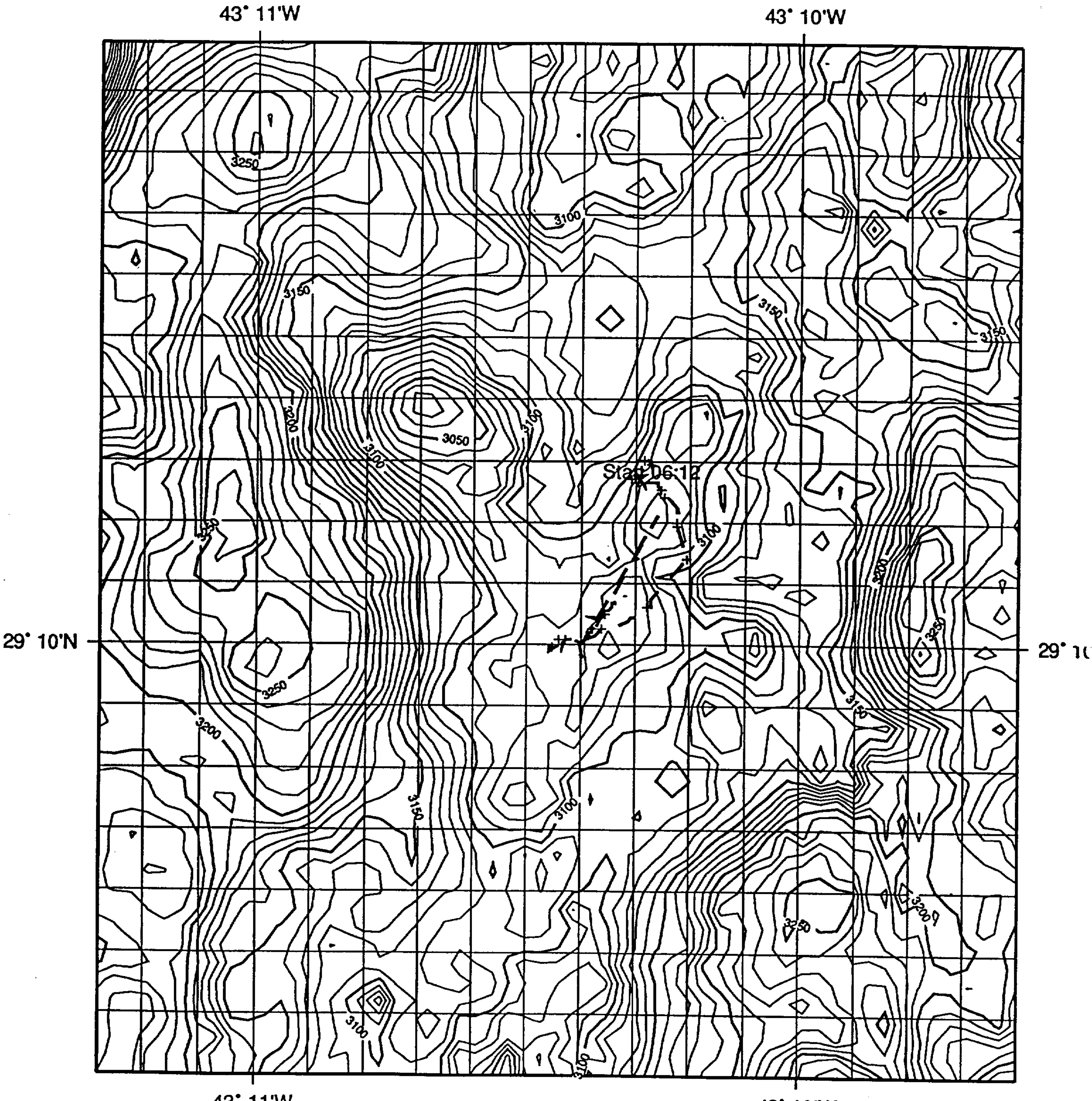
oooo ships track during bottom time 062/21:32 - 21:54

Track of Dredge No.9



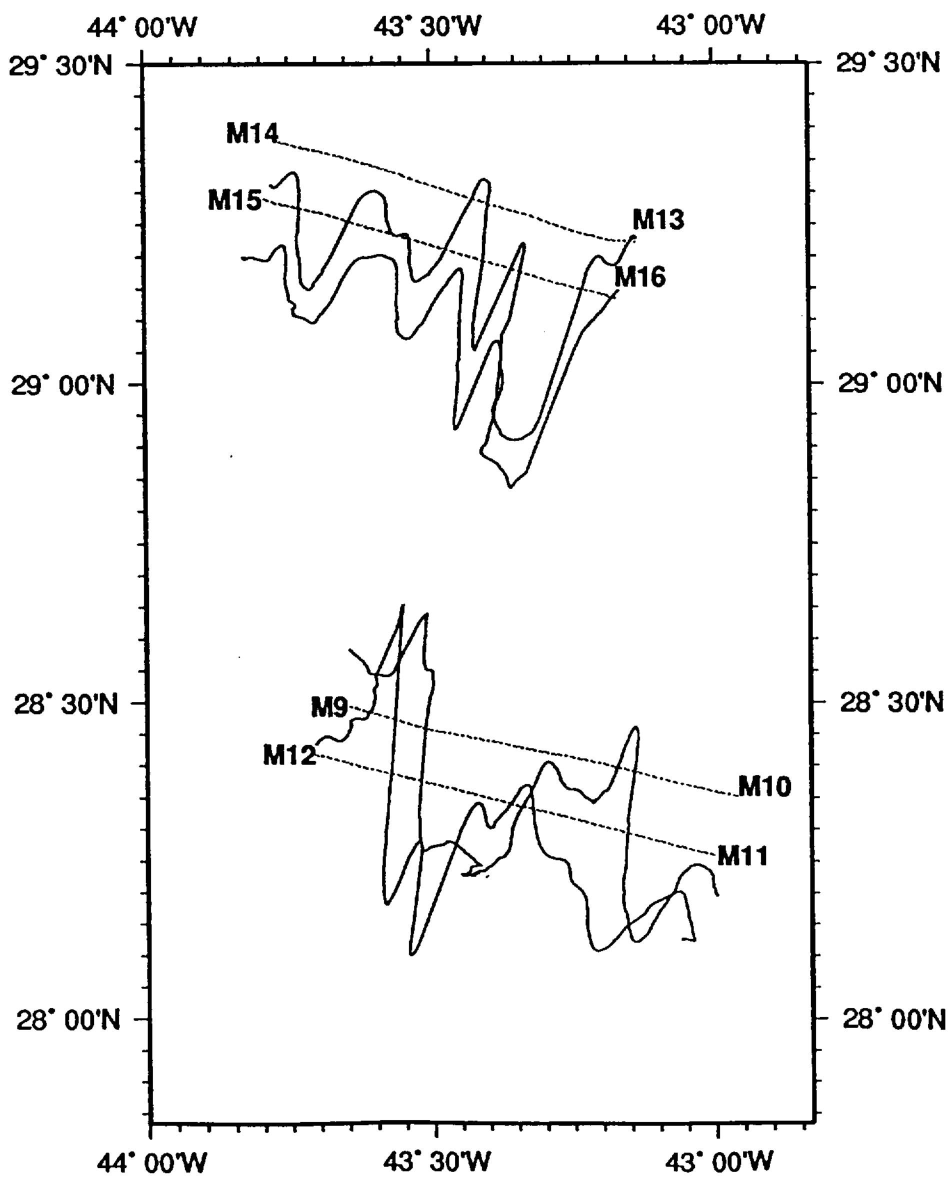
oooo ships track during bottom time 065/16:20 - 17:20

Track ZAPS-Sled No.14

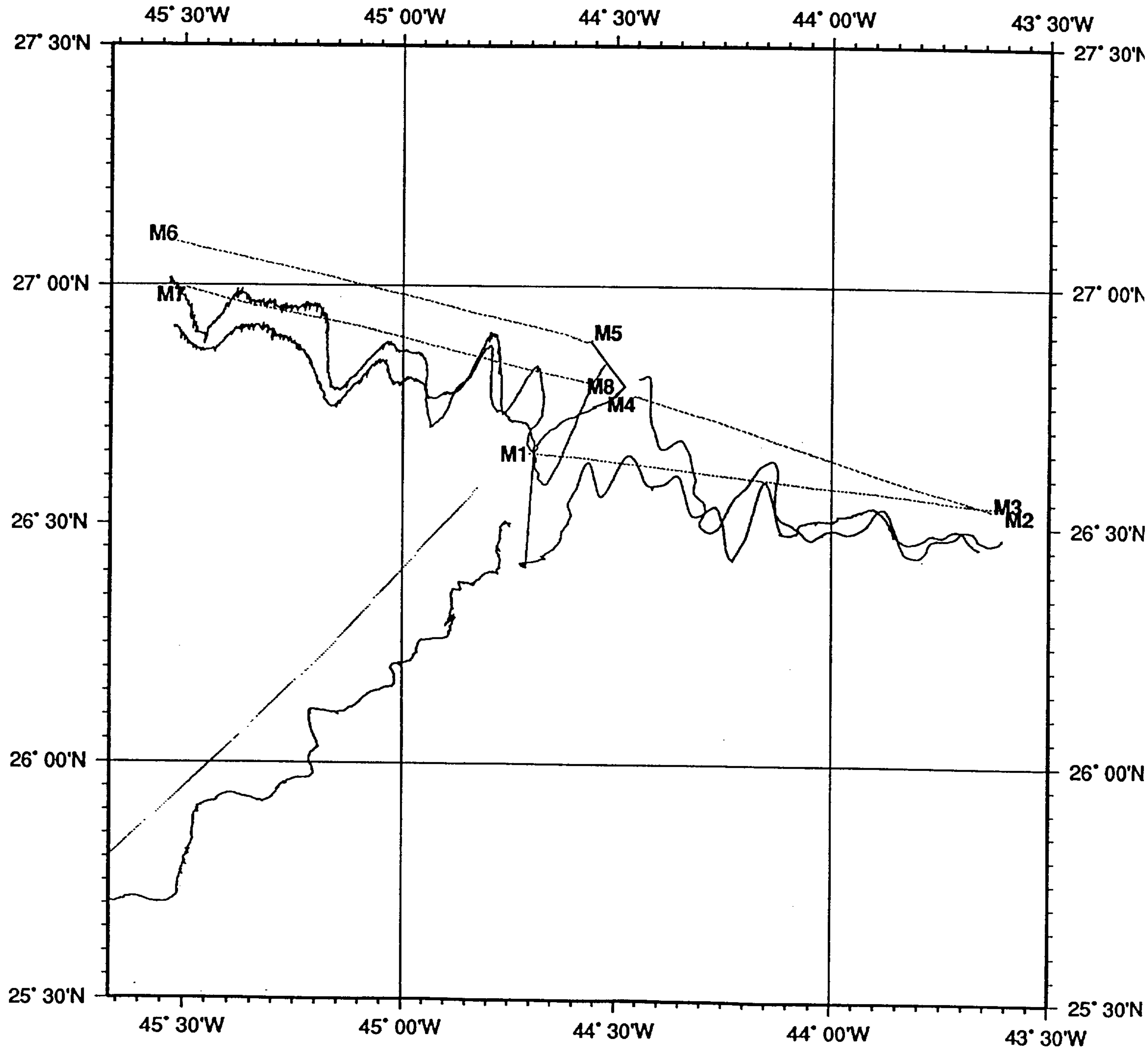


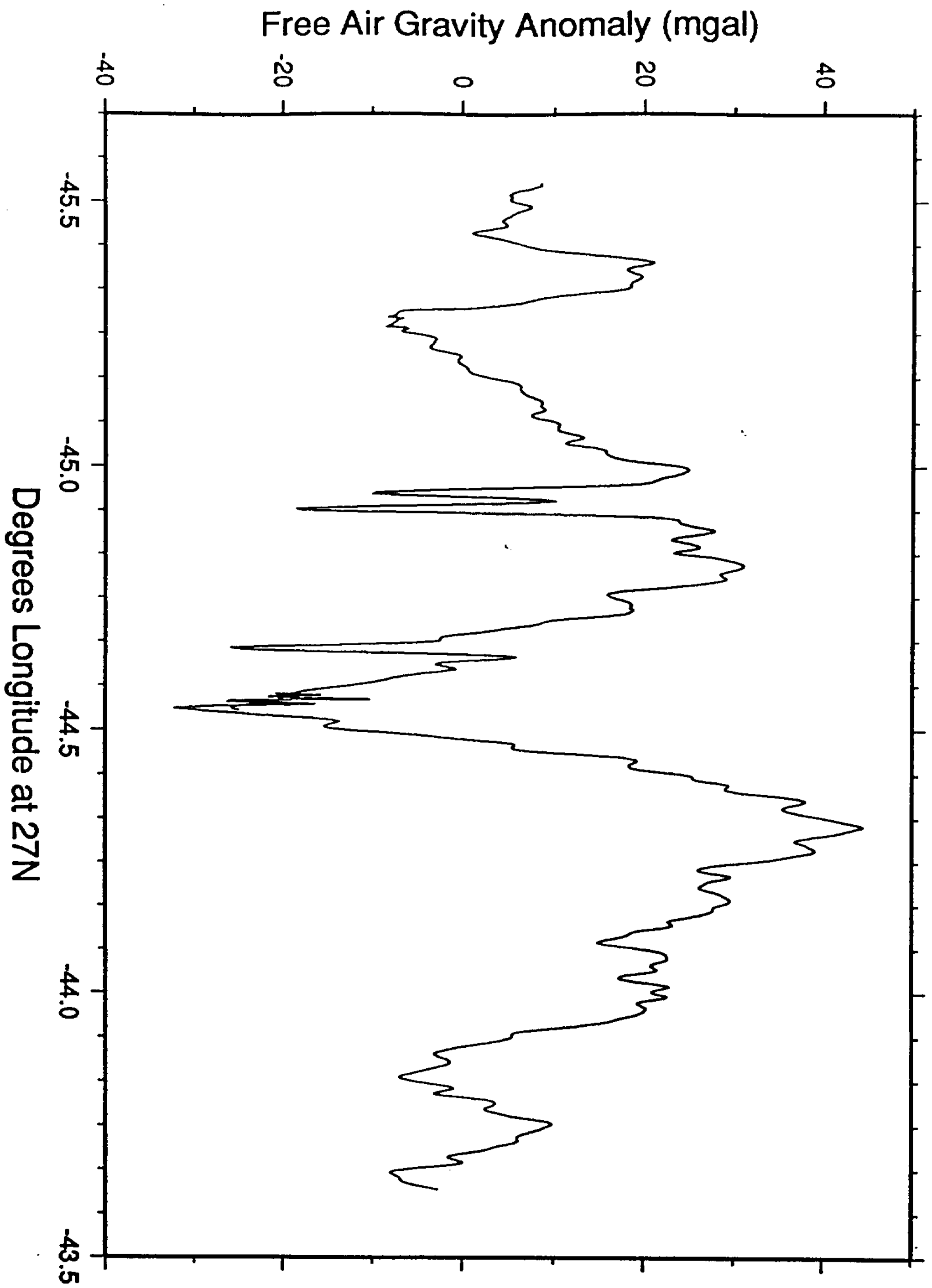
bottom time 061/06:12 - 08:40

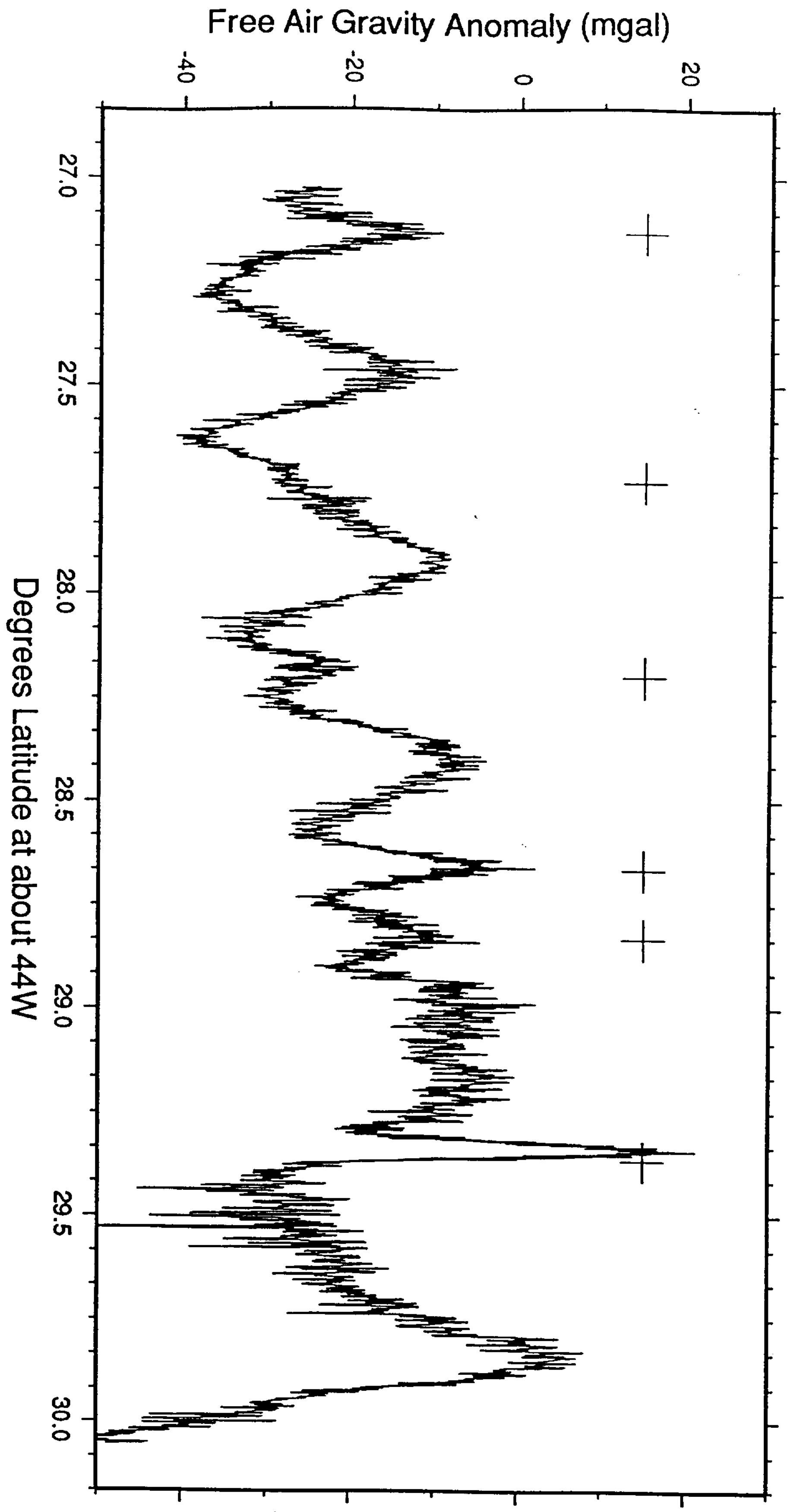
magnetic profiles (200nT/cm)



magnetic profiles (200nT/cm)




Free Air Gravity Anomaly (mgal)
-40
-20
0
20
40
Degrees Longitude at 27N
-45.5
-45.0
-44.5
-44.0
-43.5


Free Air Gravity Anomaly (mgal)
-40
-20
0
20
27.0
27.5
28.0
28.5
29.0
29.5
30.0
Degrees Latitude at about 44W