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SHACKLETON CRUISE 1/82

MECHANISMS OF SEDIMENT TRANSPORT AND DISPERSION IN A TECTONICALLY ACTIVE SUBMARINE VALLEY/CANYON SYSTEM: ZAKYNTHOS STRAITS, N.W. HELLENIC TRENCH

by

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ABSTRACT

Physical oceanographic and geophysical data sets are used to examine sediment transport processes.

Currents were directed generally along the axis of the Valley/Canyon system and, in an area of low tidal range, are attributed to regional weather patterns. Near-bed and near-surface currents are opposed, both in terms of instantaneous observations and net (Lagrangian) drift. Near-bed down-canyon water movement provides a mechanism for the offshore movement of fine-grained sediment.

Slope failures have been identified in the geophysical records and are considered to be controlled by earthquakes and salt diapirism, in a tectonically-active area. These failures, as mass displacement or slow down-slope creep, result in debris infill and the generation of turbidity currents. Fine-grained sediments, resuspended by the turbidity currents, would be transported down-canyon by the slowly-moving near-bed residual water movement.

Hence, the dominant transport mechanisms in the Valley/Canyon system are: (i) frequent mass sediment failure; and (ii) nearly-continuous down-channel fine-grained suspended sediment movement.

INTRODUCTION

Submarine valleys and canyons are distinctive morphometric features within the continental slope, which connect shelf areas to the deep water regions. Such submarine features are considered to act as conduits for the transport of sediments from the continental shelf to the deep ocean floor.

Field observations of canyon currents were initiated some 50 years ago (Stetson, 1937; Revelle and Shepard, 1943); their importance in transporting sediments from the shelf to the deep ocean had been established around 1930 (Daly, 1936; Kuenen, 1938).

During the last decade, extensive integrated studies of water circulation, sediment transport and slope stability have been undertaken in order to define water/sediment interaction within canyon systems. The majority of these studies are concerned with canyons along the western and eastern margins of the U.S.A. (Keller et al., 1973; Shepard and Marshall, 1973a, 1973b; Shepard et al., 1974; Fenner et al., 1971; Minter et al., 1975; Forde, 1981; McGregor and Bennett, 1977, 1981; Keller and Shepard, 1978) with some along the coastline of the French Mediterranean (Gennesseaux et al., 1971; Got and Stanley, 1974; Kelling et al., 1979).

The investigation described here relates to the collection and analysis of hydrographic, sedimentological and geophysical data from the Zakynthos Valley/Canyon system in the inner slope of the northwest Hellenic Trench, Ionian Sea (Fig. 1). The area is characterised by low tidal and wave energy, but is located within a regime of active salt diapirism (Brooks and Ferentinos, in press) and compressional tectonism associated with the Hellenic Trench subduction zone (Got et al., 1977; Le Quellec et al., 1980; Vittori et al., 1981; Monopolis and Bruneton, 1982).

THE STUDY AREA.

(a) Geological Setting.

The Zakynthos submarine Valley/Canyon system is located within the narrow inner shelf/slope of the Hellenic Trench, between the coastline of western Peloponnesos and the southernmost of the Ionian islands, Zakynthos (Fig. 1). The axis of the system runs almost parallel to the strike of the Peloponnesos margin.

The Quaternary landscape and sedimentary environments of the surrounding land area are controlled by salt tectonics (Kowalczyk and Winter, 1979) and compressional tectonics, associated with subduction along the Hellenic Trench (Mercier *et al.*, 1976; Sorel, 1976; Duffaure, 1977; Brooks and Ferentinos, in press).

The Zakynthos Straits are considered to have been formed during the middle Pleistocene (Kowalczy and Winter, 1979). The Quaternary sedimentary environments in the coastal zone surrounding the Zakynthos Straits vary both spatially and temporally. The deposits consist of clays, silty clays, silty sands with coarse clastics, and sands. These deposits have been formed within a variety of environments, such as low energy deep waters, high energy shallow waters,fluvial, lacustrine and brackish water areas (Hageman, 1977; Dermitzakis *et al.*, 1979; Tsapralis, 1981).

Quaternary marine terraces occur at various heights above the sea level and demonstrate that differential vertical movements have affected the area (Braune, 1973; Schröder and Kelletat, 1976). The last major vertical displacement took place in 1953, when the eastern coastline of Zankynthos Island rose by between 0.4 and 0.8m (Braune, 1973).

The area is seismically active with many earthquake epicentres in the vicinity of the valley/canyon system (see Fig. 1, Papazachos, 1976).

(b) Oceanographic Setting.

The tidal range in the area is 5cm during neaps and 35cm during springs.

Dominant wind and wave approach is from the SW and NW. The southwesterly and northwesterly winds have an effective fetch of 900km and of 500km, respectively. Observations of waves from lighthouses on the northern and southern tips of Zakynthos reveal that maximum heights are around 2m.

The general pattern of surface water circulation is from the southeast towards the northwest (Lacombe and Tchernia, 1972). A branch of this main water movement passes towards the northwest, through the Zakynthos Straits (Fabricius _et al_., 1972).

The area receives freshwater discharge and sediment input from a number of large river systems draining the western Peloponnesos; further, some inputs may originate from rivers to the northeast. The Rivers Alfios and Pinios (Fig. 1) drain the eastern margin of the area, with catchment areas of 3374km^2 and 794km^2, respectively; corresponding total annual river water inputs are 2100m^3/annum and 441m^3/annum. Comparable information for the Rivers Acheloos and Evinos draining into Patraicos Bay (inset to Fig. 1) are 4118km^2 and 5988m^3/annum and 635km^2 and 873m^3/annum, respectively (Therianos, 1973).

METHODS

The data were collected during R.R.S. _Shackleton_ Cruise 1/82, in January - February, 1982.

The bathymetric survey was carried out using a Precision Echo-Sounder. Geophysical data were collected using a 3.5kHz O.R.E. Pinger. Cruise tracks are shown in Fig. 1.

Aanderaa self-recording current meters were deployed at 7 locations in relation to the longitudinal axis and cross section of the valley/canyon system (Fig. 1). The current meters were deployed adjacent to the sea-bed, in the middle of the water column and near the sea surface. Details of the information described here are presented in Table 1.

Analysis of the current meter data has been carried out in terms of the statistical characteristics of the Eulerian observations, polar plots and progressive vector diagrams. The latter provides the means for the derivation of the net drift and rate of Lagrangian drift.

Sediment samples from the shelf, canyon floor and slope basin, where the canyon terminates, were collected using a Day grab and gravity corer (Fig. 1). Surface material from these samples have been analysed using sieving and pipette methods. The sand fractions were sieved at ½ϕ intervals. The silt/clay fraction was sampled at times equivalent to grain sizes of 4.5, 5.0, 5.5, 6.0, 7.0, 8.0 and 9.0ϕ. Statistical parameters from the grain size distributions have been determined using Folk's (1968) formulae.

Underwater photographs were taken using a UMEL 35mm underwater camera attached to the Day Grab frame.

RESULTS

(a) Bathymetry.

The Zakynthos submarine Valley/Canyon system is a major linear depression; it runs parallel to the margin of Peloponnesos from a depth of 200m to a depth of 1800m, where it runs into the Zakynthos perched slope basin (Fig. 2). The system is 47km long and 8km wide from rim to rim, at its headward end, and 23km wide at its seaward end.

The shelf surrounding the valley/canyon system extends from the coastline of the surrounding landmasses to the isobath of 100m with a very gentle slope averaging about 1:40 (Fig. 2).

The floor of the Zakynthos Valley, which forms the upper part of the system, is flat and is about 7.5km wide (Fig. 3; profiles 2 and 3). The side walls of the valley are very steep, with an average height of 300m

(Fig. 3; profiles 2 and 3). The average slope of these walls is 1:5, but, in some places the slope can be as steep as 1:2.5. At its head, the Zakynthos Valley narrows slightly and extends towards the north/northwest, terminating almost at the southern coastline of Kephallonia (Fig. 2). Along the eastern margin of the valley two subsidiary valleys enter in from the Patraicos Shelf (Fig. 2). The axial slope of the valley varies from a maximum 1:20 near the head of the valley, to a minimum of 1:300 (Fig. 4a).

The change from a wide U-shaped valley to a narrow V-shaped canyon occurs towards the shelf edge, at the northwest section of the Straits between the Island of Zakynthos and the mainland (Fig. 2). At this juncture, the floor of the valley bulges slightly, forming a hump of about 50m in height from the surrounding sea floor (Figs. 2 and 4a); this somewhat isolates the valley from the canyon. The floor of the canyon at its head is about 9km wide (Fig. 3; profiles 4 and 5) and it narrows downcanyon to 2km near the mouth (Fig. 3; profiles 7, 8 and 9). In their upper reaches, the canyon walls are, on average, 600m high with an average slope gradient of between 1:12 to 1:18 (Fig. 3; profiles 4 and 5). In their lower reaches, the walls of the canyon have an average height of 1000m and slopes of between 1:18 and 1:20. The axial slope of the canyon ranges from 1:50 in its upper part to 1:15 at mid-canyon (Fig. 4a).

At the mouth of the canyon, scattered bathymetric soundings suggest the formation of an upper fan deposit (Fig. 2).

(b) Currents.

Surface and near-bed currents, monitored at 5 min sampling intervals over a 14/15 day period, are summarised in Table 1. The data set is complete, apart from the middle section of the near-bed meter record at Station 3. The information presented in the Table includes geographical location of the stations (see also Fig. 1) and various characteristics of the instantaneous and continuous observations of speed and direction.

Near-bed currents *along the axis* of the valley/canyon system are represented by observations at either 3.5m or 5m above the bed, at horizontal distances of approx. 20km. The maximum, mean (not including zero velocity values) and standard deviation of their current speeds decrease exponentially from the head of the canyon to the perched slope basin, at the seaward end of the system (Fig. 4b). For example, at the head of the canyon (Station 7) the maximum observed speed was 32cm/s, with only a few observations above 23cm/s. Mid-way along the canyon (Station 3), the maximum recorded speed was 19cm/s, with only a few observations above 17cm/s. At Station 2 the maximum recorded speed was about 9cm/s and was 5cm/s at Station 1, in the perched basin. In contrast to the intensity of flow, the persistence of flow is indicated by the percentage of time of zero velocities (i.e., below the threshold of movement of the Savonius Rotor). For the near-bed currents along the axis of the channel, these percentages increase generally in a downcanyon direction. Percentage of time with zero velocities were 49%, 15% and 32%, 58% and 81% for Stations 7, 3, 2 and 1, respectively. The steadiness in the direction of the near-bed axial flow was over 90% at all stations, except at Station 2 where it was only 30%. Most of the time, currents were directed along the axis of the channel (Fig. 5). The Lagrangian residual currents, which represent the long-term movement of an individual water particle from the point of observation, were all downcanyon at Stations 7, 3 and 2 (Table 1). Drift rates and directions are shown in Figure 6. At Station 1, in the perched basin, a net drift of only 7km took place towards 333°W.

Near-bed current speeds and directions at Stations 5 and 6 (Fig. 7), installed *across the axis* of the canyon, are listed in Table 1. Their maxima, means and standard deviations were of a similar order of magnitude to those at the most adjacent current meter station along the longitudinal axis, Station 2. In contrast to Station 2, the steadiness of the currents at the foot of the side walls of the canyon was in excess of 90% (see Table 1). Similarly, downchannel residual drifts were much higher at Stations 5 and 6, than at Station 2 (see Table 1).

The near-surface current speeds for all the stations, both along and across the channel (Fig. 8), were much higher in comparison with those near the sea-bed. Maximum recorded speeds ranged from 33 to 44cm/s (Table 1). The steadiness of all the surface currents at Stations 2, 3, 5 and 6 were all between 94 and 98%; net drift rates were directed upchannel, ranging between 130° and 210° out of phase with the corresponding near-bed observations (Fig. 6). A comparison of the instantaneous, rather than the temporally-averaged, observations at the water surface and near the bed also demonstrates that currents were approx. 180° out of phase. Currents at the surface were directed generally upchannel; those at the bed, downchannel (Fig. 9).

Current meter Station 4 was located on the Peloponnesos continental shelf (Fig. 1); here, maximum near-bed current speeds were 24cm/s and the net flow was towards the west (Table 1).

(c) Sediment Distribution.

Results of the textural and particle size analysis of the surficial sediments of the Zankynthos Valley/Canyon system are shown in Table II. The floor of the valley/canyon system and the Peloponnesos shelf, the eastern boundary of the valley/canyon, is covered by muddy sediments (Samples IS/82/11, 12, 14, 18, 19, 20, 21, 24 and 25). These sediments are probably associated with fine-grained sediment inputs from the river. The Zakynthos shelf, the western boundary of the valley/canyon system is covered by sands, gravelly Sands and gravelly-muddy Sands (Samples, A, B, IS/8216, 17, 22 and 26).

The mean grain size of the muds ranges from 7.10 to 8.30 and they are very poorly sorted (see Discussion).

(d) 3.5kHz Profiles.

The 3.5kHz profiles across the valley/canyon system show that extensive gravitative mass movements have occurred along the walls surrounding the valley and the canyon.

Profile A (Fig. 10a) is a cross-section near the headward termination of the Zakynthos Valley (see Fig. 3 for location). Within the western wall of the valley the surface layers are faulted. This faulting does not affect the deeper sedimentary layers and it is believed, therefore, that it has been caused by creep in the overlying surface layers. The slope gradient of the sea-bed and of the deeper layer over which the creep occurs is about 1:30.

Profile B (Fig. 10b) is a cross-section near the northernmost tip of the valley (Fig. 3). The eastern part of the floor is occupied by a slumped mass which internally is acoustically amorphous. The slumped mass has an average thickness of 17m and has cut through a layered sedimentary sequence (lying just to the right of the slumped mass in the Figure).

Profile C (Fig. 10c) is across the deepest part of the valley (Fig. 3) where current meter Stations 5 and 6 were positioned (Fig. 1). At the foot of the western wall, a block of about 40m in height seems to have slid from the sidewall. The latter has an average gradient of 1:17. The foot of the eastern wall is covered by a series of overlapping debris flows. The western part of the floor is covered by layers of sediments as indicated by the parallel acoustical reflectors. This stratified sequence is assumed to represent hemipelagic sedimentation. Other parts of the valley floor are covered by similar layers.

Profile D (Fig. 10d) is along the longitudinal axis of the head of the canyon (Fig. 3). The profile shows that the floor at the head of the canyon is covered by a layered sequence, with a thickness of about 13m. The sequence has been affected by small faults, forming units which are concave upwards

This structural pattern suggests that each of these units is a small rotated slumped block, which is still in situ.

Profile E (Fig. 11a) is across the floor and the lower side slopes of the canyon (Fig. 3). The slopes of the canyon here are affected by slumping, whilst the floor of the canyon is filled with overlapping slumped masses, which apparently originated from the opposite slopes.

Profiles F, G and H (Figs. 11b, c and d) are near the shelf edge break and mid-slope (Fig. 3). The profiles show that the shelf and the upper slope, which surround the valley and the canyon, are covered by a 50m thick sedimentary sequence of acoustically well-stratified sediments (Figs. 12b,12c and 13). The layered sequence also seems to be subjected to gravitative mass movements.

Profile F shows a slipped mass about 40m thick, filling the bottom of a side canyon. Further up-slope, incipient faults indicate the retrogressive action of the slide mechanism.

Profile G, near the top of the slope, shows that the layers in the sequence have wavy foundations. In each of these wavy forms the stratified sequence thins downslope, in apparent response to creep.

Profile H represents a change in character of the gravitative mass movement, from the shelf edge down to the slope. At the shelf edge, the sedimentary layers are deformed by creep. Further down, the layers do not exhibit any wavy forms. Instead, they have been affected by incipient faulting and individual blocks have formed.

DISCUSSION

The 14 to 15 days of continuously recording current meter data for the Zakynthos Valley/Channel system, described here, are some of the longest which have been recorded for canyons anywhere. Near-bed current speed maxima in the shallow waters (200m) are similar to those recorded elsewhere, but the deeper water near-bed speeds are considerably less (cf. Tables 1 and 2, Shepard et al., 1979). For example, maximum observed near-bed currents in the Zakynthos system were 32, 13, 9 and 5cm/s in water depths of 200, 500, 800 and 2000m, respectively. Comparable average values for up- and down-canyon maxima for, mainly, canyons of the western and eastern coastlines of the U.S. are between 21 and 31cm/s, throughout all water depths.

Various mechanisms for the generation of currents in submarine canyons and valleys have been proposed; these include tides, river inputs and meteorological influences. The latter include wind-induced landward surface water movement, with return flow along the bottom, in the Salt River Canyon, Virgin Islands (Shepard *et al.*, *op.cit.*, p.39). The Zakynthos System appears to respond similarly, although the flow reversal here between top and bottom of the water column is likely to be attributable to variations in water level caused by regional changes in atmospheric pressure.

The relevance of down-canyon water movement near the sea-bed to sedimentological investigations is that suspended material, whatever its origin or mechanism of generation, will be transported here from the continental shelf to the deepwater offshore basins. It is of interest to consider in addition, however, the capacity of the measured currents to remove *in situ* material as bedload.

Maximum near-bed currents in the Zakynthos System decrease in a down-canyon direction, from 32cm/s in 200m of water, to 5cm/s in 2000m. These currents relate to observations at either 3.5m or 5m above the bed. Comparative threshold criteria are somewhat difficult to abstract from the literature, in the absence of detailed information of flow within the benthic boundary layer. Keller and Shepard (1978, Fig. 2-26) have extrapolated, to $\bar{U}_{300}$, the curve produced by Miller _et al_. (1977) for $\bar{U}_{100}$, to accommodate the majority of their own observations in canyons. This curve is valid for sediment coarser than 6.50, which is coarser than material on the floor of the Zakynthos system. The current speeds recorded in the present investigation, flowing over a bed of essentially fine-grained (mud) deposits, were generally lower than those required for transport. This interpretation is consistent with other similar field observations which suggest that fine sands move where currents are 25 to 35cm/s at small heights above bottom (Shepard et al., 1979, p.24), or that mean critical speeds for sediment ripple migration and suspension are 19 and 22cm/s, respectively, at 70cm above the bed (Wimbush _et al_., 1982).

In terms of overall sediment transport patterns, the Zakynthos system appears to be similar to canyons along the eastern coastline of the United States, which are relatively inactive in terms of the transport of coarse-grained sediments but serve as conduits for the movement of fine-grained materials. Canyons off Southern California, in comparison, are active in the seaward transfer of coarse-grained sediments (Keller and Shepard, _op.cit_.).

In addition to evidence for sediment transport provided by current observations and grain size distributions, there is extensive evidence of gravitite flow in the area under investigation. In particular, two main categories of slope failure have been identified in the (approx. 50m thick) acoustically stratified layer of Pleistocene - Holocene deposits, which cover the surrounding shelf and slope areas. These failures are:
(a) rapid displacement of large masses of sediment along a slip-plane; and
(b) slow downslope creep, giving rise to undulating surface topography.
An example of the result of such slope failures might be the retrogressive

extension at the head of the Zakynthos Valley, accompanied by debris flows. The side walls of both the valley and canyon parts of the system are affected by both types of failures, resulting in the supply of a debris infill and the generation of turbidity currents.

Slope failures in submarine sedimentary deposits have been found to be due to an effective reduction in shear strength, caused by a sudden increase in excess pore water pressures (Moore, 1961; Morgensten, 1967; Lewis, 1971). Such an increase in pore pressure can be initiated by a number of factors including wave loadings, rapid sedimentation, the generation of methane gas, earthquakes and salt diapirism. In the absence of evidence for gas pockets on the 315kHz records in the study area, slope failure is considered to be controlled by earthquakes and salt diapirism. Evidence for both generating mechanisms is available.

The seismicity of the area is known to be high, with the epicentres of many earthquakes located along the Zakynthos Straits (Papazachos, Fig. 5). As examples of such activity, nine earthquakes with a magnitude of between 5.5 and 7.0 on the Richter Scale were recorded between 1911 and 1975; similarly, ten earthquakes of between 5.0 and 5.4, and thirty of between 4.0 and 4.9, were recorded between 1950 and 1975. Geophysical investigations of the deep geological structure of the region (Brooks and Ferentinos, 1983) have revealed the presence offshore of salt diapirism. Salt diapirs have been found to occupy the northern part of the Zakynthos Valley and it seems likely that both flanks of the Zakynthos Canyon are underlain by deep-seated salt diapirs. Continuous uplift caused by the diapirs would result in slope failure.

Once a slump has been initiated, by either earthquake activity or diapirism, other failures will take place in both the upslope and downslope directions. In this manner, debris flows and turbidity currents are generated, with the associated resuspension of fine-grained material. Indeed, it has been suggested that sliding and slumping of sediment deposits can create either 'high concentration' (1.5 to 2.4 g/cm^3) or 'low concentration' (1.03 to 1.2 g/cm^3) turbidity currents, wherein suspended sediment is supported by turbulence (Middleton and Hamton, 1976). There is other sedimentological evidence for the transport of material as a low-density turbidity current in the area. Uniform mud deposits (unifites) have been identified from detailed analyses of piston cores from adjacent, deeper-water, areas of the Hellenic Arc (Trench)(Stanley and Maldonado, 1981; Blanpied and Stanley, 1981).

In conclusion, frequent mass sediment failure and nearly continuous downchannel fine-grained suspended sediment movement, related to slowly moving near-bed residual currents, are considered to be the dominant transport mechanisms in the area under investigation. On a regional basis, such mechanisms can be compared with that of "cascade feeding", which has been proposed for the transfer of material from the continental shelf, via the upper slope basins, to the offshore trenches from a specific supply area (Got et al., 1981).

ACKNOWLEDGEMENTS

The authors acknowledge gratefully the assistance provided by the Officers and crew of R.R.S. Shackleton, during Cruise 1/82. The Natural Environment Research Council is thanked for the award of ship time and an associated research support grant. Particular thanks are due to C.M.G. Adams and I. Innes of N.E.R.C. for help in the cruise organisation. The Greek Authorities are thanked for granting permission to carry out research in their territorial waters. Mr. K. Naylor is thanked for the production of drawings and Ms. J. Greengo and Mrs. A. Carr for typing and reprographic work, respectively.

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SHACKLETON 1982

TABLE 1. DETAILS OF CURRENT METER DEPLOYMENTS.

Stn. Ref.	Latitude	Longitude	Approx. Water Depth (m)	Height Above Bed (m)	Record Length (Days)	% of Time With Zero Velocity	Current Speed (cm/s)				Steadiness %	Residual Drift		
							Max.	Min.	Mean	S.D.		Distance (km)	Rate (km/day)	Dirn.
IS/82/CM1	37°27.5'	21°09.9'	2000	3.5	14	81	5.14	0.0	2.86	0.65	98	6.99	0.50	333
IS/82/CM2	37°40.7'	21°06.3'	800	5.0	14	58	9.34	0.0	3.12	1.04	30	2.41	0.17	202
IS/82/CM2	37°40.7'	21°06.3'	800	695	14	2	32.86	0.0	12.94	7.70	96	148.5	10.6	328
IS/82/CM3*	37°51.0'	20°58.6'	500	5.0	2/6	32/15	7.38/ 18.86	0.0/ 0.0	4.19/ 7.22	1.18/ 3.89	96/88	4.20/ 10.07	2.1/ 1.68	118/ 94
IS/82/CM3*	37°51.0'	20°58.6'	500	400	15	5	38.74	0.0	17.52	10.08	97	210.8	14.1	320
IS/82/CM4	37°35.5'	21°21.5'	100	5.0	13	46	24.18	0.0	9.24	4.58	98	53.3	4.10	272
IS/82/CM5	37°43.5'	21°07.0'	500	5.0	13	30	9.62	0.0	4.07	1.49	91	21.43	1.65	181
IS/82/CM5	37°43.5'	21°07.0'	500	405	13	3	43.78	0.0	16.72	6.62	98	179.8	13.8	333
IS/82/CM6	37°44.2'	21°02.2'	500	5.0	14	52	12.98	0.0	4.50	2.13	93	16.29	1.16	151
IS/82/CM6	37°44.2'	21°02.2'	500	405	14	25	33.14	0.0	15.07	9.86	94	109.0	7.79	343
IS/82/CM7	37°59.6'	20°49.3'	200	3.5	14	49	31.74	0.0	11.14	6.43	95	64.98	4.64	210

*Note: Data sets refer to records prior to and after intermittent instrument failure.

TABLE II. TEXTURAL AND PARTICLE SIZE CHARACTERISTICS OF THE SURFACE SEDIMENTS.

Sample(2)	Textural Classification(1)	Mean (M_Z)	Sorting (6_I)
IS/82/11	Mud	7.1	2.5
IS/82/12	Mud	7.9	3.0
IS/82/14	Mud	7.1	2.0
IS/82/16	silty Sands	5.6	1.7
IS/82/17	gravelly muddy Sand	3.2(4)	0.95(4)
IS/82/18	Mud	8	2.1
IS/82/19	Mud	8.3	2.1
IS/82/20	Mud	7.6	2.4
IS/82/21	Mud	7.5	1.6
IS/82/22	(gravelly) muddy Sand	2.9(4) 5.8(5)	1.0(4) 1.8(5)
IS/82/23	muddy Sand	3.6(4)	0.3(4)
IS/82/24	Mud	7.3	2.3
IS/82/25	Mud	7.8	1.9
IS/82/26	gravelly Sand	1.2(4) 6.9(5)	1.6(4) 2.4(5)
IS/82/27	Mud	7.8	1.6
A(3)	Sand	0.9	0.3
B(3)	Sand	2.9	1.0

(1) After Folk, 1968.

(2) Note that stations referred in Figure 1 should be prefixed by IS/82.

(3) Made available to the authors by the Public Electricity Corporation of Greece.

(4) Sand fraction.

(5) Mud fraction.

FIGURE CAPTIONS

Figure 1: General bathymetry of the study area, showing the locations of current meter stations, grab and core sampling sites and the P.D.R. and 3.5kHz survey lines.

Figure 2: Detailed bathymetry of the Zakynthos Valley/Canyon system, based upon survey data and U.S. Navy Hydrographic Chart No. NAR-8, 3407 and U.K. Admiralty Charts. Arrows show longitudinal axis of the valley/canyon system and its tributaries.

Figure 3: Transverse bathymetric profiles (dashed) of the Zakynthos Valley/Canyon system (Profiles 1 to 10). Solid lines are the 3.5kHz track-lines for the result illustrated in Figures 10 and 11 and discussed in the text (Lines A to H).

Figure 4:
(a) Longitudinal axial profile of the Zakynthos Valley/Canyon system.
(b) Longitudinal variations in observed current meter observations along the canyon axis.

Figure 5: Polar plots of records from near-bed current meters (Stations 7, 3, 2 and 1) along the longitudinal axis of the Zakynthos Valley/Canyon system. Down-canyon and up-canyon directions are indicated.

Figure 6: Near bottom and near surface Lagrangian residual currents along the Zakynthos Valley/Canyon system.

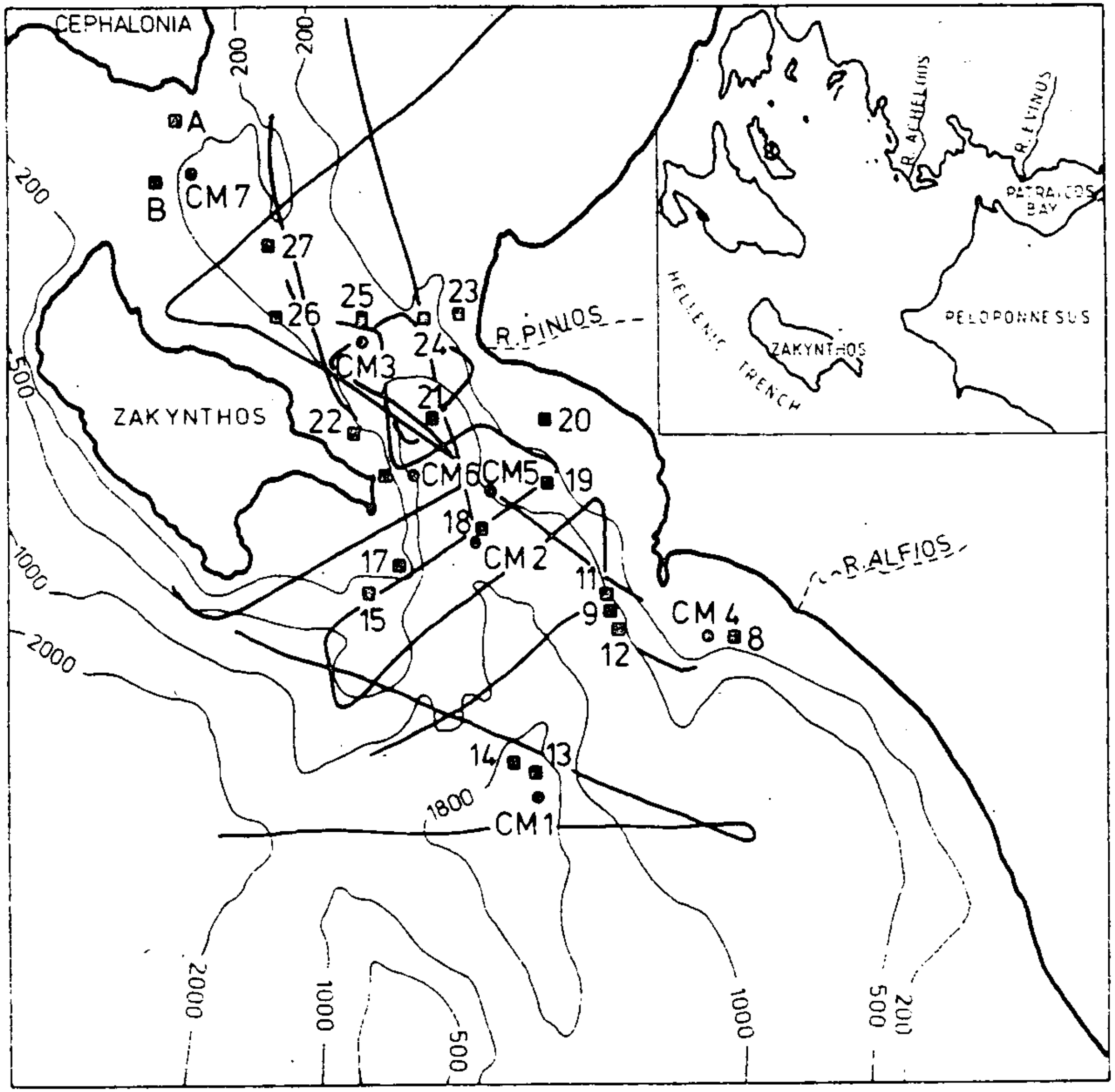
Figure 7: Polar plots of records from near-bed current meters at Stations 5 and 6 at the foot of the valley walls. Down-canyon and up-canyon directions are indicated.

Figure 8: Polar plots of records from near surface current meters (Stations 2, 3, 5 and 6). Down-canyon and up-canyon directions are indicated.

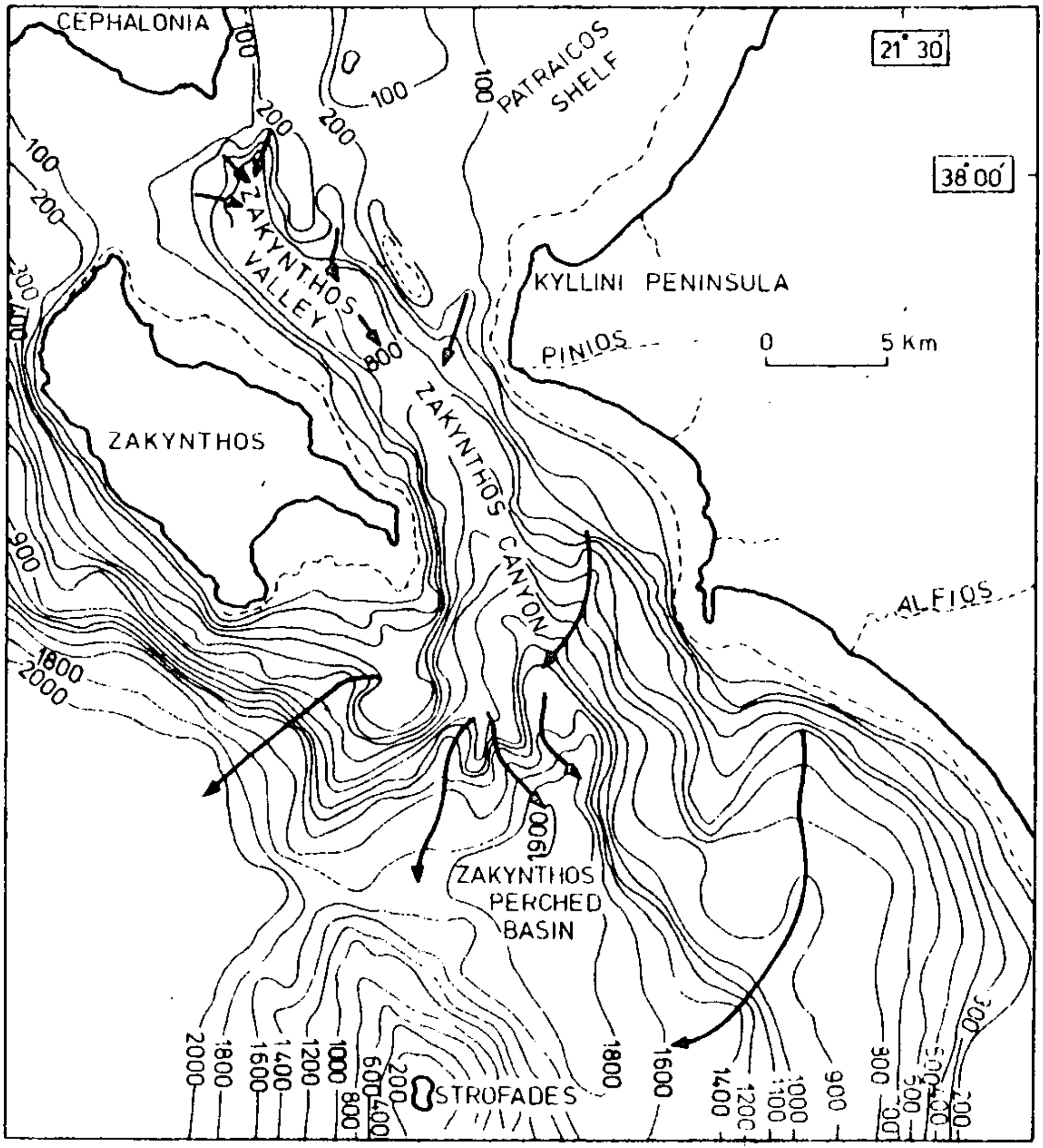
Figure 9: Sections of simultaneous near surface and near bed current meter observations at Stations 5 and 6.

Figure 10: (a), (b), (c), (d). Selected 3.5kHz profiles in the Zakynthos Valley/Canyon system showing depositional and structural features discussed in the text.

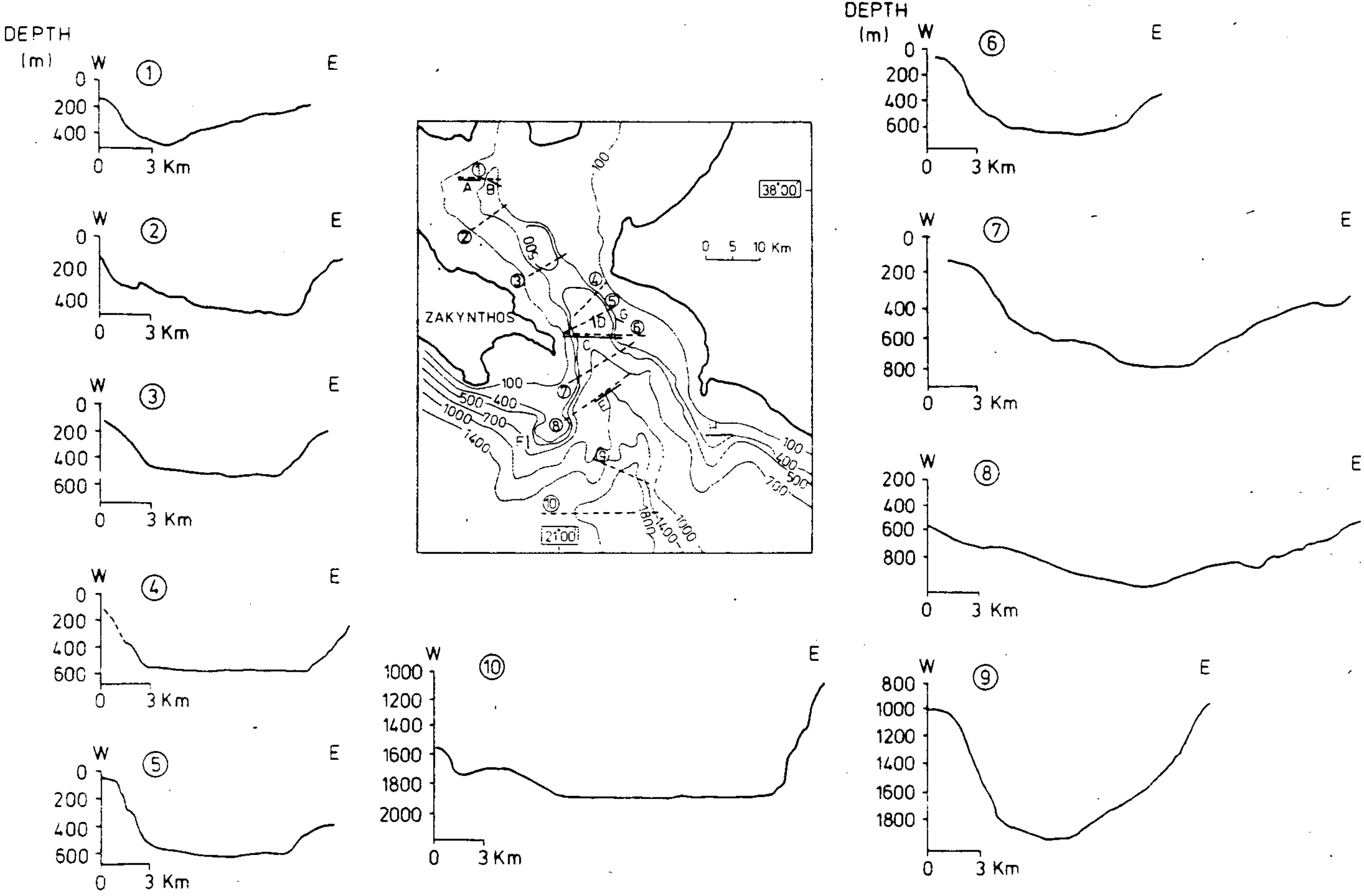
Figure 11: (a), (b), (c), (d). Selected 3.5kHz profiles in the Zakynthos Valley/Canyon system showing depositional and structural features discussed in the text.



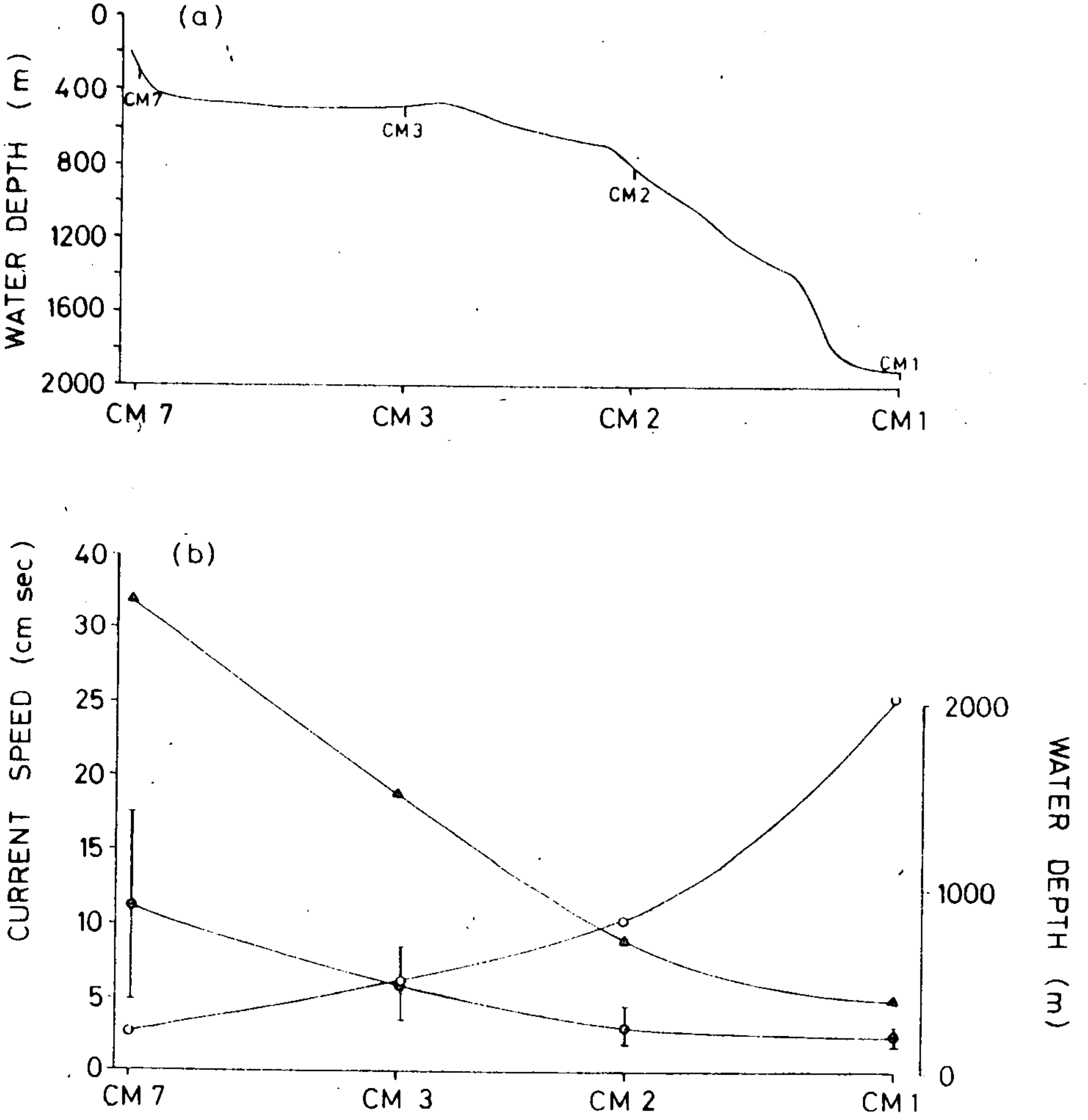
FERENTINOS et al, FIG 1



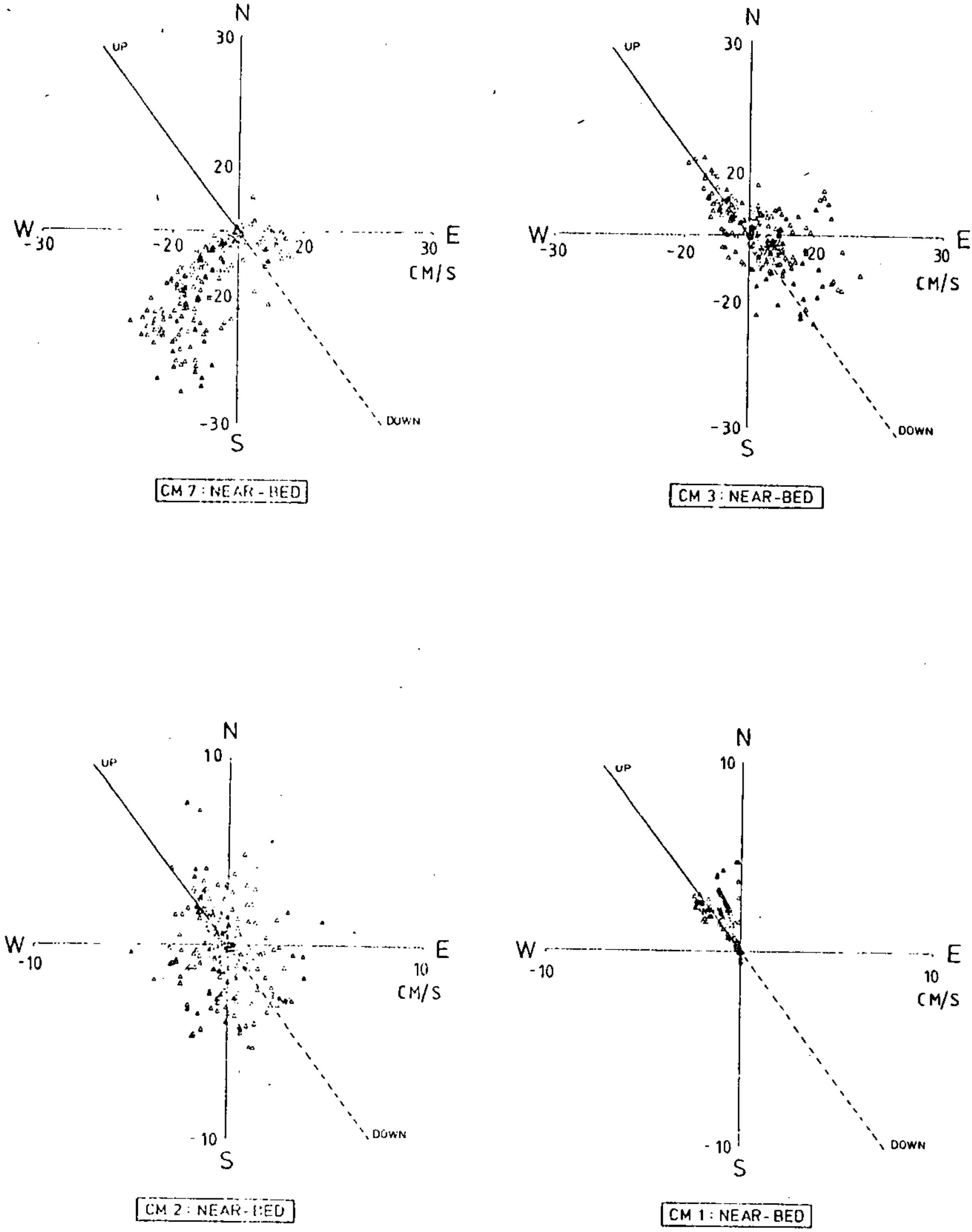
FERENTINOS et al, Fig 2



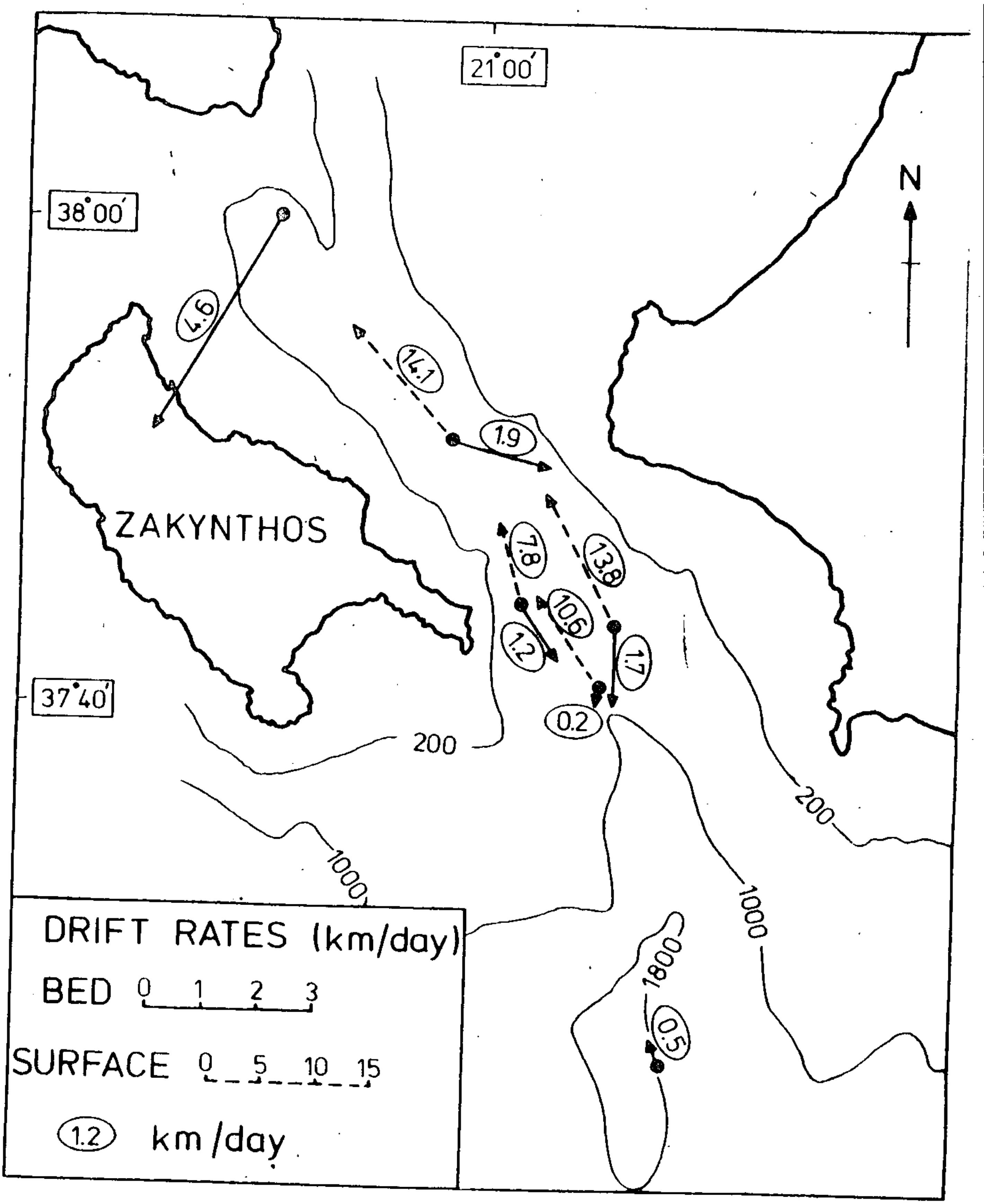
Ferentinos et al, Fig 3



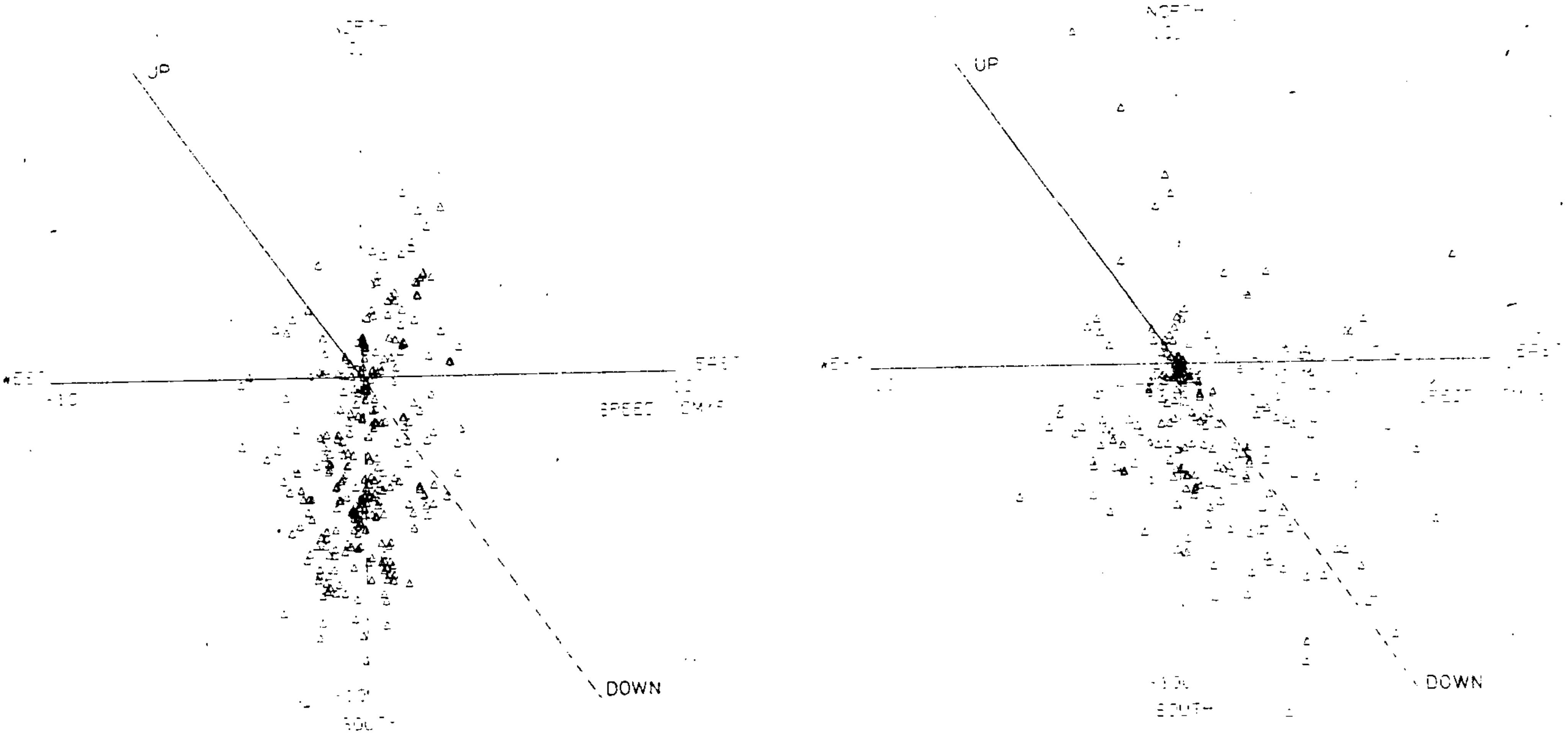
Ferentinos et al, Fig 4



Ferentinos, et al, Fig 5



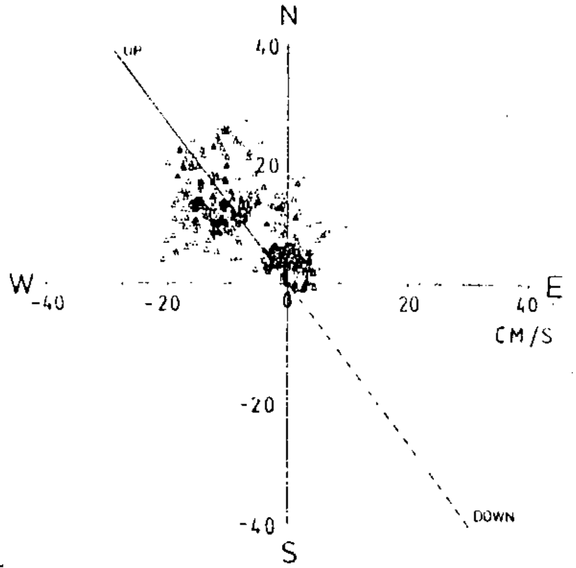
Ferentinos et al, Fig 6



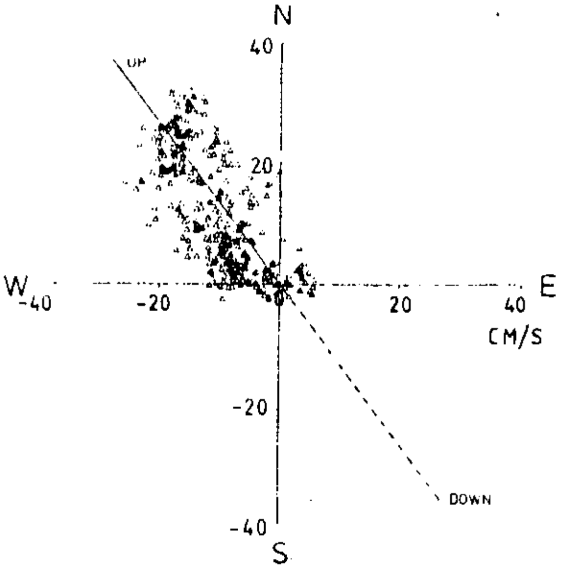
CM 5 NEAR-BED

CM 6: NEAR-BED

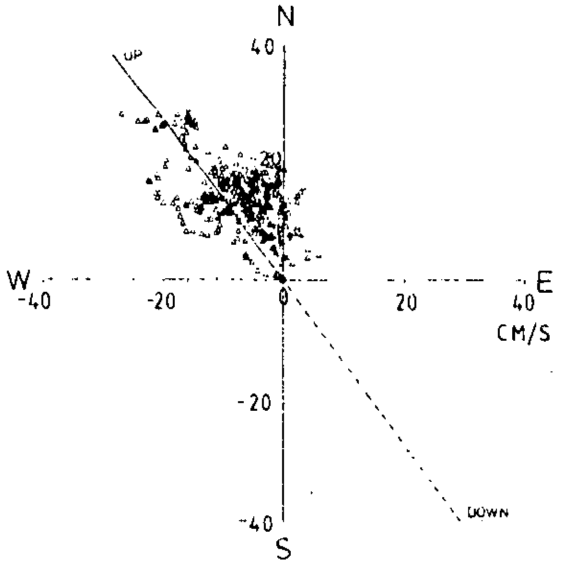
Ferentinos et al, Fig. 7



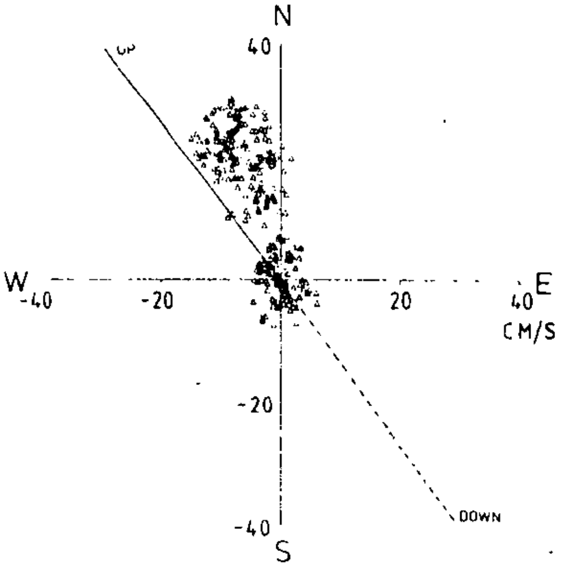
CM 2 : NEAR-SURFACE



CM 3 : NEAR-SURFACE

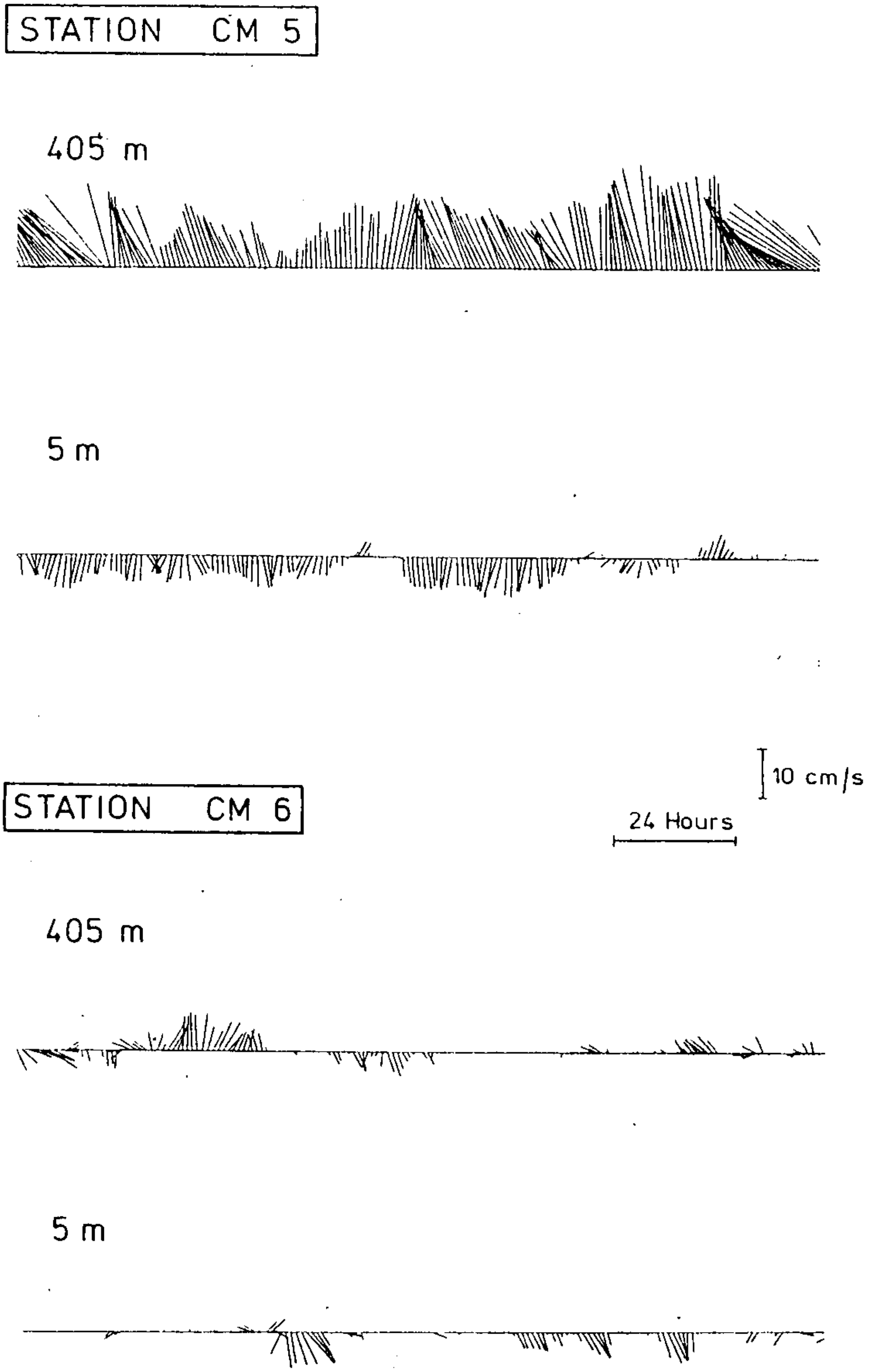


CM 5 : NEAR-SURFACE

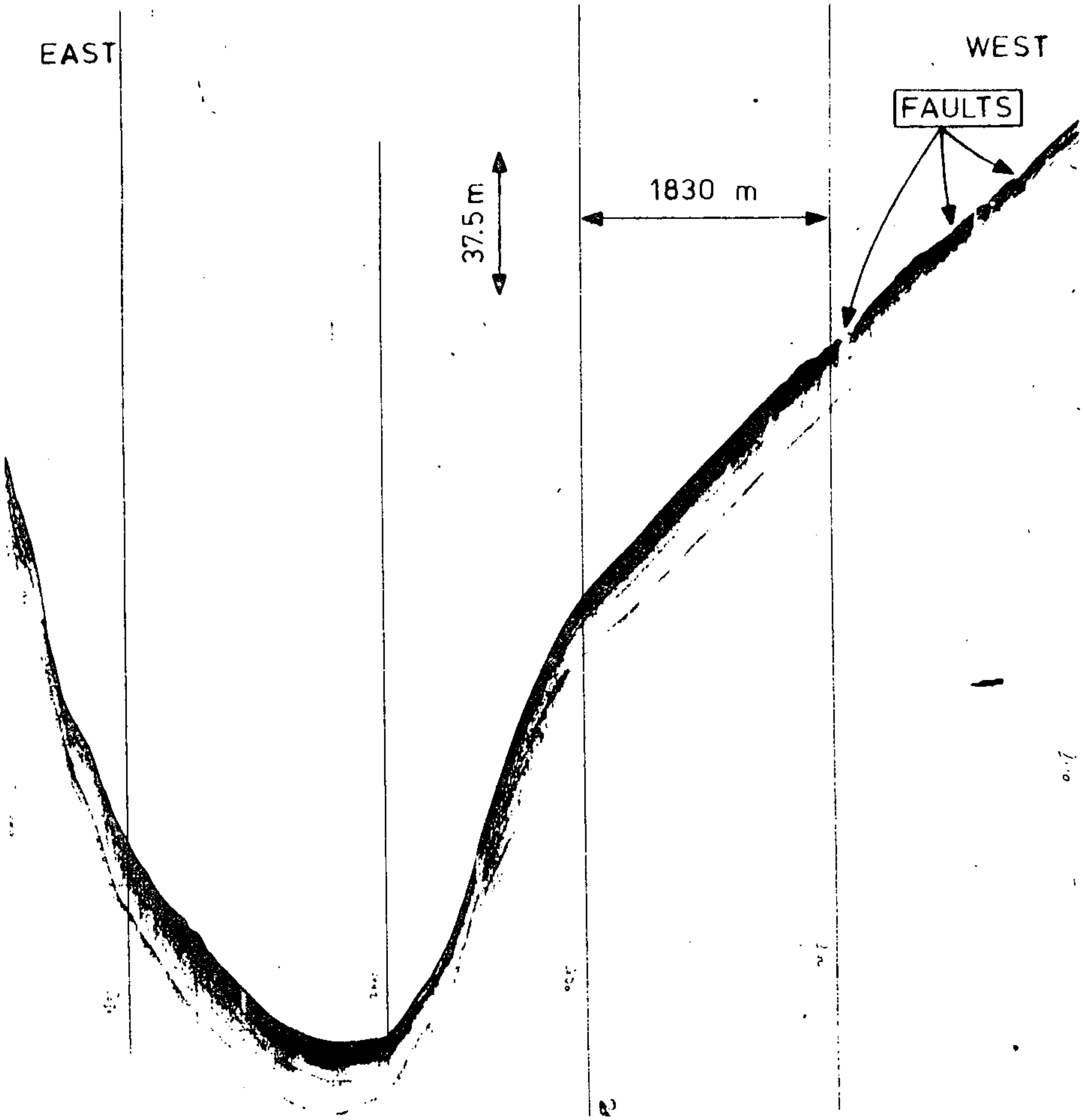


CM 6 : NEAR-SURFACE

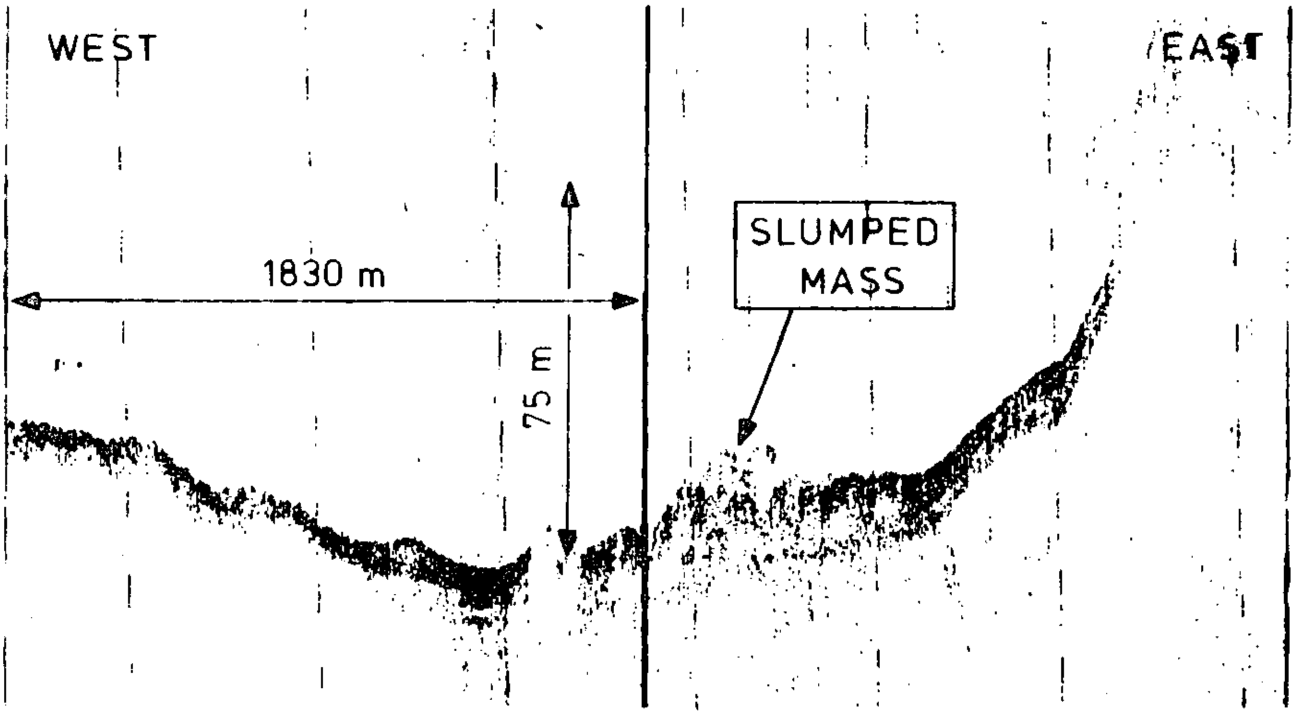
Ferentinos <u>et al</u>, Fig 8



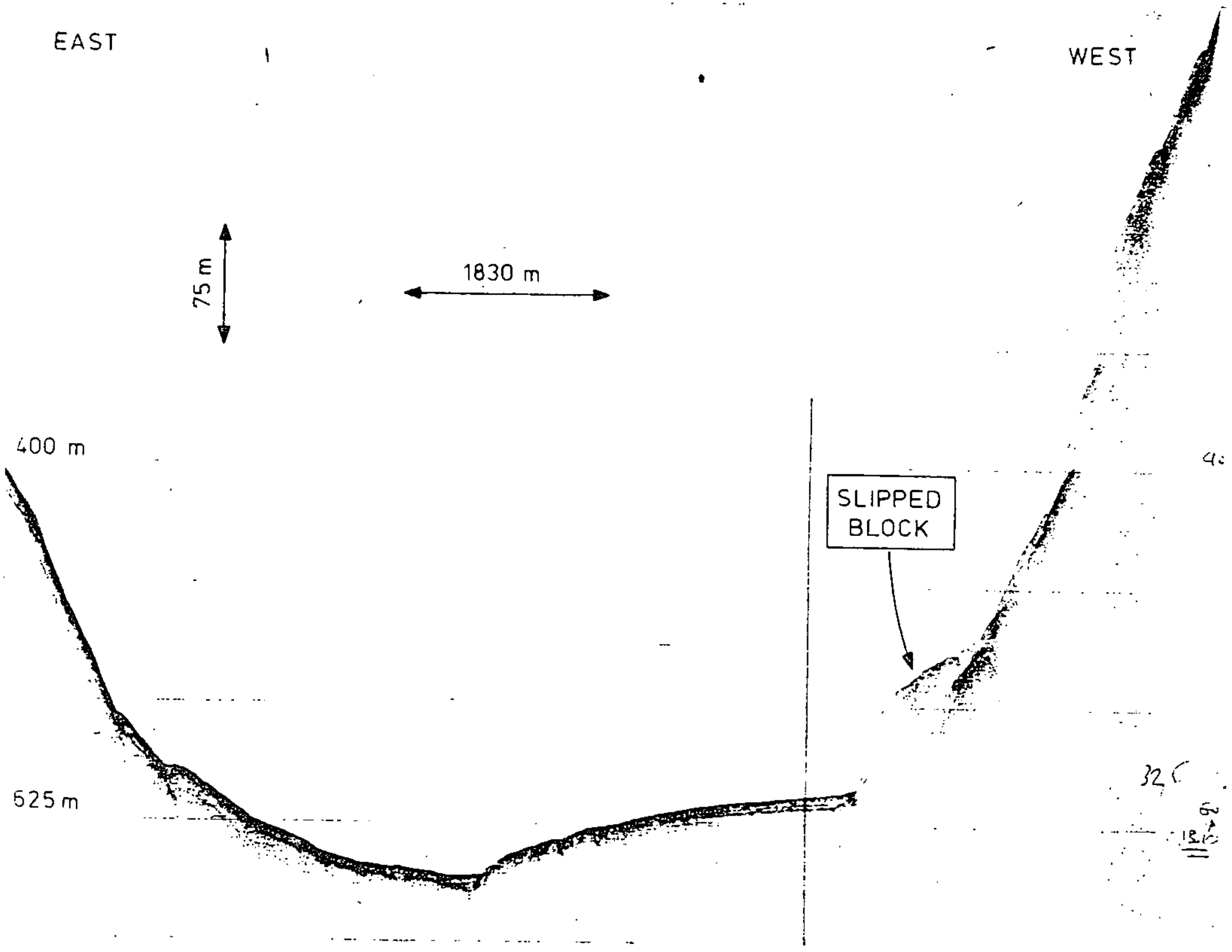
Ferentinos et al, Fig 9



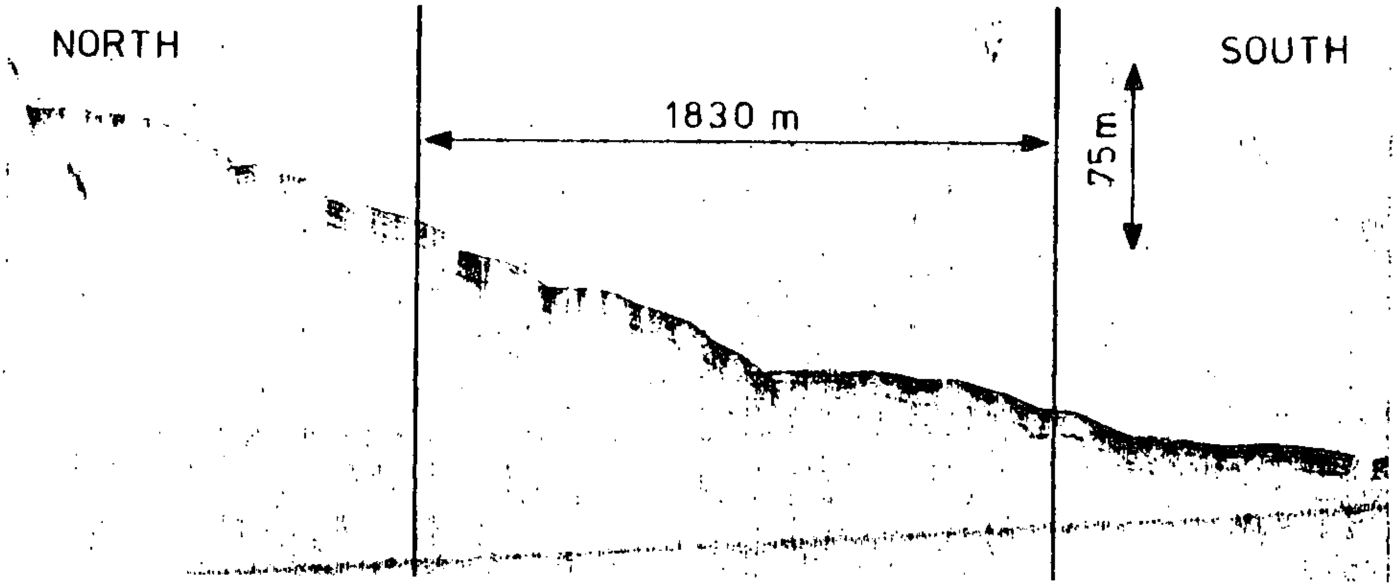
Ferentinos et al, Fig 10a



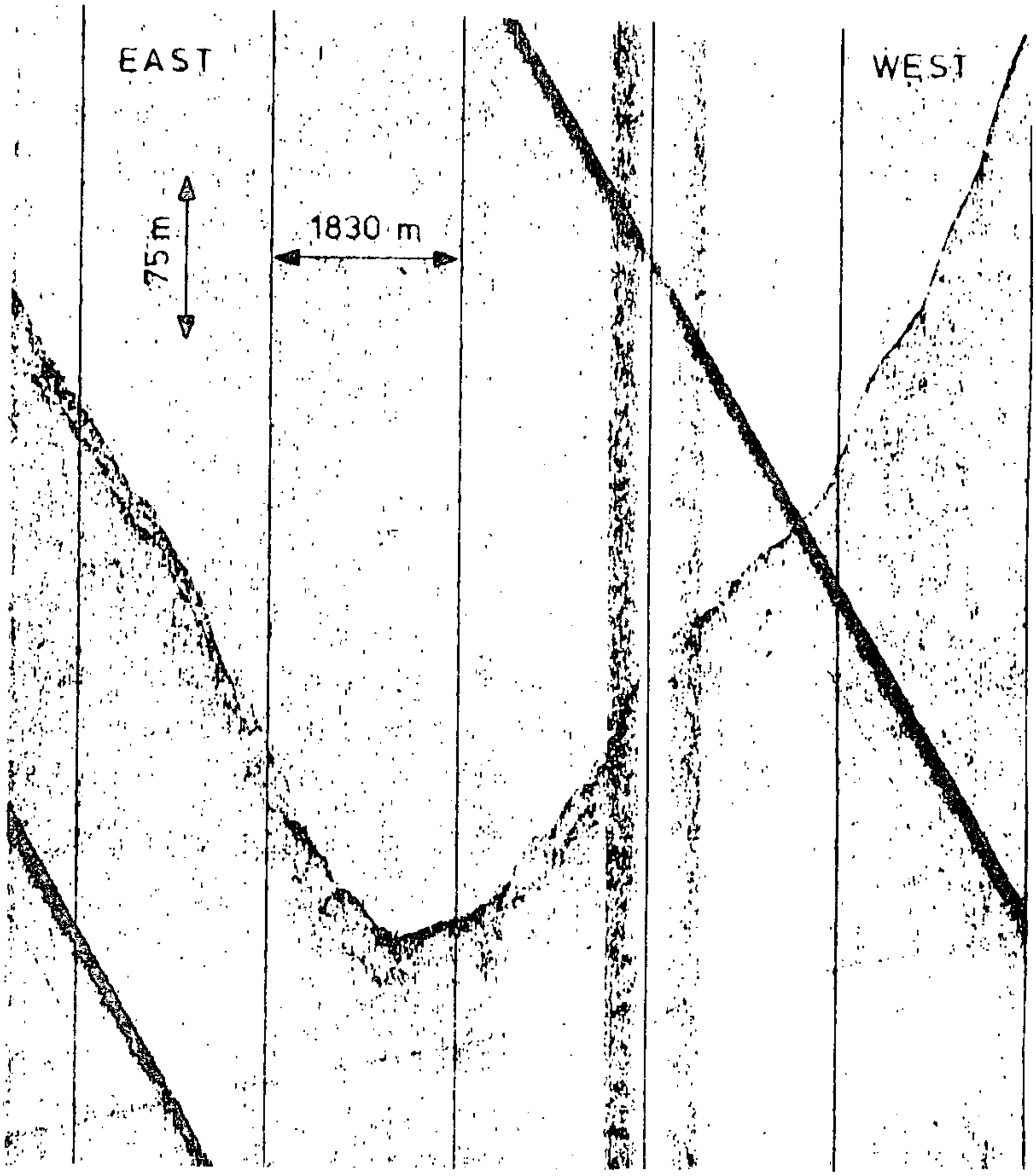
Ferentinos et al, Fig 10b



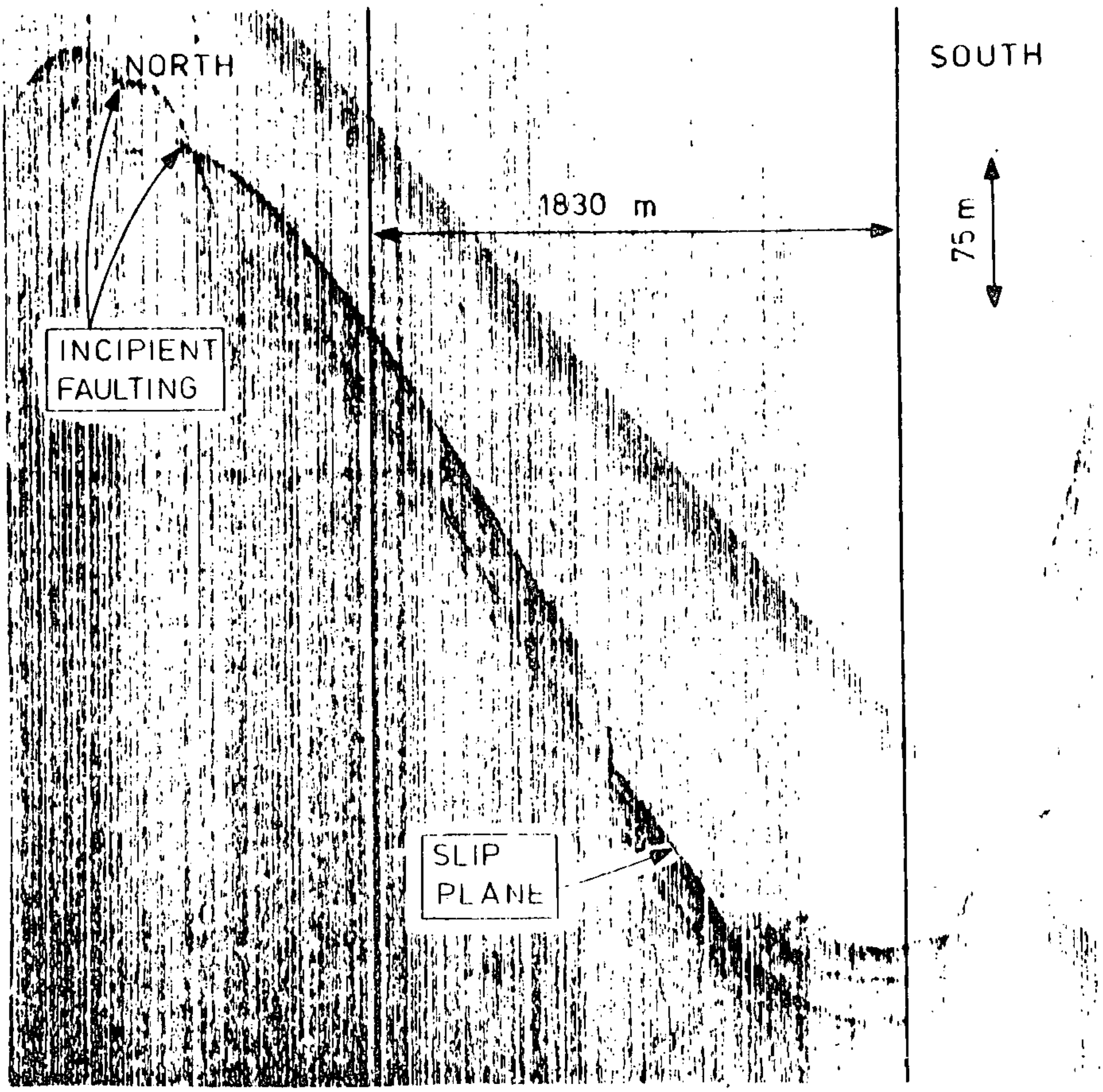
Ferentinos et al, Fig 10c



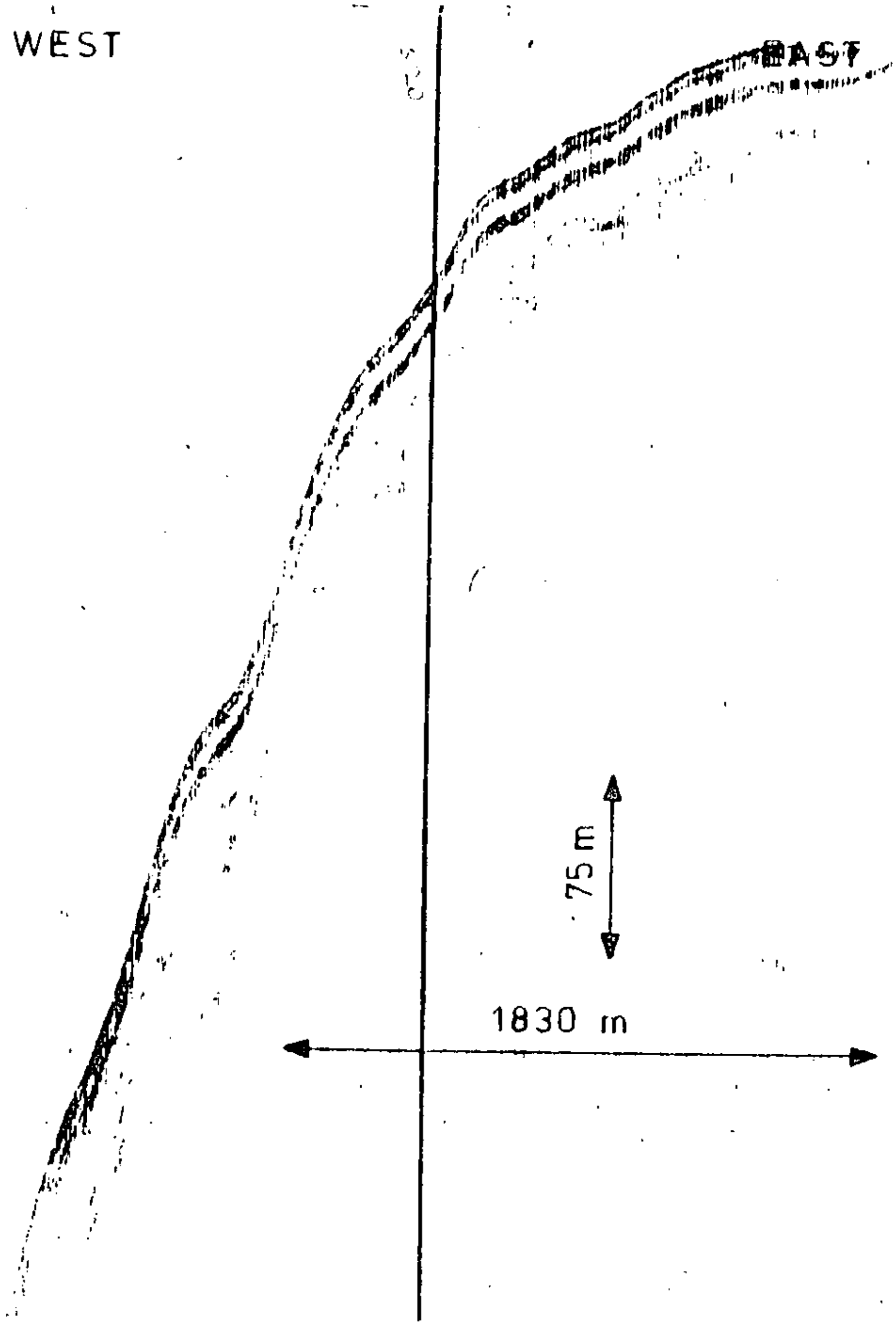
Ferentinos et al, Fig 10d



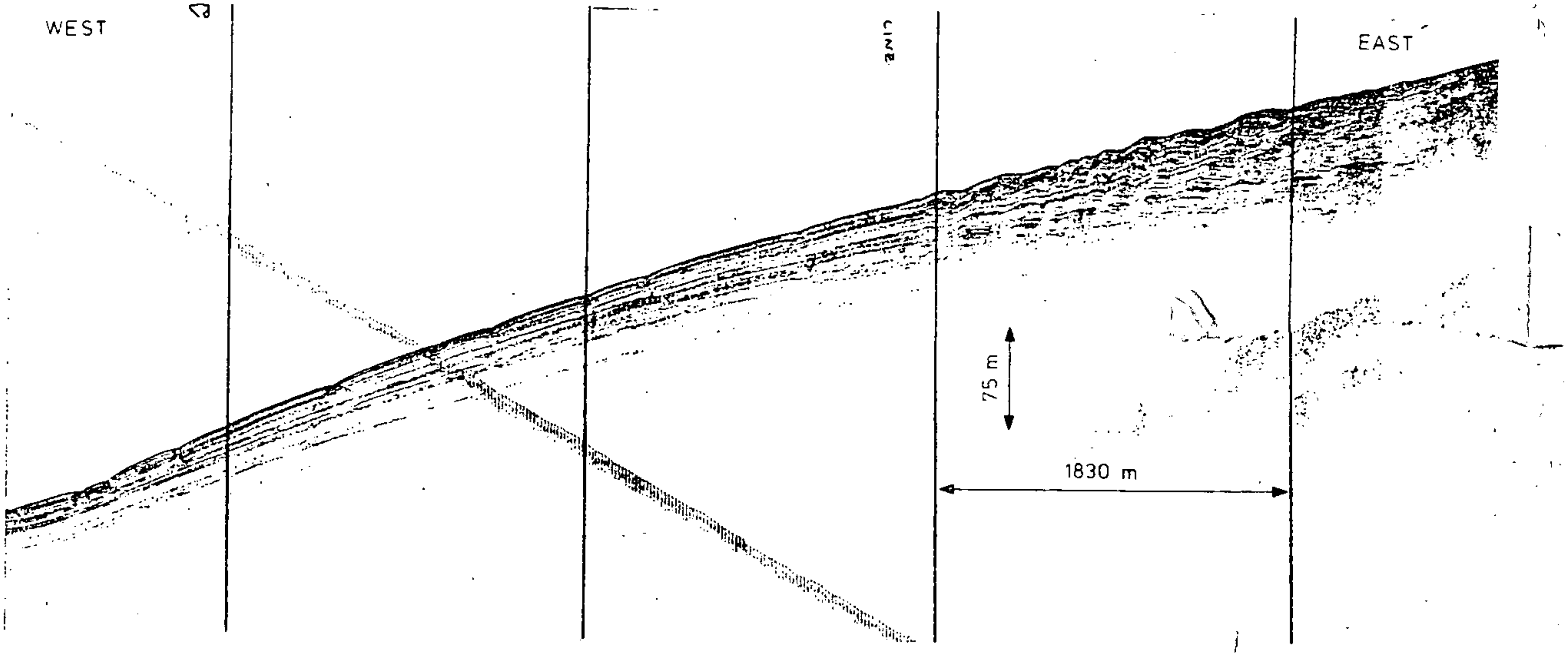
Ferentinos et al, Fig 11a



Ferentinos et al, Fig 11b



Ferentinos et al, Fig 11c



Ferentinos et al, Fig 11a