OCEAN DRILLING PROGRAM

LEG 106 SCIENTIFIC PROSPECTUS

BARE ROCK DRILLING IN THE KANE FRACTURE ZONE

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INTRODUCTION

Leg 106 of the Ocean Drilling Program will drill zero-age crust in the median valley of the Mid-Atlantic Ridge south of the Kane fracture zone. The leg will employ a specially designed bare rock guide base and use new drilling technology. The drillship JOIDES Resolution is scheduled to depart St. John's, Newfoundland on November 1 and to arrive in the drilling area after 6 days of transit. The leg will end in Malaga, Spain on December 27.

PREVIOUS STUDIES

The Kane fracture zone (Figure 1) was first identified by Sykes (1967) from the study of earthquake epicenters along the Mid-Atlantic Ridge at 23°N. Subsequent surface-ship bathymetric and magnetic surveys (van Andel and Bowin 1968; Fox et al., 1969; Purdy and Rabinowitz, 1978; Purdy et al., 1978; Rona and Grey, 1980; Karson and Dick, 1983) clearly defined the form of the fracture zone valley and the offset spreading axes (Figure 2). Magnetic anomalies show the Mid-Atlantic Ridge to be spreading at different rates to the north and south of the fracture zone. To the north, spreading is symmetrical at 1.4 cm/yr half rate, and to the south, asymmetrical at 1.7 cm/yr to the west and 1.1 cm/yr to the east (Purdy et al., 1978). Basalts have been recovered along the median valley walls, and variably deformed and metamorphosed gabbroic and ultramafic rocks have been found at both ridge-transform intersections and along the fracture zone walls (Melson et al., 1968; Miyashiro et al., 1969; 1970; 1971; van Andel et al., 1971; Dick et al., 1980; Bryan et al., 1981; Karson and Dick, 1983). Petrological and geochemical studies of basalts from the region (Melson et al. 1968; Bryan and Sargent 1978; Bryan et al. 1981) show them to be typical MORB's.

Seismic refraction data from the 120 km long rift valley segment immediately south of the Kane fracture zone reveal the presence of relatively normal crustal thicknesses (6-7 km) and upper mantle velocities of ~8 km/s (Purdy and Detrick, 1984) (Figure 3). No evidence was found for the presence of a large axial magma chamber in either the crust or upper mantle along this ridge segment. However, anomalous seismic velocities were found in the lower crust centered beneath the along-axis topographic high near $22^{\circ}55'$N (Figure 4) and interpreted as the remnants of the most recent phase of magmatic activity that has temporarily left behind a region of elevated temperatures and pervasive cracking. Anomalously thin crust has been reported from the eastern ridge-transform intersection and along the Kane fracture zone (Cormier et al., 1984; Detrick and Purdy, 1980).

This area has been the site of detailed Sea Beam (Detrick et al., 1984) and Sea MARC (Mayer et al., 1985) investigations aimed at establishing the tectonic framework of this ridge segment and identifying sites suitable for "bare-rock" drilling. Nearly complete Sea Beam and Sea MARC 1 coverage of the rift valley was obtained from $22^{\circ}44'$N to the Kane Transform. These data indicate the presence of an inner rift valley 10-15 km wide that is bounded by two 500 m high N-S trending scarps (Figure 5). The inner rift valley structure is complex with changes in both cross-section and depth along its length.

Several phases of rift valley development are evident. The earliest is a constructional phase resulting in strings of small valley-parallel volcanoes, most with broad summit plateaus and collapsed summit craters. During a later ongoing extensional stage these volcanoes are cut by valley-parallel faults and surrounded and partially buried by more recent fissure eruptions. The most recent volcanic activity appears to be associated with a several hundred meter high linear volcanic ridge which trends obliquely across the northern part of the rift valley. Evidence for recent hydrothermal activity was found along this ridge near 23°22'N (Kong et al., 1985).

SCIENTIFIC OBJECTIVES

ODP Legs 106 and 109 will concentrate on the first of the 12 COSOD top priority program recommendations: "processes of magma generation and crustal construction at mid-oceanic ridges" (COSOD, 1981).

The need to be able to spud-in on the bare rock of zero age crust at mid-ocean ridges has also been identified by COSOD. Specific questions to be addressed under these objectives are:

a) What is the origin, nature and evolution of oceanic crust at zero age in a slow spreading mid-ocean ridge environment?

b) What are the processes of magma generation and crustal accretion?

  1) Nature and relative abundance of parental and primitive melts, and their relation to 'evolved' basalts in time and space.

  2) Definition of magma 'batches' and associated small magma chambers; depth of chambers.

  3) Depth and extent of low-T alteration, of hydrothermal alteration, and nature of the transition between the two, presence of possible mineralization, effects of alteration on magnetic signature. When do these processes start affecting the crust?

  4) Nature of tilting and deformation at depth; effects on magnetic polarity.

  5) How does the crustal structure, rock type and physical properties of the rocks compare with inferences from seismic models and survey ship measurements.

The scientific objectives of the back-up program in the Kane fracture zone is to sample Layer 3 plutonics (mainly gabbros) and, possibly, oceanic mantle ultramafics.

Three possible bare-rock drill sites were identified during the recent Sea MARC 1 site survey of this area, and their positions marked by commandable beacons (Sites 1-3 in Figure 5). Details of the sites, as described by Detrick et al. (1985), are as follows.

Beacon Site 1 (Eastern Site)

Beacon Site 1 is located about 37 km south of the ridge-transform intersection at the bottom of the eastern rift valley wall (Figure 5). The site is situated on a lobate basalt flow which appears to have erupted into the median valley from a source near, or close to, the eastern scarp (Figures 6a and 6b). The site offers an area approximately 1 km^2 of very smooth sea floor composed of flows partly obscured by thin sediment cover (Figures 6c and 6d). Relief is in the order of less than 1 meter according to bottom photographs. These photographs also show that the surface is void of faulting and clearly indicates that the flows are the result of an off-axis volcanic eruption.

This site is attractive in so far as the site offers the least risk of encountering fissures or faults near to the surface, and requires the least effort in positioning the ship to deploy the bare-rock guide base. Scientifically, this site would allow the sampling of an off-axis, post-tectonic flow, and the underlying volcanics, which were presumably erupted at the spreading axis and subsequently rifted. However, the site is clearly not "zero-age" (the central magnetic anomaly is located well to the west, see Figure 6e) and it could be argued that this tectonic setting has been previously drilled at the near-axis DSDP Sites 395 and 396 (Figure 2). The site is also located in a seismically anomalous transition zone between thinner crust to the north and more normal thickness crust to the south (Figure 3).

Beacon Site 2 (Southern Site)

Beacon Site 2 is located in the shallowest portion of the median valley floor about 70 km south of the ridge-transform intersection (Figure 5) on the smooth rim of the summit plateau of a small axial volcano (Figures 7a and 7b). This is one of a string of small, valley-parallel axial volcanoes that were identified on the Sea MARC 1 records. A small crater lies at the center of the structure whose floor lies about 50 m below the rim (Figure 7c). The Sea MARC 1 records show that the western side of the volcano has been disrupted by four N-S trending faults which have been partially buried by later flows (Figures 7d and 7e). The apron of this and neighboring volcanoes cover some valley floor fissures and suggests that the volcanic activity which formed these structures must be predominantly post-tectonic. Bottom photographs show the summit area to be constructed of sheet flows with "pahoehoe" textures. Small collapse features are present with talus consisting of tabular roof rock associated with former low relief, hollow volcanic blisters.

Drilling of this site is scientifically attractive in so far as it is located in the middle of the median valley, far from the Kane fracture zone, and associated with simple, symmetric magnetic anomalies (Figure 7f). Dredge samples from this area show the basalts to be petrographically and geochemically MORB. Seismic refraction studies indicate the presence of a zone of lowered velocities at depth beneath the area that may be associated with a magma injection zone (Figure 3). The site, however, could be difficult to drill as there is a relatively high chance of encountering talus in the subsurface formed by the collapse of lava tubes. The site is also not located on the most recent surficial flows, and, as such, is not technically "zero-age".

Beacon Site 3 (Northern Site)

Beacon Site 3 is situated about 25 km south of the ridge-transform intersection (Figure 5) near the crest of a NNE-trending linear volcanic ridge (Figures 8a and 8b). The ridge is composed of bulbous-shaped flows with steep flow fronts that have shed large amounts of talus. The Sea MARC 1 records show an anomalously smooth area on the ridge crest (Figures 8c and 8d). Bottom photographs reveal a pocket of sediment of clear hydrothermal origin populated by members of a hydrothermal biological community (crabs, worms, etc.).

This site is closest to being "zero-age" and offers the opportunity to drill into what appears to be an active hydrothermal system. It also lies in the middle of the central magnetic anomaly (Figure 8e). Although of great scientific interest, this site would be the most difficult to locate a bare-rock guide base in as the target is extremely small. Furthermore, the presence of a narrow belt of fissures along the crest of the ridge suggest that the subsurface may contain rubble that has filled fissures and voids, although this may have been cemented by the circulating hydrothermal fluids.

Back-up Sites

Two back-up sites have been proposed: Site 4 is located in the nodal basin deep at the eastern intersection of the Mid-Atlantic Ridge median valley and Kane fracture zone, and Site 5 in the eastern non-transform section of the fracture zone valley (Figure 2).

The scientific objective of drilling at these sites is to sample oceanic crust within or proximal to a fracture zone associated with a ridge-ridge transform fault. This forms a high priority objective in both the COSOD Report (1981) and the IPOD France Scientific Committee on deep drilling objectives (1983). Drilling in the fracture zone would have a realistic possibility of sampling <u>in situ</u> upper mantle. Early geophysical studies by Detrick and Purdy (1980) have shown the crust beneath the north wall of the fracture zone to be as thin as 2 km in some places. More recent seismic studies have shown the crust to be of a similar thickness at the eastern nodal basin ridge-transform intersection (Cormier et al., 1984). The presence of thin crust is also supported by the gravity and bathymetric profiles described by Louden and Forsyth (1982), although their evidence suggests thin crust occurs only in local areas.

DRILLING PROGRAM

The aim of Leg 106 is to drill a single bare-rock re-entry hole in zero-age crust in the median valley of the Mid-Atlantic Ridge in the area south of the Kane fracture zone. The southern site (Beacon Site 2) has been selected as the prime drilling target for this leg. As this will be the first deployment of the bare-rock guide base, site selection was governed by having to choose a site of scientific interest which offered the best chances of success for deploying the guide base. The northern site (Beacon Site 3), although of considerable scientific interest, would be the most difficult to place the guide base, and consequently, the site forms the second prime target. The eastern site (Beacon Site 1) is not of zero-age and would only be drilled if surveys of the other two done by JOIDES Resolution, show them to be unsuitable for drilling.

Depending on the success of guide base deployment and subsequent drilling, Leg 106 might proceed in one of a number of ways. Under ideal circumstances, a single hole will be drilled to the maximum depth that time allows, following the successful deployment of the bare-rock guide base at the southern site. If deployment or drilling should fail as a result of poor geological conditions, a second bare-rock guide base will be deployed either at the same site, or alternatively, at the northern site (Beacon Site 3). If deployment or drilling should fail however, due to problems with engineering design or materials, then the ship will move to the primary back-up site located in the nodal basin. Here a standard sedimentary re-entry cone will be set, and as deep a hole as possible drilled in the time remaining. Drilling in the nodal basin would require a survey of the area to determine sediment bottom thicknesses. This would have to be done by the Resolution using a 3.5 kHz source mounted on the bottom of the drill string, with a receiver on the ship. Should sediment cover be too thin, then a site along the non-transform section of the fracture zone would be chosen from detailed Sea Beam maps (Detrick et al., 1984) and seismic reflection profiles of the area (Collins et al., 1984), to act as a final back-up site for drilling. Collins et al. (1984) report numerous sediment ponds in this region up to 200 meters in thickness.

Under ideal circumstances, Leg 106 might proceed as follows. Once the ship arrives at the prime target, the summit plateau and immediate areas will be surveyed in detail using real-time television and Mesotech sonar images, so as to identify a precise target for bare-rock guide base deployment. The base will be deployed following carefully worked out procedures and will be permanently cemented to the ocean floor prior to the commencement of drilling. The hole will be cased to a total depth of about 100 m sub-bottom through basement which is anticipated to contain large amounts of rubble and to be highly fractured. This should ensure that the hole remains open for later re-entry and further drilling during Leg 109. Current estimates predict a total penetration into basement, assuming that no serious problems are encountered during bare-rock guide base deployment or drilling, to a total depth of about 330 meters.

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Kane Fracture Zone

Location of Proposed Sites

Site[a] Number	Latitude	Longitude	Water Depth	Penetr.	Operations	Objectives
1	$23^{O}15.1'N$	$44^{O}53.2'W$	3870m	1000m+	Rotary coring/ re-entry Logging	Investigate lobate basalt flow lying against eastern rift valley wall
2	$22^{O}55.45'N$	$44^{O}56.80'W$	3312m	1000m+	Rotary coring/ re-entry Logging	Investigate flat-topped volcano and caldera located to west of ridge axis
3	$23^{O}22.15'N$	$44^{O}57.15'W$	3435m	1000m+	Rotary coring/ re-entry Logging	Investigate hydrothermally active area on ridge axis
4	$23.6^{O}N$	$44.9^{O}W$	6200	<200m	Rotary coring/ re-entry	Investigate oceanic basement beneath east nodal basin of KFZ
5	$23.4^{O}N$	$43.4^{O}W$	4000-5000m	<200m	Rotary coring/ re-entry	Investigate oceanic basement beneath east non-transform section of fracture zone valley

[a] Alternative site names:

1 Eastern Site
2 Southern Site
3 Northern Site
4 Nodal Basin Site
5 Eastern Transform Site

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Kane Fracture Zone

Site Occupation Schedule

Site	Location	Travel Time (Days)	Drilling Time (Days)	Departure Date (Approximate)
	Depart: St. Johns			1 November 1985
	Underway	6.2		
2[a] (Southern)	22°55.45'N 44°56.80'W		40.5	18 December 1985
3[a] (Northern)	23°22.15'N 44°57.15'W			
	Underway	9.3		
	Arrive: Malaga			27 December 1985
		15.5		57 days

Alternate Sites:

1[b] (Eastern)	23°15.1'N 44°53.2'W
4[c] (N. Basin)	23.6°N 44.9°W
5[c] (Transform)	23.4°N 43.4°W

[a] The Southern Site (2) forms the prime target for drilling. Failure of operations due to geological considerations will result in deployment of a second bare-rock guide base at the Northern Site using residual time.

[b] The Eastern Site will only be drilled if surveys of the prime drilling targets show them to be unsuitable for drilling.

[c] One site to be drilled if guide base deployment or drilling operations at the prime sites are unsuccessful due to non-geological reasons. The Nodal Basin Site (4) is first priority.

FIGURE CAPTIONS

1. Map showing the location of the Kane fracture zone (KFZ) and DSDP Sites 359 and 396.

2. Bathymetric map of the KFZ. Contour intervals at 500 m. Depths greater than 4000 m are shaded. Location of the Mid-Atlantic Ridge shown by diagonal lines. Prime drill sites are numbers 2 and 3, back-up sites are 1, 4, and 5. Locations of DSDP Sites 395 and 396 are shown. (After Detrick and Purdy, 1980)

3. Seismic crustal structure of the Mid-Atlantic Ridge rift valley south of the Kane Fracture Zone from Purdy and Detrick (in press) with location of beacon sites superimposed.

4. Along axis profile of the median valley in Figure 2, showing relation of drill sites to possible minor transforms at about 22° 40'N and 23° 12'N. The median valley high overlies the seismically defined low-velocity zone and is the most likely locus of current magmatic upwelling.

5. Detailed bathymetry of Mid-Atlantic Ridge median valley south of the Kane fracture zone, showing position of drill sites.

6. Beacon Site 1 (Eastern site)
   a. 20 m contoured bathymetry of site showing location of the beacon.
   b. Sea MARC 1 and camera track coverage.
   c. High resolution near-bottom bathymetry record near the beacon site. Processed sub-bottom pinger record for Sea MARC 1 2 km swath width profile.
   d. Interpreted Sea MARC 1 image across the beacon site; 2 km swath width.
   e. Magnetic anomaly and center beam bathymetry profiles across the rift valley in this area.

7. Beacon Site 2 (Southern site)
   a. 20 m contoured bathymetry of site showing location of the beacon.
   b. Sea MARC 1 and camera track coverage.
   c. High resolution near-bottom bathymetry record near the beacon site. Processed sub-bottom pinger record from Sea MARC 1 swath width profile showing collapsed center 50 m below summit plateau.
   d. Interpreted Sea MARC 1 image across the beacon site; 2 km swath width.
   e. Interpreted Sea MARC 1 image across the beacon site; 5 km swath width.
   f. Magnetic anomaly and center beam bathymetry profiles across the rift valley in this area

8. Beacon Site 3 (Northern site)
   a. 20 m contoured bathymetry of site showing location of beacon.
   b. Sea MARC 1 and camera track coverage.
   c. High resolution near-bottom bathymetry record from Sea MARC 1 2 km swath width profile. A flat bench area can be seen near the crest of the ridge.
   d. Interpreted Sea MARC 1 image across the beacon site along axial high; 2 km swath.
   e. Magnetic anomaly and center beam bathymetry profiles across the rift valley in this area

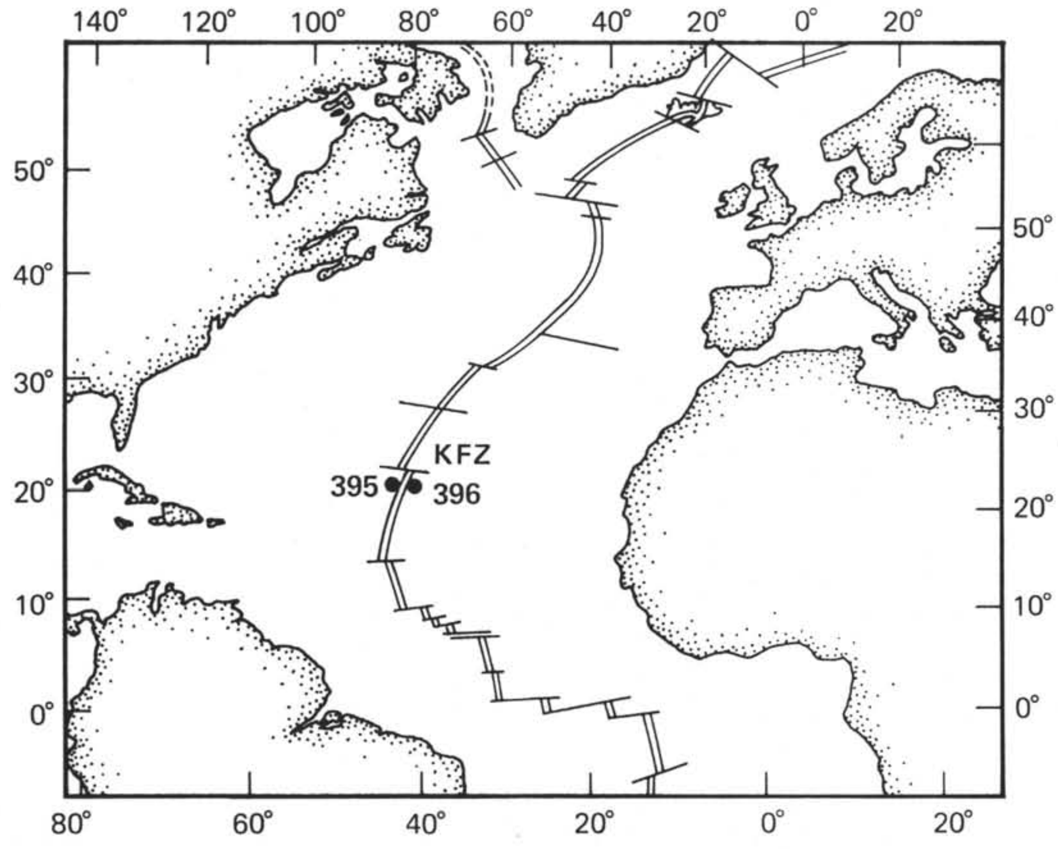
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Figure 1

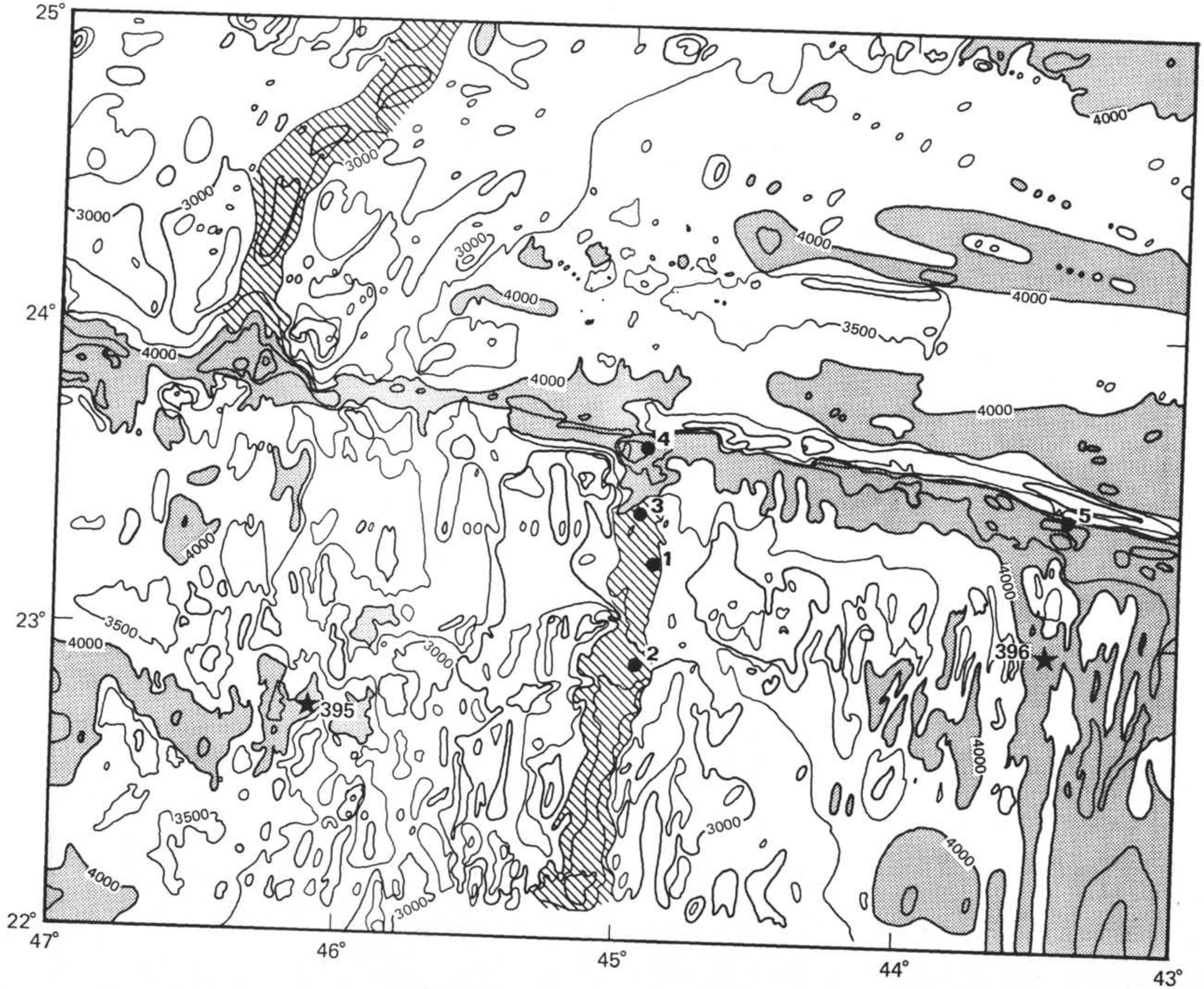

Figure 2

Figure 2
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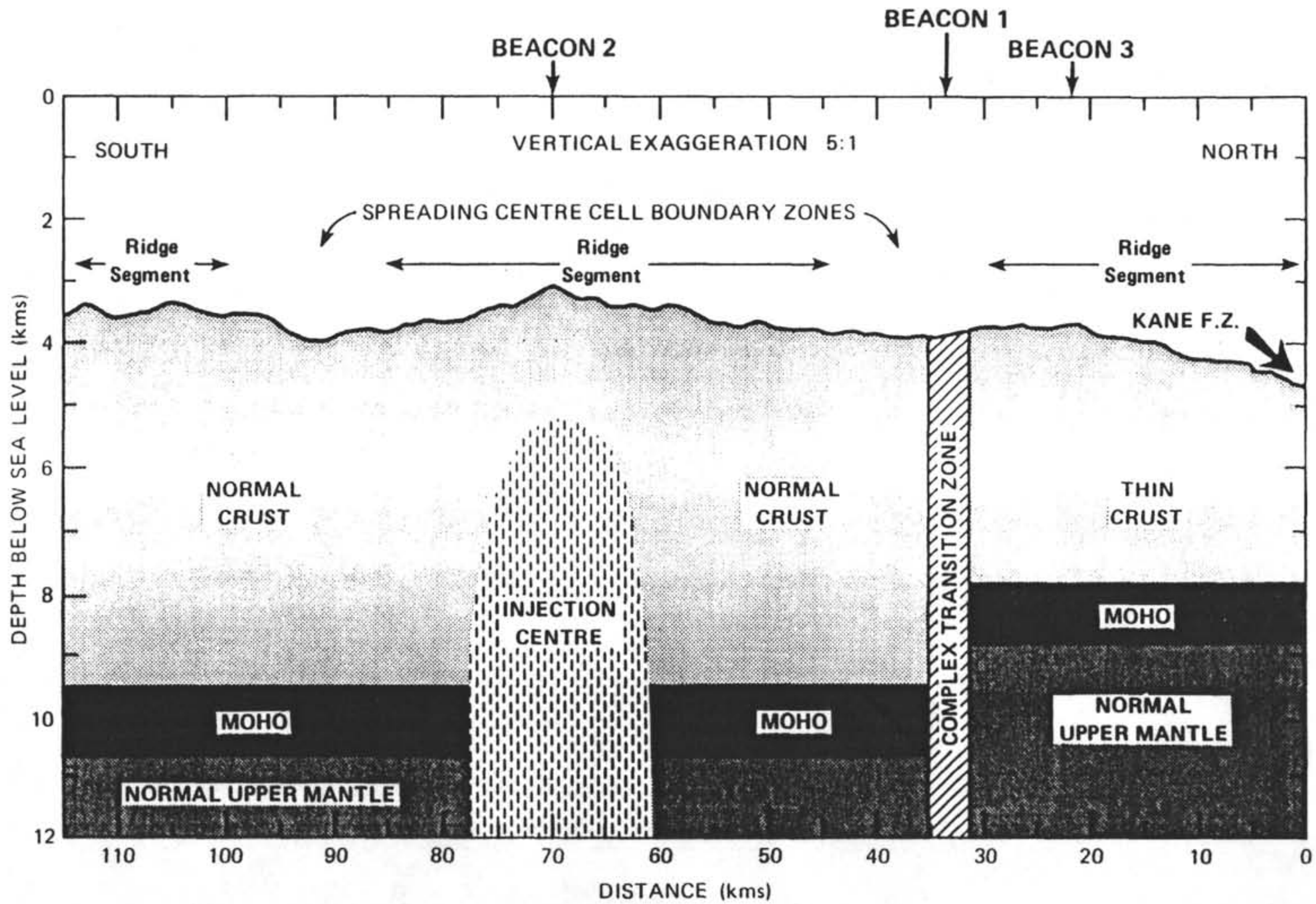


Figure 3

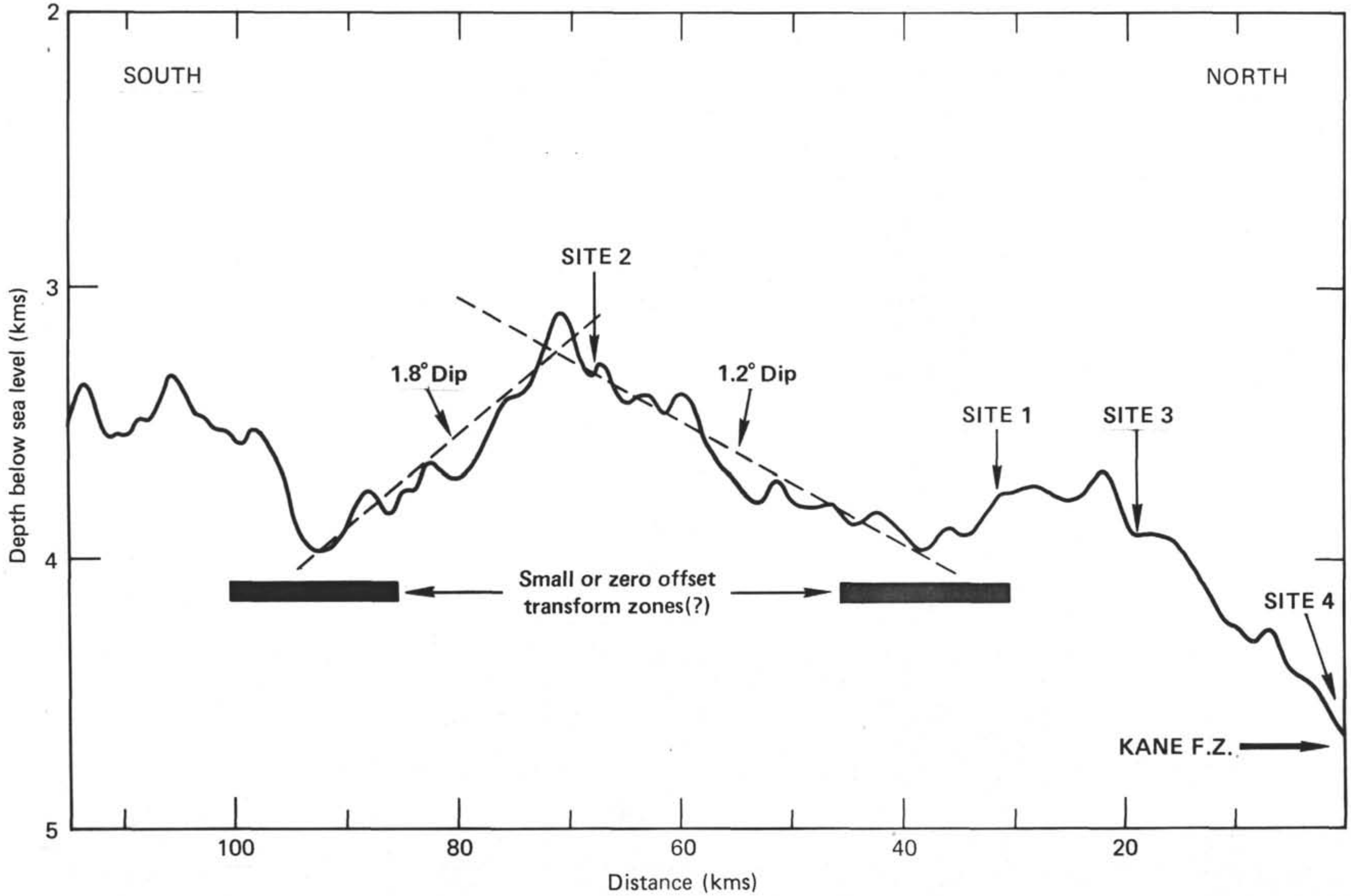
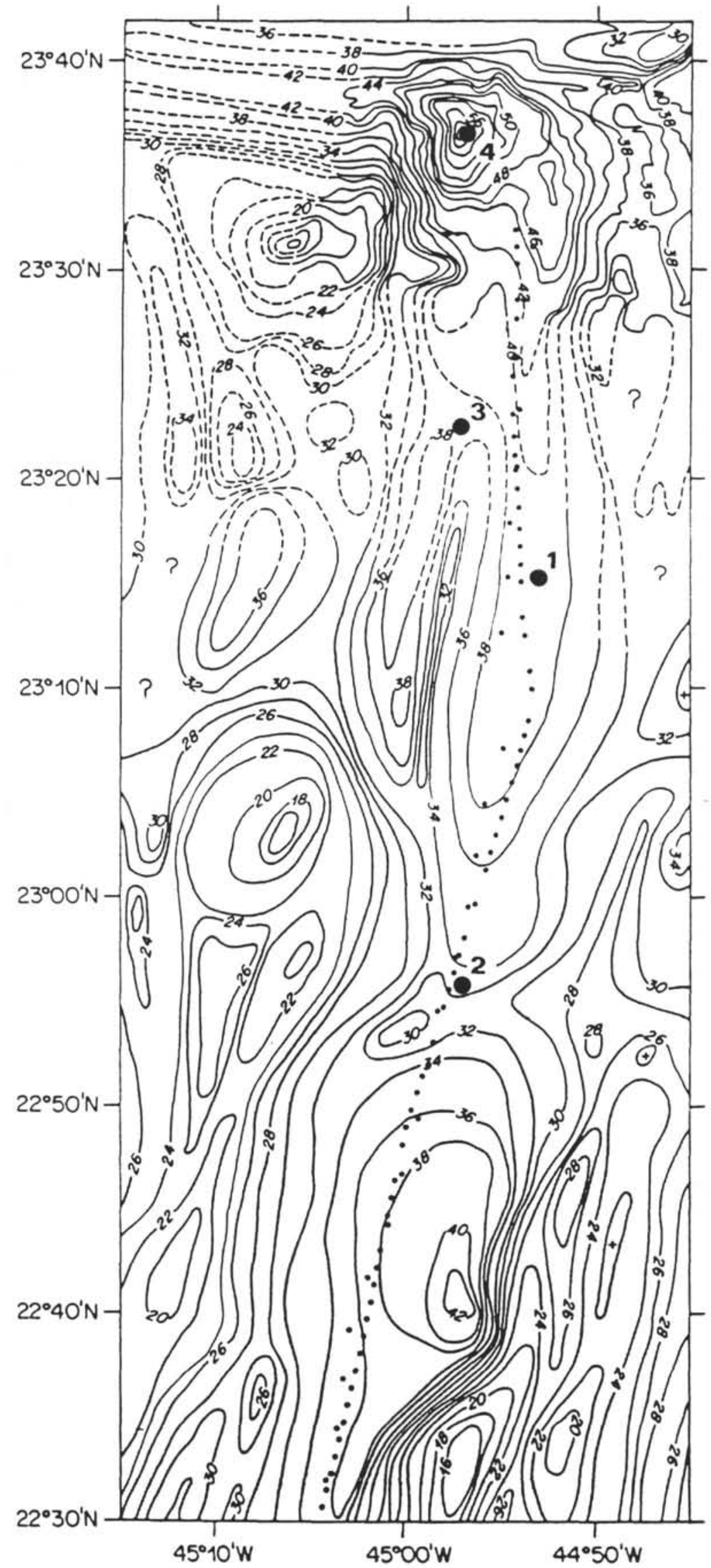
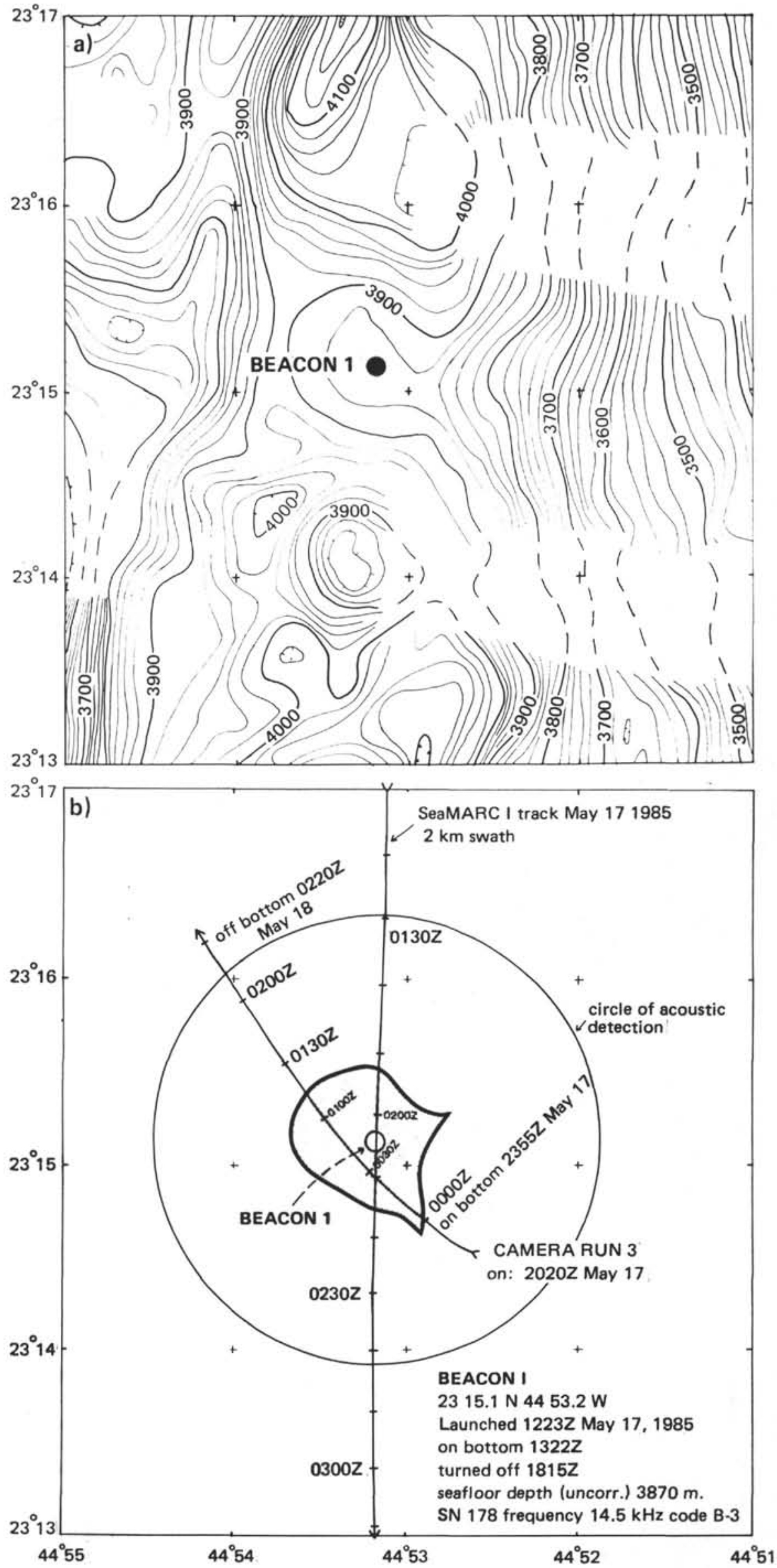

2
3
4
5
Depth below sea level (kms)
SOUTH
NORTH
SITE 2
1.8° Dip
1.2° Dip
SITE 1
SITE 3
SITE 4
Small or zero offset
transform zones(?)
KANE F.Z.
100
80
60
40
20
Distance (kms)

Figure 4

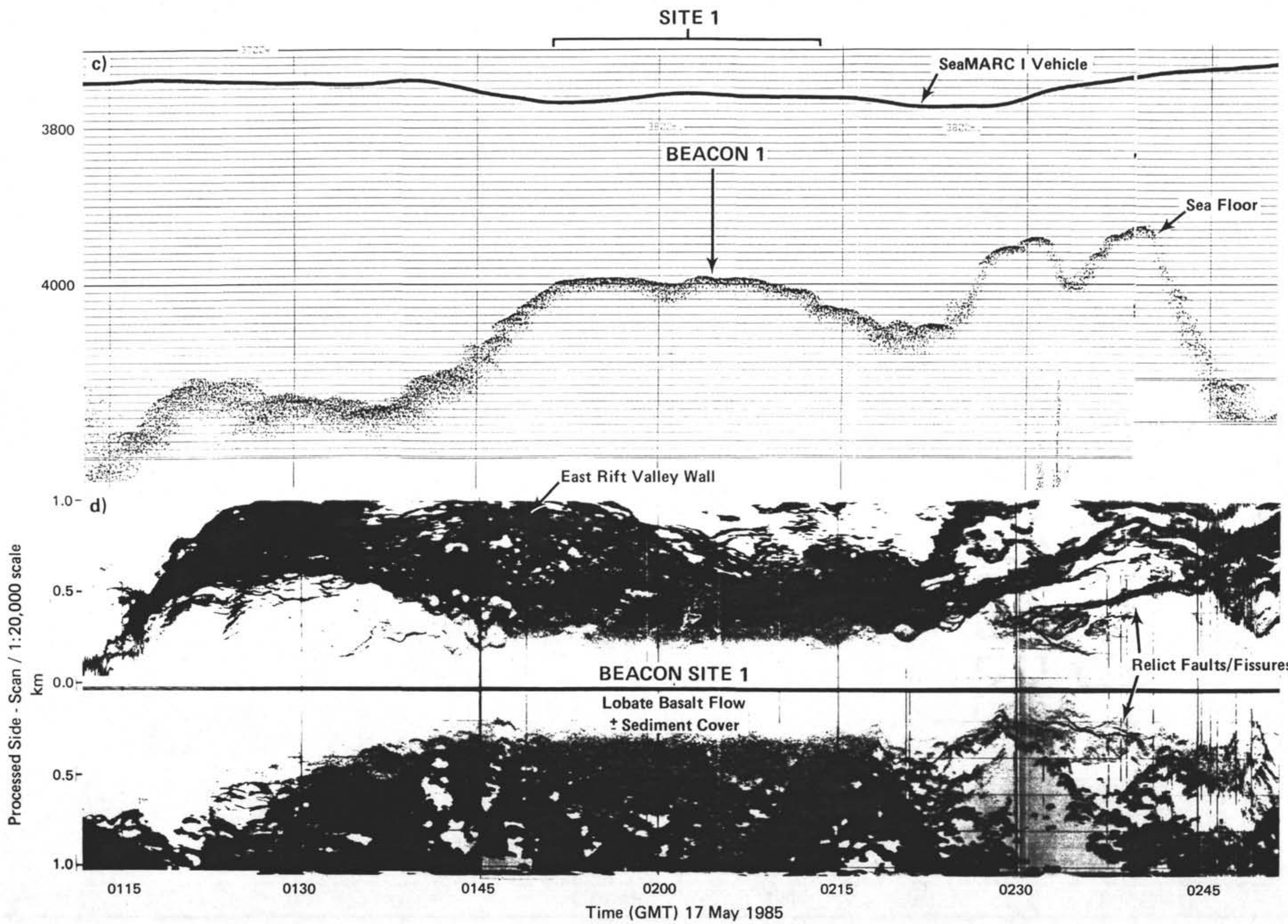


23°40'N
23°30'N
23°20'N
23°10'N
23°00'N
22°50'N
22°40'N
22°30'N
45°10'W
45°00'W
44°50'W
1
2
3
4

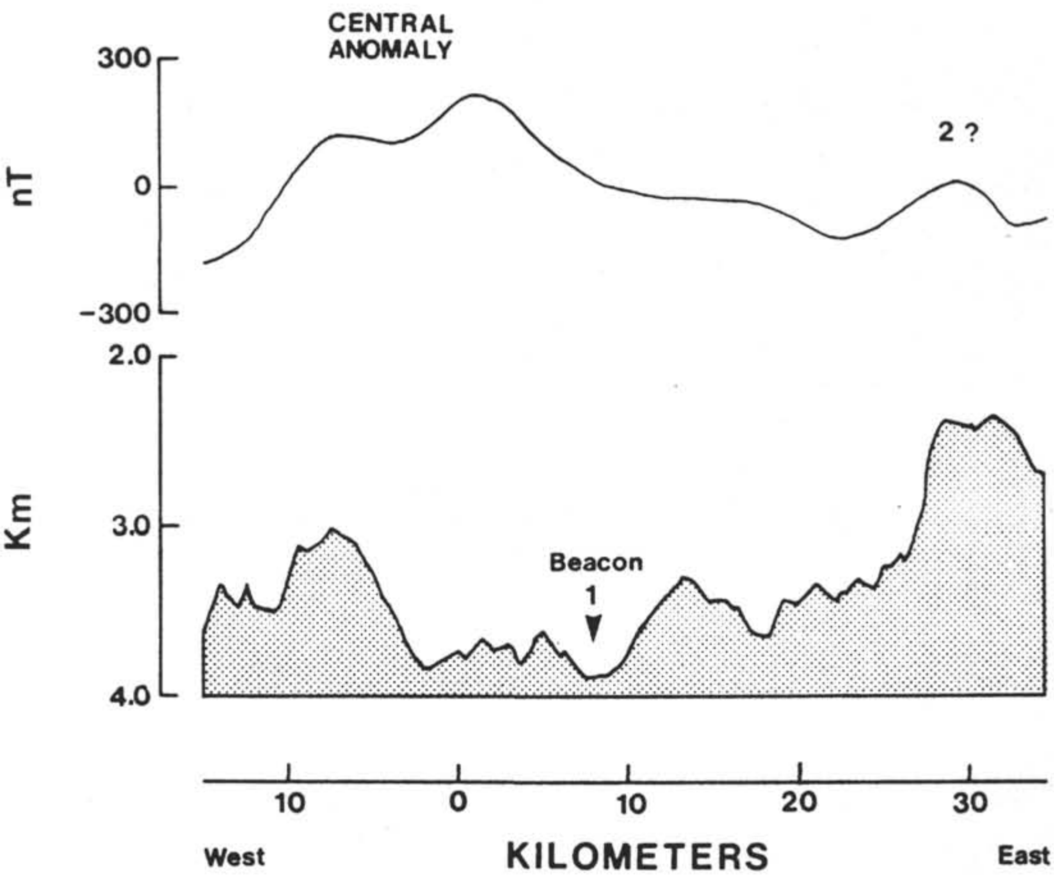
Figure 5



Figures 6a and 6b



Figures 6c and 6d



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Km
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East

Figure 6e

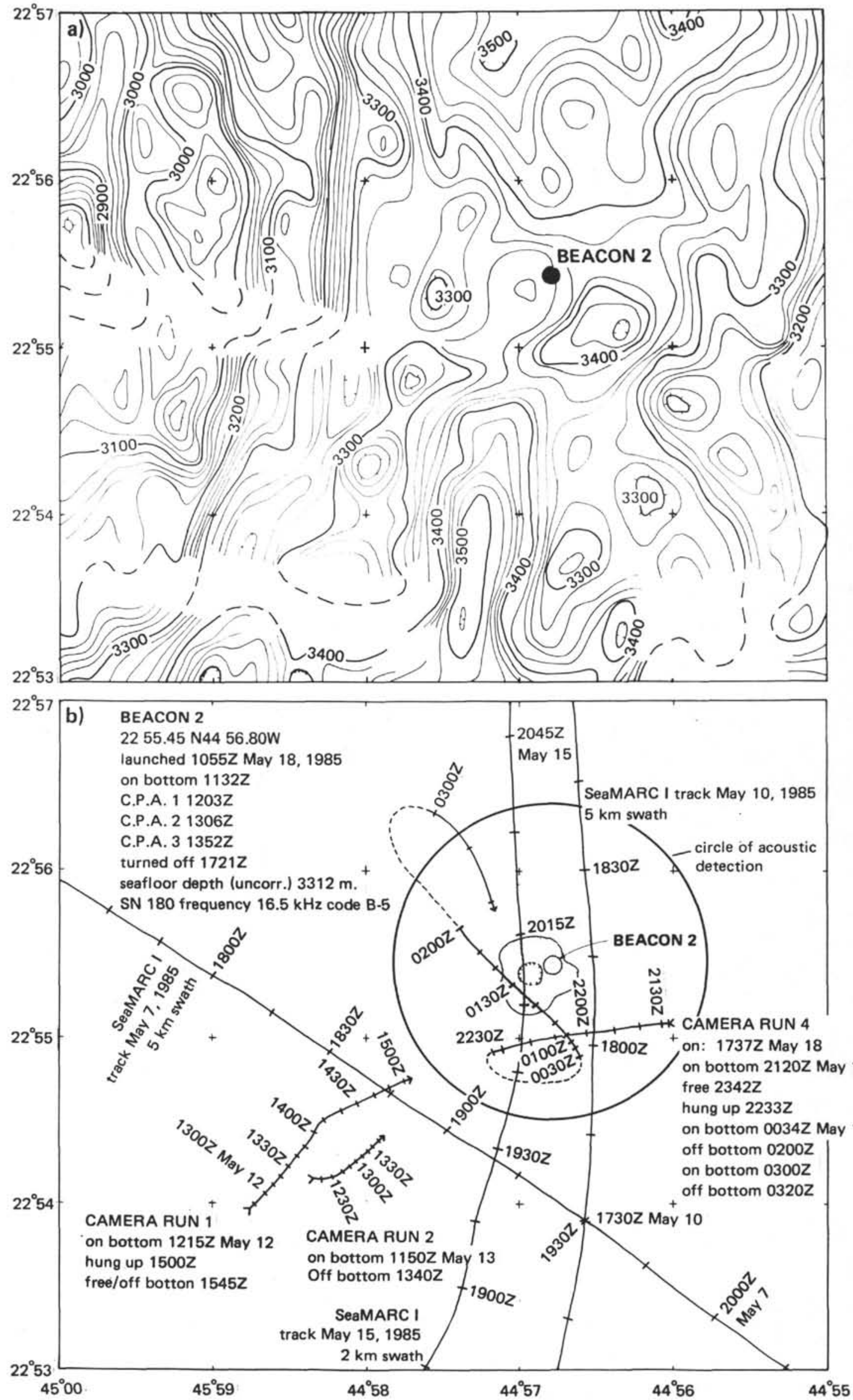
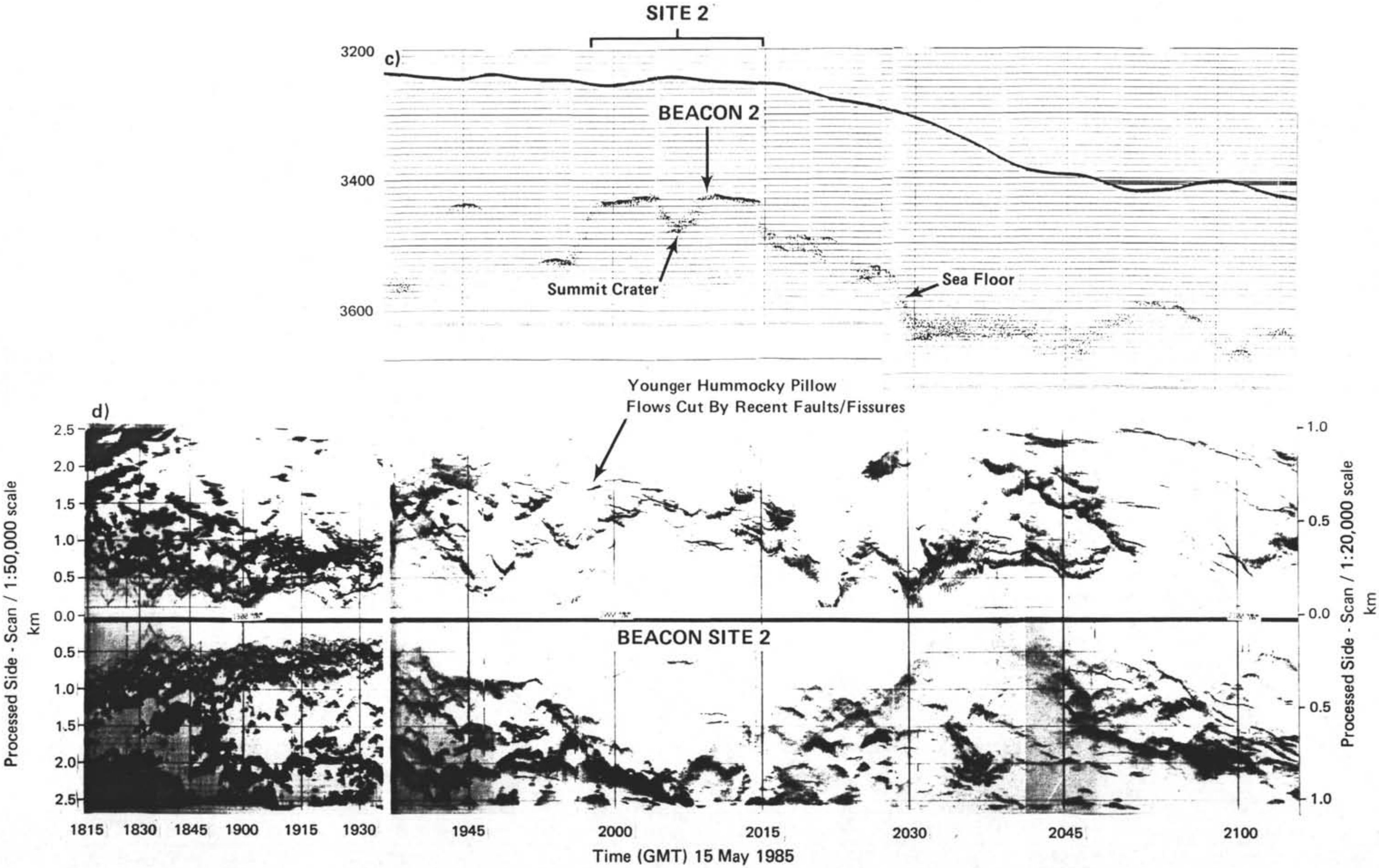
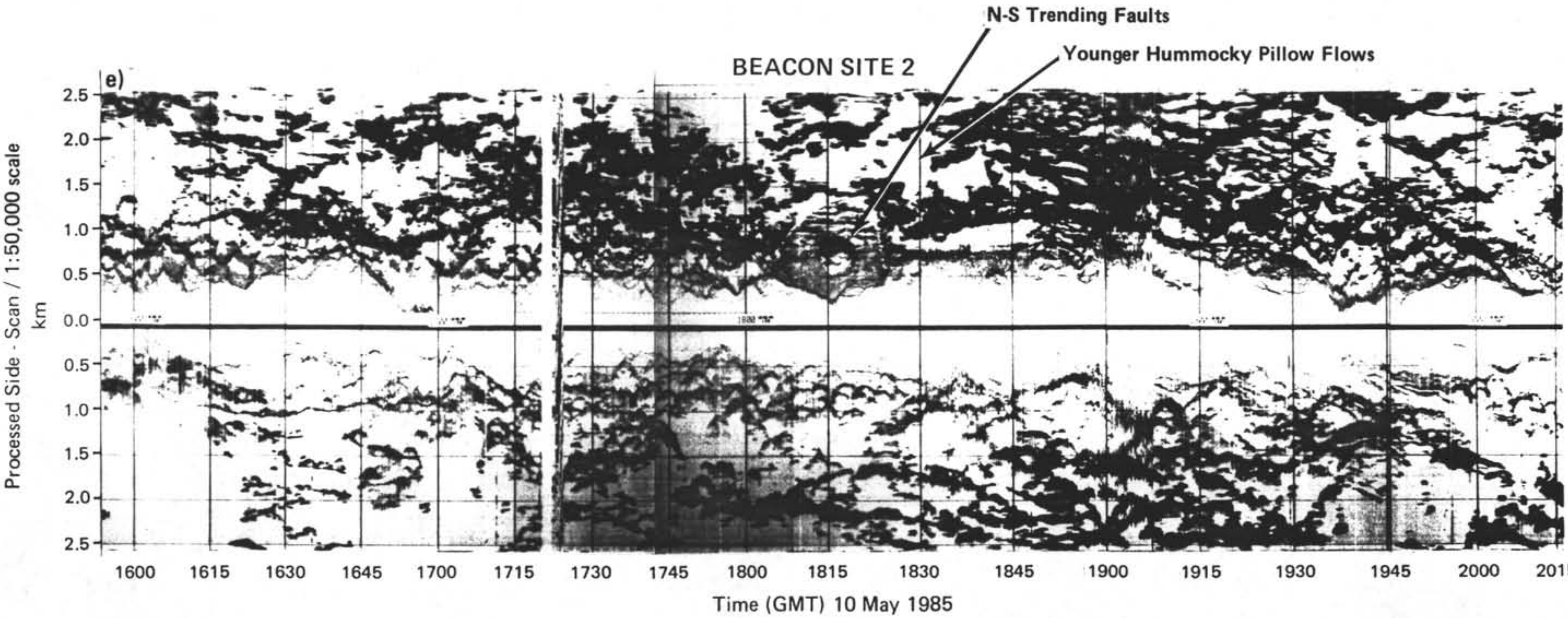


Figure 7a and 7b

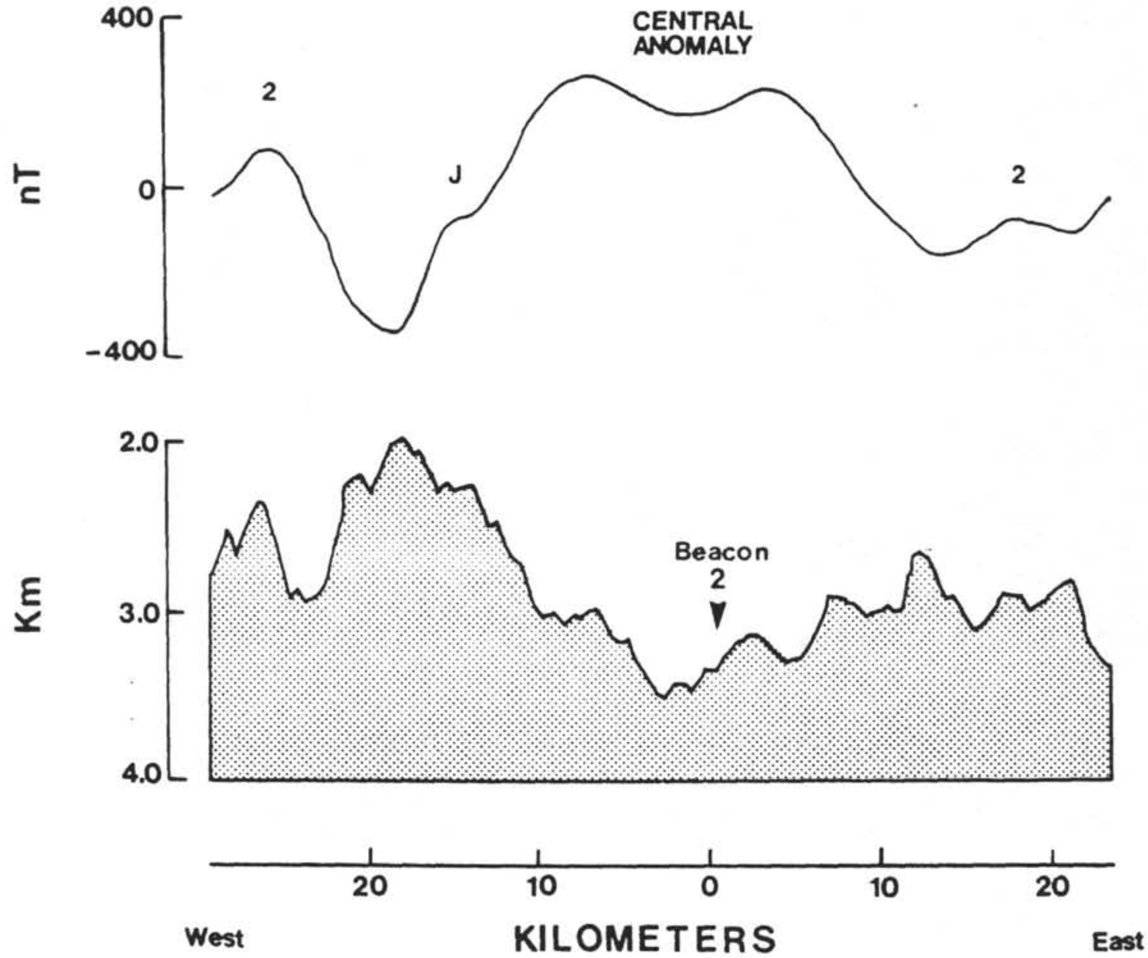


Figures 7c and 7d



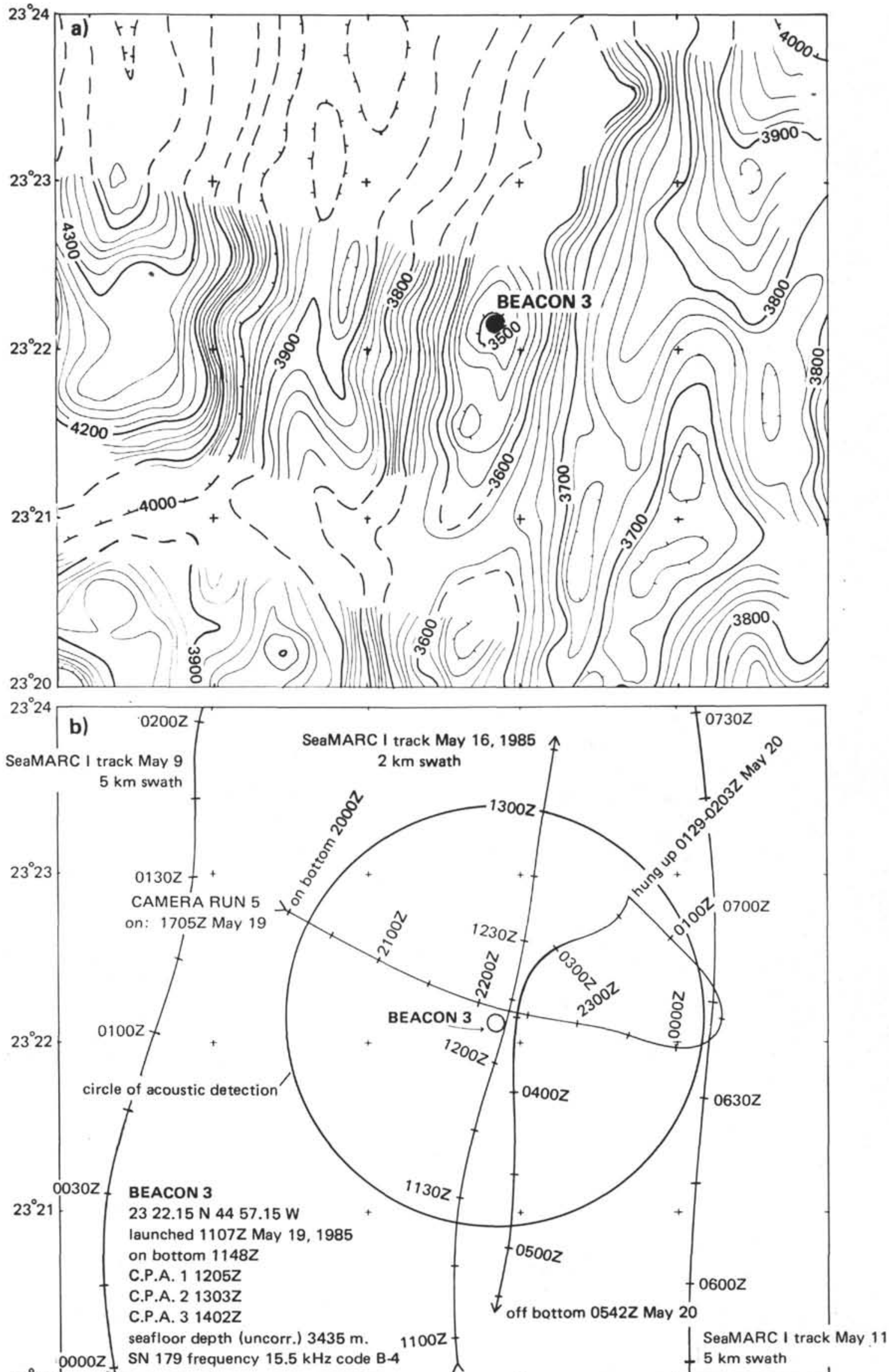
N-S Trending Faults
Younger Hummocky Pillow Flows
BEACON SITE 2
e)
Processed Side - Scan / 1:50,000 scale
km
2.5
2.0
1.5
1.0
0.5
0.0
0.5
1.0
1.5
2.0
2.5
1600 1615 1630 1645 1700 1715 1730 1745 1800 1815 1830 1845 1900 1915 1930 1945 2000 2015
Time (GMT) 10 May 1985

Figure 7e

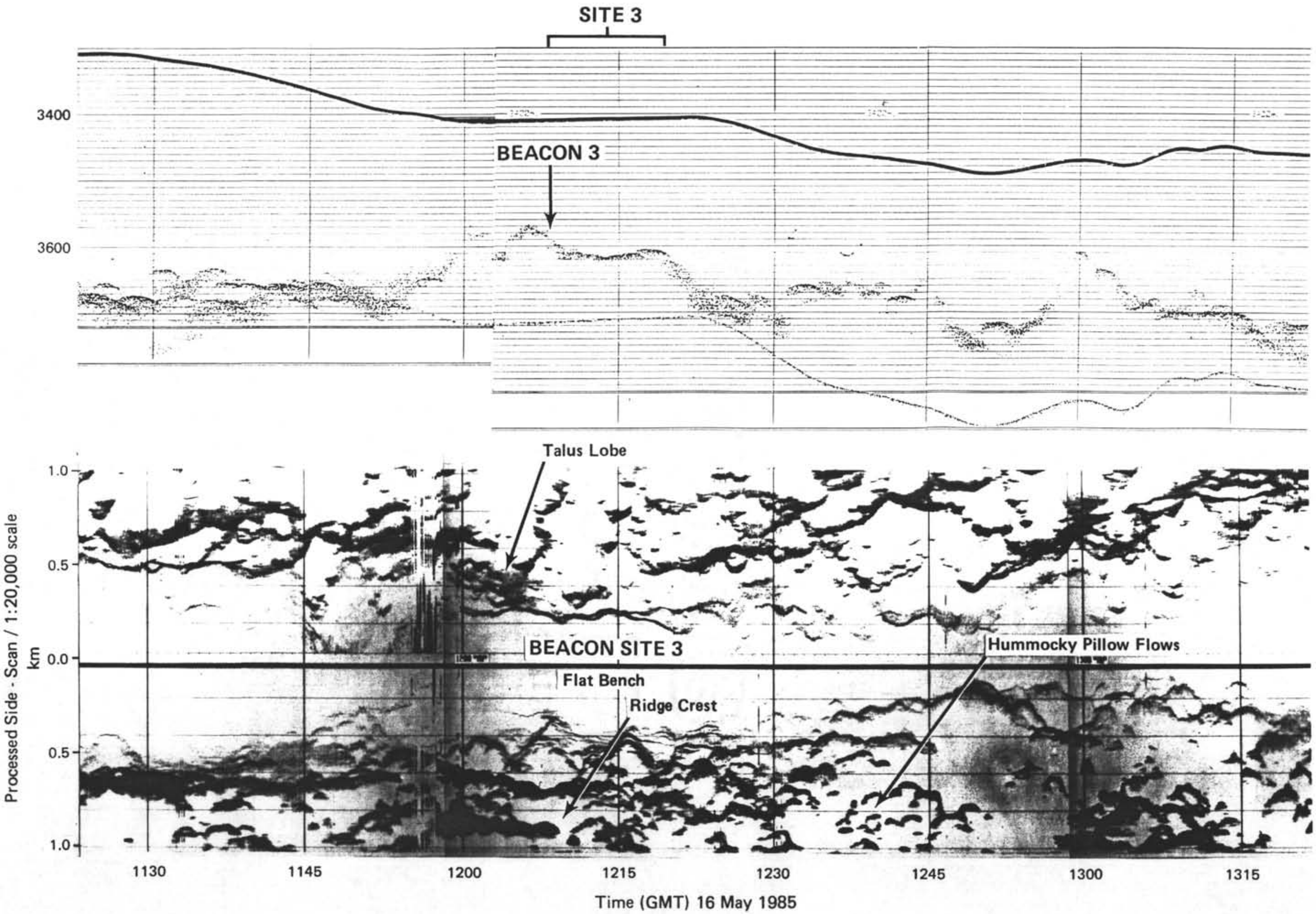


400
0
-400
nT
CENTRAL
ANOMALY
2
J
2
2.0
3.0
4.0
Km
Beacon
2
20
10
0
10
20
West
KILOMETERS
East

Figure 7f



Figures 8a and 8b



Figures 8c and 8d

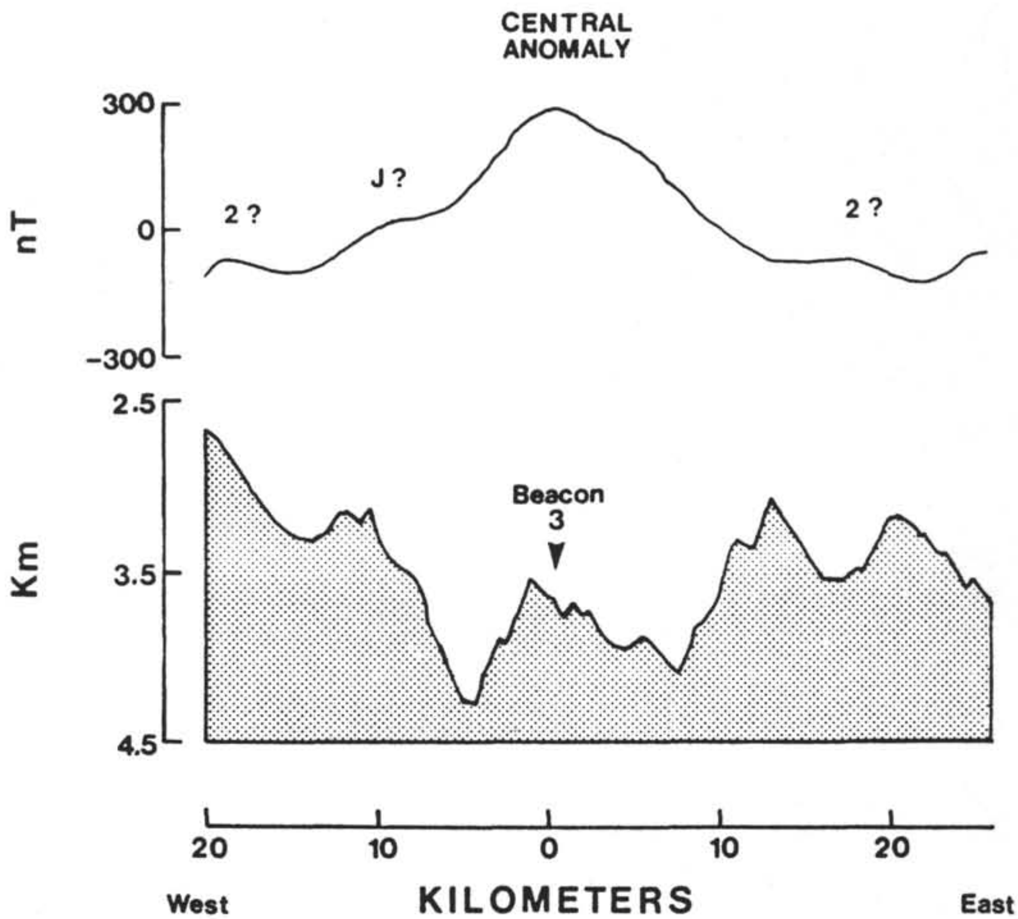

CENTRAL
ANOMALY
300
nT
0
-300
2 ?
J ?
2 ?
2.5
Km
3.5
4.5
Beacon
3
20
10
0
10
20
West
KILOMETERS
East

Figure 8e

SITE NUMBER: 1 (Eastern Site)

POSITION: $23^{\circ}15.10'N$ $44^{\circ}53.20'W$ SEDIMENT THICKNESS:

WATER DEPTH (UNCORR.): 3870 m PRIORITY: 1C

PROPOSED DRILLING PROGRAM:

Continuous rotary coring in zero age crust for maximum penetration using bare-rock re-entry.

SEISMIC RECORD:

3.5 kHz, OBS and OBH measurements

HEAT FLOW:

LOGGING:

OBJECTIVES:

Origin, evolution and nature of oceanic crust at a slow spreading ridge. Processes of magma generation and crustal accretion.

BASEMENT TYPE:

Basalt forming a lobate flow approximately 200 m thick lying in the median valley at the foot of the eastern rift wall. Site is approximately 1 km^2. The surface shows locally low relief (<1 m) with flows partly covered by sediment.

SITE NUMBER: 2 (Southern Site)

POSITION: 22°55.45'N 44°56.80'W SEDIMENT THICKNESS: 10-20 cms

WATER DEPTH (UNCORR.): 3312 m PRIORITY: 1A

PROPOSED DRILLING PROGRAM:

Continuous rotary coring in zero age crust for maximum penetration using bare-rock re-entry.

SEISMIC RECORD:

3.5 kHz, OBS and OBH measurements

HEAT FLOW:

LOGGING:

OBJECTIVES:

Origin, evolution and nature of oceanic crust at a slow spreading ridge. Processes of magma generation and crustal accretion.

BASEMENT TYPE:

Basalt forming a flat topped volcano with collapsed summit crater (approximately 50 m deep) located to the west of the ridge axis in the shallowest portion of the median valley. The summit area is constructed primarily of ropy flows with talus. Faults disrupt the west side of the volcano.

SITE NUMBER: 3 (Northern Site)

POSITION: $23^{\circ}22.15'N$ $44^{\circ}57.15'$ SEDIMENT THICKNESS: <1 m (?)

WATER DEPTH (UNCORR.): 3435 m PRIORITY: 1B

PROPOSED DRILLING PROGRAM:

Continuous rotary coring in zero age crust for maximum penetration using bare-rock re-entry.

SEISMIC RECORD:

3.5 kHz, OBS and OBH measurements

HEAT FLOW:

LOGGING:

OBJECTIVES:

Origin, evolution and nature of oceanic crust at a slow spreading ridge. Processes of magma generation and crustal accretion.

BASEMENT TYPE:

Basalt forming a flat topped hydrothermally active area on the ridge axis. The flanks consist of bulbous shaped flows with steep flow fronts and with large amounts of talus.

SITE NUMBER: 4 (Nodal Basin Site)

POSITION: 23.6°N 44.9°W SEDIMENT THICKNESS: <200 m

WATER DEPTH: 6200 m PRIORITY: 2

PROPOSED DRILLING PROGRAM:

Continuous rotary coring through <200 m of sediment with maximum penetration into basement using standard re-entry.

SEISMIC RECORD:

Many 3.5 kHz records and Deep-Towed Vertical Array Experiment across the proposed area.

HEAT FLOW:

LOGGING:

OBJECTIVES:

Drilling as deep as possible into the oceanic basement beneath the eastern nodal basin of the Kane Fracture Zone.

SEDIMENT TYPE:

Carbonate ooze, and breccias or rubble zones(?).

BASEMENT TYPE:

Basalt, gabbro, peridotite and serpentinite.

SITE NUMBER: 5 (Eastern Transform Site)

POSITION: 23.4°N 43.4°W SEDIMENT THICKNESS: <200 m

WATER DEPTH: 4000-5000 m PRIORITY: 3

PROPOSED DRILLING PROGRAM:

Continuous rotary coring through <200 m of sediment with maximum penetration into basement using standard re-entry.

SEISMIC RECORD:

Many 3.5 kHz records and Deep-Towed Vertical Array Experiment across the proposed area.

HEAT FLOW:

LOGGING:

OBJECTIVES:

Drilling as deep as possible into the oceanic basement beneath the eastern non-transform section of the fracture zone valley.

SEDIMENT TYPE:

Carbonate ooze, and breccias or rubble zones(?).

BASEMENT TYPE:

Basalt, gabbro, peridotite and serpentinite.

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