FAULT ACTIVITY AND PALAEOSEISMICITY DURING QUATERNARY TIME IN SCOTLAND

Volume 2 : Figures and Appendices

This thesis is submitted
for the degree of
Doctor of Philosophy

by

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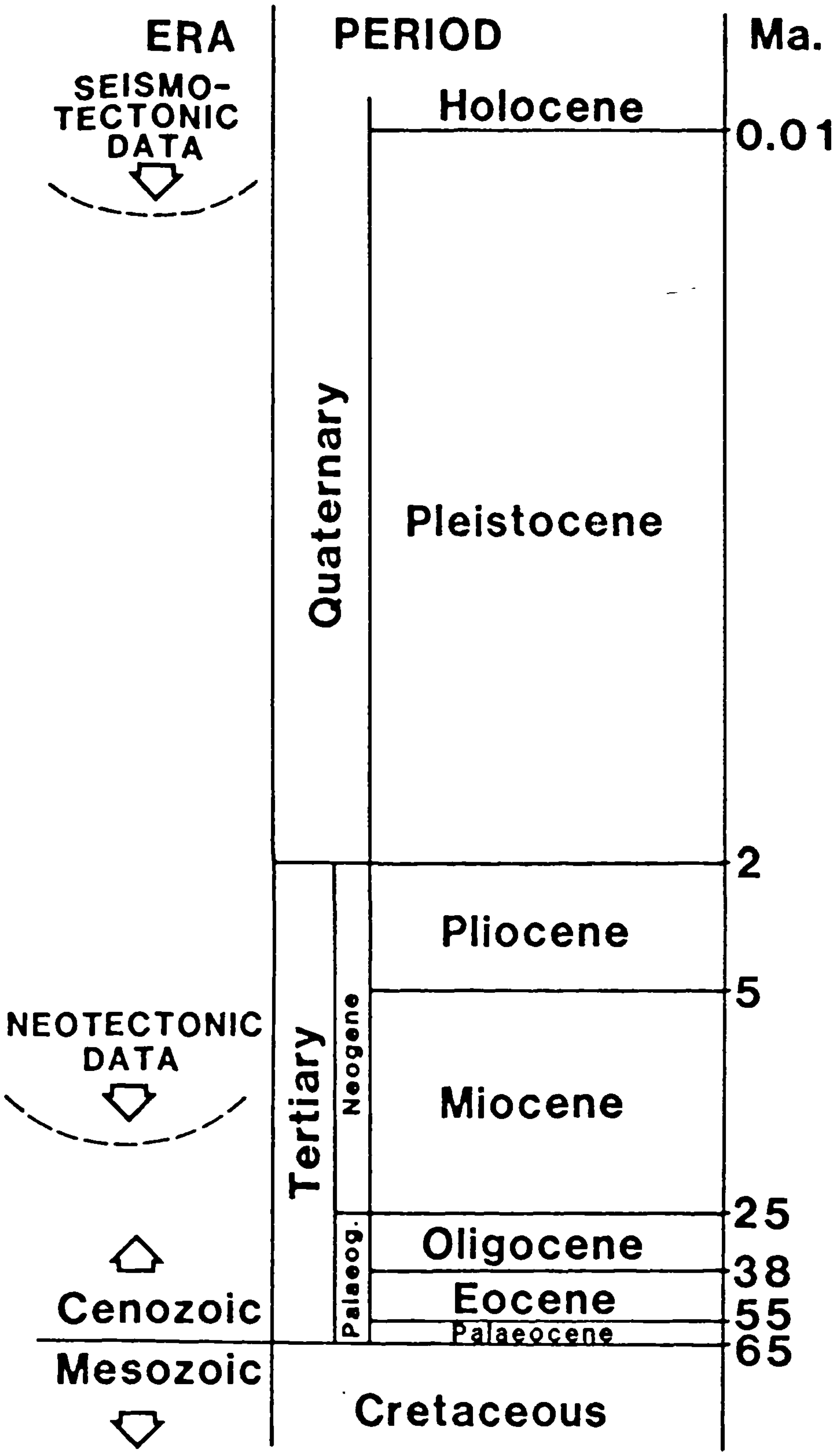


Fig.2-1. An inverse-logarithmic geological column illustrating the relative contributions of geological data in seismotectonic hazard analysis. The seismotectonic and neotectonic 'time-domains' are shown on the left; geological time in millions of years (Ma) is indicated on the right.

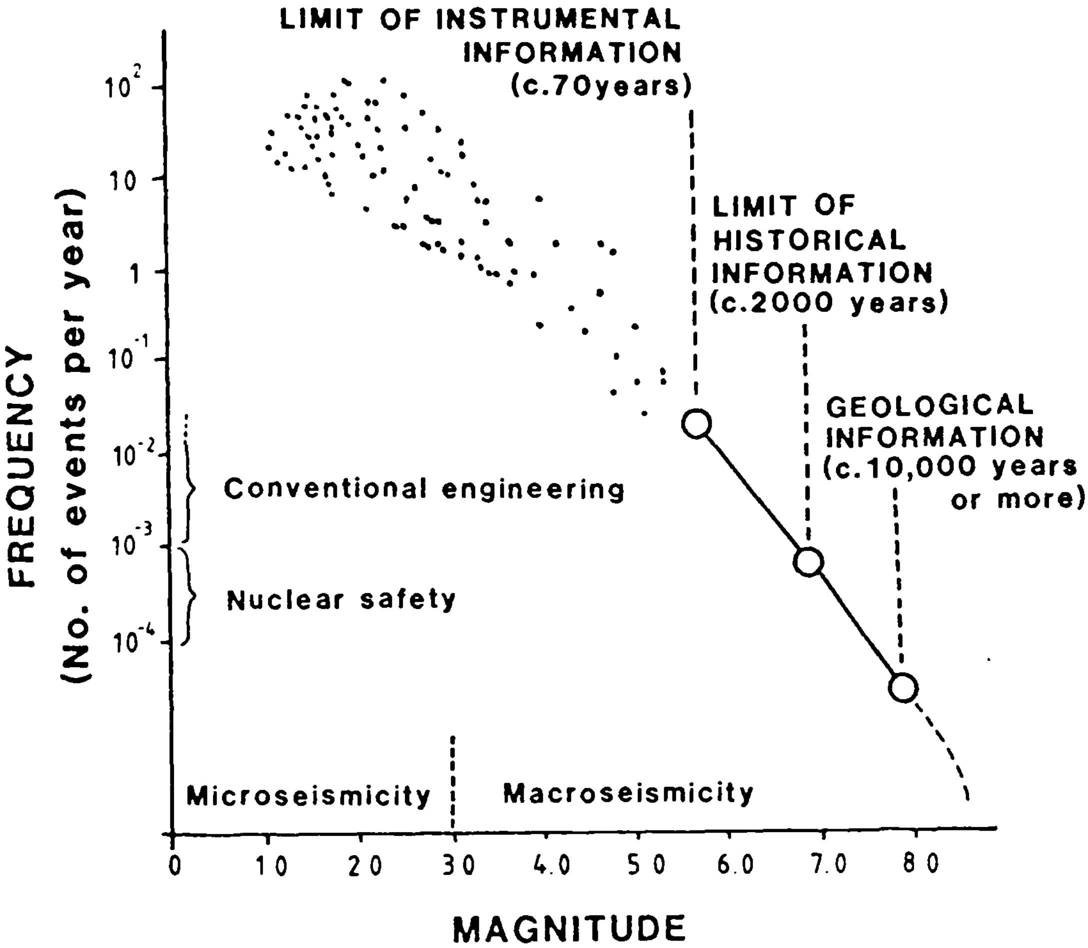


Fig.2-2. Schematic Frequency-Magnitude plot illustrating the sources of information on earthquake recurrence. The frequencies of concern to conventional and nuclear engineering are indicated.

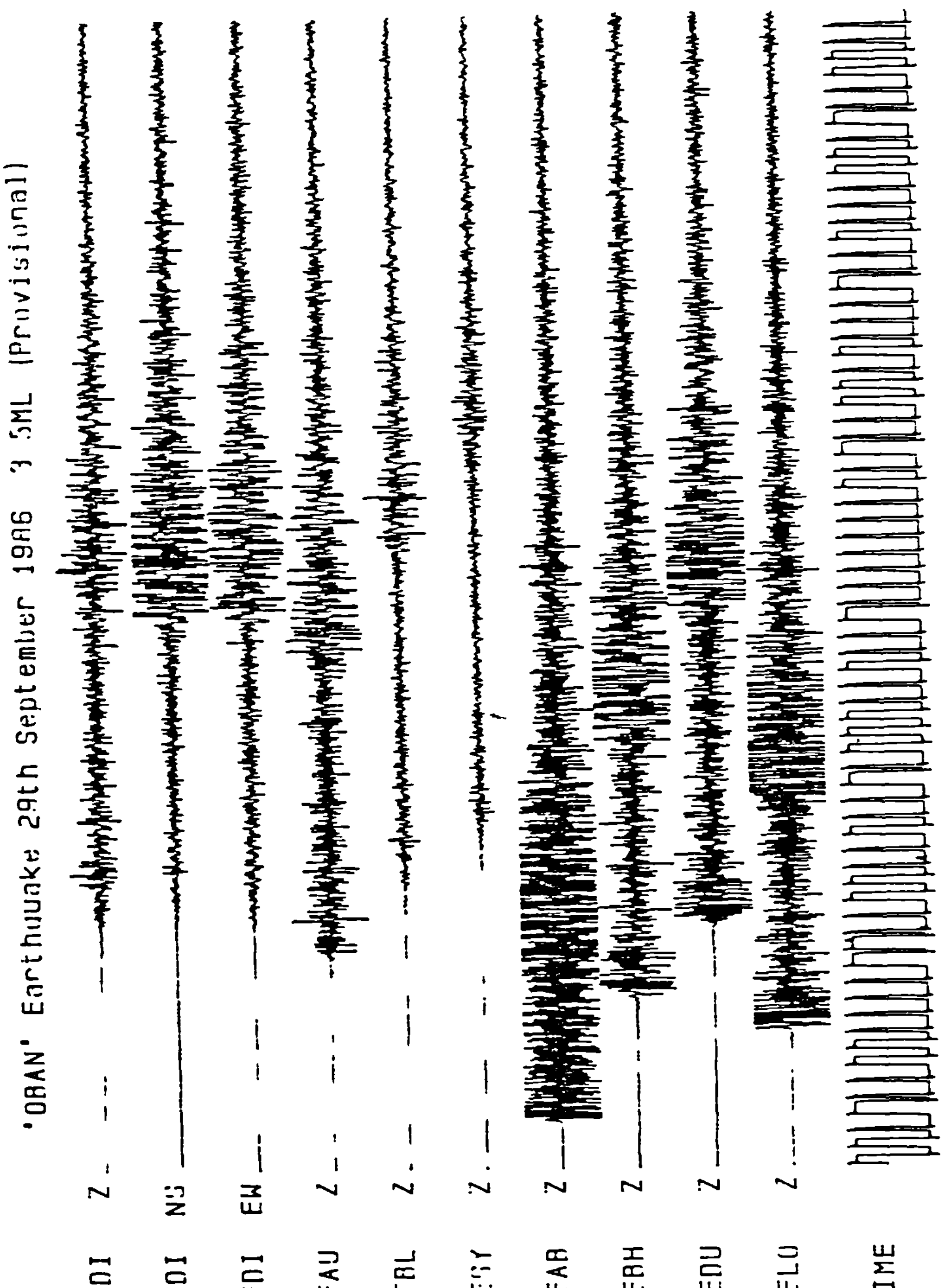


Fig.2-3. Seismic traces of the 'Oban' earthquake of 29th September 1986, magnitude 3.5, as recorded by the British Geological Survey on LOWNET (recording stations EDI etc. are all in the LOWNET array - shown in Fig.5-9).

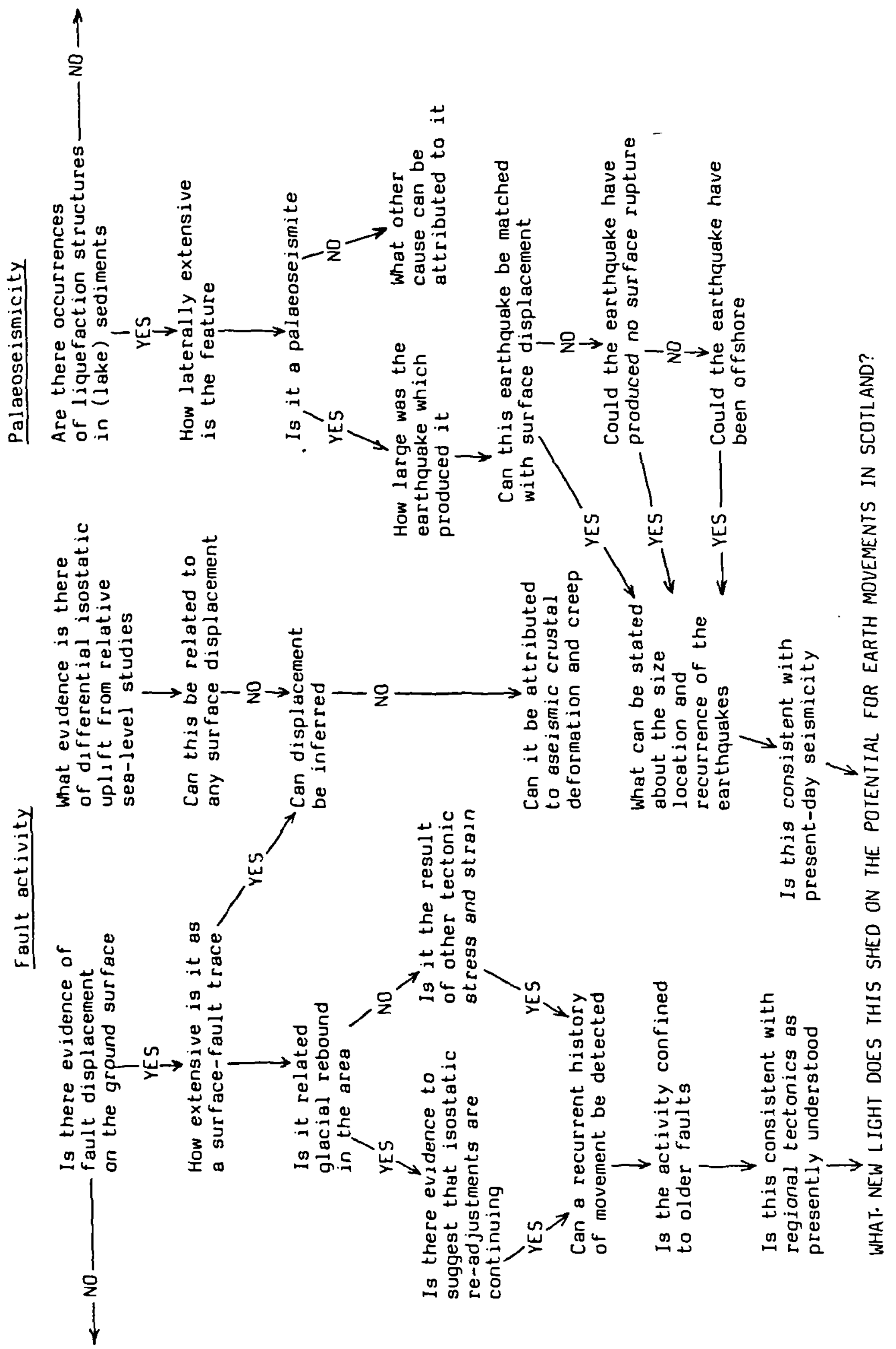


Fig.3-1. Flow diagram showing the questions and thought-paths considered relevant to this study, as perceived in November 1983 at the commencement of the research programme (1983-1987).

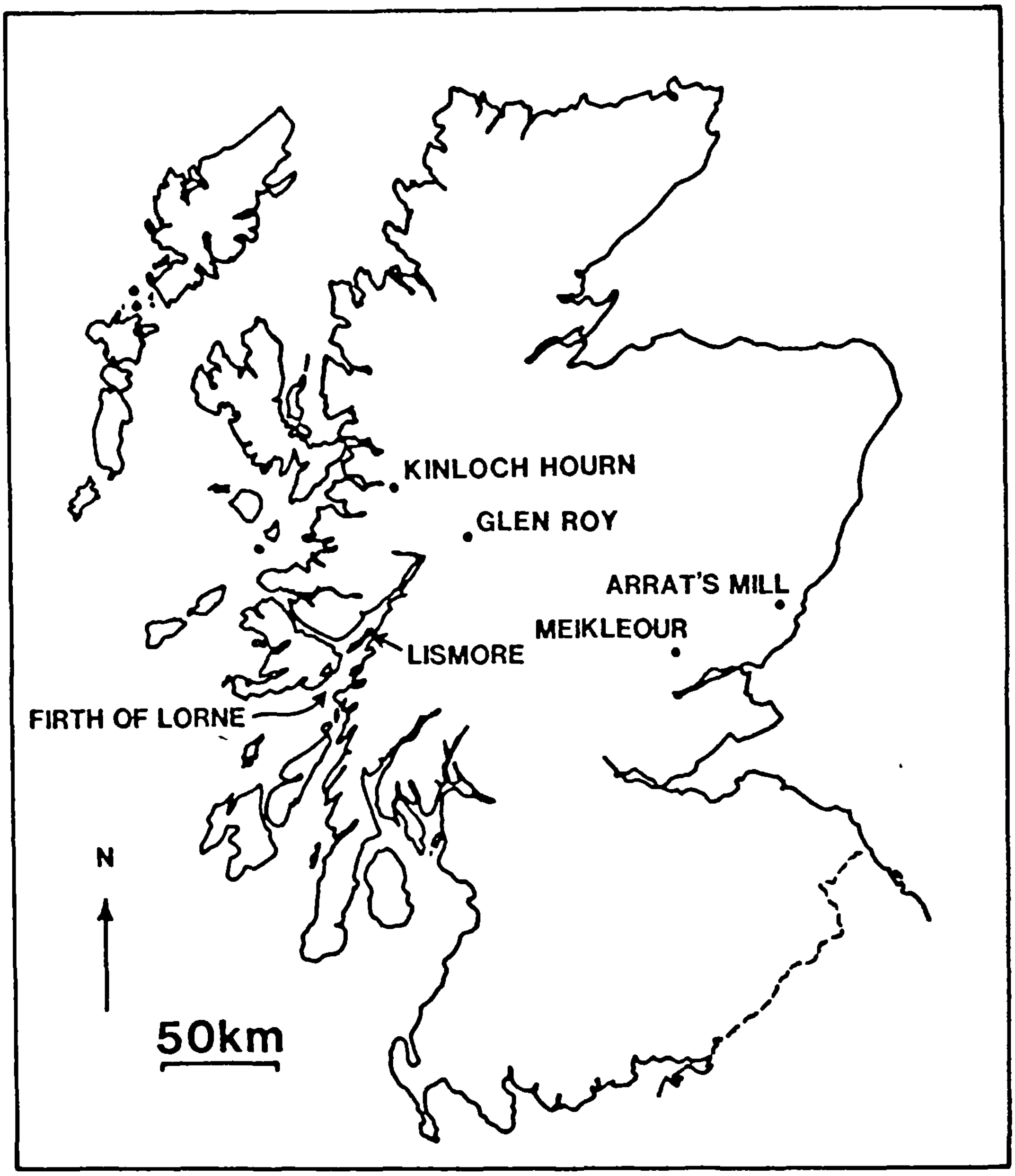


Fig.3-2. The main localities of field study documented in this thesis (the chapter headings in 'Part III - Science' refer to these localities).

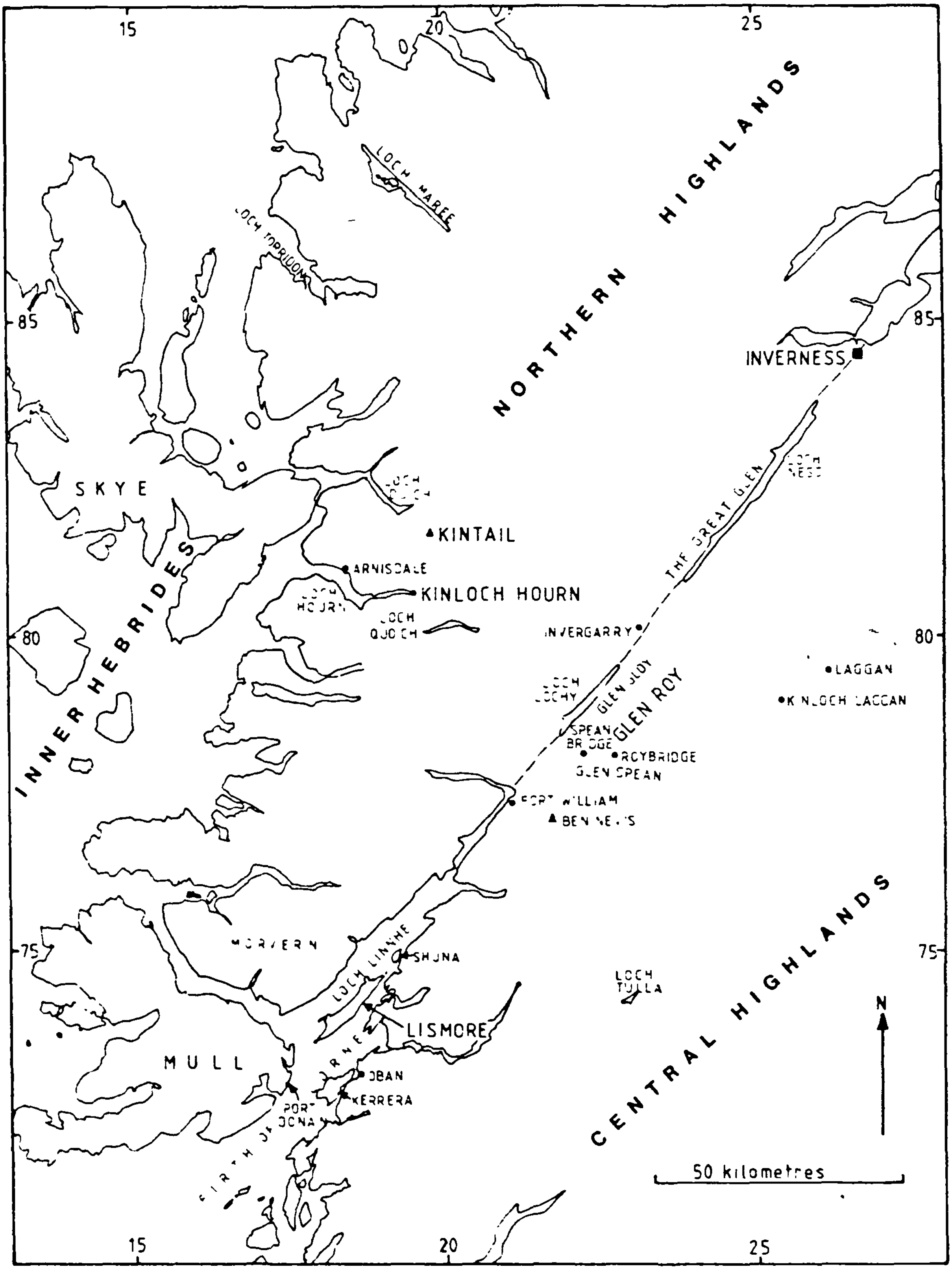


Fig.3-3. Localities, in the west of Scotland, referred to in the thesis.

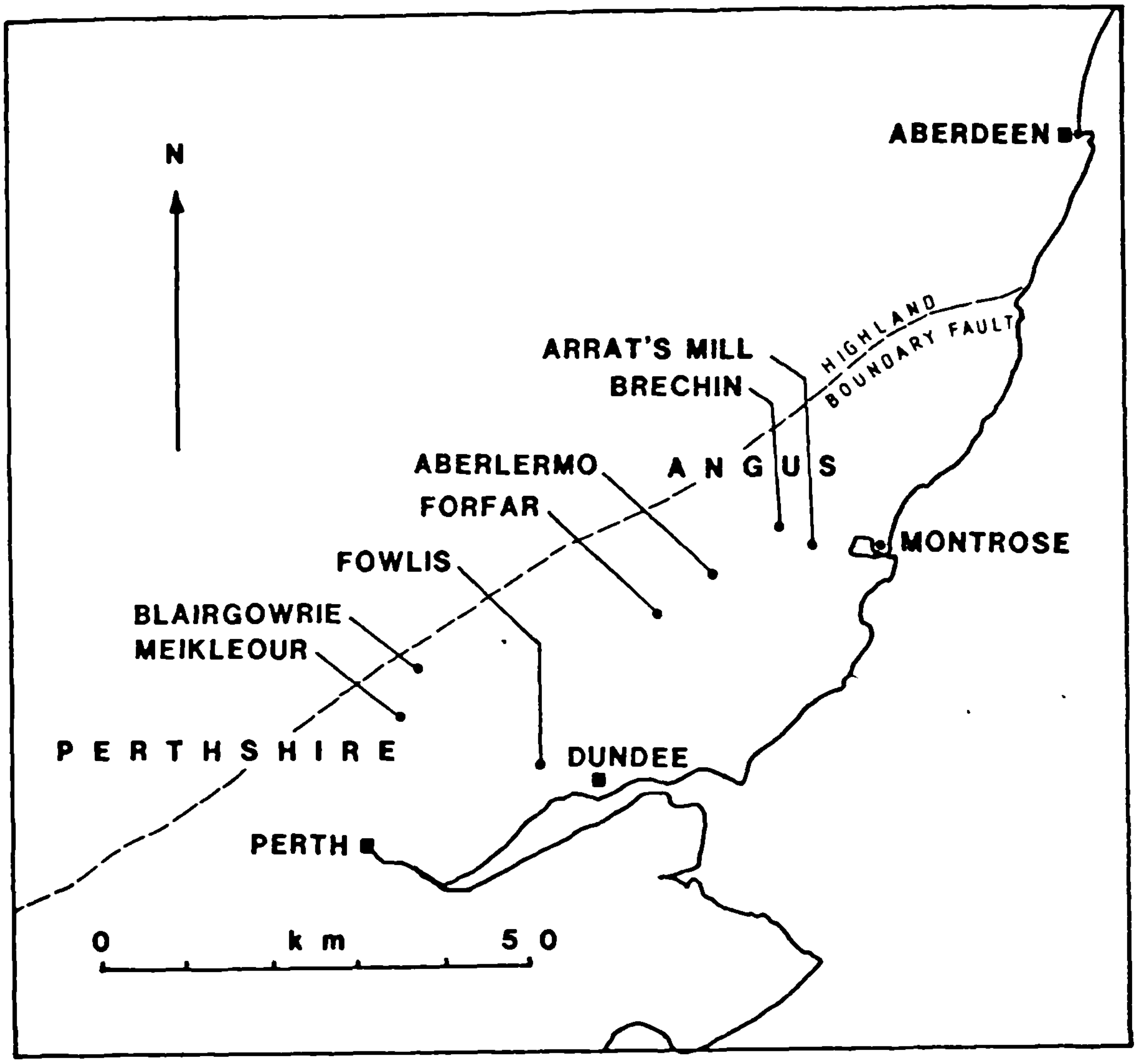


Fig.3-4. Localities, in the east of Scotland, referred to in the thesis.

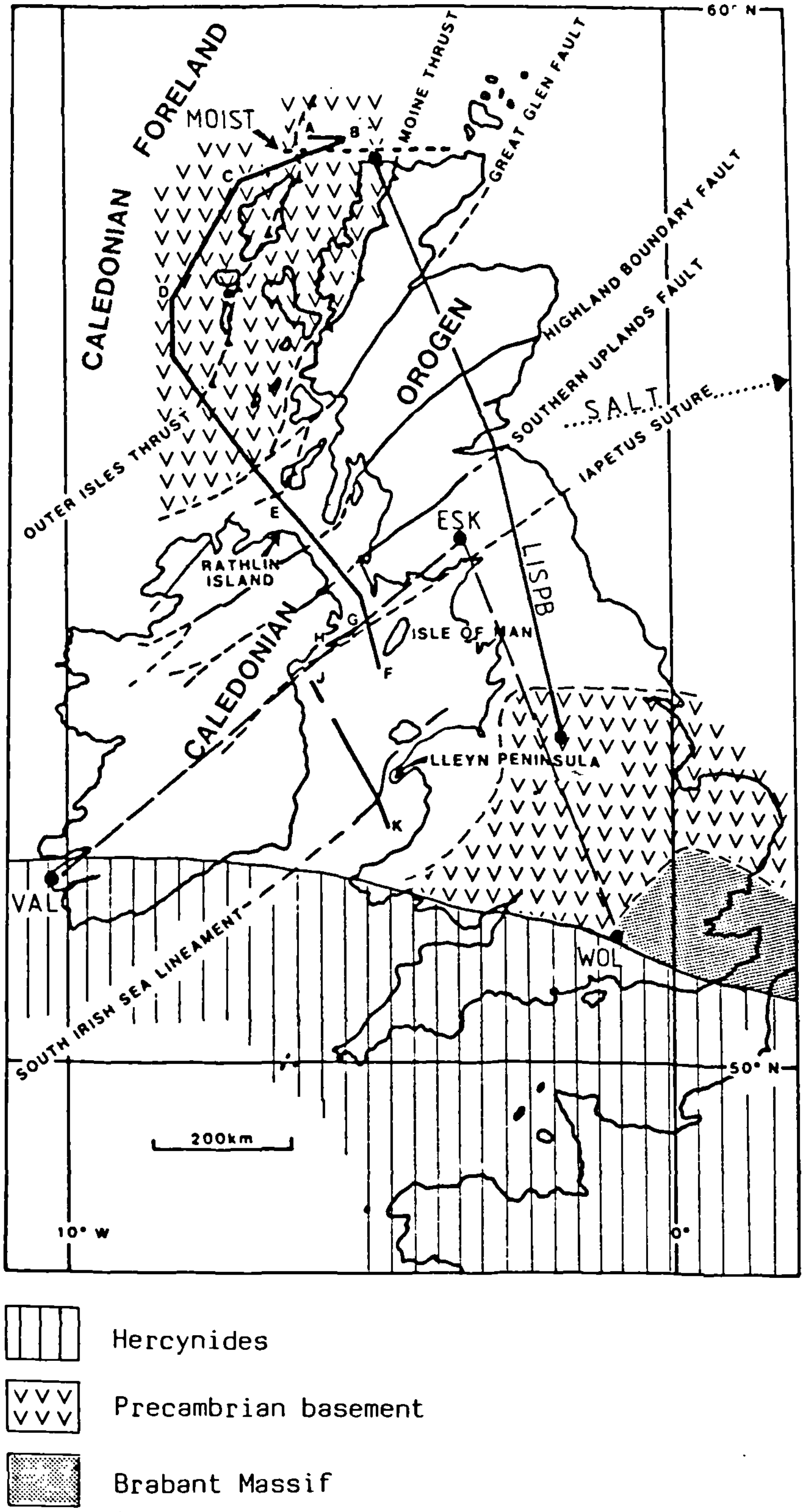


Fig.4-1. Major basement provinces of the British Isles with the geophysical profiles mentioned in the text (4.2): WINCH profile = heavy line A-K; MOIST profile = dashed line; LISPB = solid line; SALT = dotted line (continuing eastwards off map); and the shear wave profiles of Stuart & Clark (1981) = dashed line between seismograph stations, VAL, ESK and WOL. (Based on Fig.1 of Brewer et al. 1983, reprinted with permission from Nature, Vol.305, No.5931, p.207. Copyright (c) 1983, Macmillan Journals Limited.)

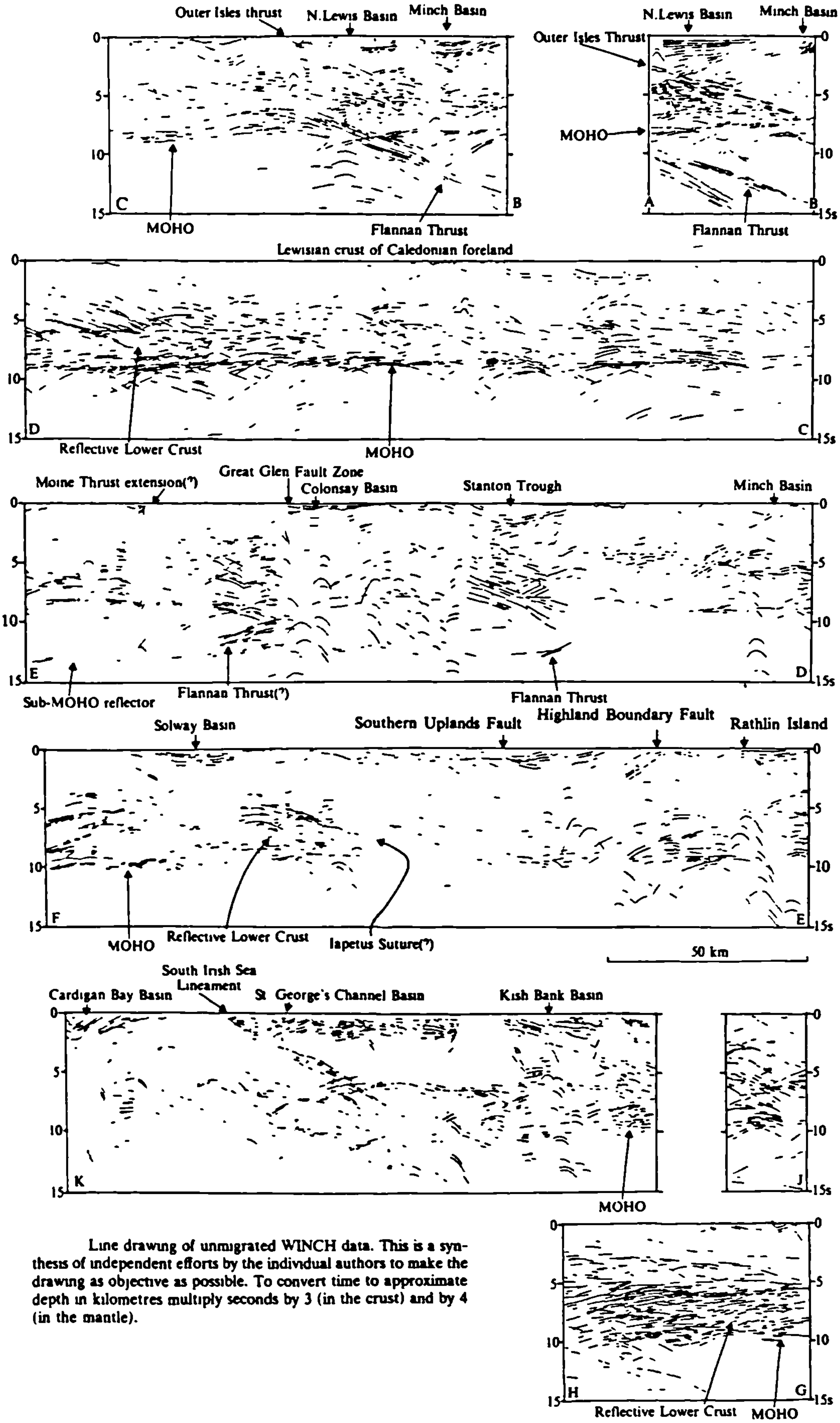


Fig.4-2. The WINCH seismic reflection profile. Lettered positions refer to Fig. 4-1. (Reprinted from Brewer et al. 1983 with permission from Nature, Vol.305, No.5931, p.207. Copyright (c) 1983, Macmillan Journals Limited.)

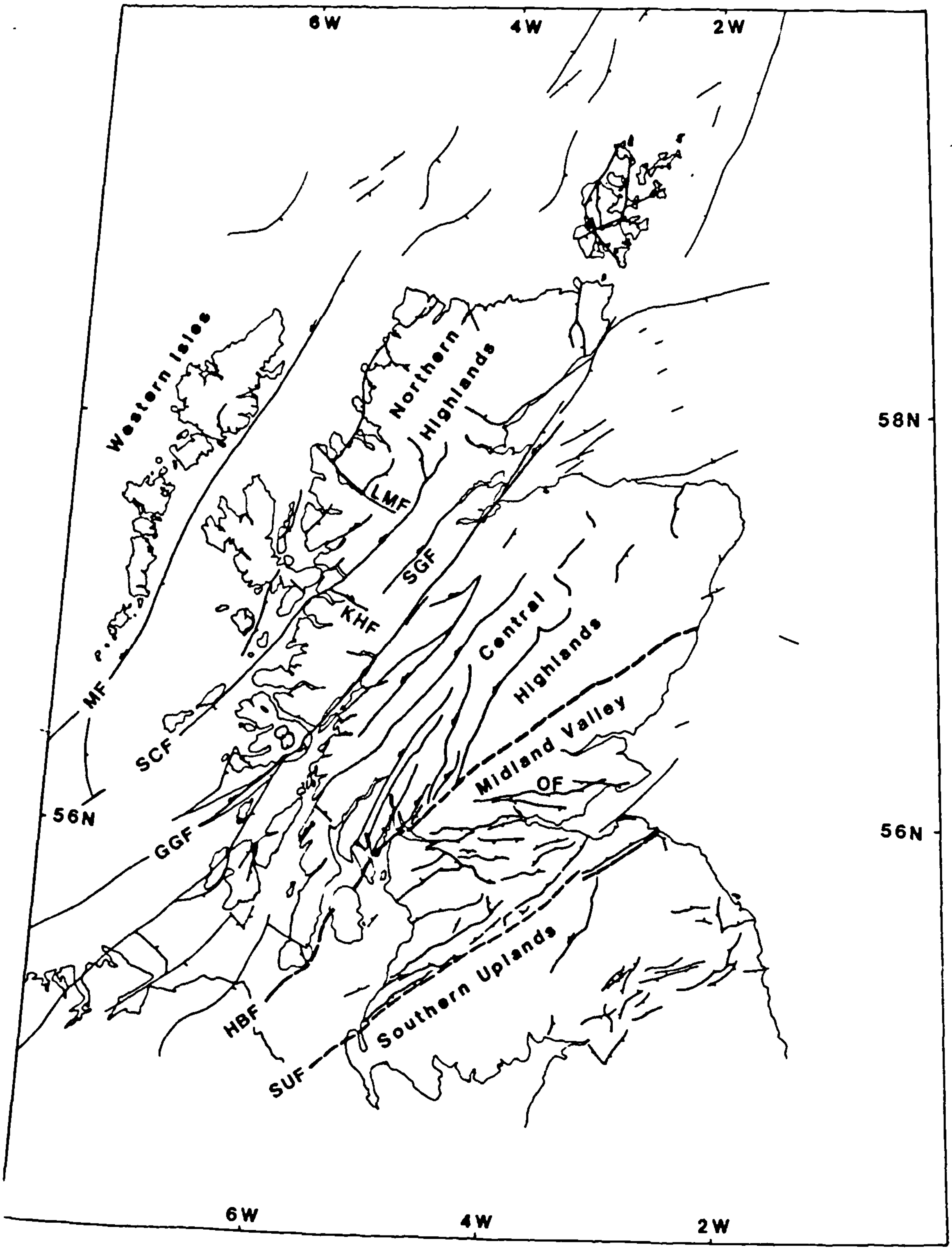


Fig.4-3. The major faults of Scotland. Thick dashed lines = deep-seated faults bounding blocks and controlling sedimentation; SUF = Southern Uplands Fault, OF = Ochill fault, HBF = Highland boundary fault, SGF = Strath Glass Fault, SCF = Strath Conon Fault, KHF = Kinloch Hourn Fault, LMF = Loch Maree Fault, MF = Minch Fault. (Onshore faults from "Tectonic map of Great Britain and Northern Ireland", I.G.S. 1966; offshore faults from Evans et al. 1982).

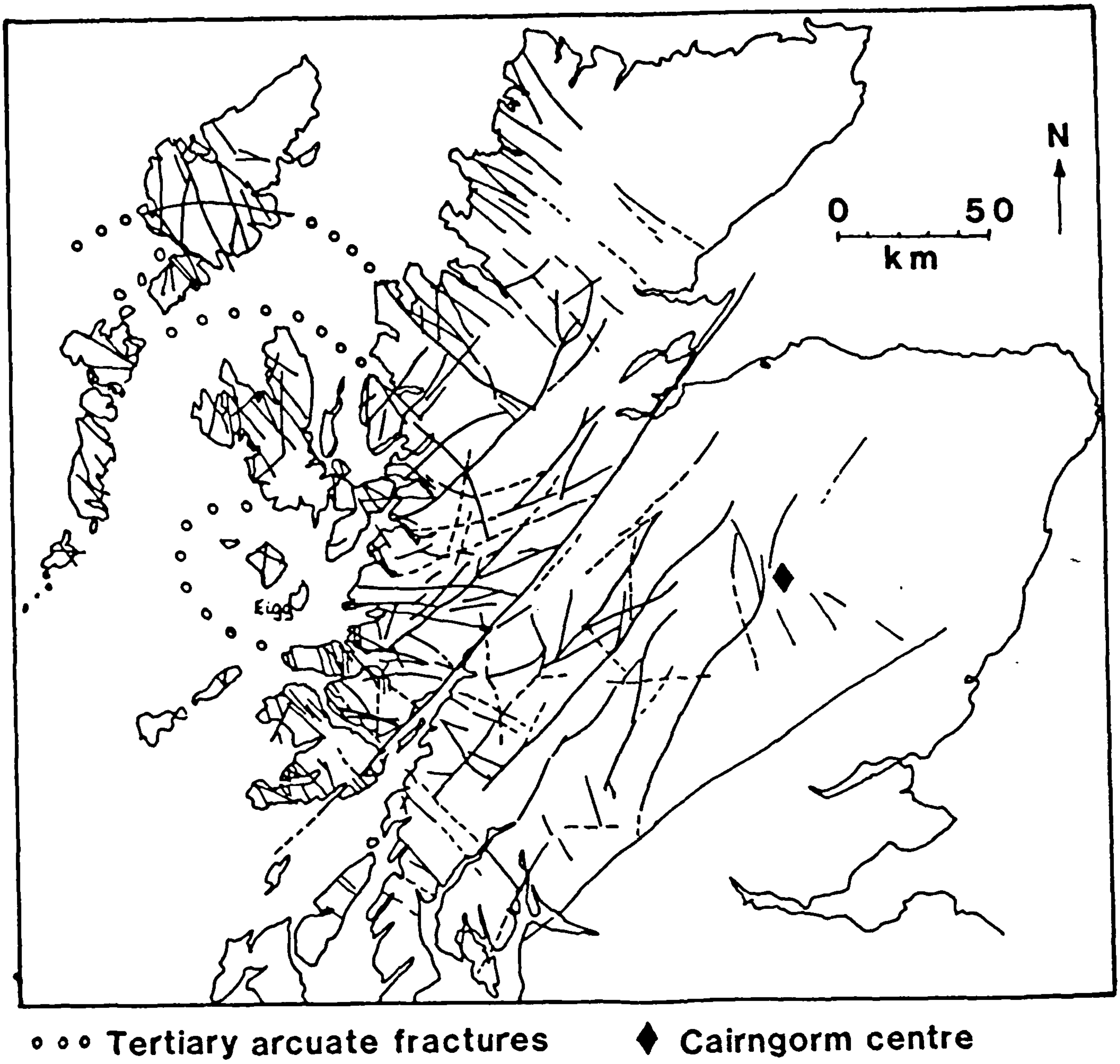
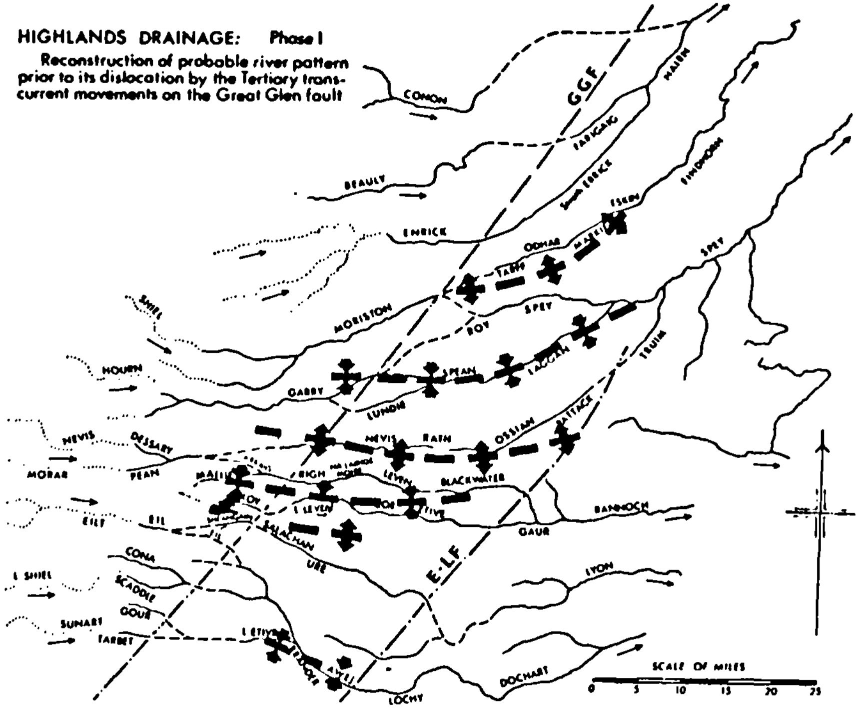
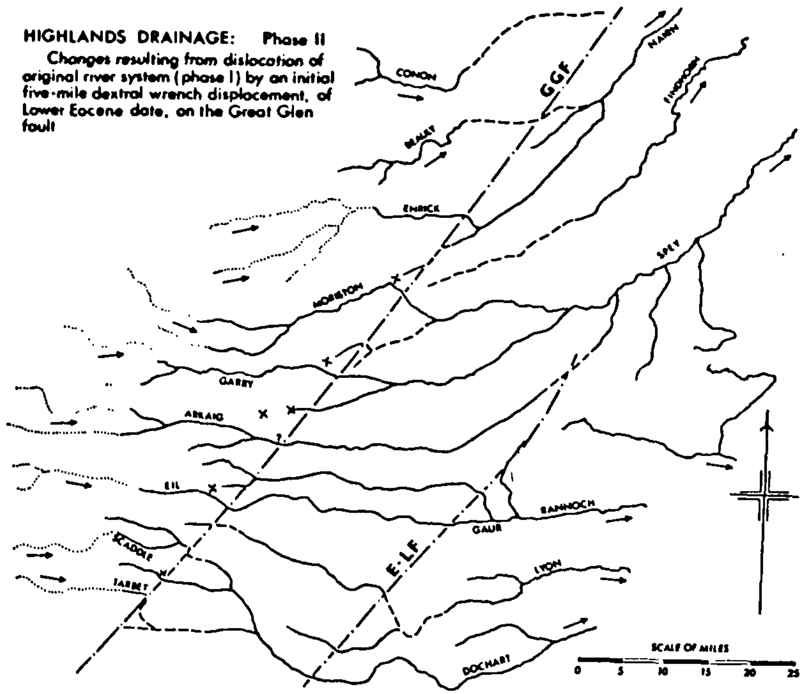


Fig.4-4. Auden's (1954) map of fractures in Scotland compiled from published maps and by inference from topographic features. His suggestions for Tertiary arcuate fractures around a point near Eigg and for radial fractures around Cairngorm are indicated.



The Highlands Tertiary drainage: Phase I. The disposition of a late pre-wrench folding system is shown, and the initial readjustments of drainage pattern which followed are indicated. An apparent late sinistral wrench of approximately three and a half miles amplitude on the Ericht–Laidon fault (E-LF) is also eliminated in this reconstruction.



The Highlands Tertiary drainage: Phase II. Windgaps consequent upon readjustment of drainage are shown by an 'opposed-U' symbol.

Fig.4-5. Holgate's (1969) two phase reconstruction of Tertiary drainage. The traces of fold axes marked were inferred from heights of Tertiary river valleys (colls, windgaps and watersheds). The recontruction has been made by restoration of an 18 mile (30km) dextral shift.

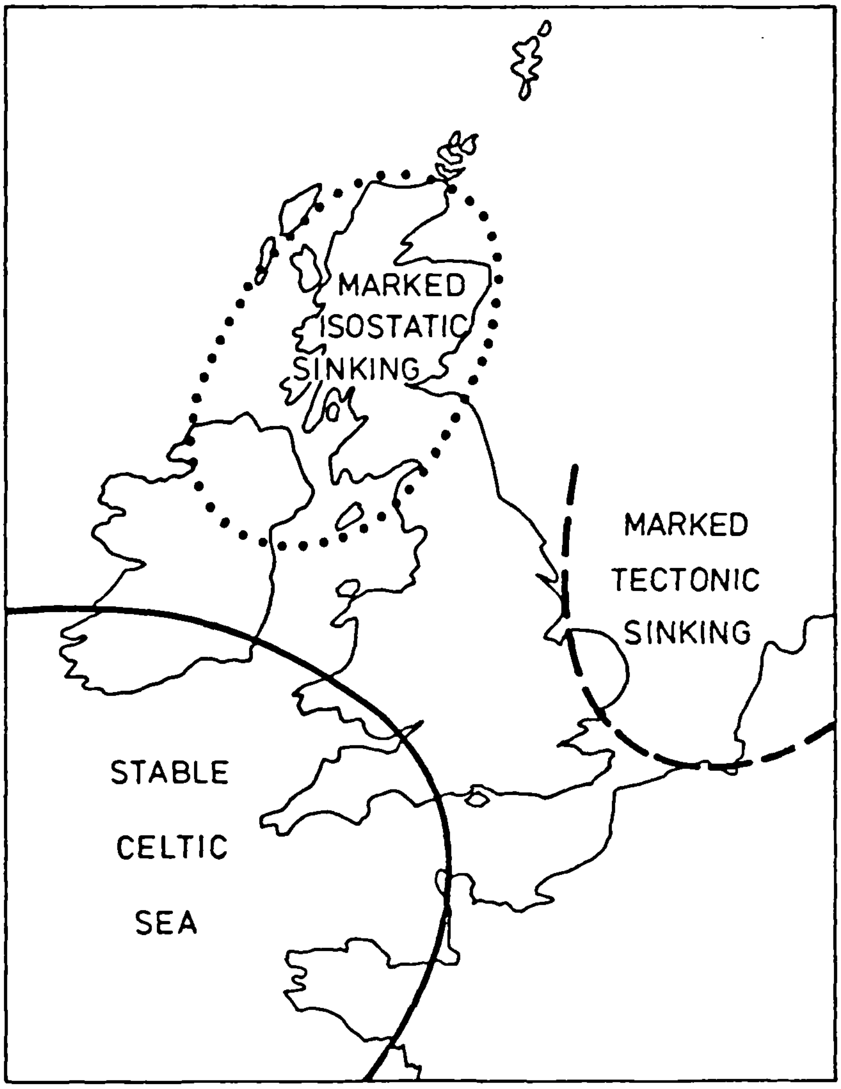


Fig.4-6. Mitchell's (1977) map of Quaternary tectonic (epeirogenic) provinces. Note that 'marked isostatic sinking' is presently undergoing uplift due to rebound. (For discussion see section 4.4.4).

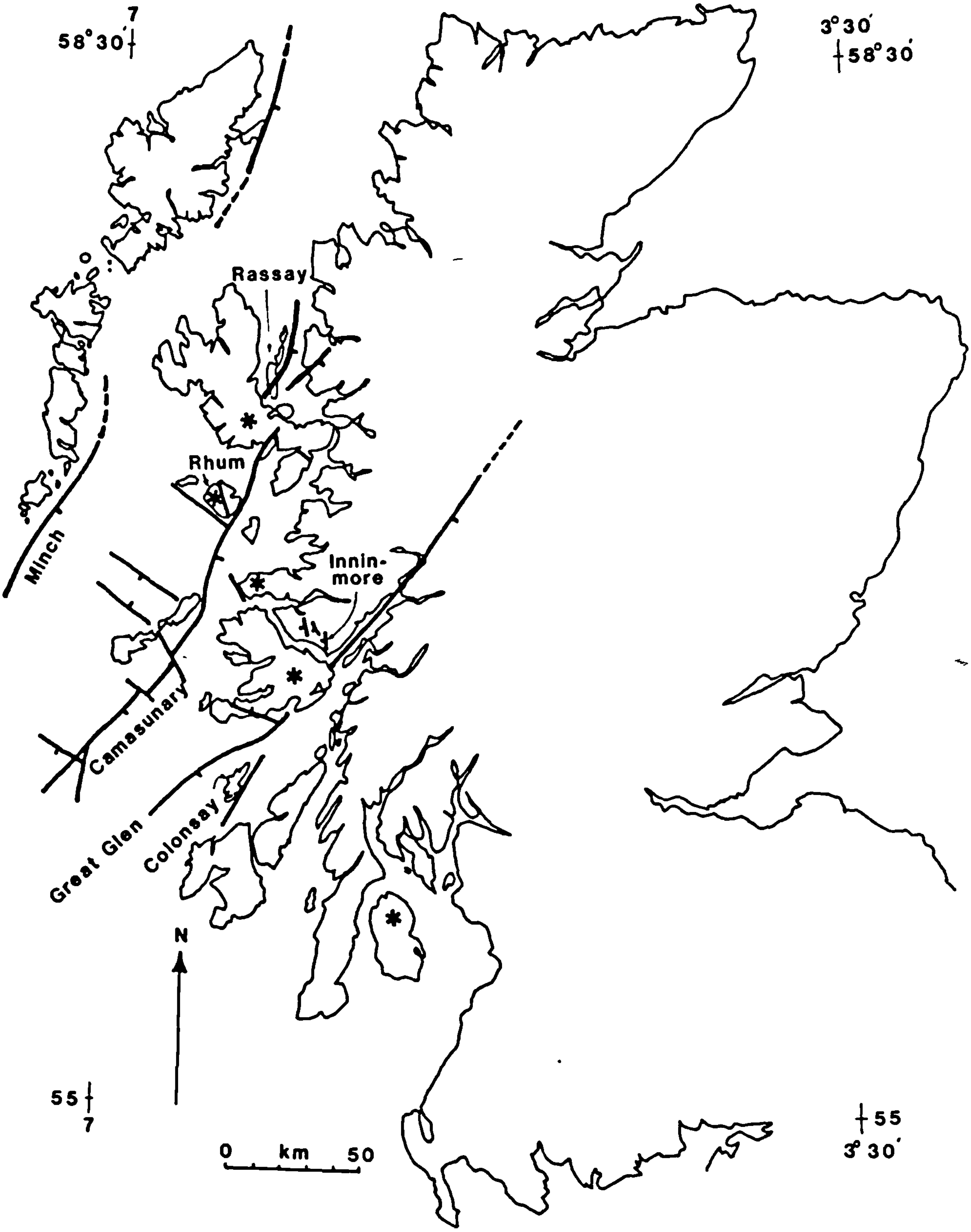


Fig.4-7. Major Tertiary faults (compiled mainly from Binns et al. 1975). The main onland Tertiary igneous centres are marked by an asterisk.

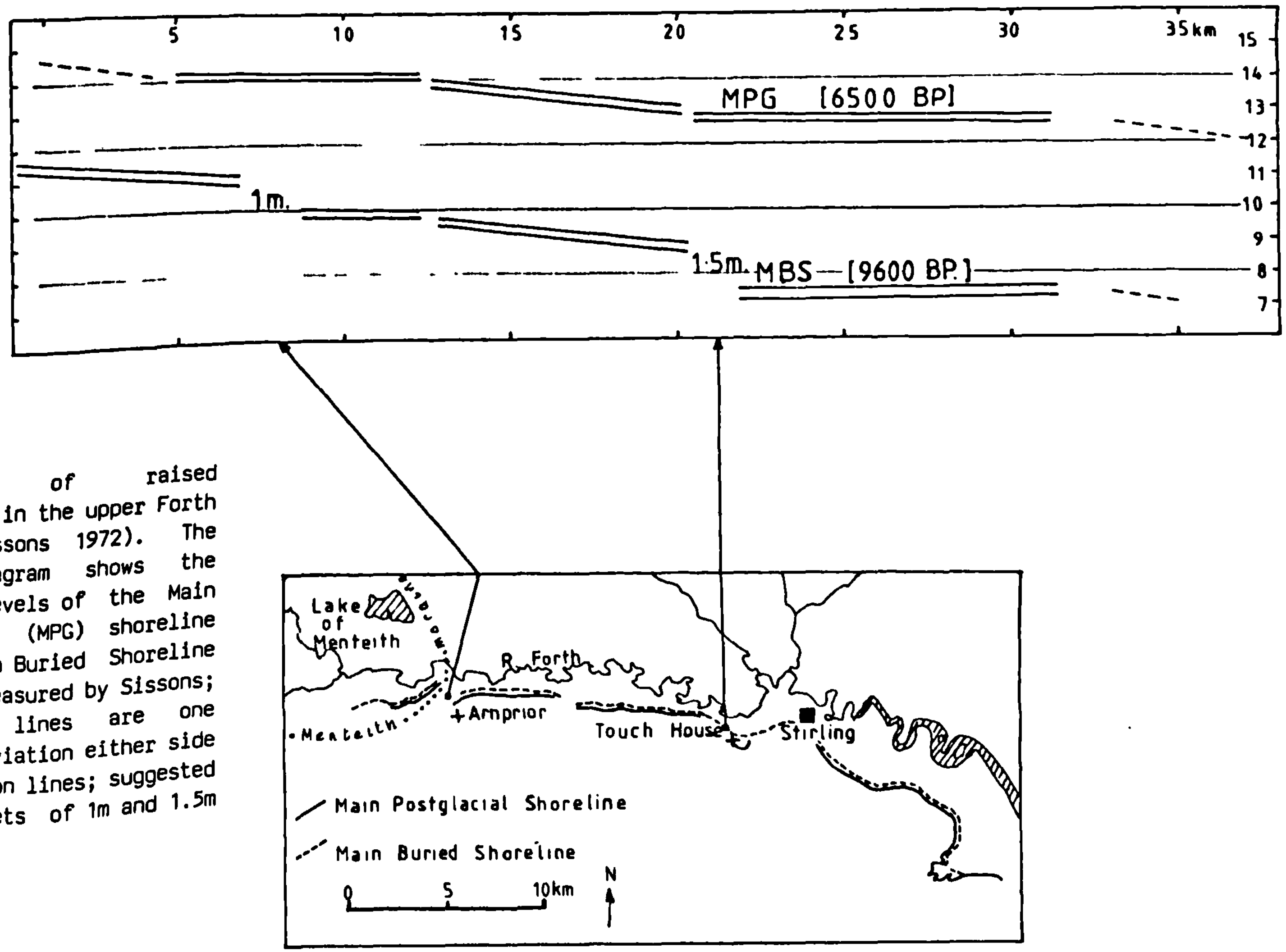


Fig.4-8. Dislocation of raised shorelines in the upper Forth Valley (Sissons 1972). The upper diagram shows the shoreline levels of the Main Postglacial (MPG) shoreline and the Main Buried Shoreline (MBS) as measured by Sissons; the double lines are one standard deviation either side of regression lines; suggested fault offsets of 1m and 1.5m are shown.

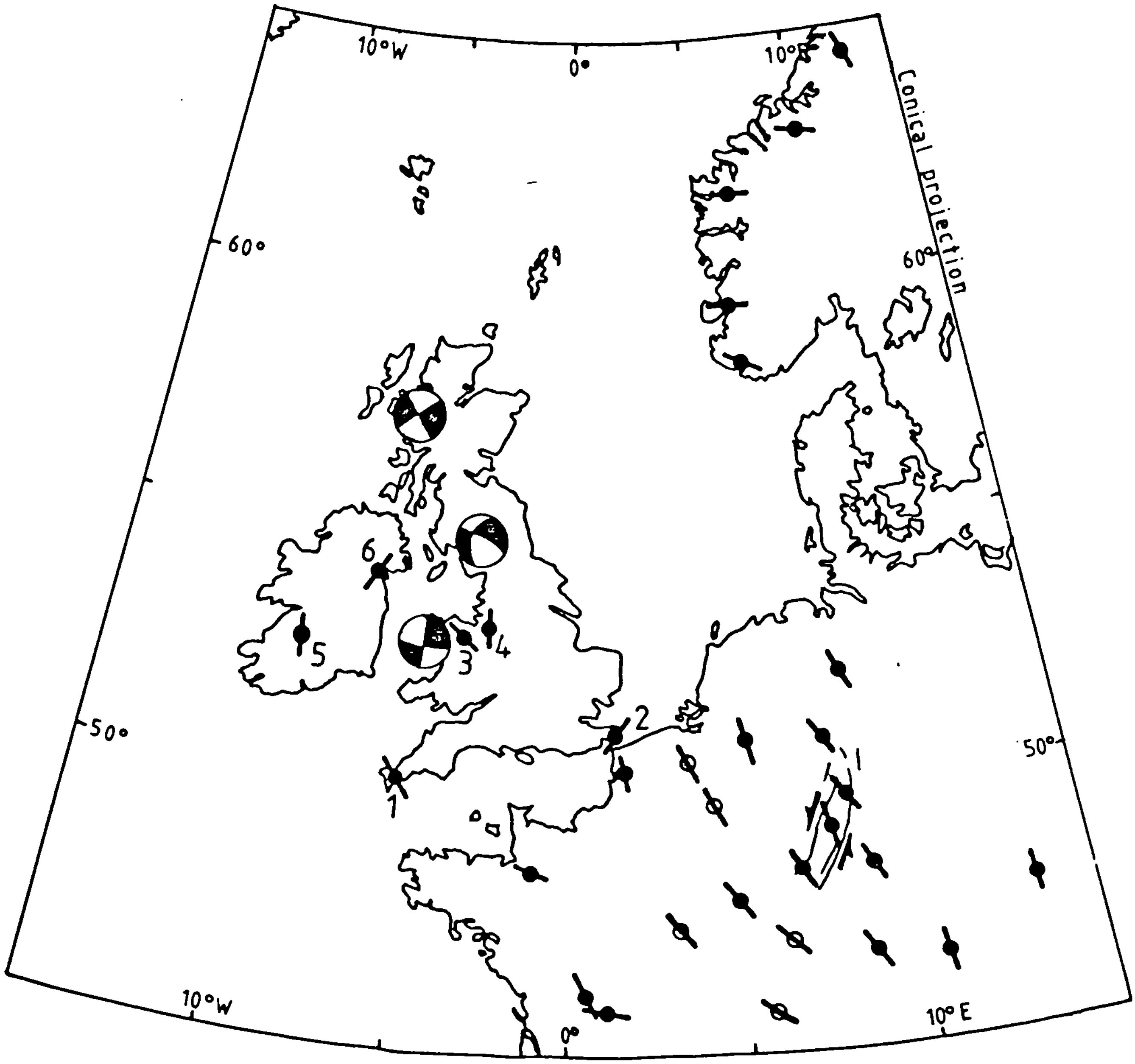


Fig.4-9. Stress measurements in NW Europe. Bars = directions of maximum horizontal compressive stress; solid circles = in situ stress measurements; open circles = derivation from fault plane solutions. The six British in situ stress measurements detailed in Table 4-1 (section 4.5.3) are numbered. Also shown are the three fault plane solutions for Britain and the upper Rhine graben strike slip motion. (Compiled from Ahorner 1975, Ranalli & Chandler 1975, Klein & Brown 1983, and Bevan & Hancock 1986.)

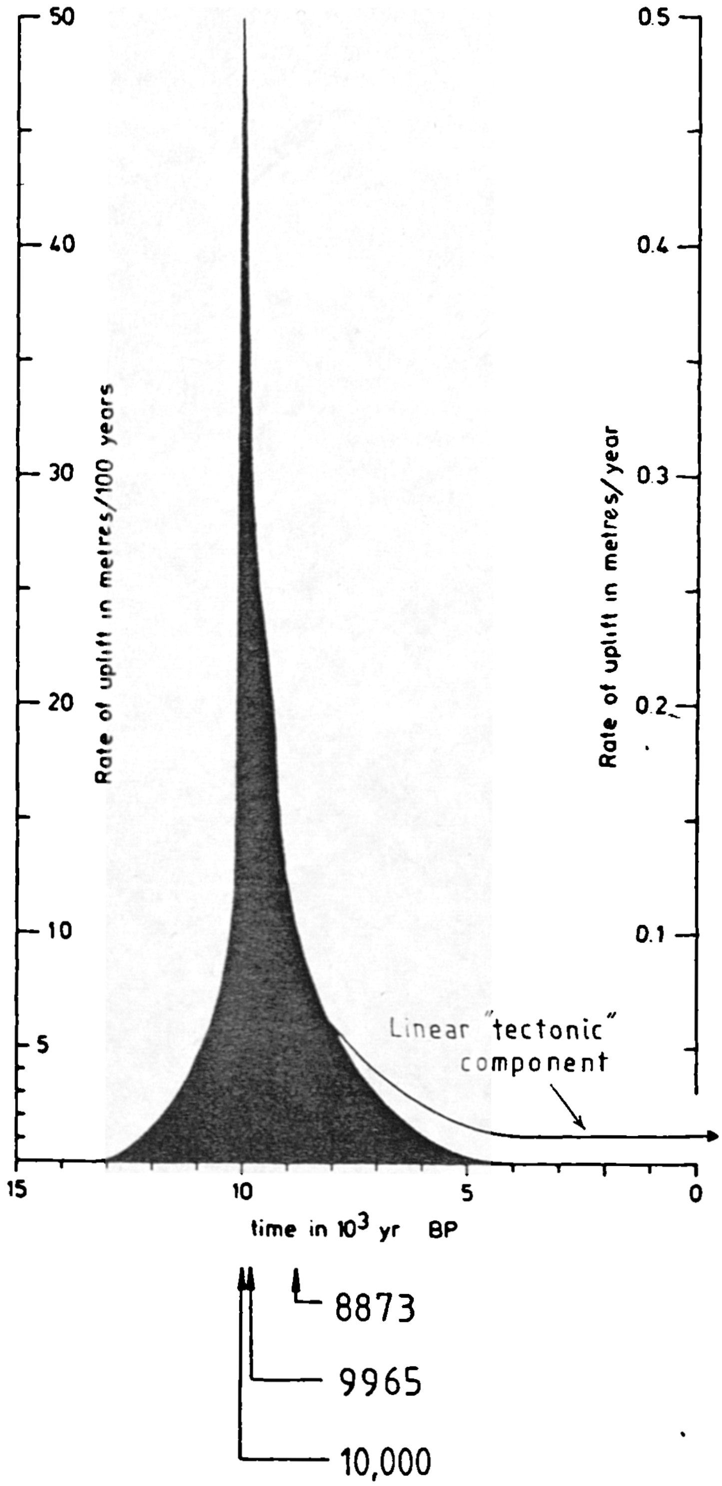


Fig.5-1. Rate of glacio-isostatic uplift at the centre of uplift in Fennoscandia (from Morner 1978) with the occurrences of three 'seismic varves' (Morner 1985): 8873 varve years BP (zero-varve); 9965 varve years BP (varve -1073); 10,000 radiocarbon years BP.

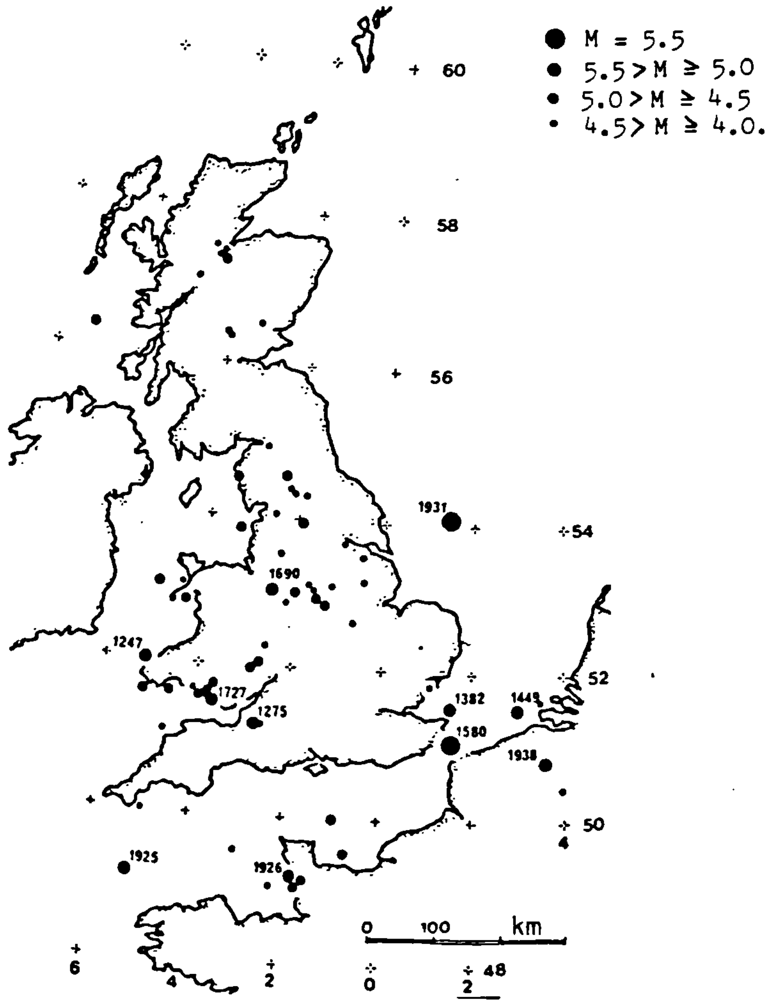
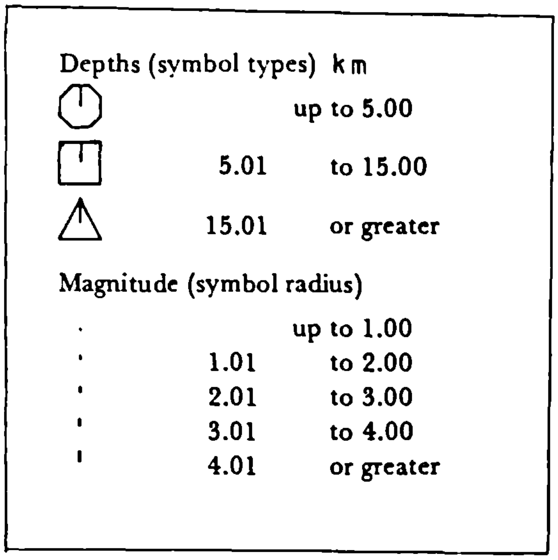
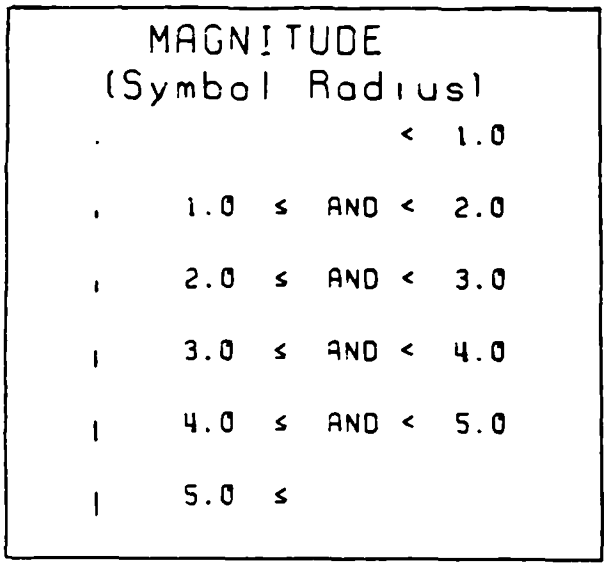


Fig.5-2. Distribution of British earthquakes during the last seven centuries (from Ambraseys & Jackson 1985).



SYMBOL KEY FOR FIGURES 5-3, 5-4 & 5-7.



SYMBOL KEY FOR FIGURES 5-5, 5-6 & 5-8.
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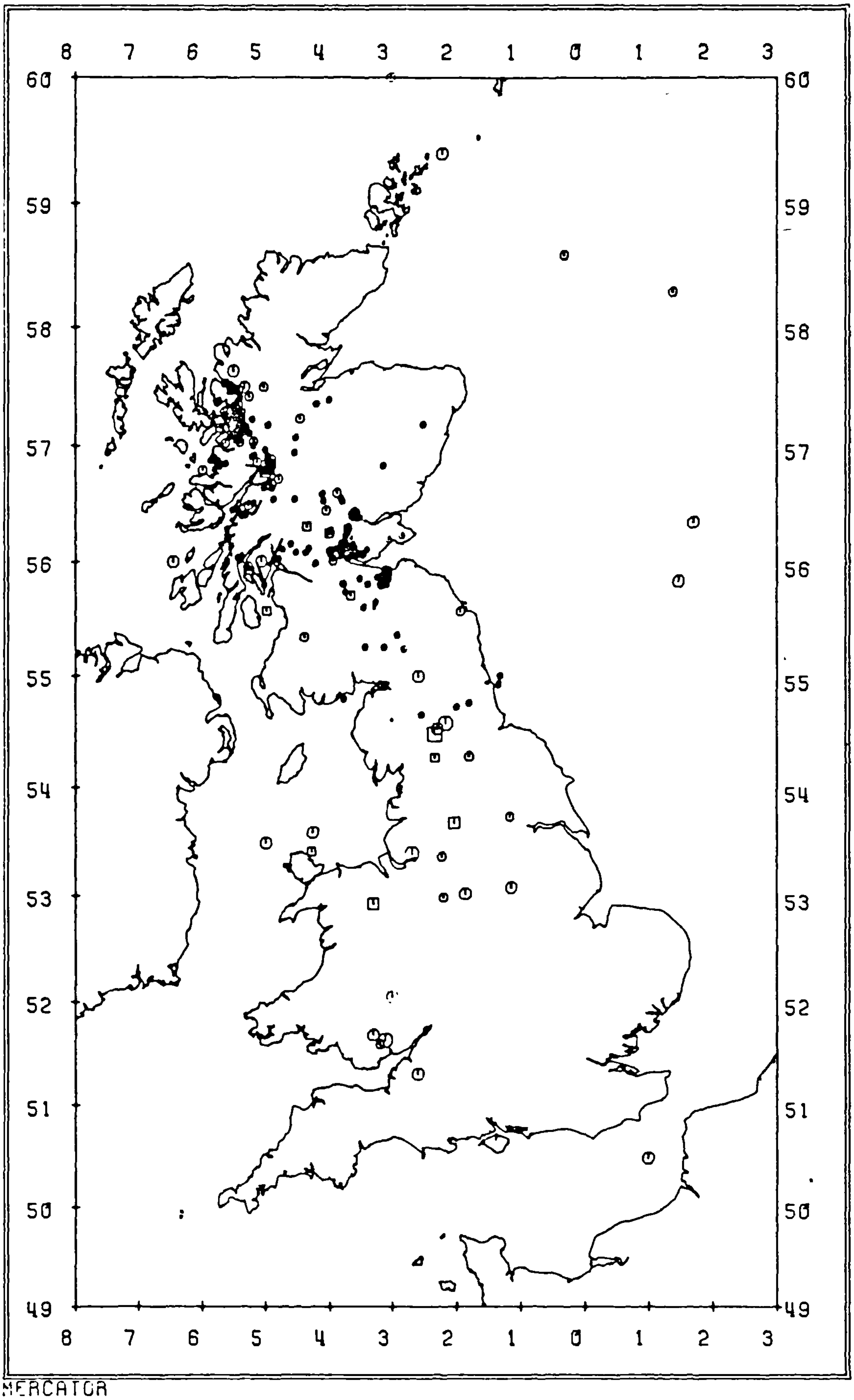
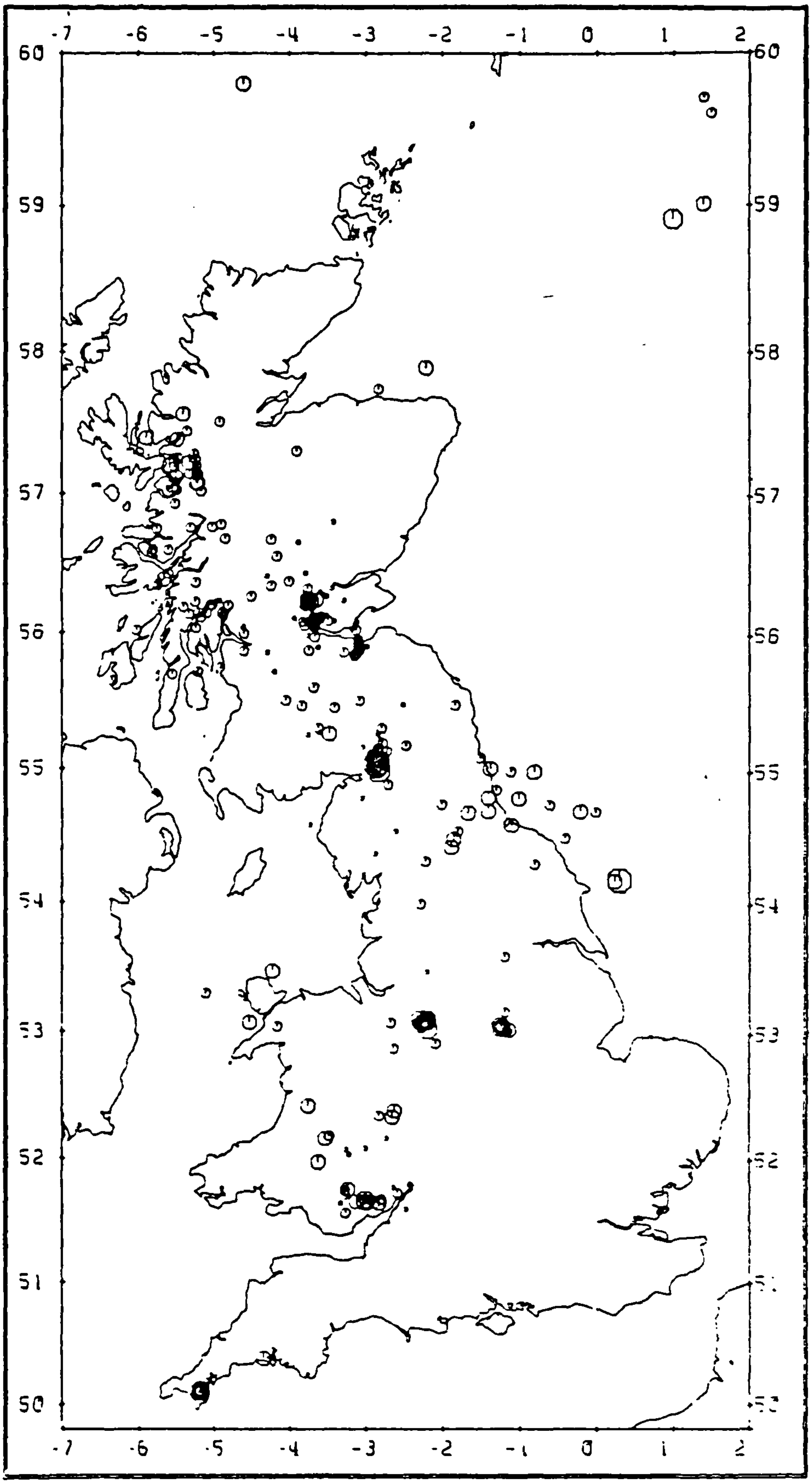


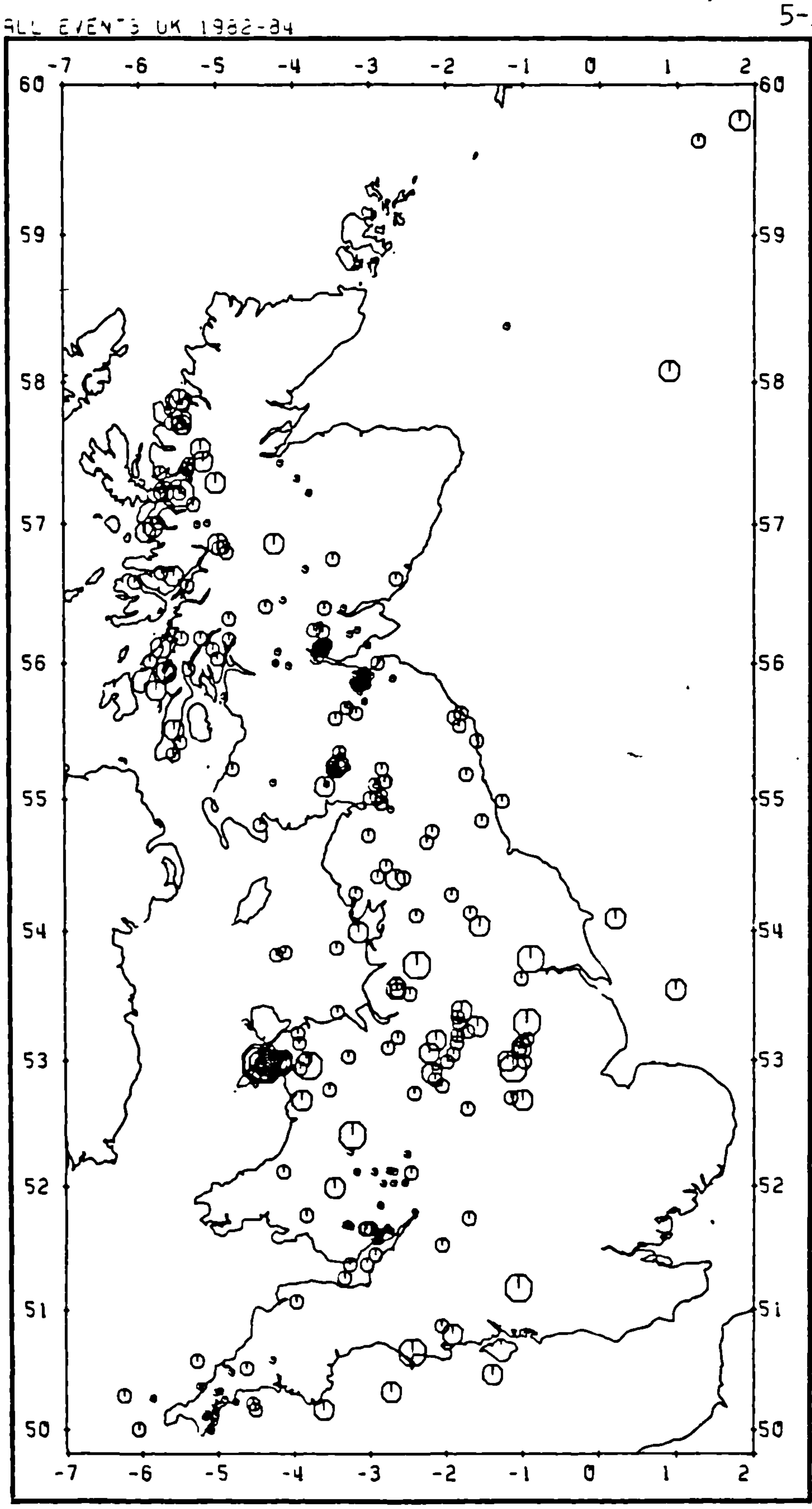
Epicentres of earthquakes with magnitude 1.0 or greater in Great Britain 1967-1978.

Fig.5-3. B.G.S. data (from Burton & Neilson 1980).



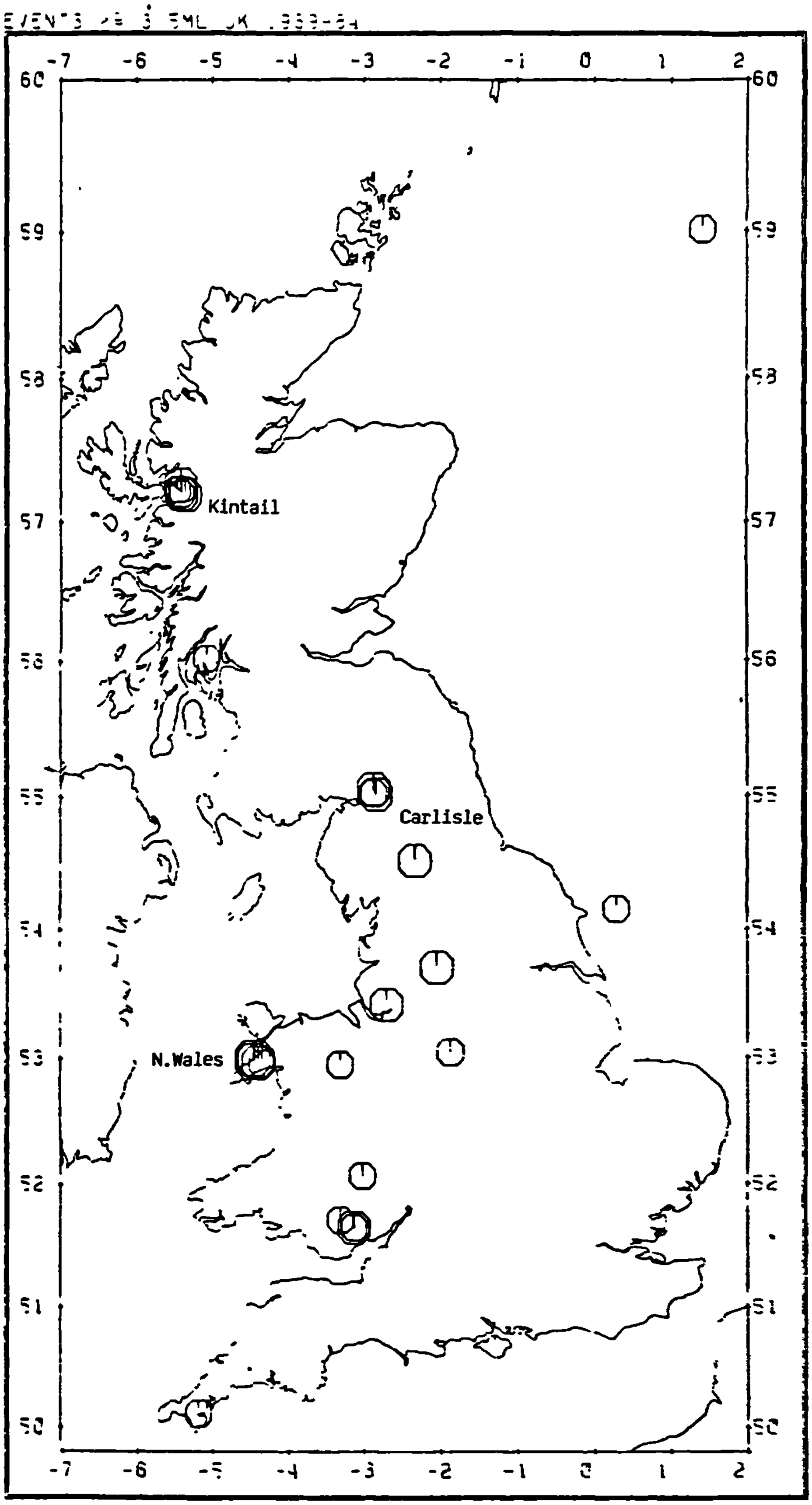
Epicentres in Britain, 1979, 1980, 1981

Fig.5-4. B.G.S. data (from Turbitt 1984).



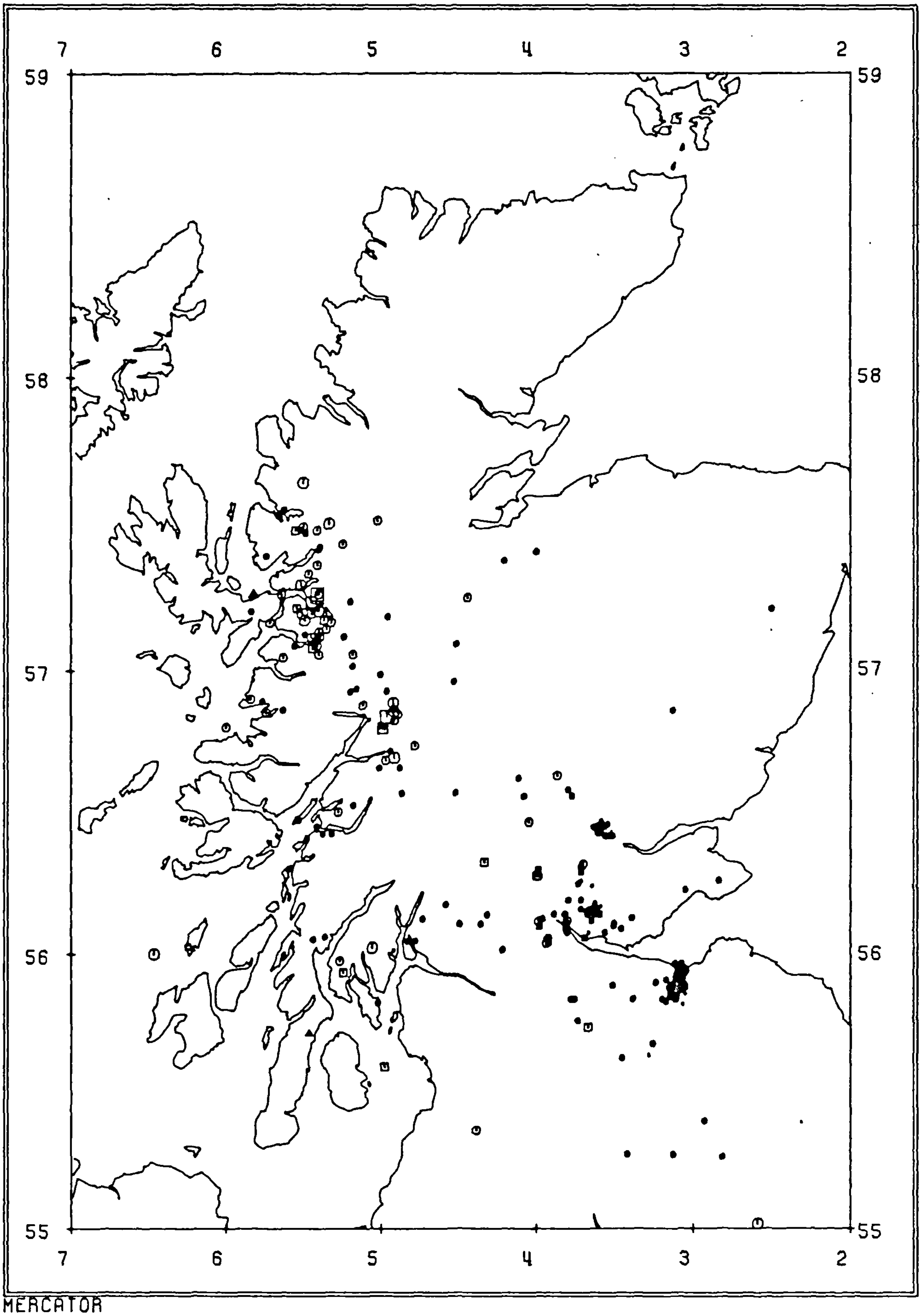
Epicentres in Britain 1982, 1983, 1984.

Fig.5-5. B.G.S. data (from Turbitt 1985).



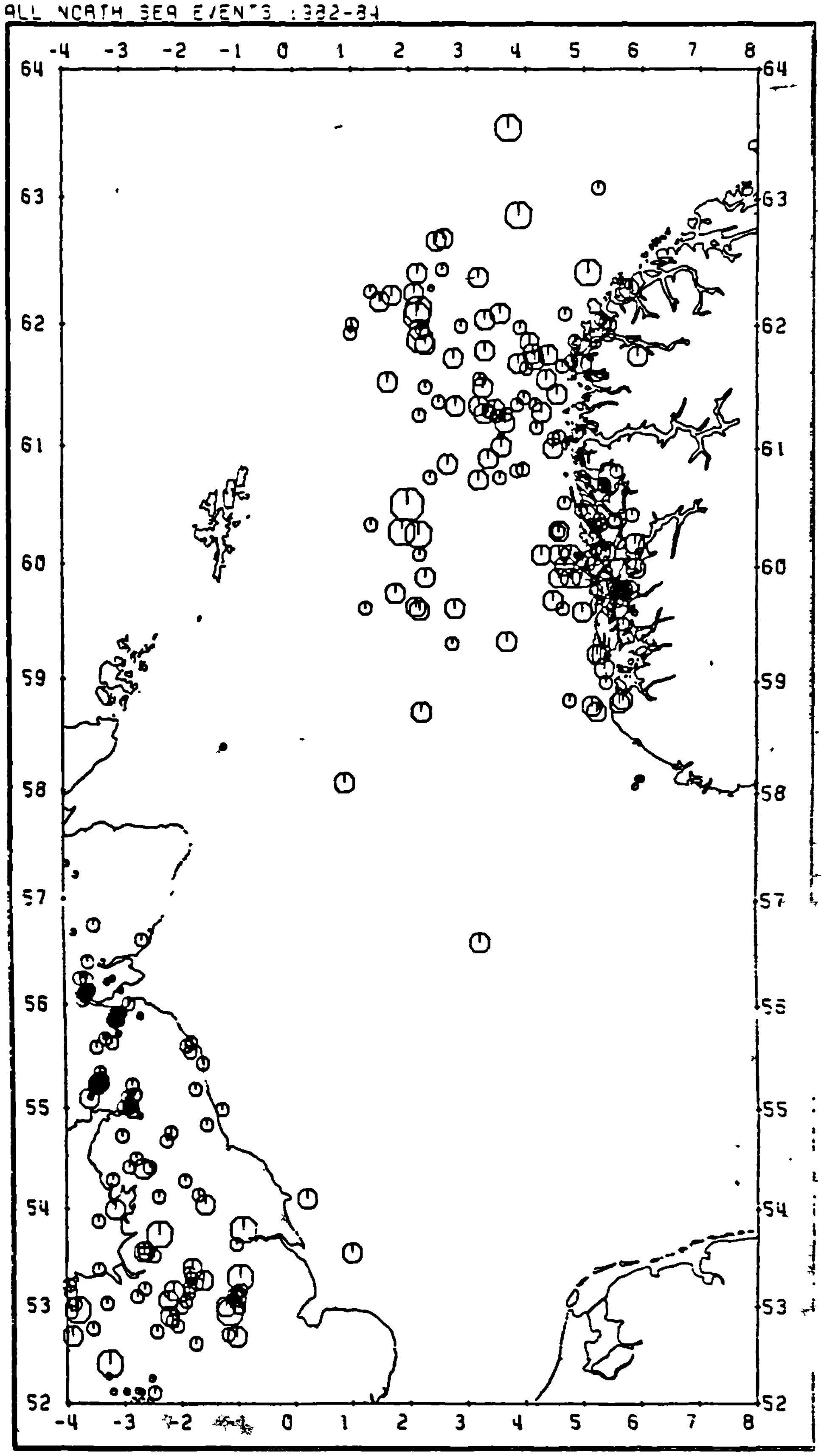
Epicentres of earthquakes with magnitudes 3.5 ML or greater 1969 to 1984.

Fig.5-6. B.G.S. data (from Turbitt 1985).



Epicentres of earthquakes with magnitude M_L =1.0 or greater in Scotland 1967-1978.

Fig.5-7. B.G.S. data (from Burton & Neilson 1980).



Epicentres in the North Sea 1982, 1983, 1984.

Fig.5-8. B.G.S. data (from Turbitt 1985).

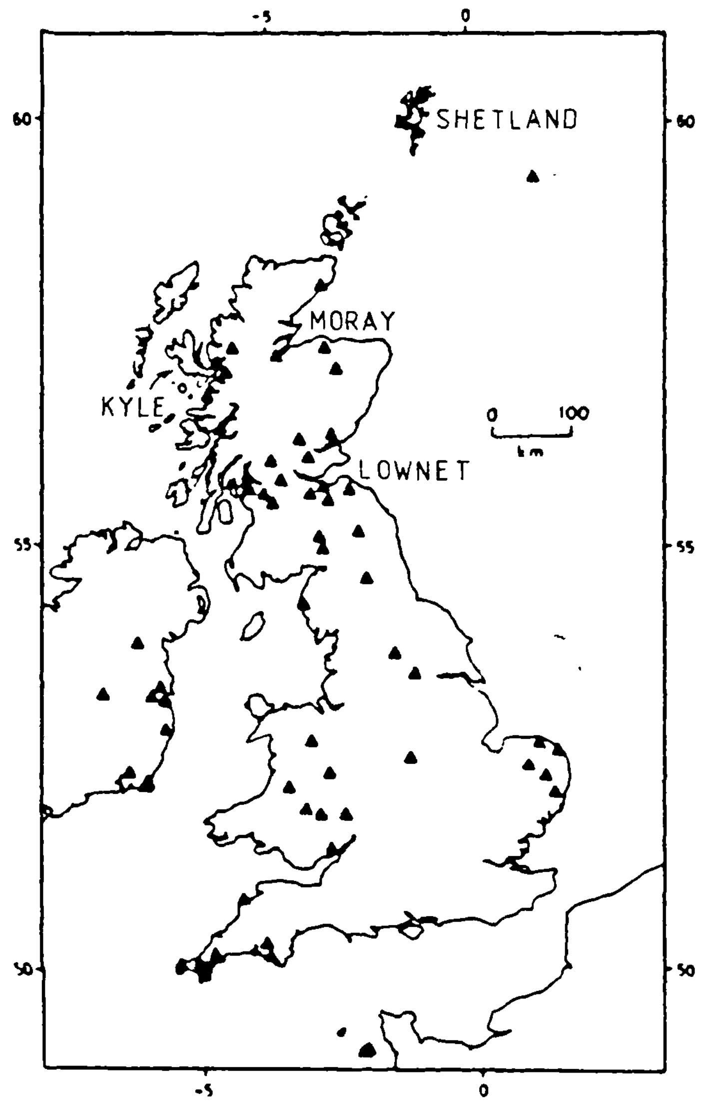


Fig.5-9. Seismographic stations of the British Geological Survey including the four Scottish networks (from Turbitt 1985).

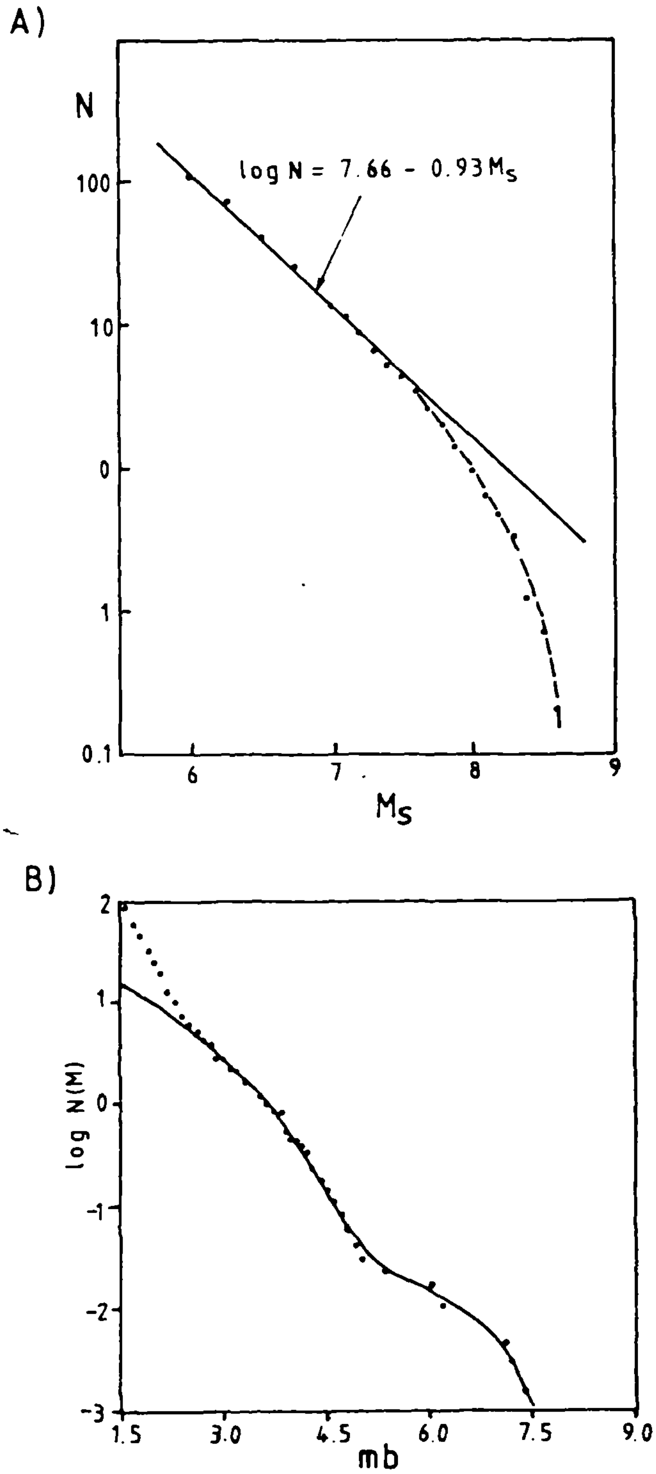


Fig.5-10 A. Gutenberg and Richter's cumulative frequency plot of large shallow earthquakes. A linear relationship is observed for events less than Ms=7, but for larger events the relationship tends towards the vertical in the vicinity of Ms=8.6 (redrawn from Chinnery & North 1975).

B. Cumulative frequency plot for the New Madrid area, U.S.A., recent and historical data, showing a clear bimodal seismicity distribution (form Main and Burton 1986).

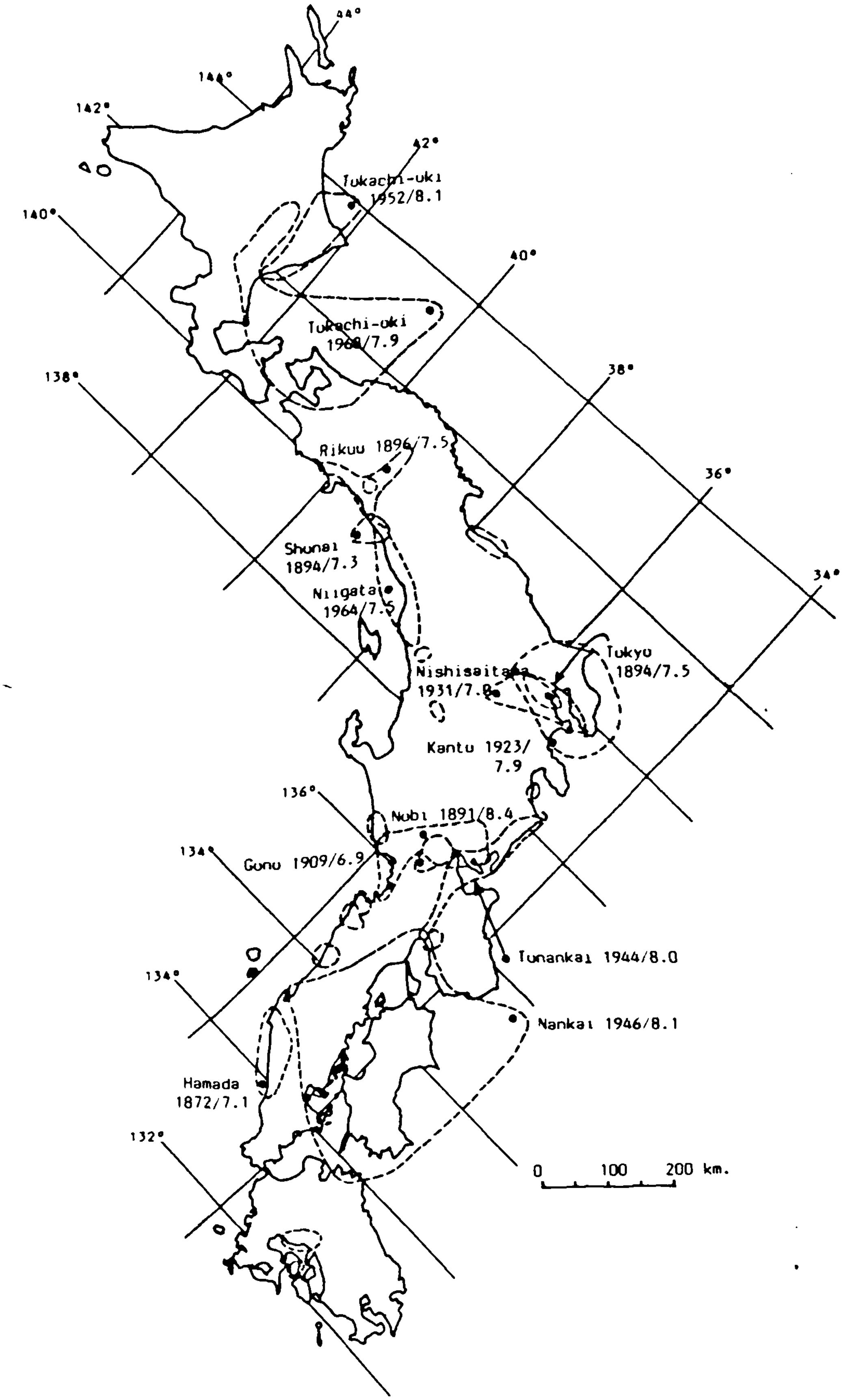


Fig.6-1. Major occurrences of earthquakes causing liquefaction in Japan (redrawn from Kuribayashi & Tatsuoka 1975). Earthquake events (dots) are given by year/magnitude. Dashed envelopes enclose sites where liquefaction occurred during each event.

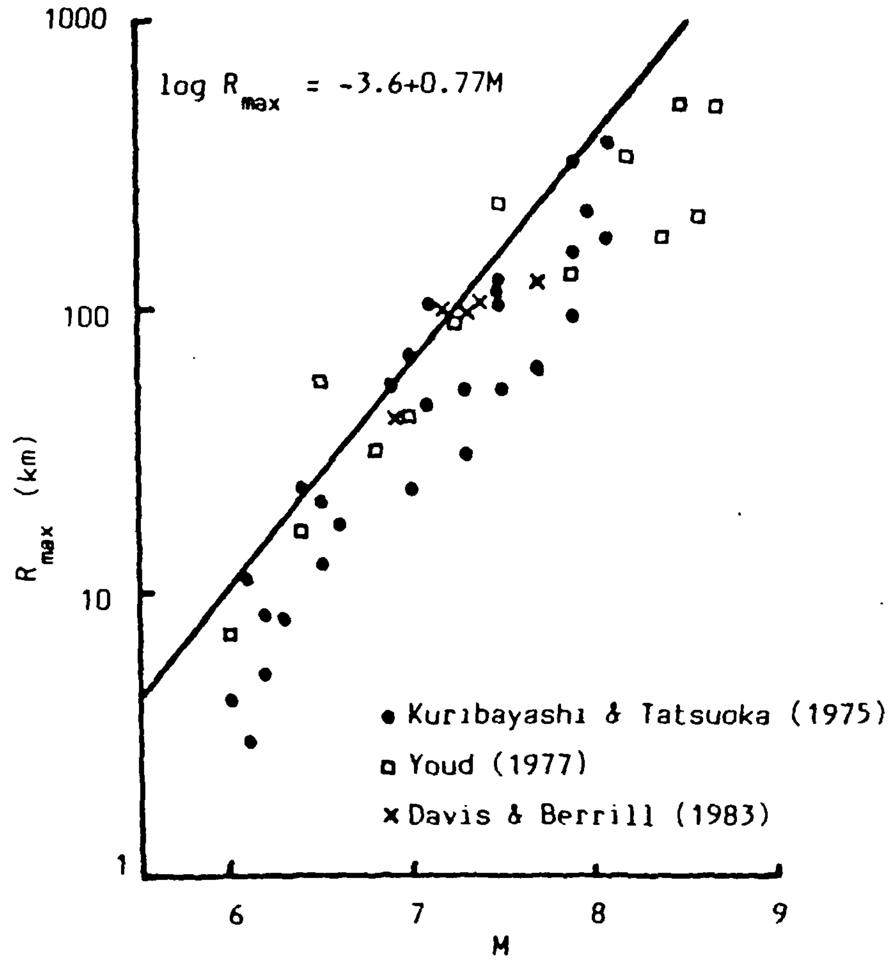


Fig.6-2. Plot of maximum distance to site of liquefaction against earthquake magnitude. Sources of data points shown. The relationship shown (line & formula) is that of Kuribayashi & Tatsuoka (1975). (Redrawn from Davis & Berrill 1983).

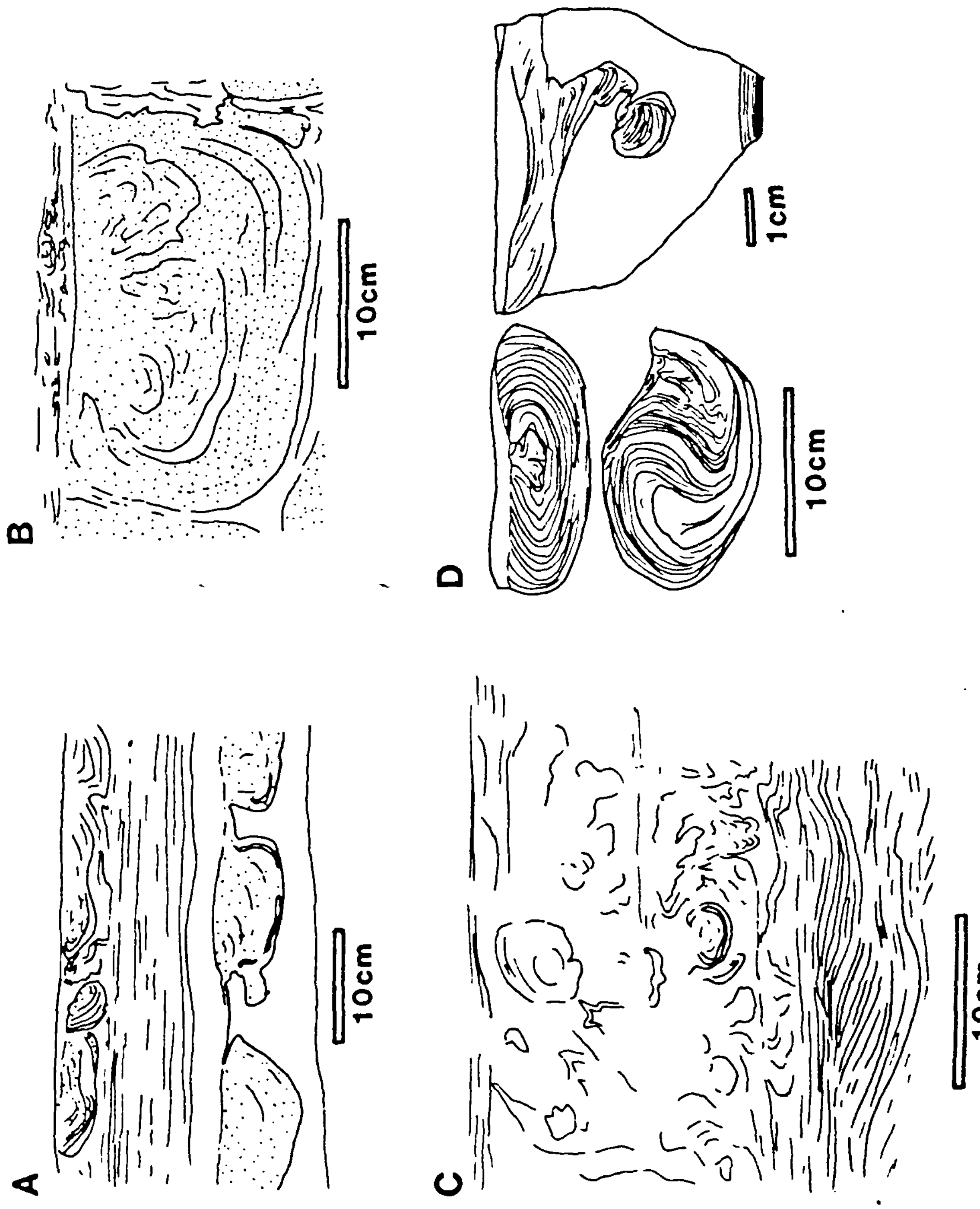


Fig.6-3. Ball-and-pillow structures in:

A&B) Lake Hazar (Holocene), Turkey (Hempton & Dewey 1983).

C) Lake Cahuilla (Holcene), California (Sims 1975).

D) Devonian sandstone, Ardennes, Luxemburg (Kuenen 1958).

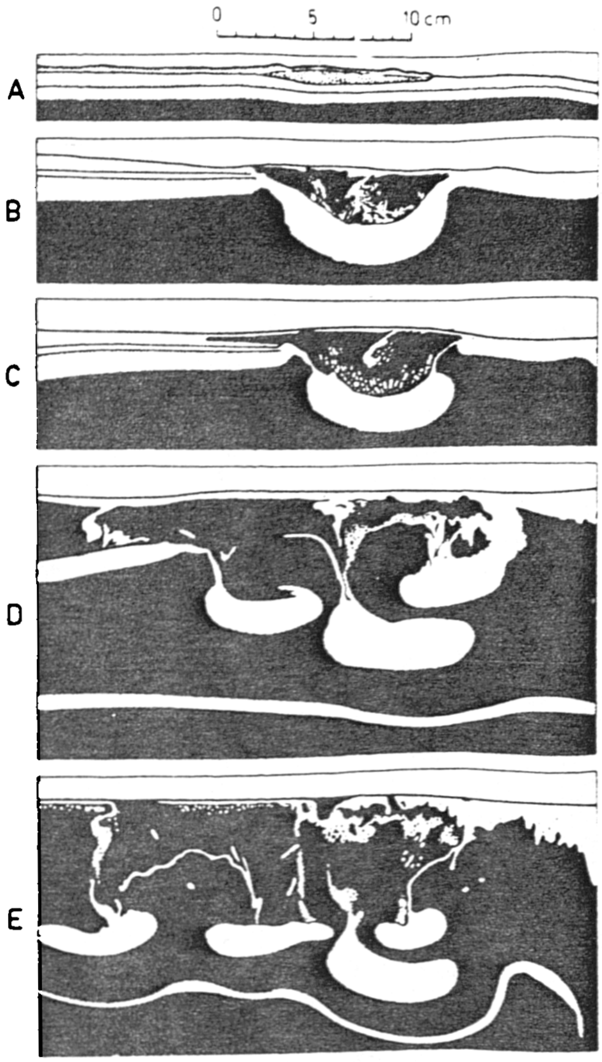


Fig.6-4. Kuenen's experimental pseudonodules. Five stages (A-E) in the loading of sand beneath a slight burden of coarse sand (A) into mud. The experiment was made by subjecting a sediment-filled aquarium to shocks from a rubber hammer or vibrations from an electric motor (Pettijohn et al. 1973, as redrawn from Kuenen (1958).).

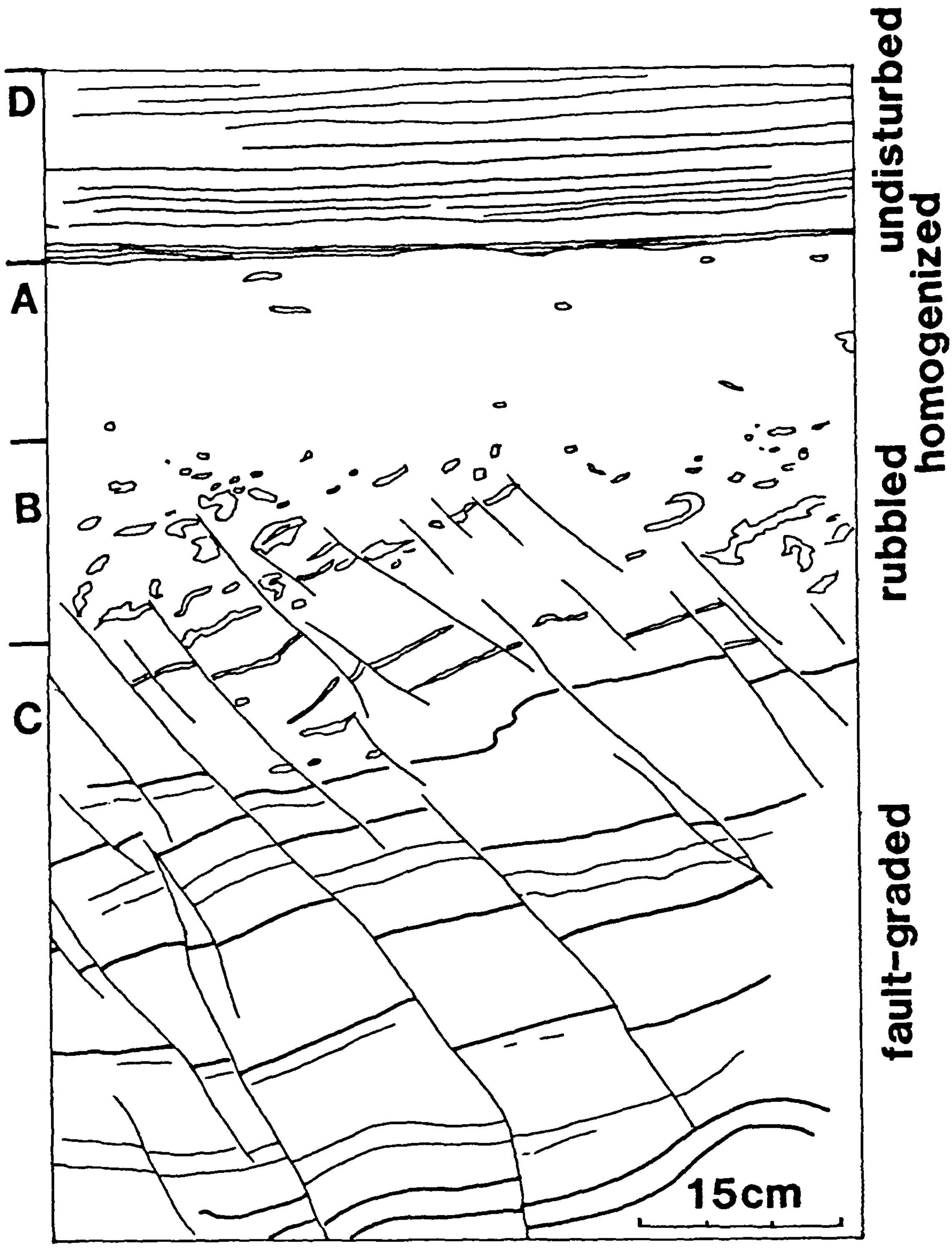


Fig.6-5. Fault-grading stratigraphy as described by Seilacher (1969, 1984) in the Miocene, Monterey Shale, California. For descriptions of units see text in section 6.1.3.

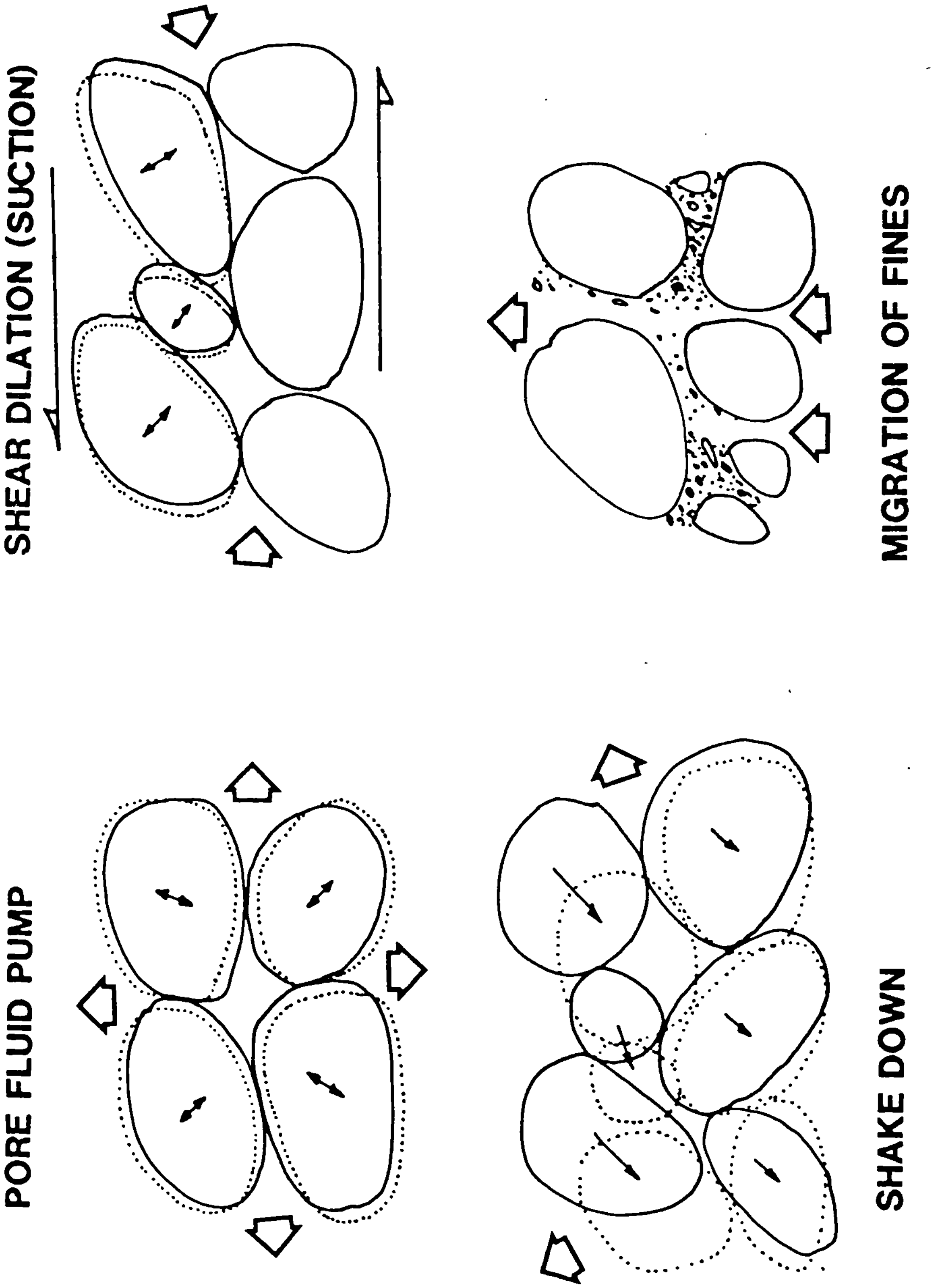


Fig.6-6. Illustrations of some grain/pore-fluid processes functioning during cyclic loading of a sediment.

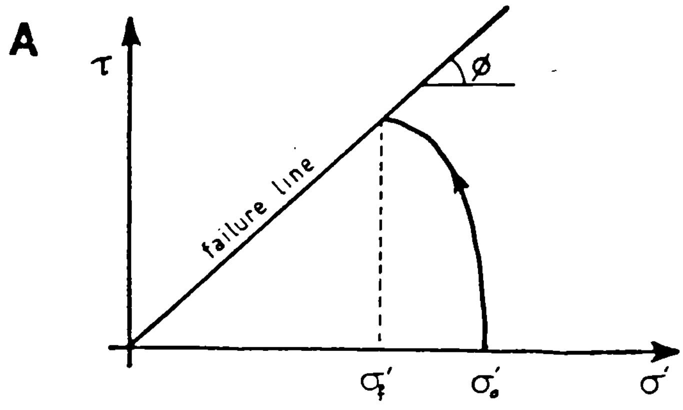
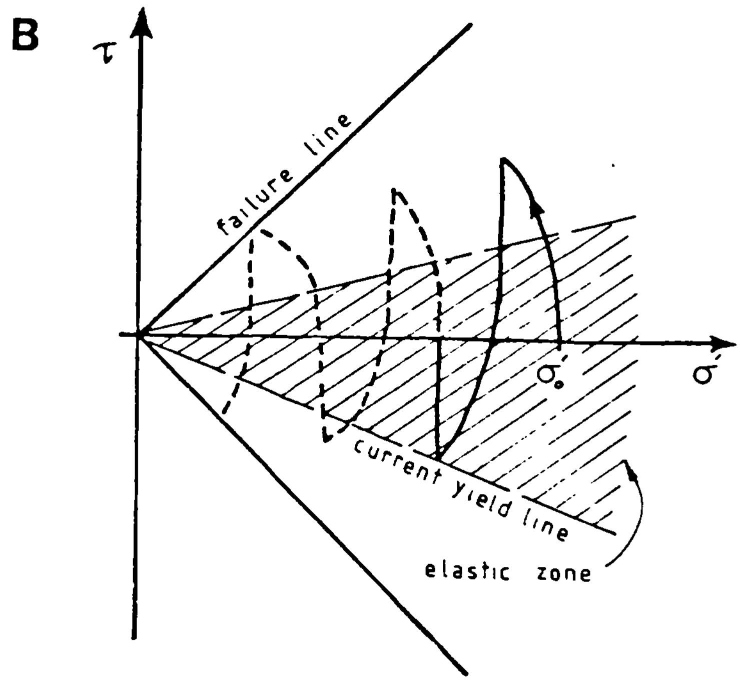


Fig.6-7. A) Effective stress path for monotonically increasing shear stress in an undrained soil, from an initial value of σ_o' to failure at σ_f'. The shape of the stress ellipse is determined by the properties of the soil. (Redrawn from Dikmen & Ghaboussi 1984).



B) Effective stress path for cyclic loading of an undrained soil. During unloading, effective stress is assumed constant. The elastic zone shown is for the first stress-cycle only, and defined by the 'current yield line'. As the effective stress decreases the stress ratio (τ/σ') increases. As the stress ratio approaches the failure line 'initial liquefaction' is achieved; complete failure results in complete liquefaction. (Adapted from Dikmen & Ghaboussi 1984).

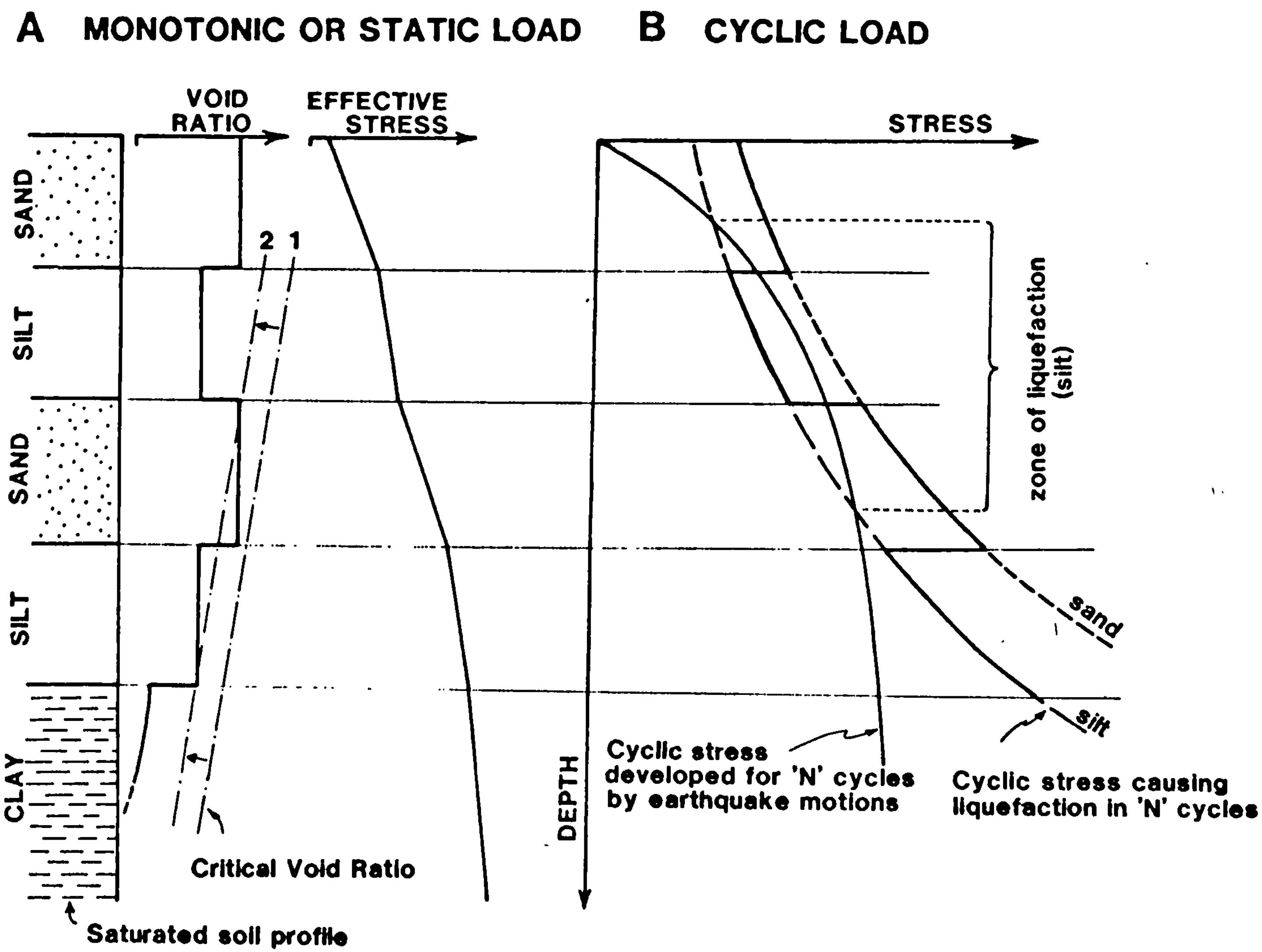


Fig.6-8. The onset of liquefaction in a hypothetical soil profile subjected to monotonic (A) and cyclic (B) loads. The different response of silt and sand layers is illustrative: monotonic loading tends to preferentially induce liquefaction in fine to medium-grained sands, whereas cyclic loading favours silt and very fine grained sand. (Based on the experimental results of Casagrande (1970), Castro (1975) and Seed & Idriss (1971).).

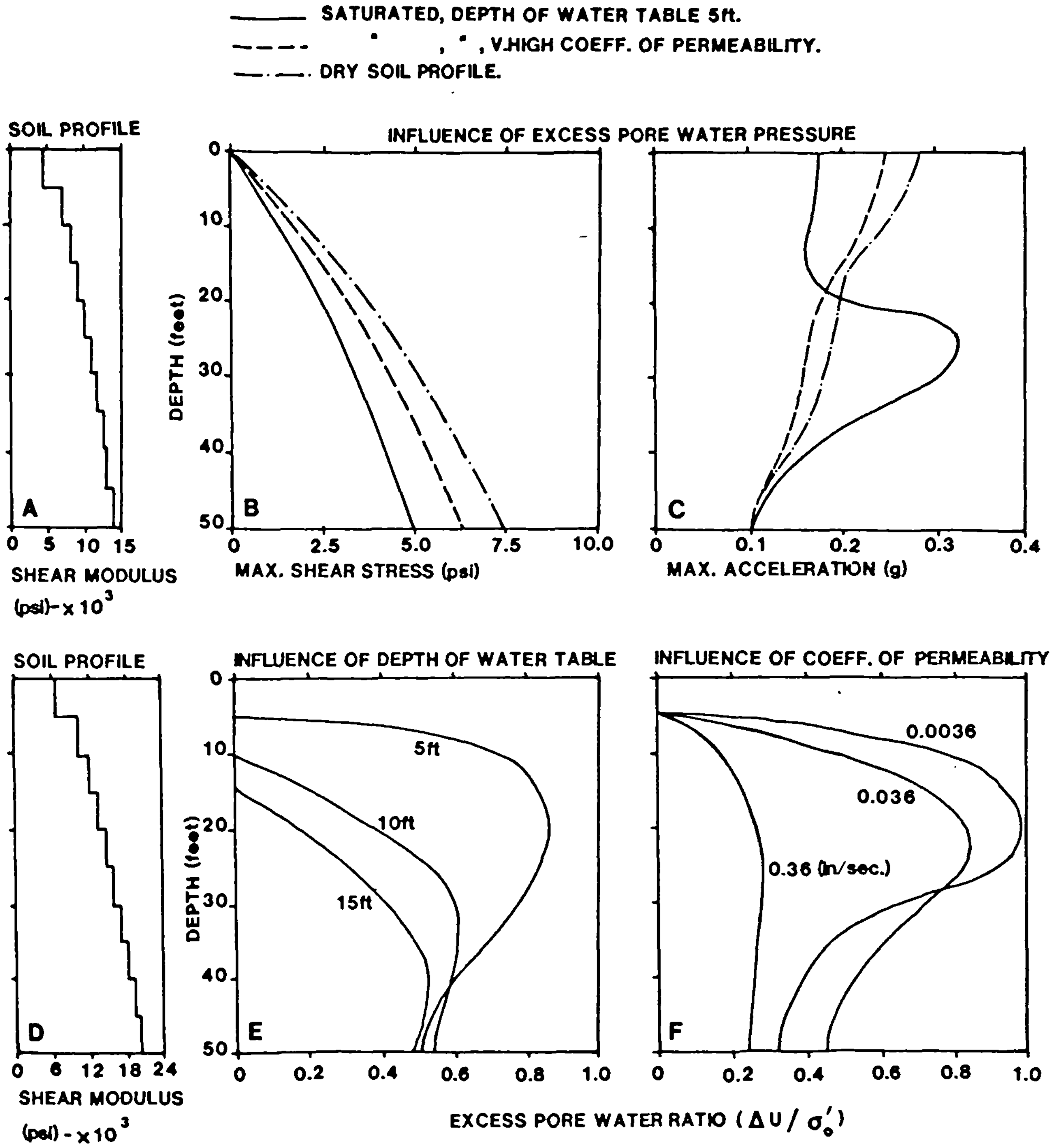


Fig.6-9. Theoretical and experimental studies on effective stress and liquefaction from the companion papers: Dikmen & Ghaboussi, Ghaboussi & Dikmen (1984). (For discussion see text in section 6.2.3).

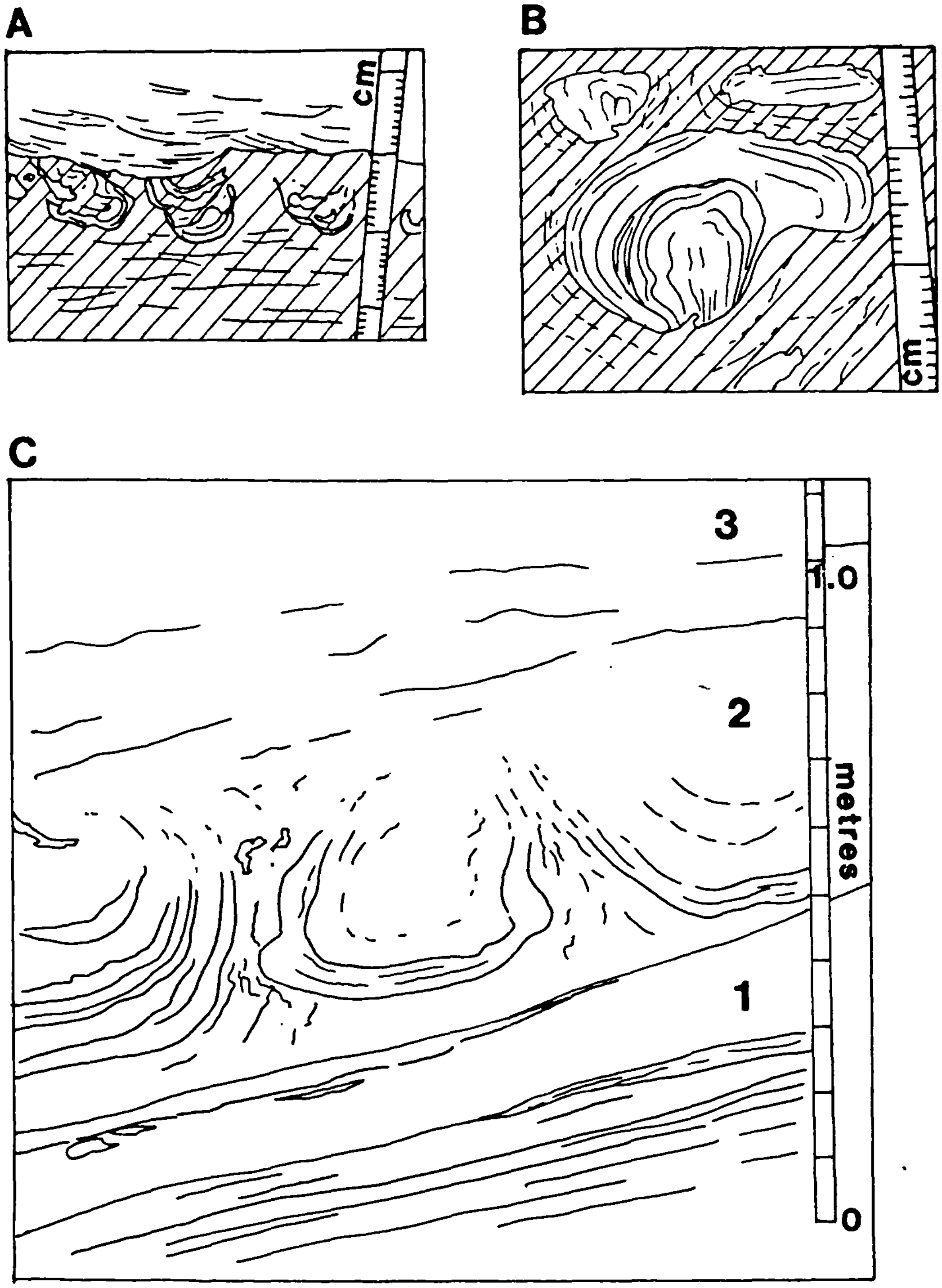


Fig.6-10. Ball-and-pillow horizons in Finland (drawings of photographs by Vesajoki (1982)).

A) Stratigraphy exposed in the artificially drained Lake Höytiäinen, showing near-shore sands overlying silts (hatched) containing pillowed sands.

B) Overturned pillow of sand in silt (hatched) in glacio-fluvial deposits at Ahvensalo.

C) Glacio-fluvial deposits at Nisäjärvi, showing intrusion and loading in silts and fine sands.

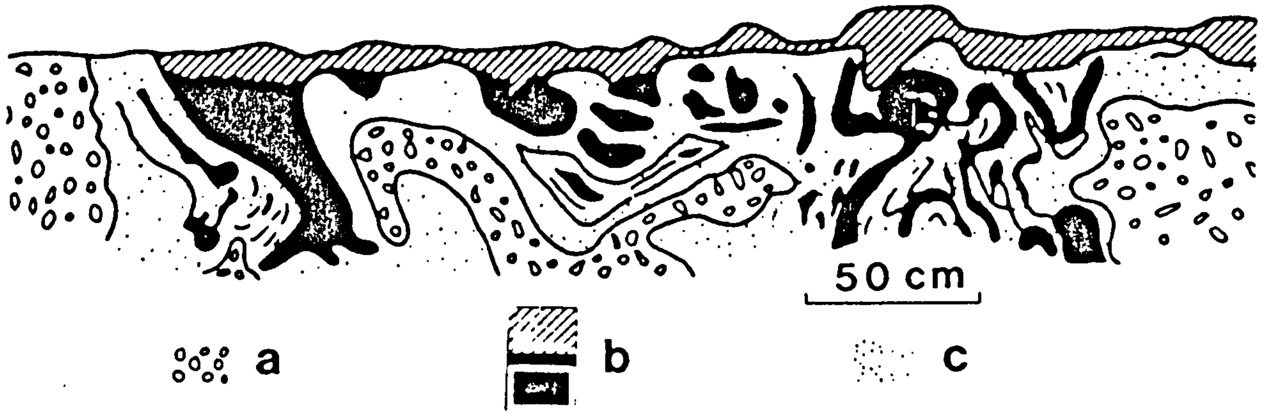


Fig.6-11. Cryoturbations in a section from Banks Island, Arctic Canada. a, pebbles in silty sand; b, humic sands; c, yellow sands. (from French 1976).

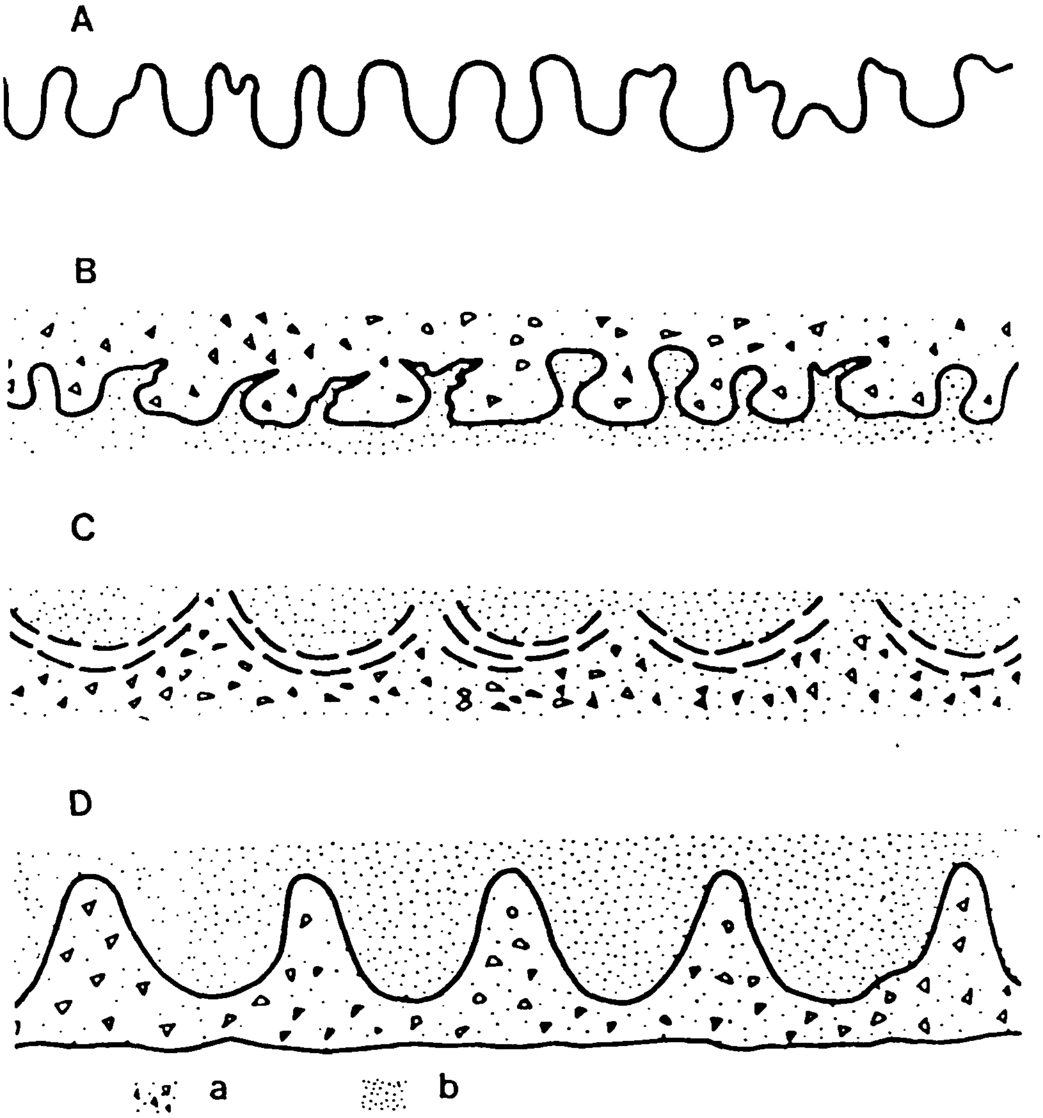


Fig.6-12. Types of involuted structures (after French 1976).
a, fine, b, coarse sediments. A, pocket and plug involutions; B, flame and club-shaped involutions; C, festoons; D, stone pillars.

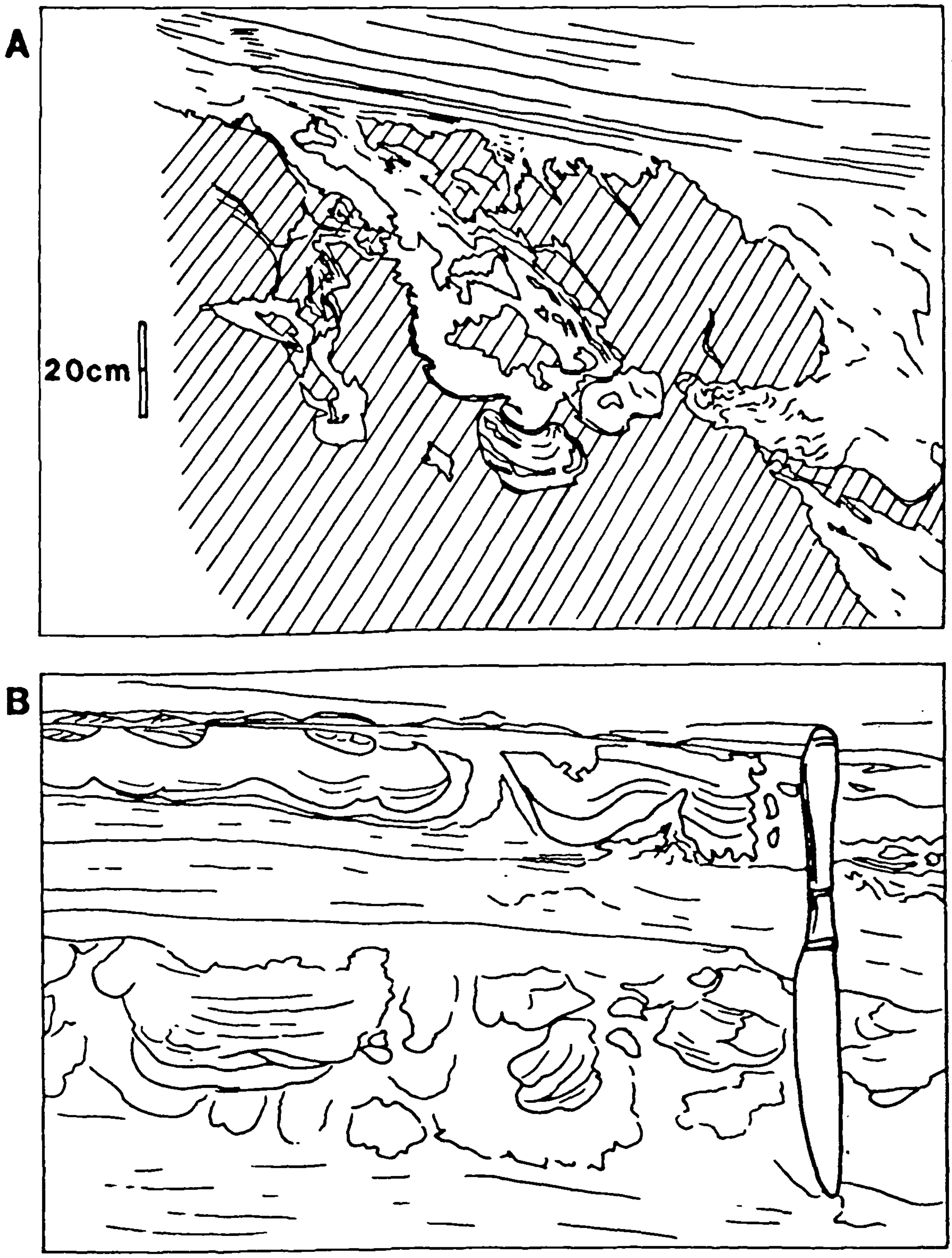


Fig.6-13. A) Load structures in cryoturbated (Saalian) till, Netherlands (redrawn from Ter Wee (1983).

B) Two layers of load casts developed in fine sands with silt layers. Meltwater deposits, Lower Saxony, Germany (redrawn from Ehlers & Grube 1983).

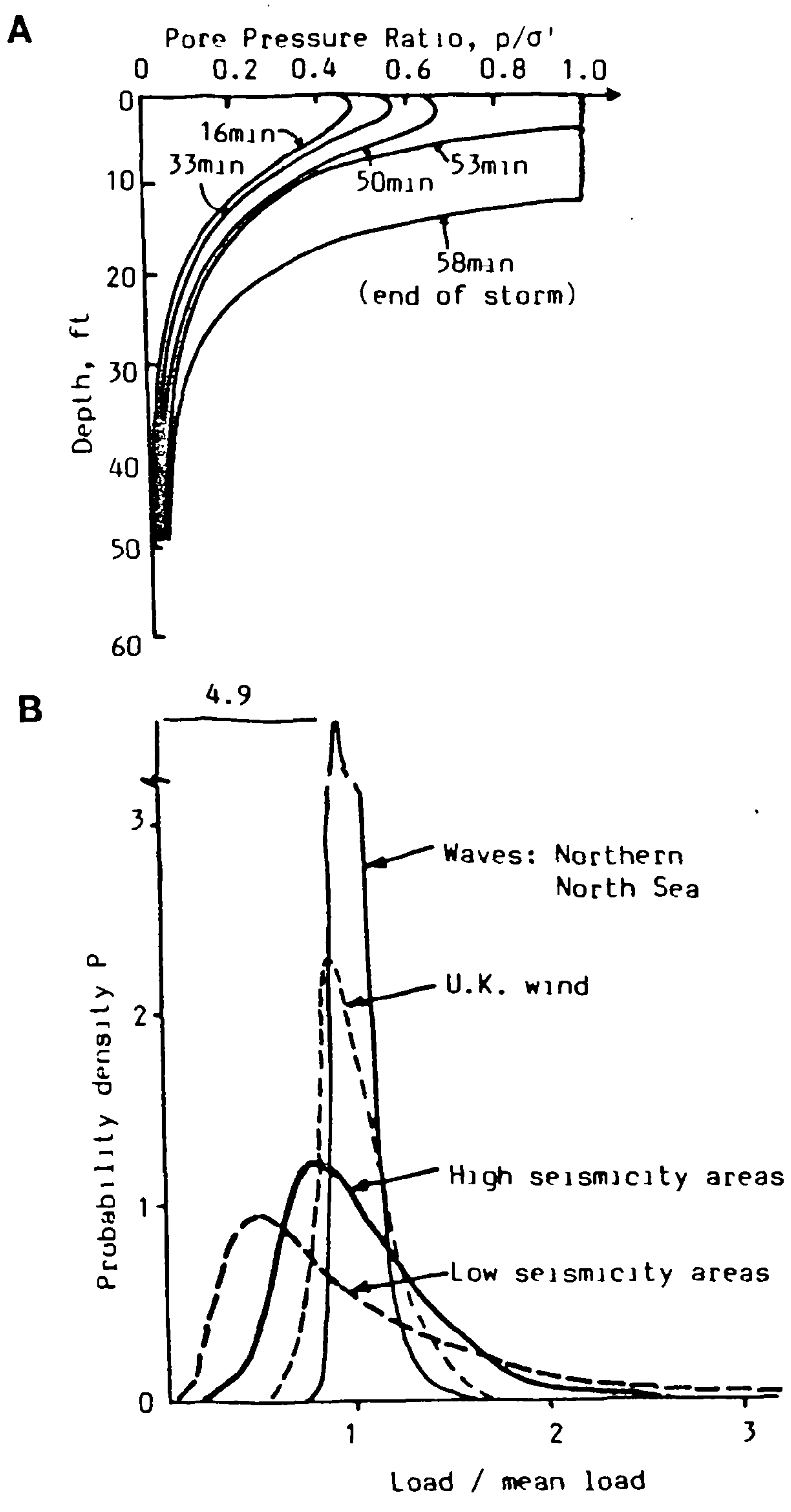


Fig.6-14. A) Pore pressure ratio at different stages during a 'design' storm in a hypothetical soil profile of sand; relative denisity 54%, coeff. of permeability 10^{-3} cm/s (redrawn from Seed & Idriss 1982).

B) Extreme value distributions for 50 year exposure, for storm and earthquake loads (redrawn from Booth & Roberts 1985).

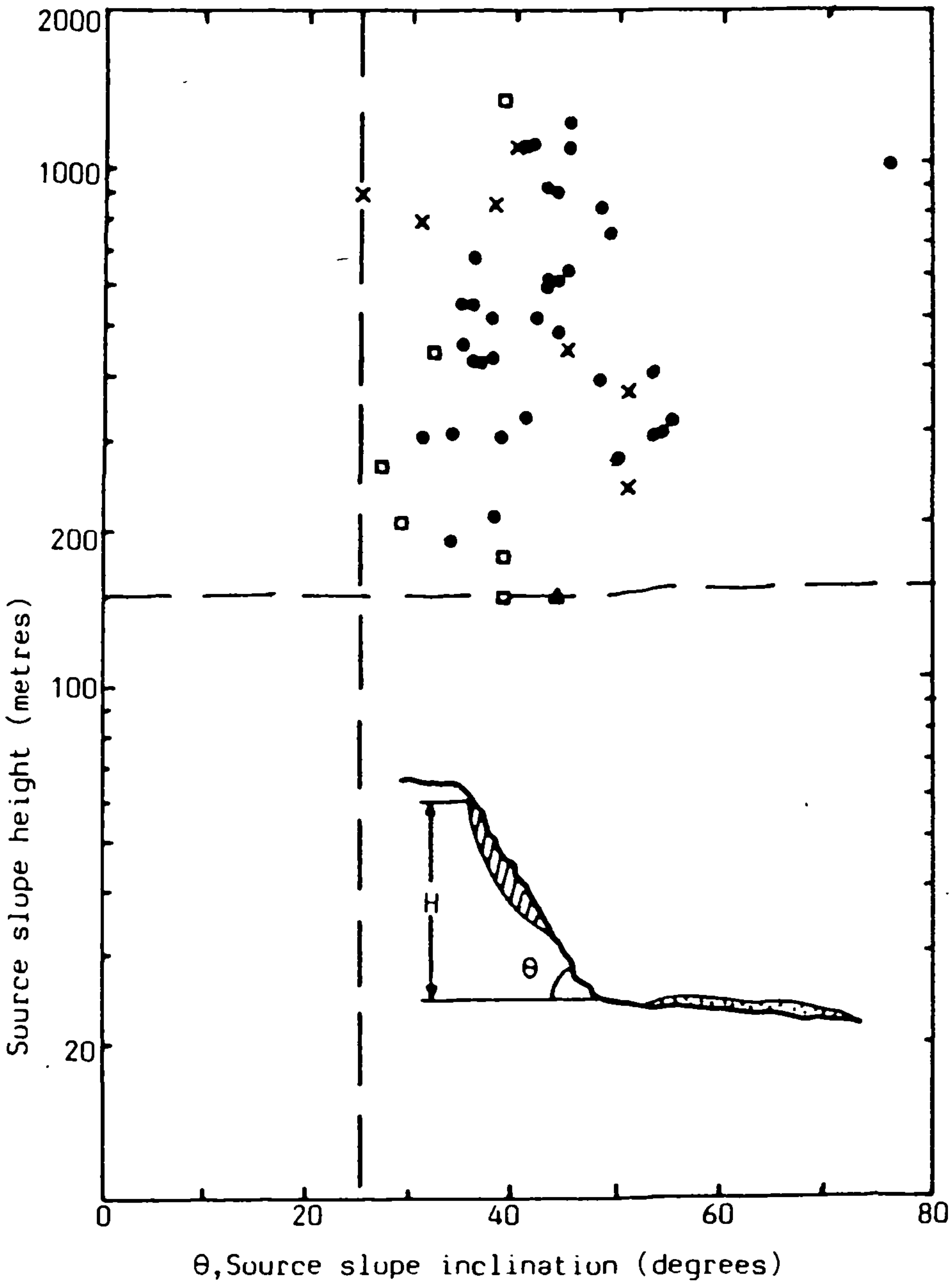


Fig.6-15. Heights and inclinations of source slopes of earthquake-induced rock avalanches. Inclination (θ) is the average inclination of the slope, H is the height difference between the highest point on the scarp and the base of the steep slope. Dashed lines indicate minimum height (150m) and inclination (25°) at which falls occurred. (redrawn from Keefer 1984b).

Circles, slopes undercut by active glacial erosion.

Squares, slopes undercut by active fluvial erosion.

Crosses, slopes undercut by Holocene or late Pleistocene glacial erosion.

Triangle, slope not undercut by fluvial or glacial erosion.

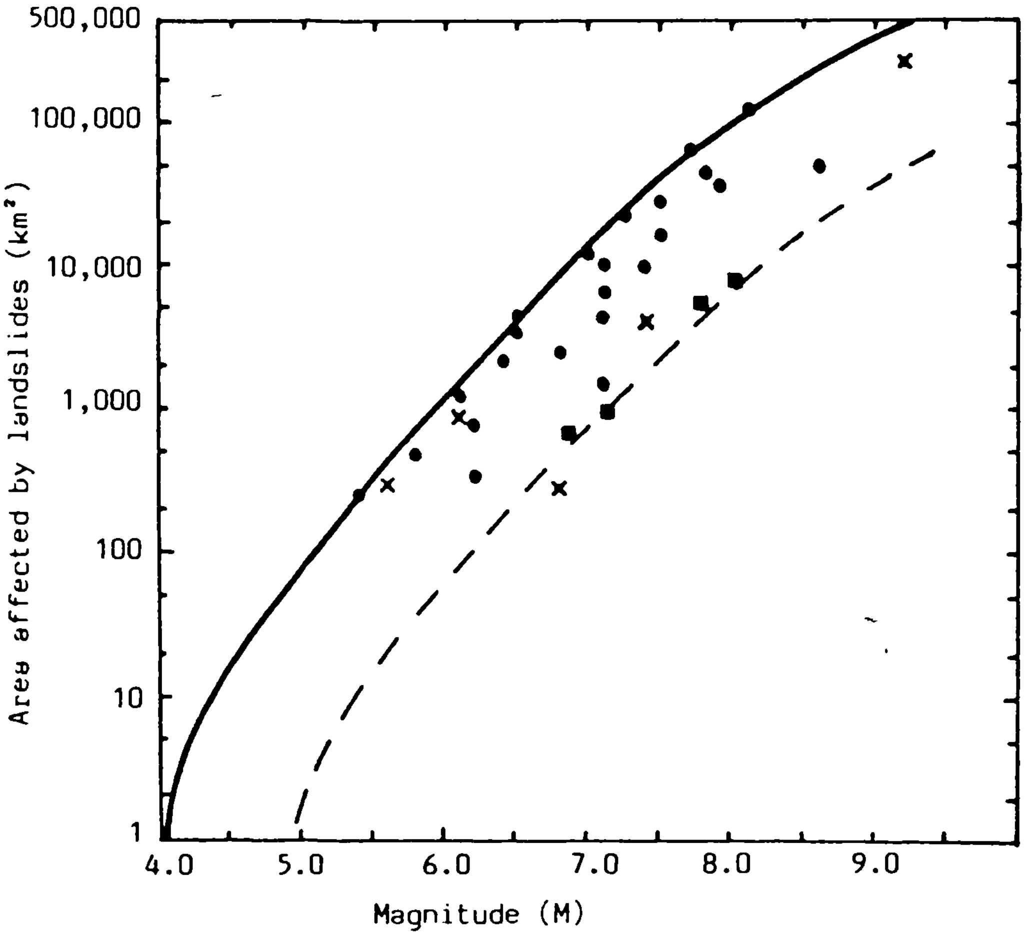


Fig.6-16. Plot of area affected by landslides against magnitude, world-wide data-base (redrawn from Keefer 1984a).
Dots, onshore earthquakes.
Crosses, offshore earthquakes.
Squares, New Zealand (onshore) earthquakes (from Adams 1980).
Solid line is approximate upper bound enclosing all data (from Keefer), dotted line is a lower bound limit as an aid for palaeoseismic interpretation (added).

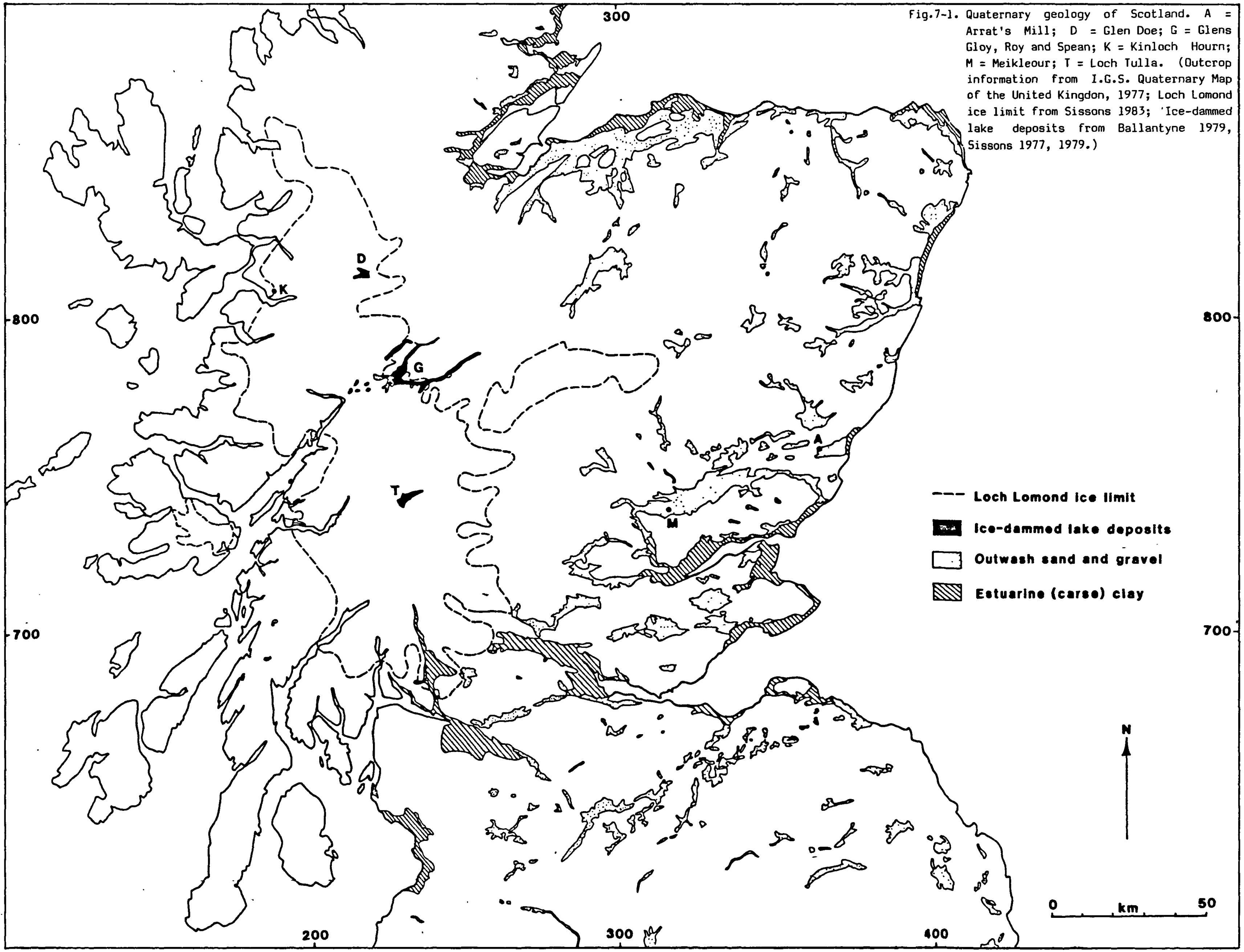


Fig.7-1. Quaternary geology of Scotland. A = Arrat's Mill; D = Glen Doe; G = Glens Gloy, Roy and Spean; K = Kinloch Hourn; M = Meikleour; T = Loch Tulla. (Outcrop information from I.G.S. Quaternary Map of the United Kingdon, 1977; Loch Lomond ice limit from Sissons 1983; 'Ice-dammed lake deposits from Ballantyne 1979, Sissons 1977, 1979.)

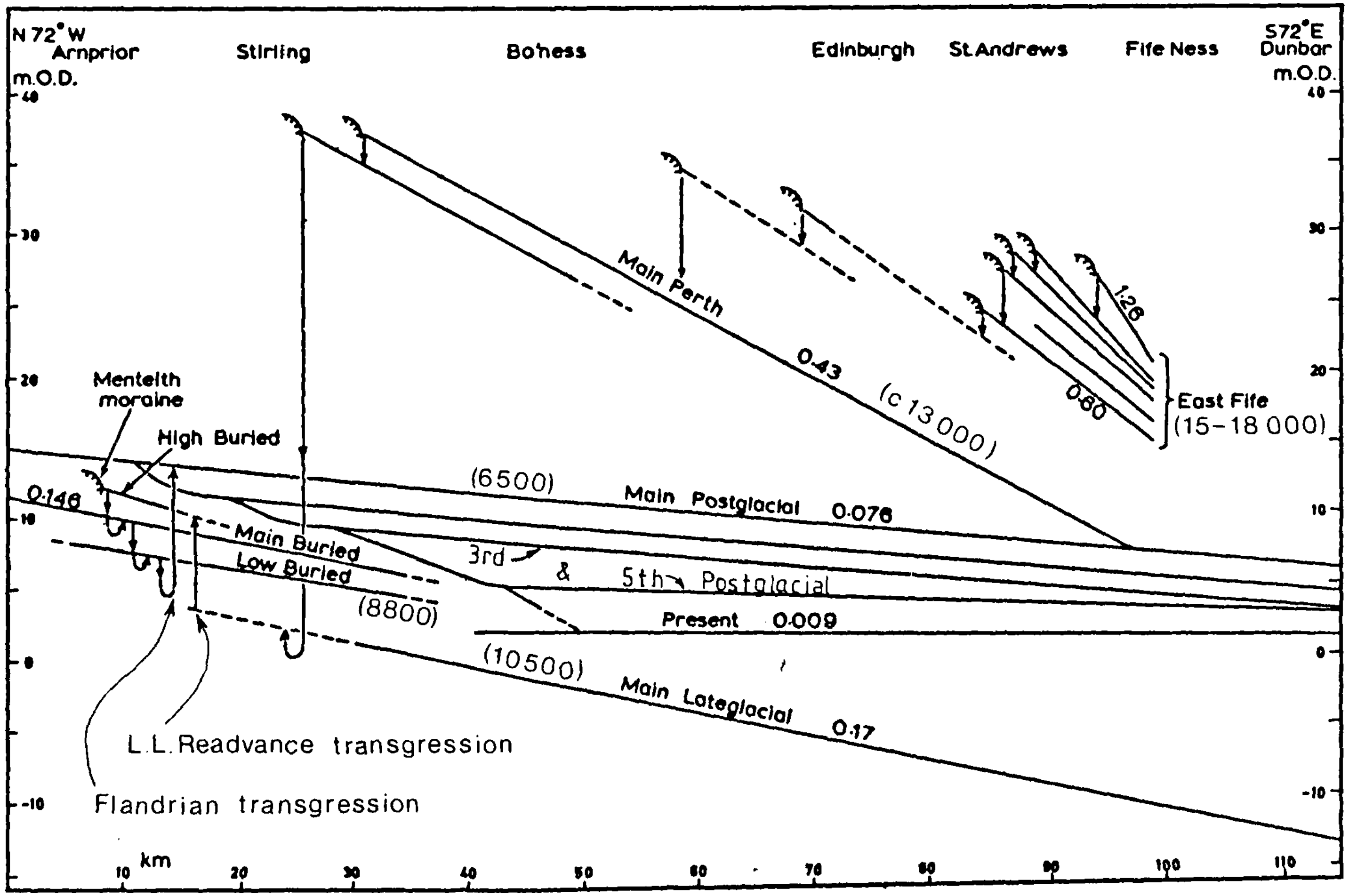


Fig.7-2. Sisson's (1974) height-distance diagram for shorelines in southeast Scotland. Gradients of shorelines in m/km; ages (in radiocarbon years) are shown in brackets.

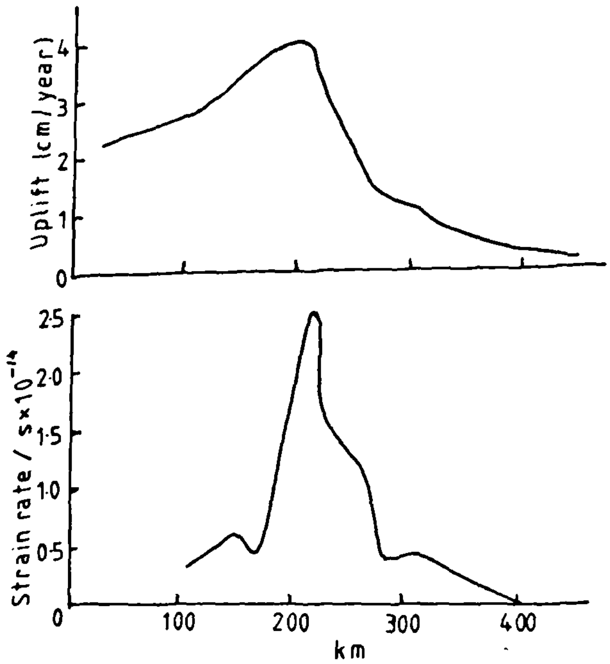


Fig.8-1. Present uplift and strain rate at Glacier Bay, Alaska, measured from tide-gauge records (Hicks and Shofnos 1965). Glacier Bay has been a site of rapid ice retreat for the last 200 years. Up to 15 feet of uplift has been accomplished during that time. (redrawn from Crittenden 1967).

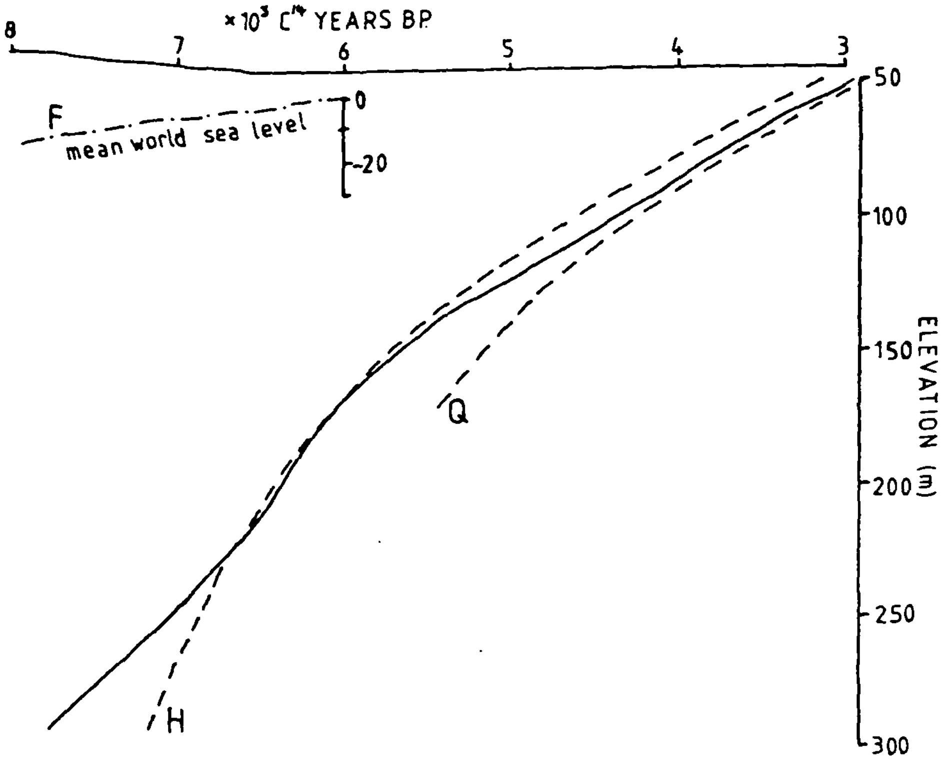


Fig.8-2. Uplift at Richmond Gulf, Quebec. The observed emergence curve (solid line) is interpreted as the result of three components: the Flandrian transgression (F), the unloading of Hudson Bay (H) and the delayed unloading of New-Quebec (Q) (redrawn from Hillaire-Marcel 1980).

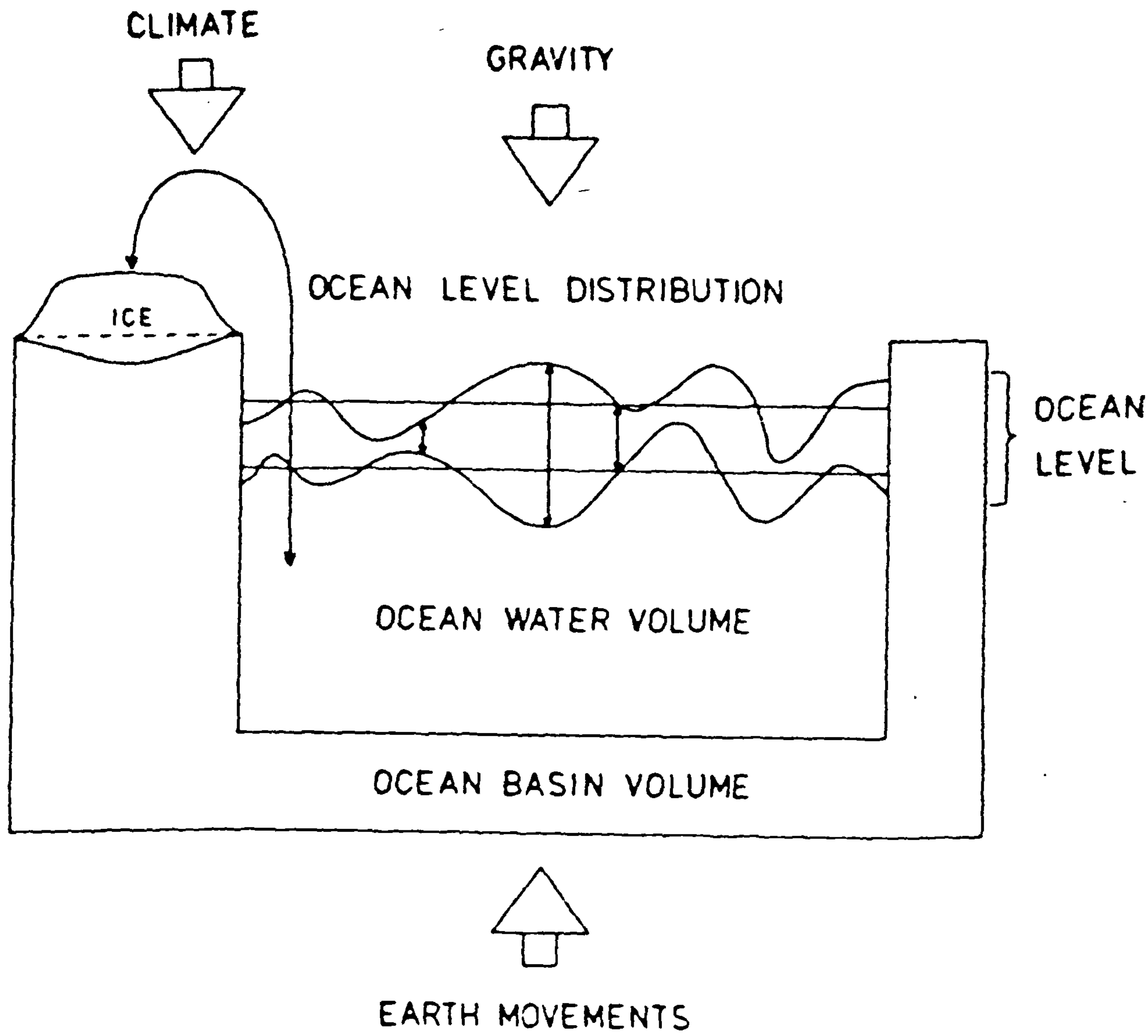


Fig.8-3. Morner's (1976) diagram of factors influencing sea level. The vertical arrows indicate how sea level rise can differ dramatically according to changes in the equipotential surface of the geoid.

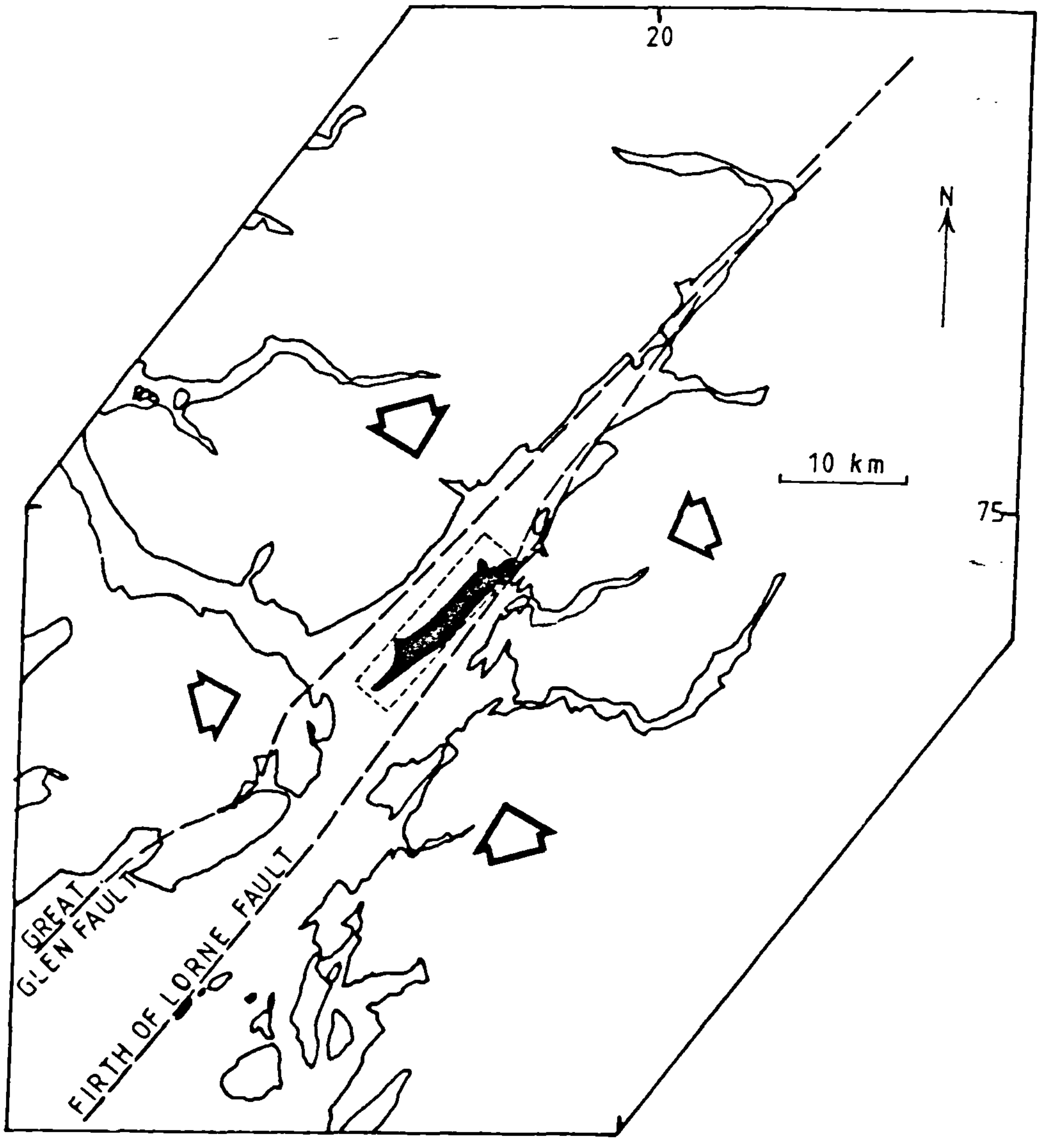


Fig.9-1. The Isle of Lismore (black), sandwiched between the the Great Glen and Firth of Lorne faults, illustrated as a giant 'triaxial test cell' (Stress arrows are hypothetical). (See section 9.1 for discussion).

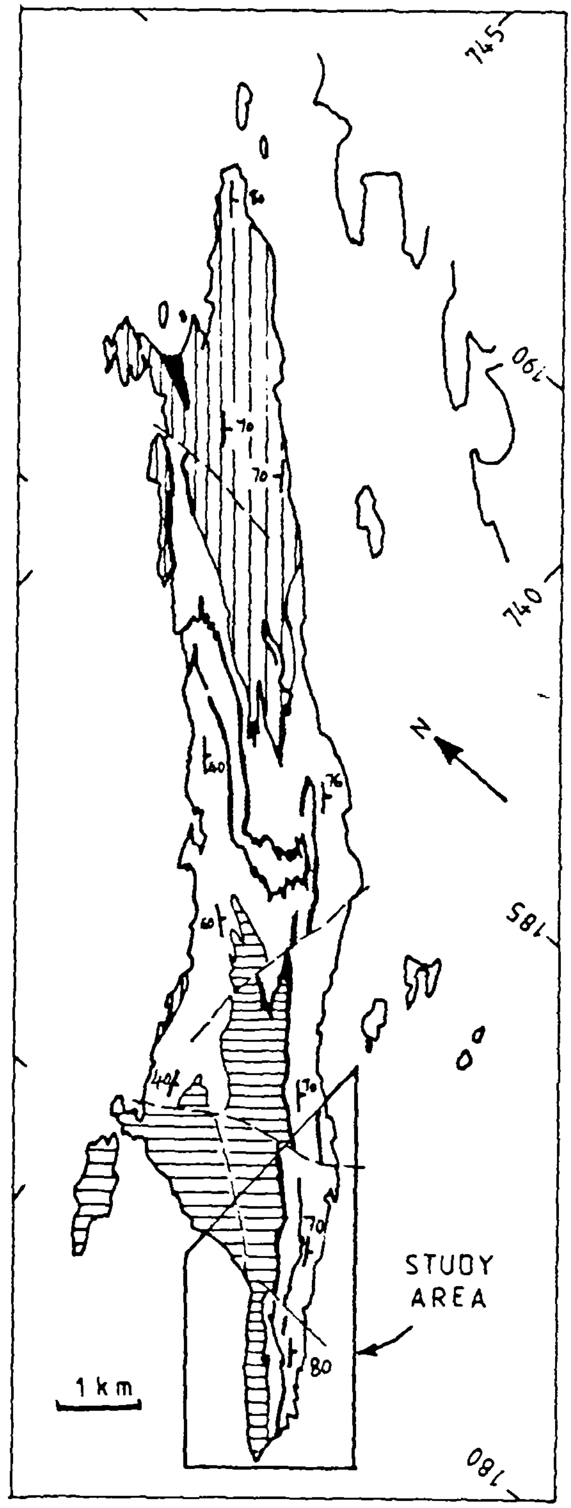


Fig.9-2. Simplified geological map of Lismore, excluding dykes (after Hickman 1975). The following members of the Lismore Limestone Formation (Lower Dalradian) are illustrated: Barr Mor Limestone - horizontal hatching; Middle Limestone - blank; Lower Limestone - vertical hatching; Slate units - black; faults - dashed lines.

Fig.9-3. Map of south Lismore (air photo overlay) showing dykes and faults mapped. Numbered localities are described in Appendix 1.

MILLER'S PORT FRACTURE ZONE

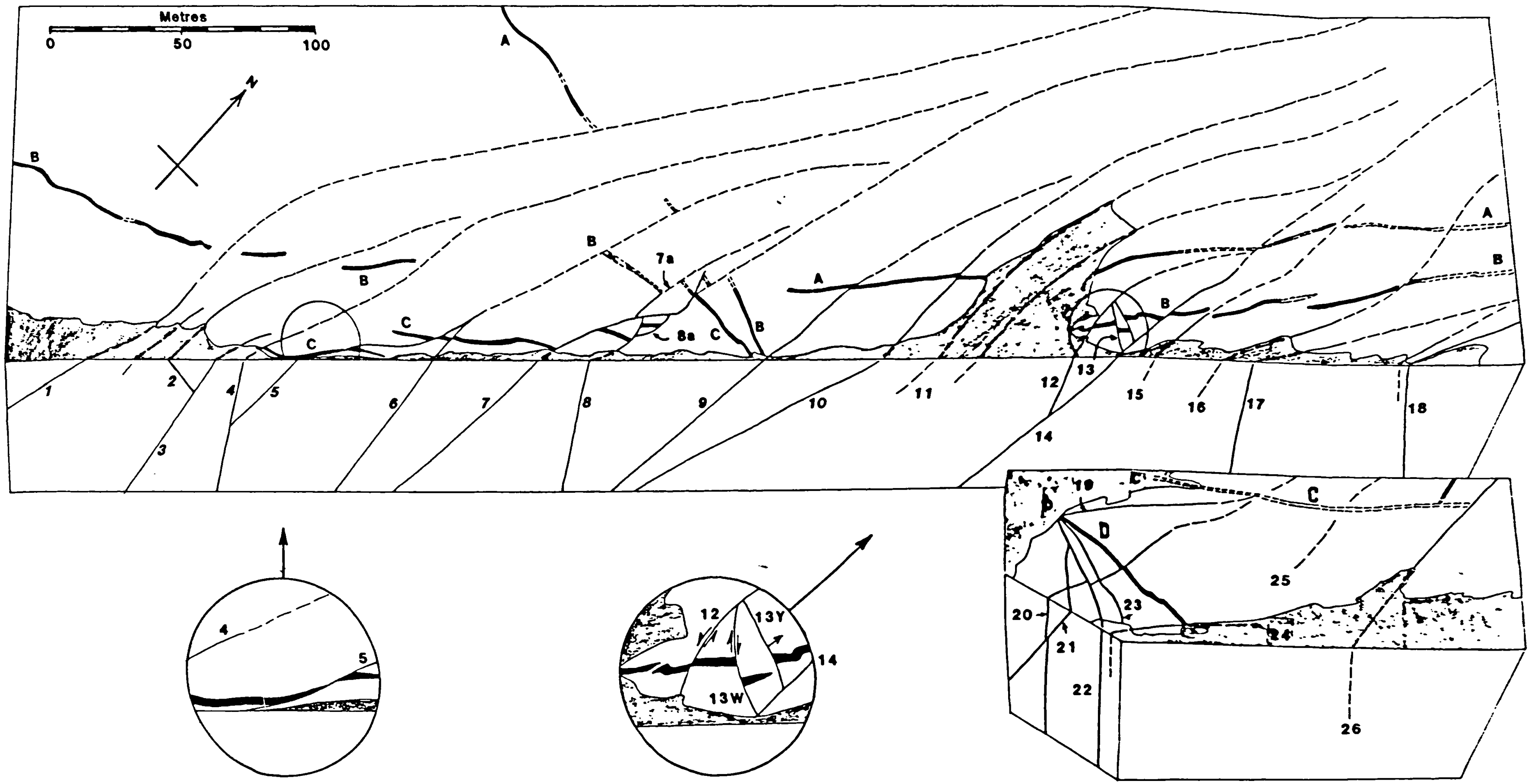


Fig.9-4. Block Diagram of the coastal section of the Miller's Port Fracture Zone (Fig.9-3). Numbered fractures are described in Appendix 1. Dykes A,B,C and D are labelled. The vertical dimension has been constructed by extrapolating fracture planes, measured at the surface, downwards.

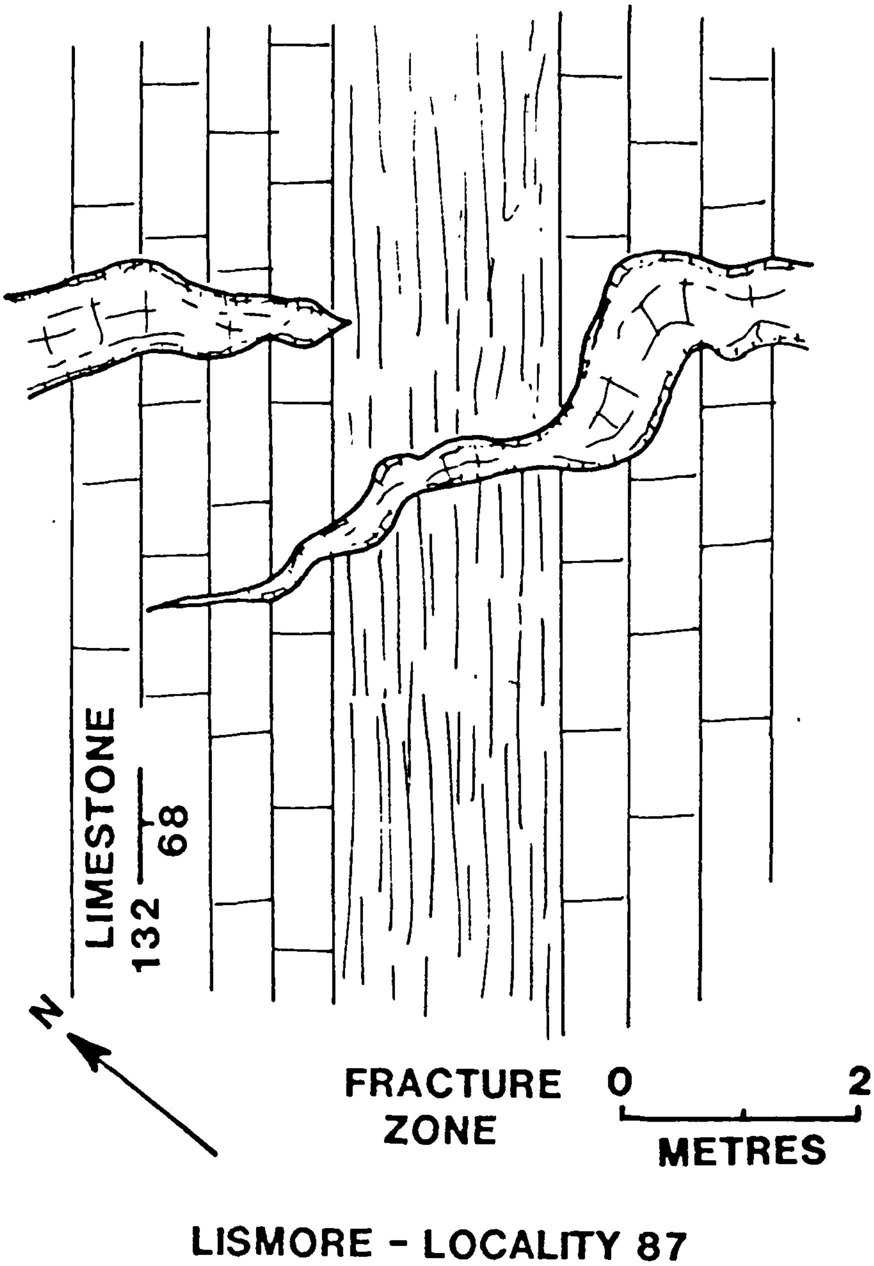


Fig.9-5. Field sketch of locality 87, Lismore, showing a dyke offset in an 'en echelon' manner where it crosses a fracture zone.

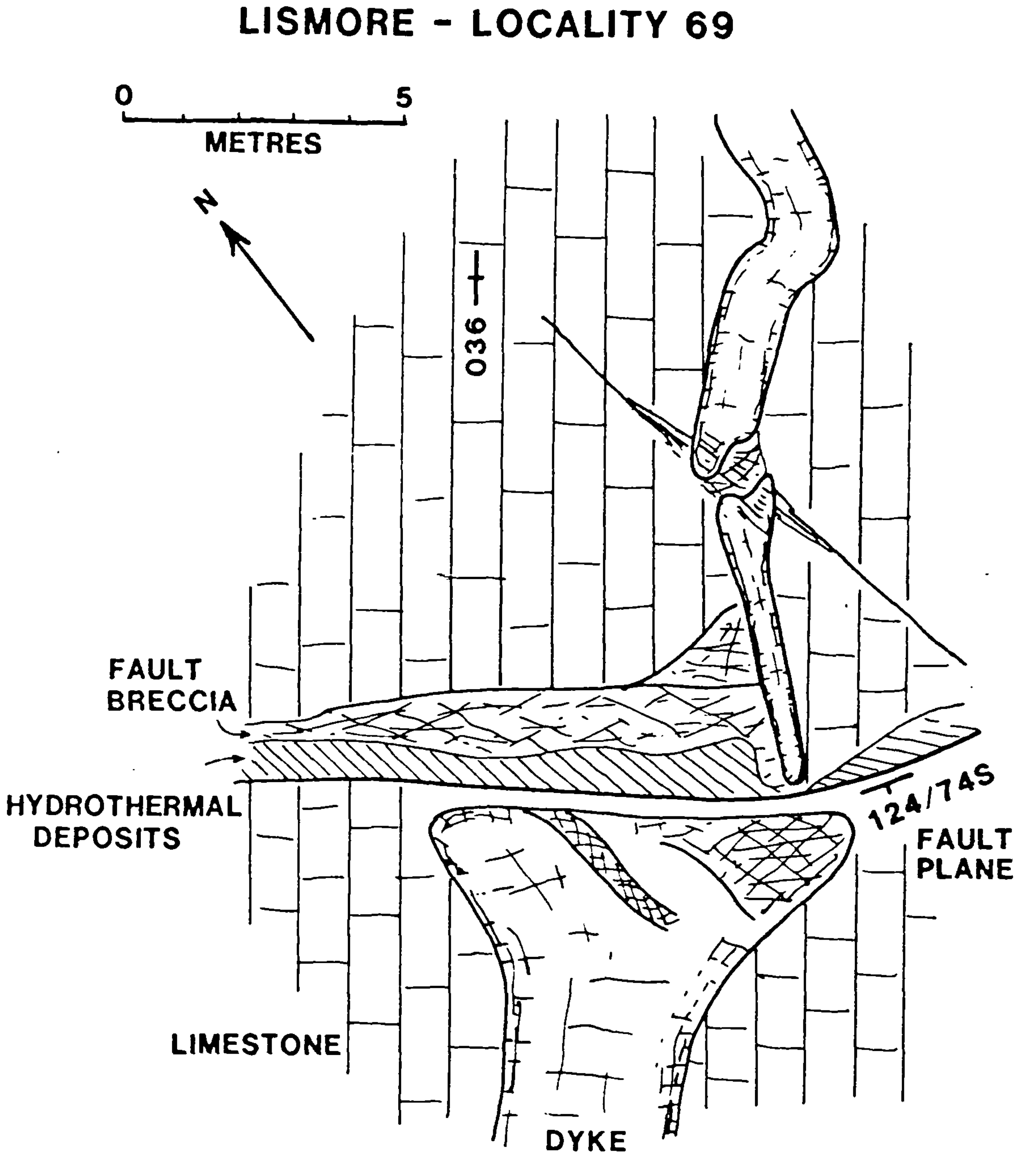


Fig.9-6. Field sketch of locality 69, Lismore, showing an emplacement offset of a dyke, with marked thickness change, at a fracture containing breccia and hydrothermal deposits. The dyke is probably of Caledonian age (on the basis of its orientation) and the hydrothermal deposits are probably Permo-Carboniferous (c.f. section 9.4.1).

LISMORE - LOCALITY 67

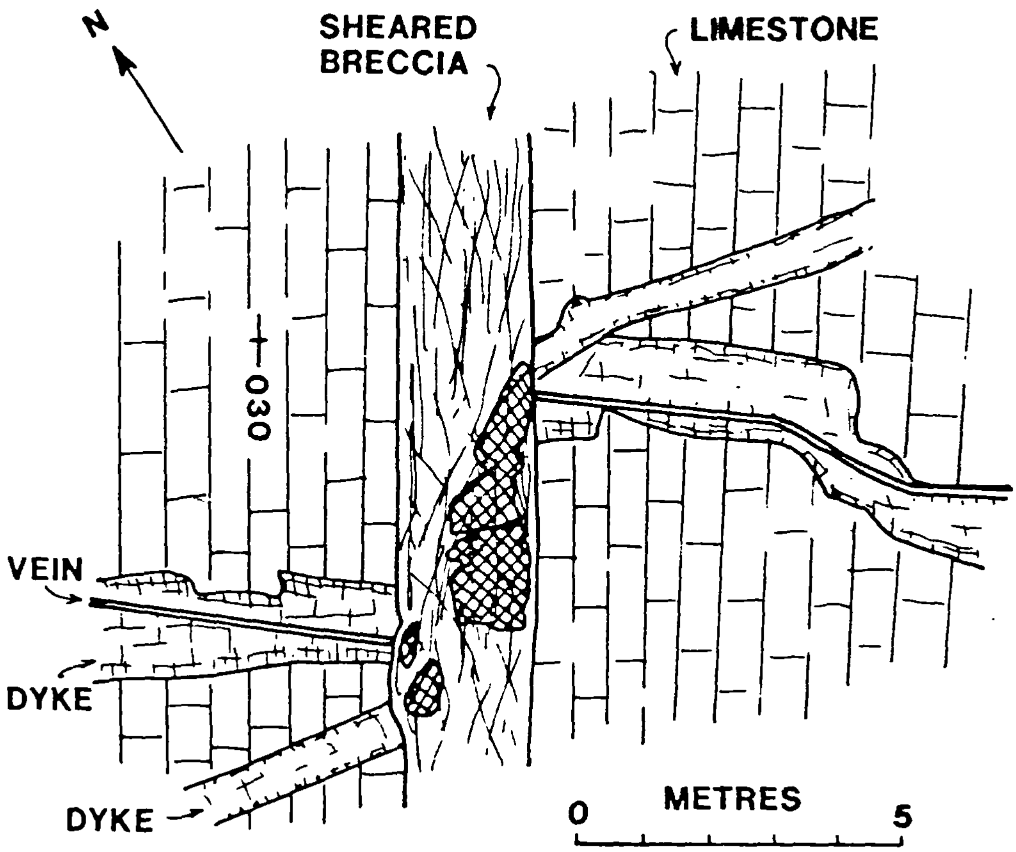


Fig.9-7. Field sketch of locality 67, Lismore, showing a faulted offset. Two dykes and a hydrothermal vein are offset by the same amount (4.5m). The cross-hatched material is sheared and altered dyke material within the fracture zone. Its presence would appear to suggest that dyke emplacement and faulting were closely associated (temporally).

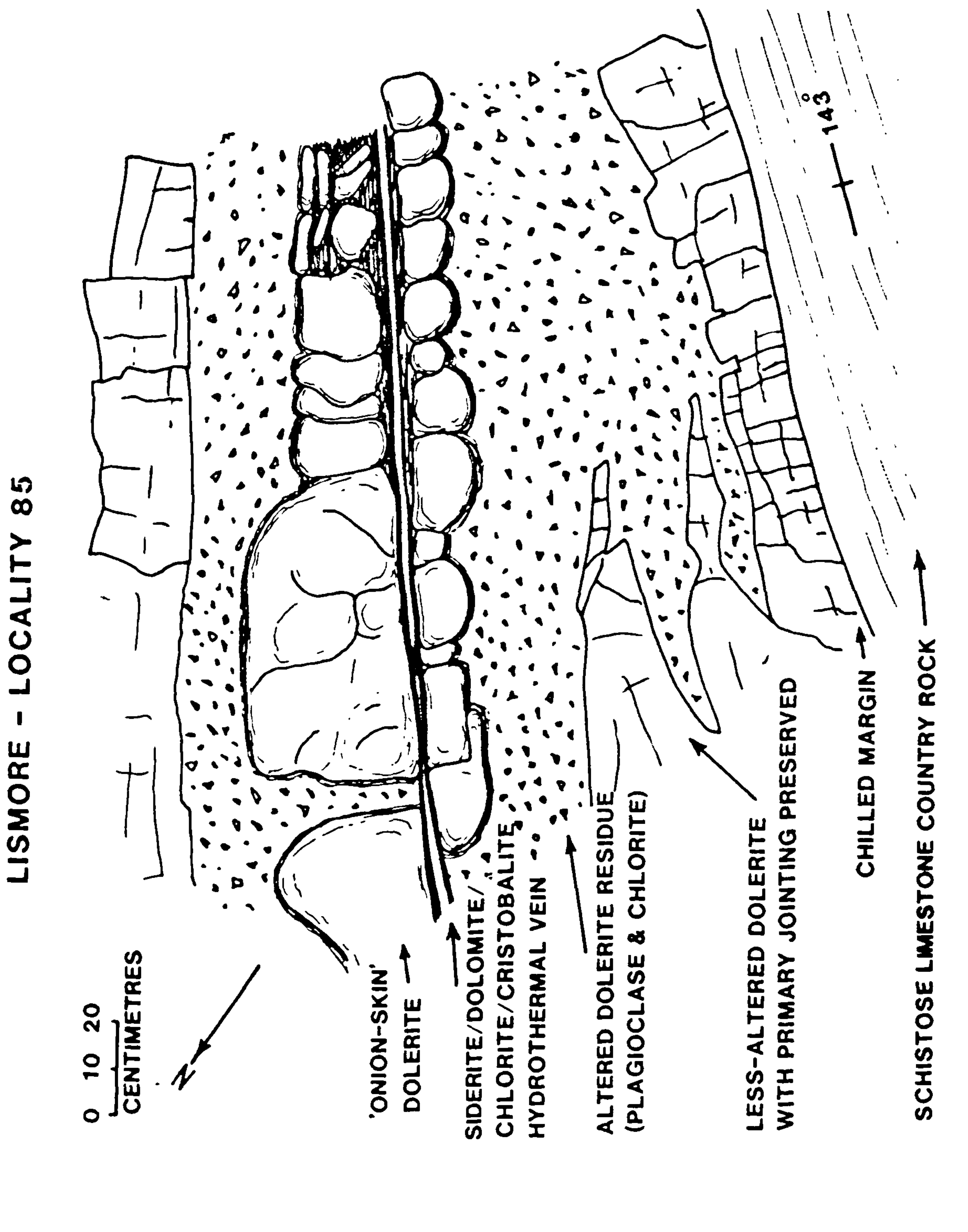


Fig.9-8. Field sketch of locality 85, Lismore, showing alteration fabrics in a dyke and their relationship to a hydrothermal vein.

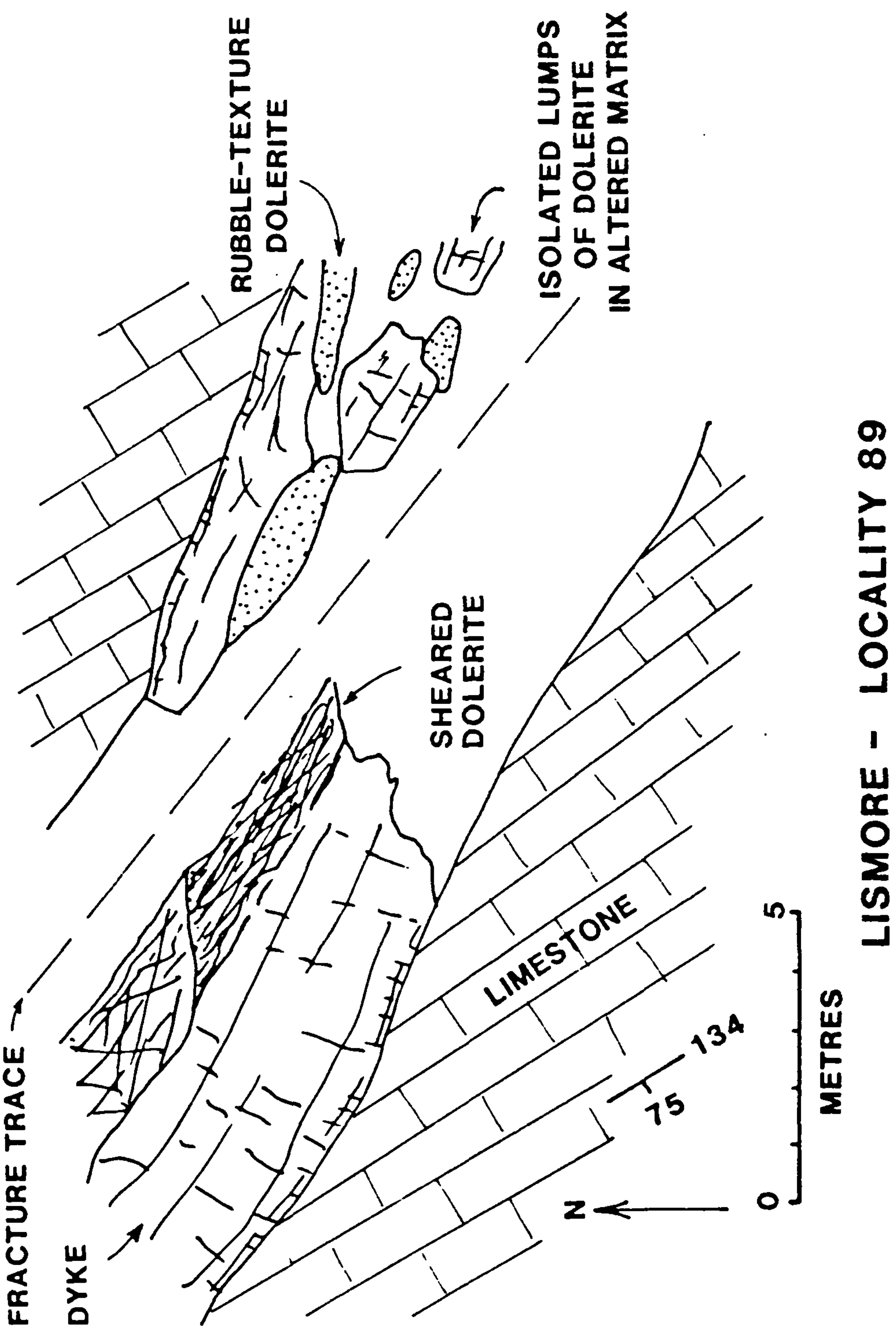


Fig.9-9. Field sketch of locality 89, Lismore, showing shearing and alteration of a dyke along a fracture trace, without measureable offet. The 'rubble-textured' dolerite is thought to be a product of hydrothermal alteration.

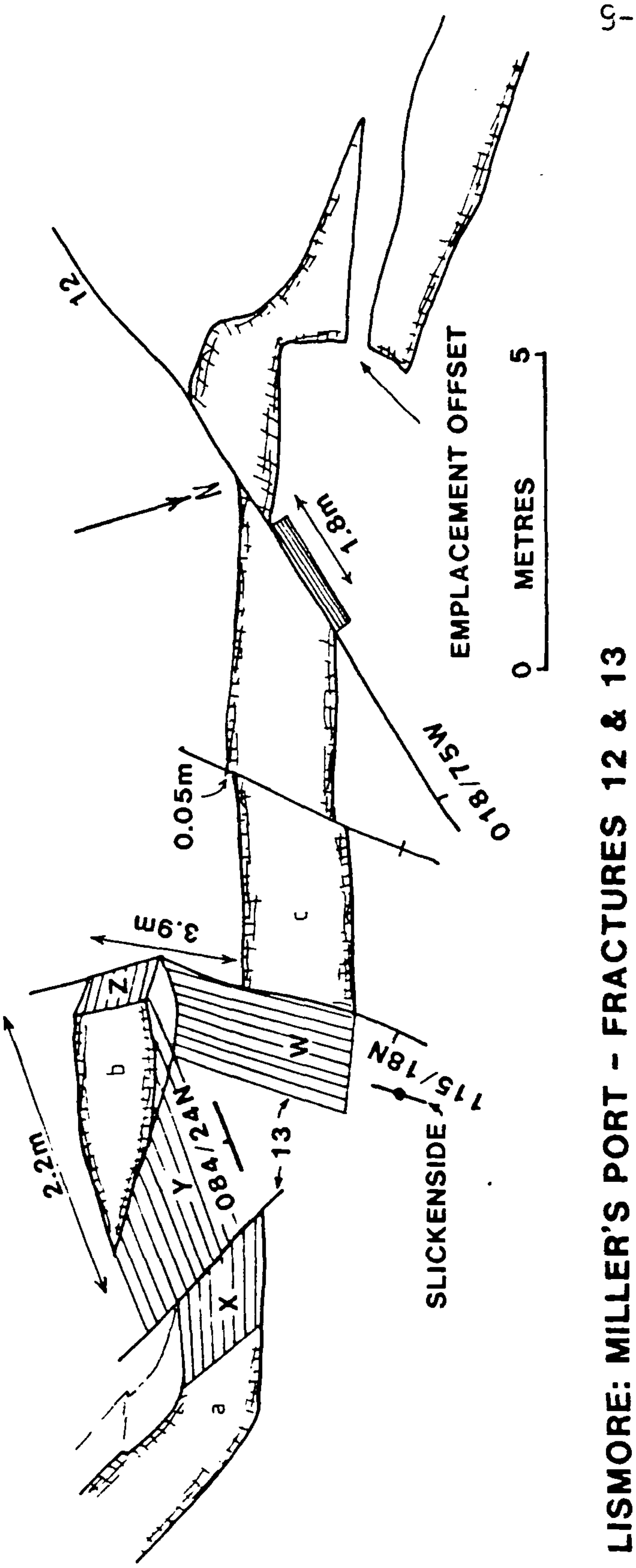


Fig.9-10. Field sketch of the complicated net of fault offsets of a dyke at Miller's Port, fractures 12 and 13. (For discussion see section 9.3.3).

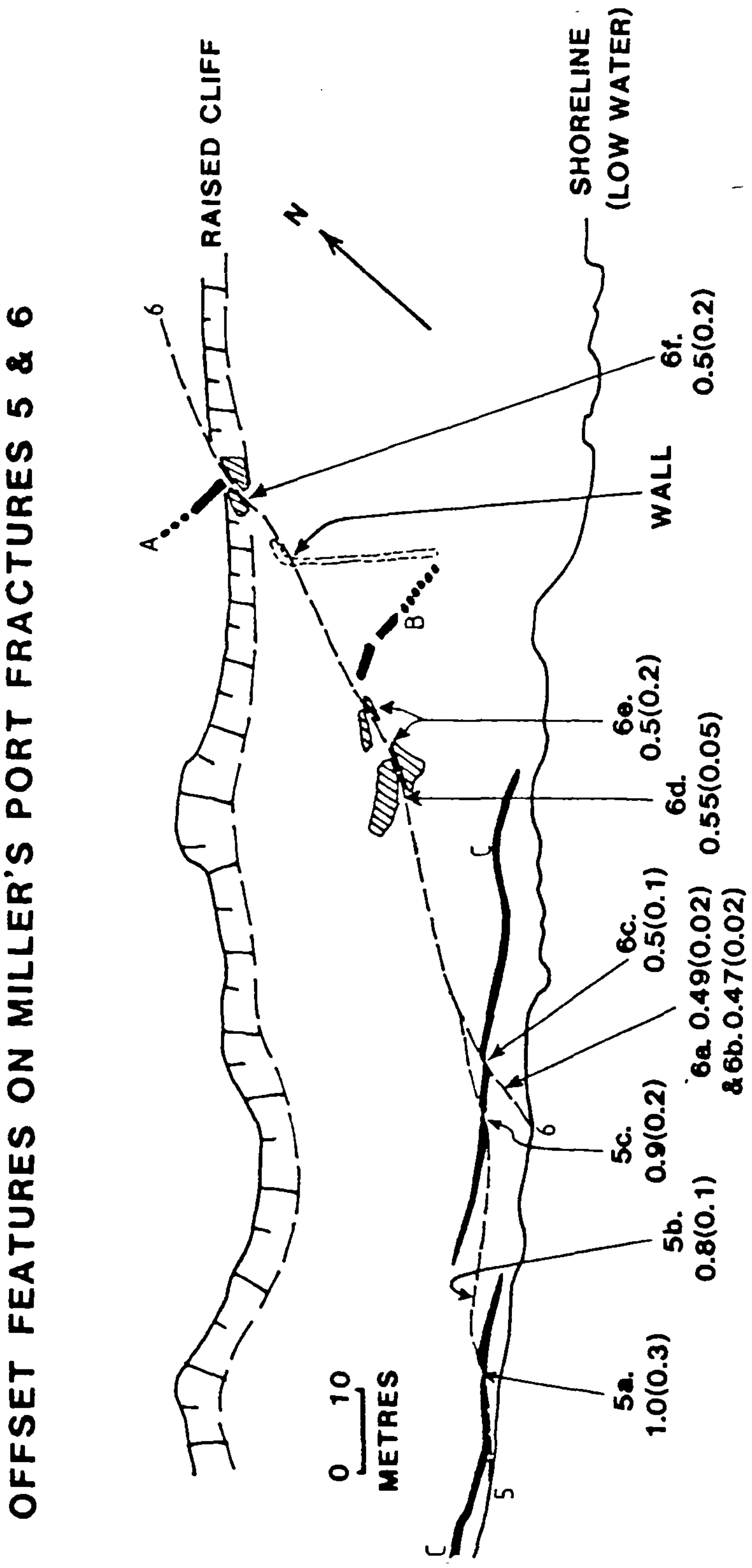
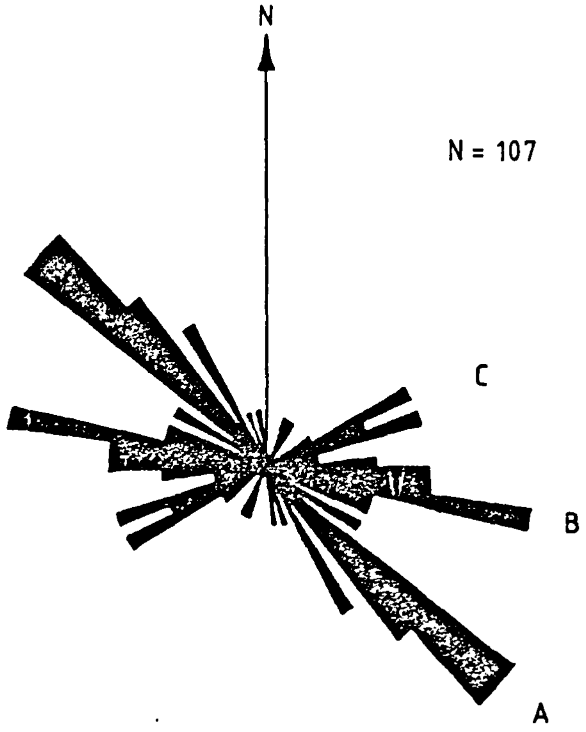


Fig.9-11. Field sketch of the locations of offset features on fractures 5 and 6, at Miller's Port, Lismore, which indicate recent movement. The figures give measured lateral offsets in metres; errors are shown in brackets. (For discussion see section 9.3.4).

A.



B.

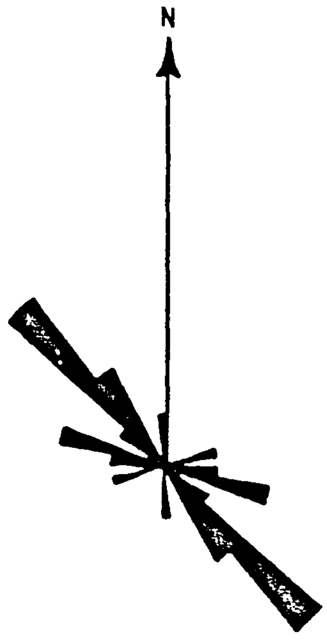


Fig.9-12. A. Rose diagram of orientations of dykes on south Lismore (orientations estimated to the nearest 5 degrees). Three populations, A,B, and C are evident (see section 9.4.1 for discussion).

B. Rose diagram of orientations of fractures containing hydrothermal deposits on south Lismore (orientations estimated to the nearest 10 degrees).

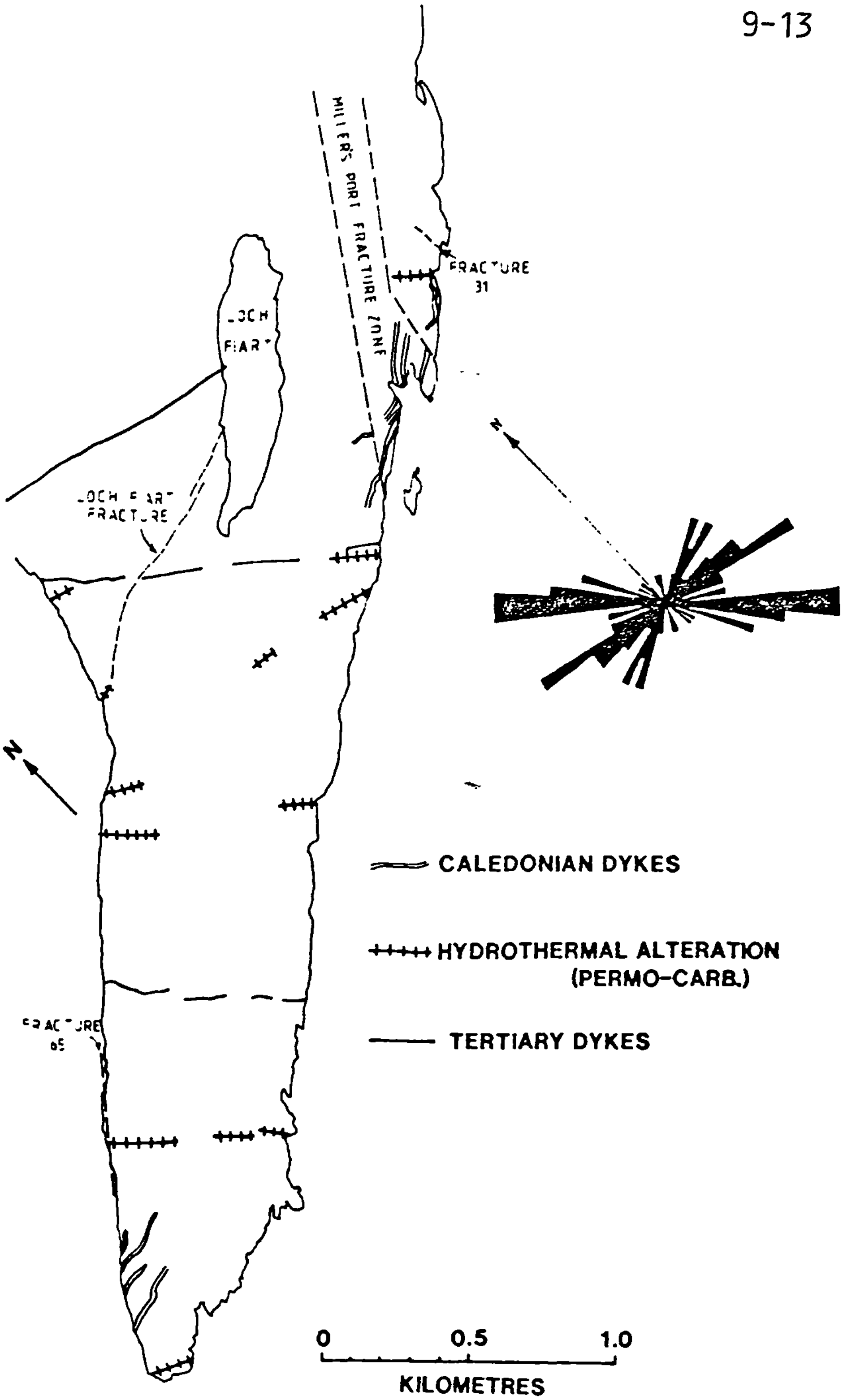


Fig.9-13. Summary map of south Lismore, illustrating the main localities of fractures with fault offsets and of hydrothermal deposits (note regular spacing). Also shown is the rose diagram for dyke orientations (from Fig.9-12A). The majority of (Permo-Carboniferous) dykes are not shown, however the few dykes which can be fairly confidently identified as Tertiary or Caledonian are shown.

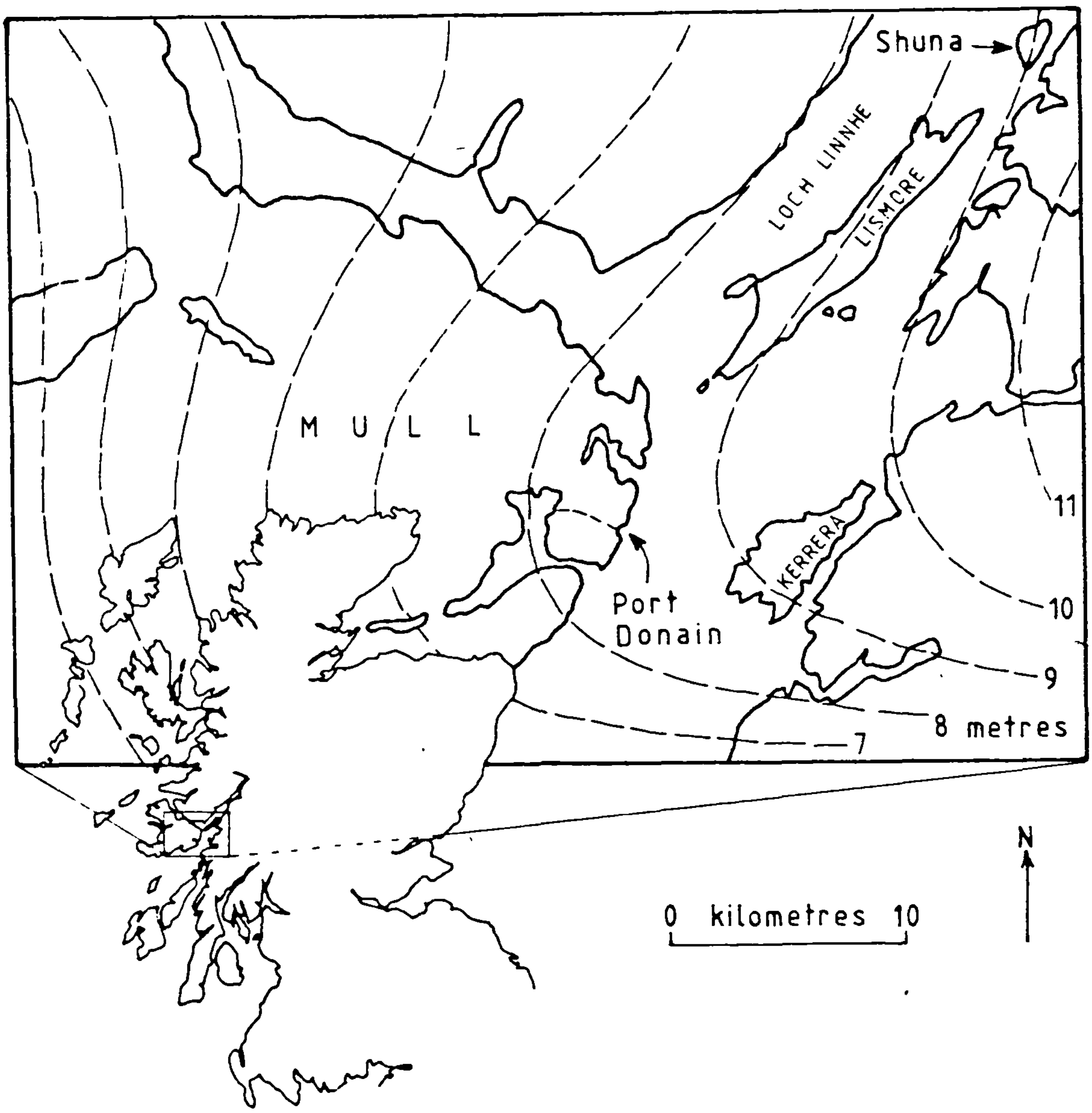


Fig.10-1. Map showing the locations of the two raised beach levelling survey sites - Shuna and Port Donain, Mull. Also shown are contours for the raised beach (the Main Rock Platform) constructed by Gray (1974). The short dashed line at Port Donain is a Mesozoic fault. (Redrawn from Gray 1974).

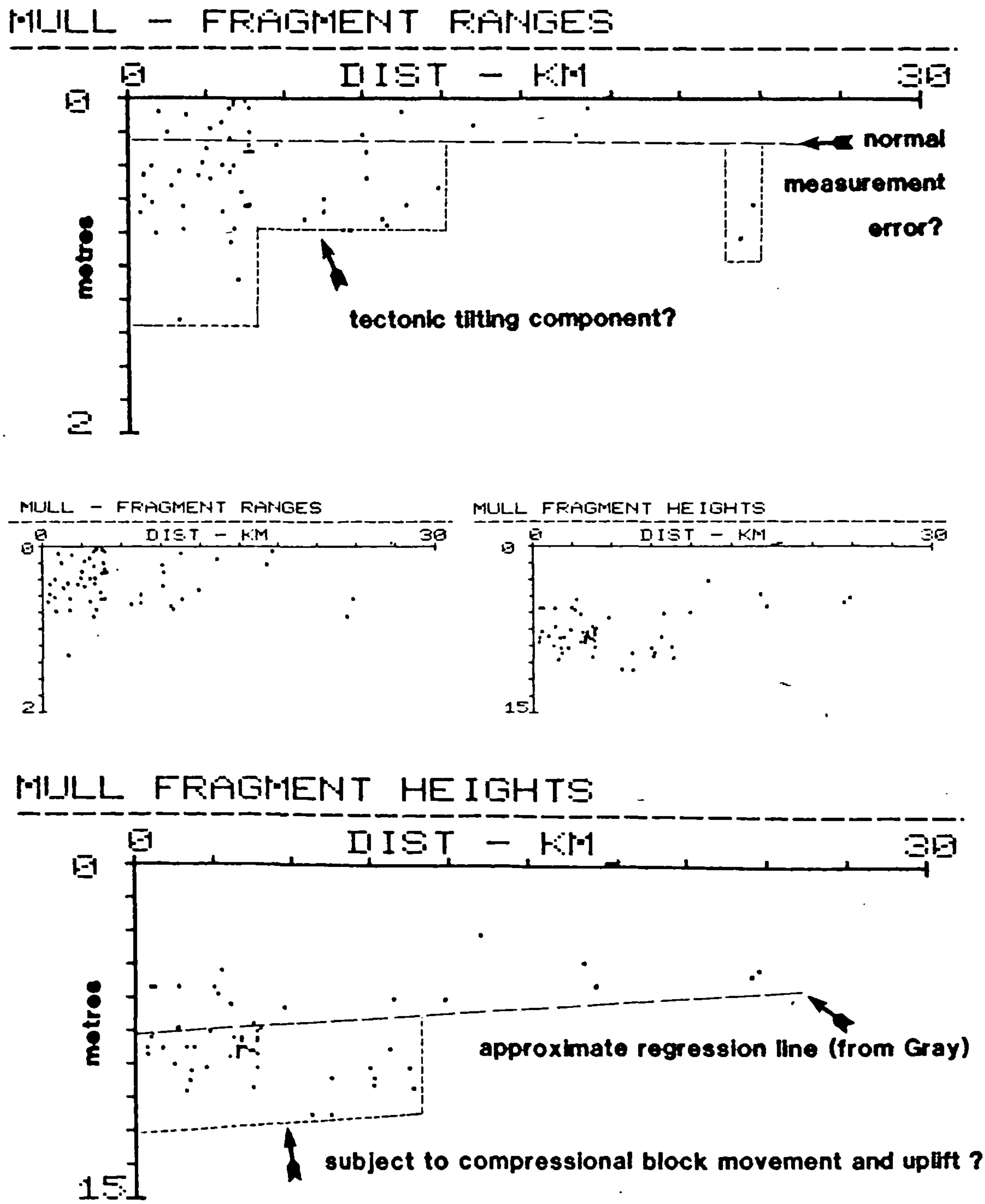


Fig.10-2. Graphs showing Gray's (1974) levelling data plotted with distance from the Great Glen fault. Two of Gray's parameters were plotted in this manner: 'fragment ranges' (that is, the variation in height of each fragment of the platform measured) and 'fragment heights' (that is, an average value for the heights of each platform fragment). The plot of 'fragment ranges' appears to display greater range (possibly resulting from greater tilt) near the Great Glen fault, and the plot of 'fragment heights' shows anomalously high values near the fault. Interpretations of the data are indicated. The two smaller plots show the data without interpretation lines.

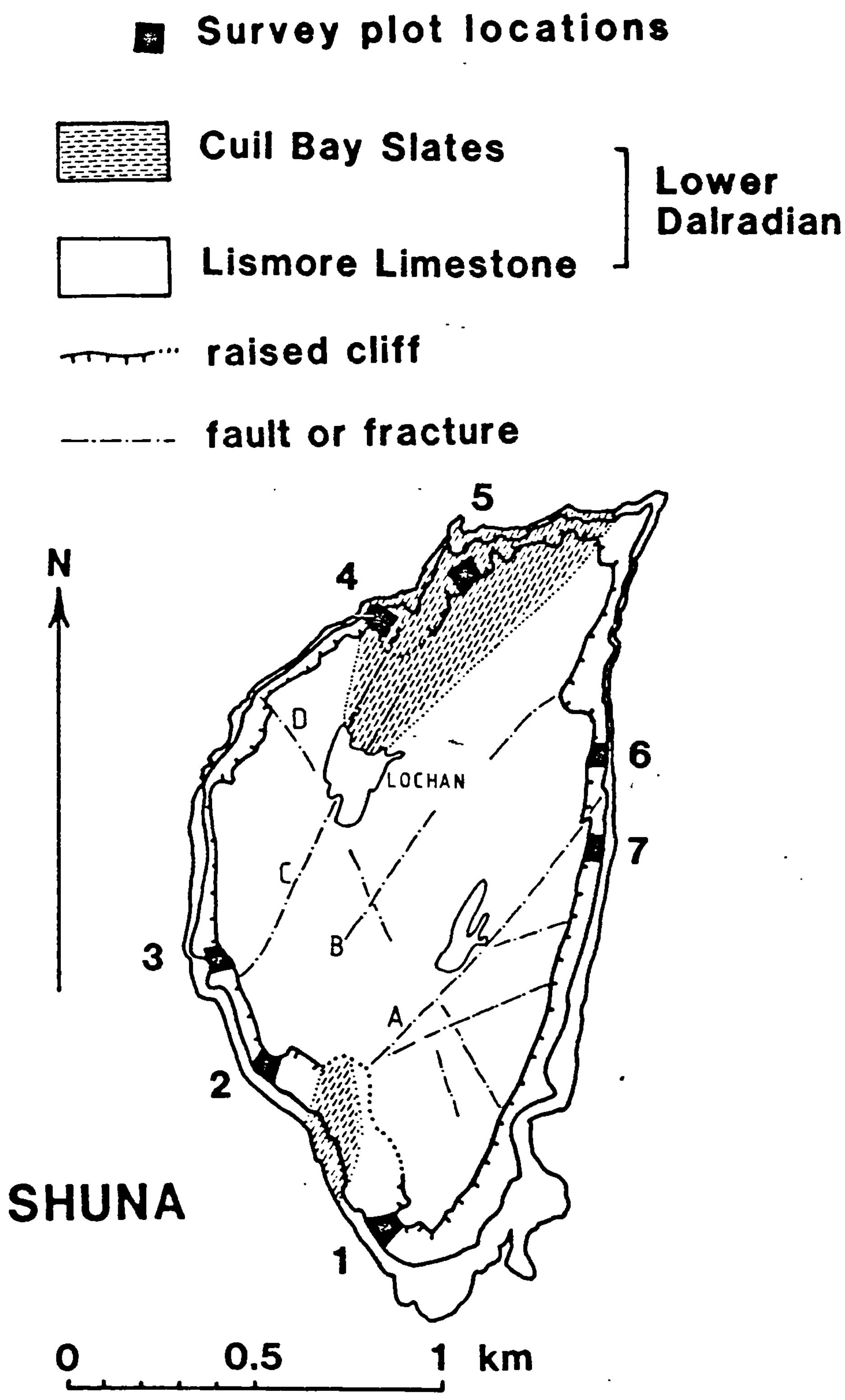


Fig.10-3. Map (air photo overlay) of the Isle of Shuna showing geology and survey plot locations. The two lines outside the raised cliff symbol are the low and high water marks. Fractures A,B,C and D are also shown.

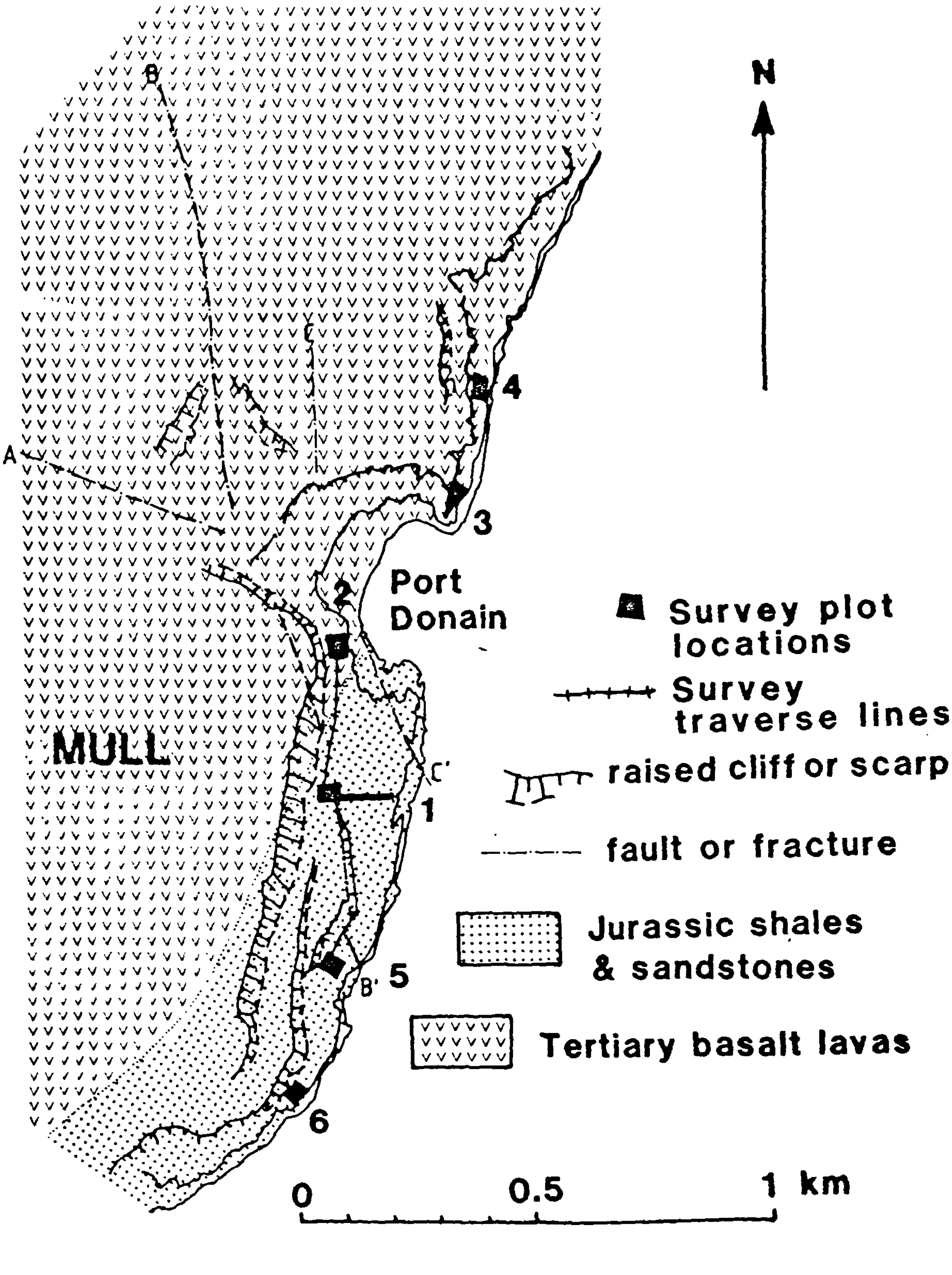
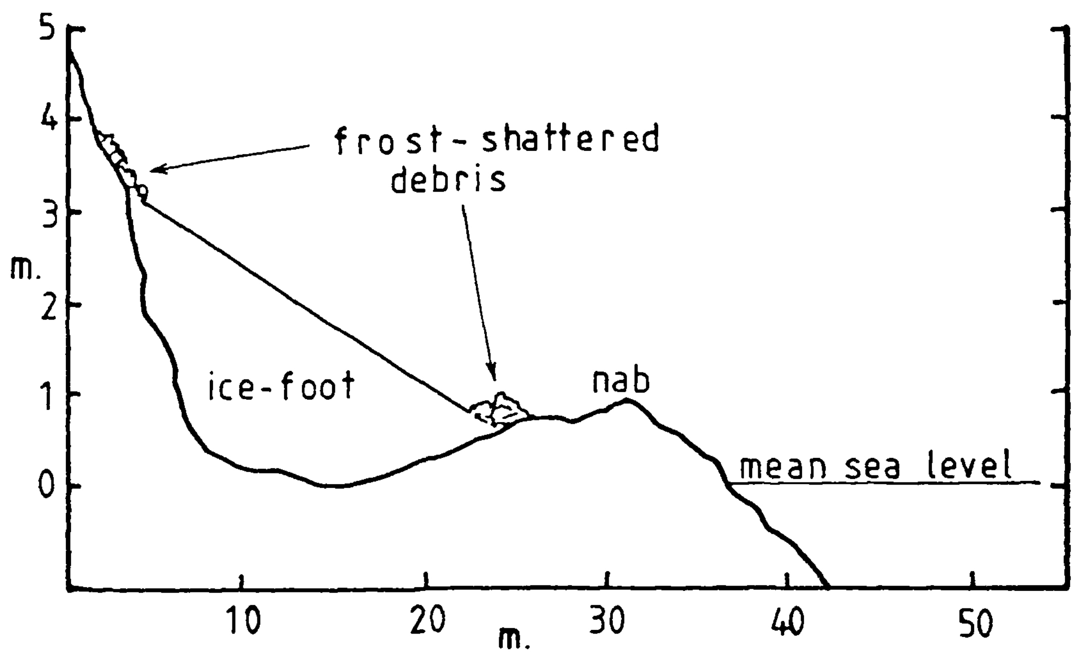
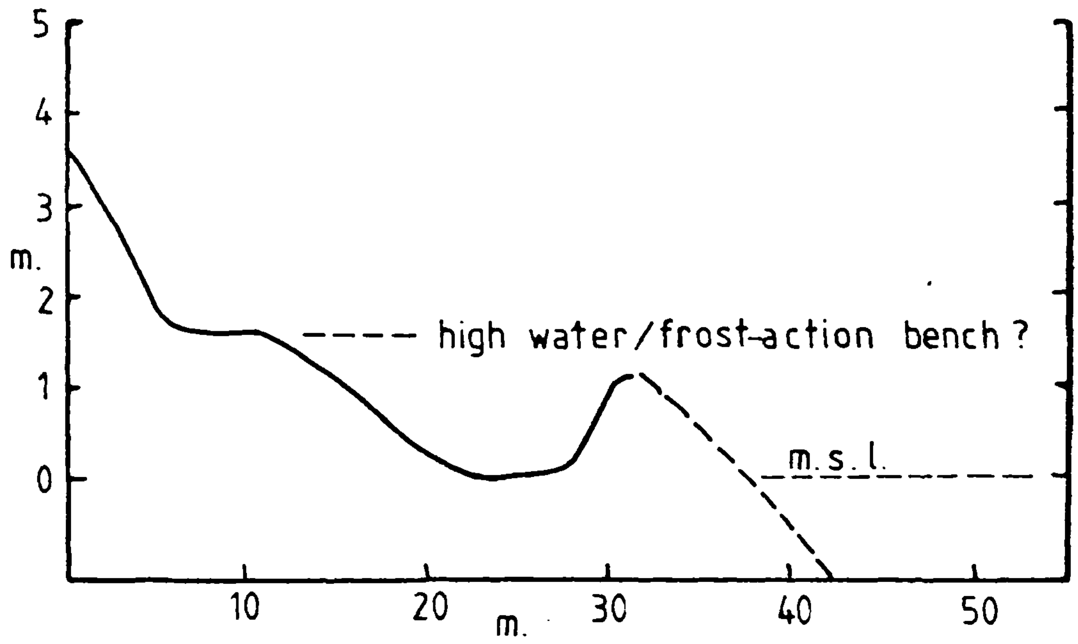


Fig.10-4. Map (air photo overlay) of the area around Port Donain, Mull, showing geology and survey plot locations. The two lines seaward of the raised cliff are high and low water marks. Fractures A, B-B' and C-C' are also shown.





ig.10-5. A. Idealized diagram of coastal 'nab' development in polar environments as proposed by Nansen (1922) (after Dawson 1980). B. Typical Main Rock Platform profile measured in this study (idealized from Mull: Plot 2). Both profiles display a coastal lip or 'nab', however the Main Rock platform has a prominant, landward notch developed.

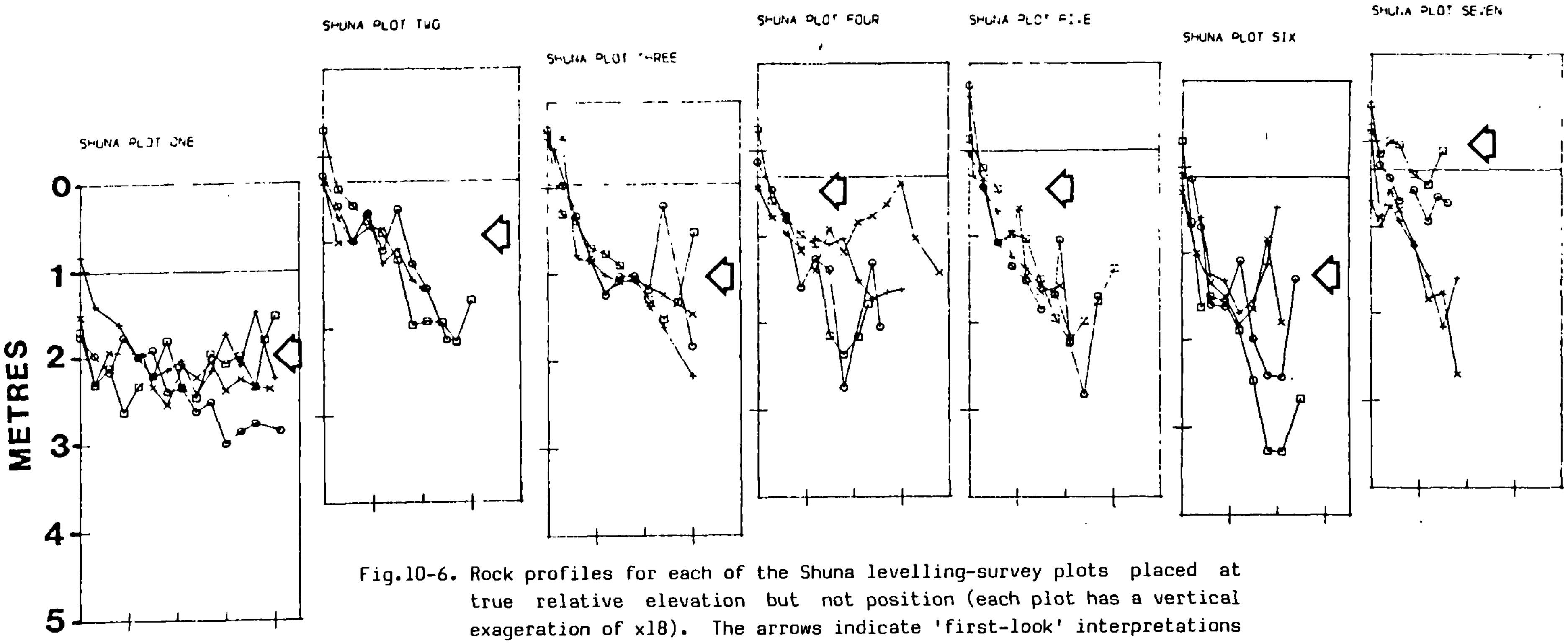


Fig.10-6. Rock profiles for each of the Shuna levelling-survey plots placed at true relative elevation but not position (each plot has a vertical exageration of x18). The arrows indicate 'first-look' interpretations of the position of the platform notch - note the considerable variation in its elevation. The different point-symbols correspond to individual line profiles: squares - first line, circles - second line, crosses - third line, X - fourth line.

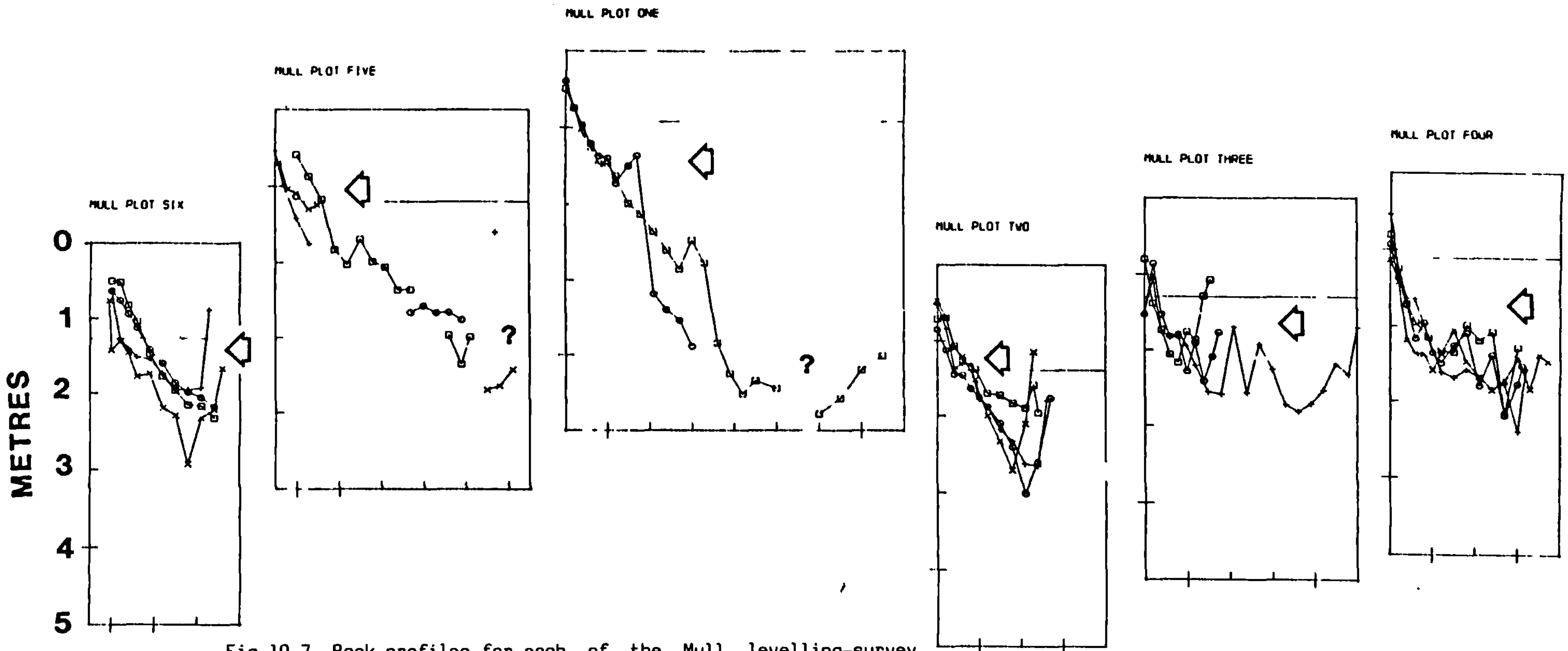
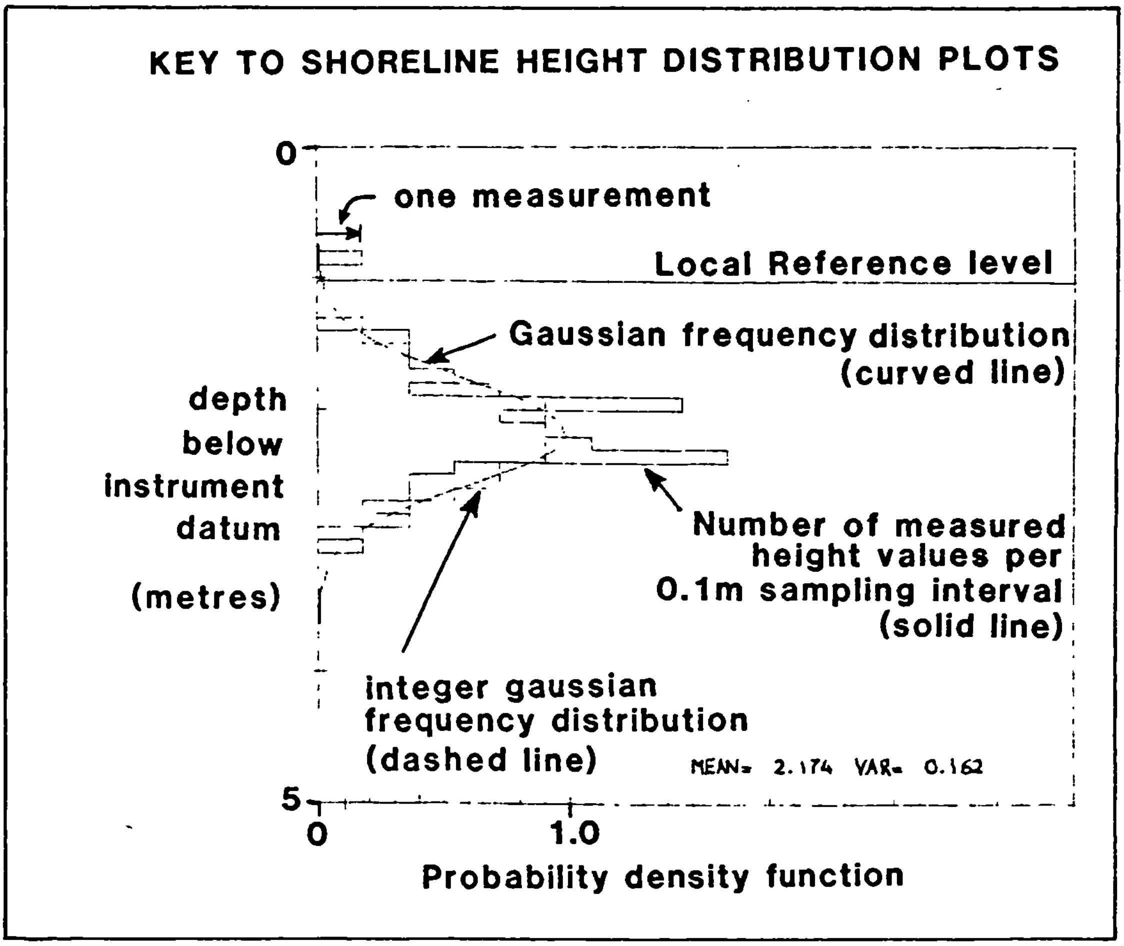


Fig.10-7. Rock profiles for each of the Mull levelling-survey plots placed at true relative elevation but not position (each plot has a vertical exageration of x18). The arrows indicate 'first-look' interpretations of the position of the platform notch - note that plots five and one are considerably higher. The different point-symbols correspond to individual line profiles: squares - first line, circles - second line, crosses - third line, X - fourth line.



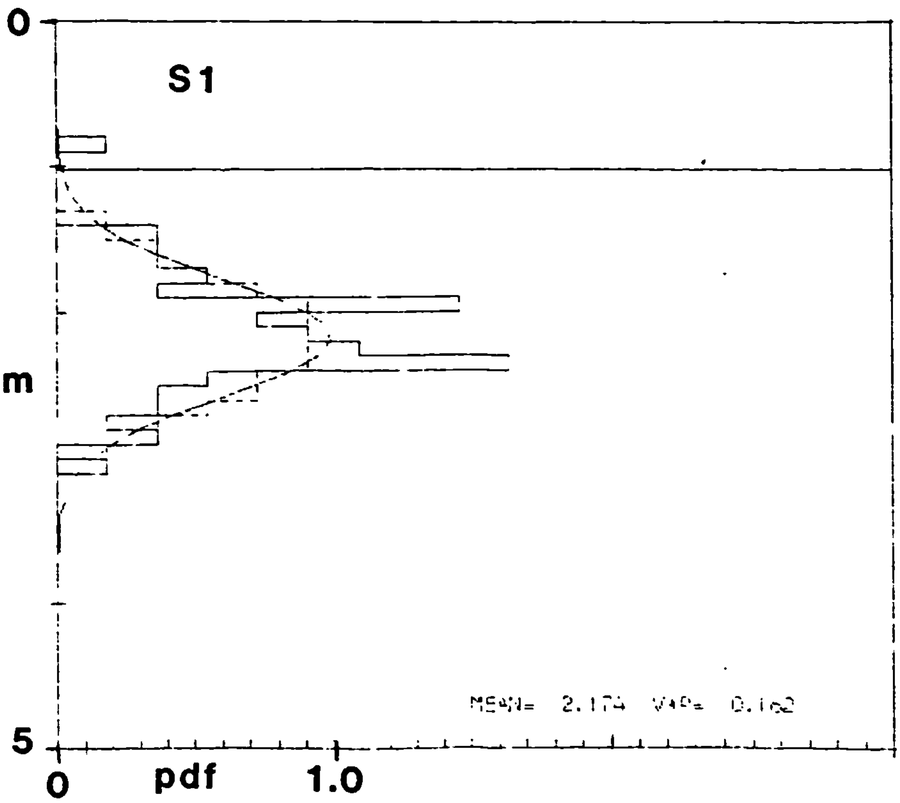
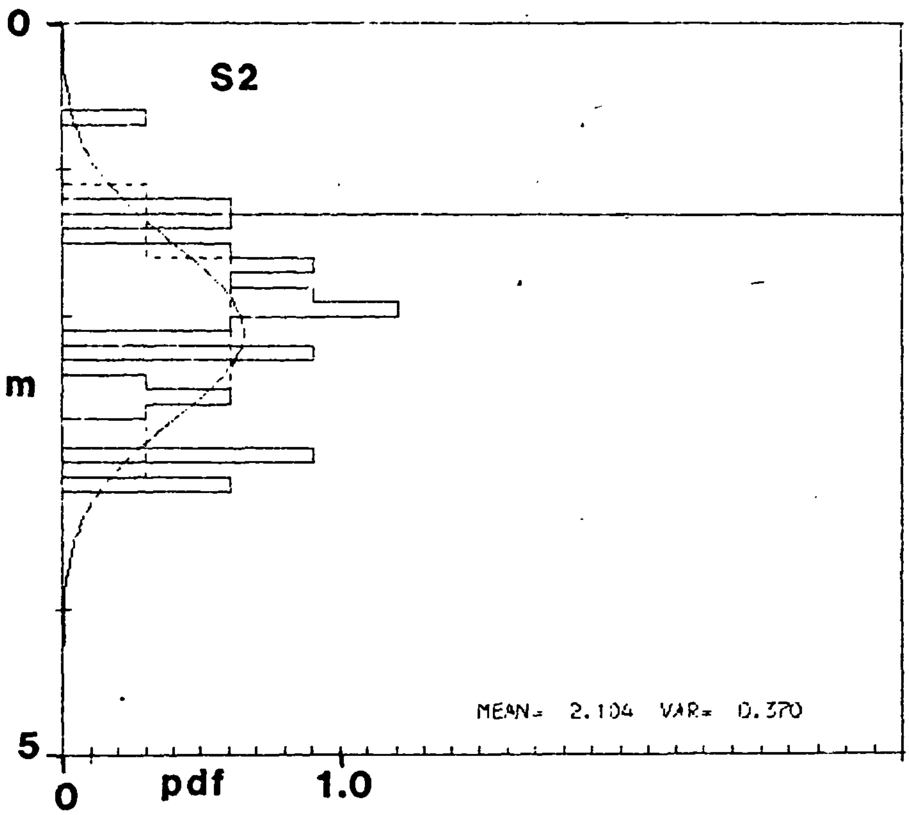


Fig.10-8. Shoreline height distribution plots: Shuna, plot 1 (also Key above).



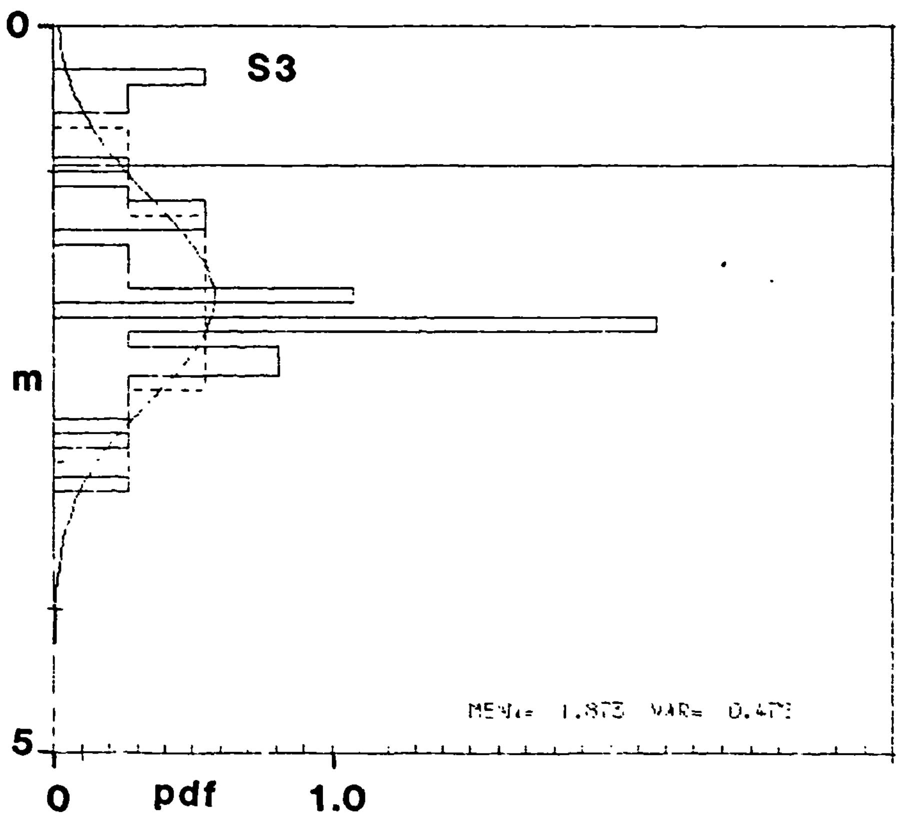


Fig.10-9. Shoreline height distribution plots: Shuna, plots 2 and 3.

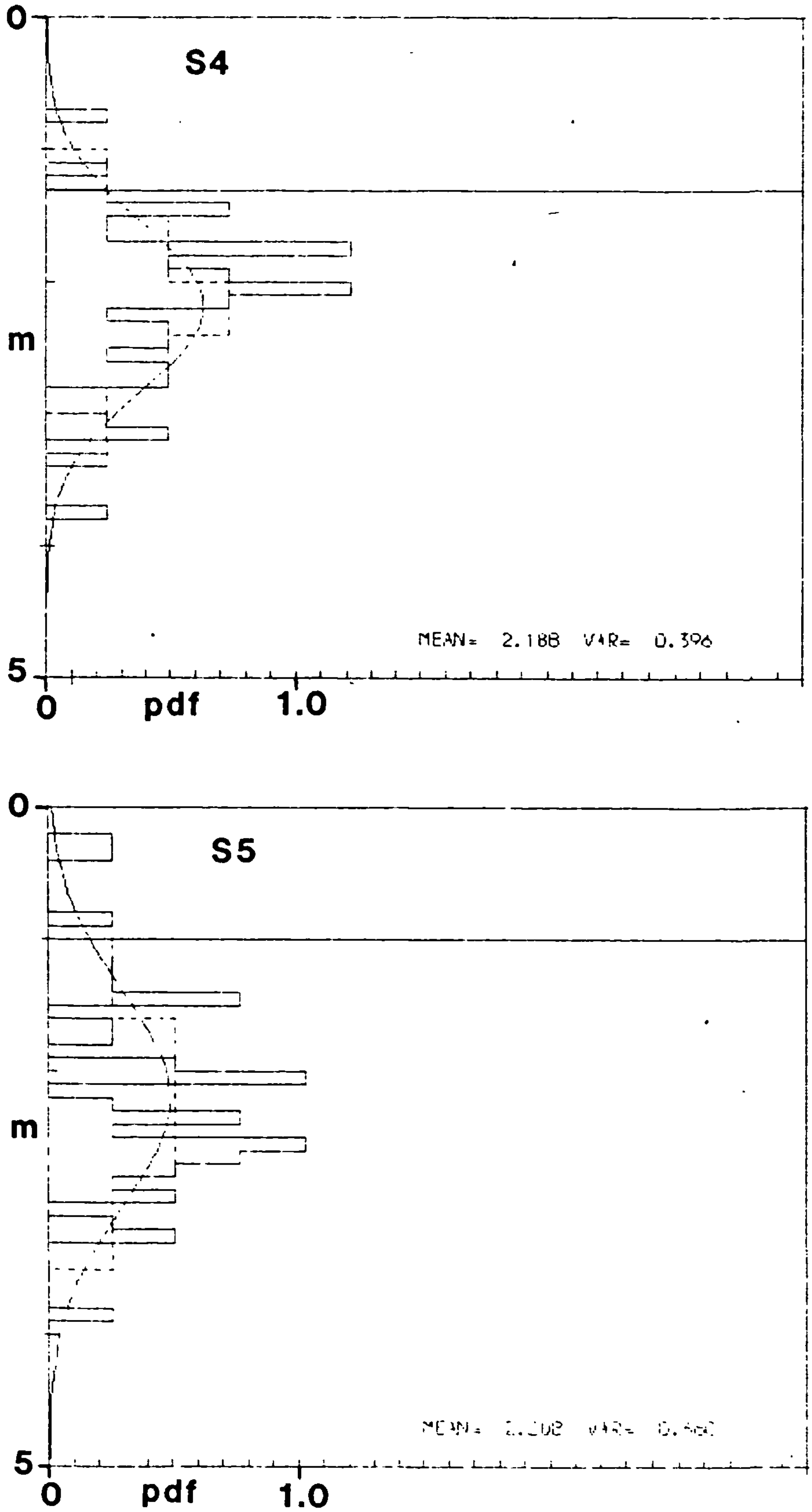


Fig.10-10. Shoreline height distribution plots: Shuna, plots 4 and 5.

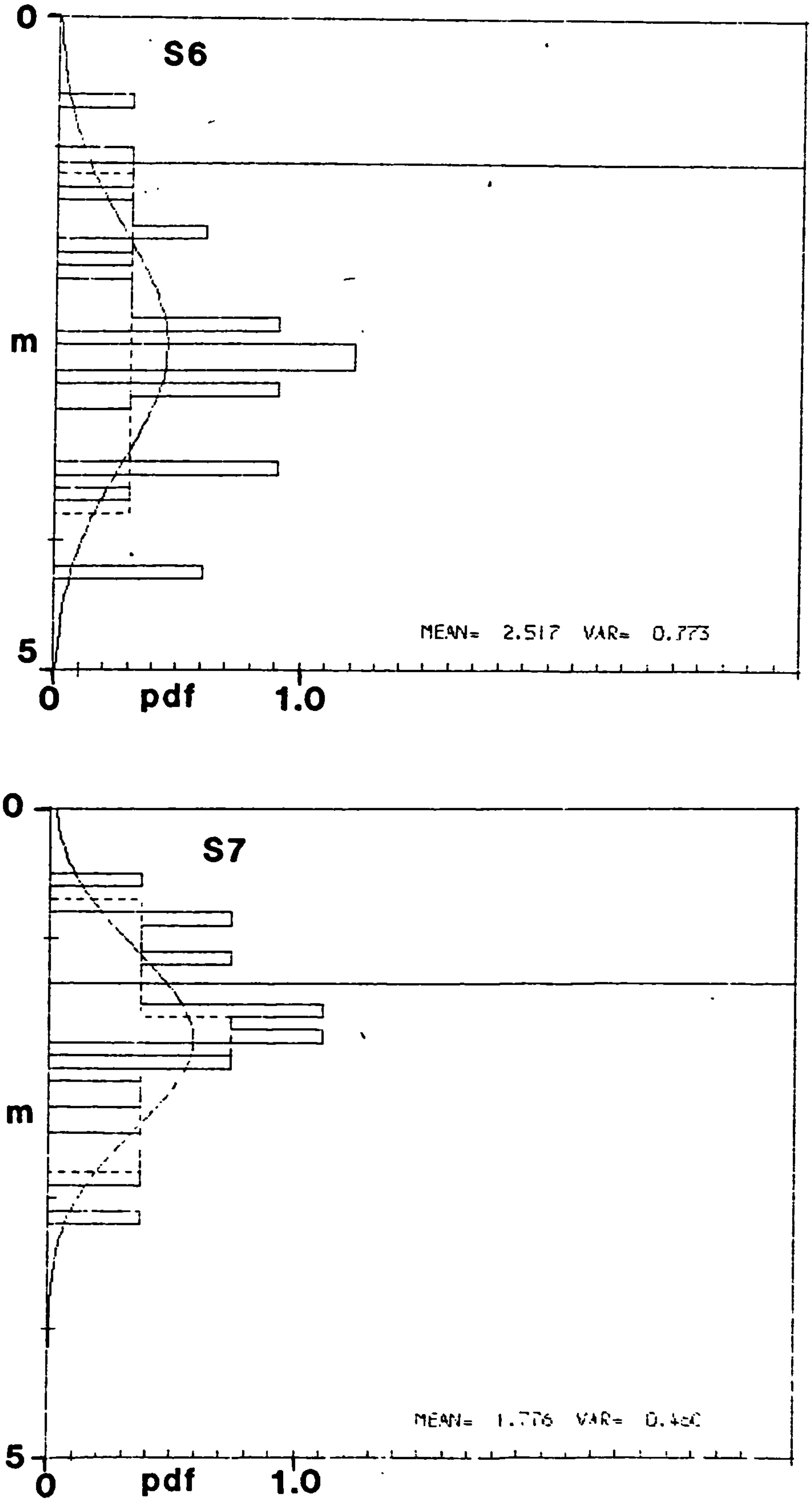
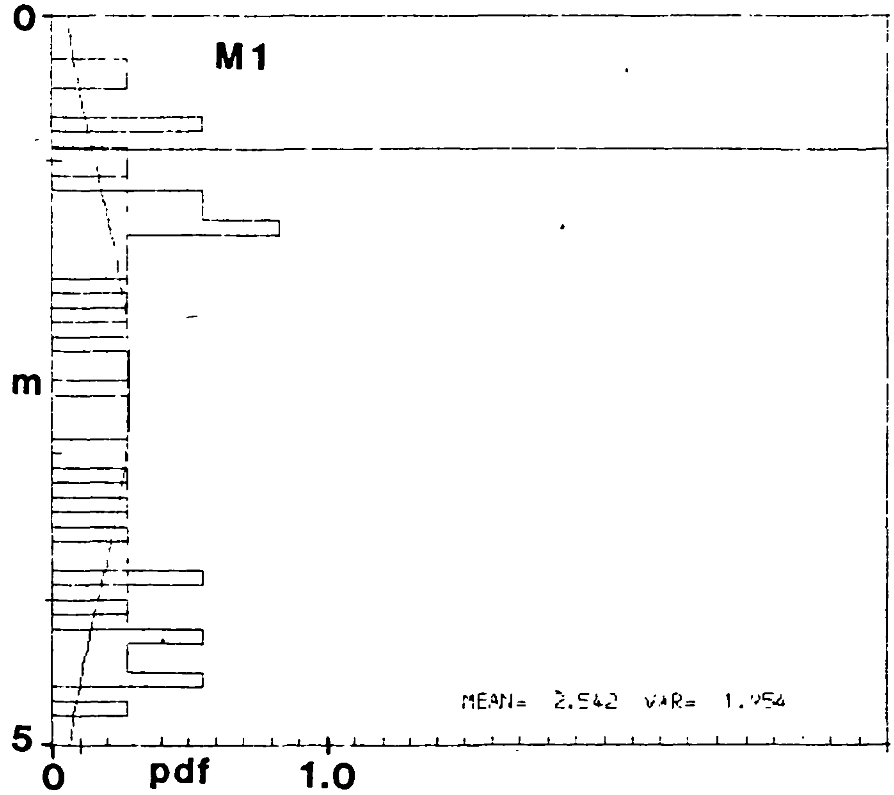


Fig.10-11. Shoreline height distribution plots: Shuna, plots 6 and 7.



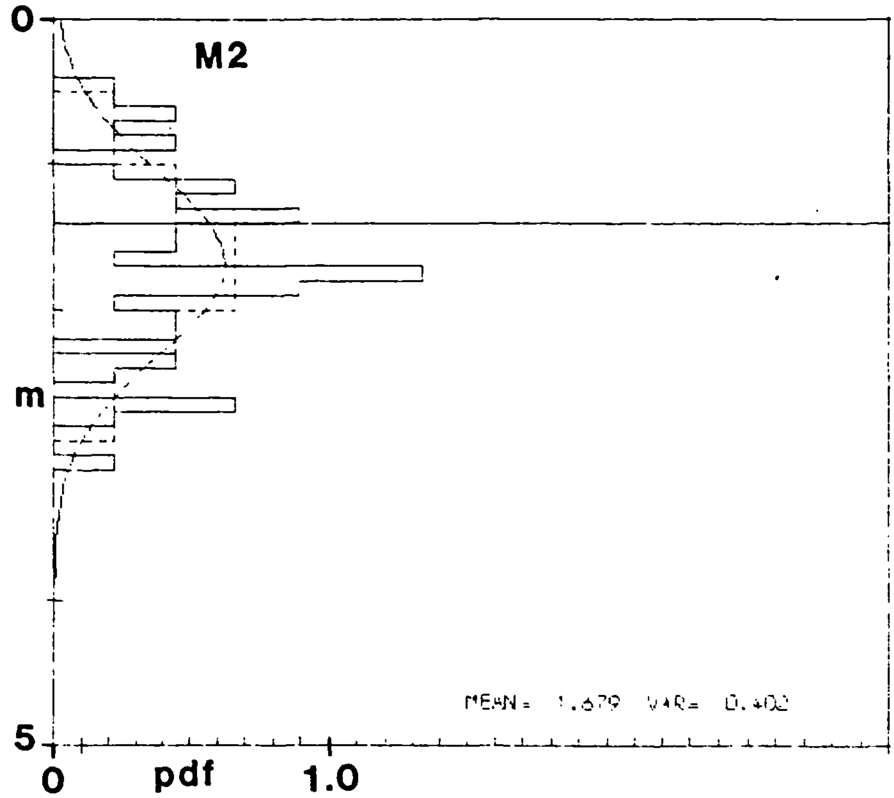


Fig.10-12. Shoreline height distribution plots: Mull, plots 1 and 2.

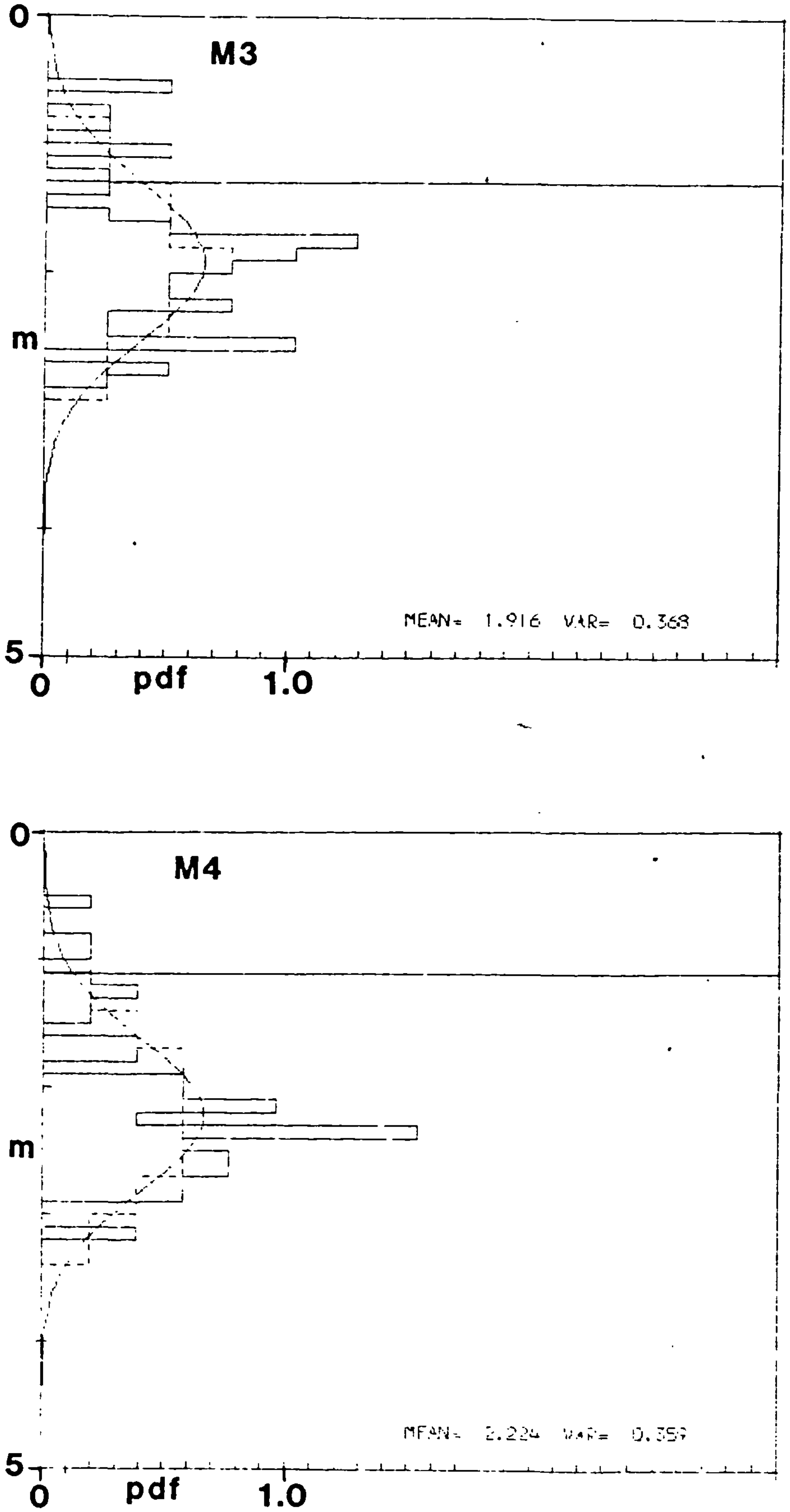
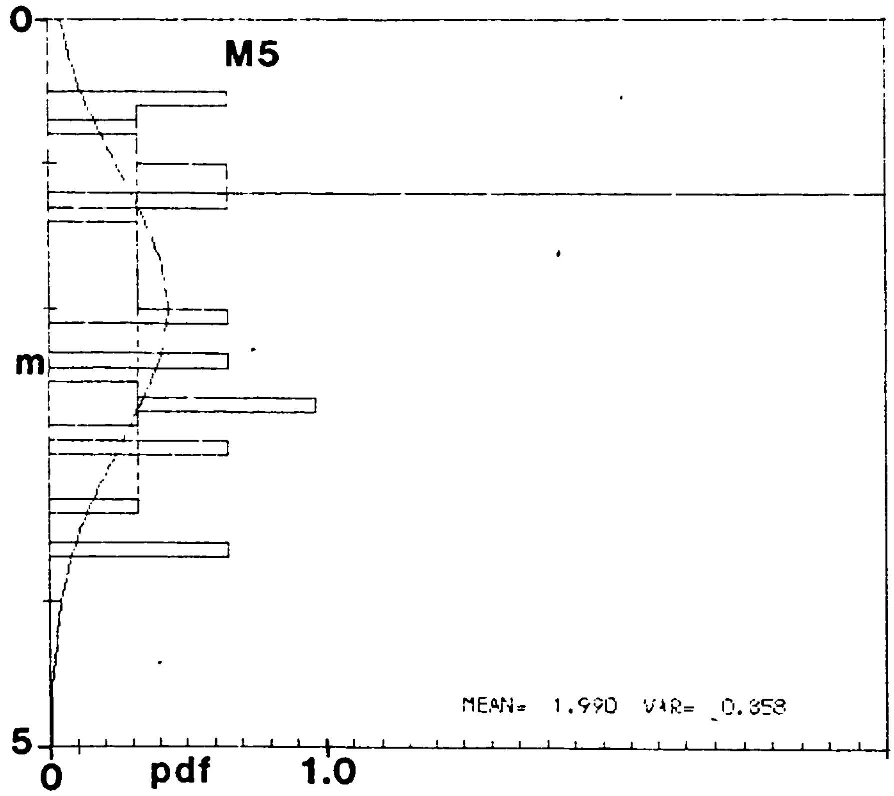


Fig.10-13. Shoreline height distribution plots: Mull, plots 3 and 4.



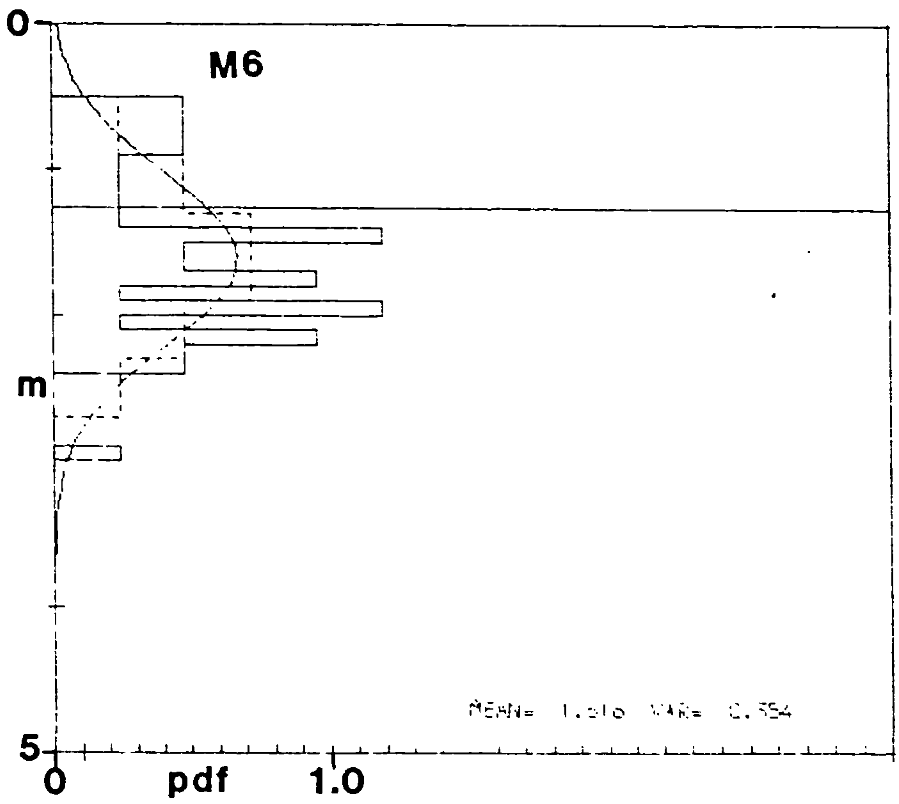
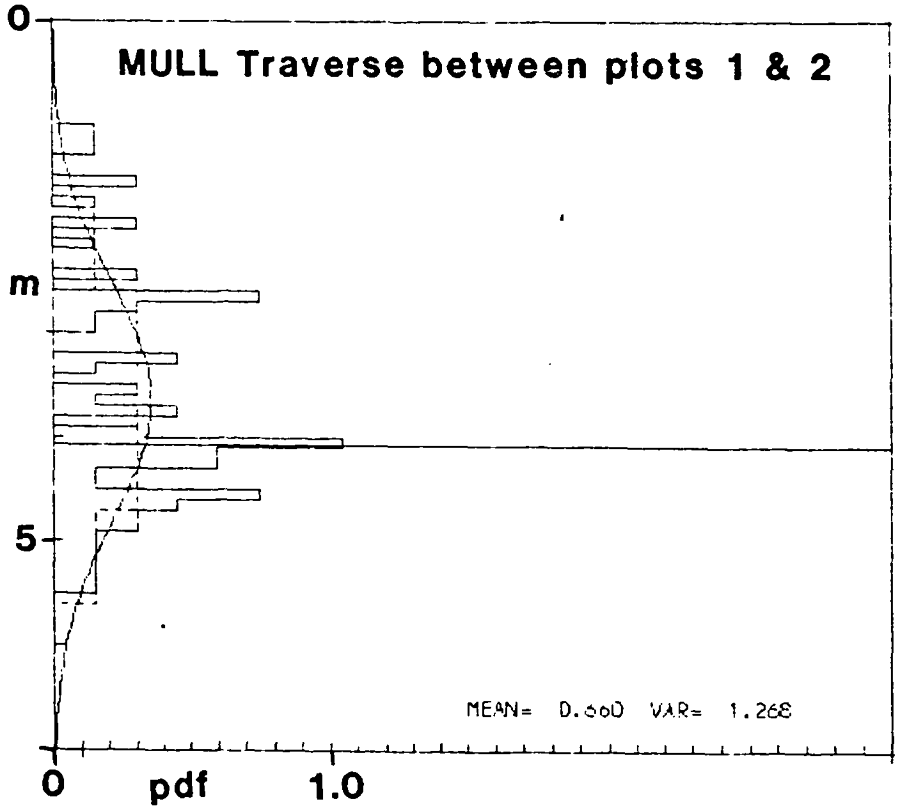


Fig.10-14. Shoreline height distribution plots: Mull, plots 5 and 6.



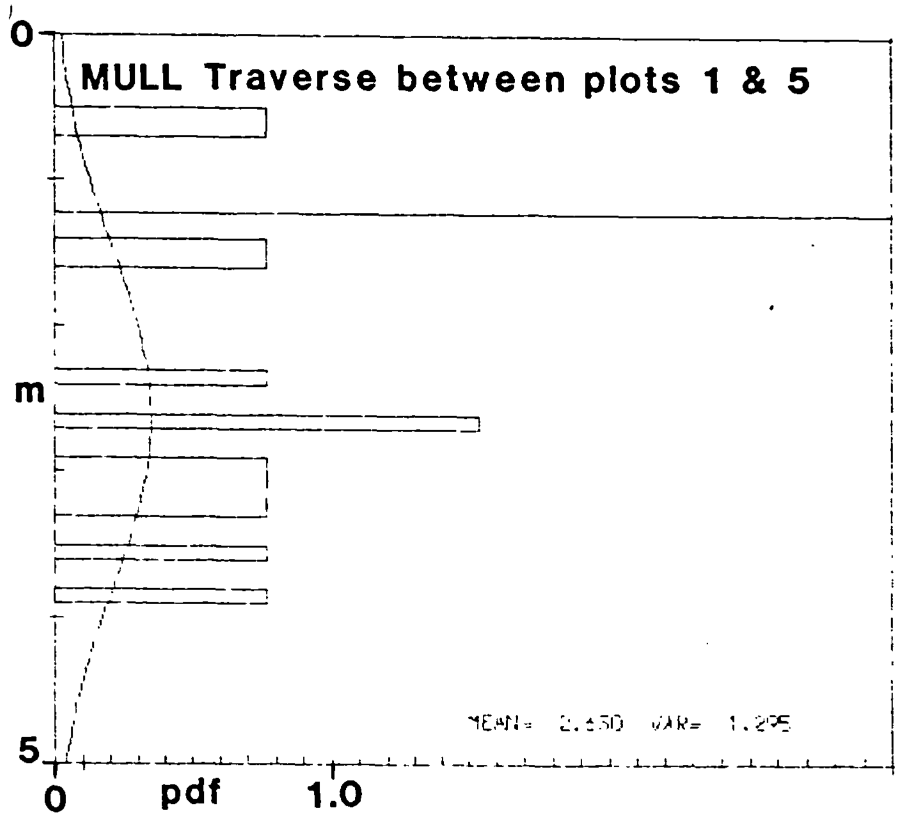


Fig.10-15. Shoreline height distribution plots: Mull, traverse lines.

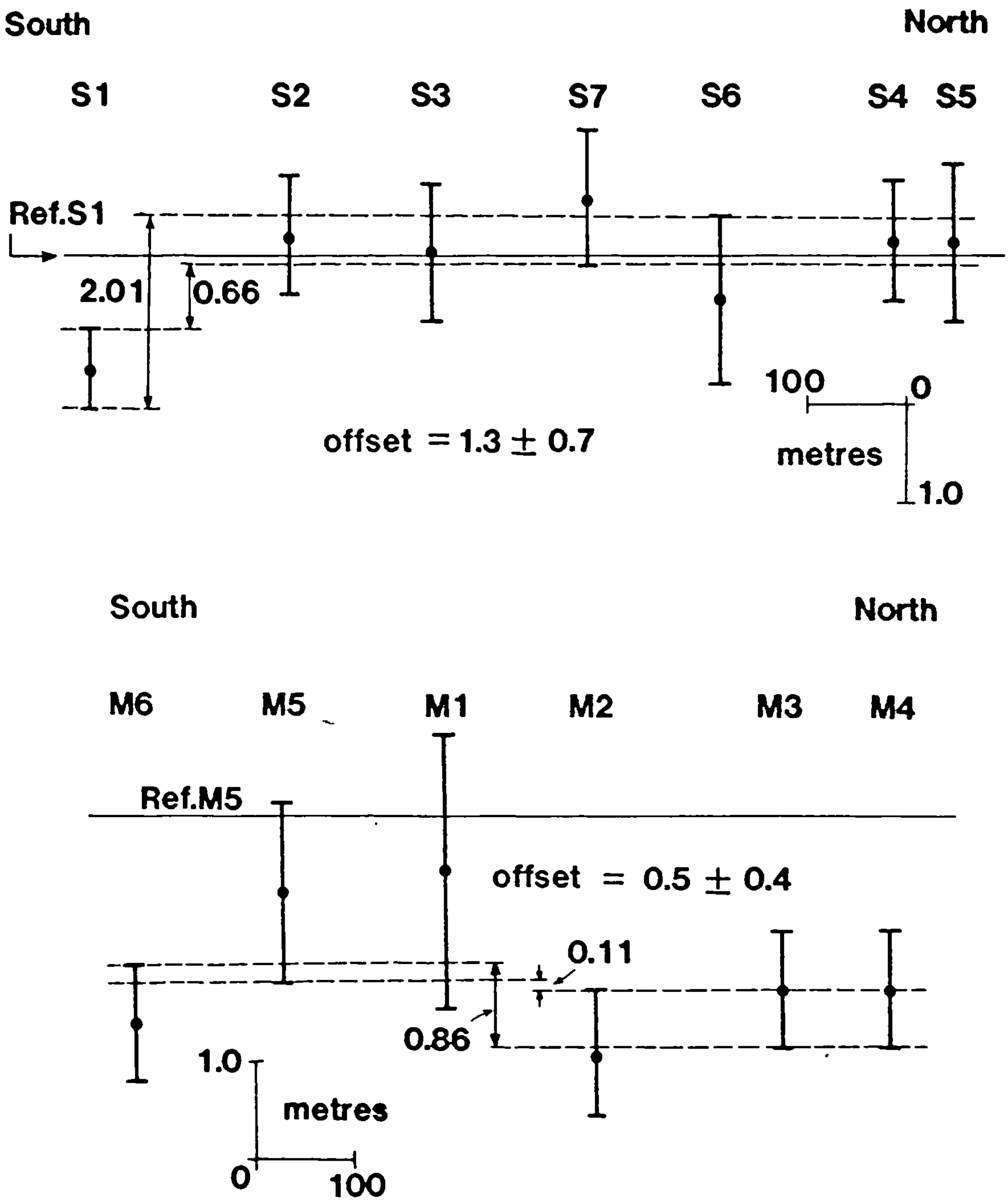


Fig.10-16. Graphs showing elevations (relative to references S1 and M5) and positions (on north-south profiles) of the mean values of measured heights at each plot. Vertical bars represent one standard deviation. Horizontal, dashed lines represent highest and lowest 'shorelines' if drawn within the one standard deviation bars. The offsets implied in this statistical scheme are indicated.

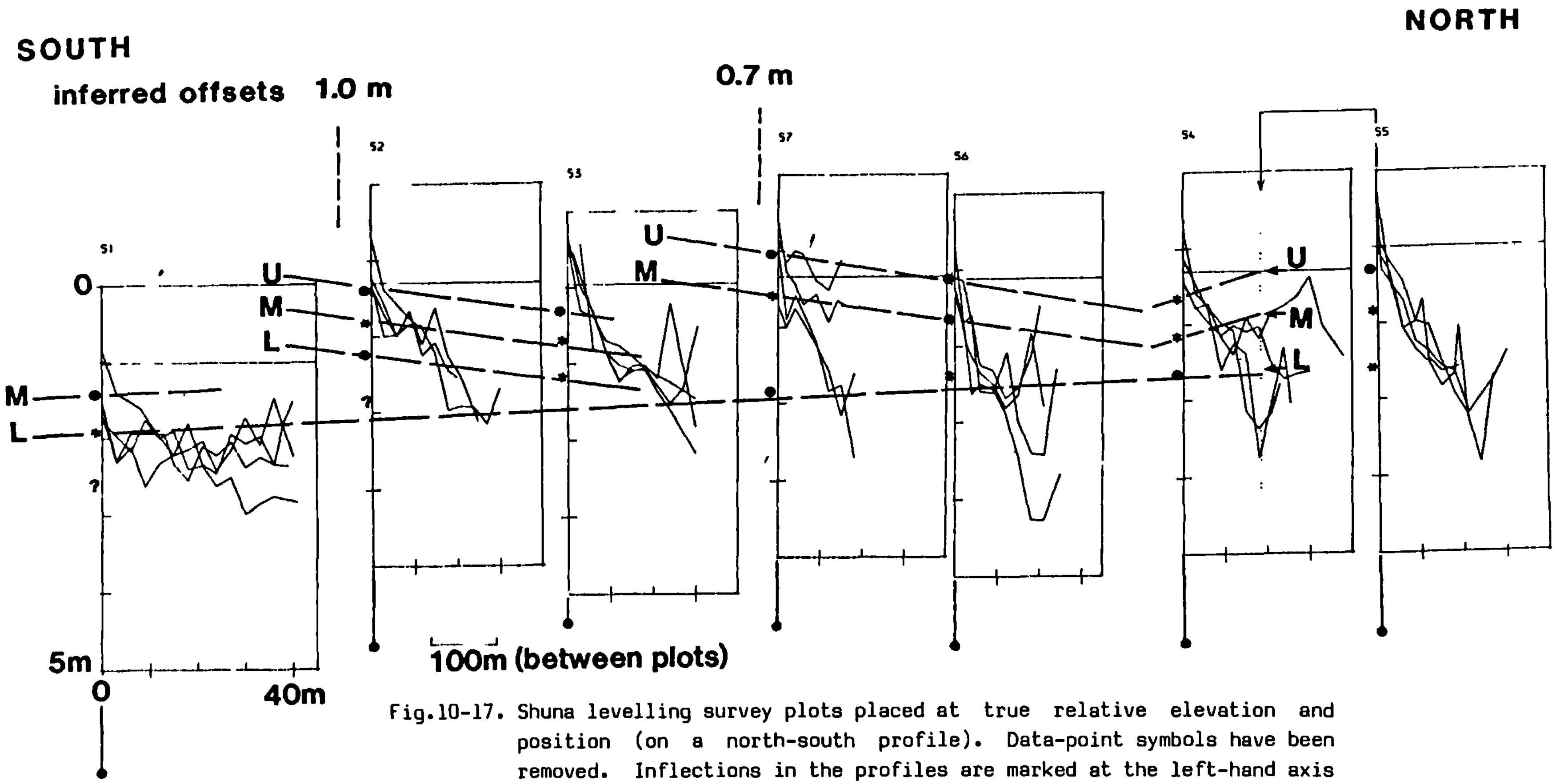


Fig.10-17. Shuna levelling survey plots placed at true relative elevation and position (on a north-south profile). Data-point symbols have been removed. Inflections in the profiles are marked at the left-hand axis with a dot (inflection seen in only one of the profiles) or a star (inflection seen in more than one of the profiles). Lines have been constructed through these points and have been marked upper (U), middle (M) and lower (L). Note that the position of S5 is within the S4 plot and is marked by a dotted line. Inferred offsets of 1.0 and 0.7m are indicated.

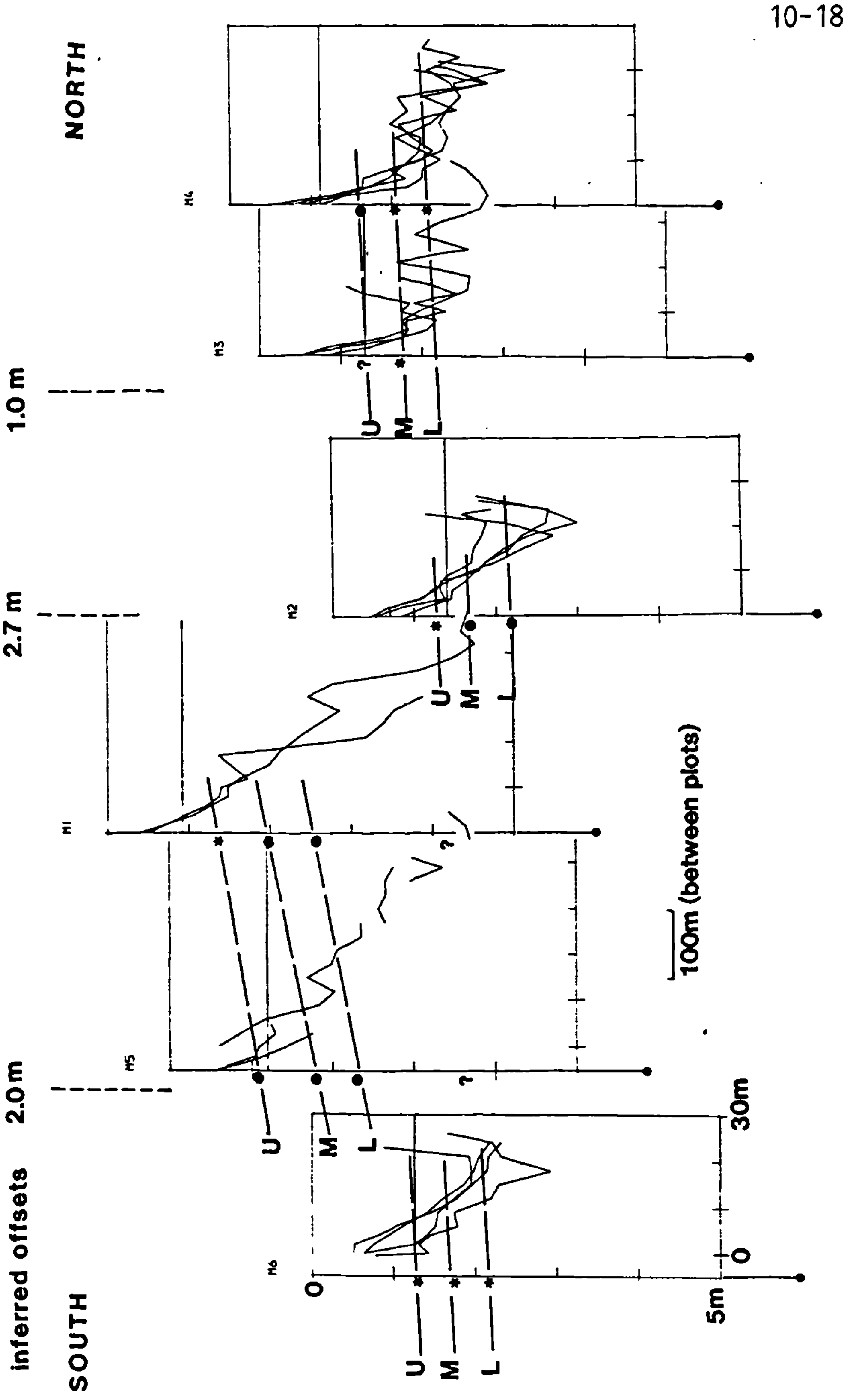


Fig.10-18. Mull levelling survey plots placed at true relative elevation and position (on a north-south profile). Data-point symbols have been removed. Inflections in the profiles are marked at the left-hand axis with a dot (inflection seen in only one of the profiles) or a star (inflection seen in more than one of the profiles). Line have been constructed through these points and have been marked upper (U), middle (M) and lower (L). Questionable inflections in the lower portions of plots M5 and M1 are marked by '?'. Inferred offsets of 2.0, 2.7 and 1.0m are indicated.

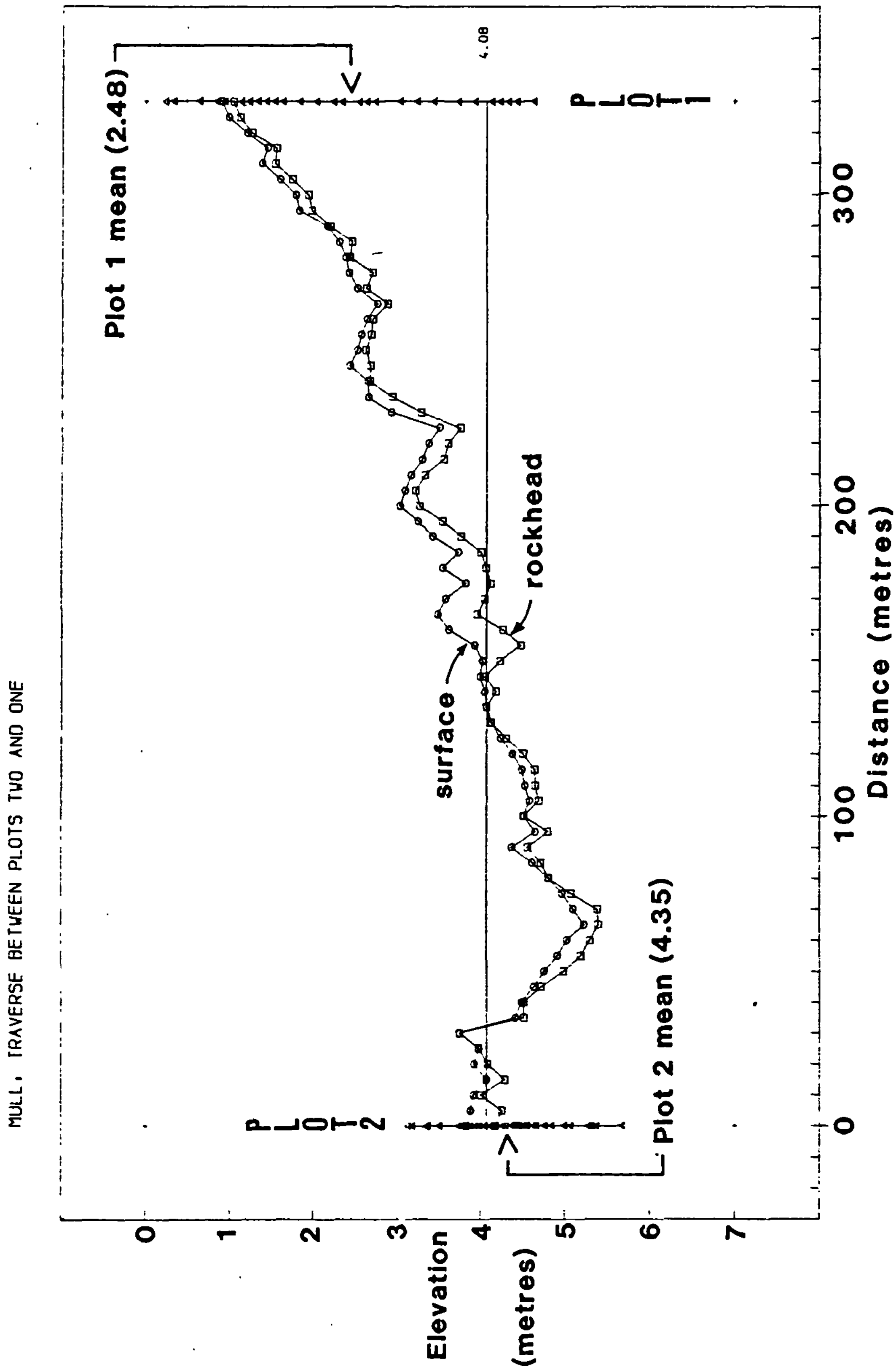


Fig.10-19. Profile of the traverse between Mull plots two and one. At each end of the profile the points within each plot have been drawn on a vertical line to give an indication of the range within each plot (mean values are indicated).

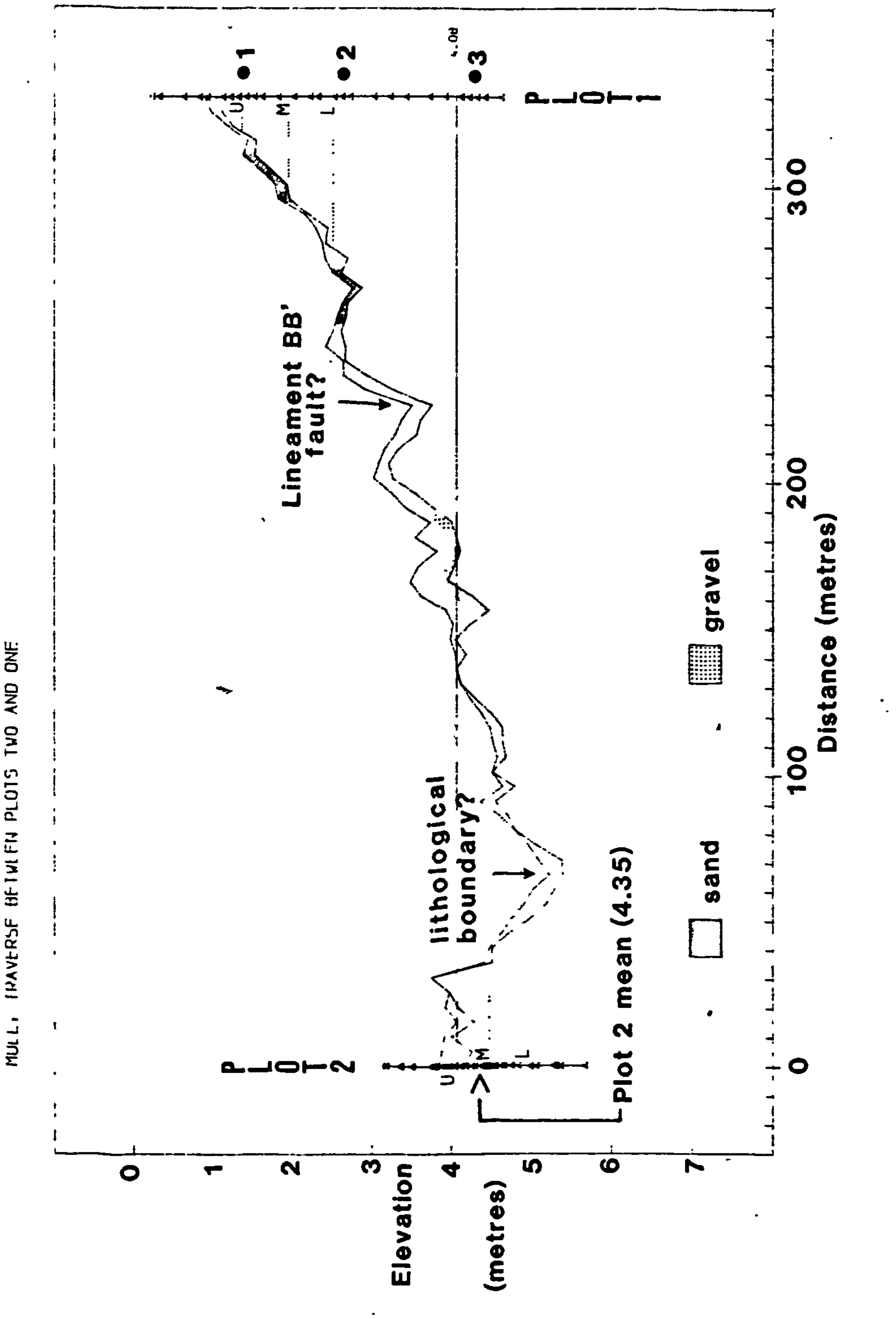
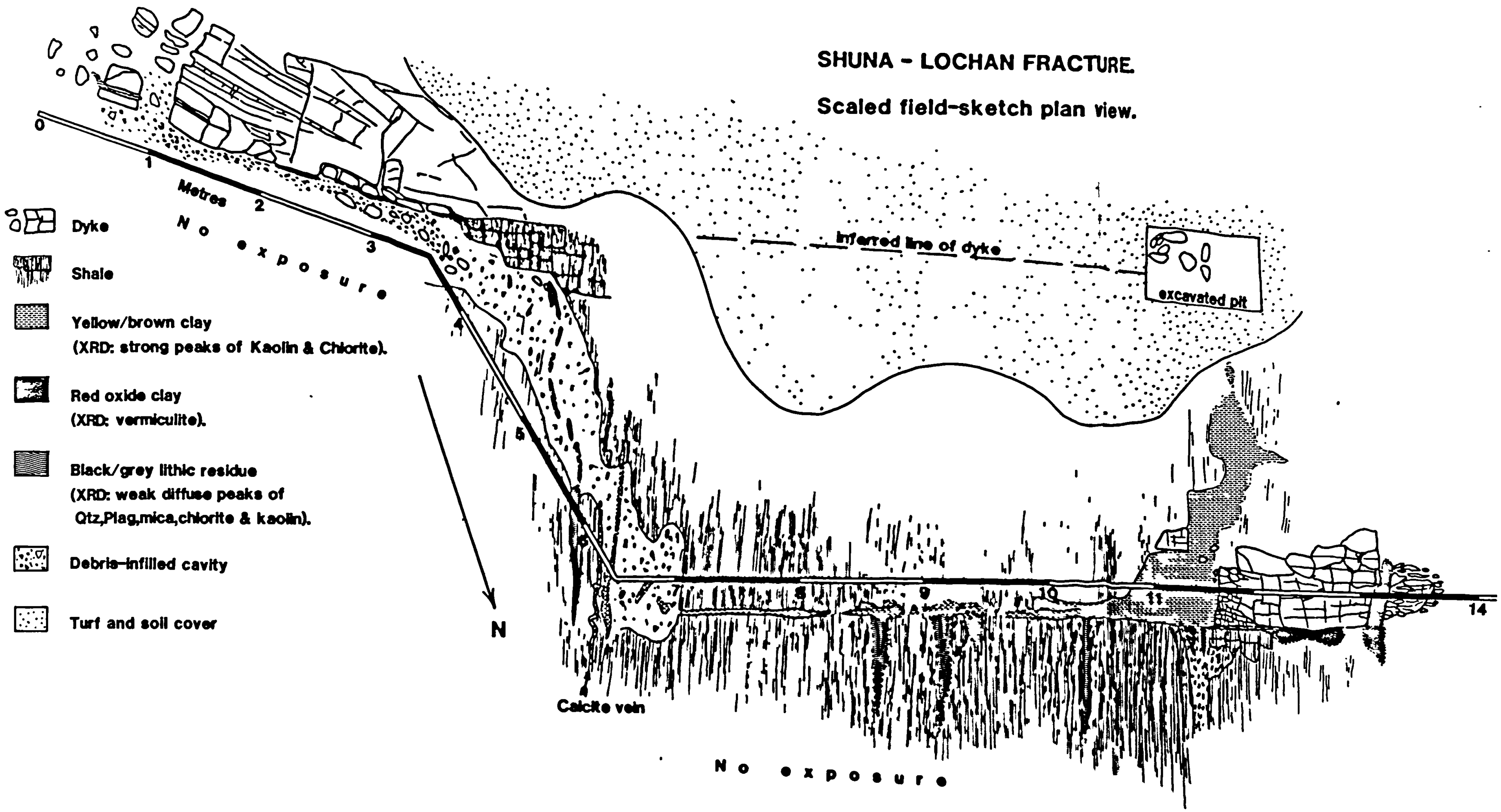


Fig.10-20. Profile of the traverse between Mull plots two and one drawn without data-point symbols. The occurrences of sand and gravel detected by inspection of the soil-auger are shown (the rest of the surficial material is peat). On the plot one and two ranges, drawn at each end of the profile, the upper, middle and lower inflection levels (inferred in Fig.10-18) are indicated. These correspond closely to inflections in the traverse profile, as indicated by dotted lines. Also shown are inferred locations of a fault and a lithological boundary (see discussion in sections 10.3.5 and 10.5).

Fig.10-21. Field sketch (plan view) of the Lochan Fracture exposure on Shuna.



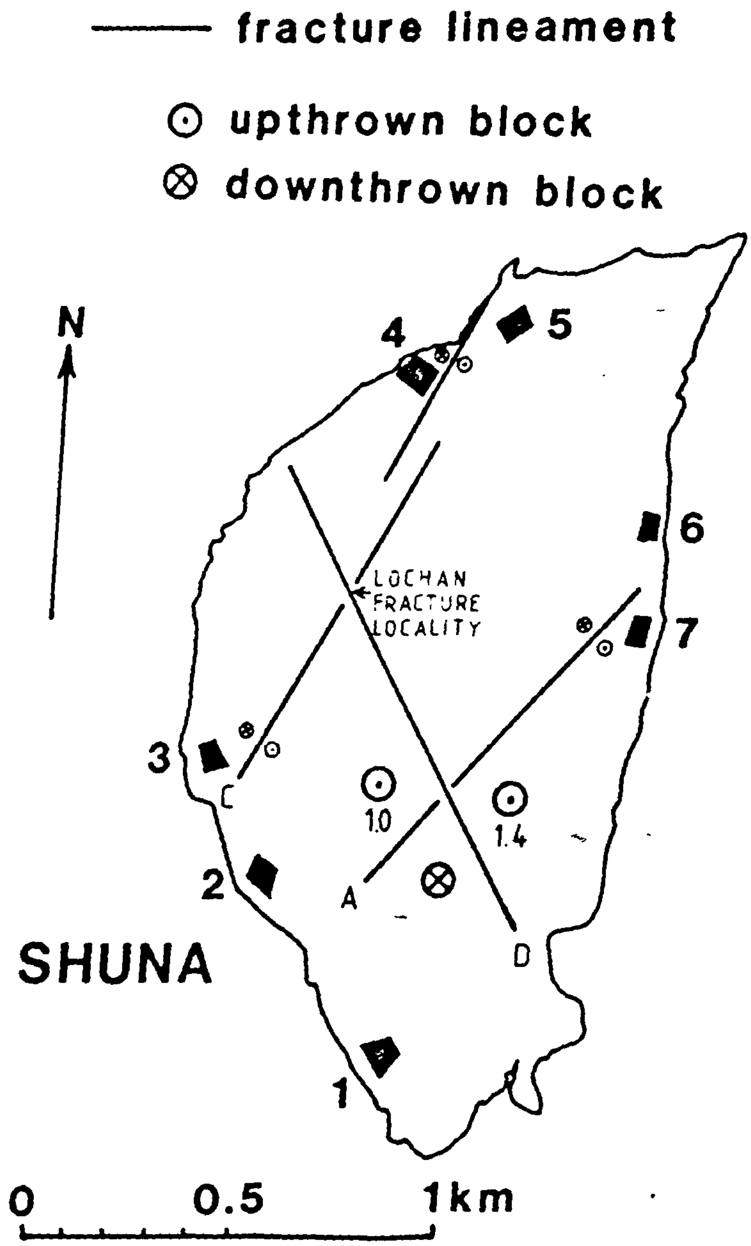


Fig.10-22. Summary of the findings of the raised beach levelling studies on Shuna. The main vertical displacements of 1.0 and 1.4m are shown (relative to S1). Possible smaller displacements (of the order of decimetres) are indicated by the smaller block movement symbols. Active fractures A, C and D are shown.

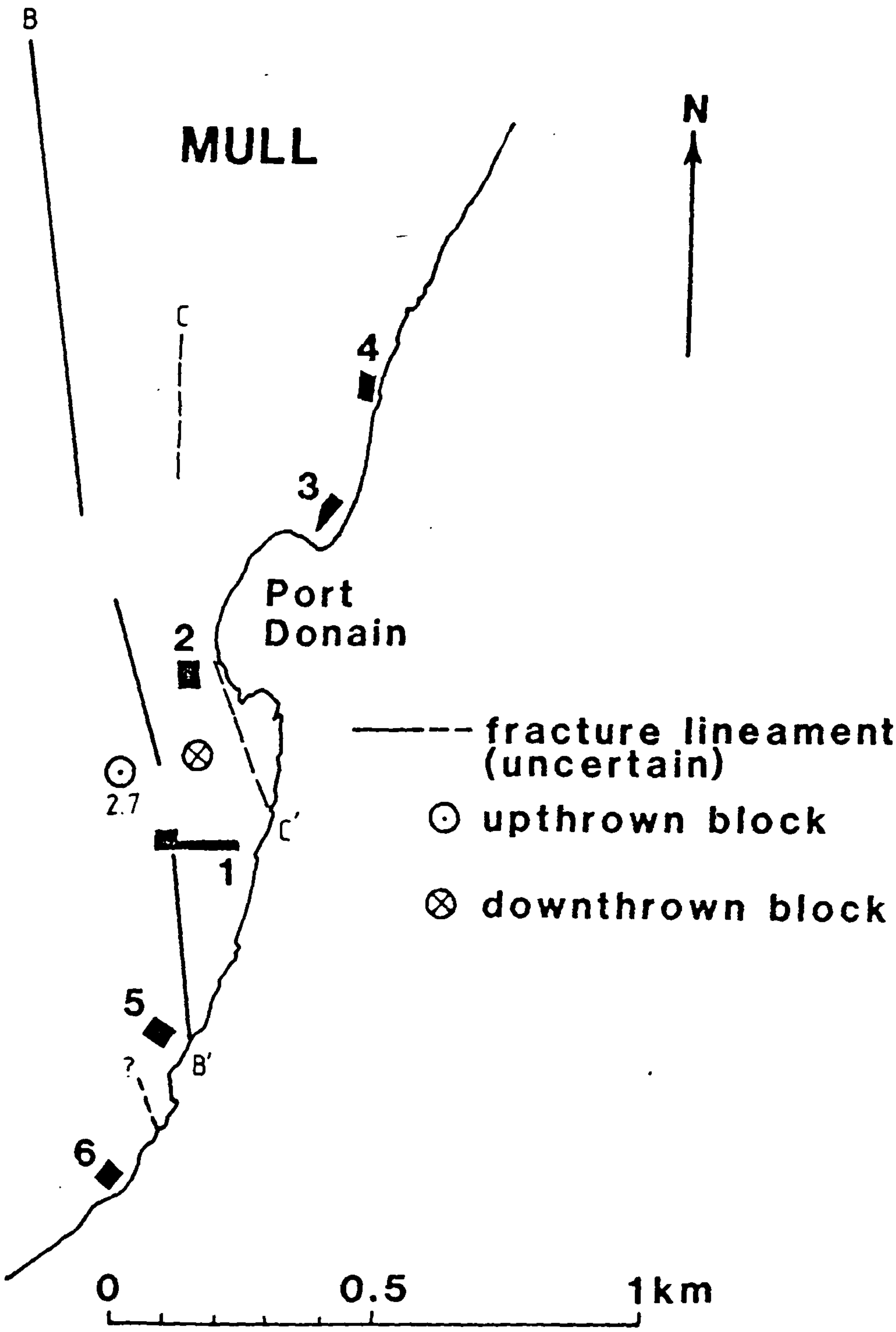


Fig.10-23. Summary of the findings of the raised beach levelling studies on Mull. The main vertical displacement of 2.7m occurring on fracture B-B' is shown.

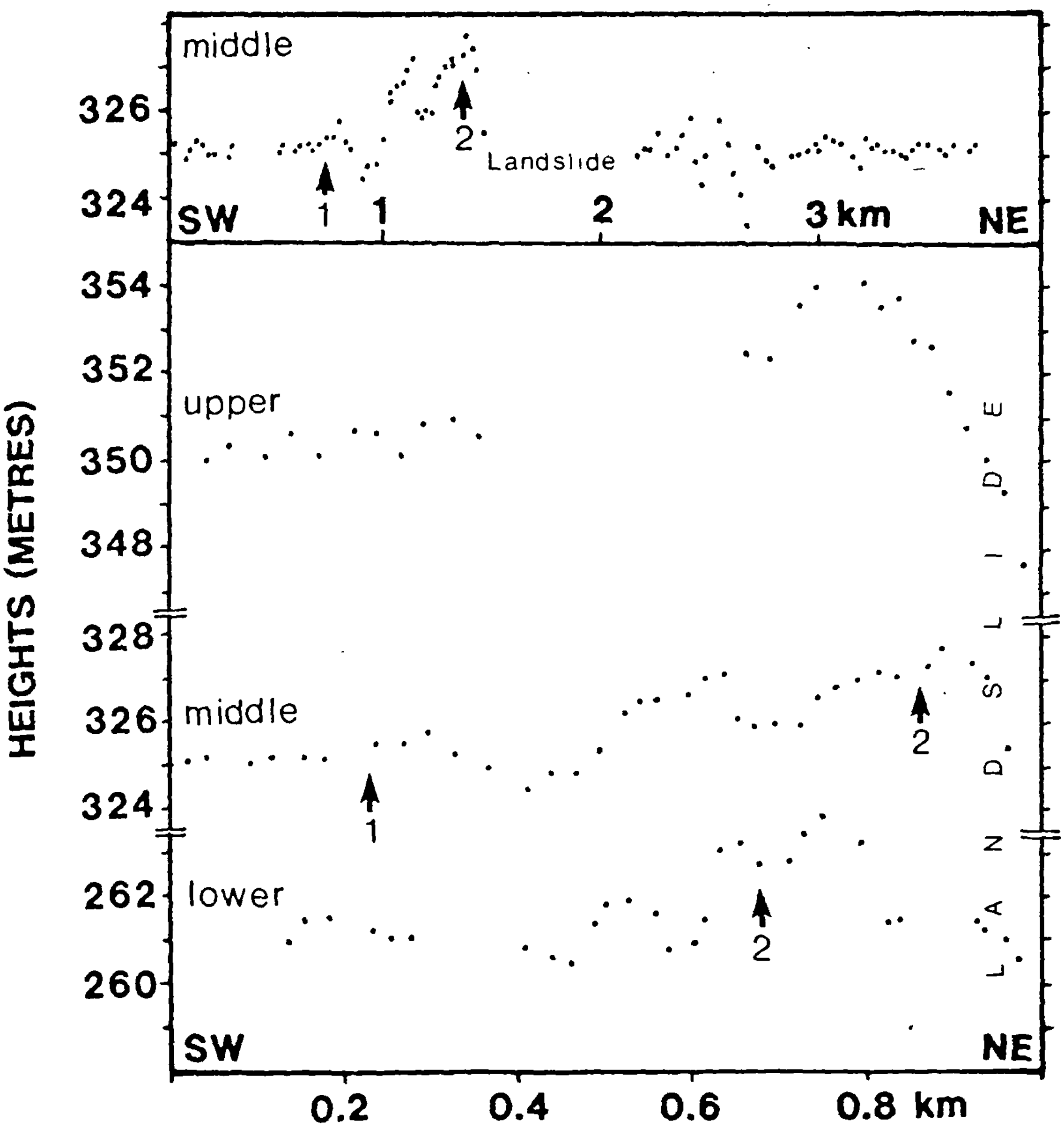


Fig.11-1. Heights of the three 'parallel-road' shorelines of Glen Roy in the vicinity of the Main Roy Landslide, from the study of Sisson's and Cornish (1982). The upper, middle and lower shorelines are indicated. The top portion of the diagram shows a 4km long section of the middle shoreline (note the anomalously high levels to the SW of the (Main Roy) landslide. The lower portion of the diagram shows all three shorelines in a 1km section immediately SW of the landslide. Points '1' and '2' mark the loci of fracture traces (see sections 11.2.1 & 11.2.2 for discussion).

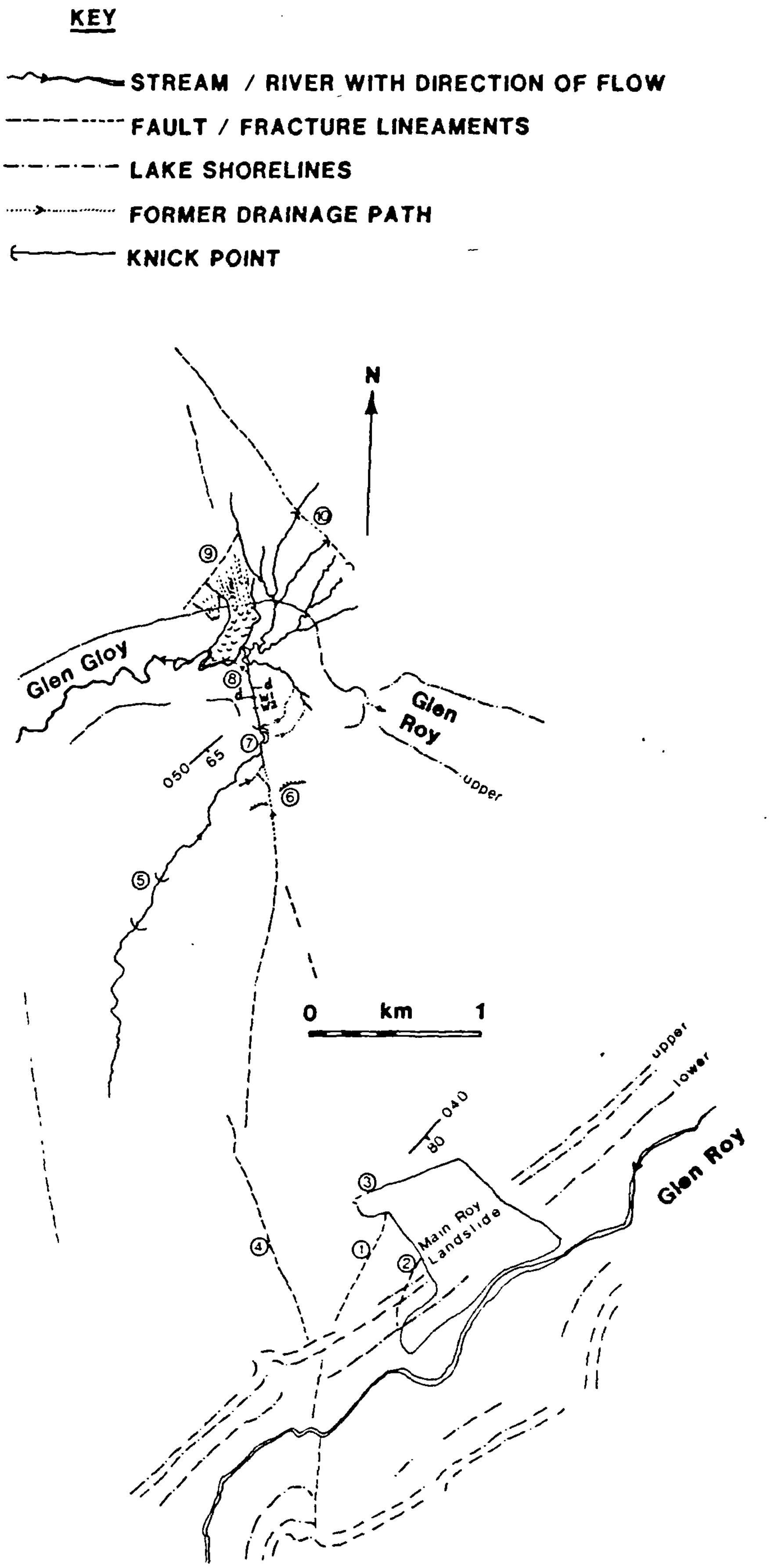


Fig.11-2. Photogeological interpretation along the 'main fracture lineament' at Glen Roy. The numbered features are described in section 11.2.

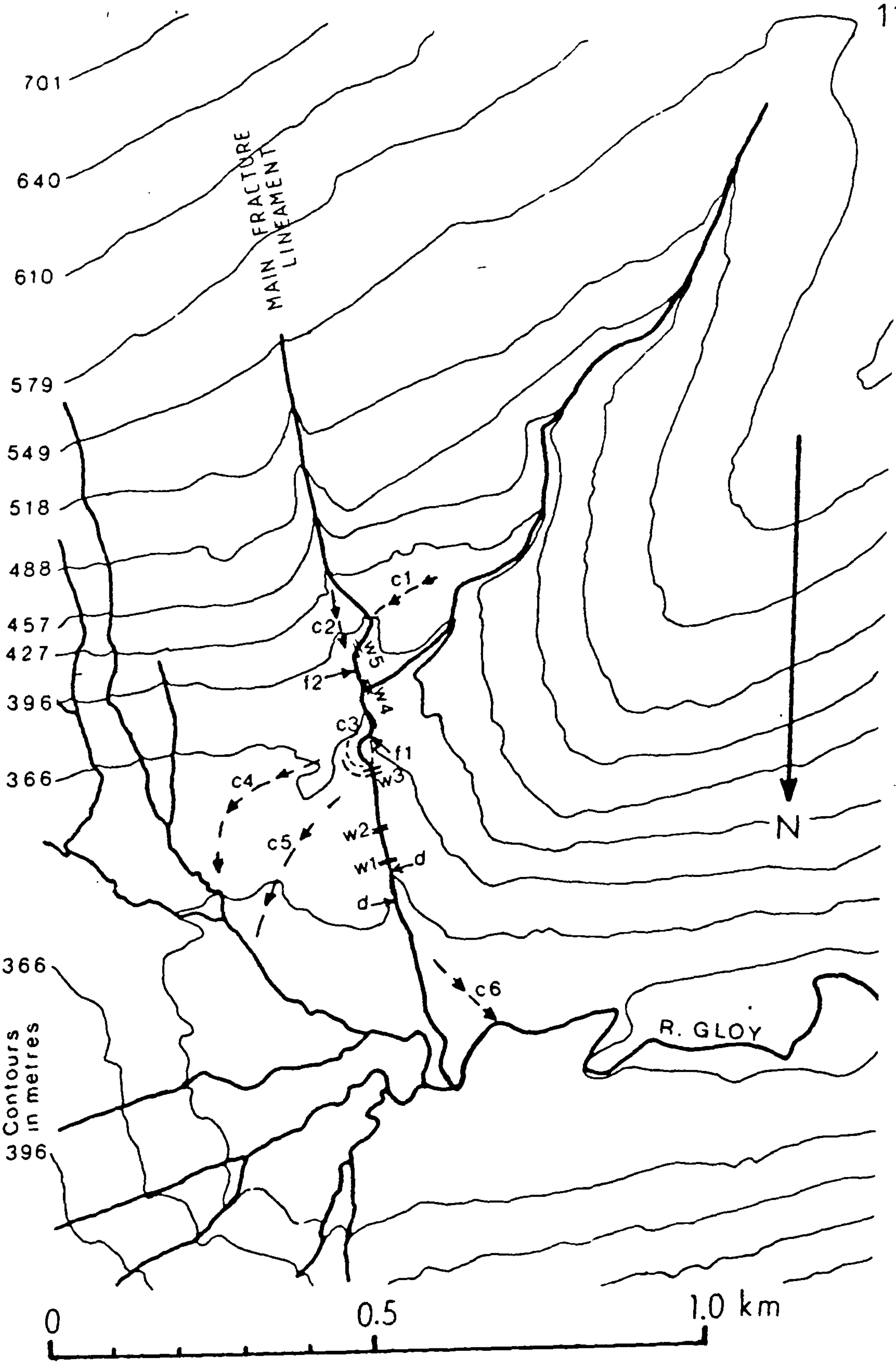
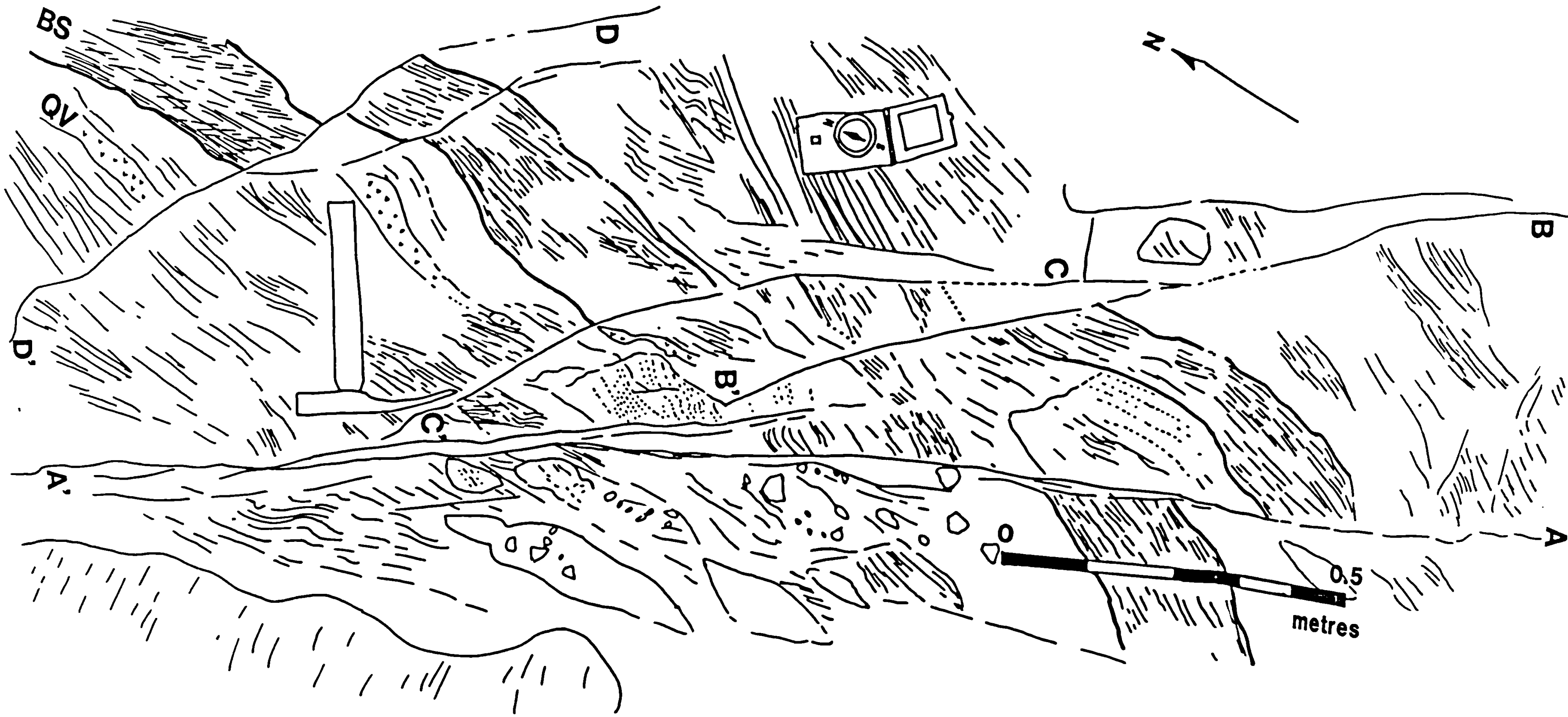


Fig.11-3. Map of the Upper Glen Gloy stream section, showing features of stream capture (discussed in section 11.2.7) and apparent fault movement (discussed in section 11.2.8).

Fig.11-4. Field sketch of fractures within the 'main fracture lineament' exposed in the Upper Glen Gloy stream section (at f2, Fig.11-3) (see section 11.2.8 for discussion).



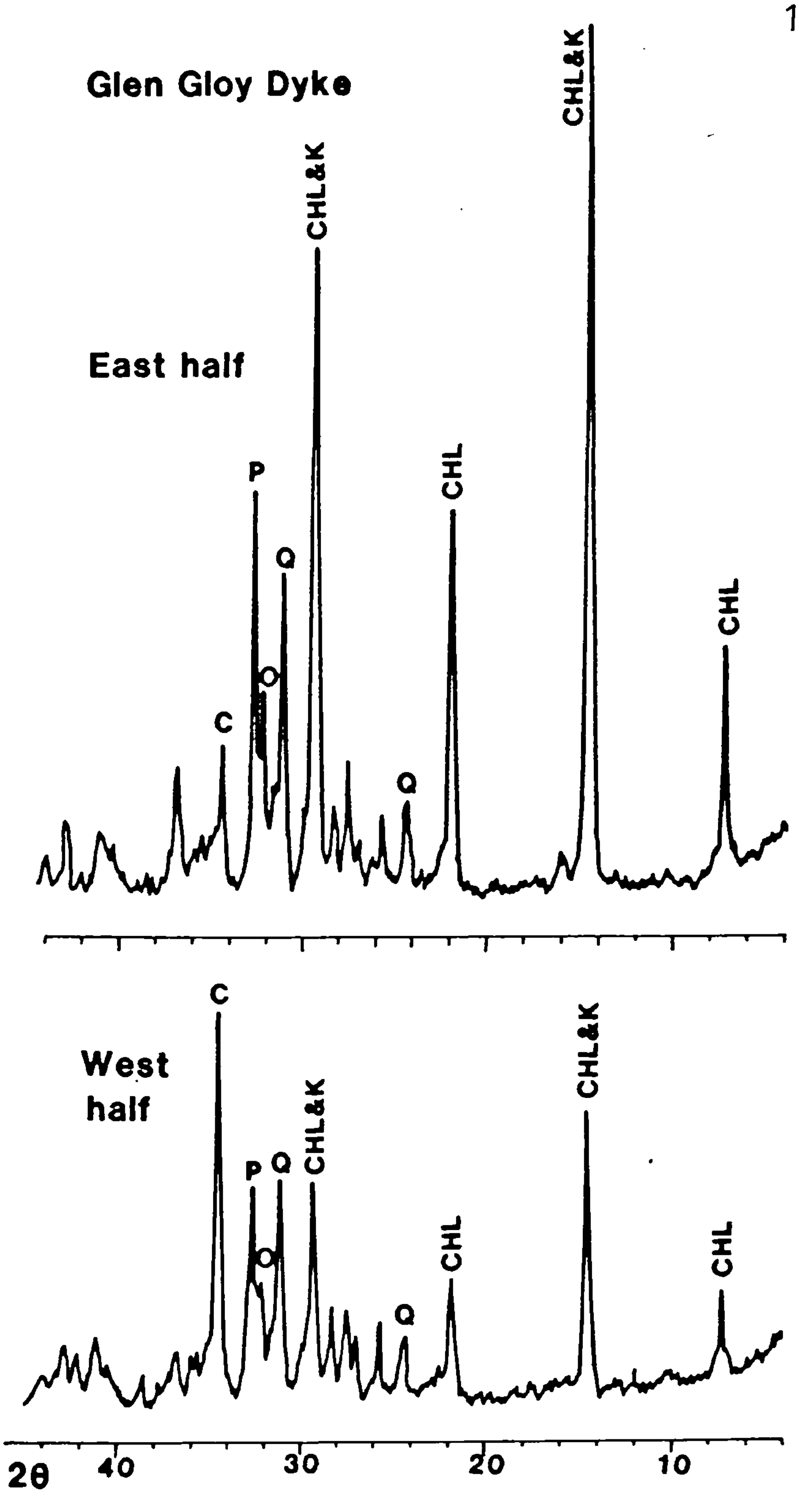


Fig.11-5. XRD spectrometric analyses of the two halves of the Glen Gloy dyke, indicating their essentially similar mineralogy. C = calcite, P = plagioclase, Q = quartz, CHL = chlorite, K = kaolin. (see section 11.2.8 for discussion).

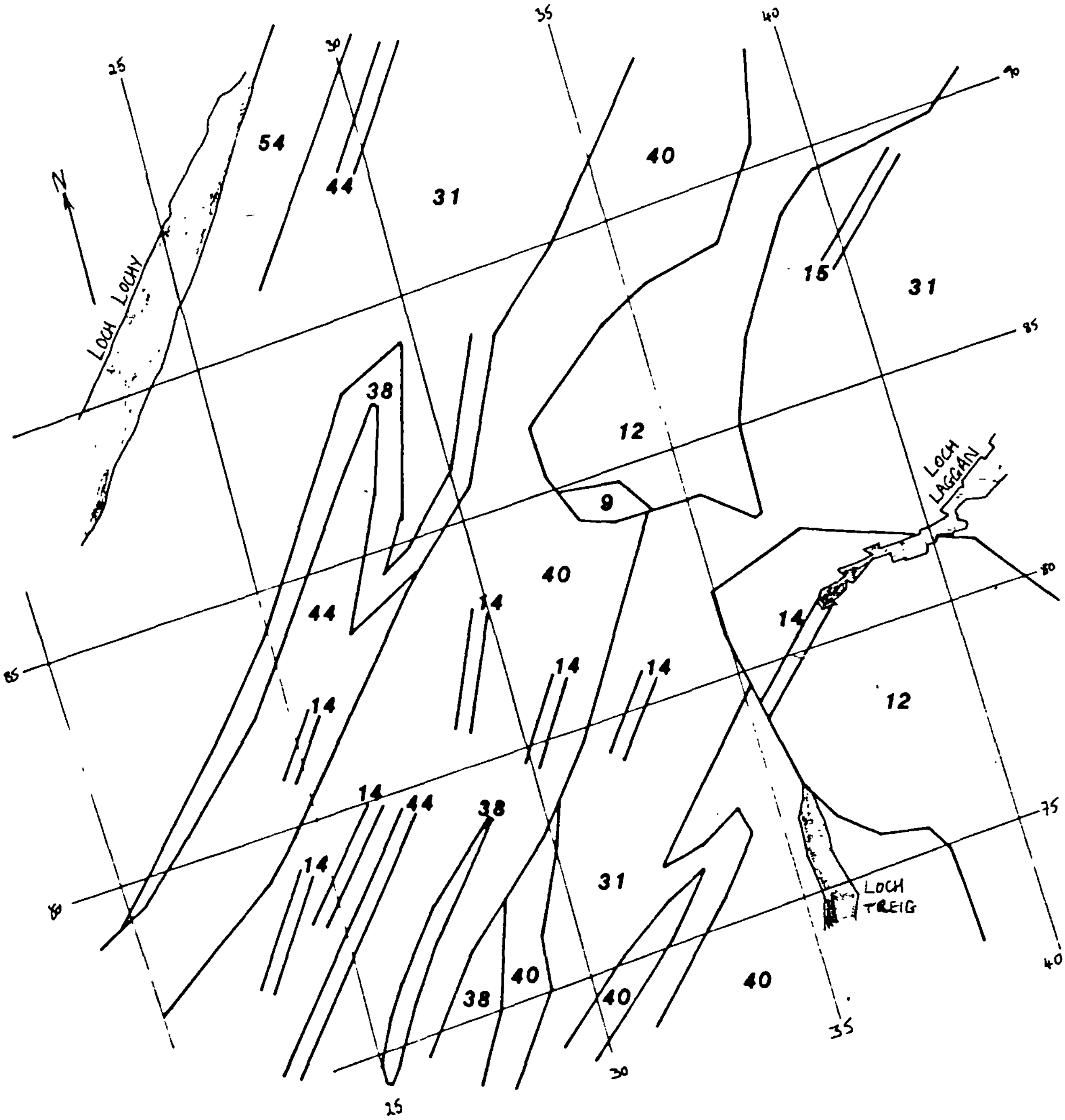


Fig.11-6. Simplified geological map of the vicinity of Glen Roy (scaled to fit LANDSAT study area). (Constructed from Geological Map of Great Britain, sheet 1; BGS 1957). Key:

9 - Ultrabasic intrusives
12 - Granite
14 - Porphyrite, lamprophyre intrusives
15 - Felsite, trachyte intrusives
31 - Undifferentiated Moine
40 - Dalradian schists and slates
44 - Dalradian limestones
54 - Old Red Sandstone (Devonian)

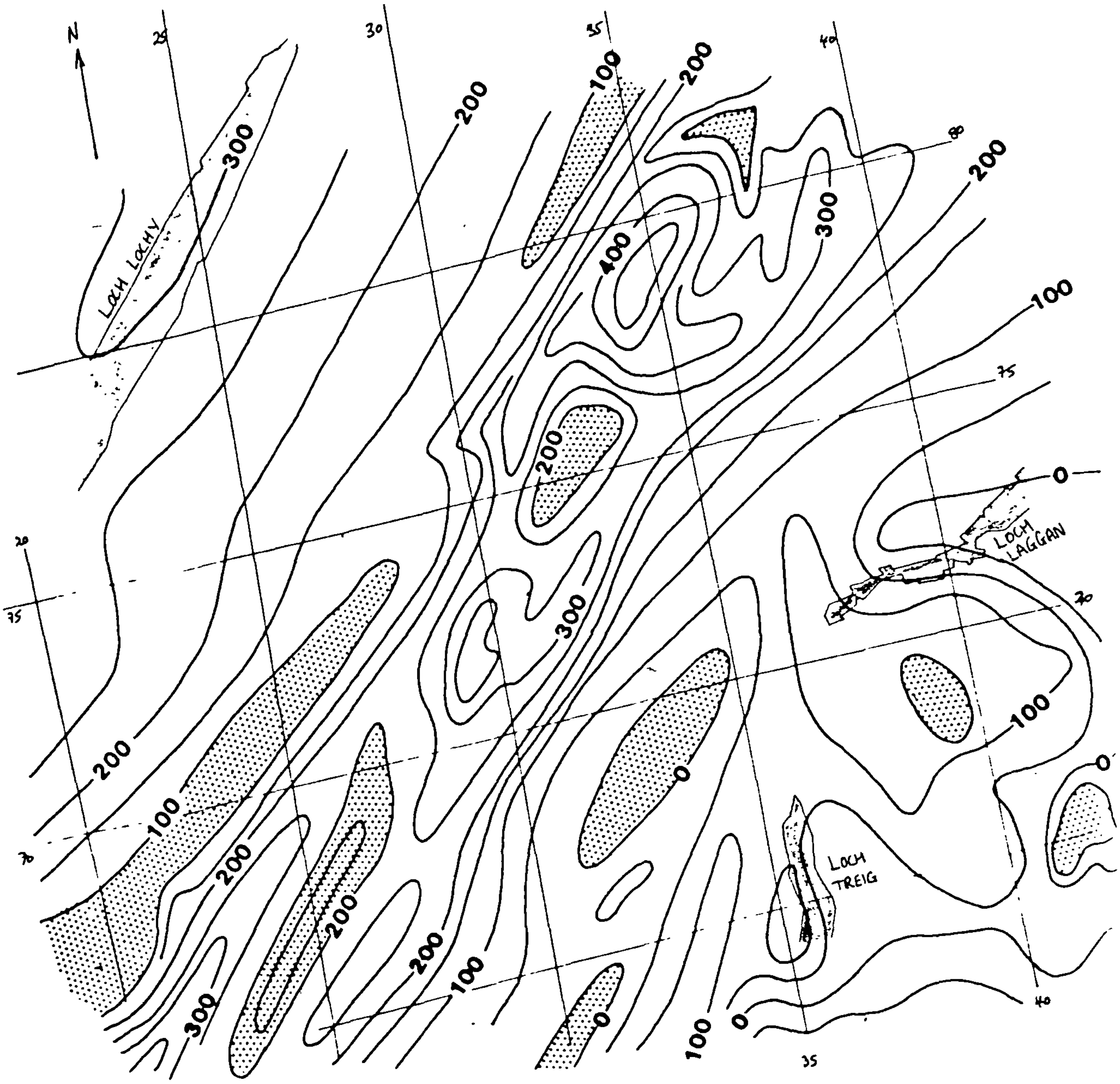


Fig.11-7. Aeromagnetic anomaly map of the vicinity of Glen Roy (scaled to fit LANDSAT study area). Contours in 50 nT intervals. Stippled areas - local magnetic lows. Note the north-easterly grain of the Caledonian basement (Redrawn from IGS 1:250 000, Argyll sheet).

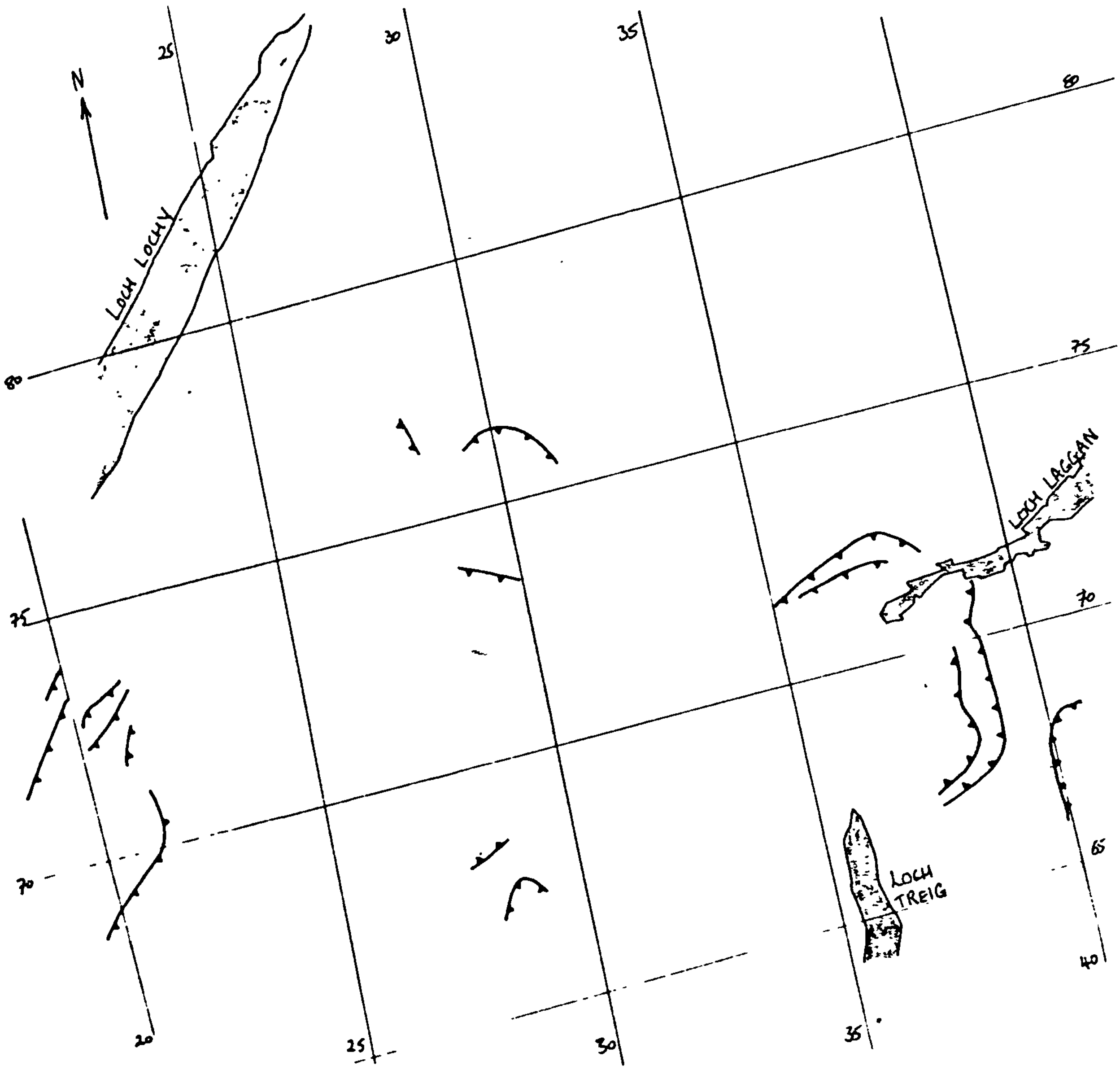


Fig.11-8. Occurrences of glacial moraines (barbed lines) within the Glen Roy LANDSAT study area (collated from Sissons 1979b).

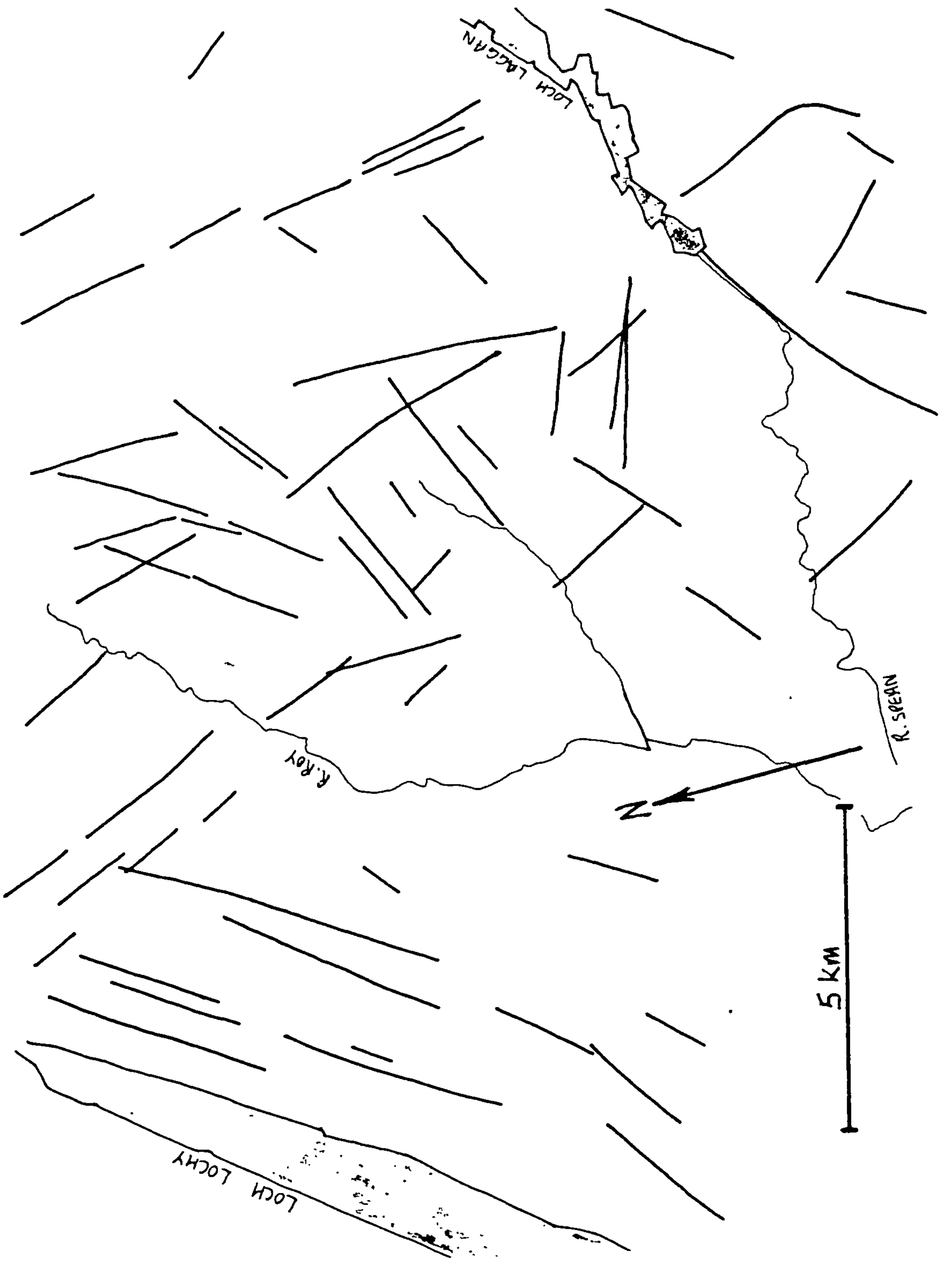


Fig.11-9. Lineaments occurring on more than one image of LANDSAT Thematic Mapper images (Glen Roy area): principal components 1-5, negative and positive.

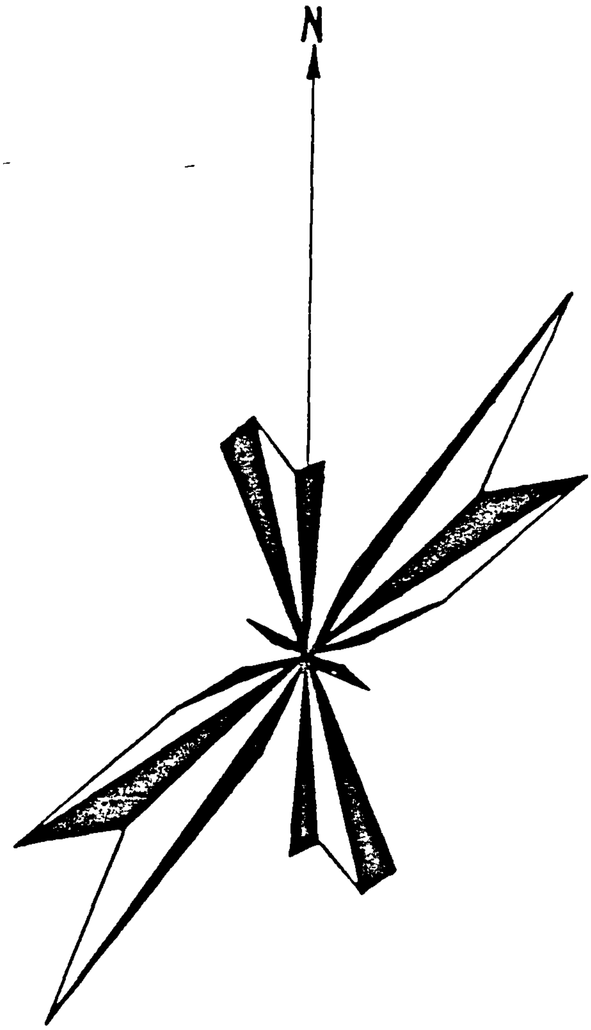


Fig.11-10. Rose diagram for the lineaments of Fig.11-9. The total length of lineaments having orientations within each ten-degree sector are plotted as radial lines. Sectors in between the lines are shown in alternating black and white tone for clarity.

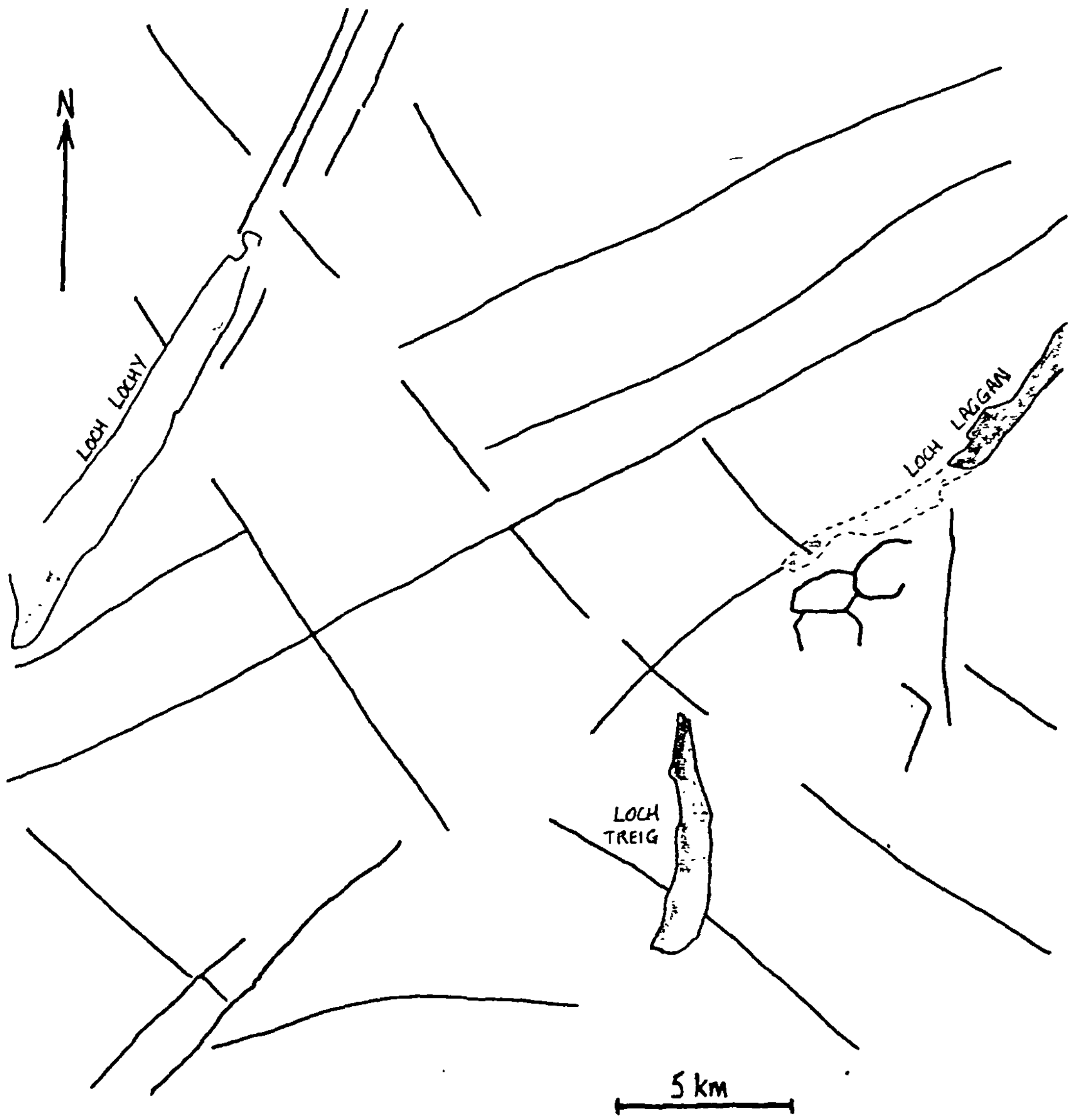


Fig.11-11. Lineaments occurring on a principal-component-3 image of the Glen Roy LANDSAT Thematic Mapper scenes, with a 16x16 edge enhancement matrix. Note the large polygonal features SW of Loch Laggan.

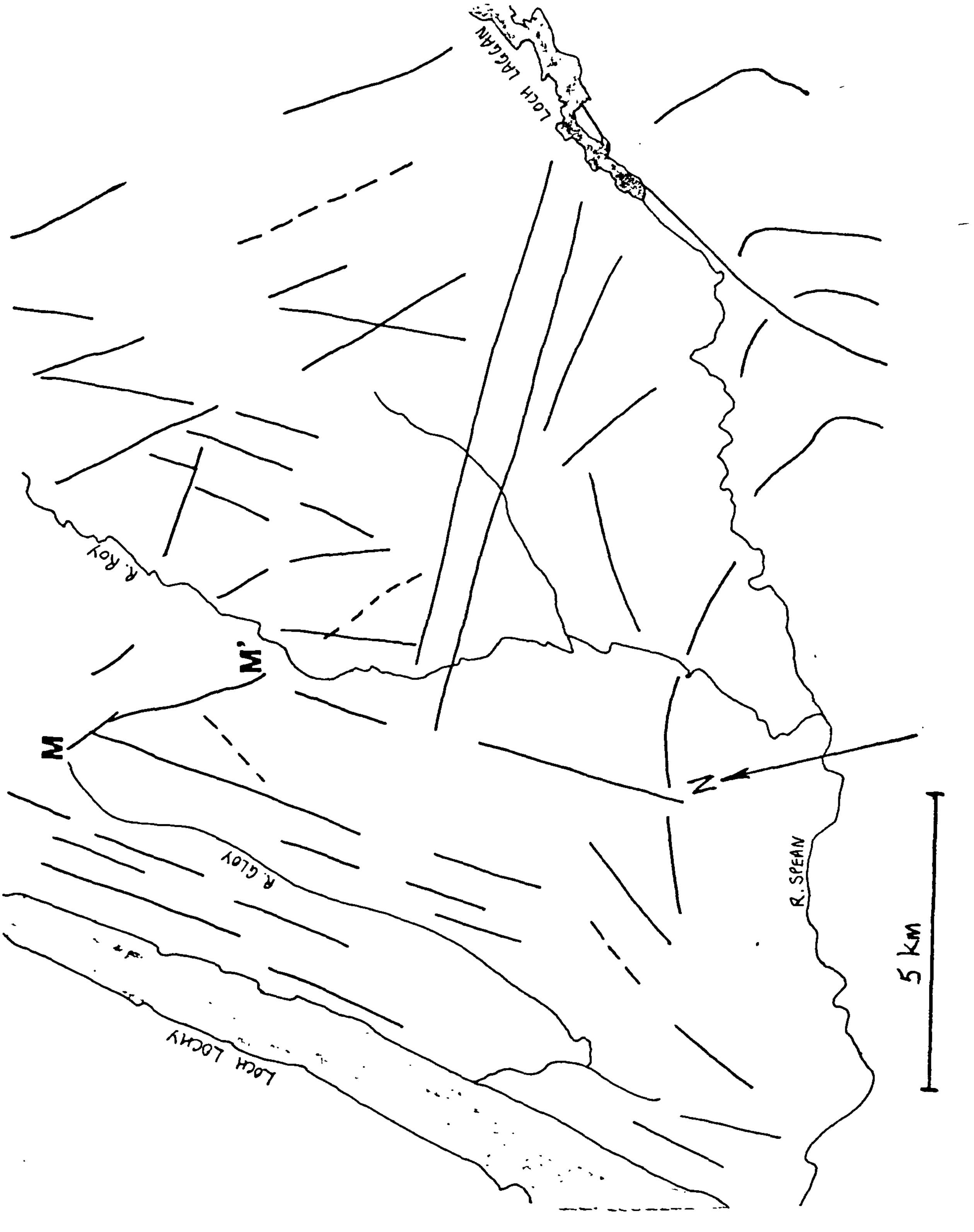


Fig.11-12. Lineaments occurring on a negative of a Band-4 image of the Glen Roy LANDSAT Thematic Mapper scenes. Note the curved moraine (?) features west of Loch Laggan. M-M' is the main fracture lineament identified in the field and air photographs (note its possible southward extension on this image). (See also Plate 36.)

The intensity of this earthquake appears to have exceeded that of August 22, 1924, in the same locality (namely, IV (C. Davison scale)), for on this recent occasion not only were the chairs of several seated observers noticeably moved at Gairlochy and Spean Bridge, but also a plaster ceiling was thrown down in Achnacarry at the east end of Loch Arkaig ; a chimney-pot dislodged from a house at the north-east end of Loch Laggan ; two heavy shop-safes moved in Fort William, and windows, doors and crockery rattled at many places in the area. These, and similar phenomena, are consistent with a maximum intensity of about VI (C. Davison scale). Further, the position and form of the central disturbed area, and distribution of intensities within it, suggest a close association of this earthquake with the Great Glen fault-system. On the other hand, present information suggests there was no significant sympathetic movement in the Highland Boundary fault-system at or about the time when these recent Spean Bridge disturbances took place.

A weak fore-shock connected with this earthquake appears to have occurred at about 17 hr. 20 min. (G.M.T.) on November 19, 1946, and a second one close to 24 hr. (G.M.T.) on December 23, 1946. The latter, which was noticed in Inverness-shire, Argyll and north Ayrshire, consisted of two tremors lasting about four seconds and three seconds respectively, separated by an interval of about two seconds.

The after-shock of January 5, 1947, would seem to have taken place at about 09 hr. 35 min. (G.M.T.), when a slight rumble was heard in West Glen Roy and Glen Spean, having a duration of about three seconds.

Fig.11-13. Extract from Dollar's (1947) report of the Inverness-shire earthquake of December 25th, 1946.

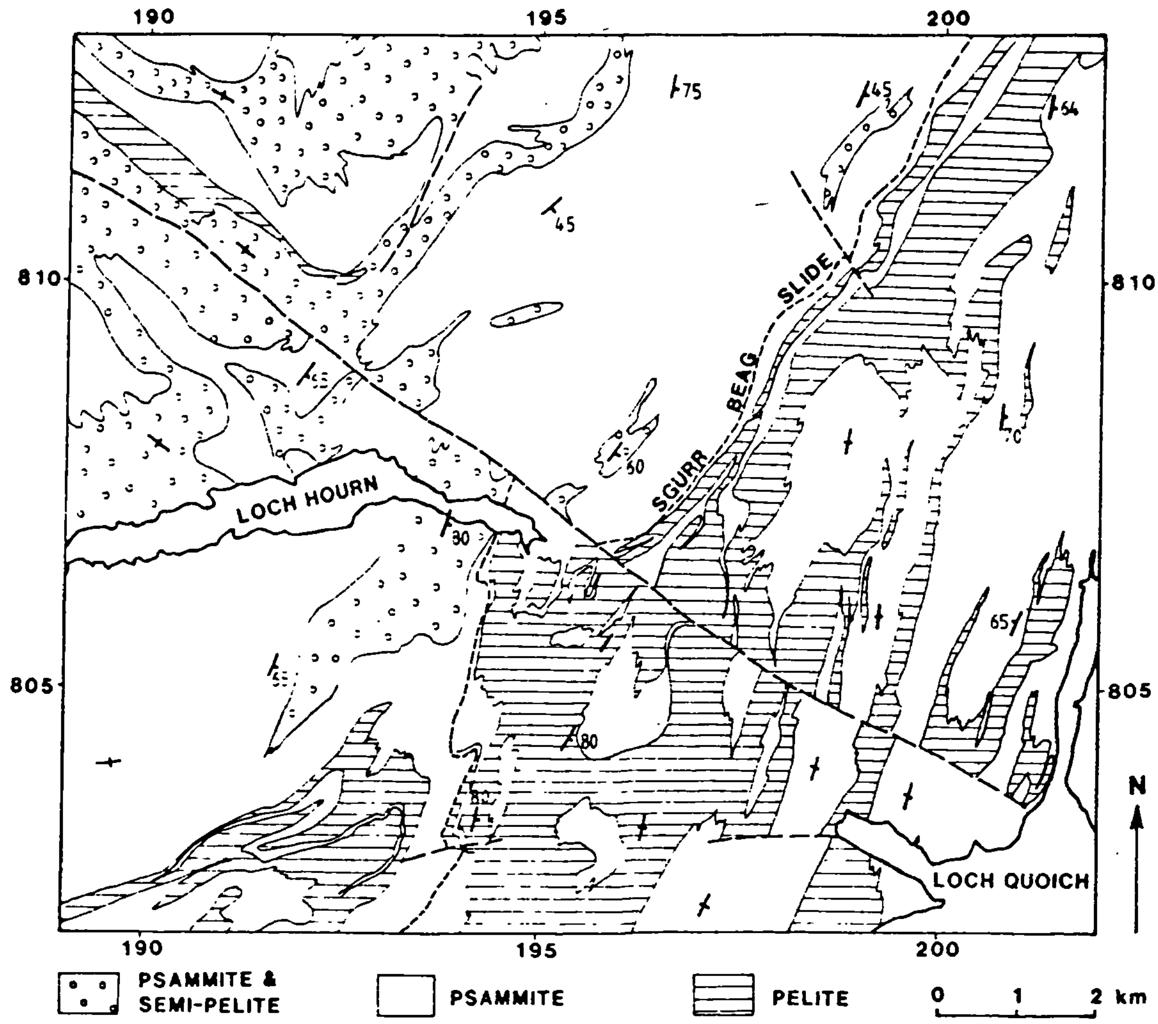


Fig.12-1. Geological map of the Moinian basement rocks in the vicinity of Kinloch Hourn fault (running NW-SE across the map).

Fig.12-2. Map showing features along and around the Kinloch Hourn fault. Labelled localities are discussed in section 12.2.3.

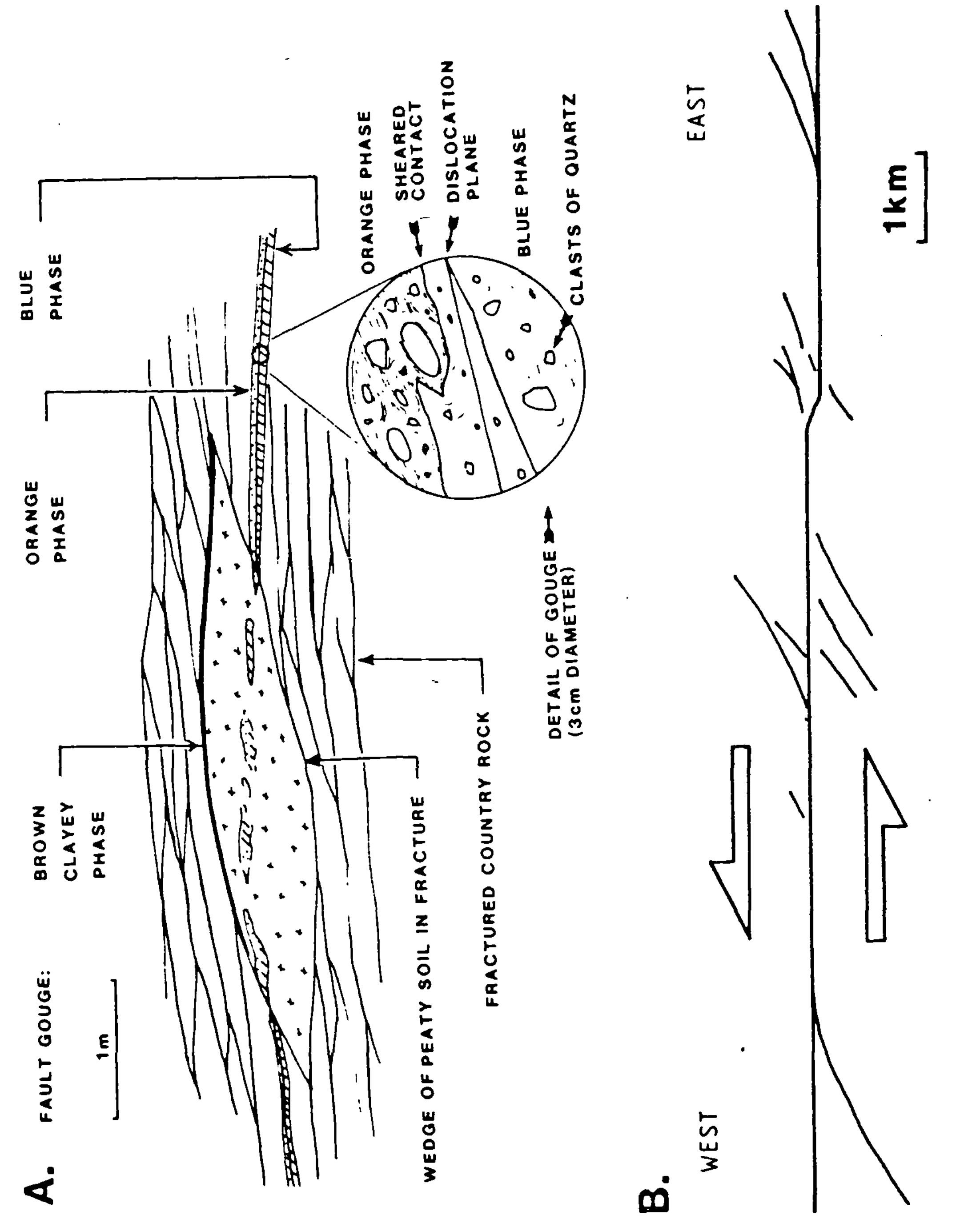


Fig.12-3. A. Sketches of fracture infilling material at the 'soil wedge' locality 'X'.

B. Tracing of the Kinloch Hourn fault and associated fracture lineaments. The pattern of fractures appears to indicate sinistral shear of the fault.

PRESENT DRAINAGE PATH

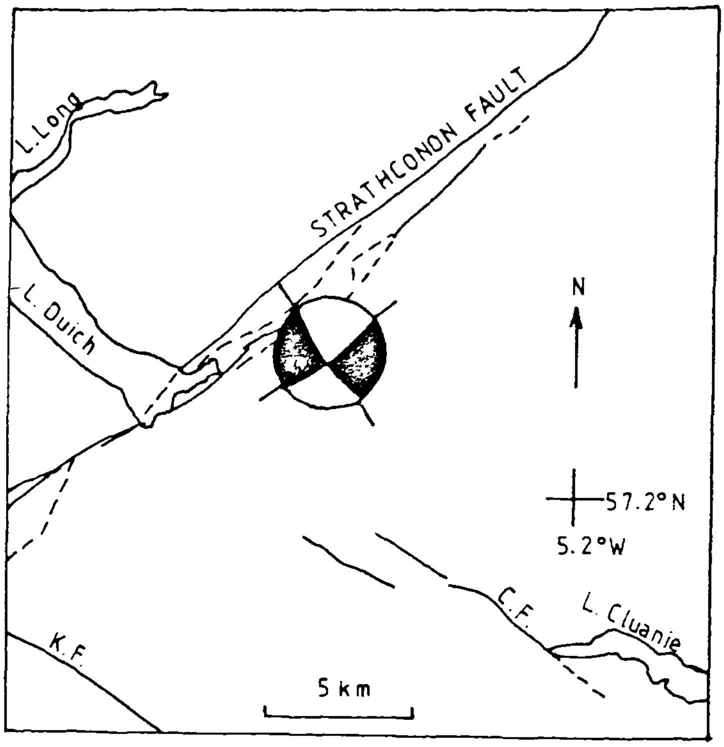
FORMER DRAINAGE PATH

'OVER-STEEPENED' GULLEY

HEAD OF NEW DRAINAGE PATH

LOCH

Fig.12-4. Map of drainage paths across the Kinloch Hourn fault. Numbered localities are discussed in section 12.3.5 and listed in Table 12-1.



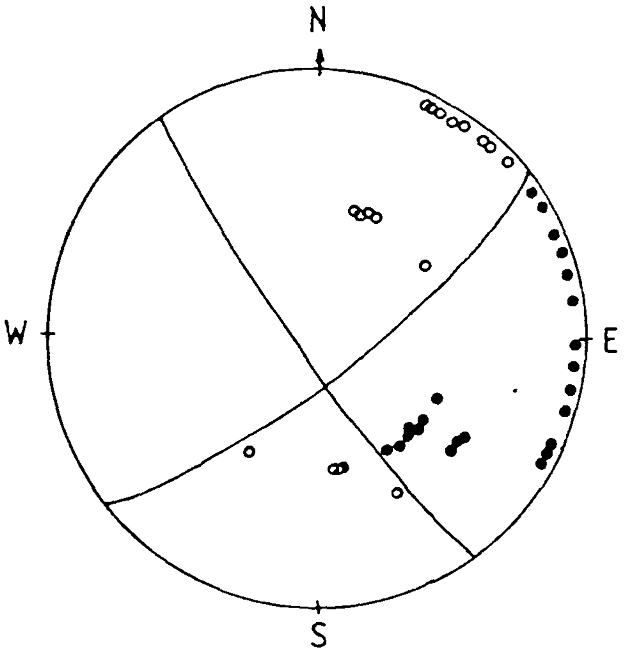


Fig.12-5. The fault plane solution for the Kintail, 1974, KEQ event, constructed by Assumpcao (1981) and its position relative to the Strathconon fault. Open circles - dilation, dots - compression. K.F. - Kinloch Hourn Fault, C.F. Cluanie fault.

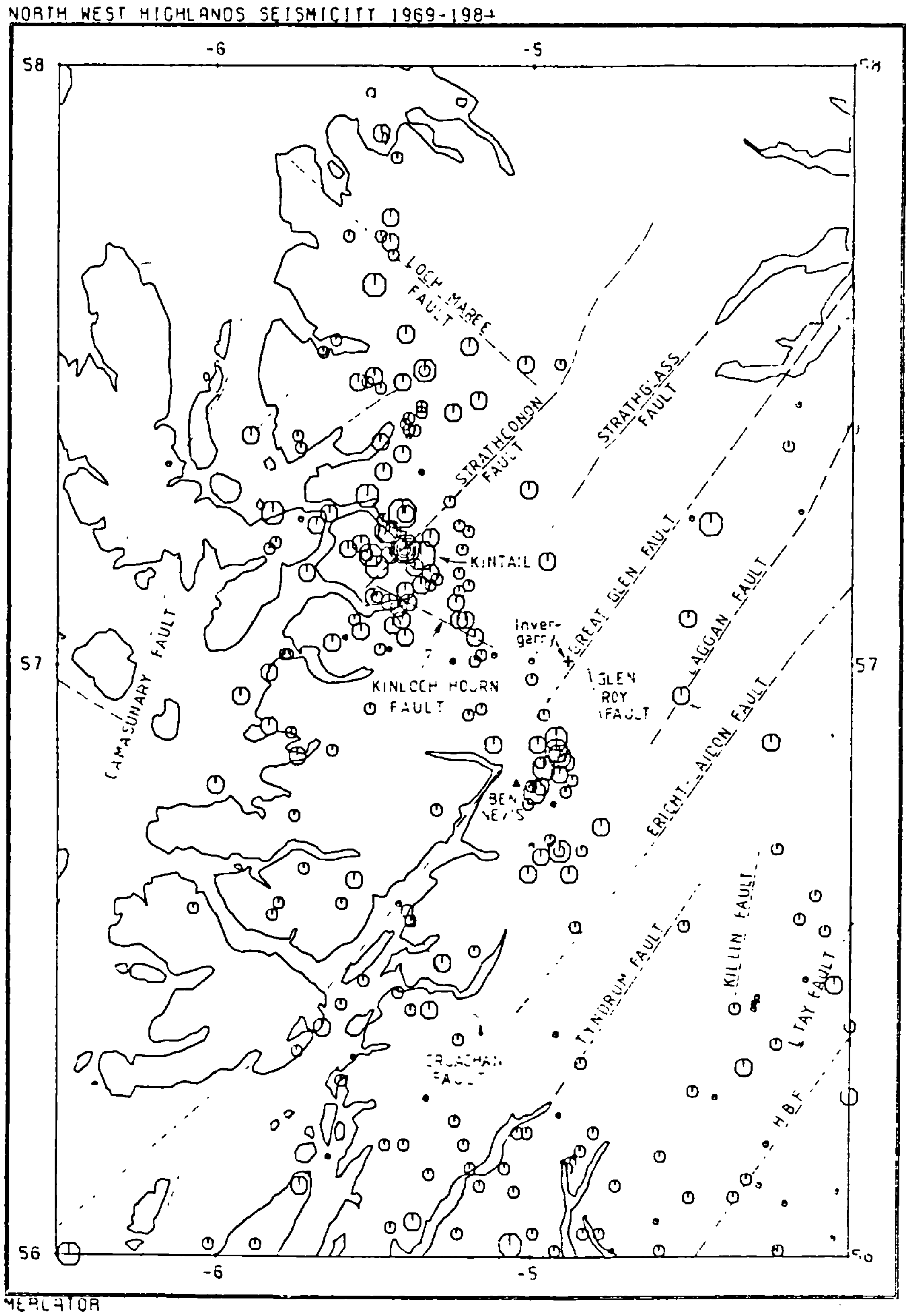


Fig.12-6. Map of seismicity in the NW Highlands between 1969 and 1984 (recorded by the BGS) and the major faults in the area. The symbol sizes correspond to magnitude 0 (smallest) to magnitude 4 (largest) in increments of one magnitude.

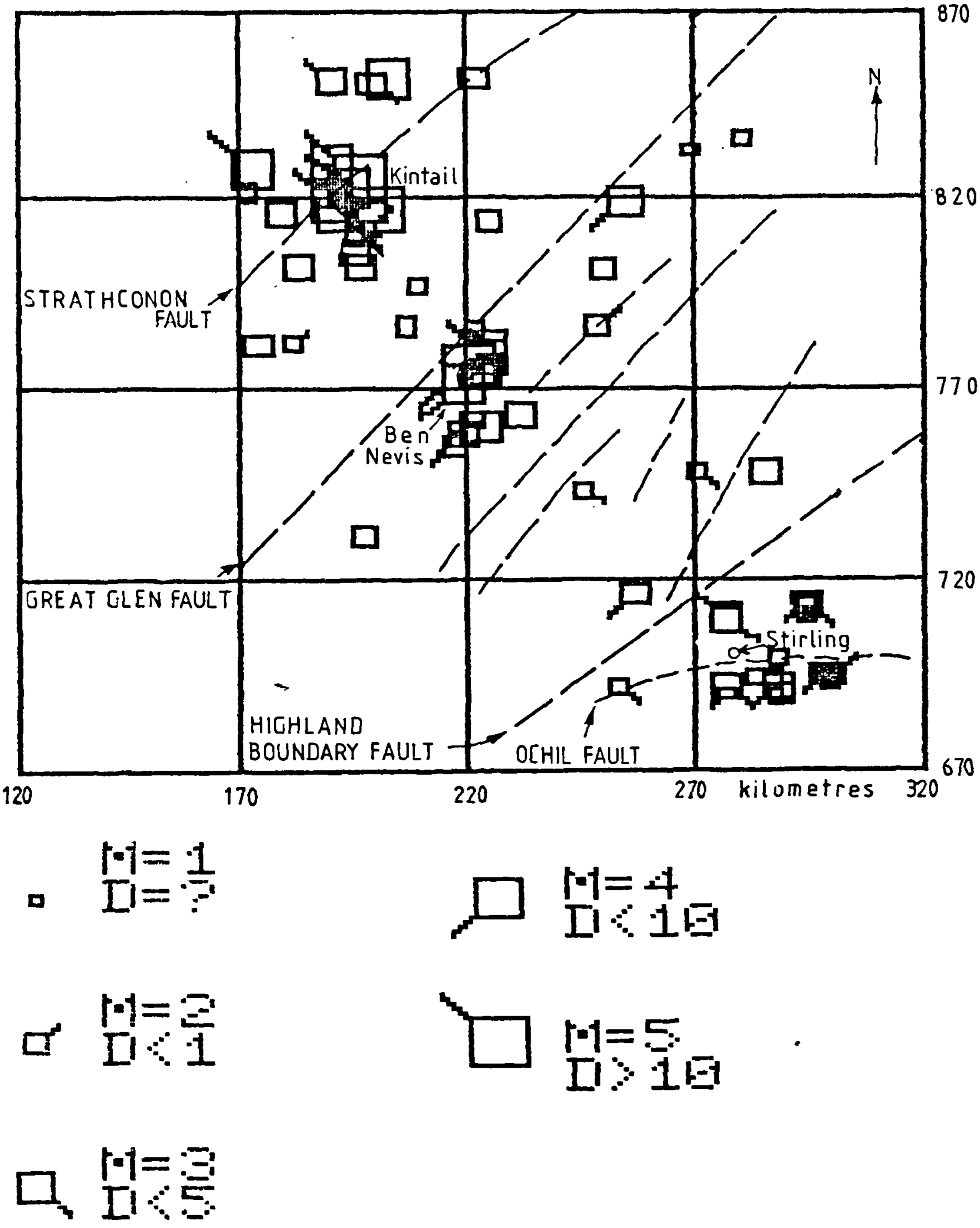


Fig.12-7. Seismicity data from the BGS file for 1969-1978 (Burton & Neilson 1980) with all events less than 1.0ML, or which were clearly aftershocks of large events, removed. (M = Local Magnitude, D = hypocentral depths in kilometres).

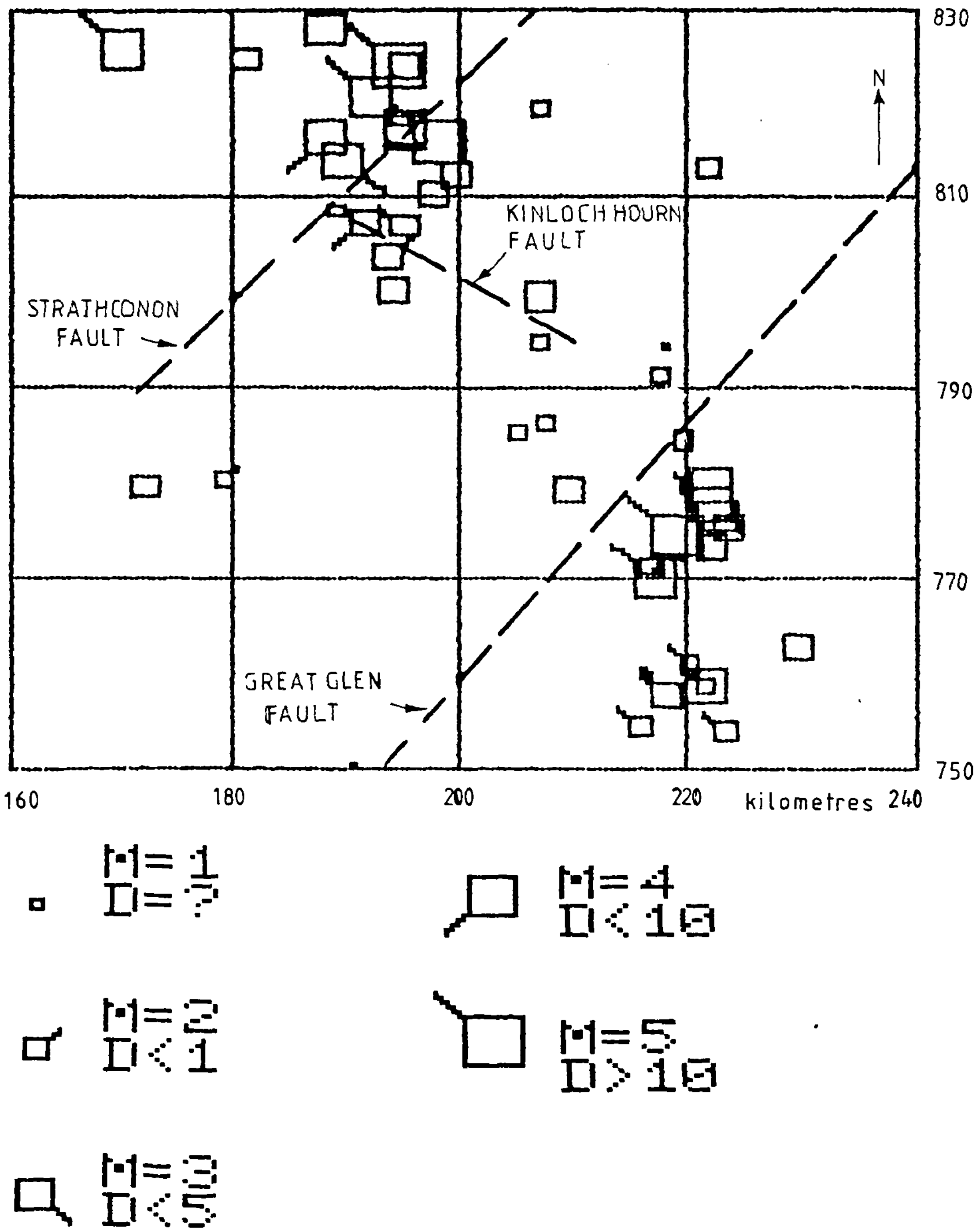


Fig.12-8. As for Fig.12-7 but showing an enlargement of the area around the Kinloch Hourn fault.

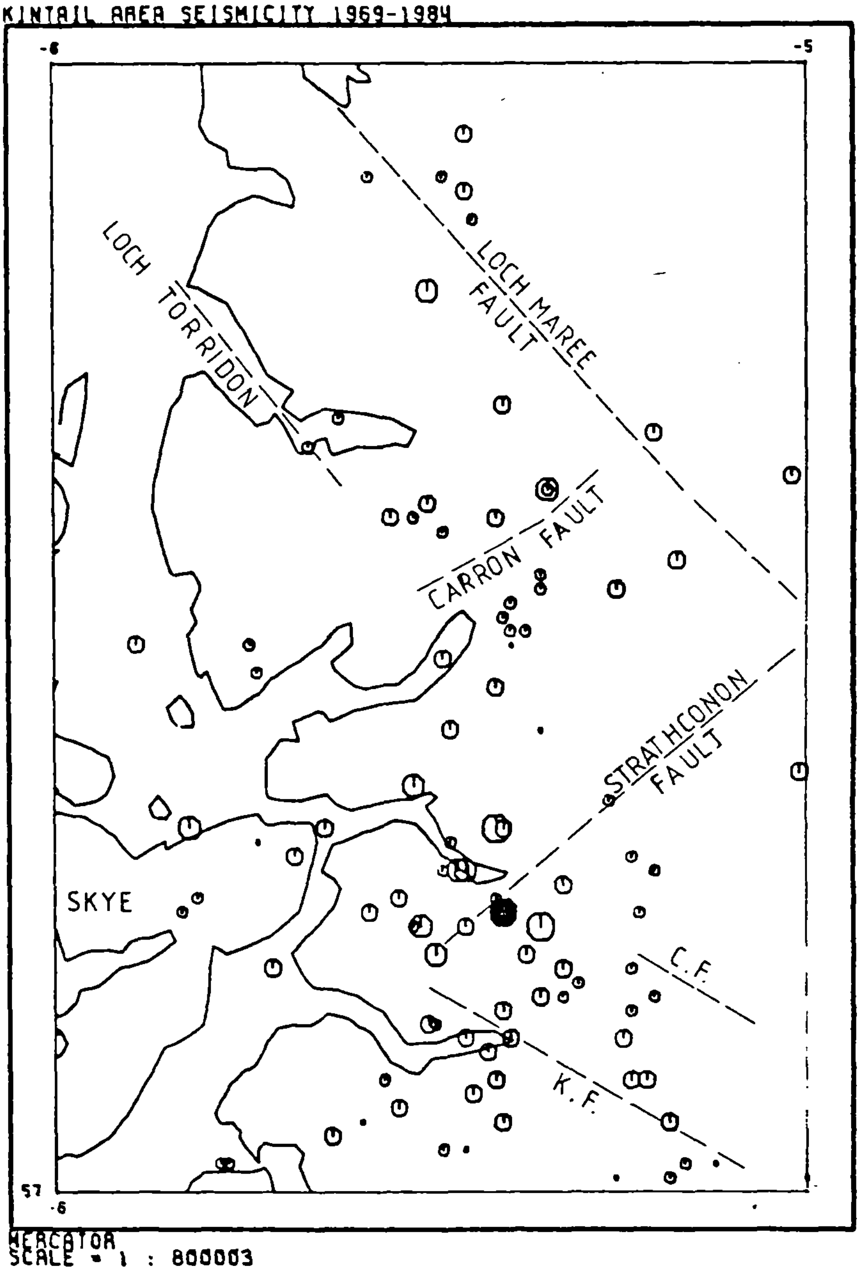


Fig.12-9. BGS seismicity in the Kintail study area - all events between 1969 and 1984. Symbol sizes indicate increasing magnitudes from ML=0 upwards in increments of one magnitude. K.F.- Kinloch Hourn Fault, C.F.- Cluanie fault.

Fig.12-10. BGS seisimicity, Kintail study area - swarm of 4th to 29th August 1974 (18 events - most of which are not spatially resolved at this scale).

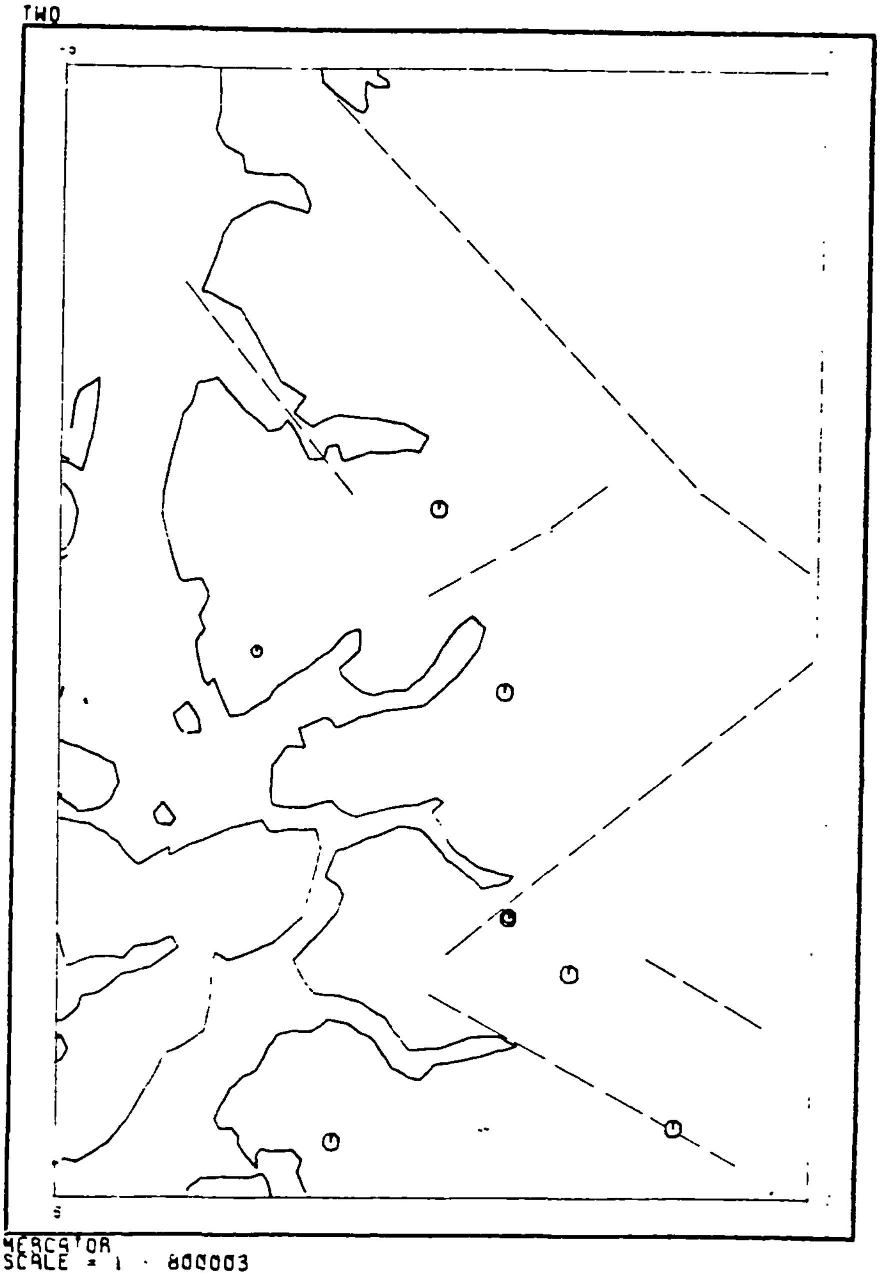


Fig.12-11. BGS seisimicity, Kintail study area - diffuse activity between 24/9/74 and 26/6/75 (9 events).

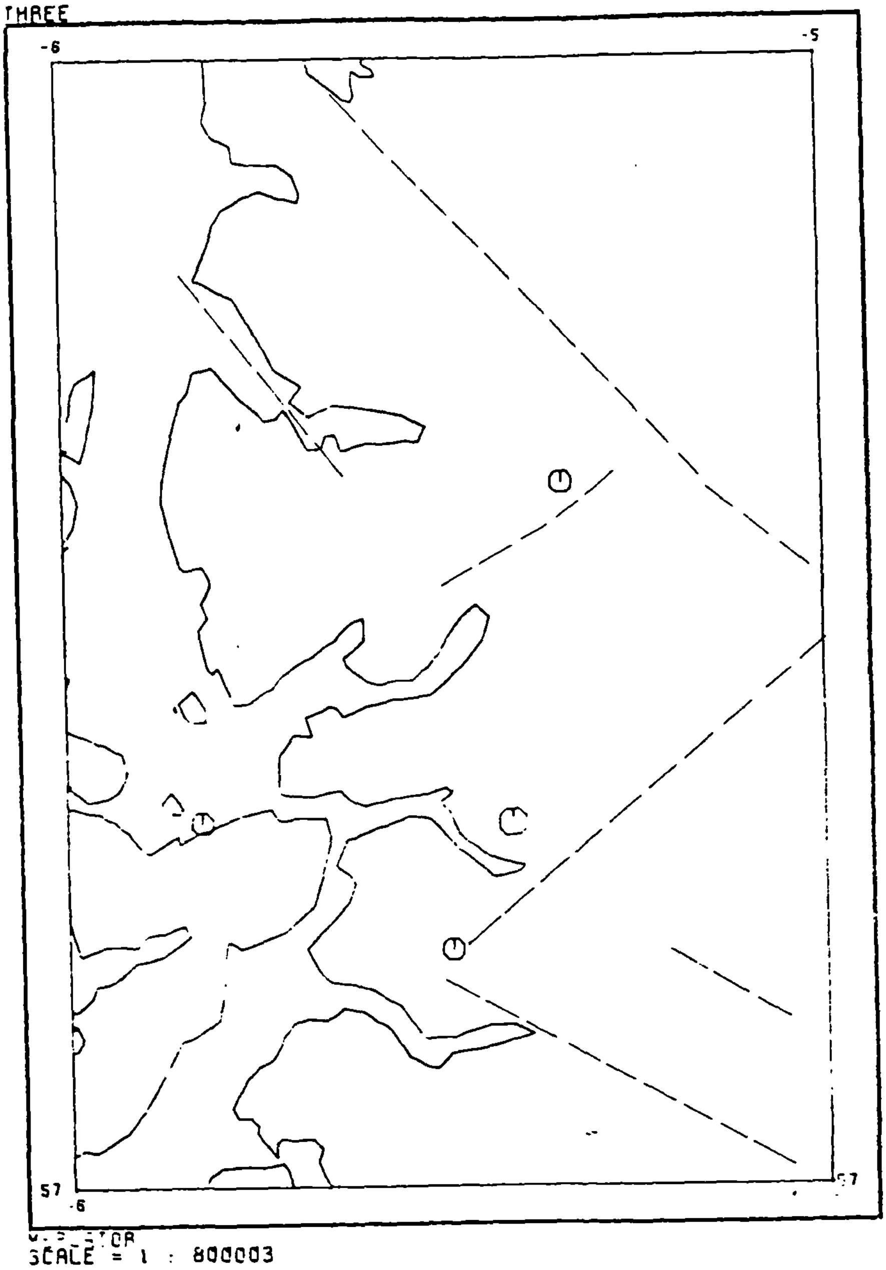


Fig.12-12. BGS seisimicity, Kintail study area - cluster of events between 21/11/75 and 27/11/75 (4 events).

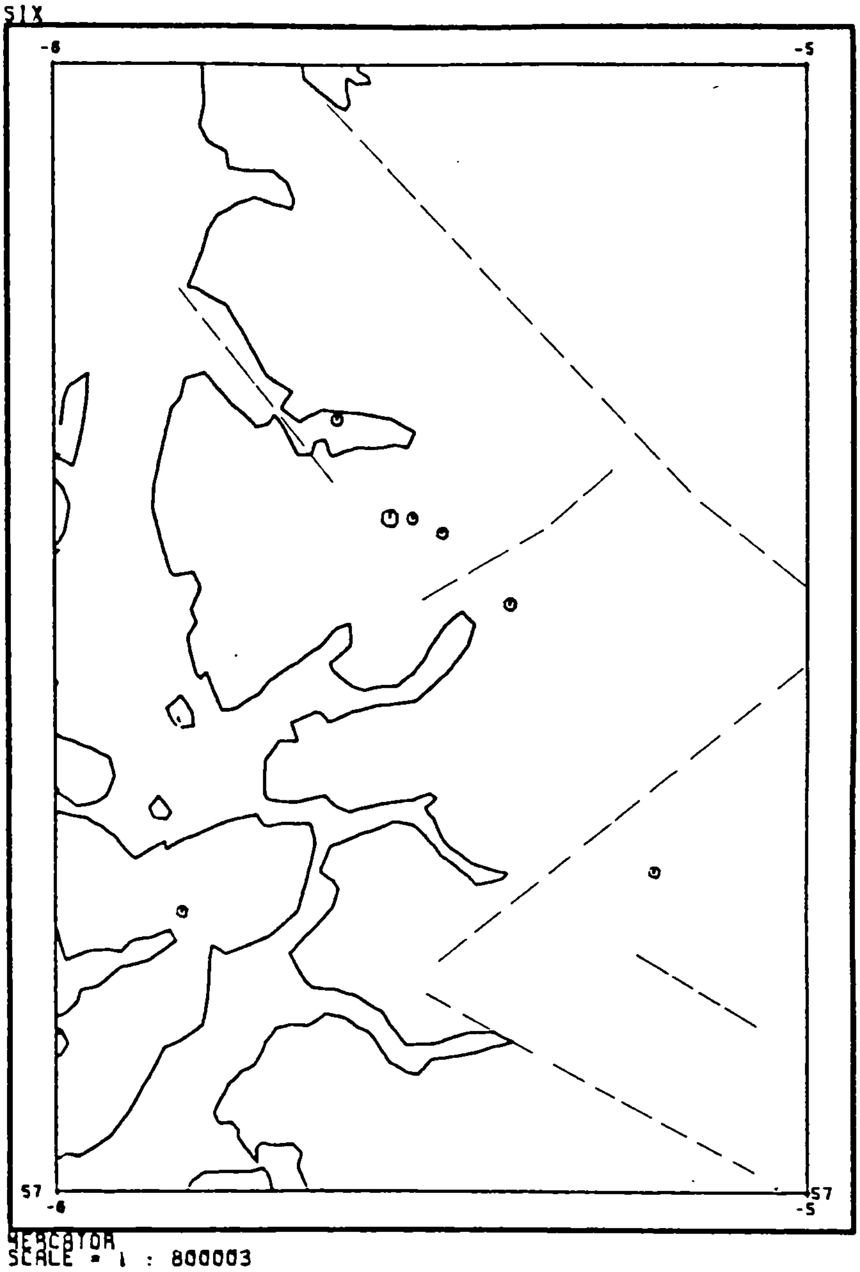


Fig.12-13. BGS seisimicity, Kintail study area - swarm of 26th to 28th May 1978 (7 events).

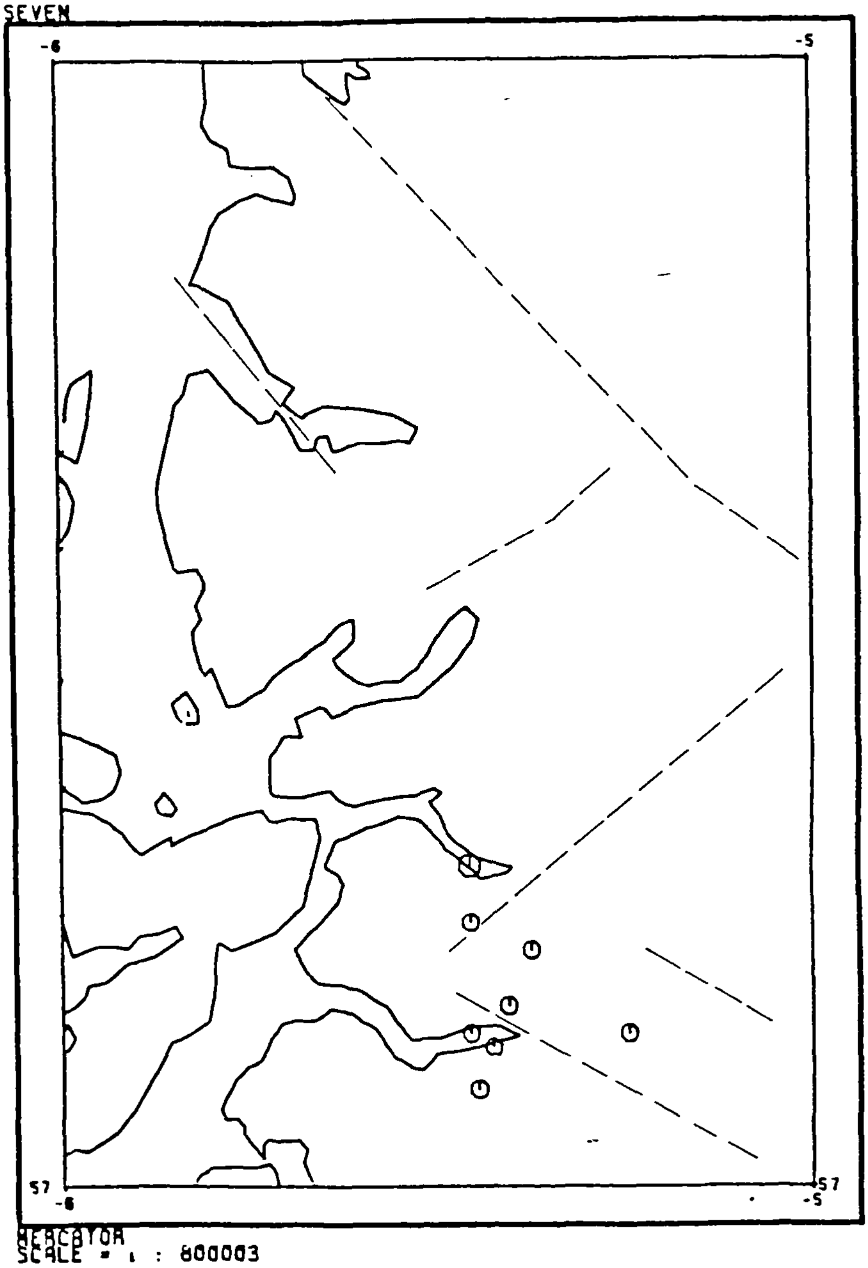


Fig.12-14. BGS seisimicity, Kintail study area - swarm of 9th to 10th September 1978 (8 events).

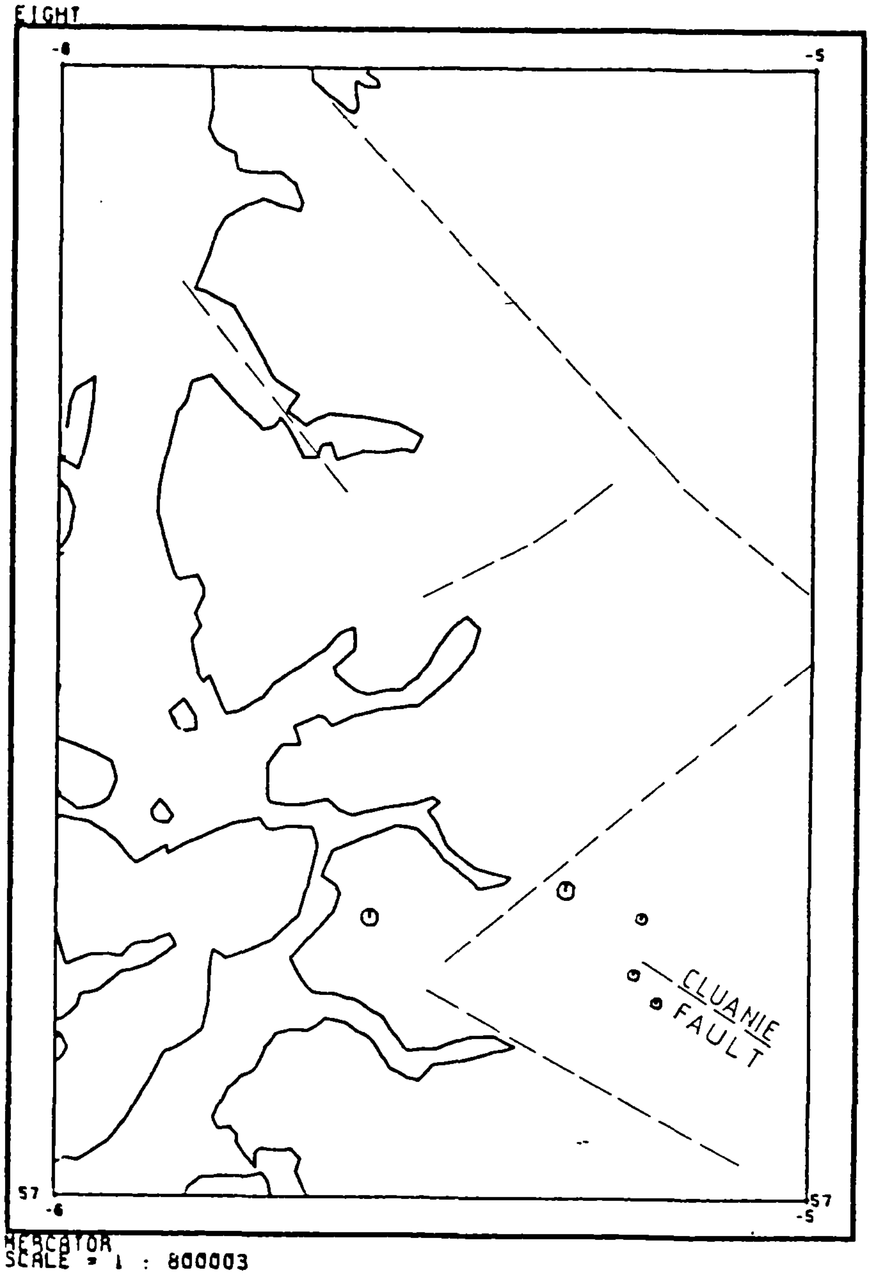


Fig.12-15. BGS seisimicity, Kintail study area - swarm of 9th to 12th April 1980 (5 events).

Fig.12-16. BGS seisimicity, Kintail study area - swarm of 7th to 8th February 1982 (5 events).

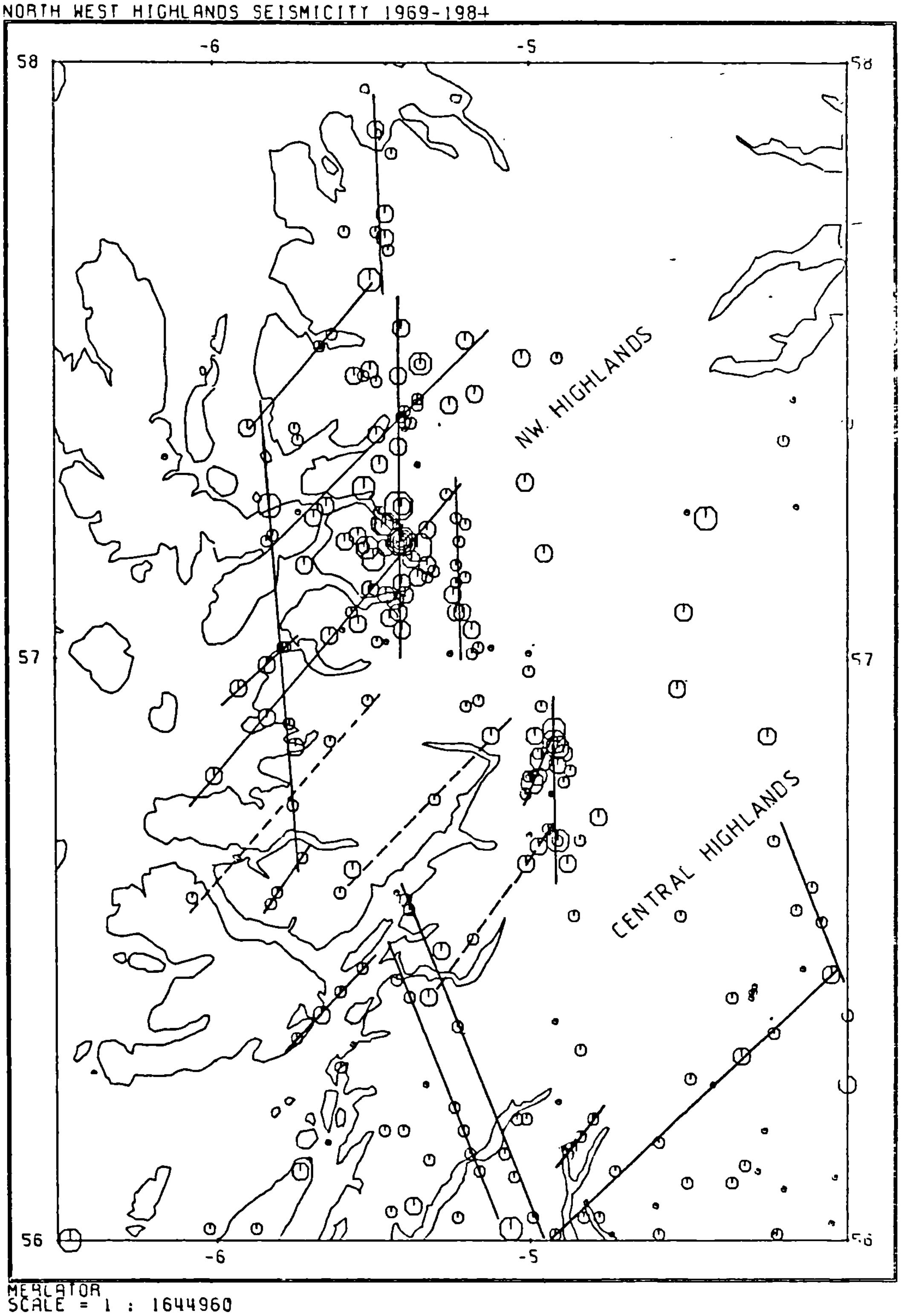


Fig.12-17. Regional microseismic lineations apparent in the BGS seismicity file, 1969-1984, in the NW Highlands.

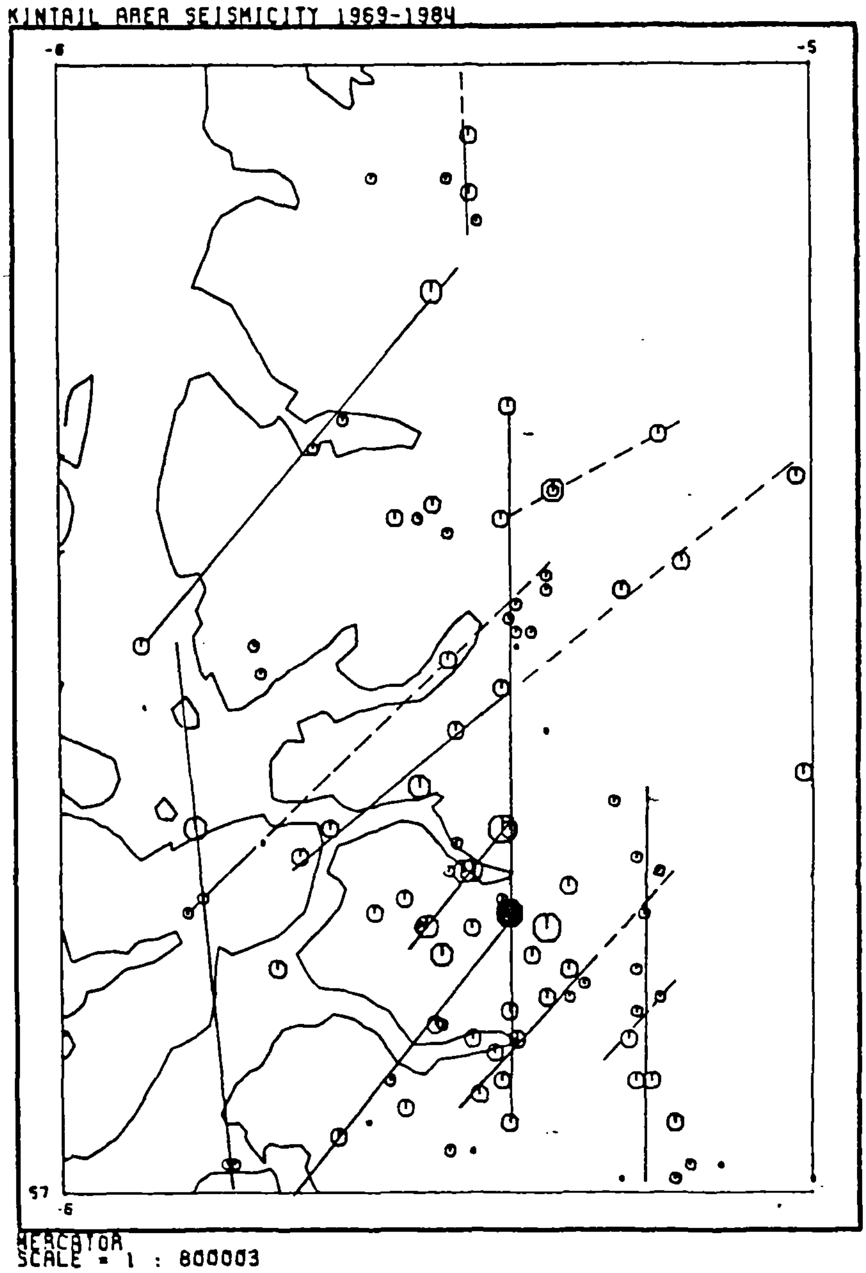
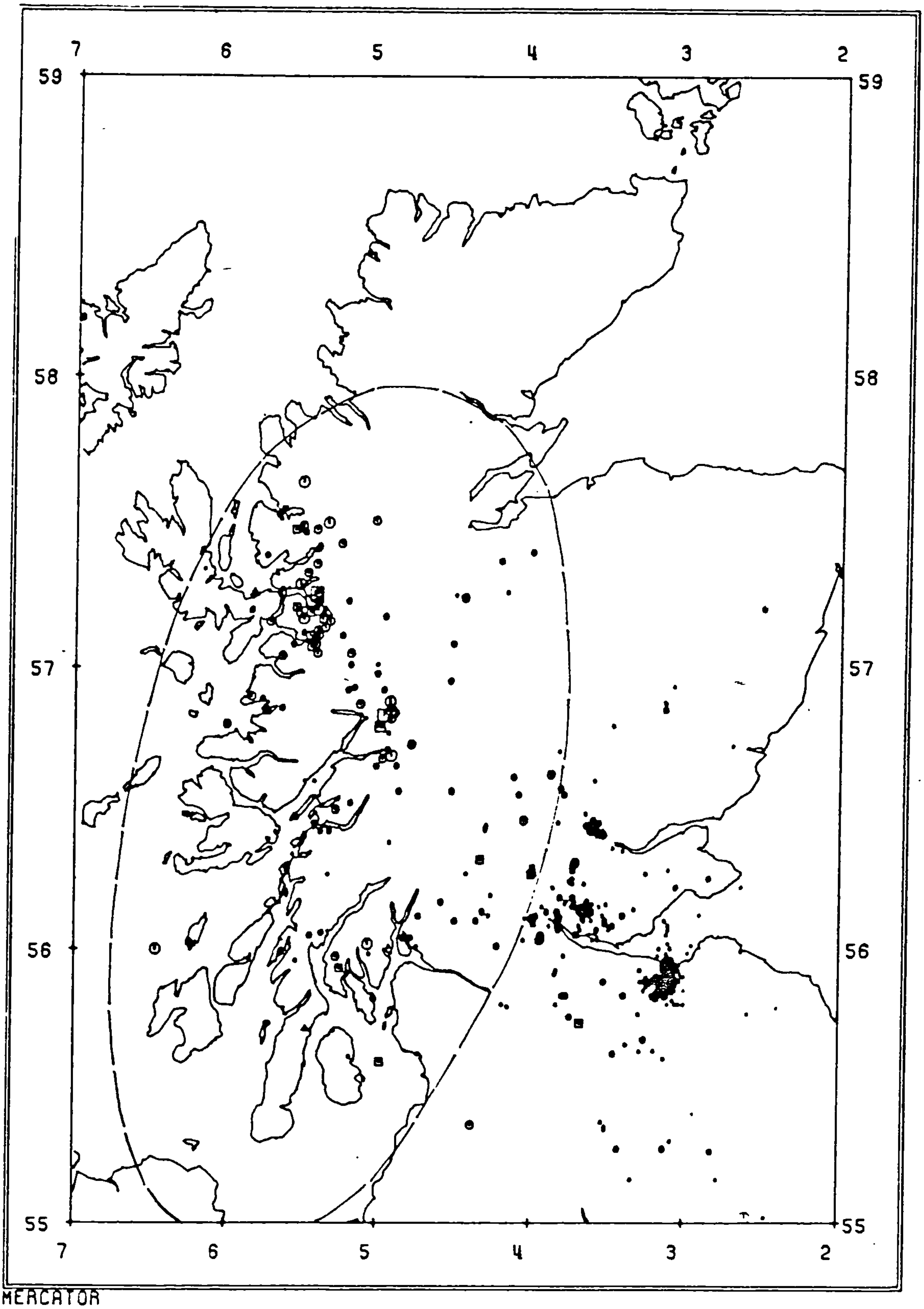


Fig.12-18. Regional microseismic lineations apparent in the BGS seismicity file, 1969-1984, in the Kintail study area.



All epicentres in Scotland 1967-1978.

Fig.12-19. Seismicity in Scotland (1967-1978) in relation to the area of maximum post-glaical uplift - the dashed contour shown is the 2.5mm/year contour for present uplift rates (from Fleming 1982).

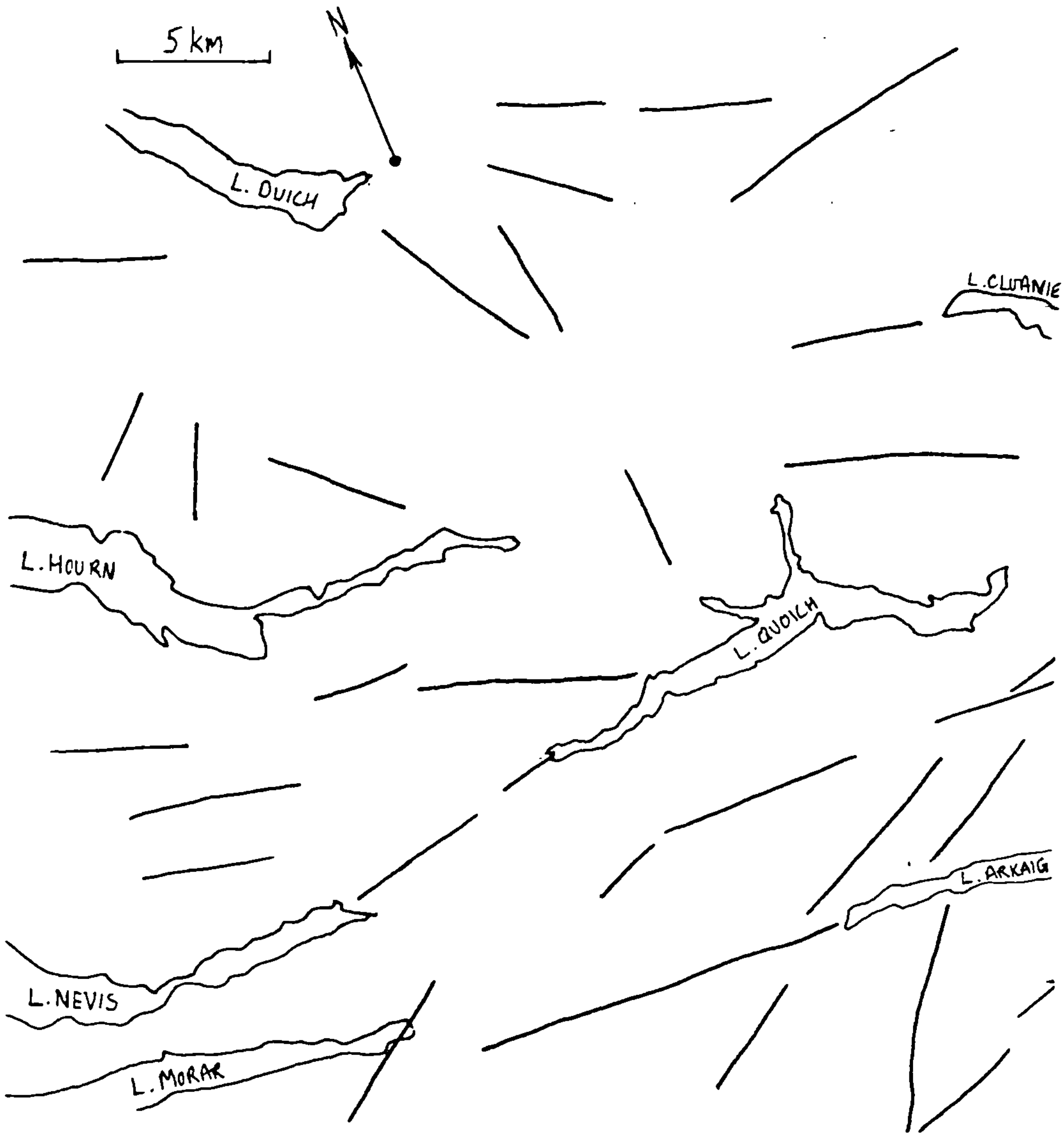


Fig.12-20. Lineaments occurring on the positive of a principal-component-1 image for the LANDSAT scenes of the Kinloch Hourn area.

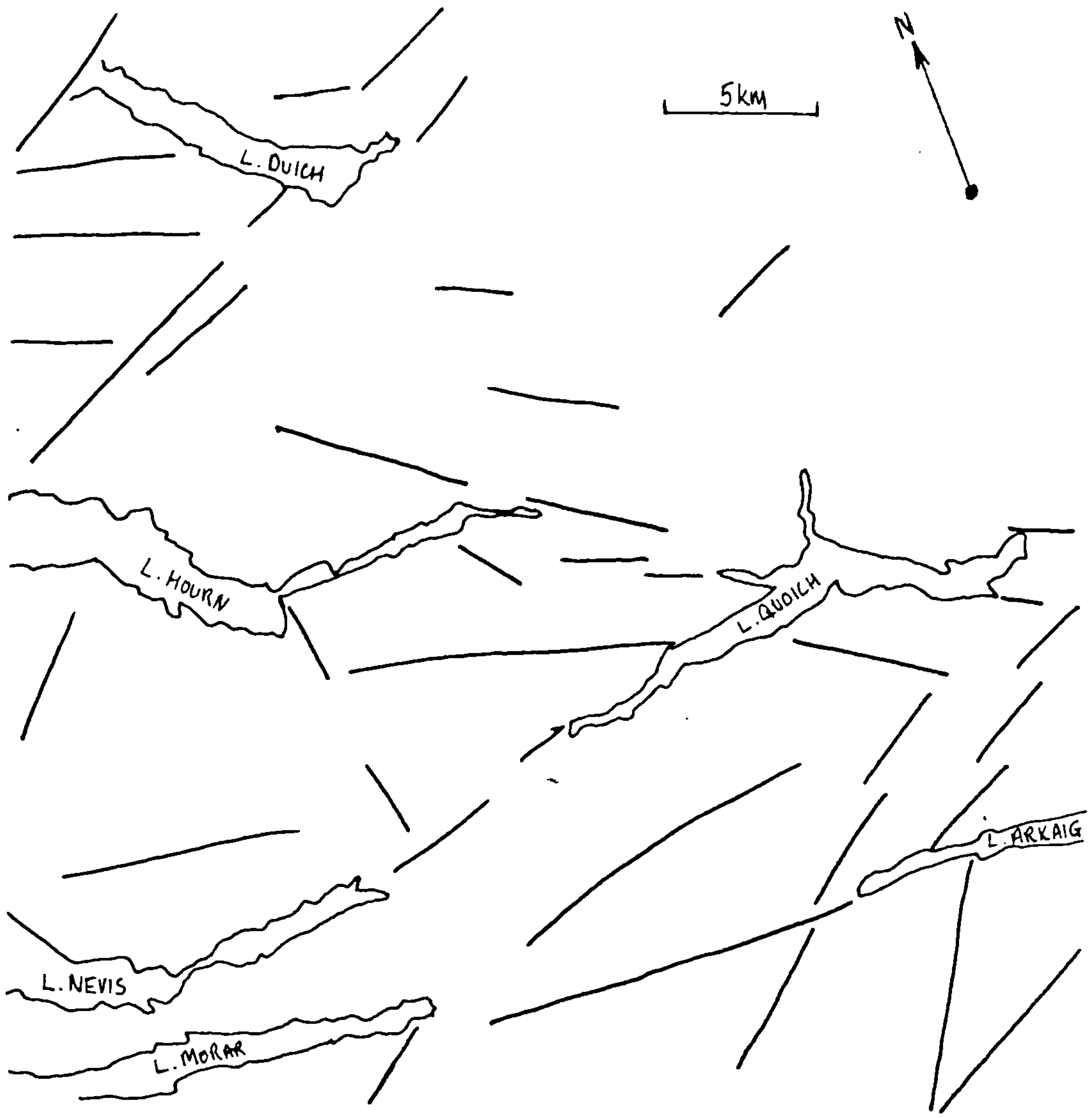


Fig.12-21. Lineaments occurring on the positive of a principal-component-2 image for the LANDSAT scenes of the Kinloch Hourn area.

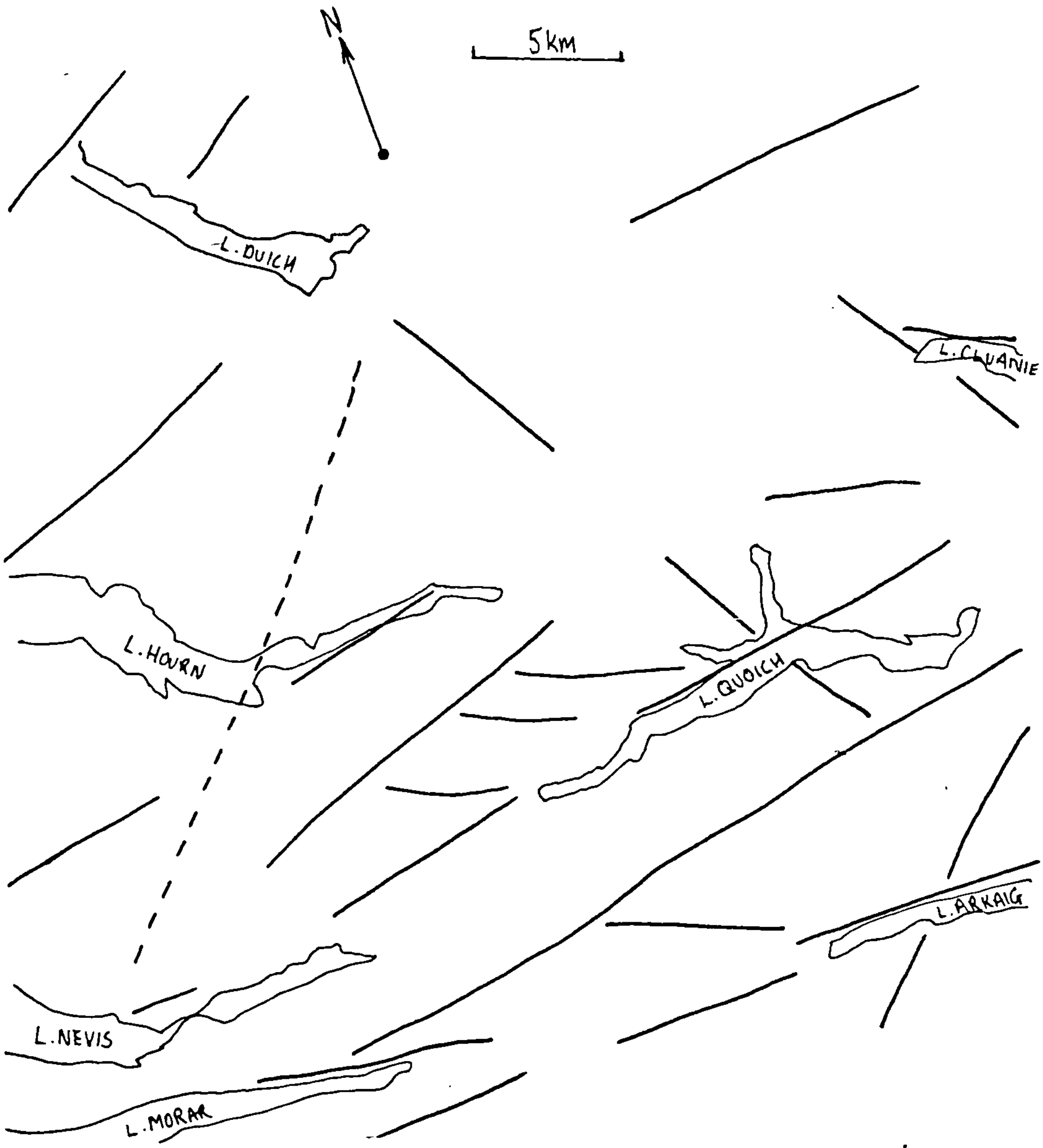


Fig.12-22. Lineaments occurring on the positive of a principal-component-3 image for the LANDSAT scenes of the Kinloch Hourn area.

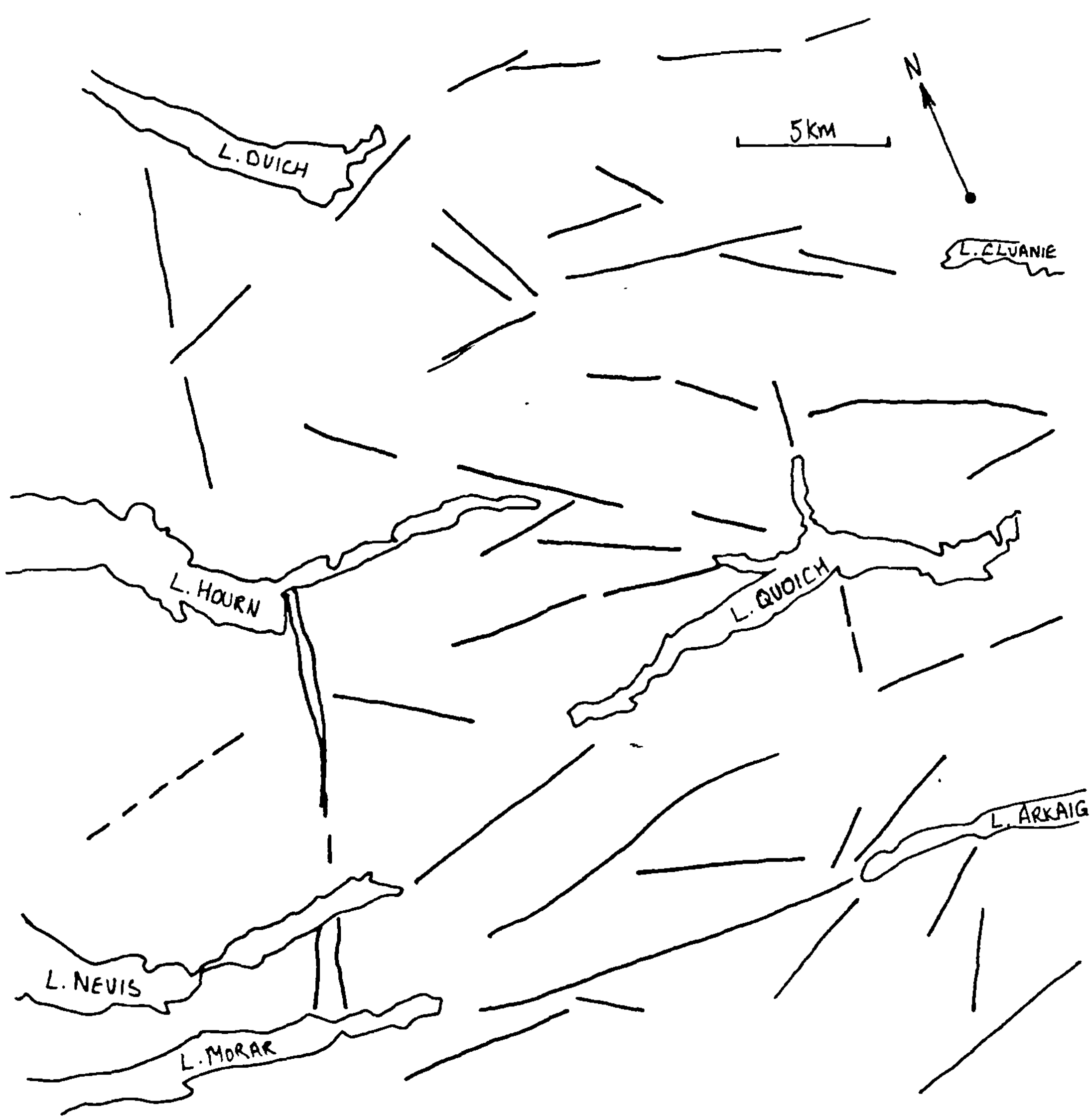


Fig.12-23. Lineaments occurring on the negative of a principal-component-1 image for the LANDSAT scenes of the Kinloch Hourn area.

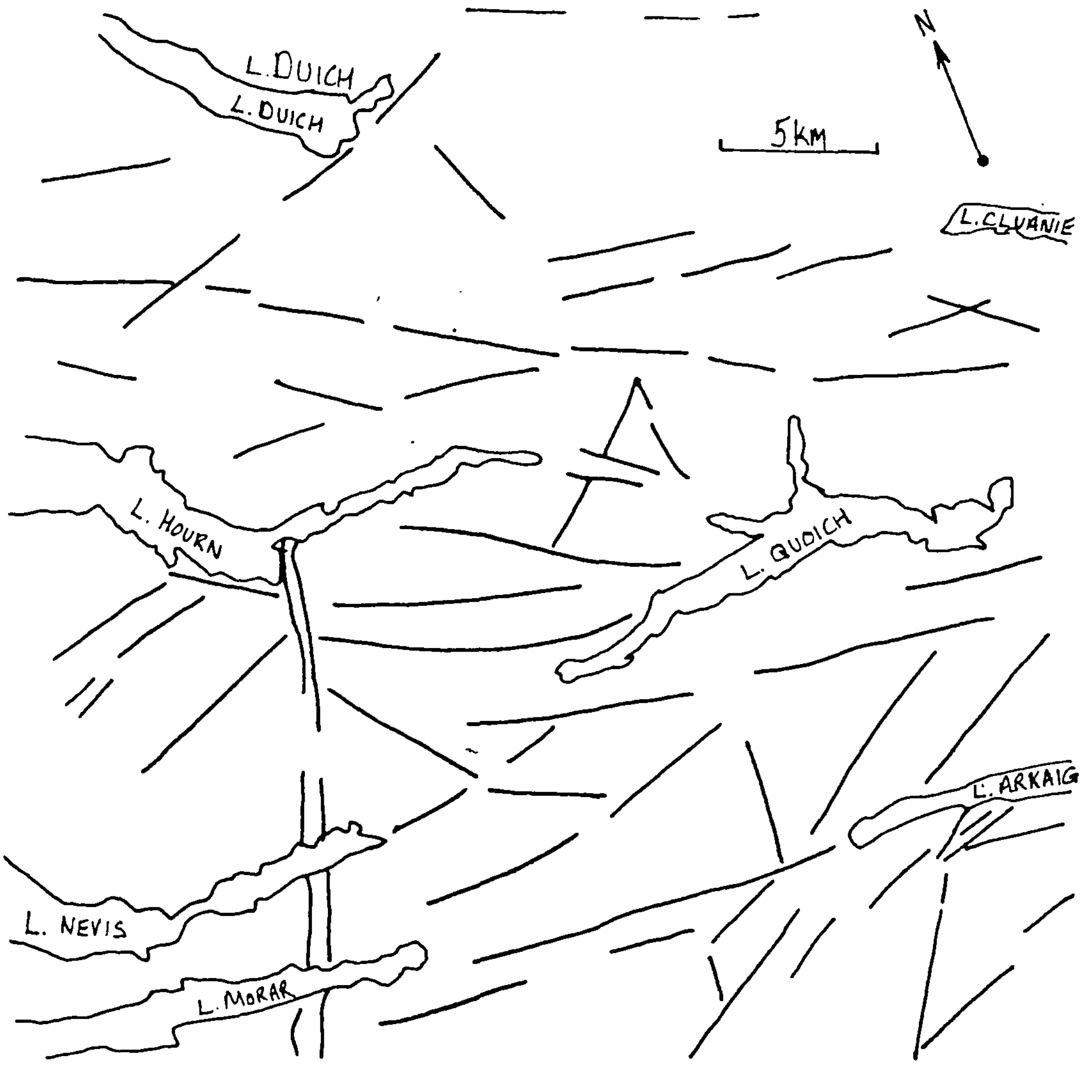


Fig.12-24. Lineaments occurring on the negative of a principal-component-2 image for the LANDSAT scenes of the Kinloch Hourn area.

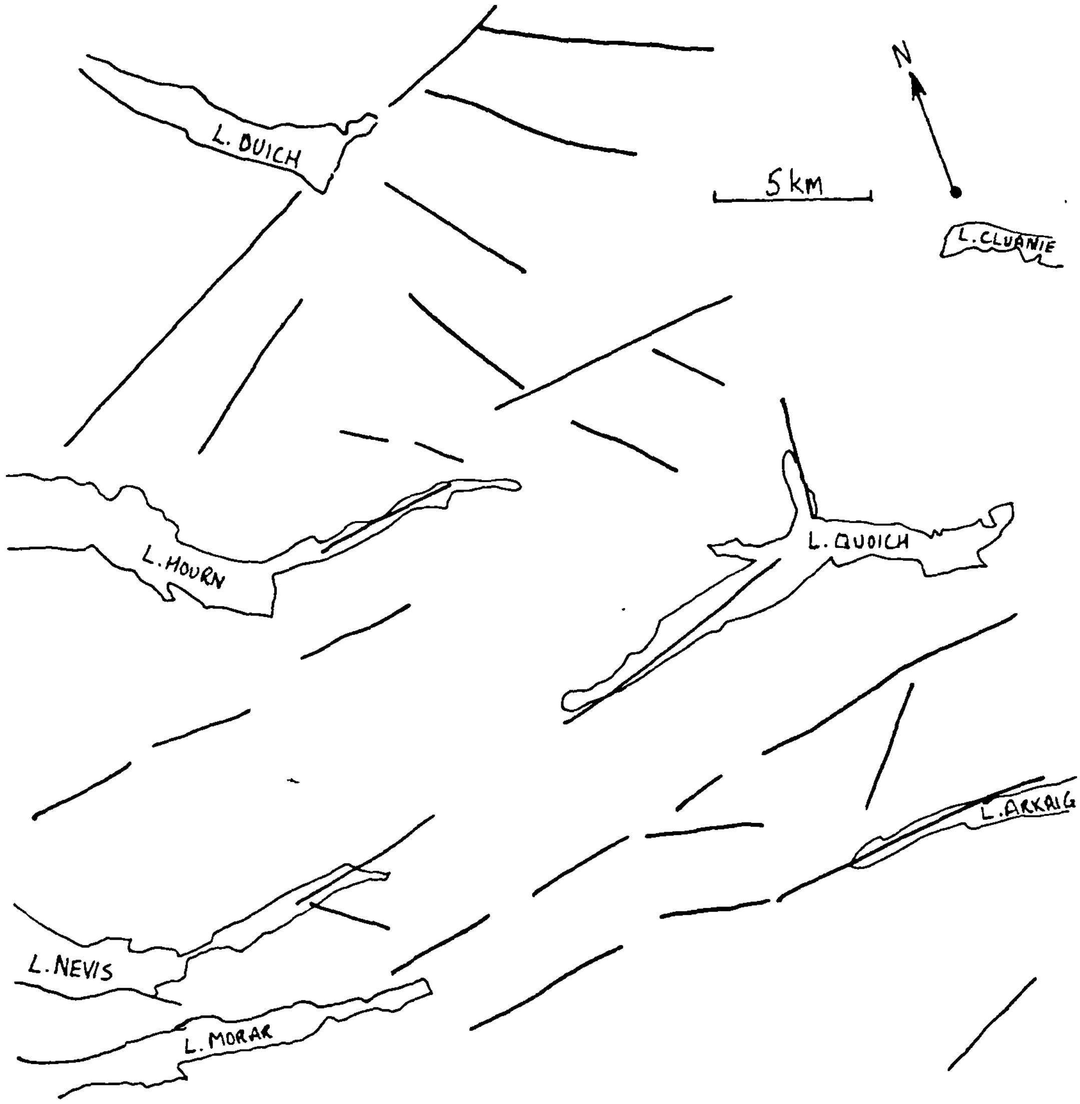


Fig.12-25. Lineaments occurring on the negative of a principal-component-3 image for the LANDSAT scenes of the Kinloch Hourn area.

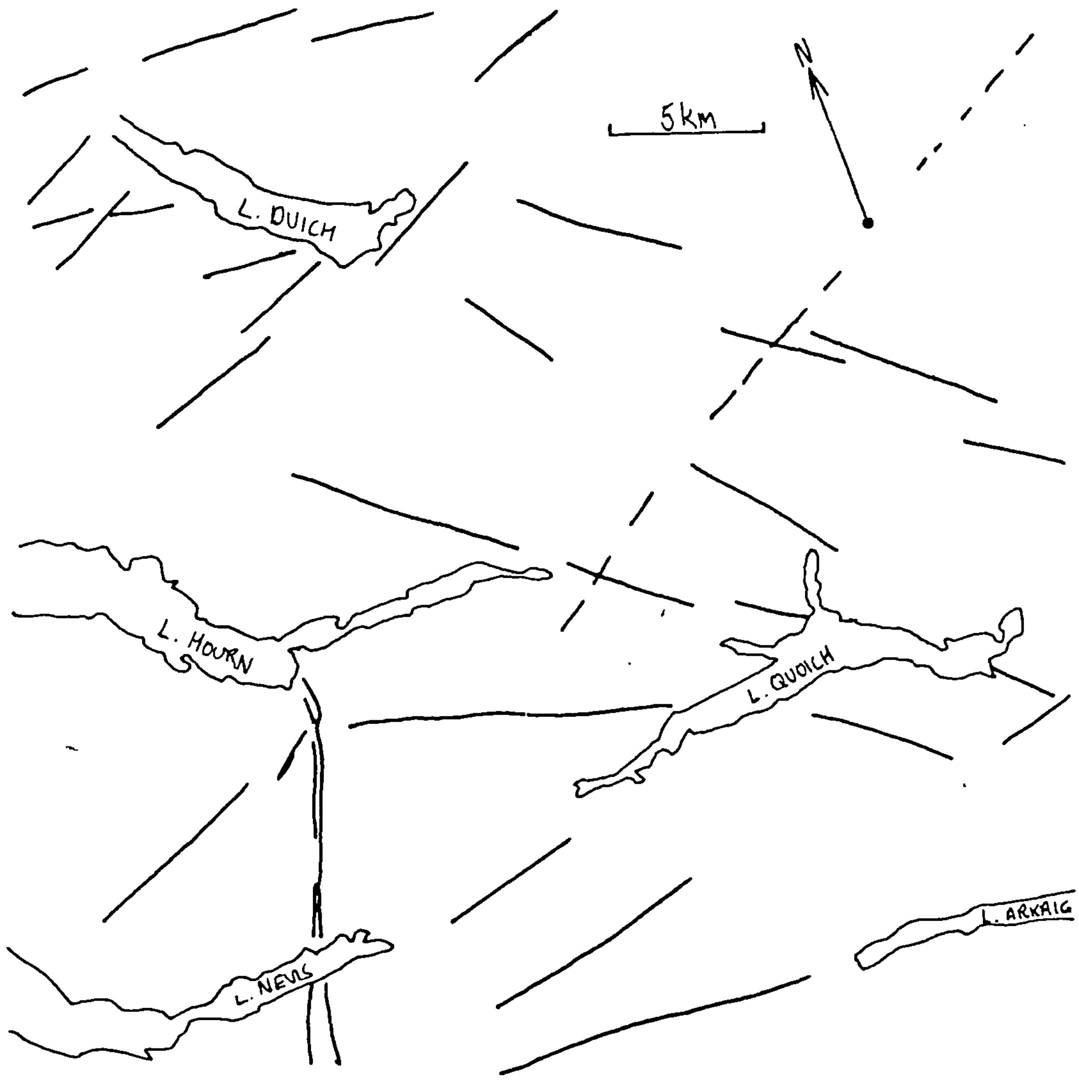


Fig.12-26. Lineaments occurring on the negative of a principal-component-1&2 image for the LANDSAT scenes of the Kinloch Hourn area.

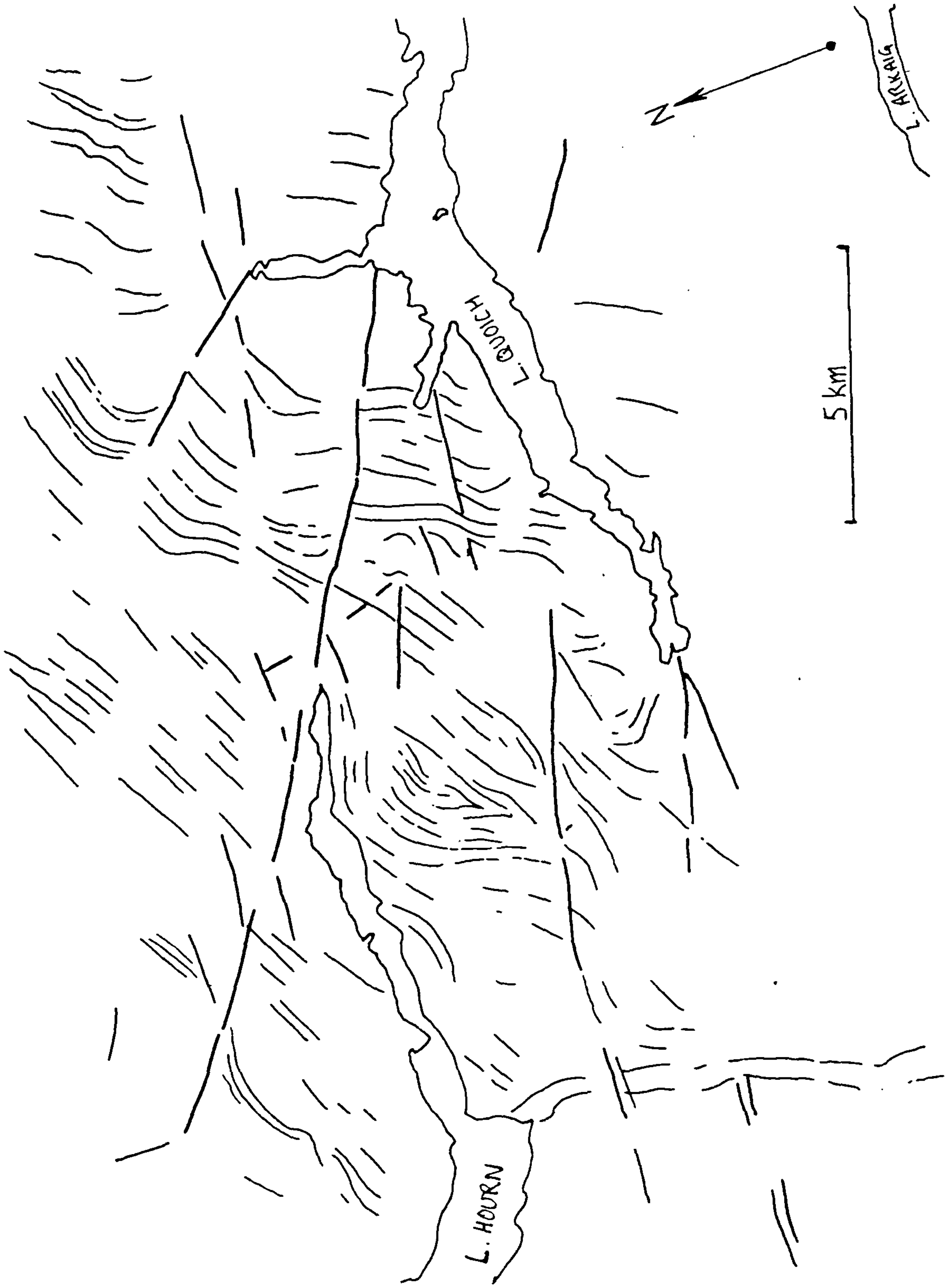


Fig.12-27. Enlargement of the Kinloch Hourn fault on a principal-component-1&2 image for the LANDSAT scenes of the Kinloch Hourn area, showing the basement foliation and structure and a clear trace of the fault itself.

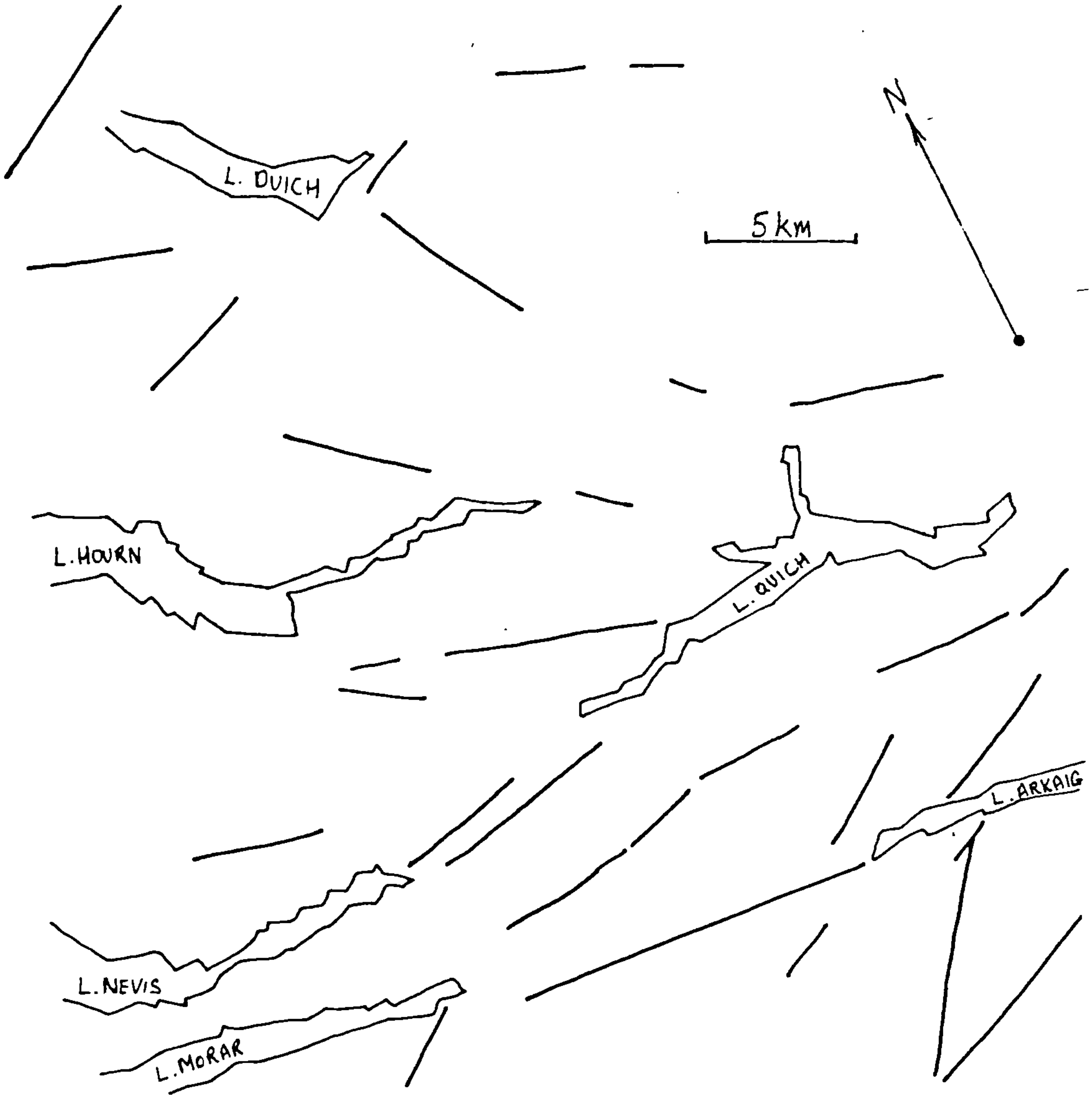


Fig.12-28. Lineaments occurring on more than one of the negatives and positives of all principal components of the LANDSAT scenes of the Kinloch Hourn area.

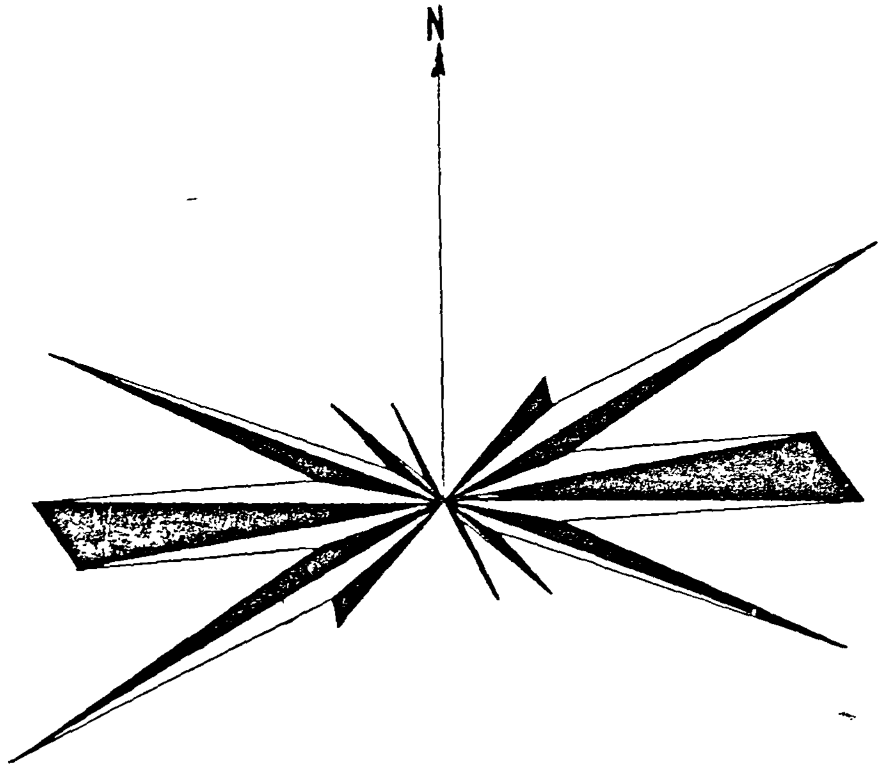


Fig.12-29. Rose diagram showing the lineament orientations for Fig.12-28. The total length of lineaments having orientations within each ten-degree sector are plotted as radial lines. Sectors in between the lines are shown in alternating black and white tone for clarity.

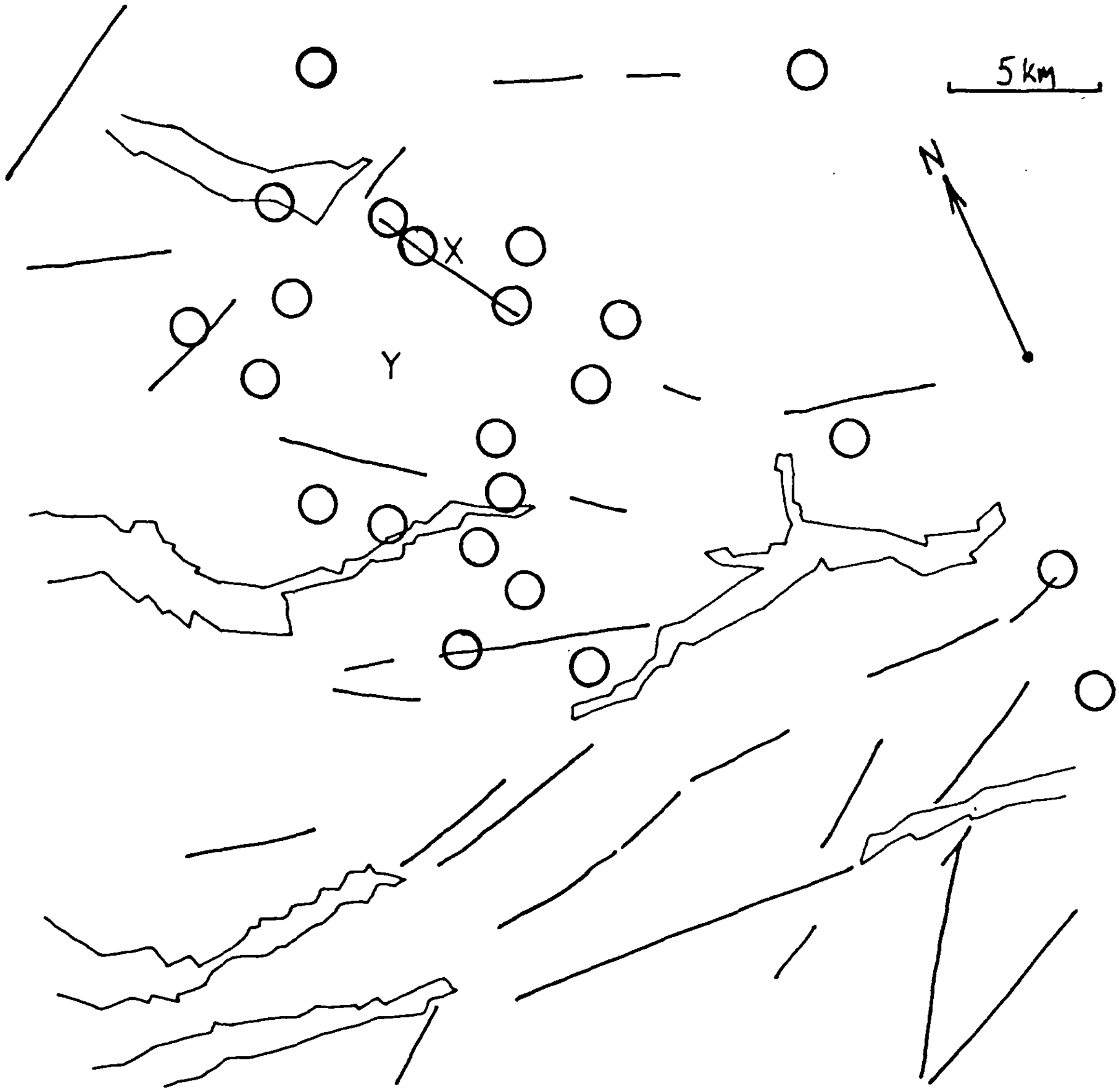


Fig.12-30. Seismicity in relation to lineaments (of Fig.12-28). The epicentres drawn include only those of the published list for 1967-78 (Burton & Neilson 1980). Epicentres are drawn with a 1km diameter circle (a minimum location error). (For discussion see section 12.4.3).

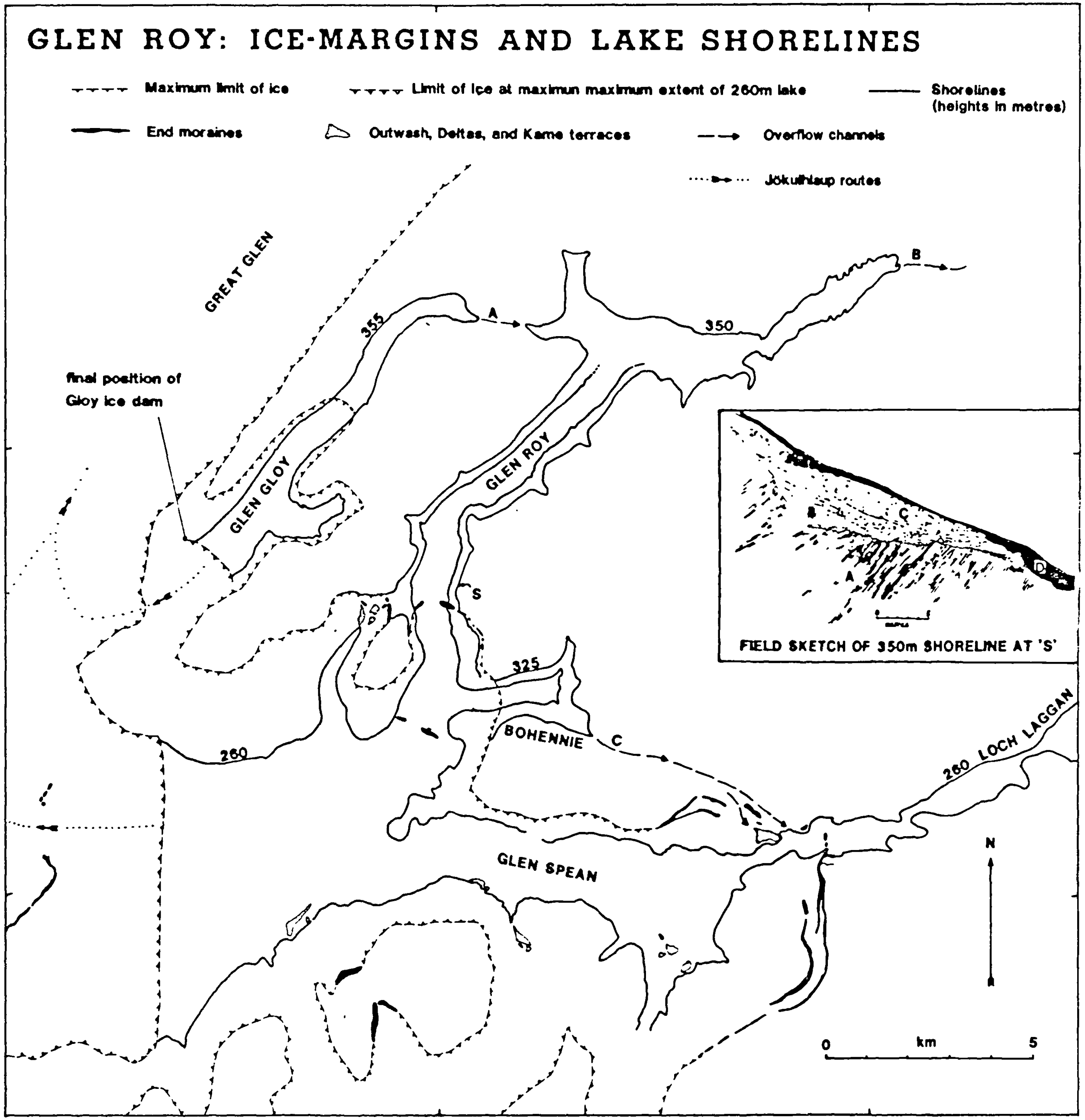


Fig.13-1. Ice-margins and lake shorelines in the Glen Roy area, after Sissons (for discussion see section 13-2.1). The insert is a field sketch, at point 'S' on the 350m shoreline, showing a sharp bench cut into steeply dipping, foliated metamorphic rock (A). Well-bedded glacial talus (B) can be seen infilling the bench, and this has been covered by post-glacial, hillslope debris (C), and soil and vegetation (D).

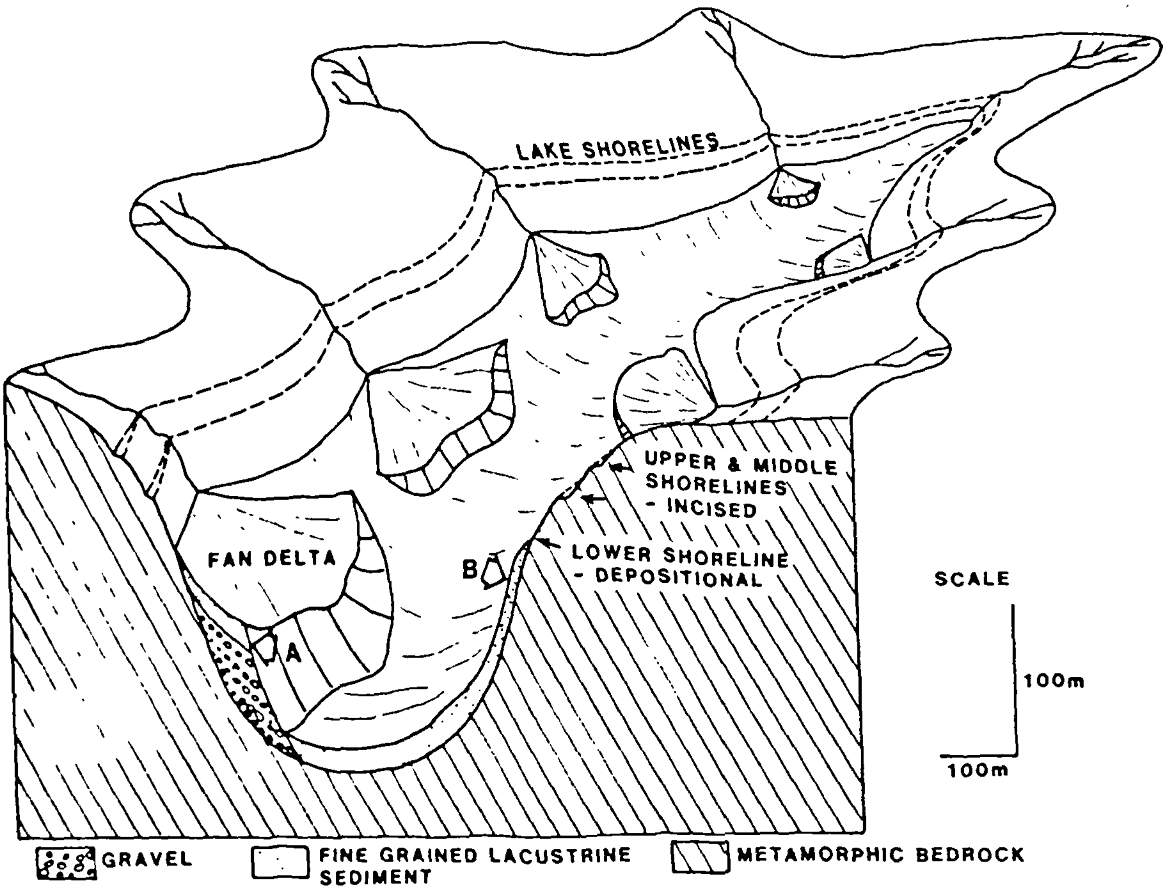
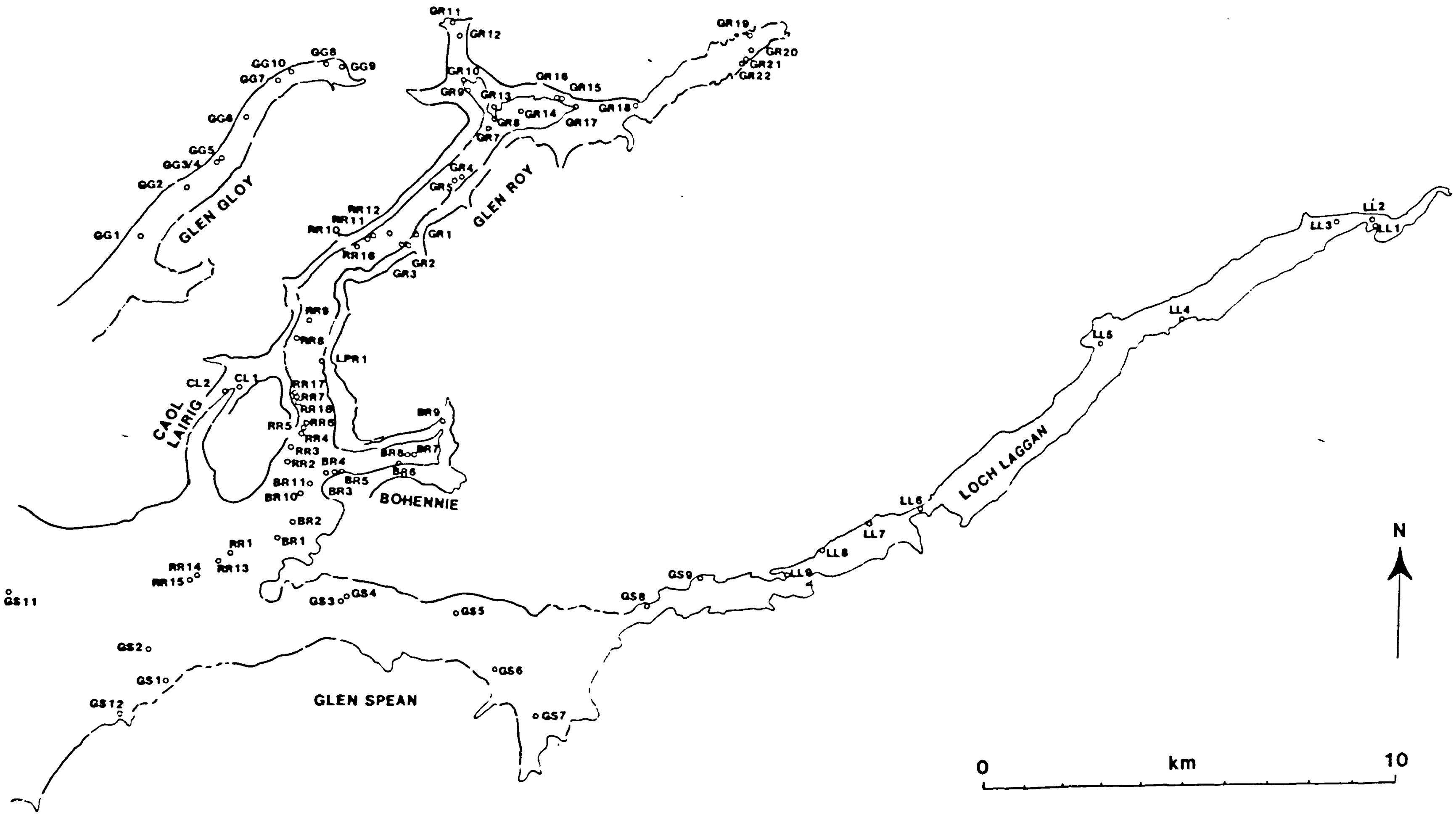


Fig.13-2. Sketch illustrating the form of sediment deposition within the Glen Roy glacial-lake basins. Fine-grained lacustrine sediment occurs in two forms: A) as a 'blanket' on the gently dipping surfaces of earlier fan deltas, and B) as an overall mantle on the steep-sided lake floor. The fine-grained sediment was mostly deposited during the existence of the lowest (260m) shoreline as illustrated here.

Fig.13-3. Locations of the 90 sections (logs) cut into sediment of the Glen Roy lakes. Each sediment log is documented in Appendix 4.



GLEN ROY: SEDIMENT LOG LOCATIONS

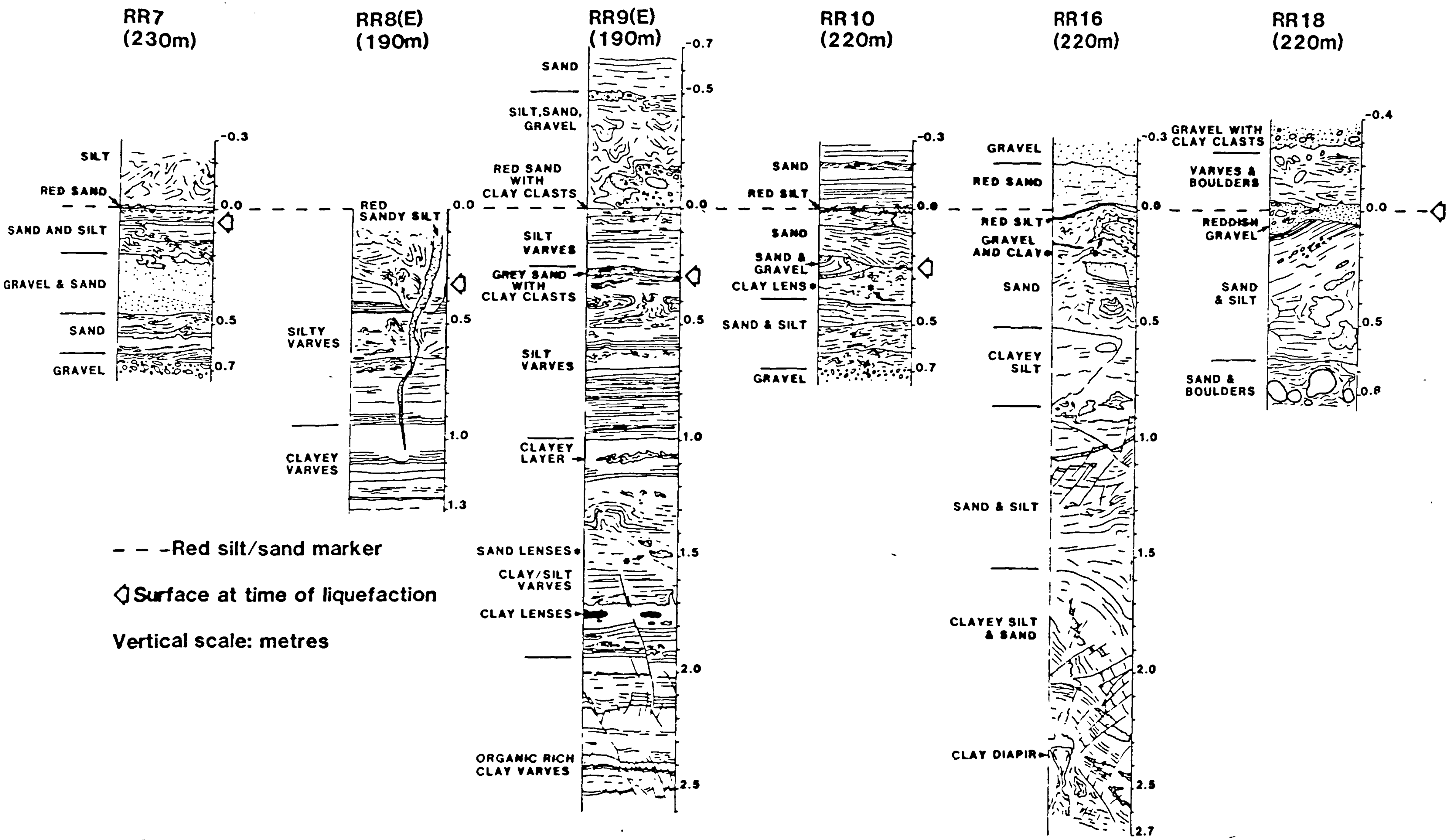


Fig.13-4. Detail of 6 key sediment sections in Glen Roy. The elevation of each section is given in brackets (all below the 260m shoreline). Each log section has been constructed relative to the red silt/sand marker (dotted line). The surface at the time of the first (liquefaction) event is indicated by broad arrows.

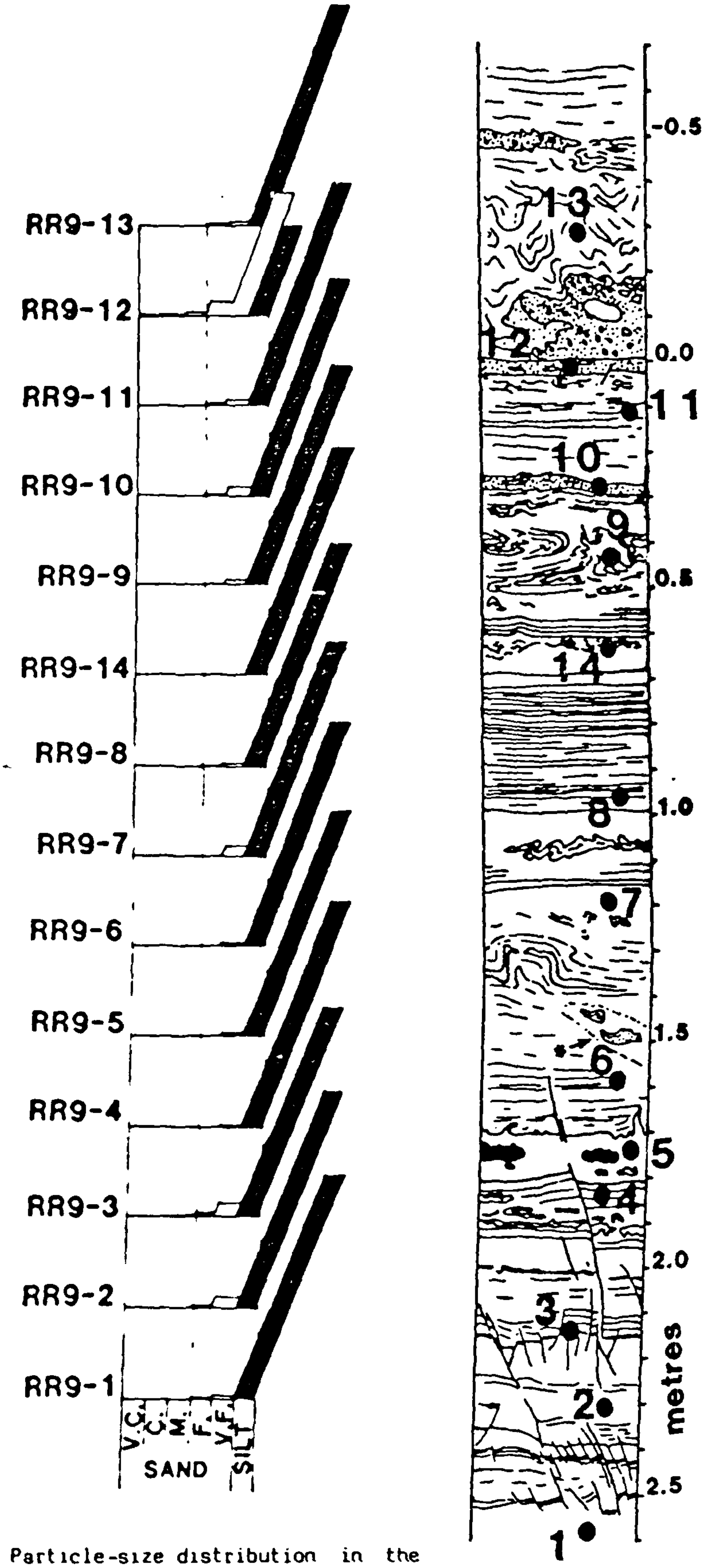


Fig.13-5. Particle-size distribution in the Glen Roy, RR9(E) section.

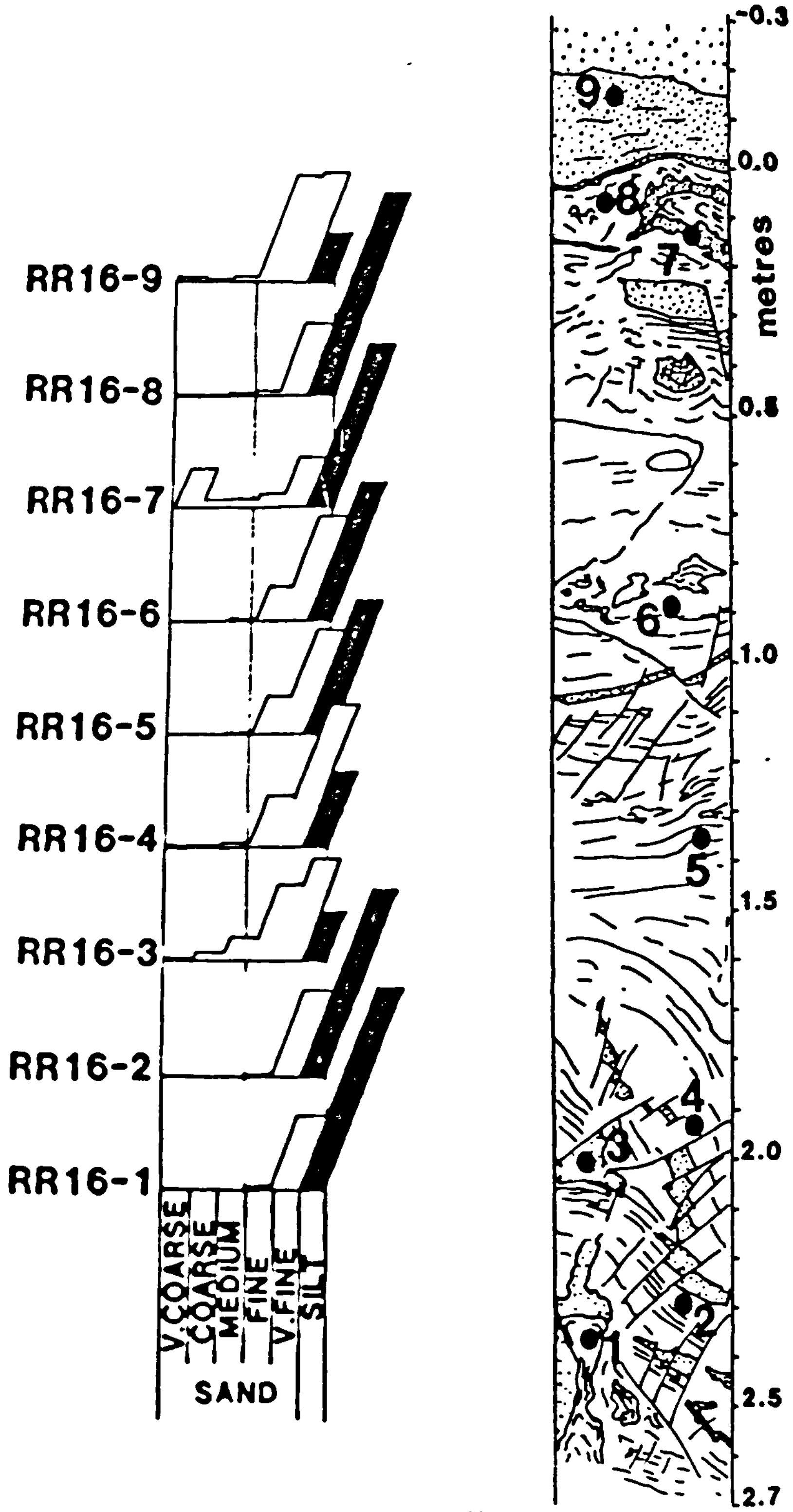


Fig.13-6. Particle-size distribution in the Glen Roy, RR16 section.

Fig.13-7. Line drawing of a portion of the Glen Roy, RR9 section, showing a 'fault-grading' stratigraphy.

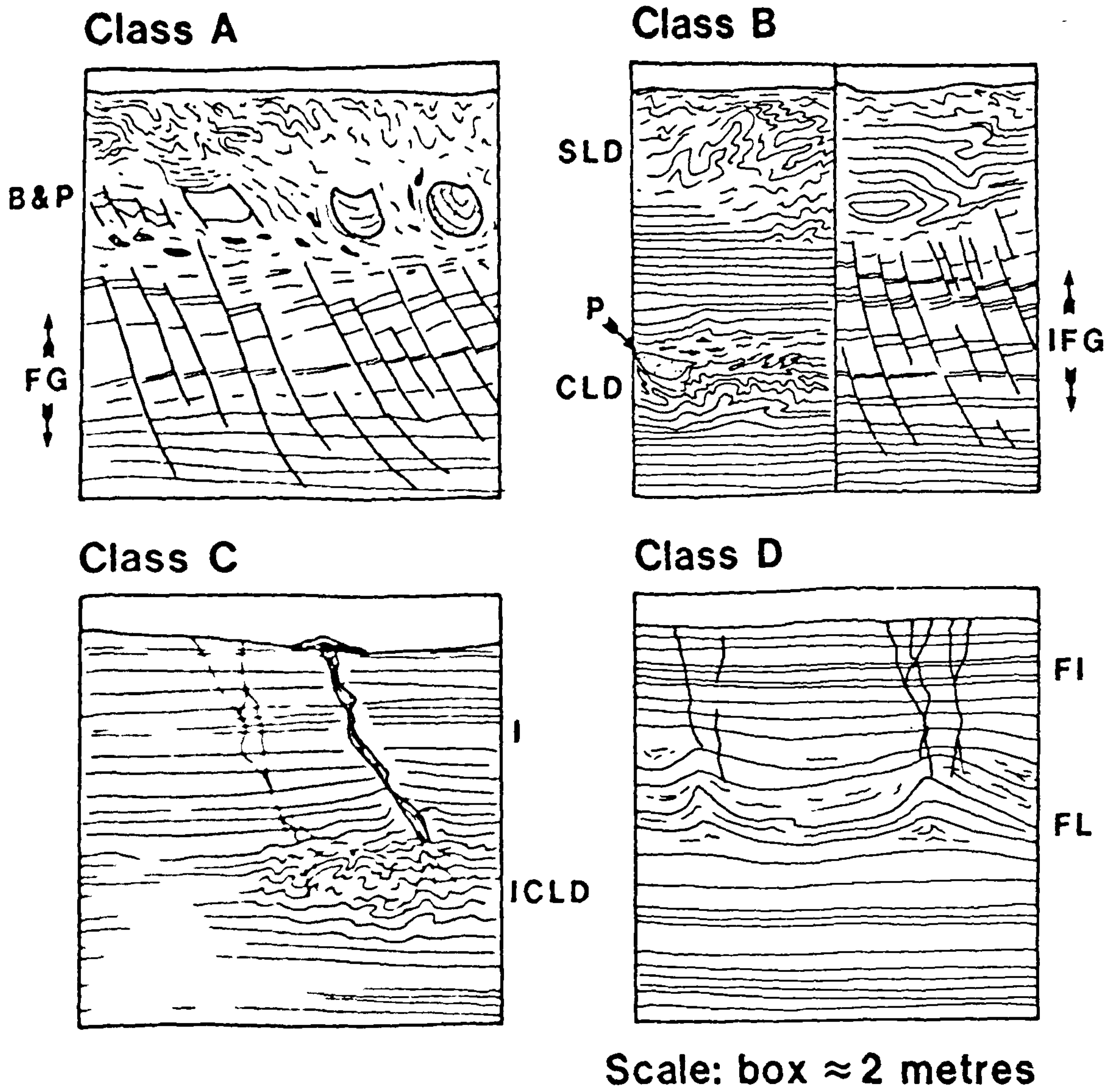
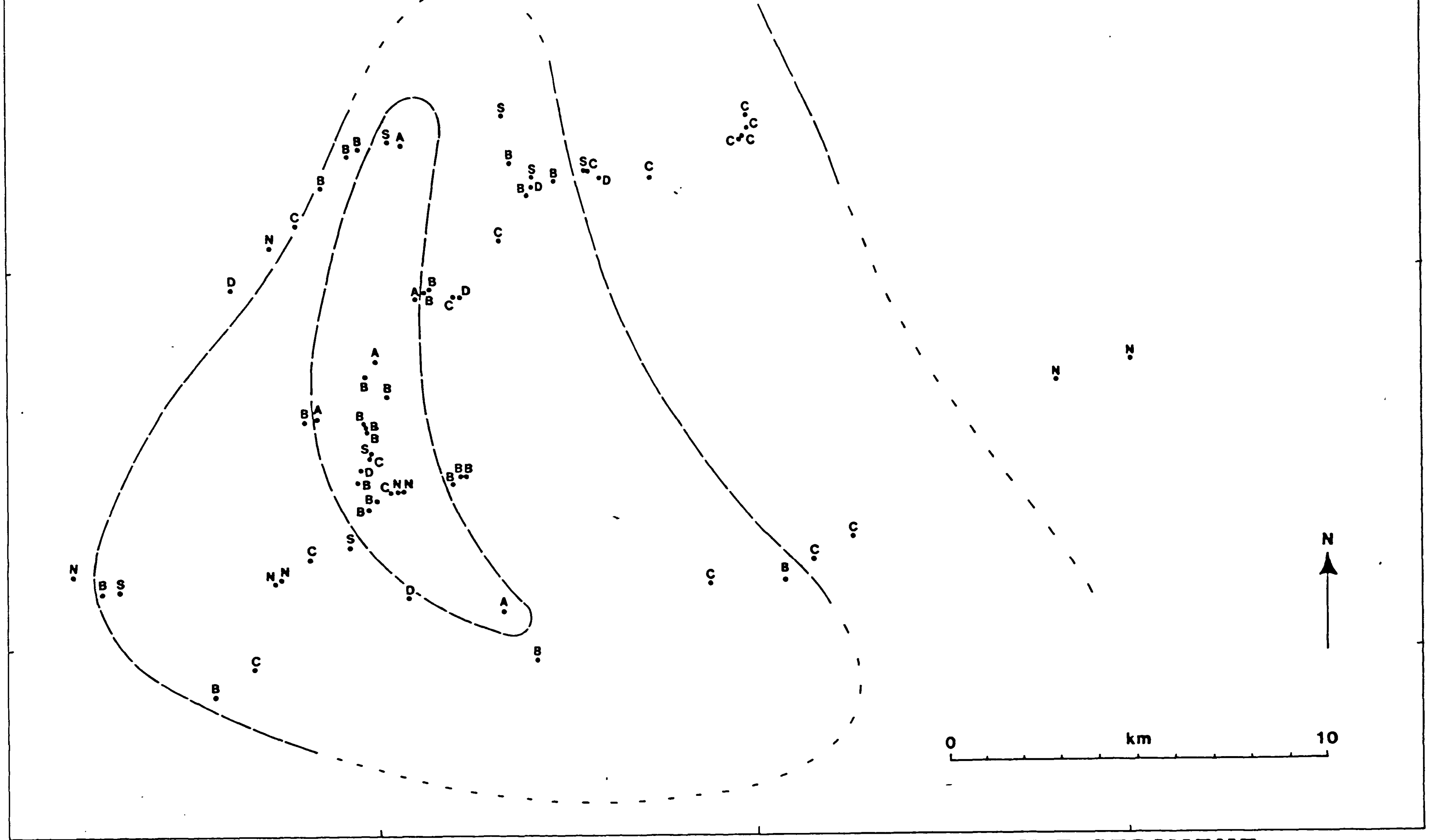


Fig.13-8. Schematic illustration of the classification of deformation styles seen in the Glen Roy area (for text see section 13.5.1 .

Fig.13-9. Classification of the Glen Roy sediment logs according to style of deformation (as defined in section 13.5.1). Contours mark the limit of A-type structures, B-type structures and C&D-type structures. (For discussion see section 13.5.2).



GLEN ROY: DEFORMATION STYLE IN LACUSTRINE SEDIMENT

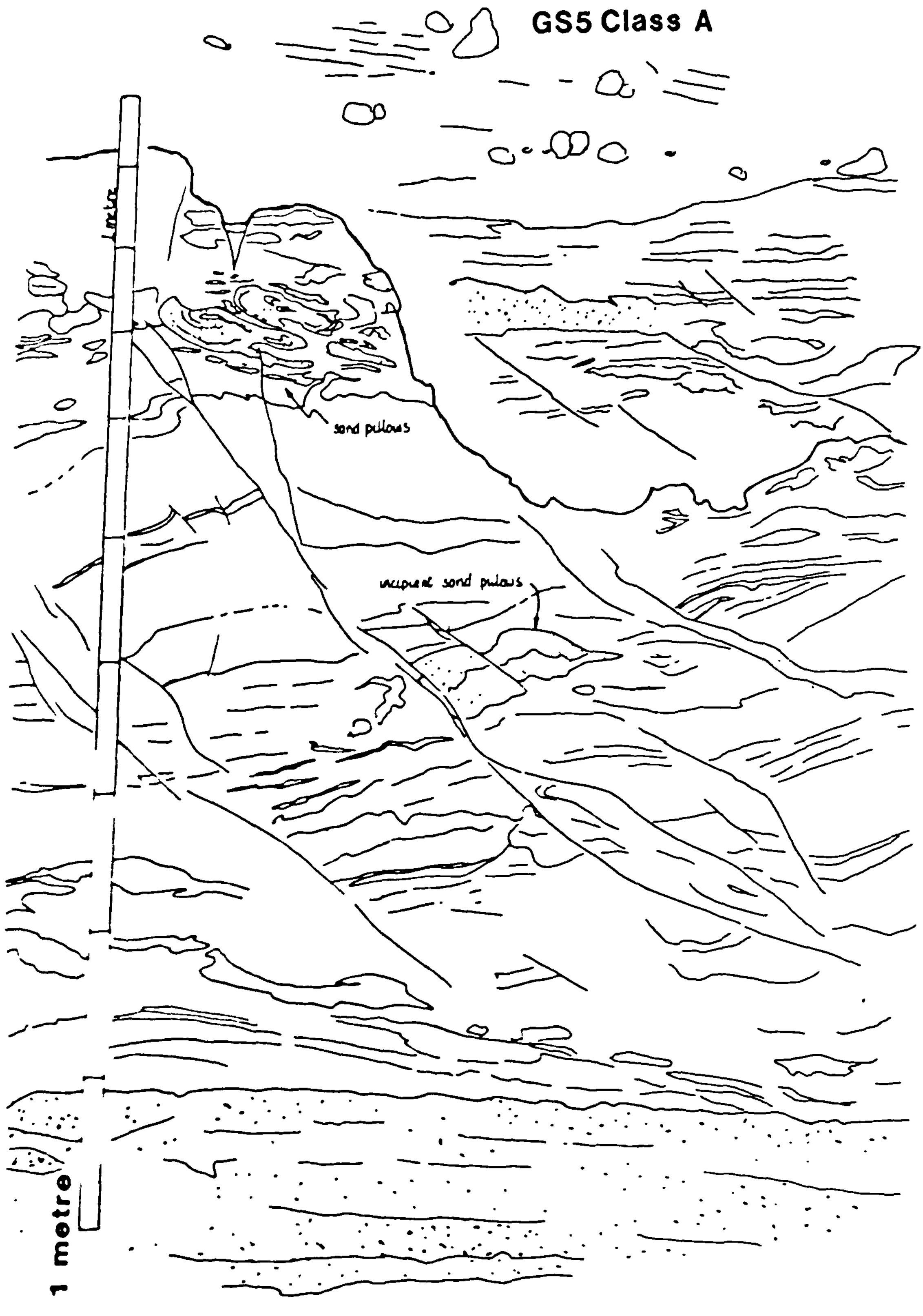


Fig.13-10. Field sketch of section GS5, showing a completely faulted lacustrine sediment sequence, grading up into pillowed sediment, and later eroded and infilled with sandier sediment. Class A.

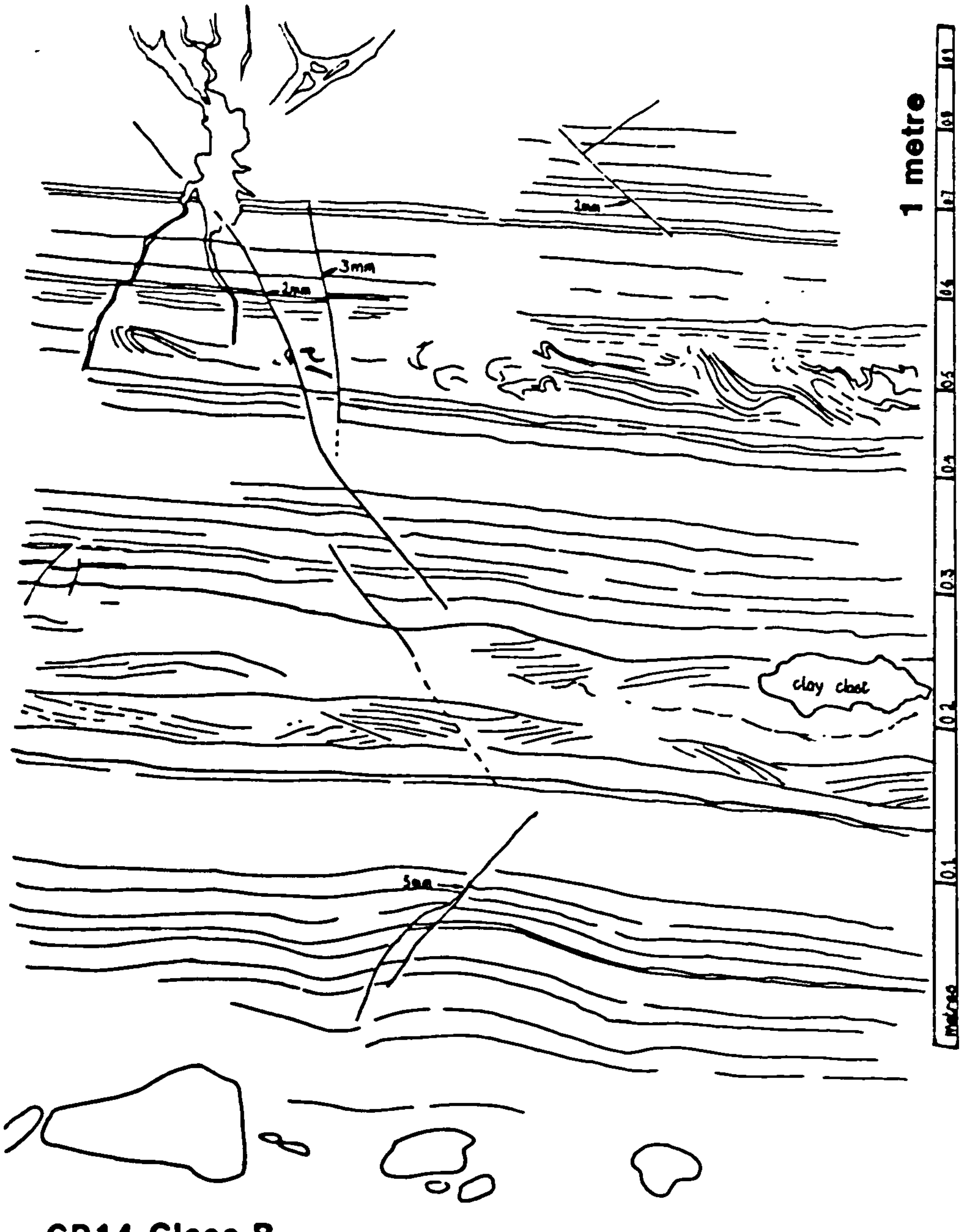


Fig.13-11. Field sketch of section GR14, showing confined layer deformation, faulting and fissuring. Class B.

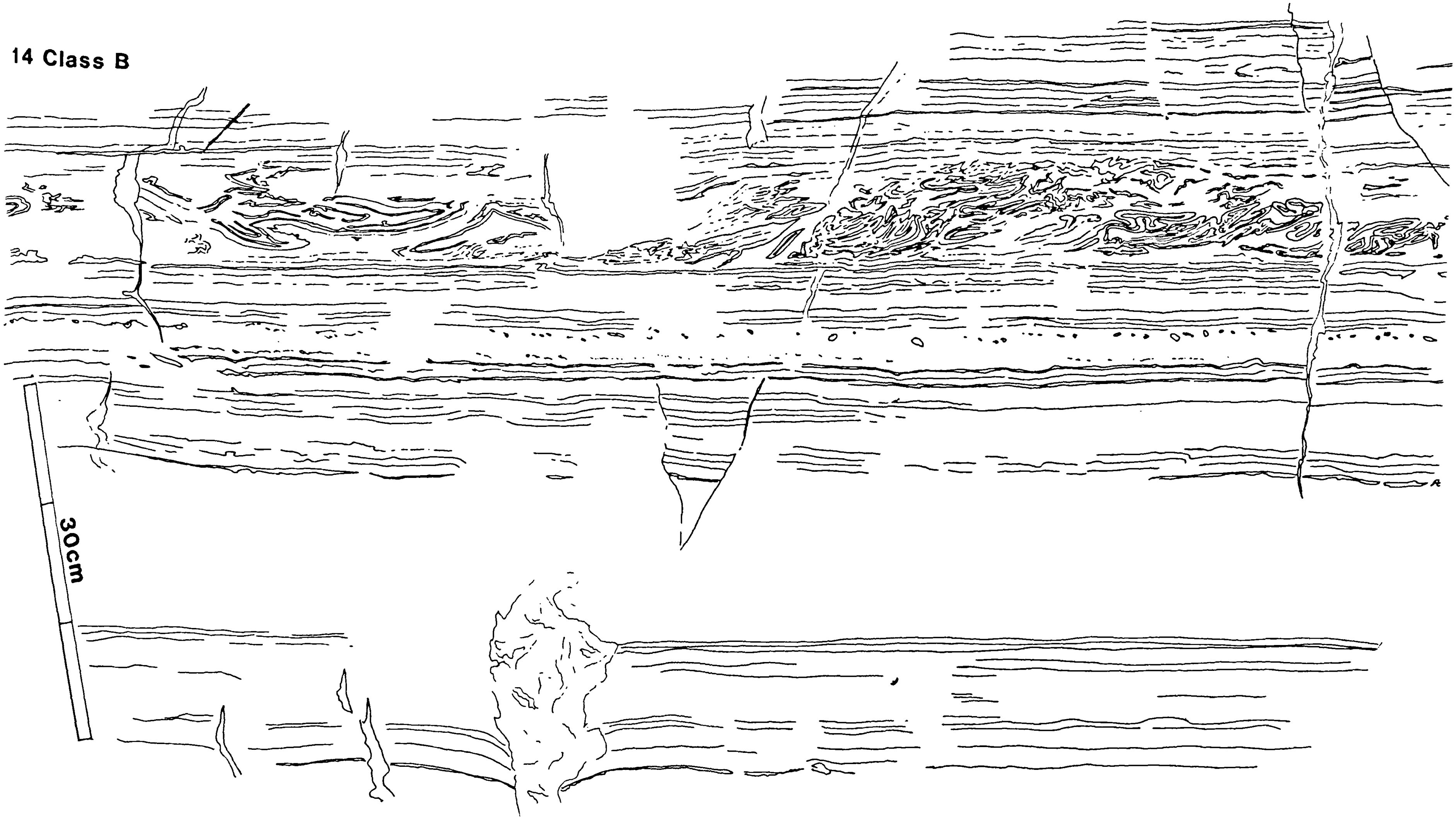


Fig.13-12. Field sketch showing detail of section GR14 at the confined deformation layer. No top-truncation surface is seen; the deformation is interpreted as having occurred at depth within the varve sequence. Class B.

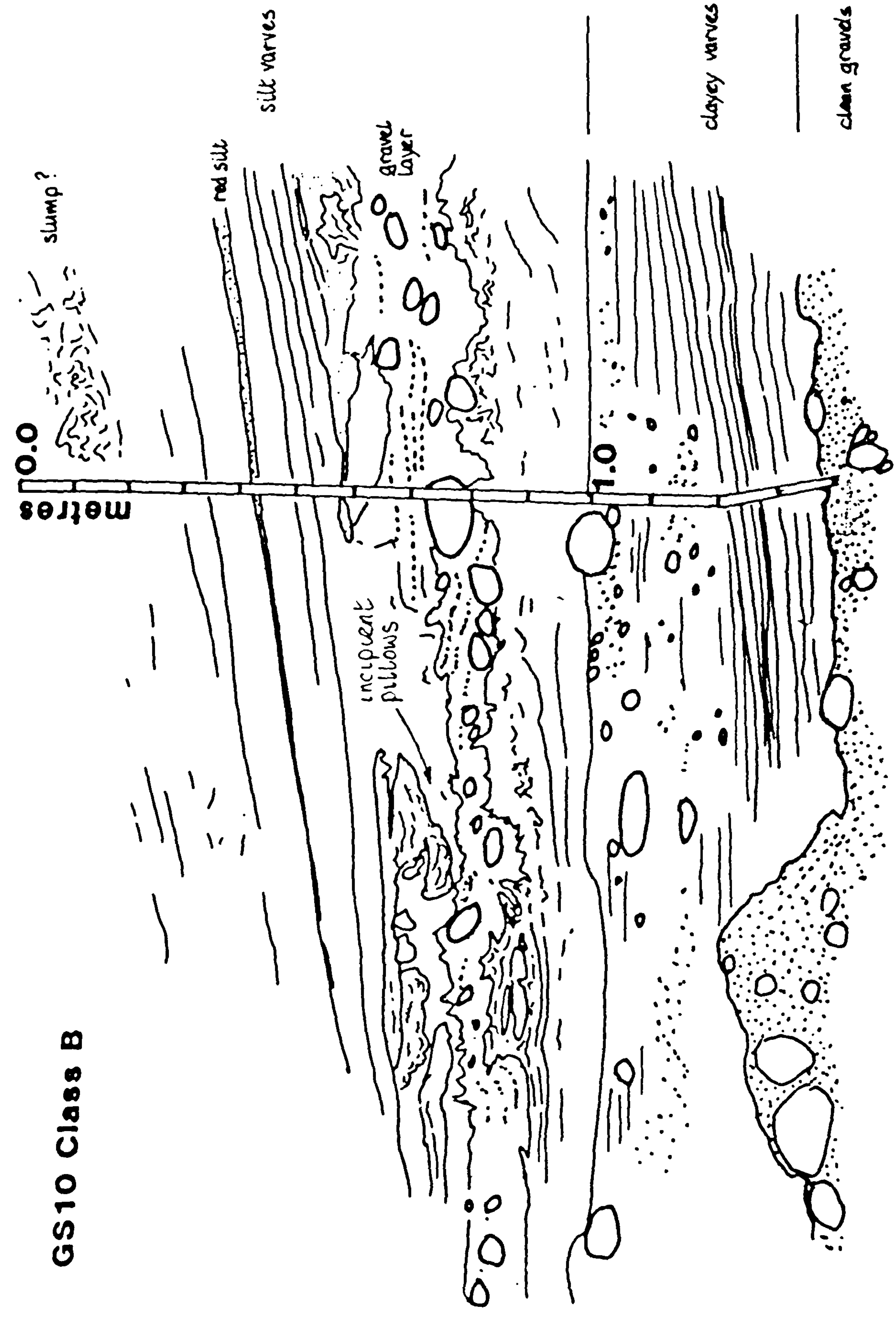


Fig.13-13. Field sketch of section GS10, showing incipient pillow and loading structures in a sub-surface layer. Class B.

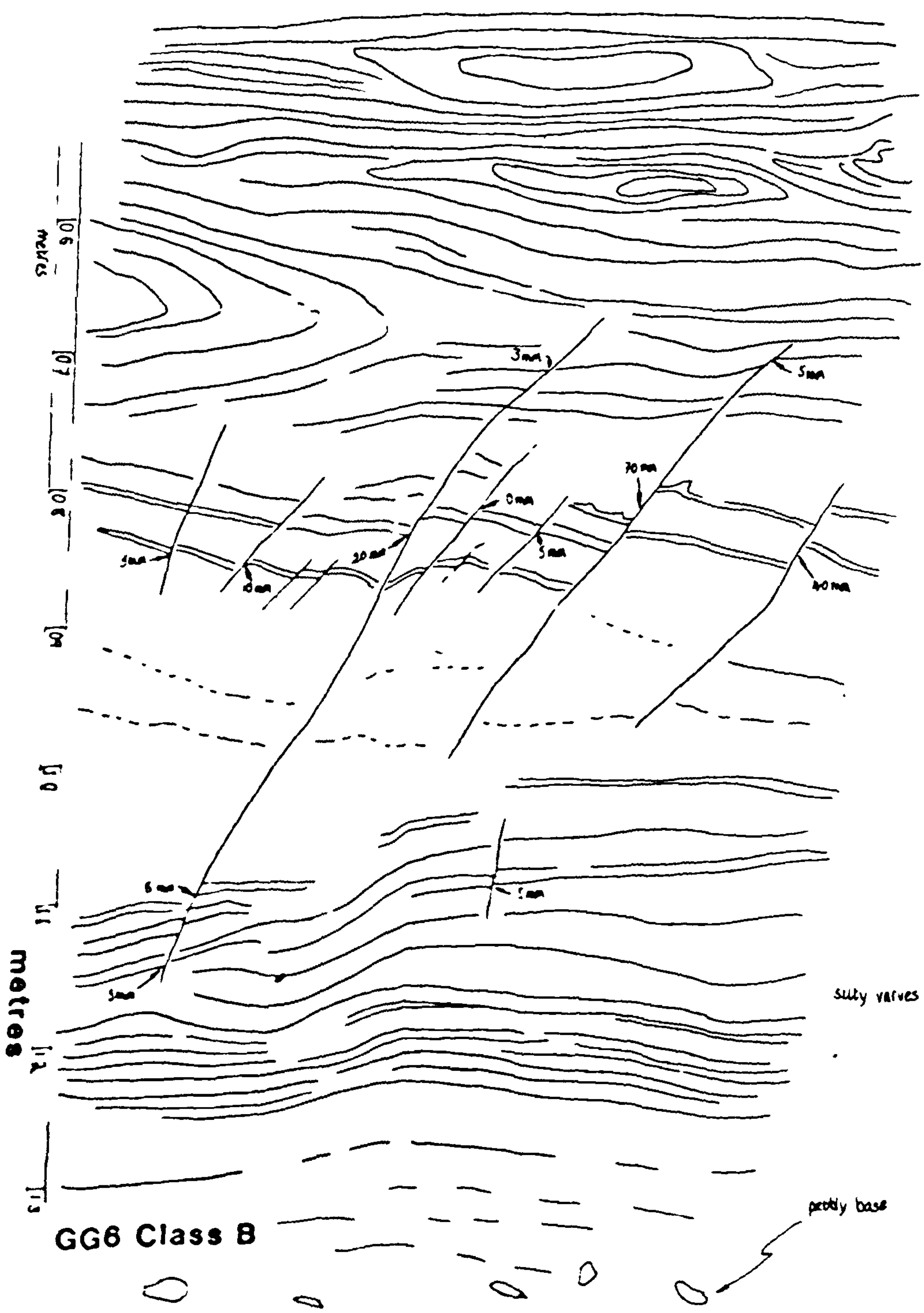


Fig.13-14. Field sketch of section GG6, showing faulted varves grading up into plastically deformed varves. Note that the throws of the faults increase upwards and then decrease into the plastically deformed region. Class B.

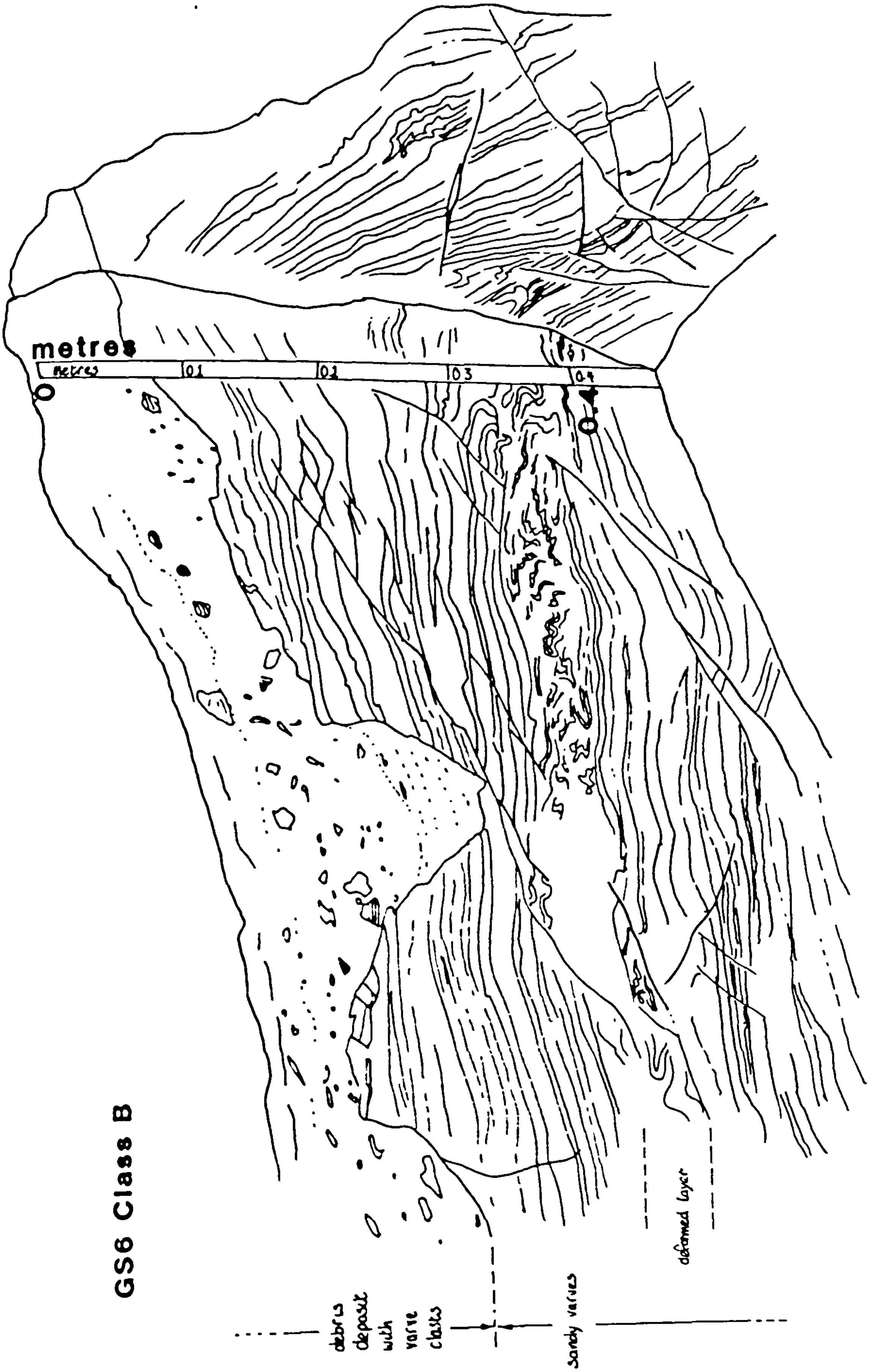


Fig.13-15. Field sketch of section GS6, showing faulted varves with a confined deformation laver, later eroded, infilled by undisturbed sediment, and than overlain by a debris deposit. Class B.

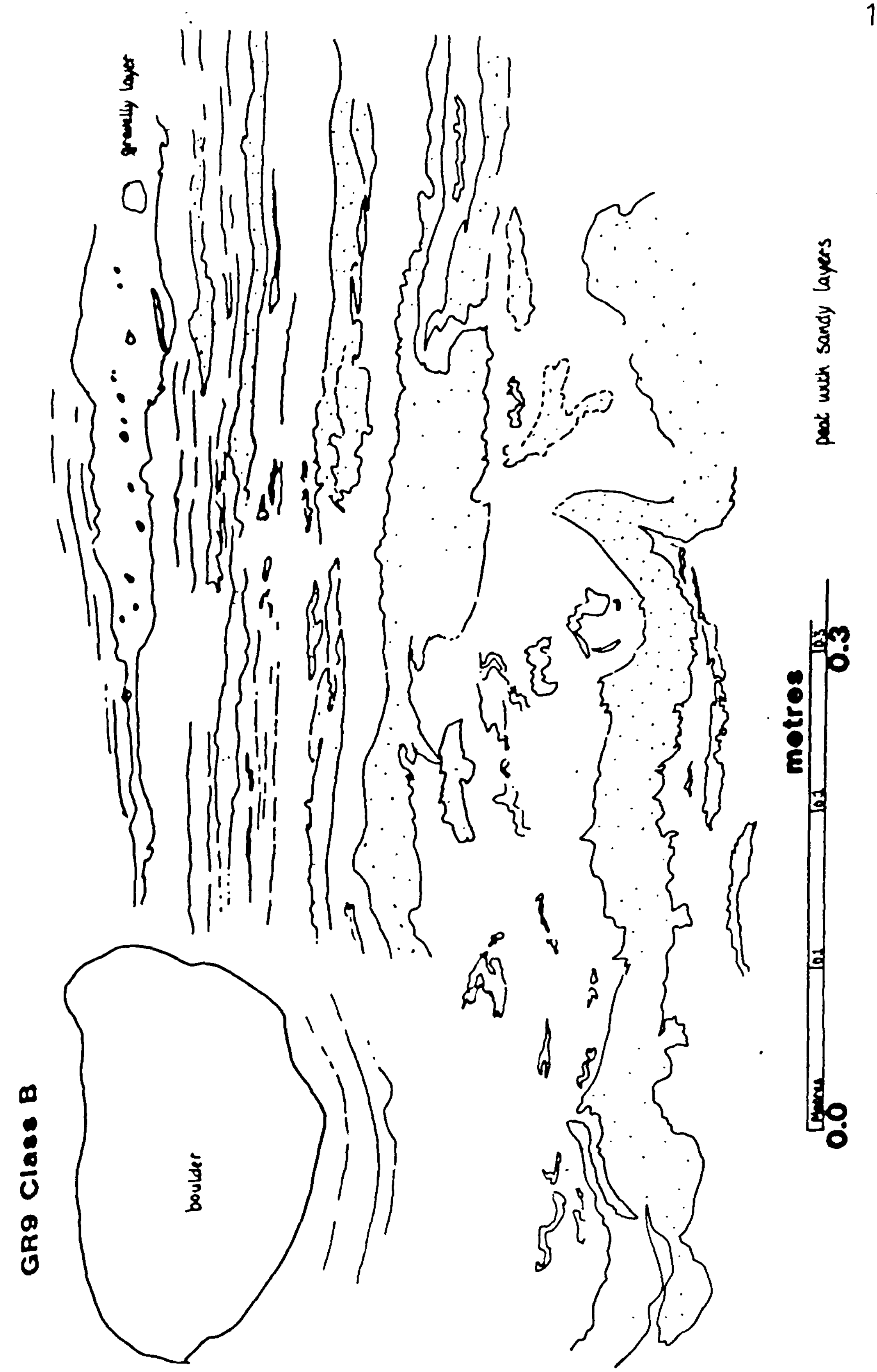


Fig.13-16. Field sketch of section GR9, showing flaming and loading of sandy layers into peaty layers. (The presence of 'peaty' material in this section is thought to result from its shoreline location, at an elevation of 260m).

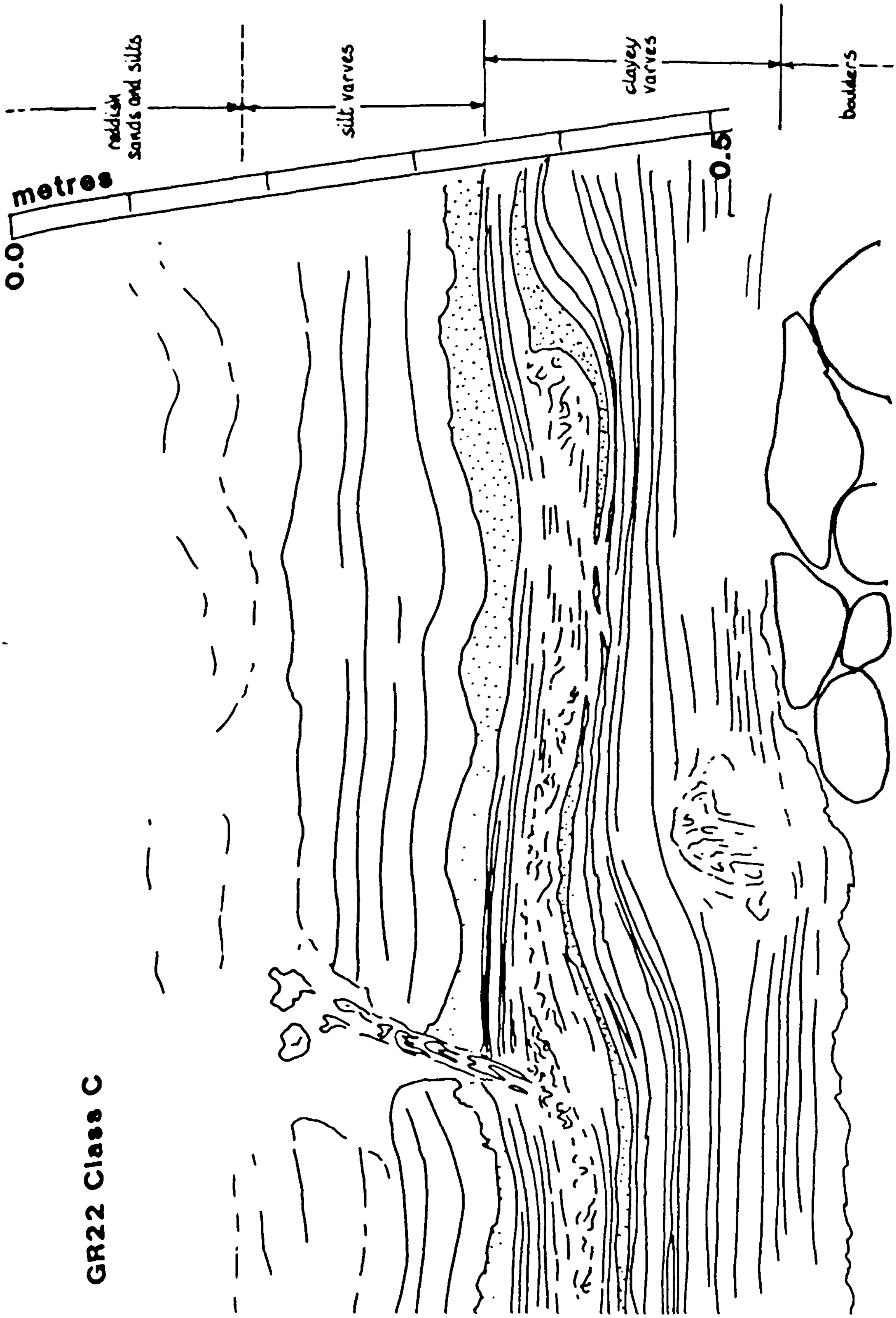


Fig.13-17. Field sketch of section GR22, Showing two incipient (not laterally continuous confined deformation layers. The upper deformed layer has injected material upwards through undeformed silts above. Class C.

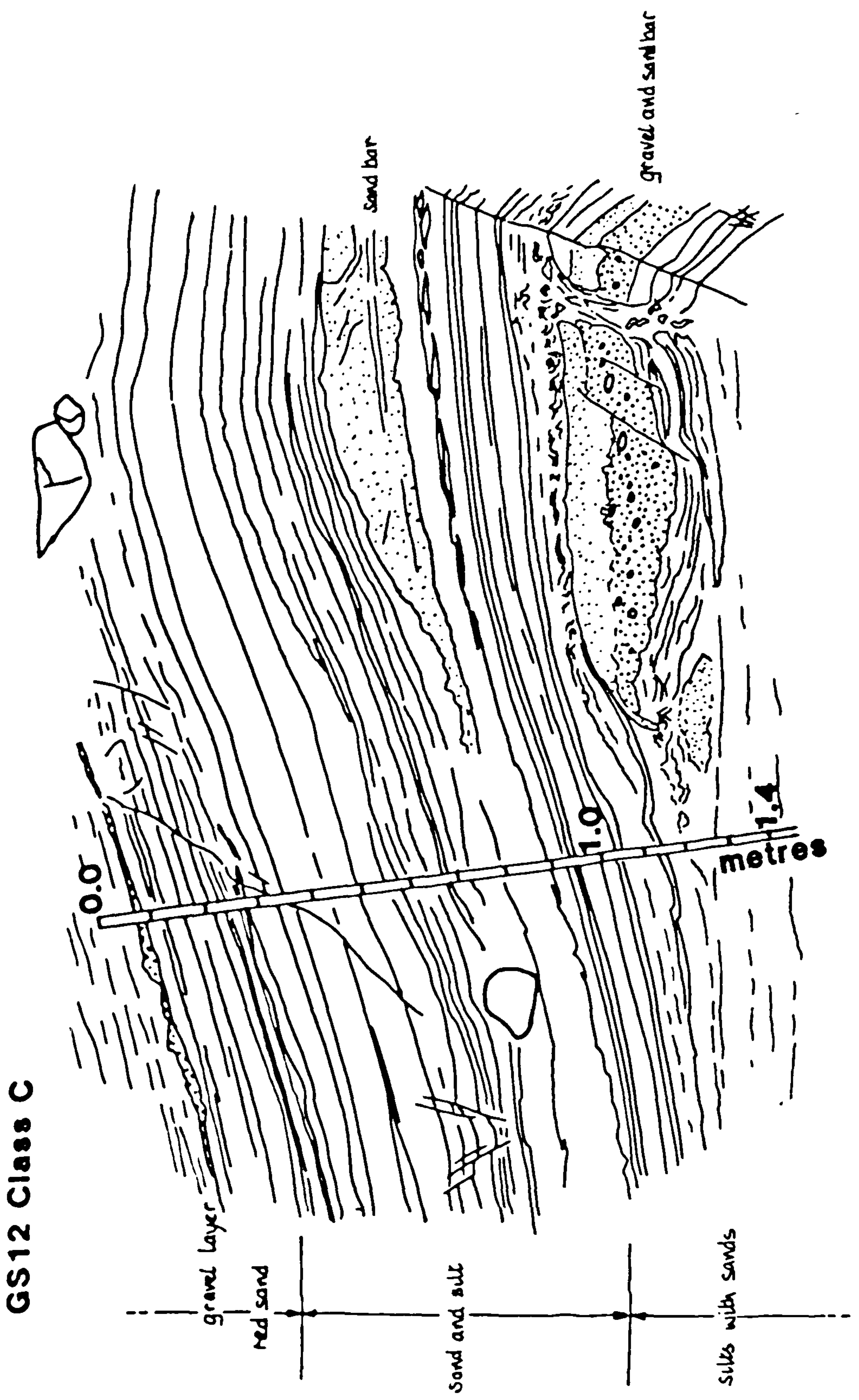


Fig.13-18. Field sketch of section GS12, showing incipient confined layer deformation beneath a gravel lens, which has been punctured by an injection structure. Normal faulting is seen in the upper portion of the section. Class C.

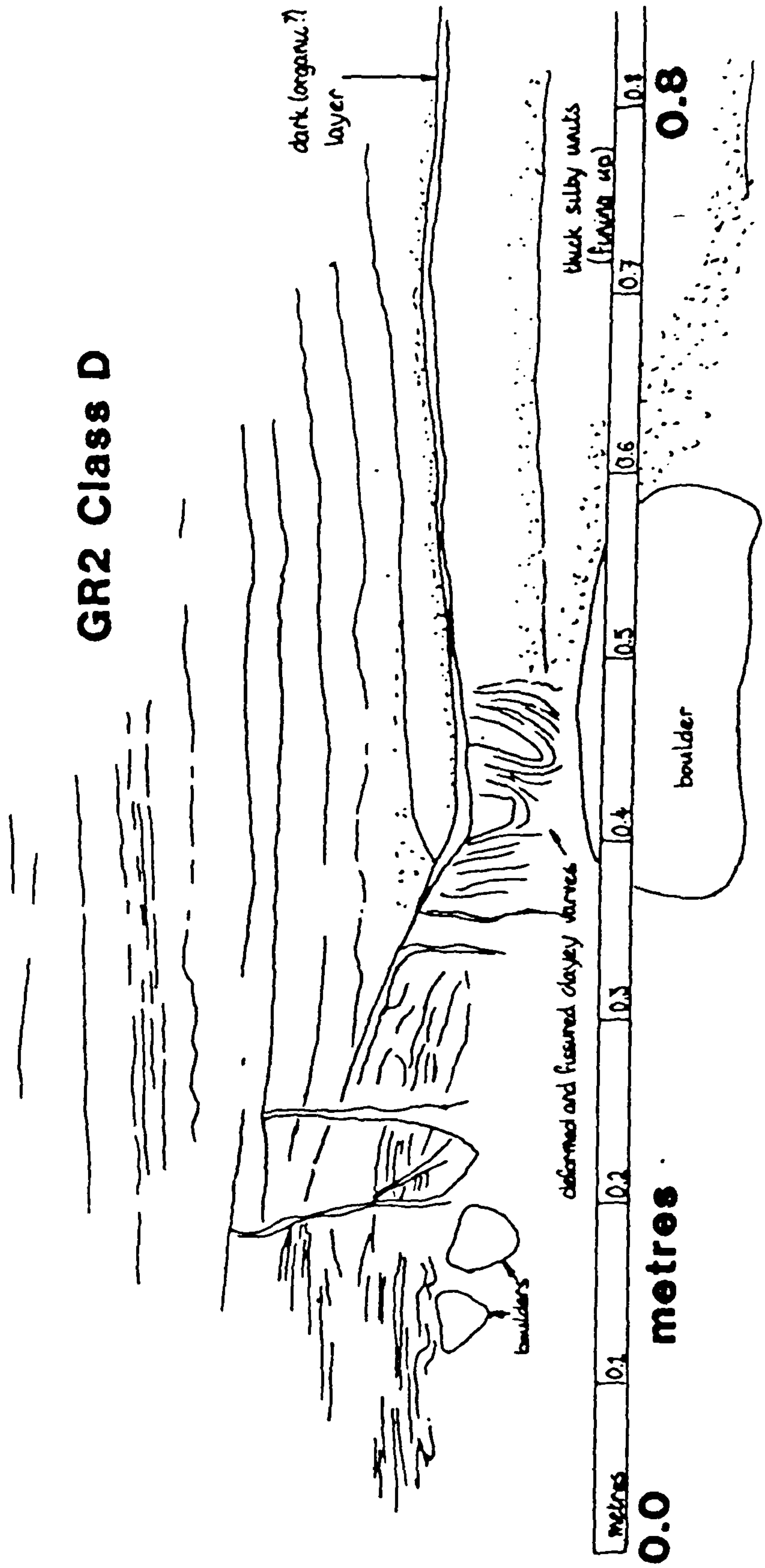


Fig.13-19. Field sketch of section GR2, showing fissuring in clay varves. Class D.

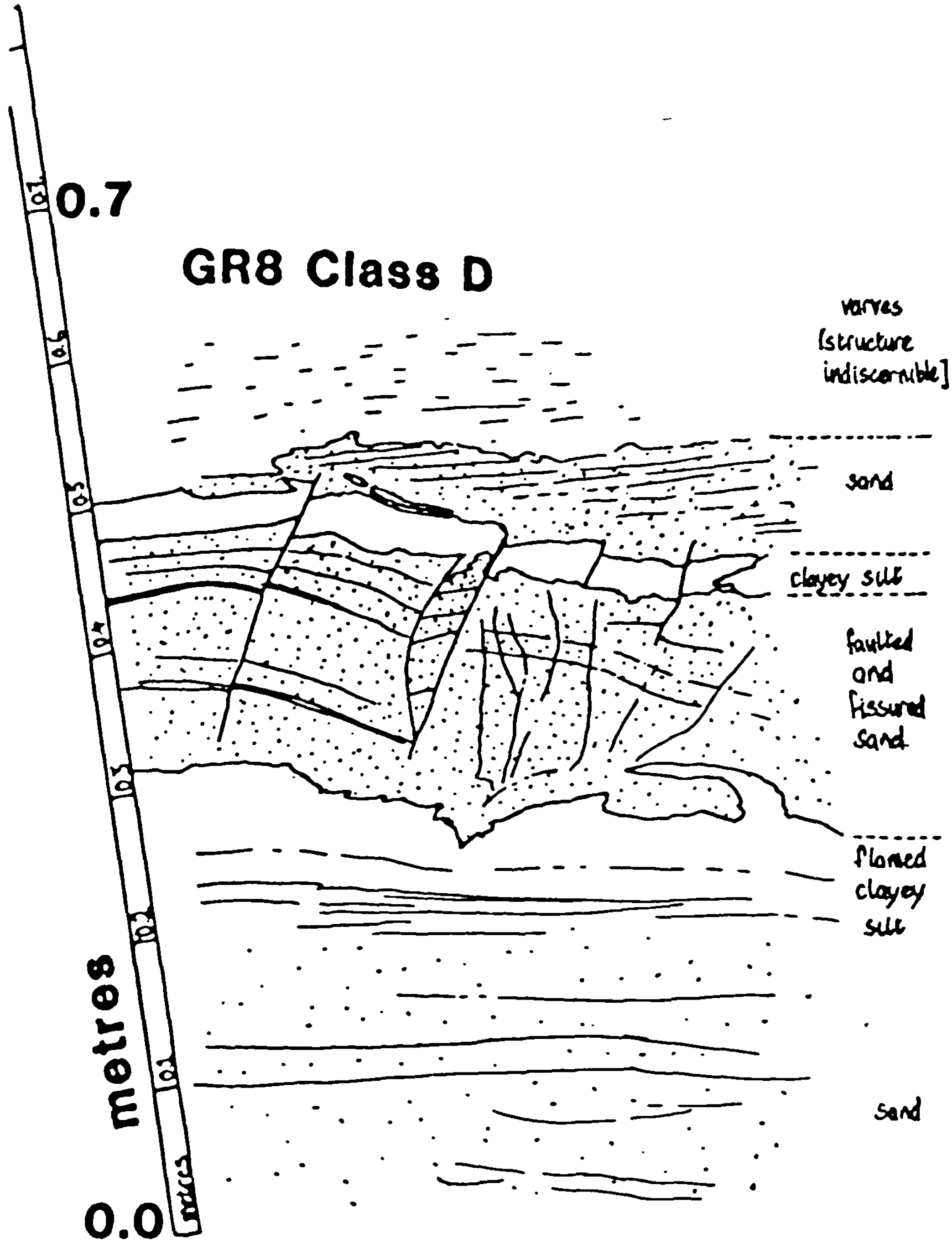
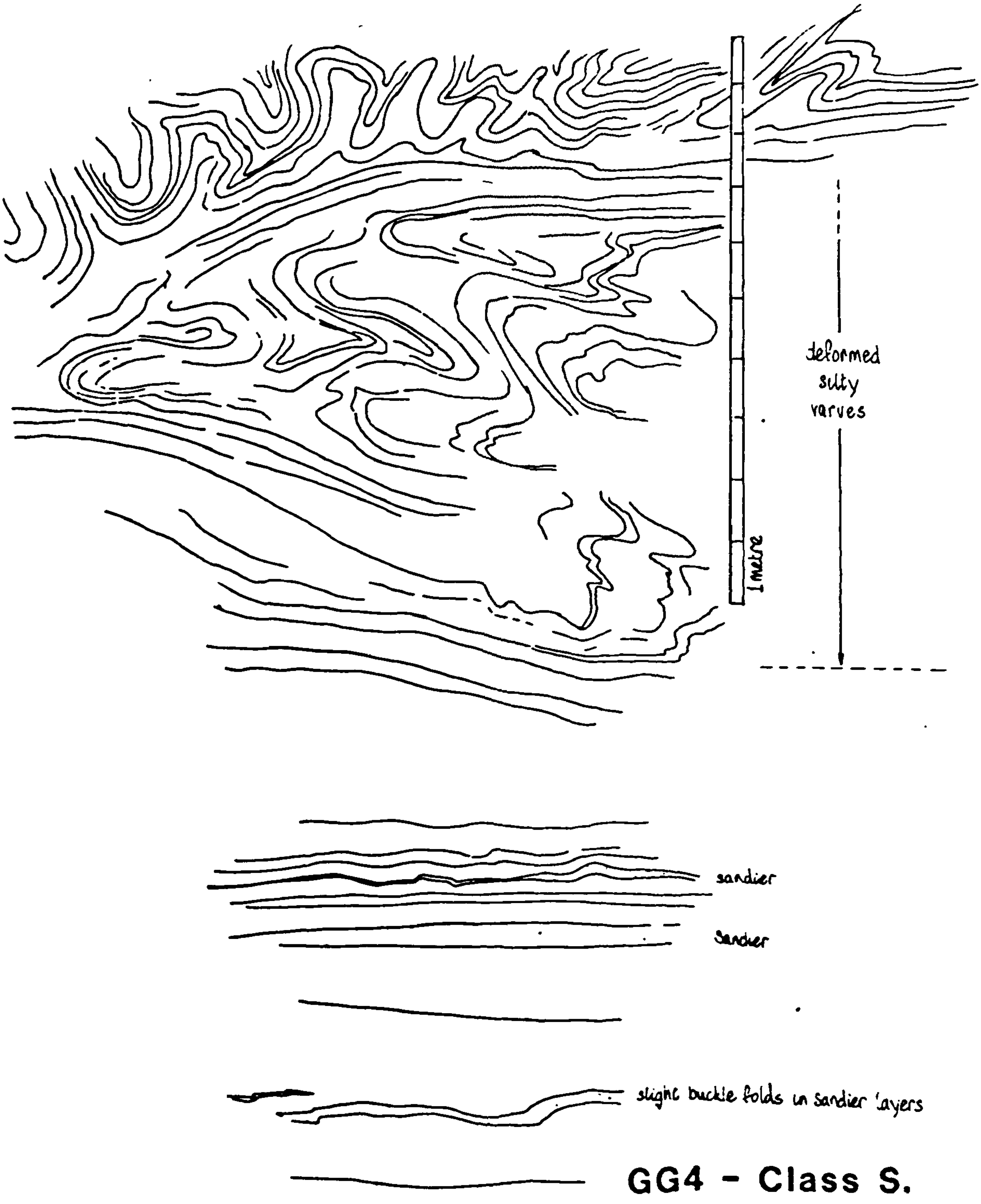


Fig.13-20. Field sketch of section GR8, showing a faulted and fissured sand layer in silt. Class D.



GG4 - Class S.

Fig.13-21. Field sketch of section GG4, showing plastic, coherent slumping of the upper portion of the sequence. Class S.

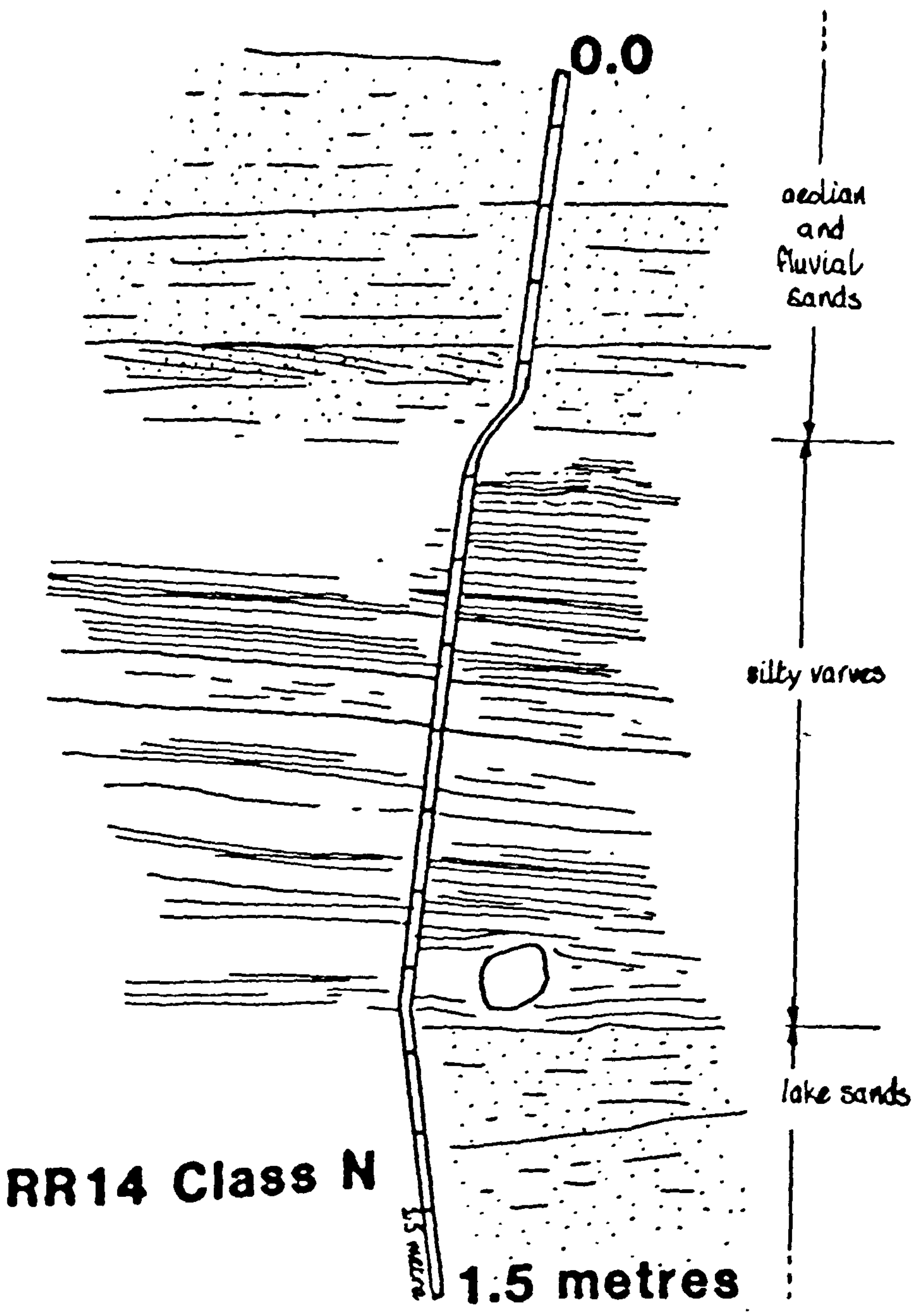


Fig.13-22. Field sketch of section RR14, showing undeformed varves. Class N.

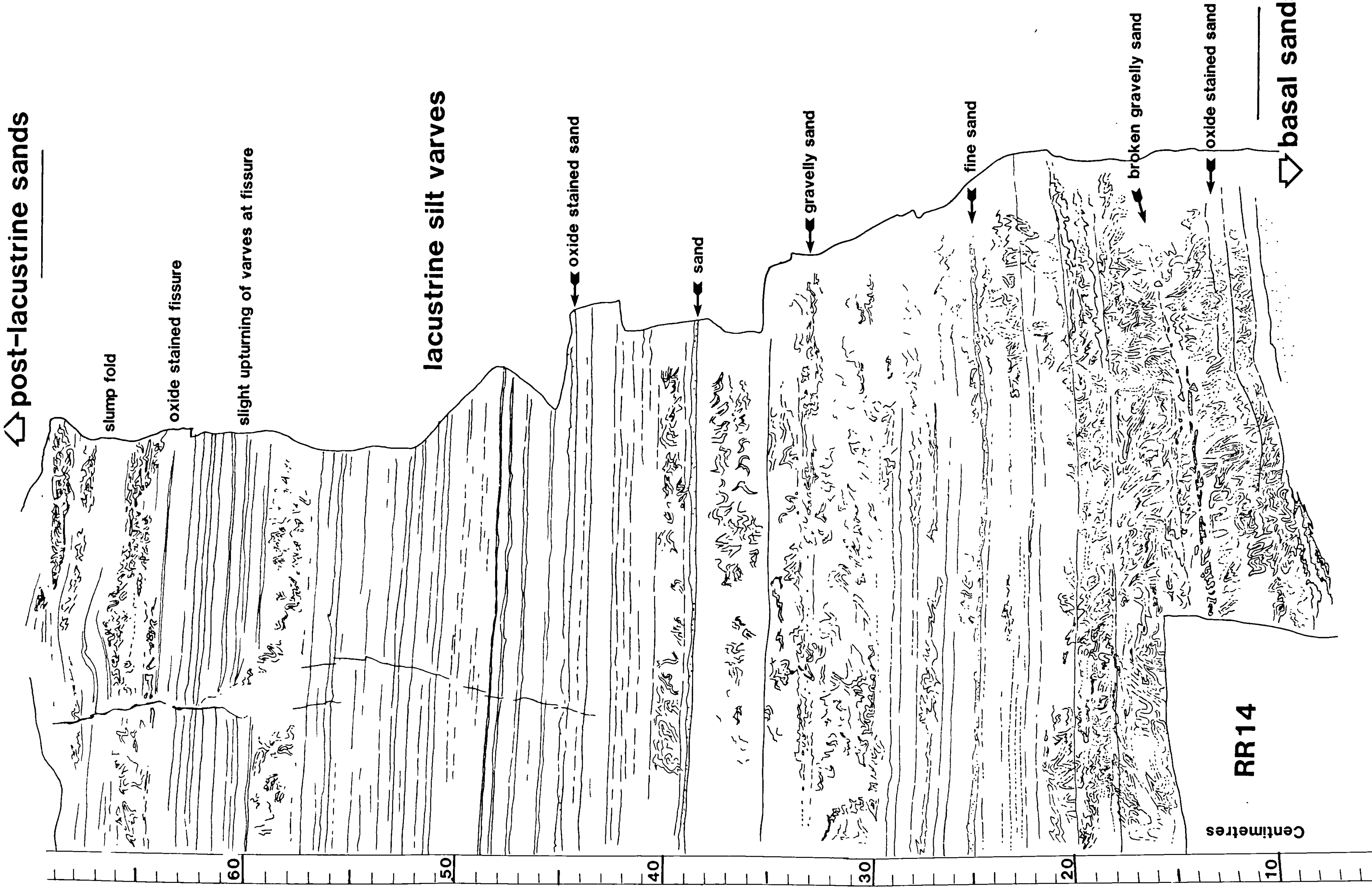


Fig.13-23. Field sketch of section RR14, showing detail of the 'undeformed' varves, which on close inspection reveal intricate deformation, not disturbing the overall layering and interpreted as involution structures.

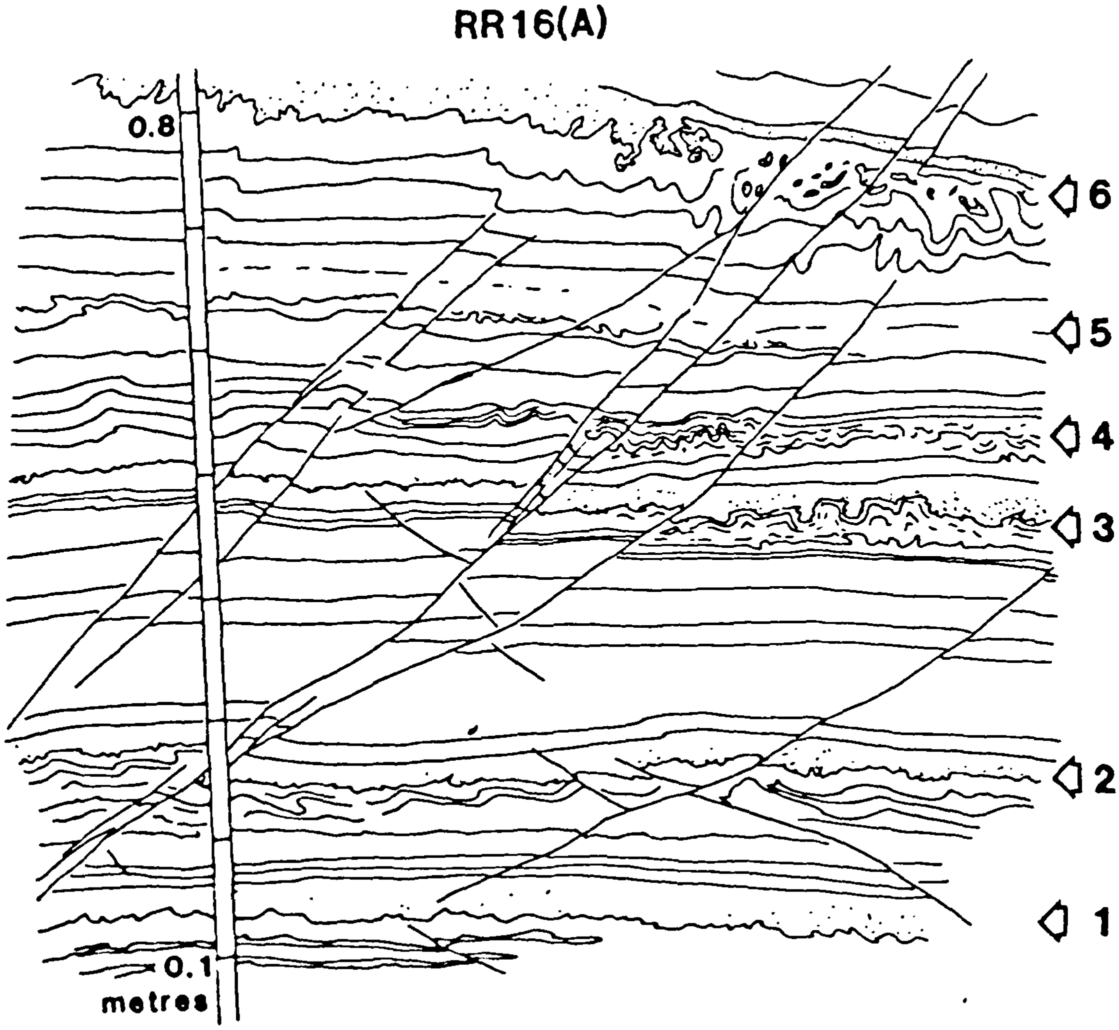
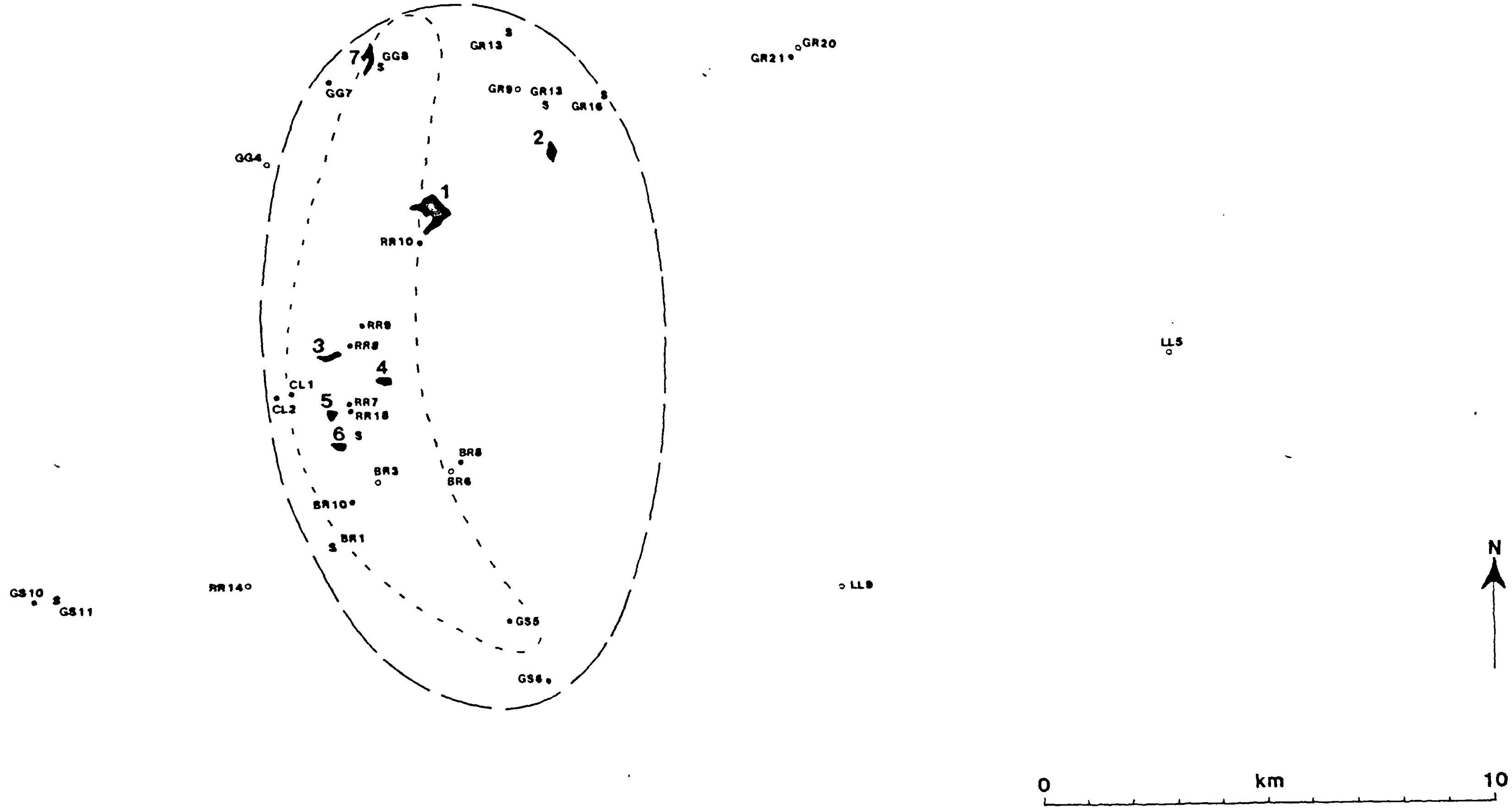


Fig.13-24. Field sketch of section RR16(A), showing involution layers and reverse faulting in outwash sands.

Fig.13-25. Locations of sites in the Glen Roy area which show a second deformation event (solid circles). Sites with complete lacustrine stratigraphies and definitely not showing a second event are indicated by open circles. Sites which have slumped material only are indicated by 'S'; landslips (numbered 1 to 7) are shown in black. The dashed line marks the limit of slumping. It coincides approximately with the central contour of the first event (pecked line). (For discussion see section 13.6).



GLEN ROY: SEDIMENT SLUMPING AND LANDSLIPS

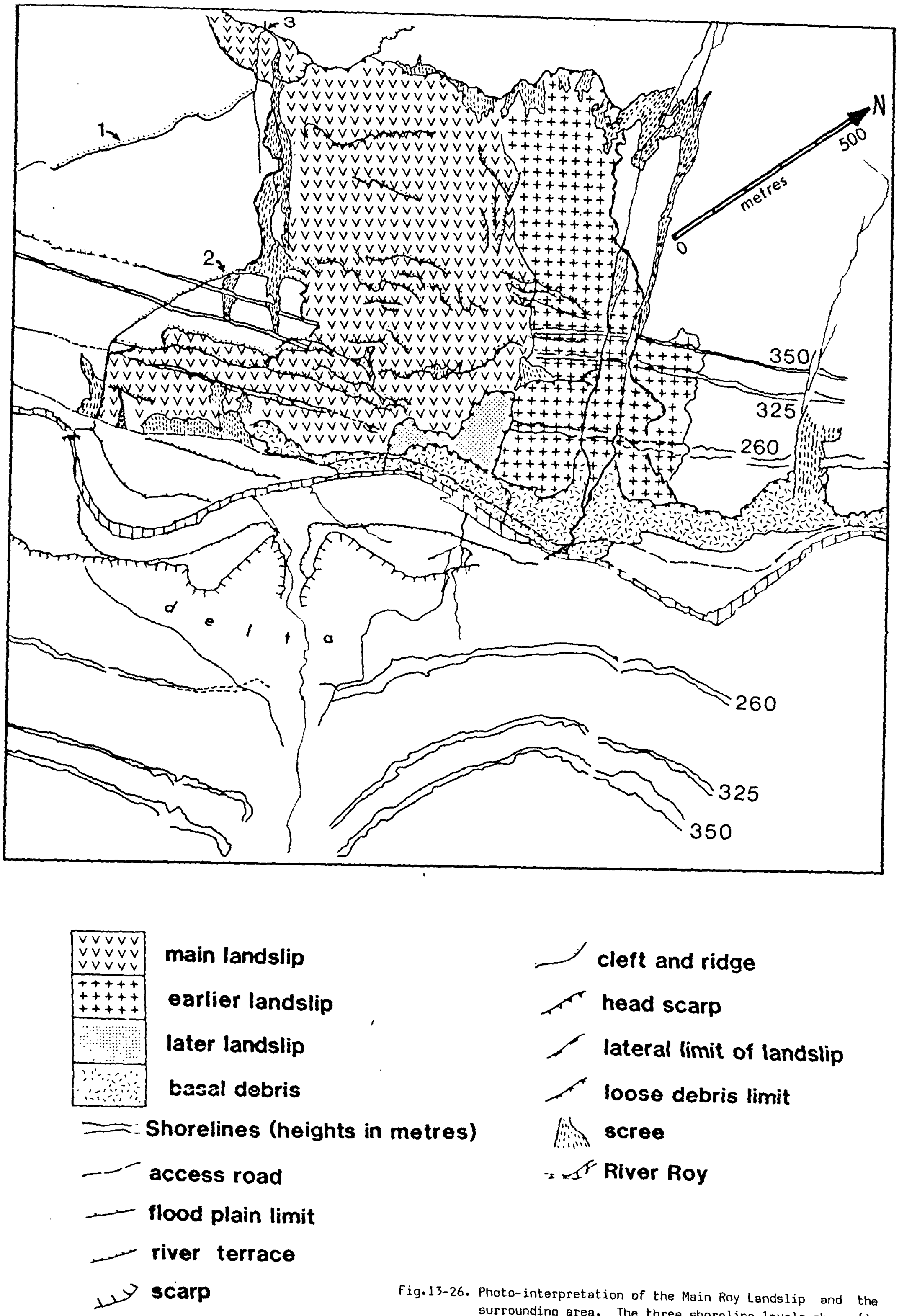


Fig.13-26. Photo-interpretation of the Main Roy Landslip and the surrounding area. The three shoreline levels shown (in metres) give an impression of the valley topography.

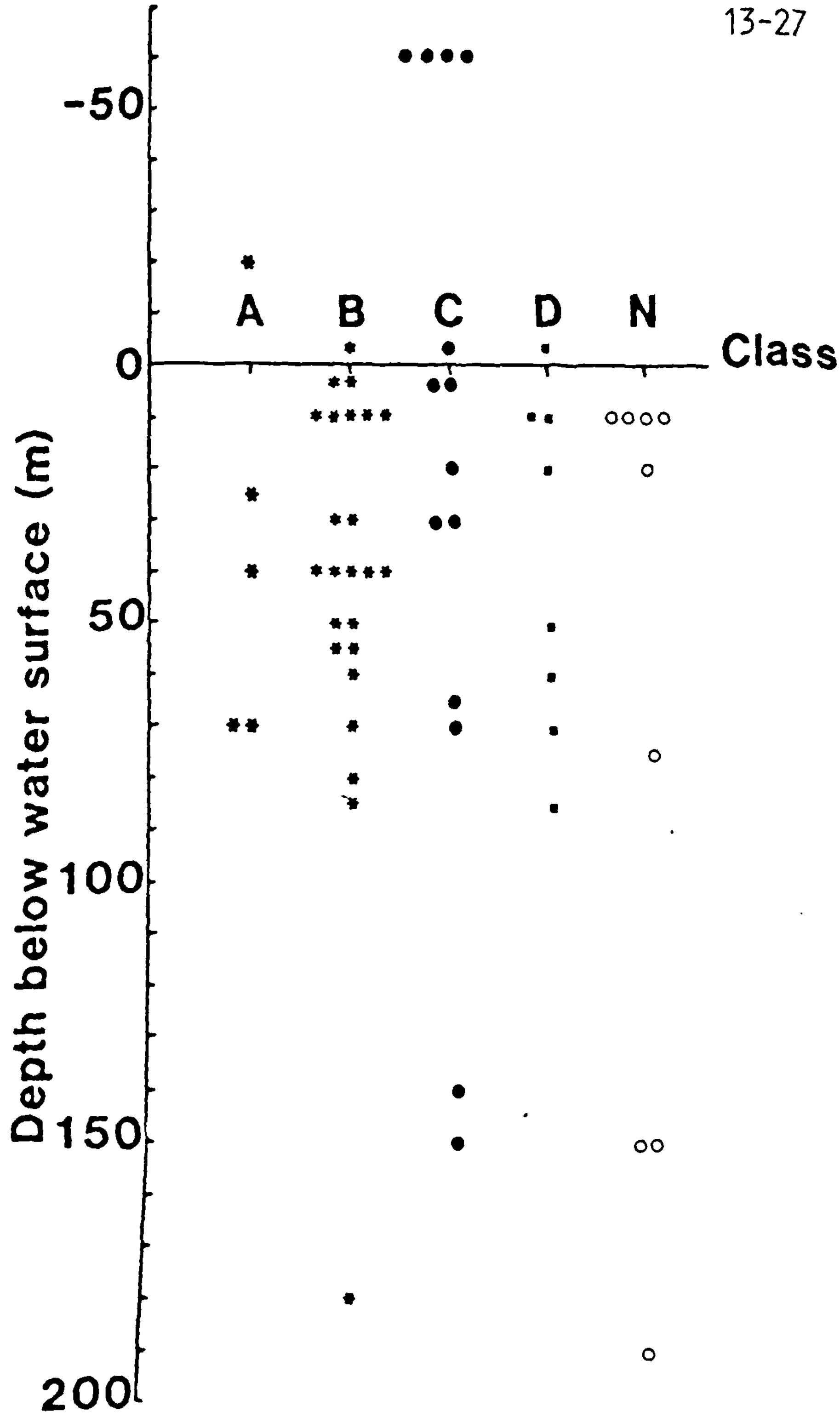


Fig.13-27. Graph of sediment-deformation class-types plotted against depth below water surface, taken as 260m for the Glen Roy and Spean sections and as 355m for the Glen Gloy sections. (For discussion see section 13.8.2. .

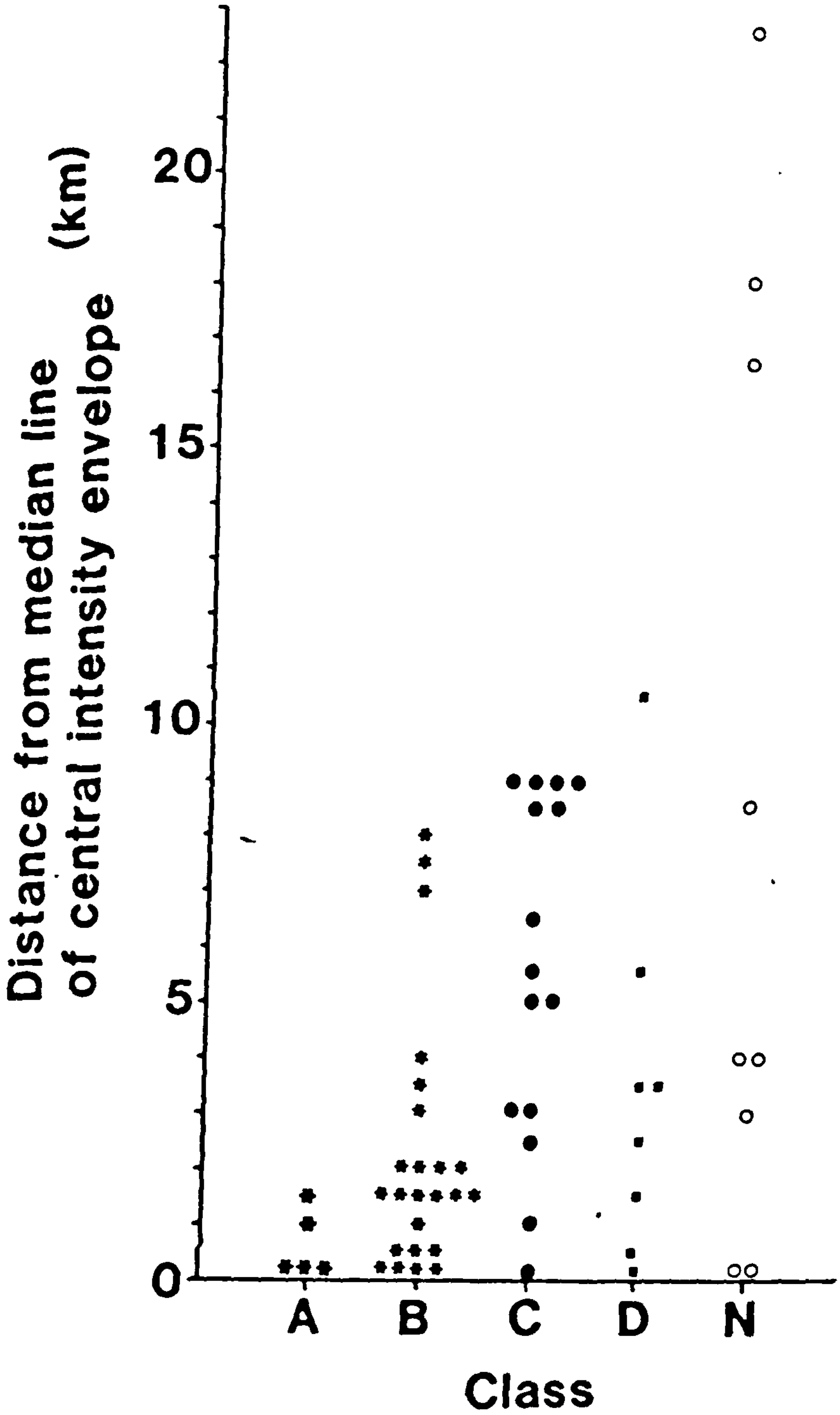


Fig.13-28. Graph of sediment-deformation class-types plotted against minimum distance from a median line, drawn by hand, through the central intensity envelope (Fig.13-9). (For discussion see section 13.8.2.).

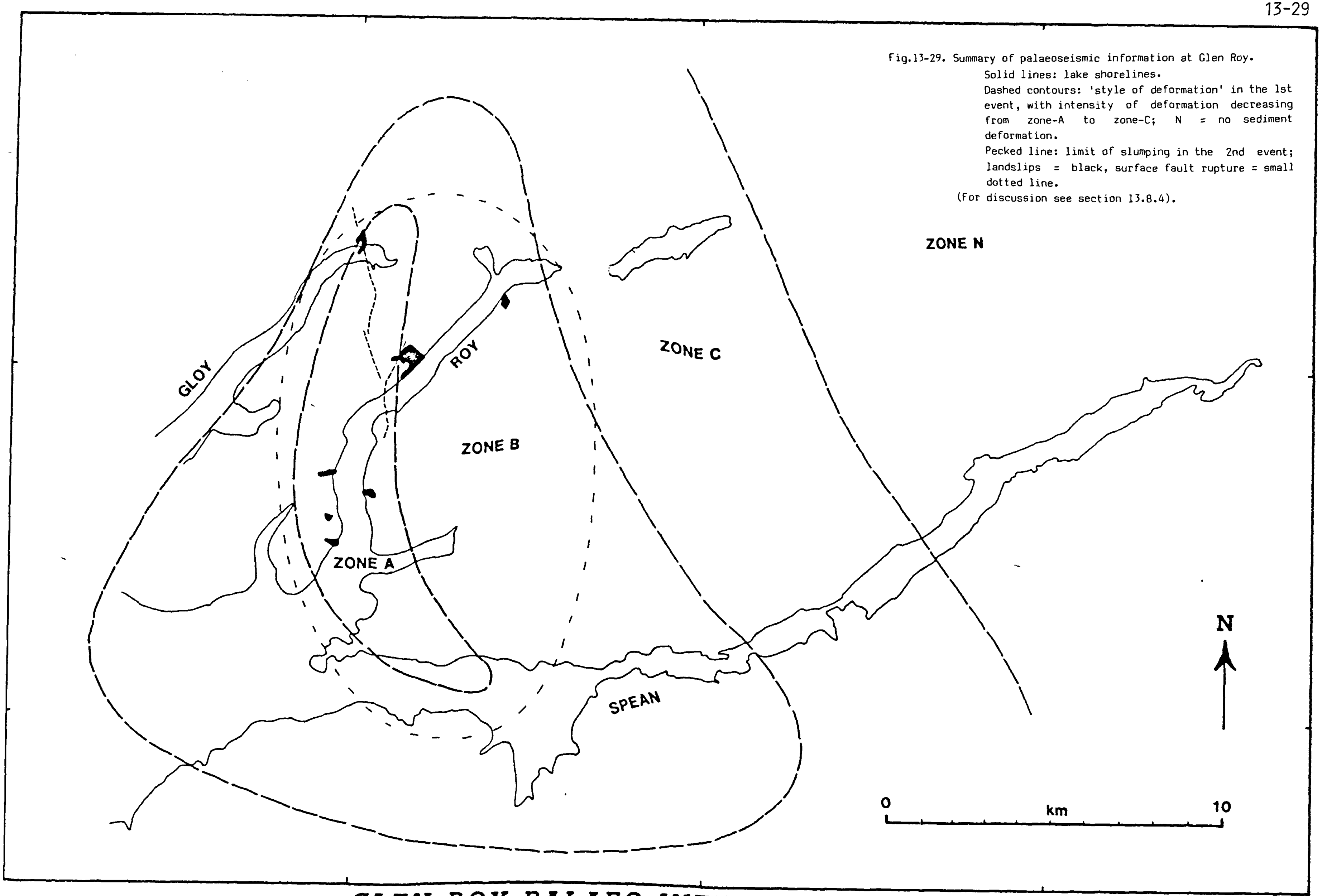
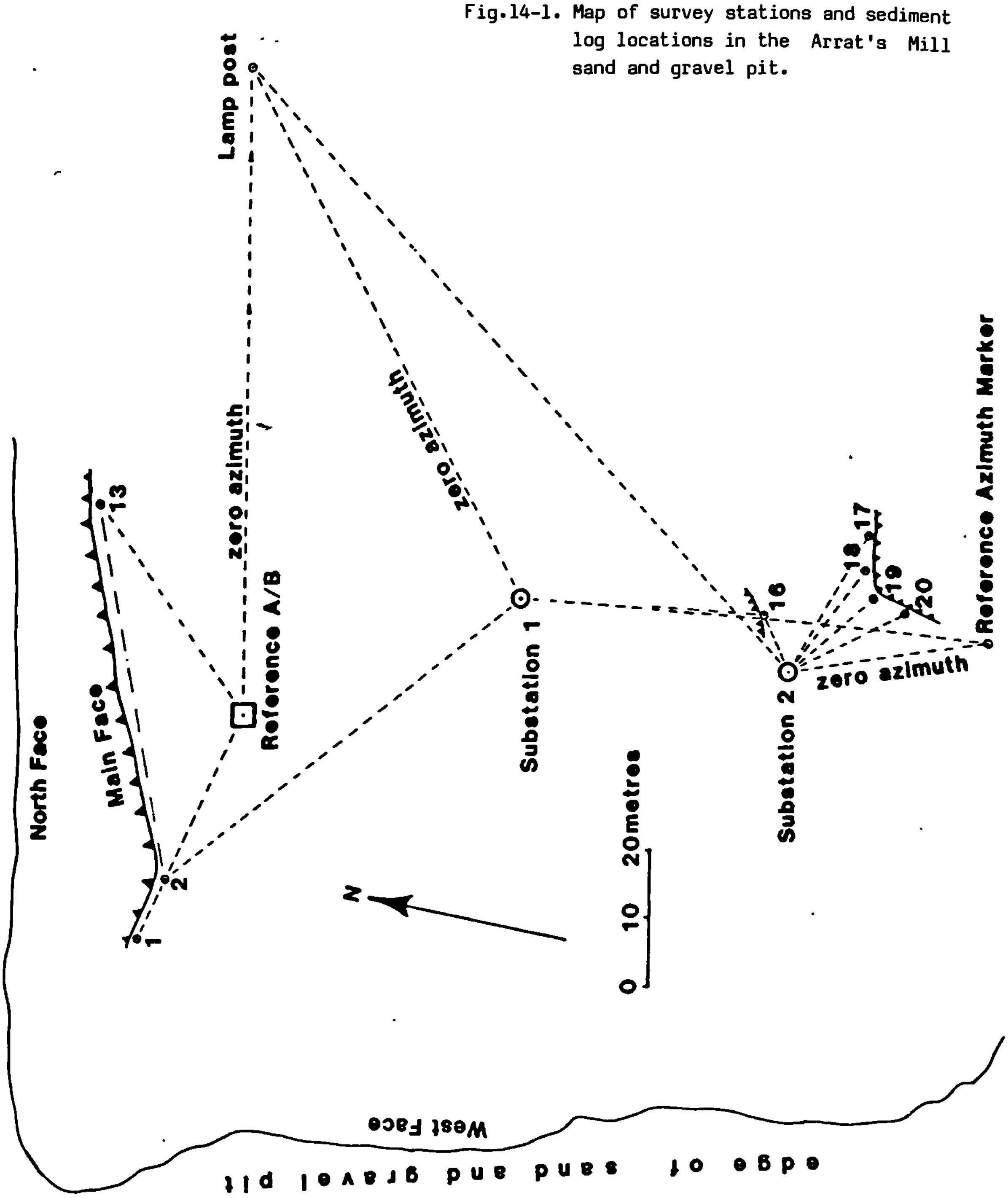


Fig.13-29. Summary of palaeoseismic information at Glen Roy.
Solid lines: lake shorelines.
Dashed contours: 'style of deformation' in the 1st event, with intensity of deformation decreasing from zone-A to zone-C; N = no sediment deformation.
Pecked line: limit of slumping in the 2nd event; landslips = black, surface fault rupture = small dotted line.
(For discussion see section 13.8.4).

GLEN ROY PALAEO-INTENSITY MAP.

Fig.14-1. Map of survey stations and sediment log locations in the Arrat's Mill sand and gravel pit.



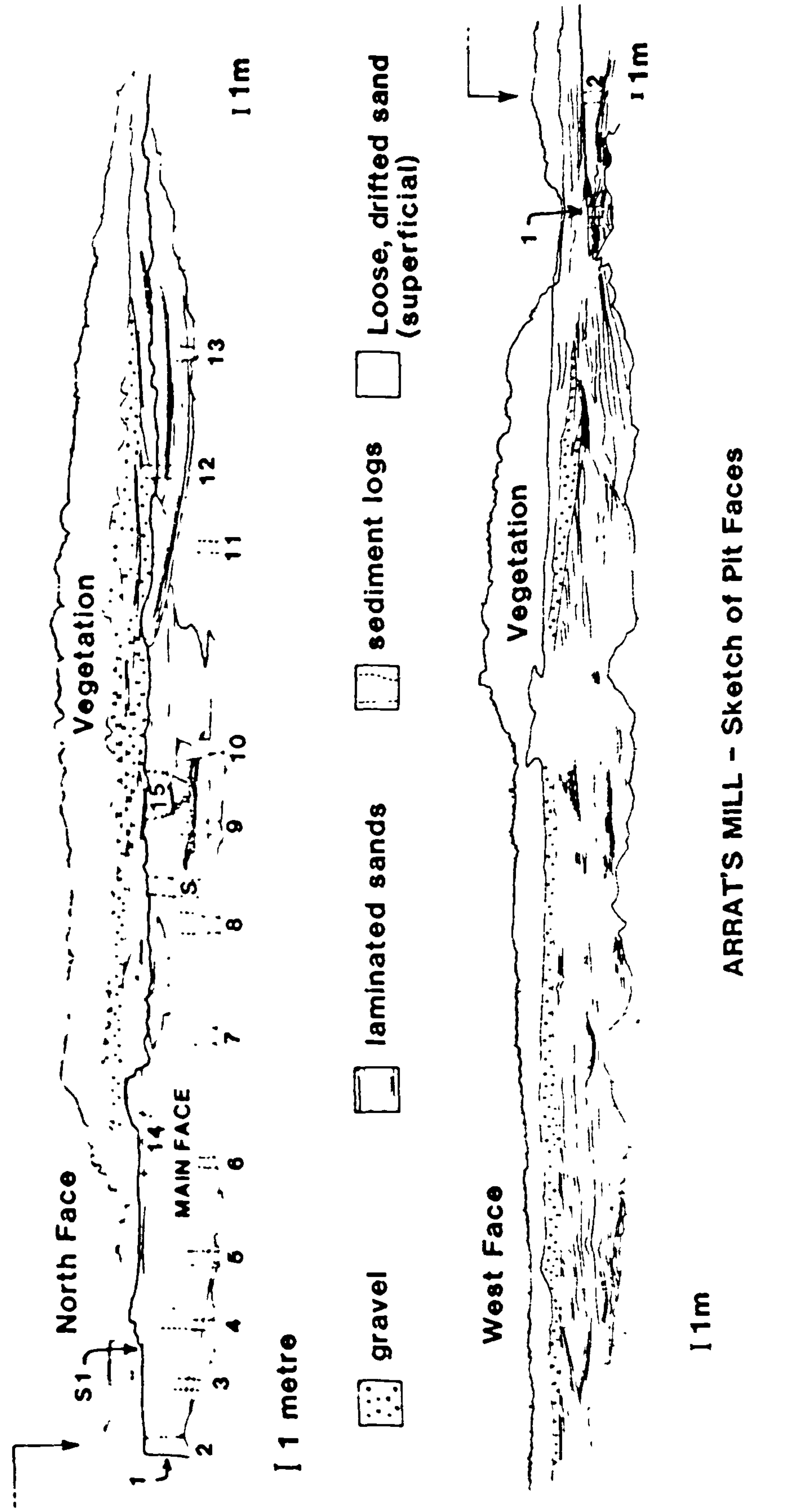


Fig.14-2. Sketches of the north and west faces of the Arrat's Mill site showing the locations of the 'Main Face' sediment logs (1 to 15 and S & S1). Note that the scale changes across the sections.

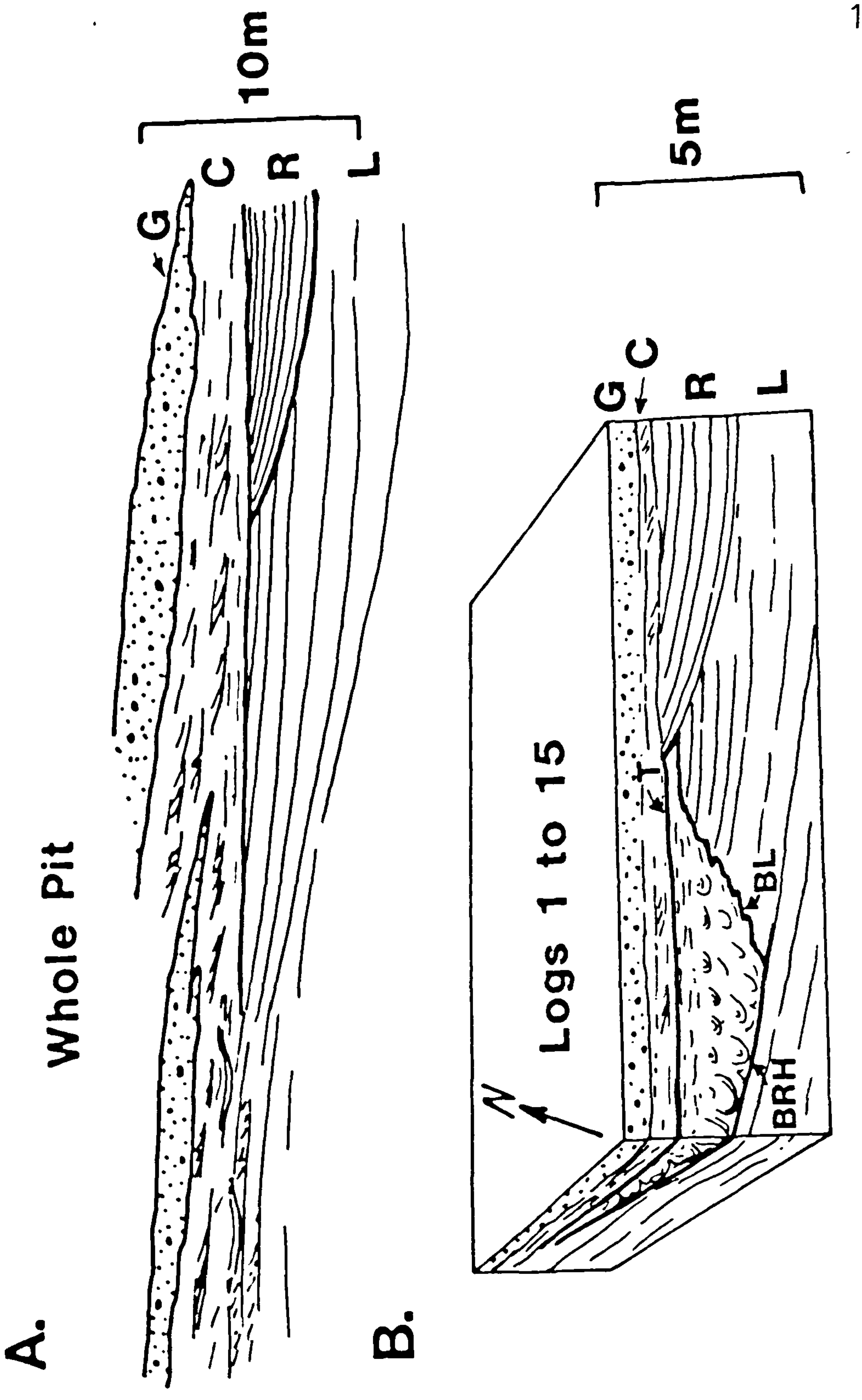


Fig.14-3. Illustrative sketches of the Arrat's Mill sediment and deformation:

A) Stratigraphy seen across the whole site (G= gravel, C= cross-bedded sands, R= river deposit, L= lacustrine deposit).

B The deformed lens in the Main Face section (BRH= basal reference horizon, BL= base of liquefaction, T= top of deformation).

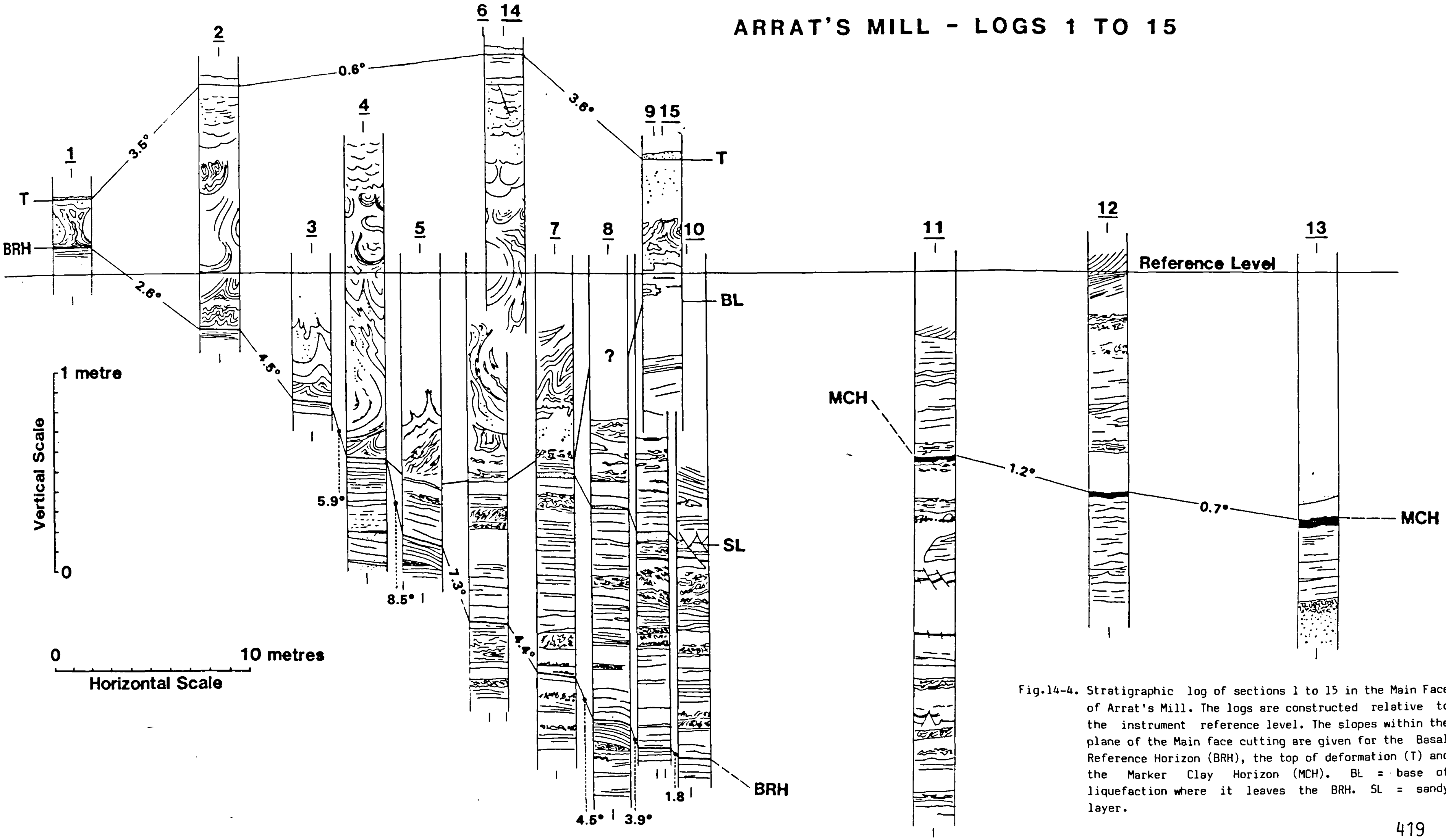


Fig.14-4. Stratigraphic log of sections 1 to 15 in the Main Face of Arrat's Mill. The logs are constructed relative to the instrument reference level. The slopes within the plane of the Main face cutting are given for the Basal Reference Horizon (BRH), the top of deformation (T) and the Marker Clay Horizon (MCH). BL = base of liquefaction where it leaves the BRH. SL = sandy layer.

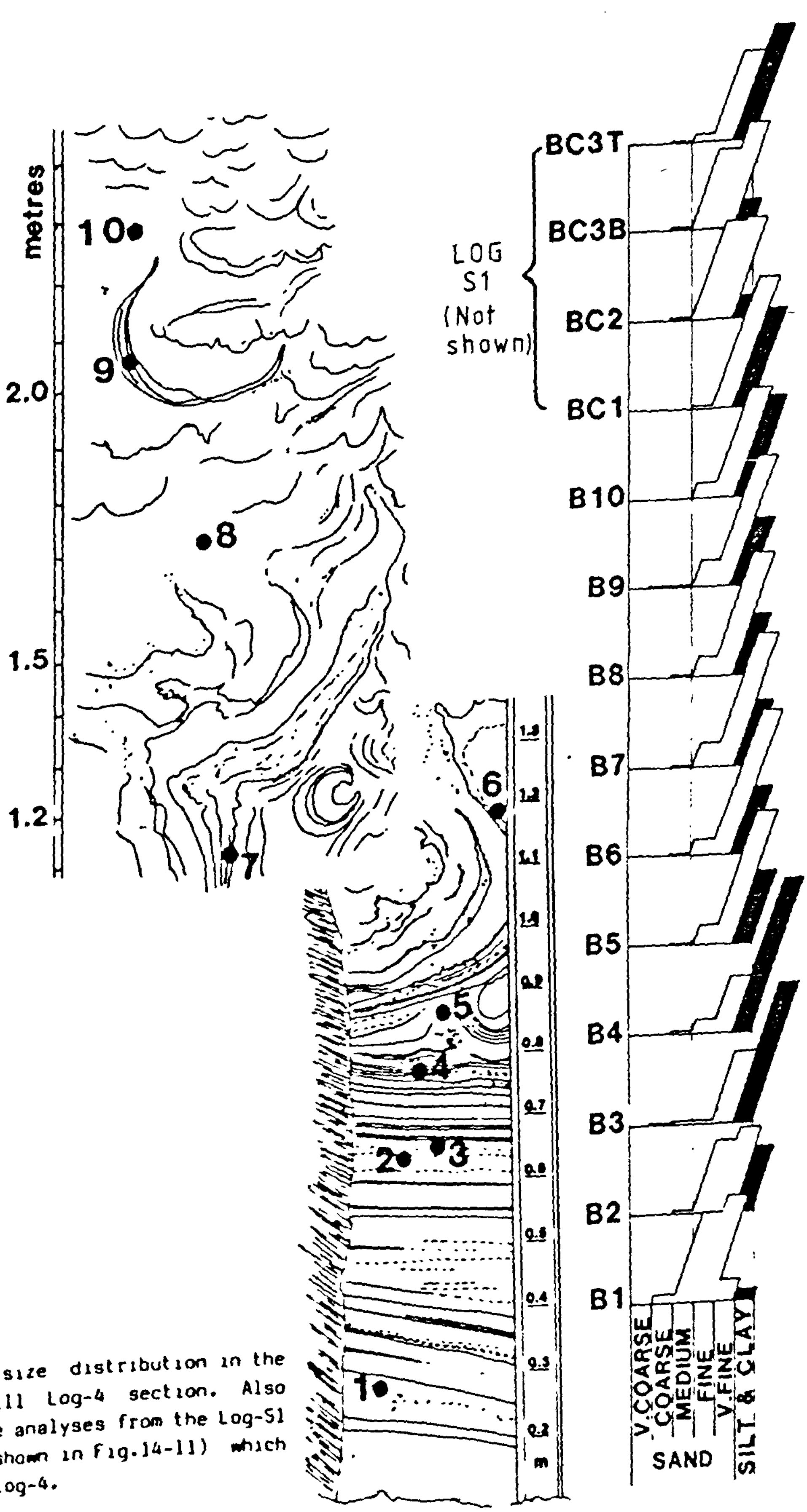


Fig.14-5.

Particle-size distribution in the Arrat's Mill Log-4 section. Also shown are analyses from the Log-S1 section shown in Fig.14-11) which is above Log-4.

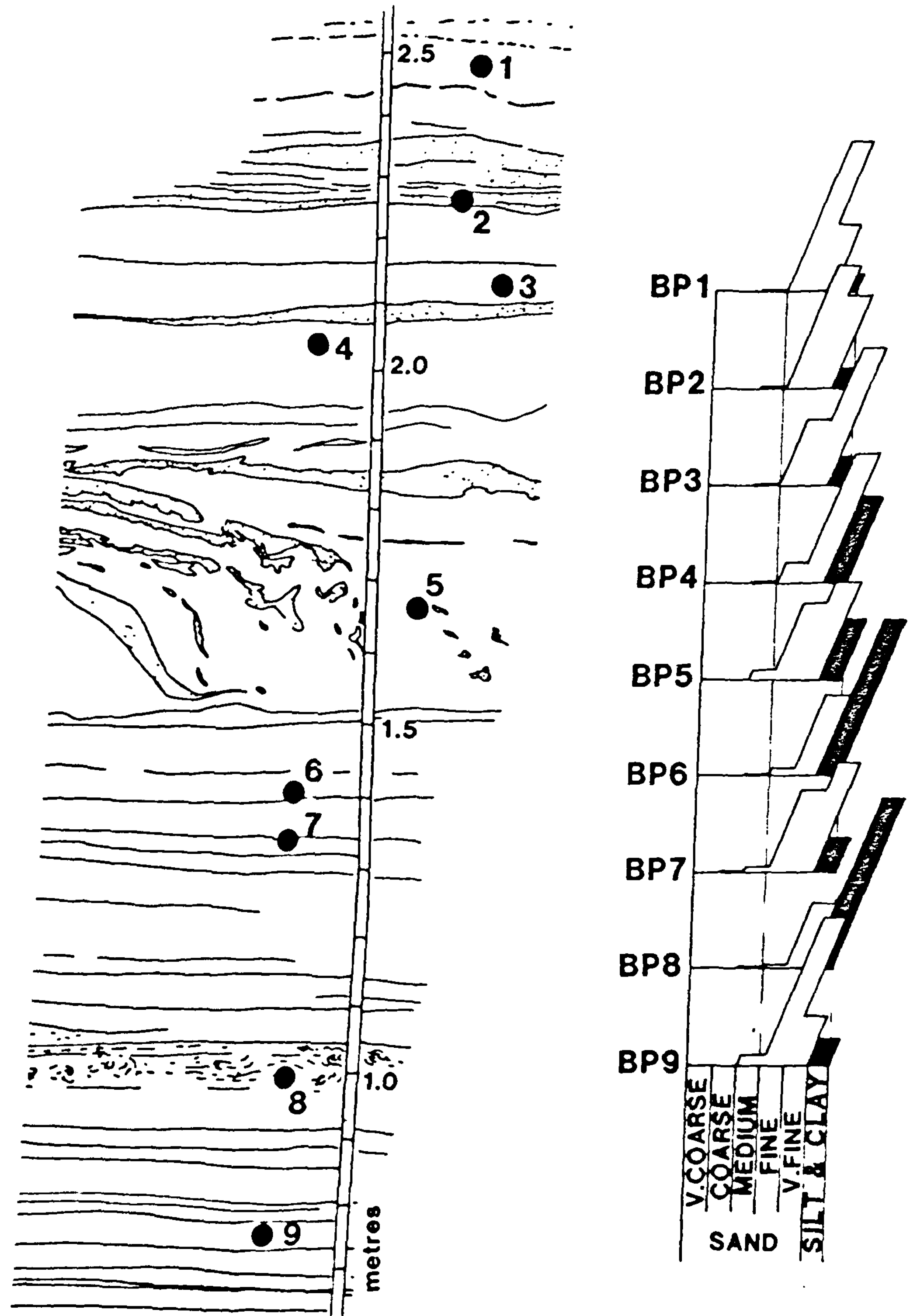


Fig.14-6.

Particle-size distribution in the Arrat's Mill Log-S section.

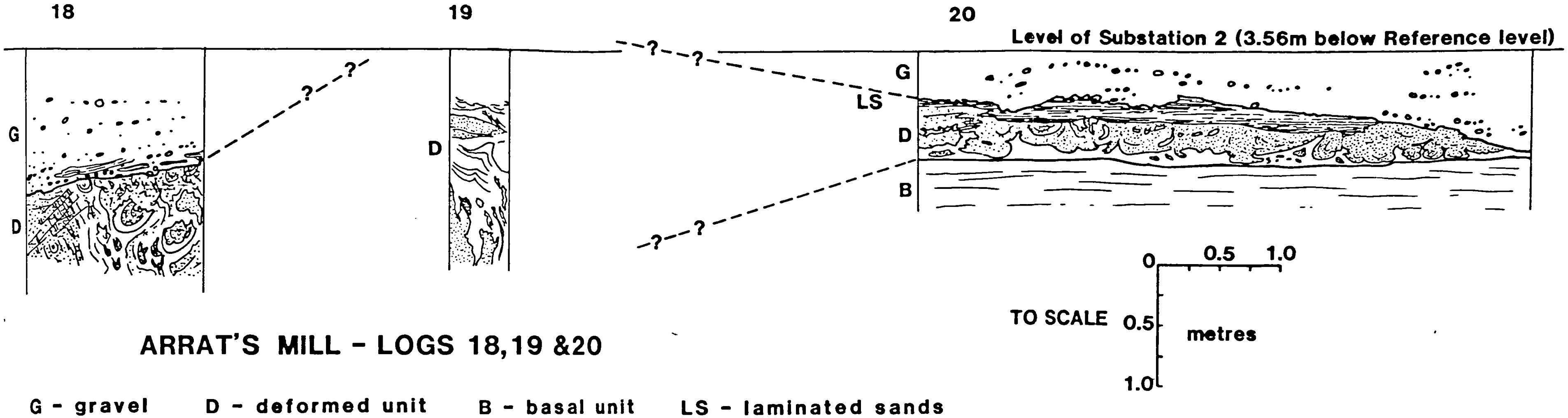


Fig.14-7. Stratigraphic log of sections 18, 19 and 20 at Arrat's Mill (see also Plates 13, 18 & 19).

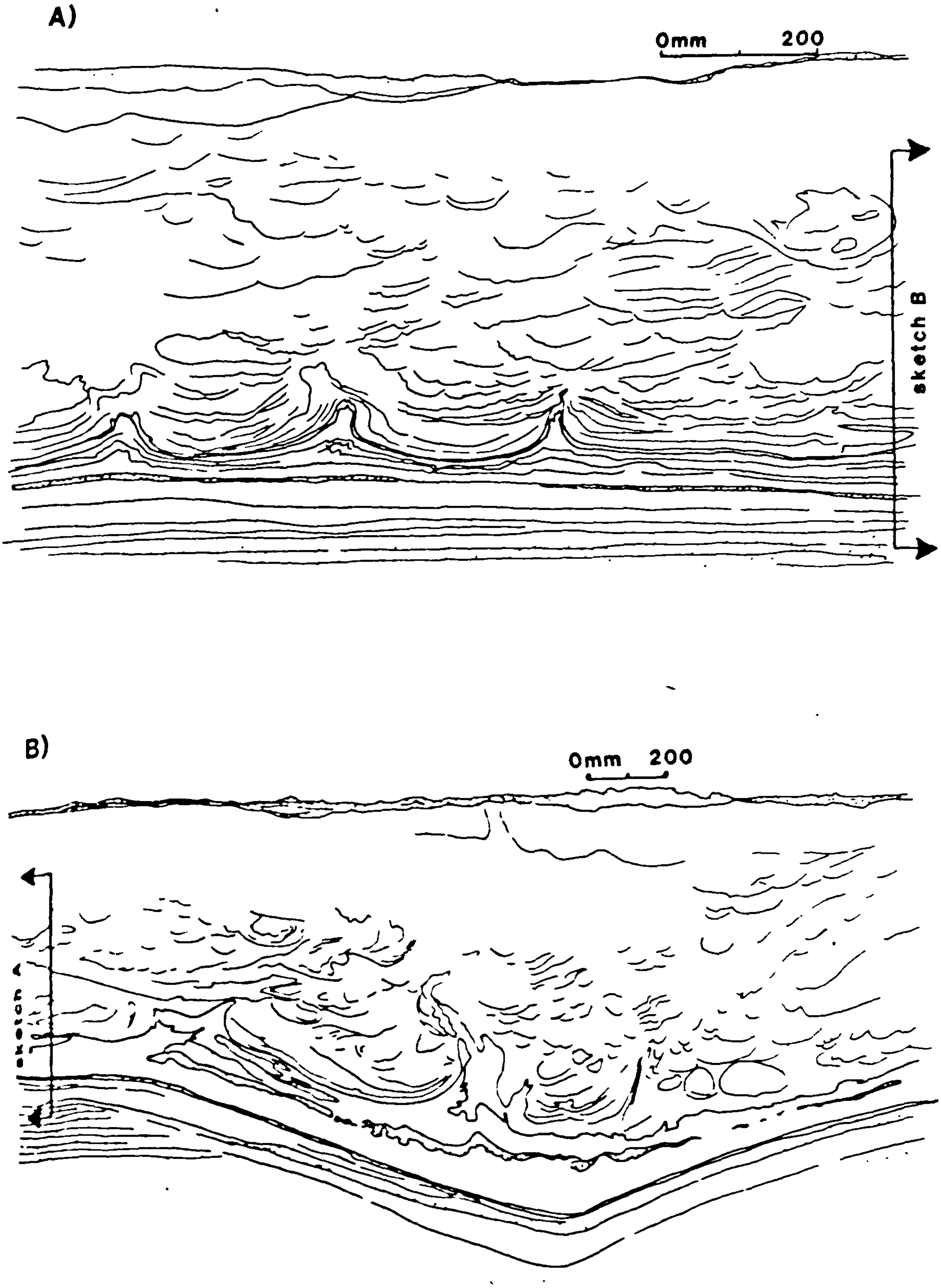


Fig.14-8. Sketches of cuttings between Arrat's Mill logs-1&2.

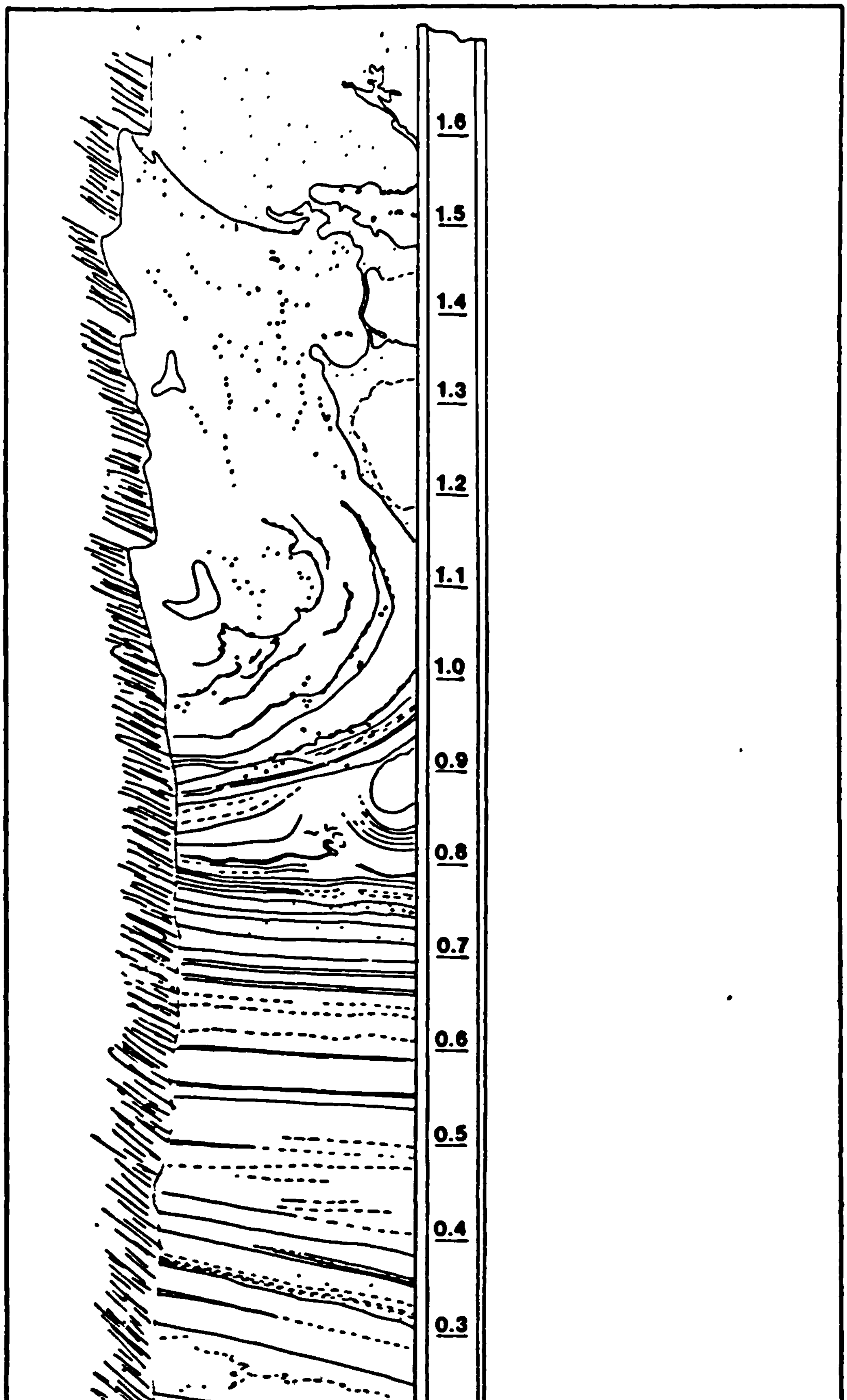


Fig.14-9. Sketch of Arrat's Mill Log-4, showing the base of the deformed lens (see also Plate-15).

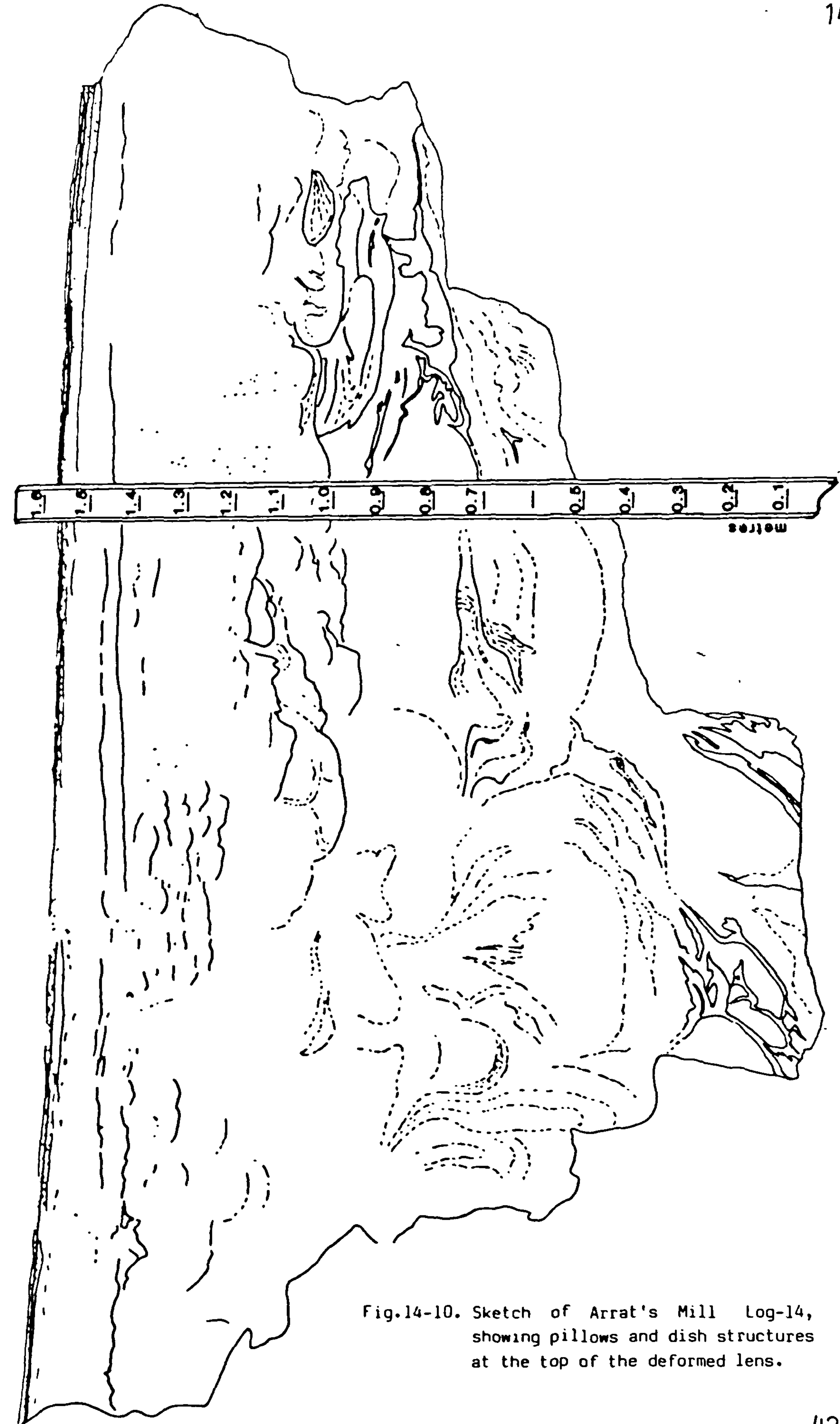


Fig.14-10. Sketch of Arrat's Mill Log-14, showing pillows and dish structures at the top of the deformed lens.

Fig.14-11. Sketch of Arrat's Mill Log-14, showing detail of the top of the deformed layer. Clayey sediment in heavy tone, silts in light tone (see also Plate-17).

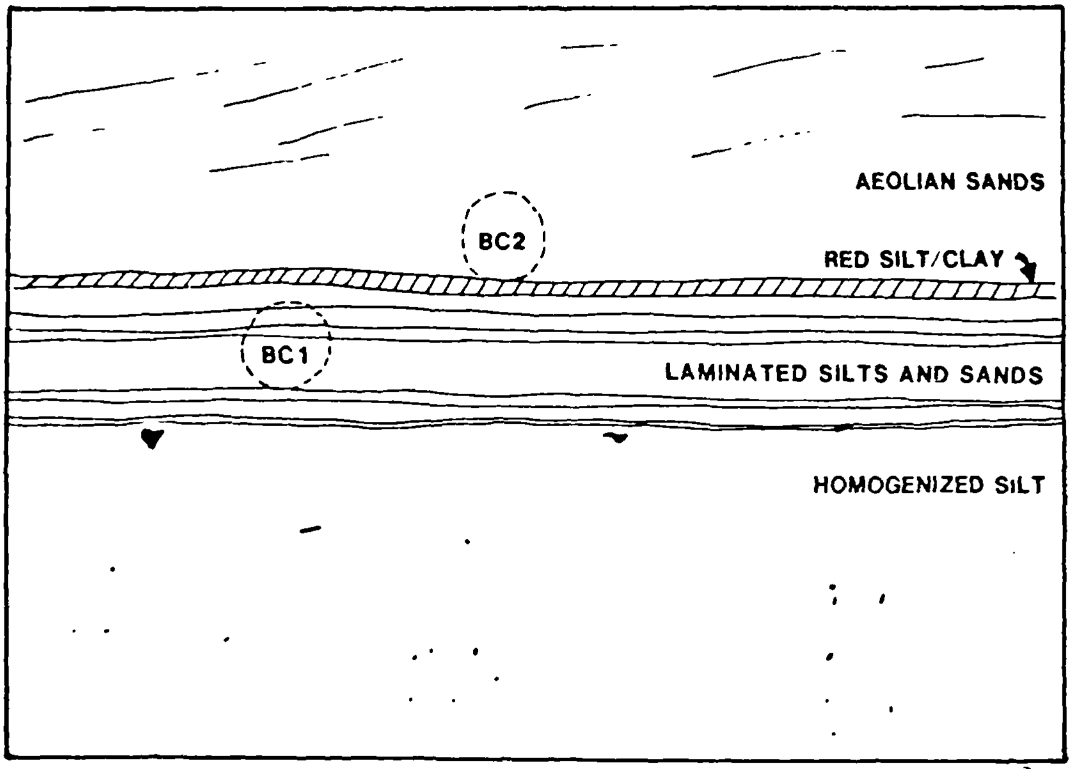


Fig.14-12. Sketch of Arrat's Mill Log-S1, showing layers at the top of the deformed lens and undeformed, massive aeolian sands above. Particle-size distributions for samples BC1, BC2, BC3-B & BC3-T are shown in Fig.14-5. The positions of BC3-B & BC3-T (top and bottom ends of a vertical 15cm sample tube) are not shown but were taken from the massive aeolian sands above the portion illustrated here.

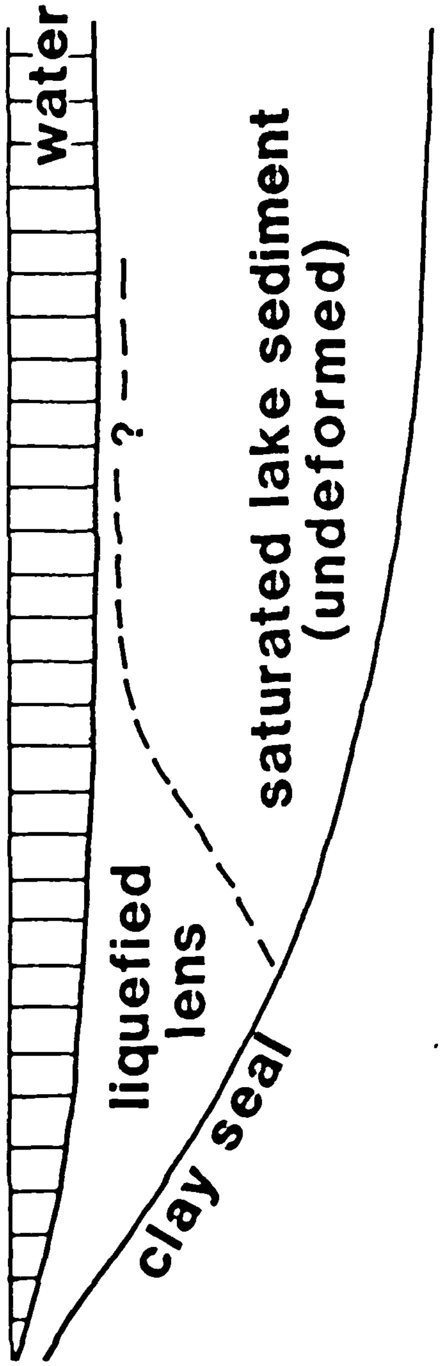


Fig.14-13. The proposed scenario at the time of deformation at Arrat's Mill.

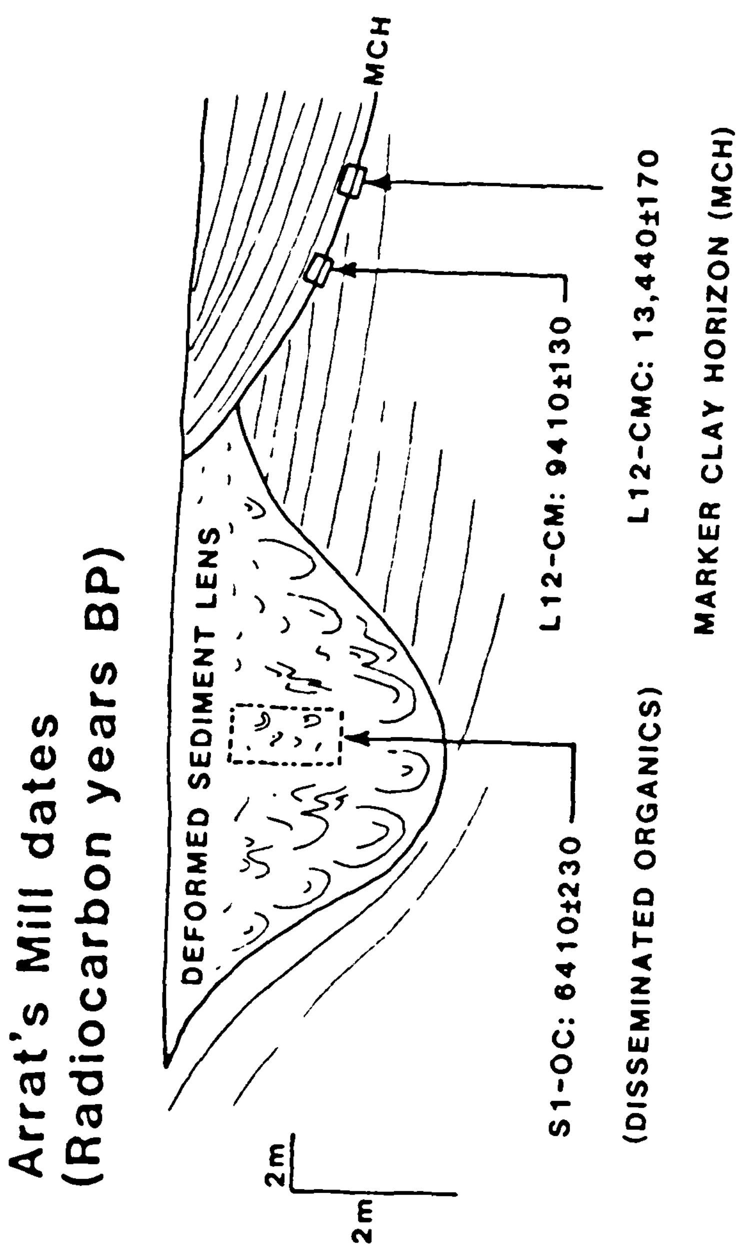


Fig.14-14. Positions of samples retrieved for radio-carbon dating at Arrat's Mill and the dates achieved.

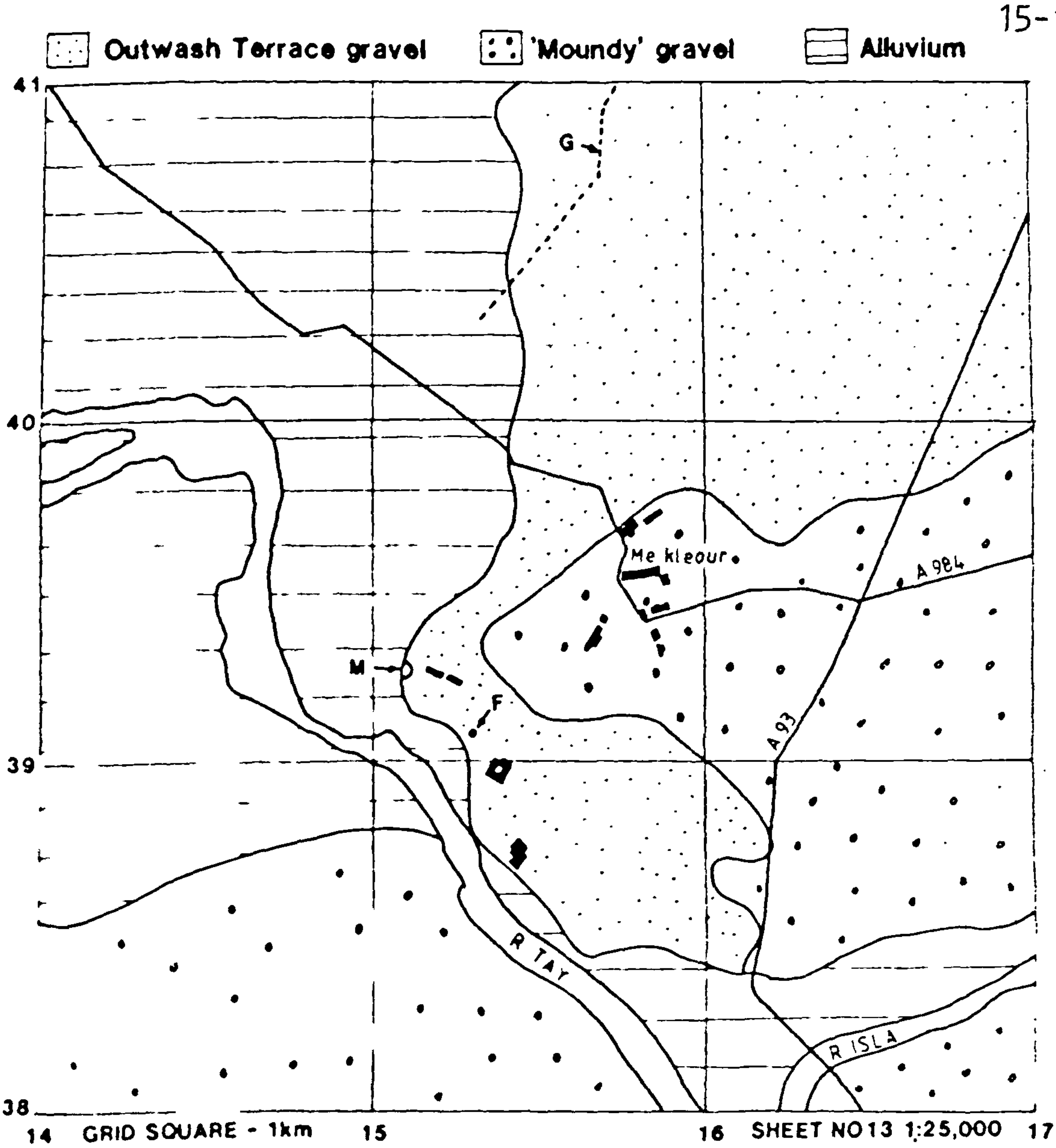


Fig.15-1. Map of the Quaternary geology around Meikleour, showing excavation sites: M= Main Face, F= Forest Pit, G= course of gas pipeline. (Compiled from Paterson 1974.)

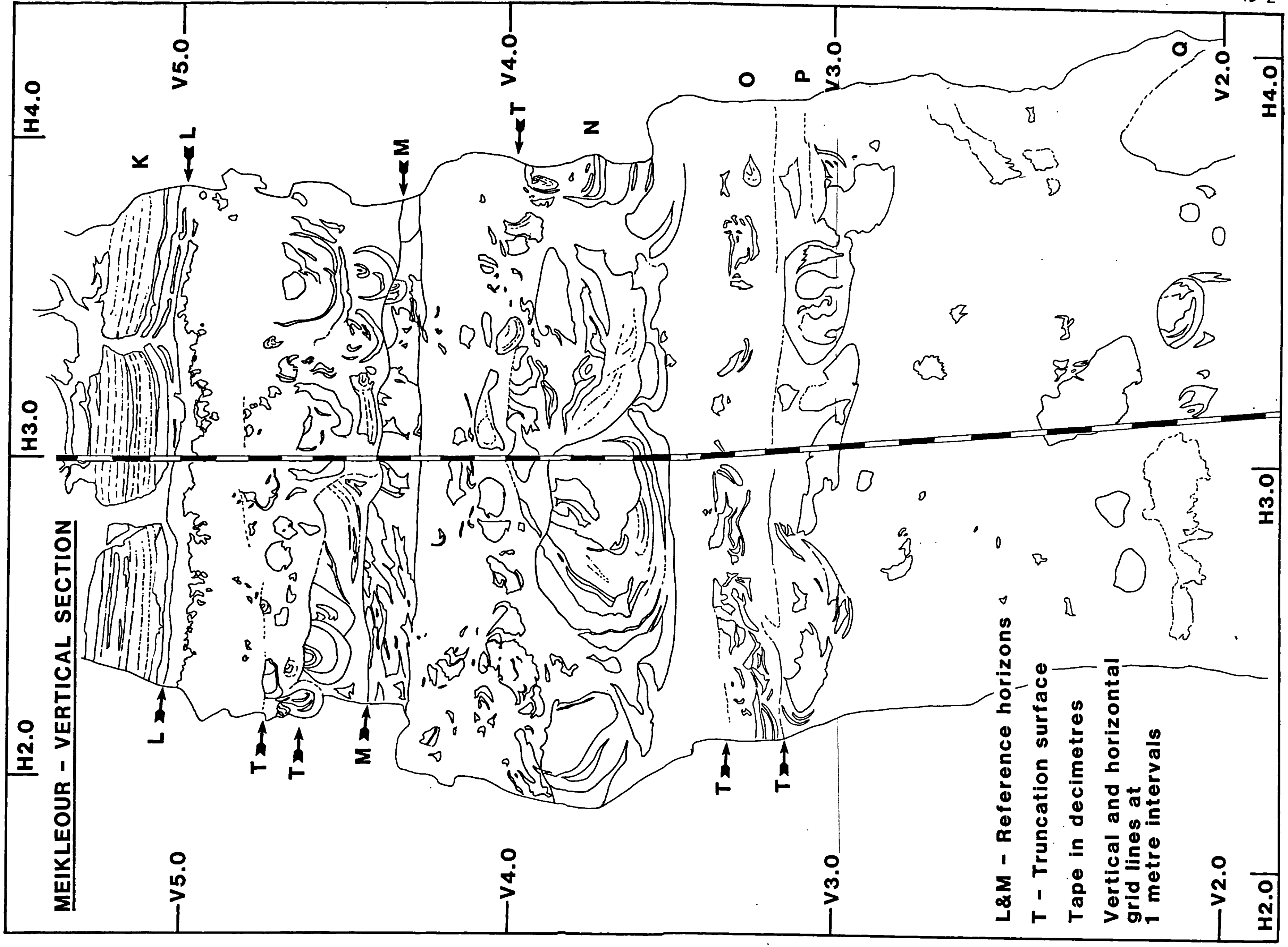


Fig.15-2. Line drawing of the vertical section at Meikeour.

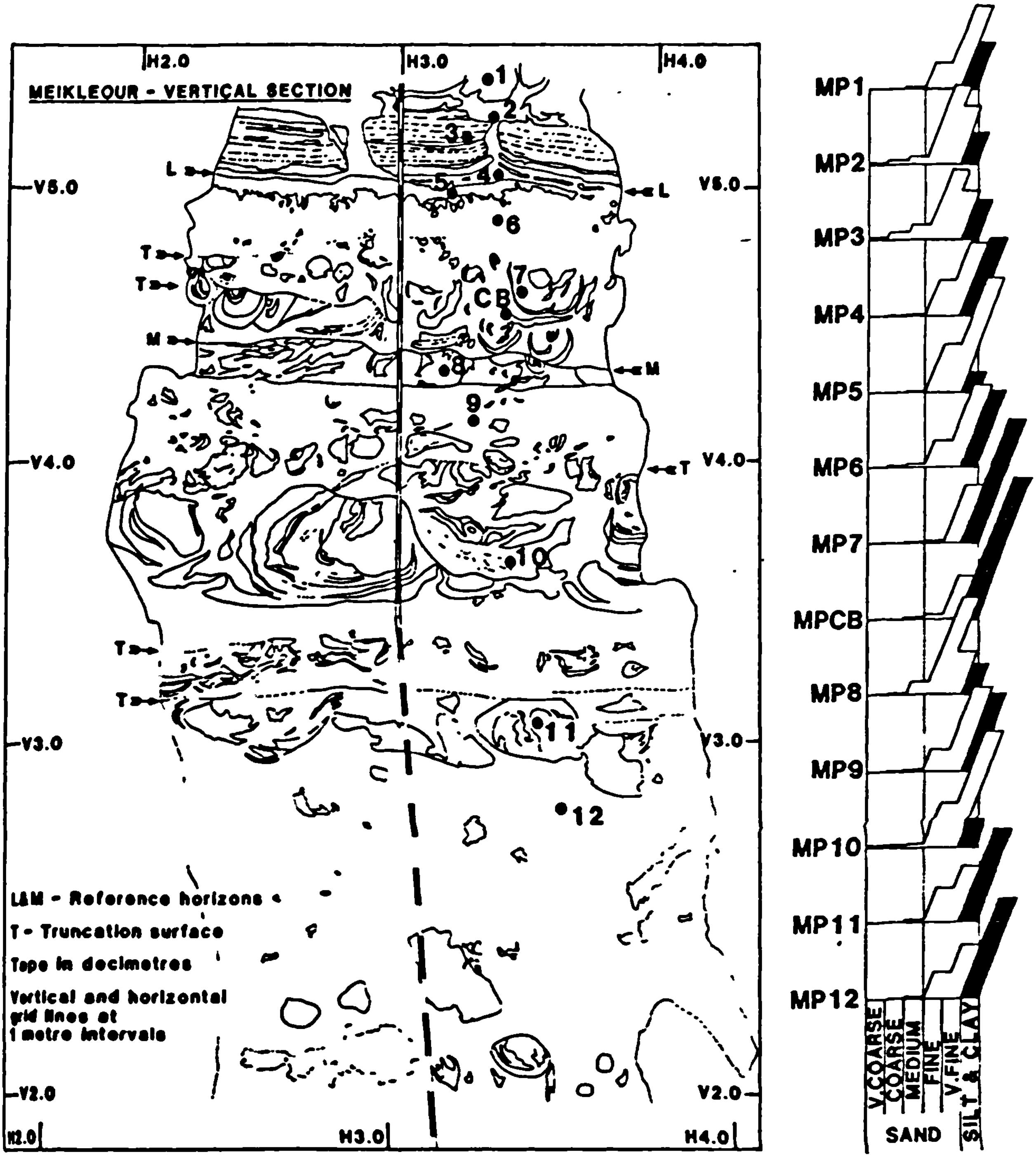


Fig.15-3. Particle-size distribution in the Meikleour vertical section.

Fig.15-4. Line drawing of the horizontal section at Meikeour (see also Plates-24&25).

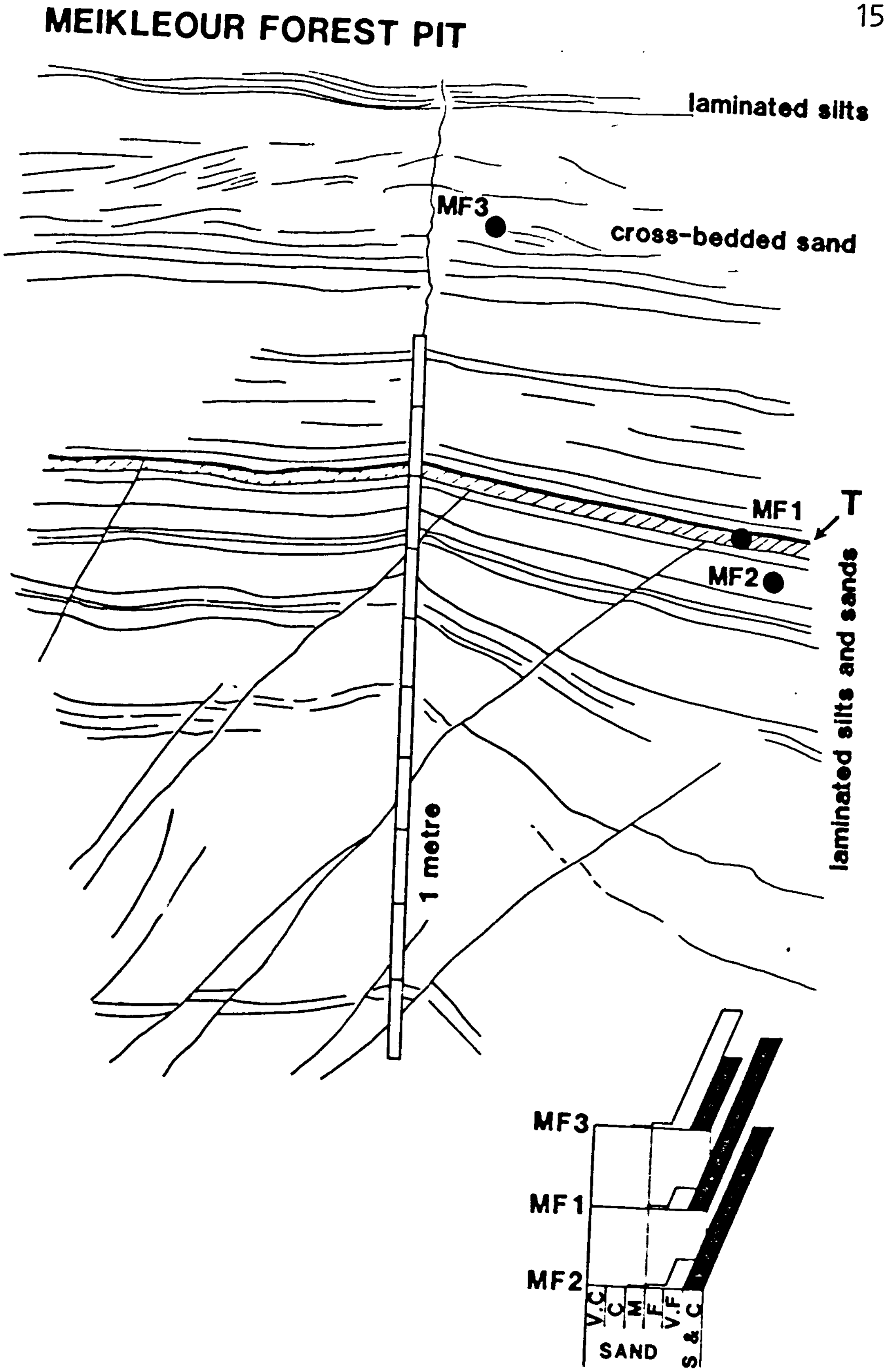


Fig.15-5. Line drawing of the Forest Pit with particle-size distributions. The 'brown clayey silt' is shown in hatched ornament, the 'red silt' by a heavy black line.

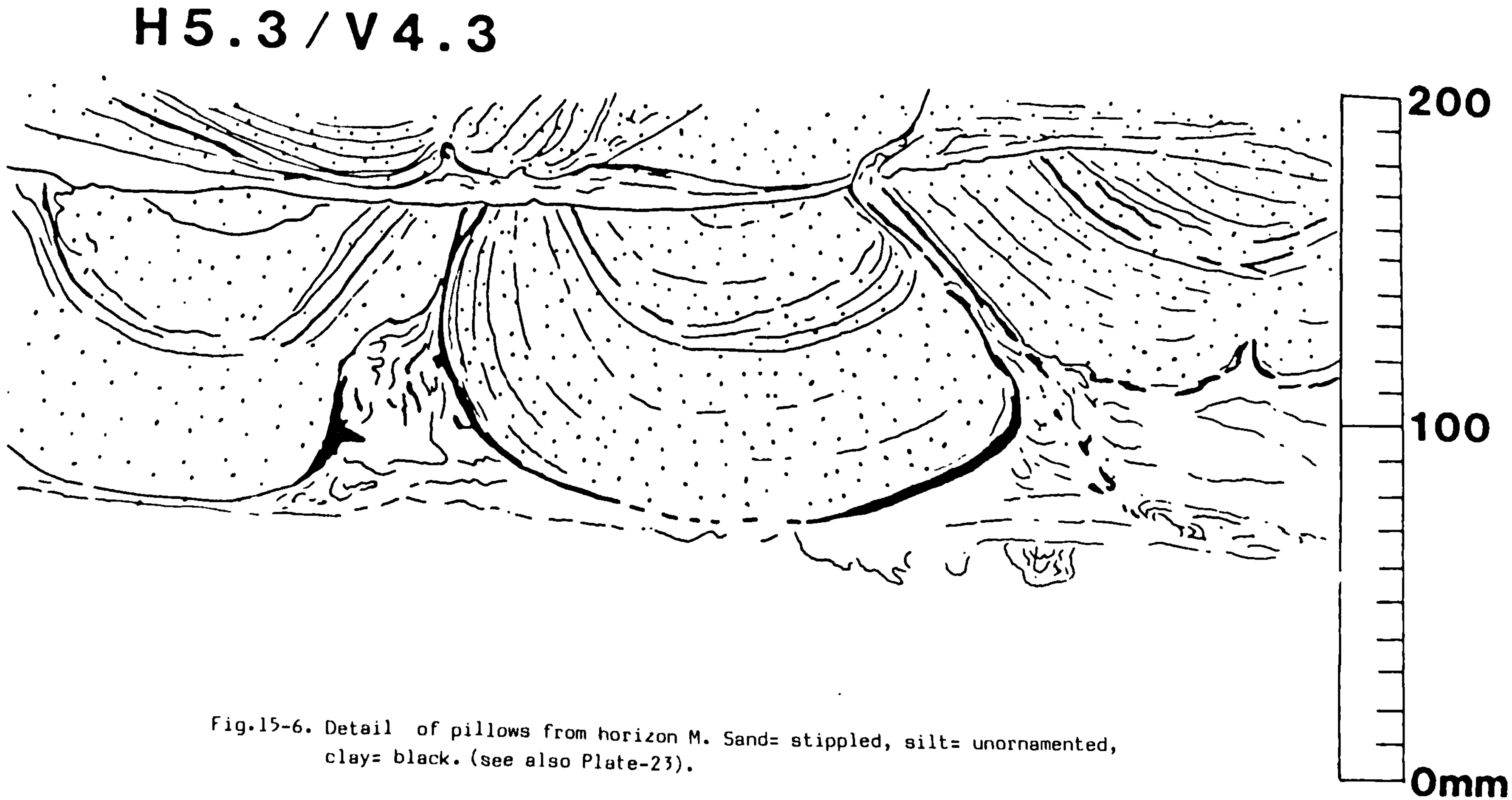


Fig.15-6. Detail of pillows from horizon M. Sand= stippled, silt= unornamented, clay= black. (see also Plate-23).

Fig.15-7. Detail of a nest of pillows from the 'N' layer. Sand= stippled, silt= unornamented, clay= black.

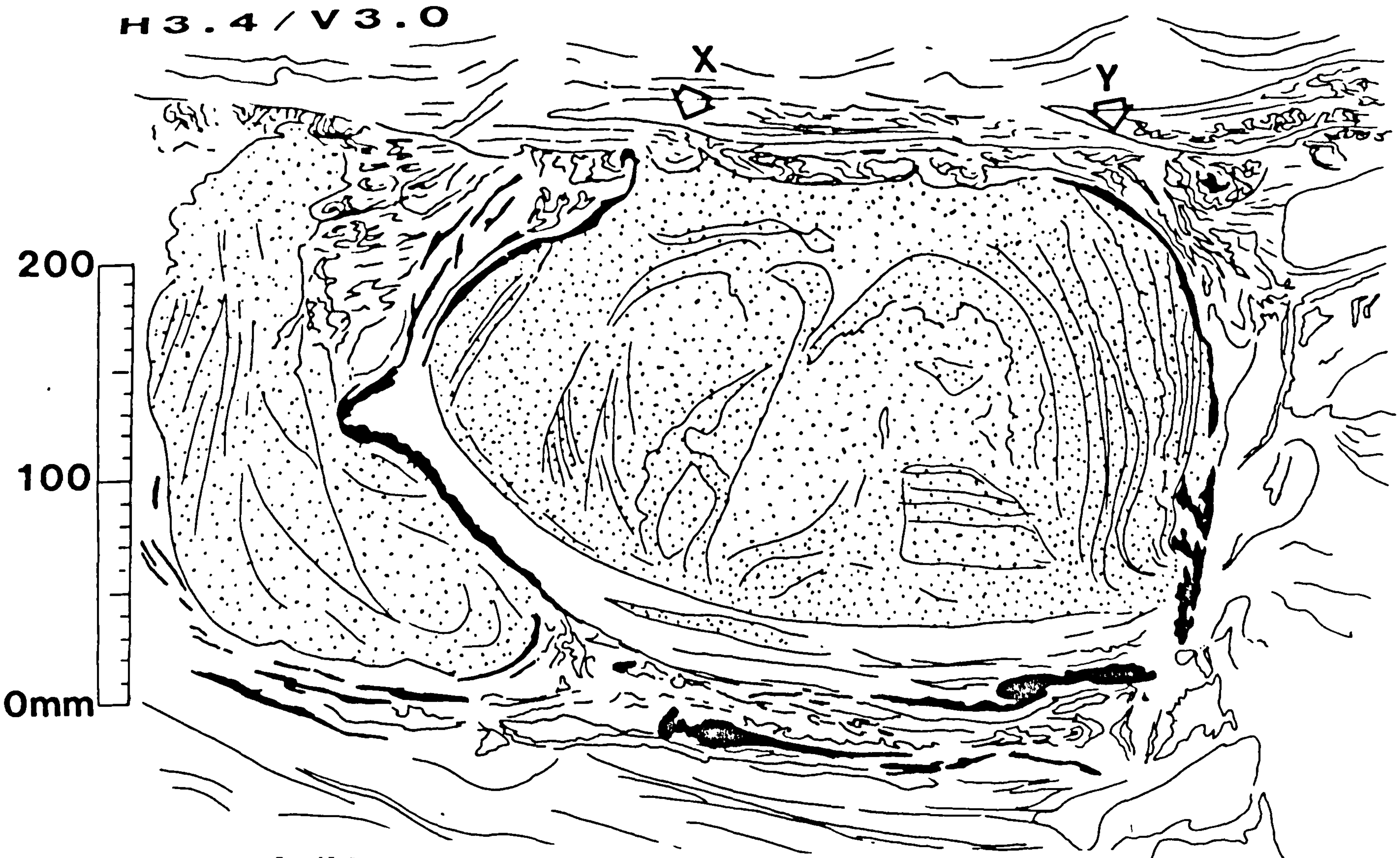


Fig.15-8. Detail of a pillow from the 'P' layer. Sand= stippled, silt= unornamented, clay= black.

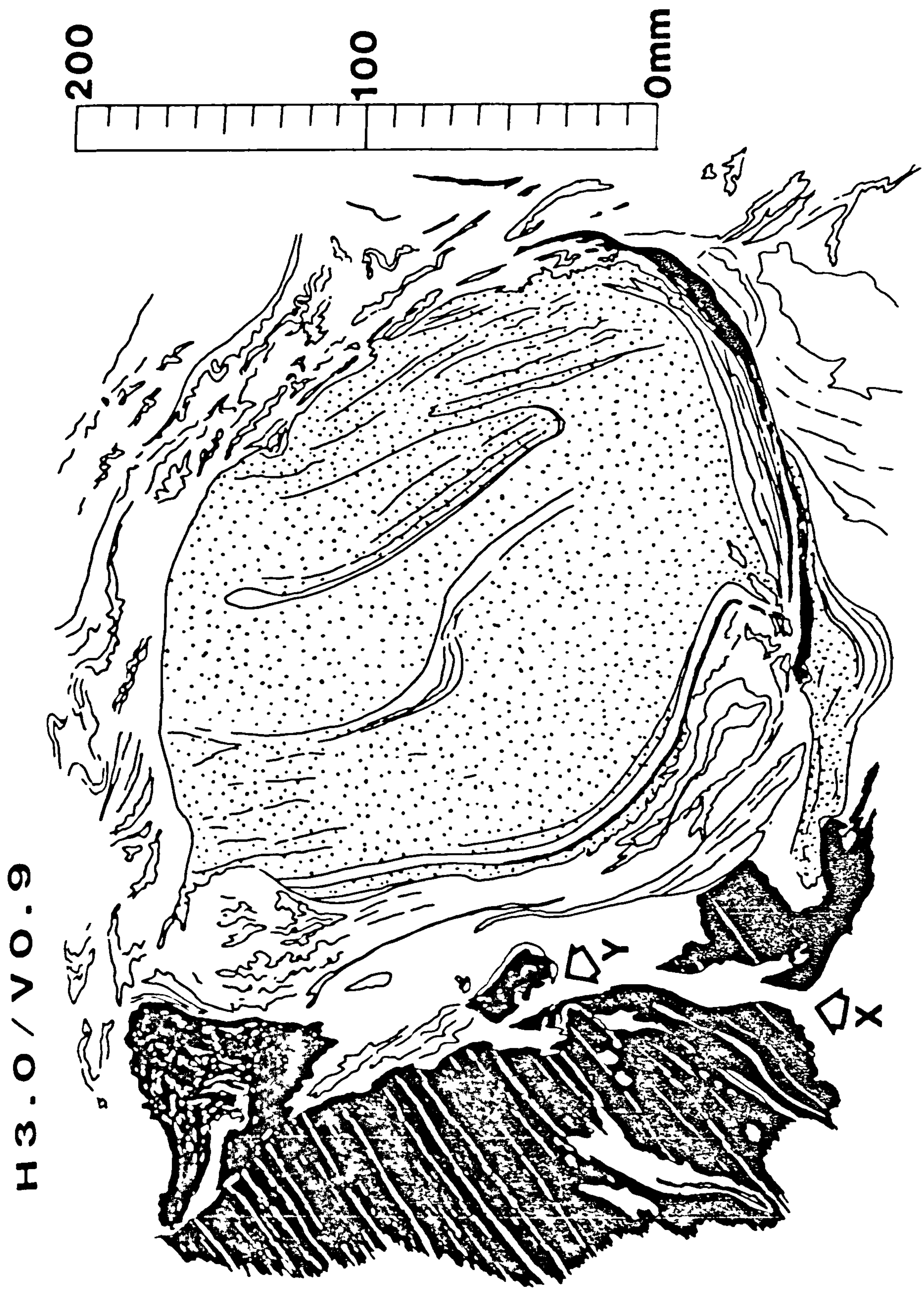


Fig.15-9. Detail of a pillow near the base of the section. Sand= stippled, silt= unornamented, clay= black.

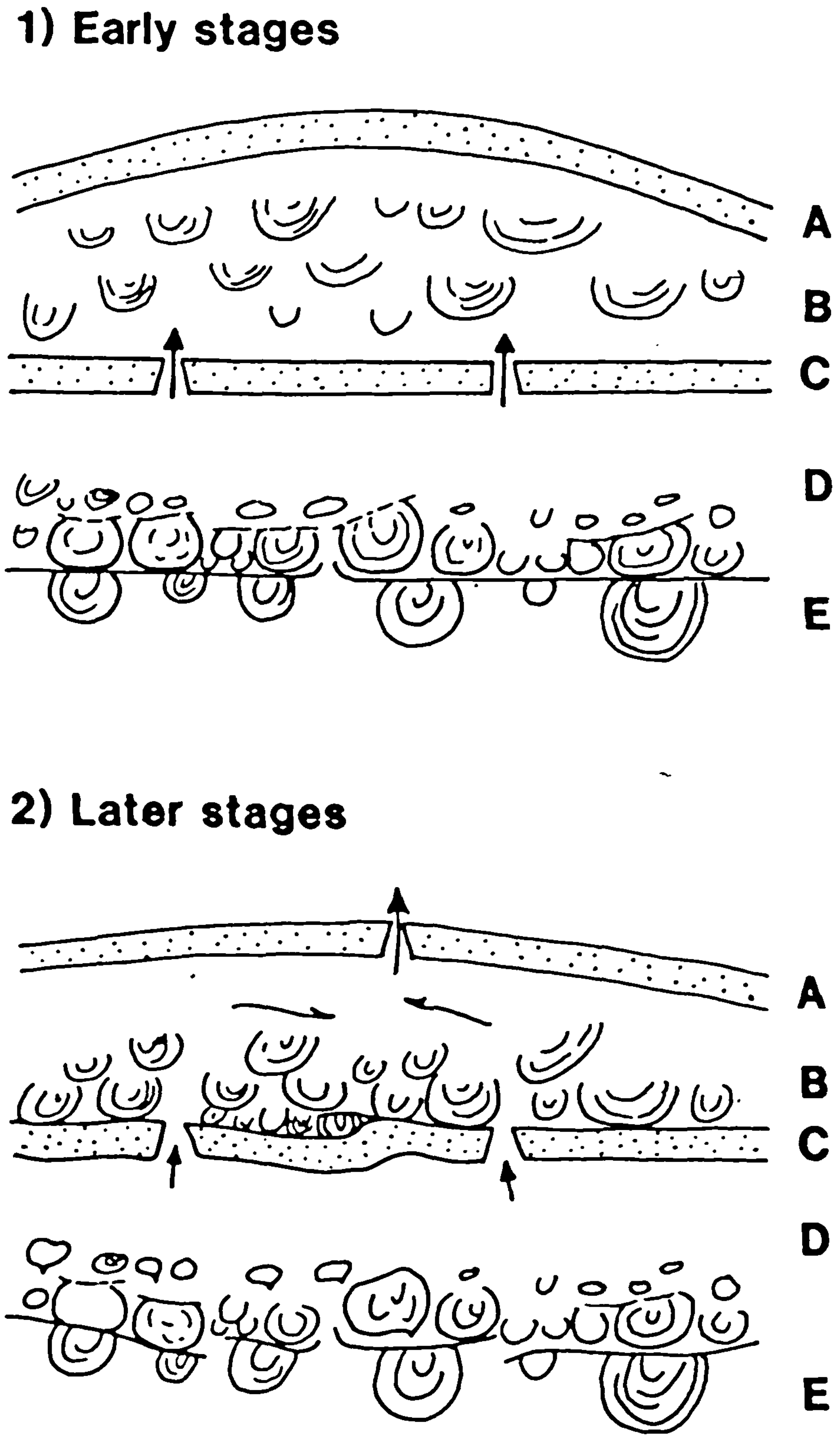


Fig.15-10. Illustrative sketches of the deformation processes at Meikleour. Two competent sand layers, A&C, contain layers of liquidized silt in which pillows form and descend. Injection of liquidized silt through the sand layers results in thickness changes, and lateral thrust movements (above the buckle in layer C). A truncation surface between layers D and E is broken up in the later stages as deformation progresses.

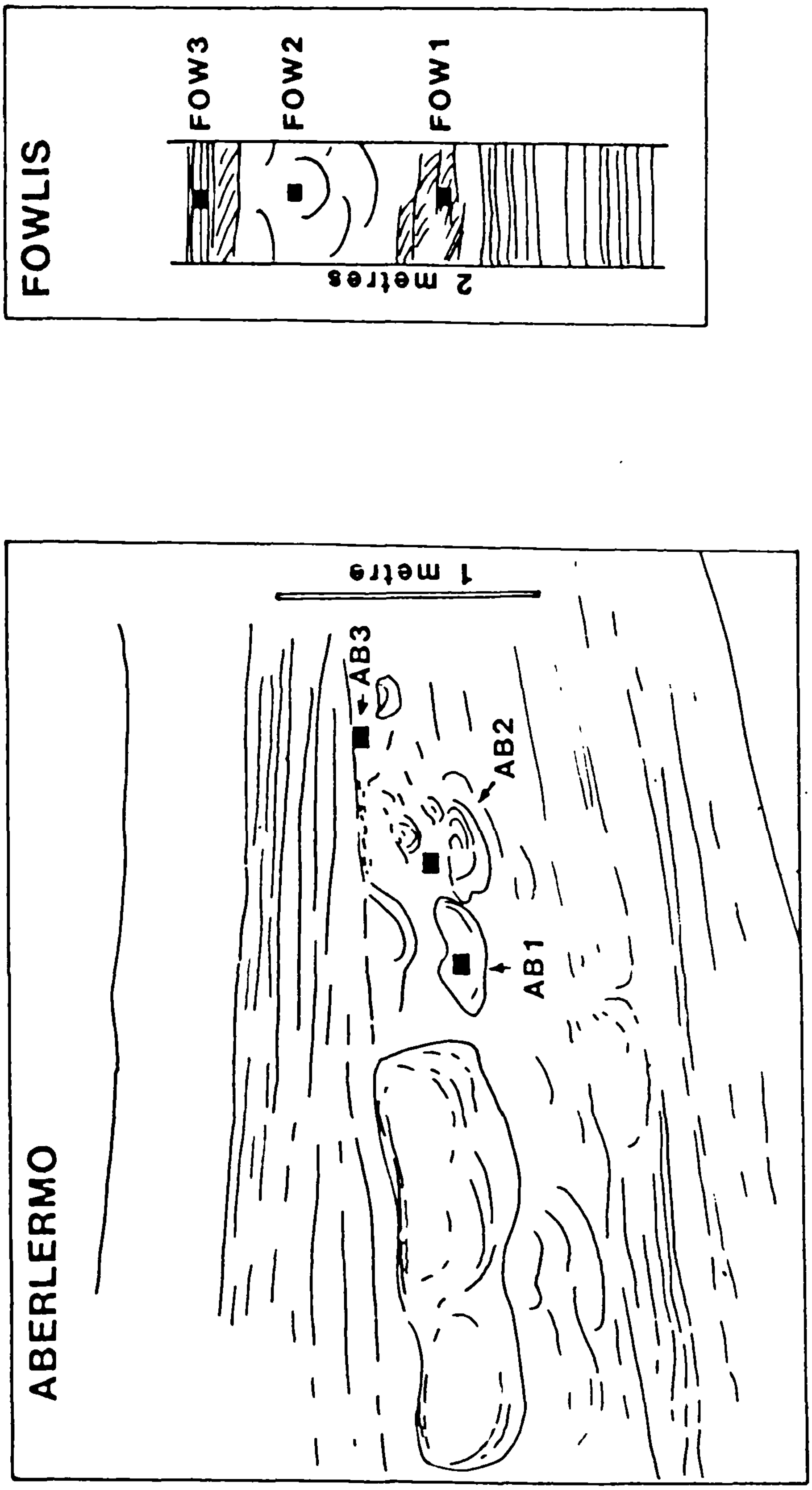


Fig.15-11. Sketches of Lower Devonian ball-and-pillow horizons in the Tayside area.

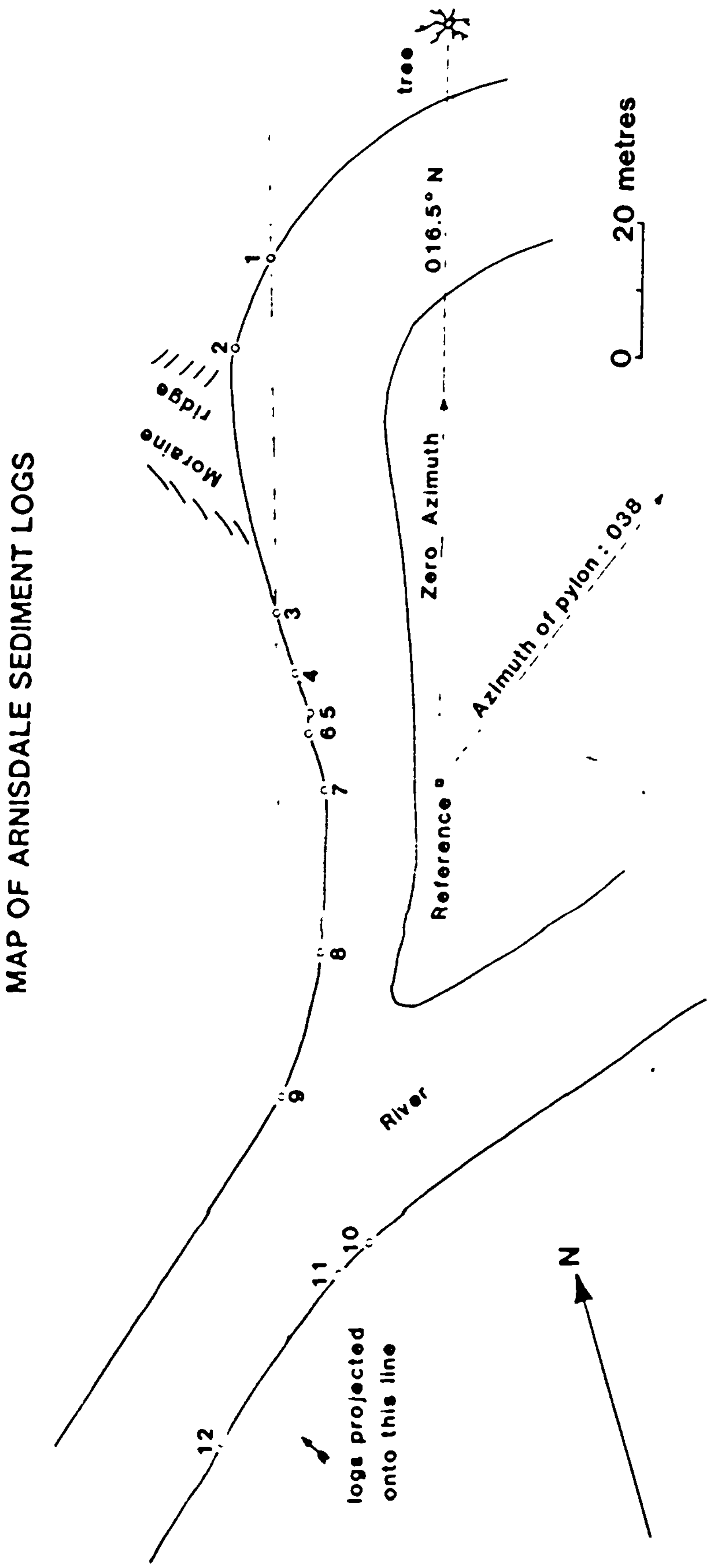


Fig.16-1. Map of the Arnisdale sediment logs cut into the banks of the Arnisdale River.

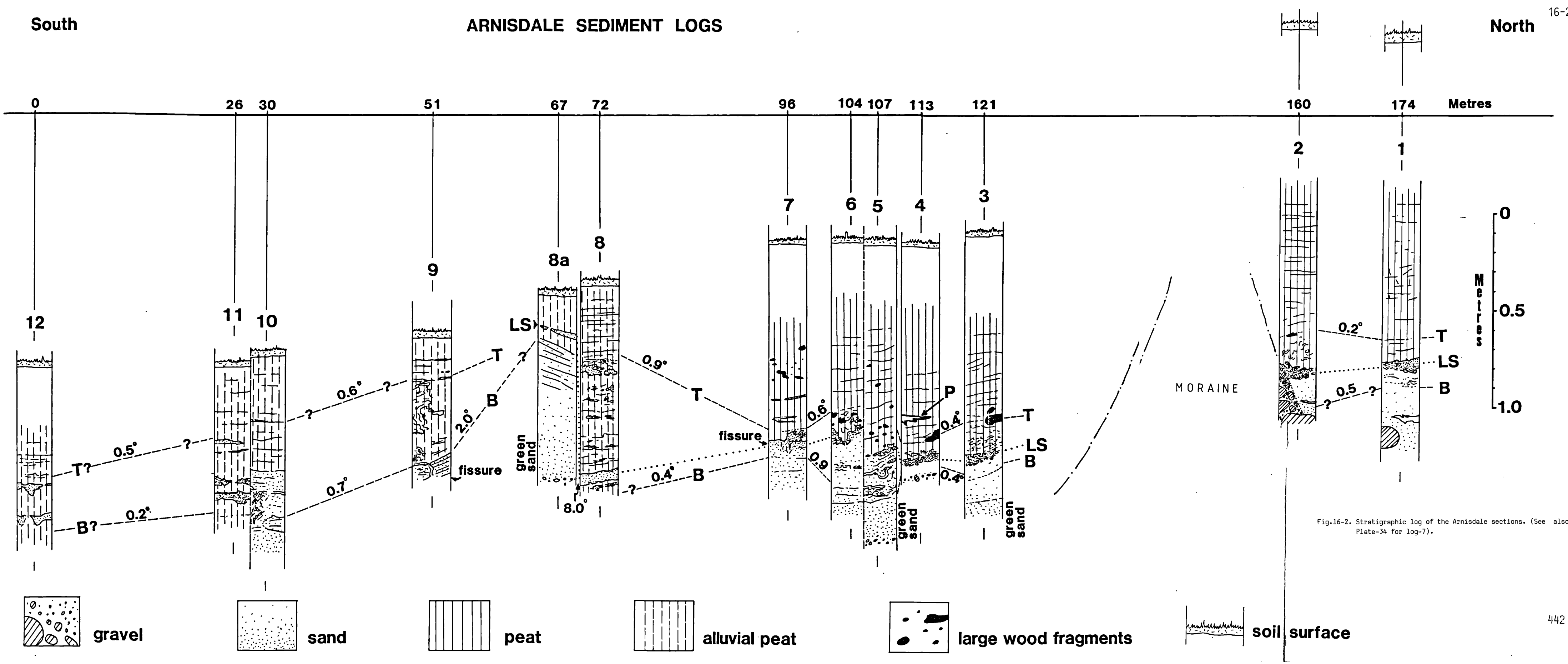


Fig.16-2. Stratigraphic log of the Arnisdale sections. (See also Plate-34 for log-7).

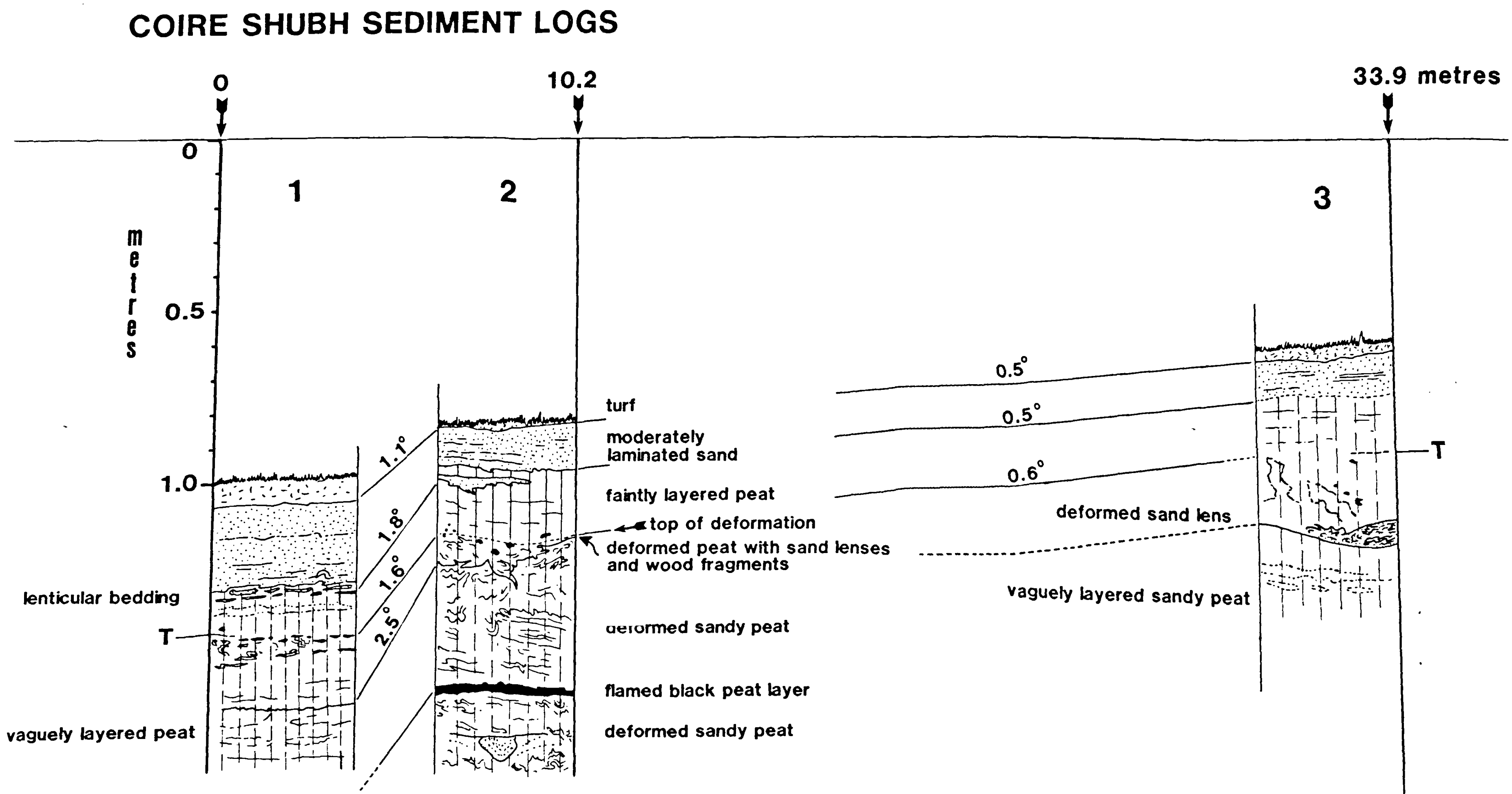


Fig.16-3. Stratigraphic log of the Coire Shubh sections. The ornament is the same as that used in Fig.16-2. (See also Plate-31).

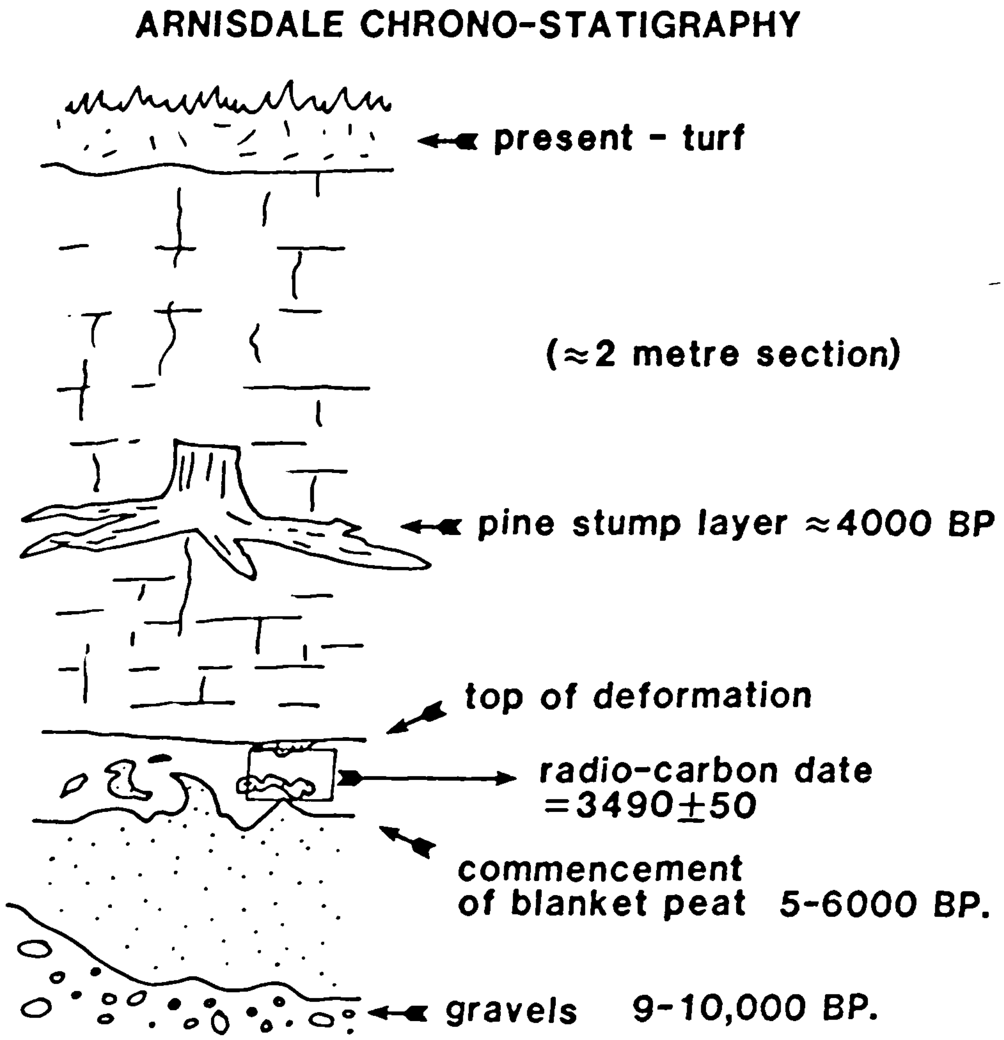


Fig.16-4. Summary of the known chrono-stratigraphic relationships to the deformed layer in the Arnisdale sequence.

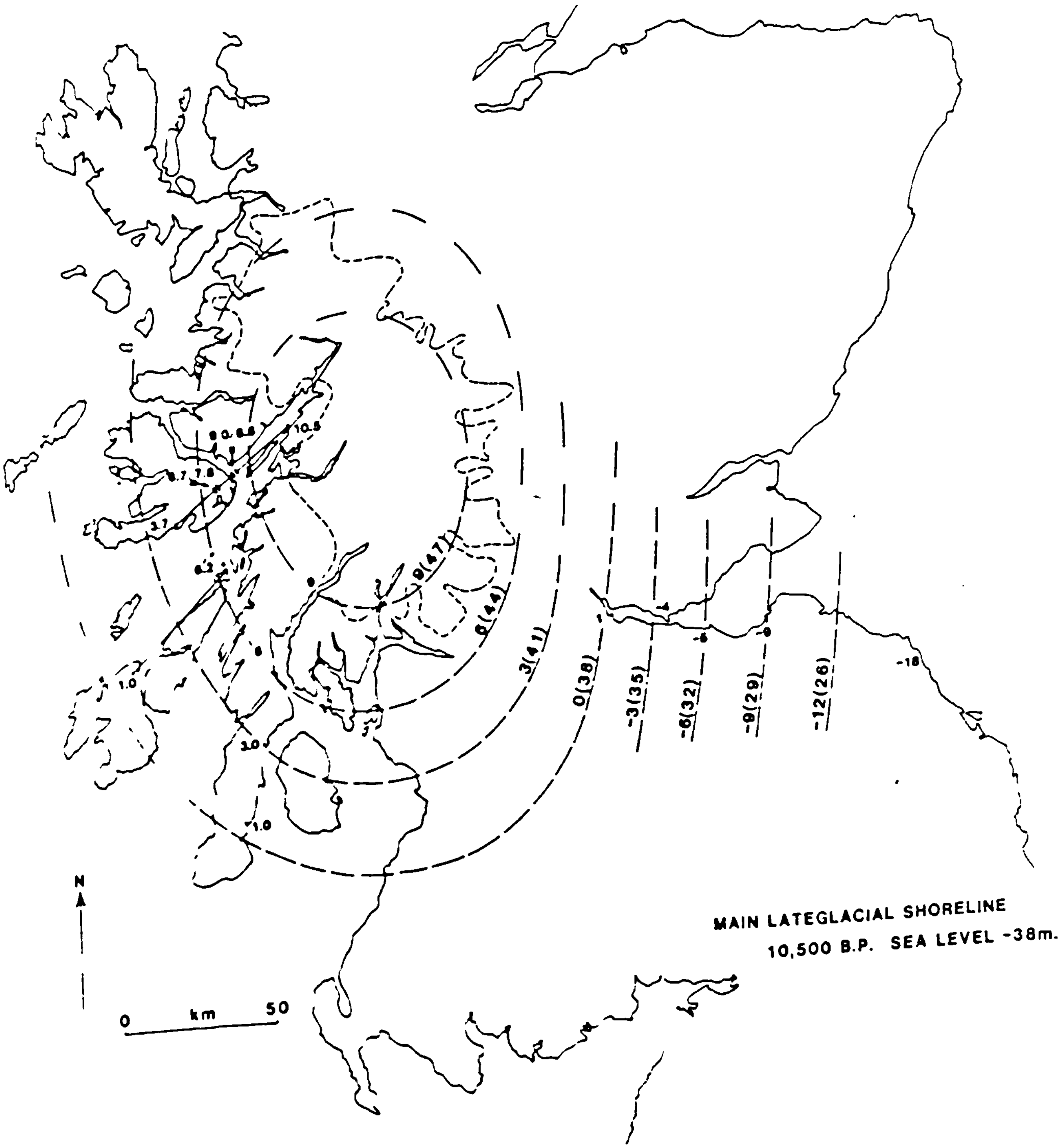


Fig.17-1. Shoreline-isobase map of the Main Lateglacial Shoreline.

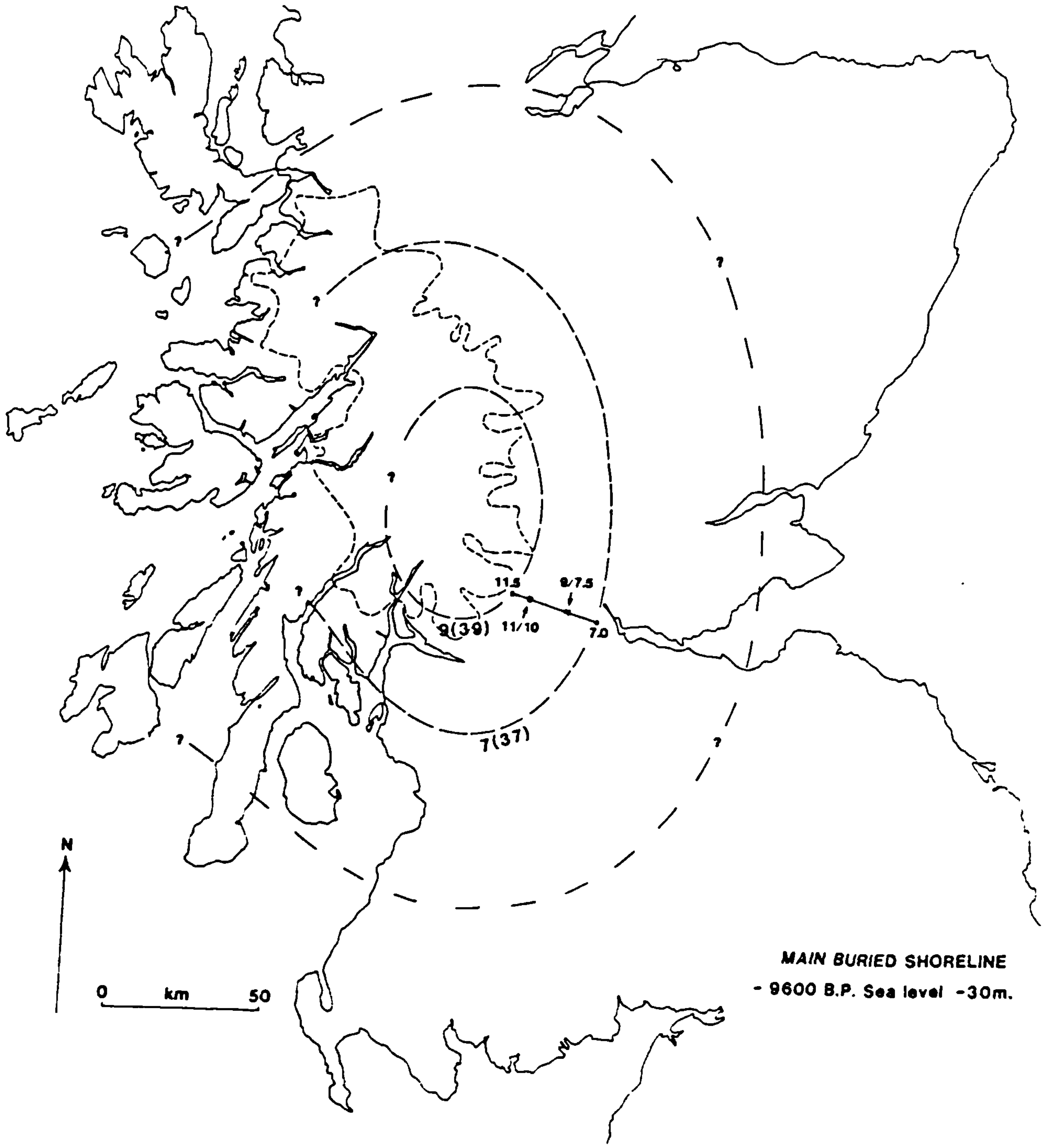


Fig.17-2. Shoreline-isobase map of the Main Buried Shoreline.

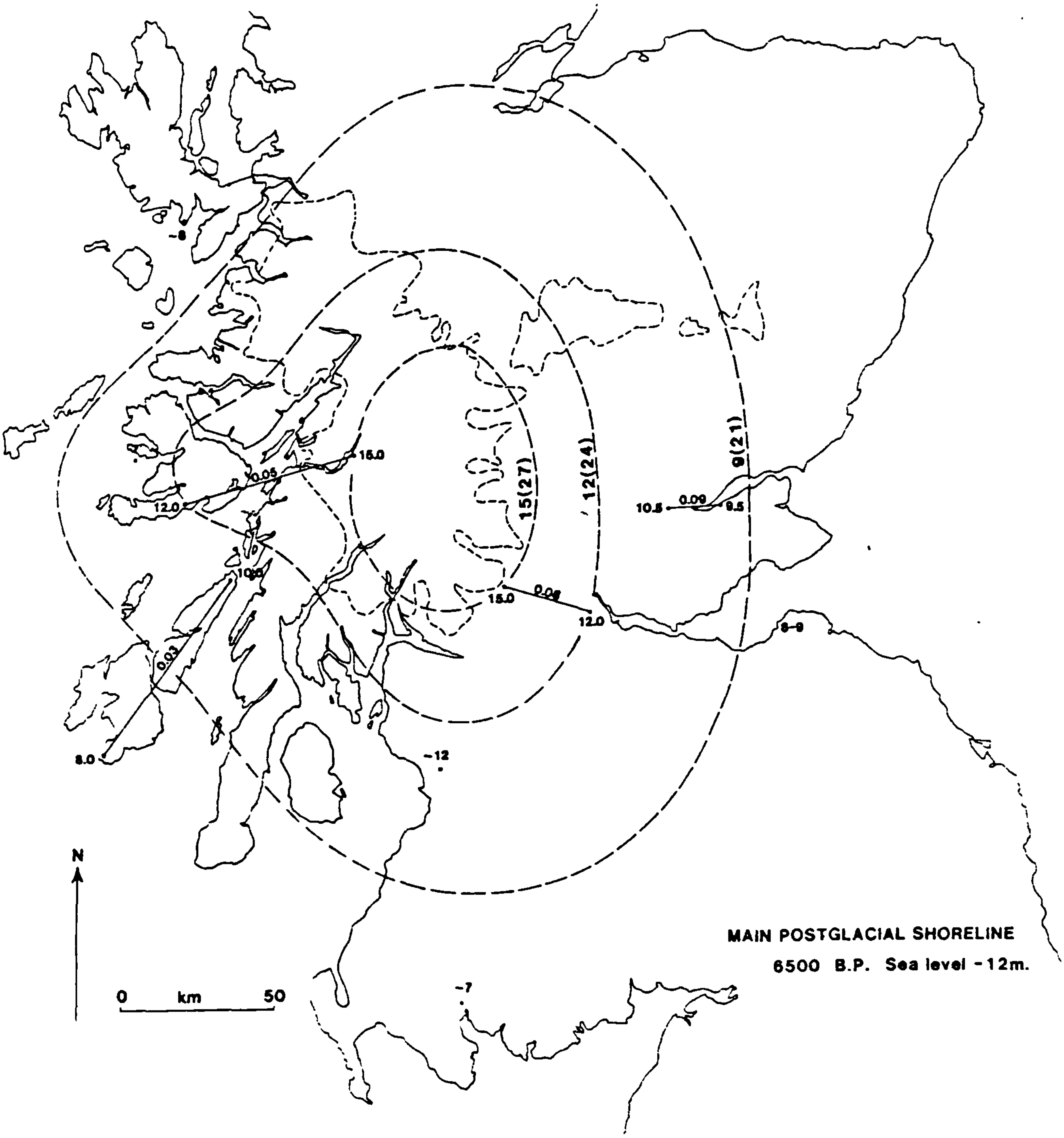


Fig.17-3. Shoreline-isobase map of the Main Postglacial Shoreline.

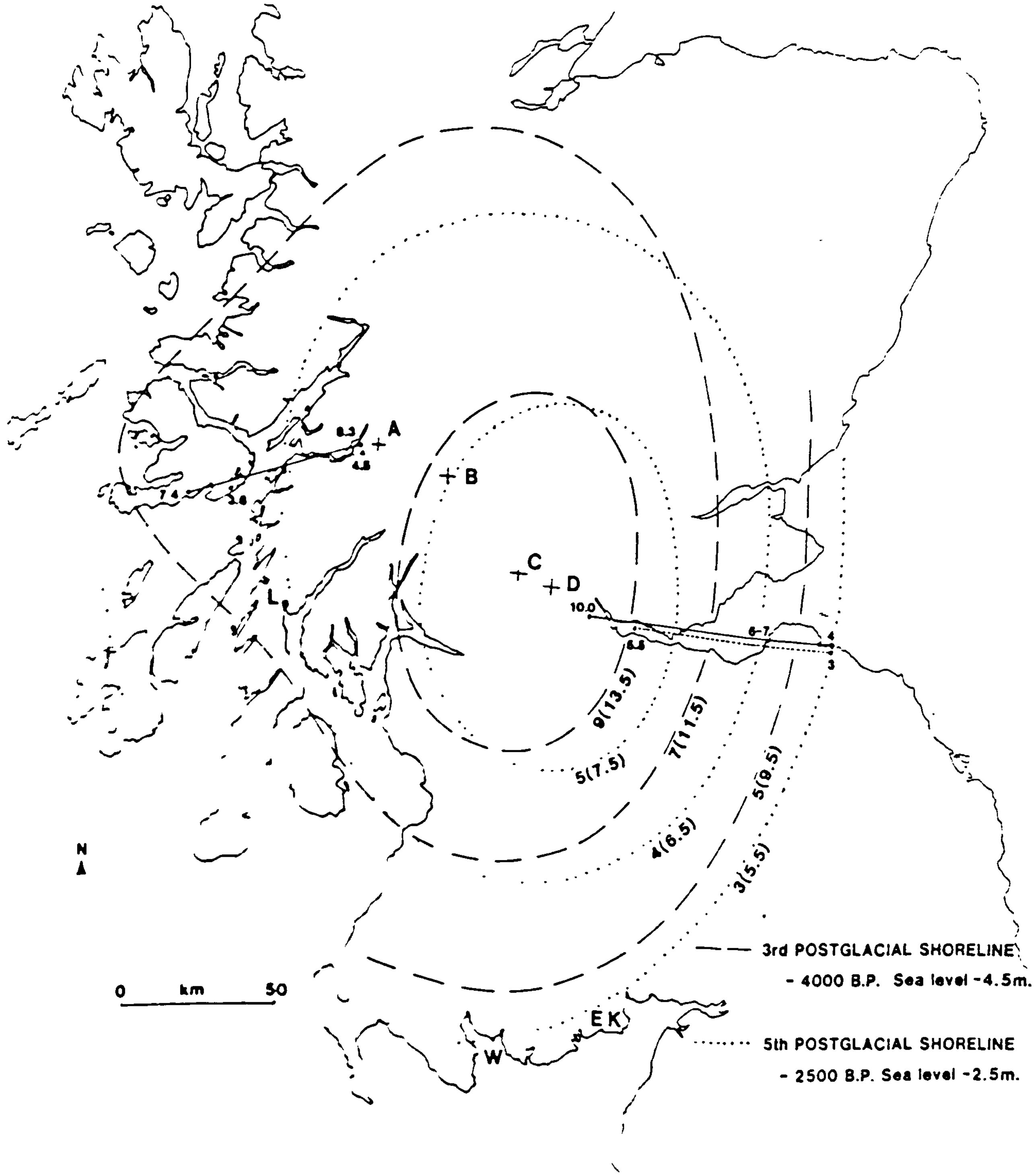


Fig.17-4. Shoreline-isobase map of the 3rd and 5th Postglacial Shorelines.

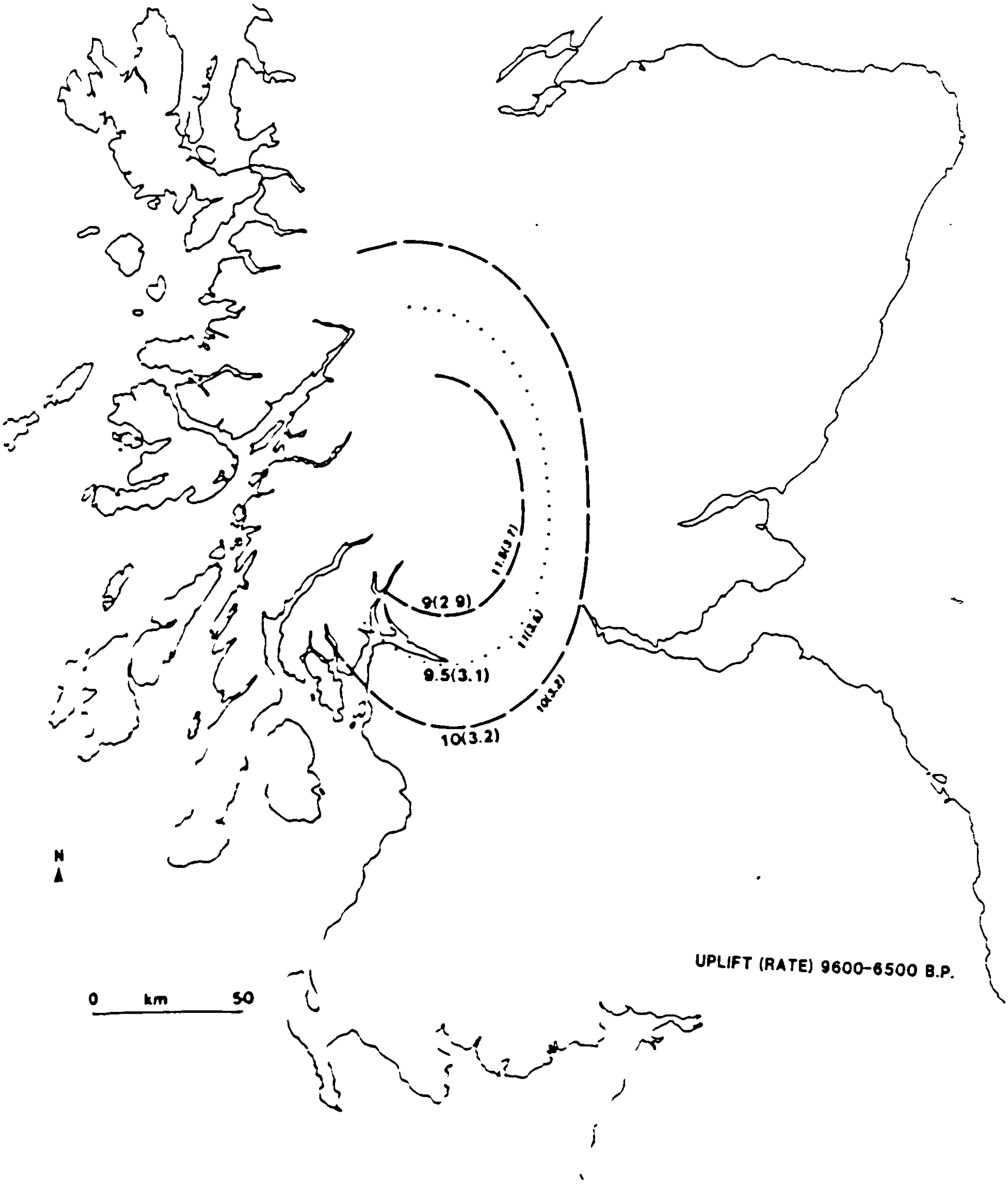


Fig.17-5. Map of contours of equal uplift between 9600 and 6500 years BP. (Uplift rate in metres per millennia).

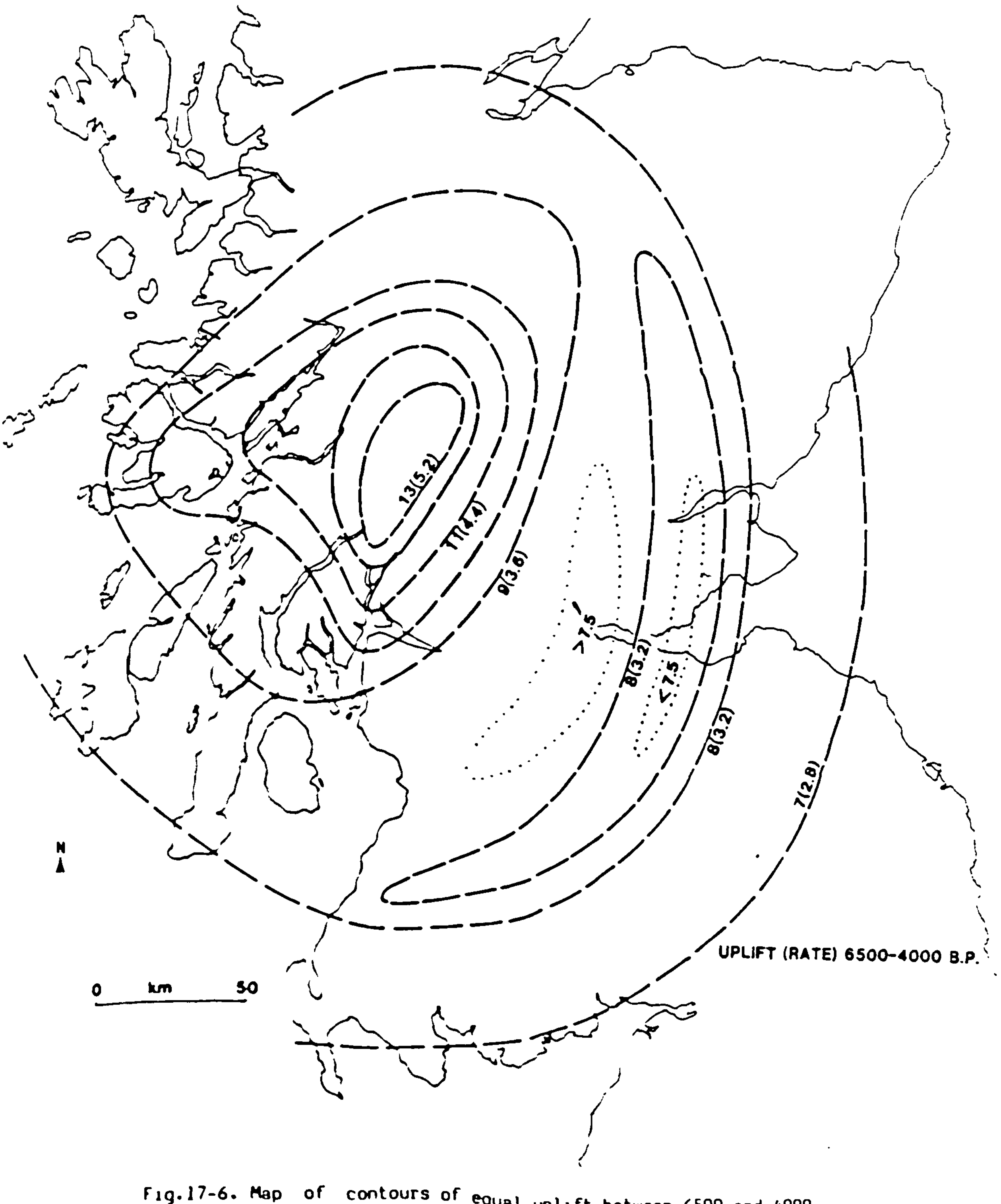


Fig.17-6. Map of contours of equal uplift between 6500 and 4000 years BP. (Uplift rate in metres per millennia).

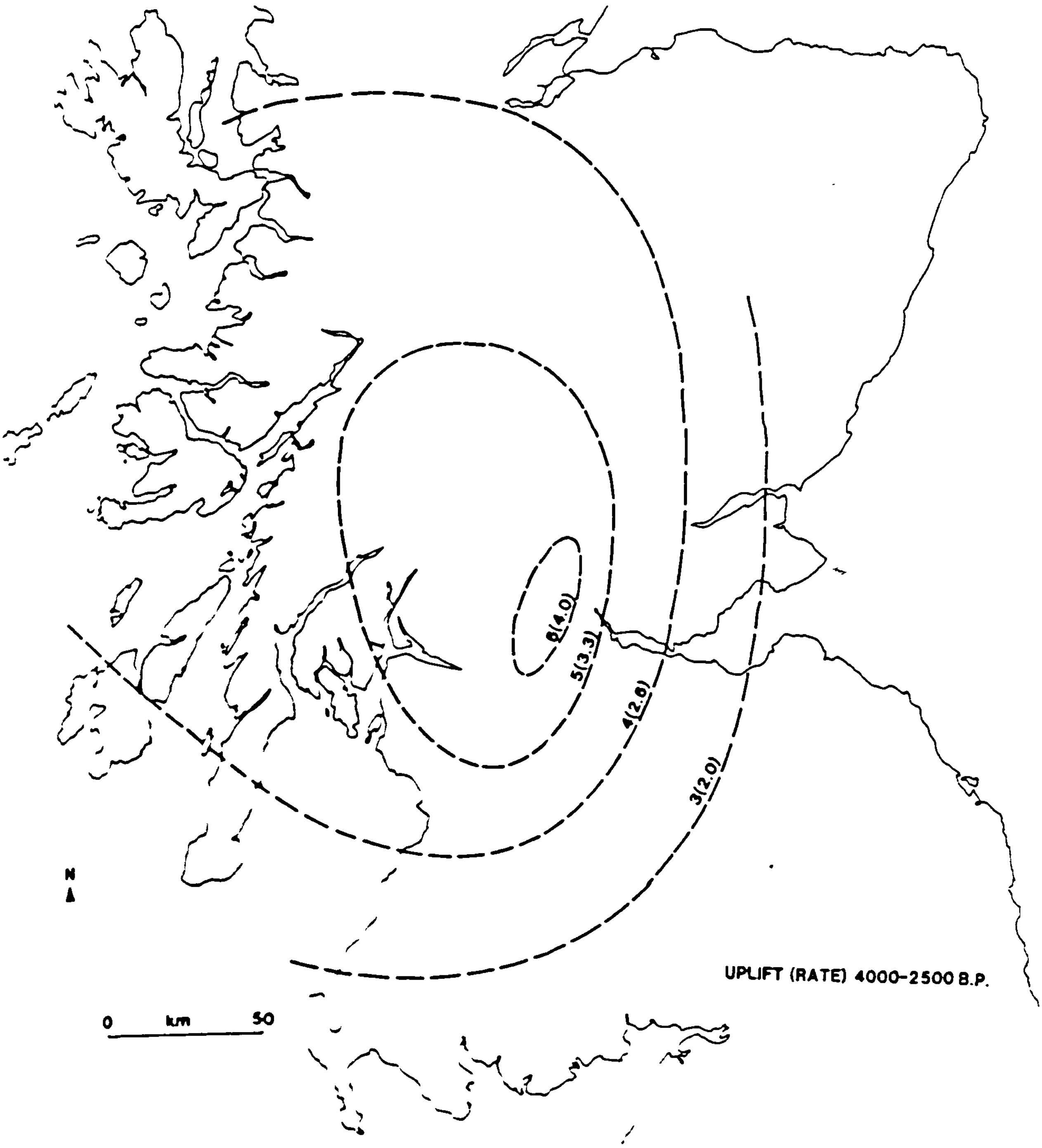


Fig.17-7. Map of contours of equal uplift between 4000 and 2500 years BP. (Uplift rate in metres per millennia).

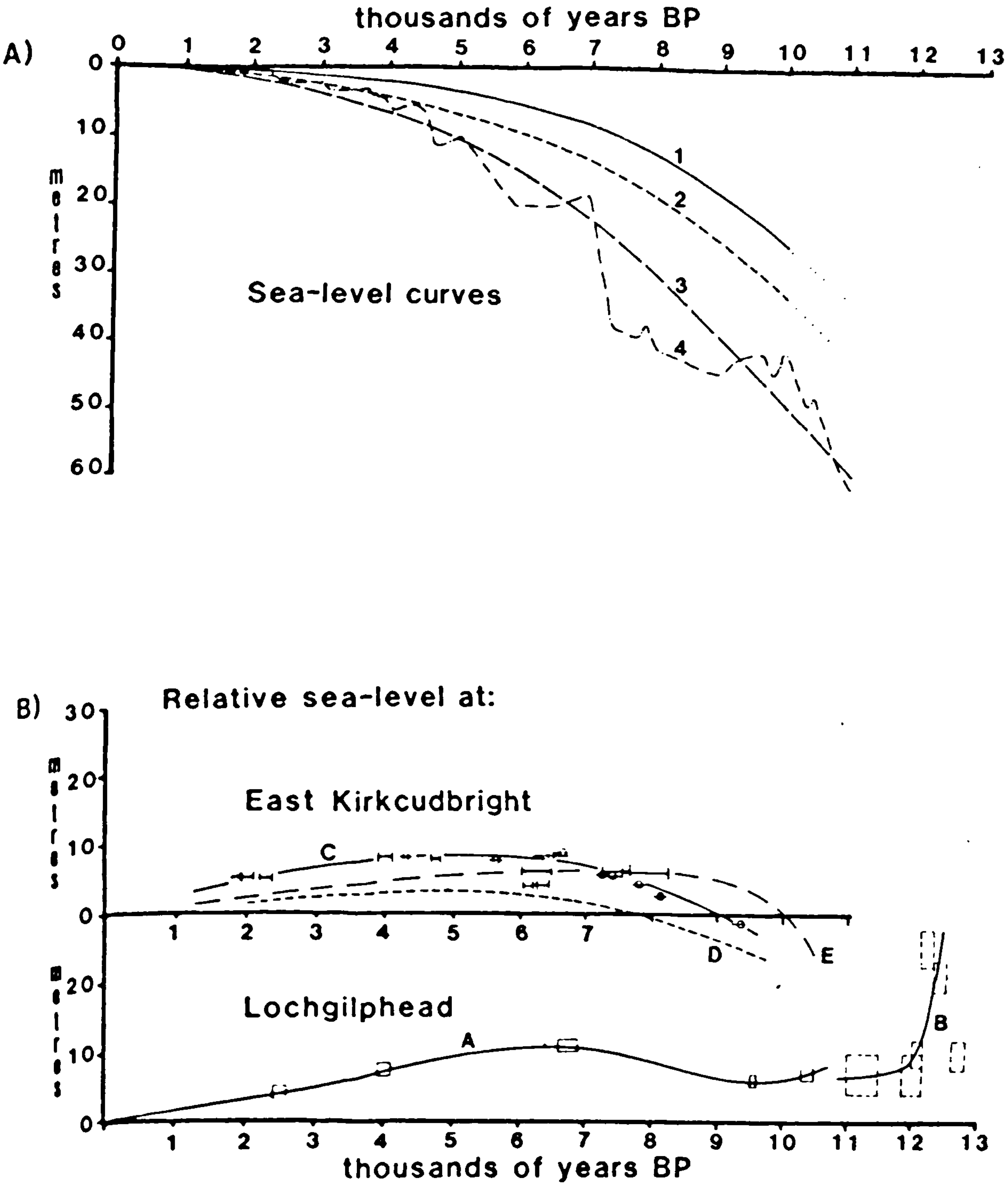


Fig.17-8. A. 'Eustatic' sea-level curves (see Table.17-2 for explanation).
B. Relative sea-level curves for two Scottish sites (see Table.17-2 for explanation).

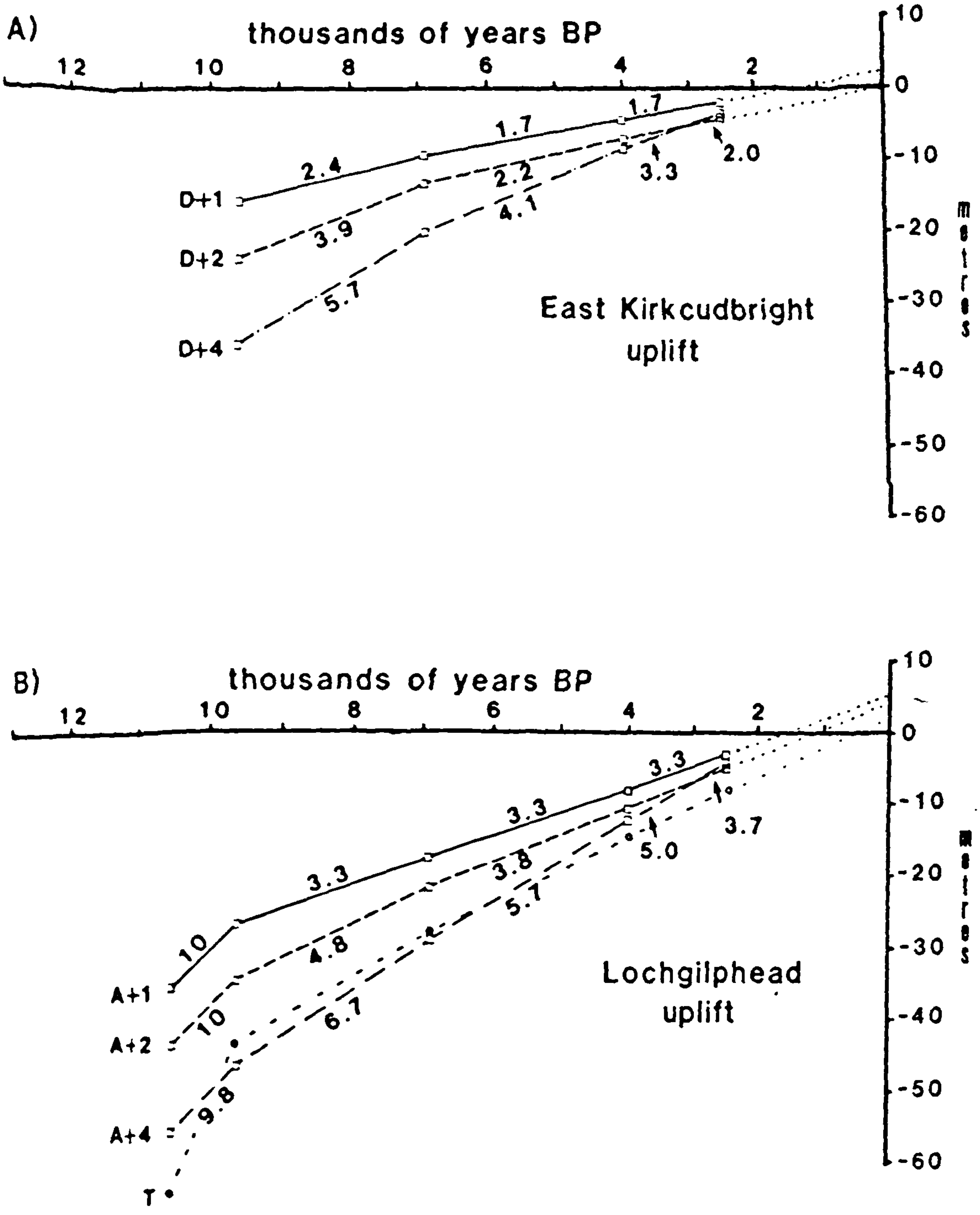
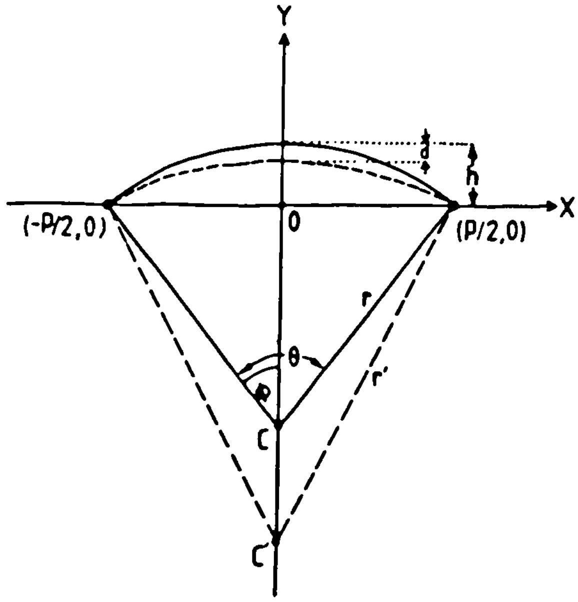


Fig.17-9. Crustal uplift at the two Scottish sites, determined by adding the eustatic *and relative* sea-level curves of Fig.17-8 as indicated. The values on each segment of the curves indicate uplift rates in metres/millenia. Curve 'T' is 'A+2' with an added tectonic factor of 1m of uplift per millenium (c.f. section 17.2.4).



Step 1: Consider a circle through points $(-P/2, 0)$, $(0, h)$ and $(P/2, 0)$ on a cartesian co-ordinate system origin 'O', as shown. Let the centre of the circle 'C' have co-ordinates (a,b).

$a = 0$,

if the radius of the circle is 'r', then,

$$r^2 = \frac{P^2}{4} + b^2 \quad \text{— (1)}$$

also $r^2 = (h-b)^2 = h^2 - 2hb + b^2$. — (2)

Then from 1 + 2.

$$\frac{P^2}{4} + b^2 = h^2 - 2hb + b^2$$

$$\therefore 2hb = h^2 - \frac{P^2}{4} = \frac{4h^2 - P^2}{4}$$

$$\therefore b = \frac{4h^2 - P^2}{8h} \quad \text{— (3)}$$

$\therefore$ from 3 + 1,

$$r = \left[\frac{P^2}{4} + \left(\frac{4h^2 - P^2}{8h}\right)^2\right]^{1/2} \quad \text{— (4)}$$

Step 2: Consider the triangle $C, O, (-P/2, 0)$.

$$\phi = \sin^{-1}\frac{P}{2r}$$

$$\theta = 2\phi = 2\sin^{-1}\frac{P}{2r}$$

The length of the arc of the circle $= r\theta$.

$\therefore$ arc length between $(-P/2, 0)$ and $(P/2, 0)$ is,

$$2r\sin^{-1}\left(\frac{P}{2r}\right) \quad \text{— (5)}$$

Now replace 'h' by $(h-d)$ to find arc-length of a circle with radius r'.

$$r' = \left[P^2 + \left(\frac{4(h-d)^2 - P^2}{8(h-d)}\right)^2\right]^{\frac{1}{2}} \quad \text{— (6)}$$

Note: this can be simplified to,

$$r'^2 = \frac{4(h-d)^2 + P^2}{8(h-d)} \quad \text{— (7)}$$

For the special case where $d = 0$,

$$r^2 = \frac{P^2}{4} + \left(\frac{4h^2 - P^2}{8h}\right)^2 \quad \text{— (8)}$$

this can be rearranged to give

$$P^2 = 8hr - 4h^2 \quad \text{— (9)}$$

Thus for any arc of a circle specified by 'P' and of known initial radius 'r' the change in length, caused by displacement 'd', can be found. This assumes that points $(-P/2, 0)$ and $(P/2, 0)$ remain fixed.

Fig.17-10. Mathematical proof for determining the change in length of an arc of a circle (developed by I. Stewart, pers. comm.).

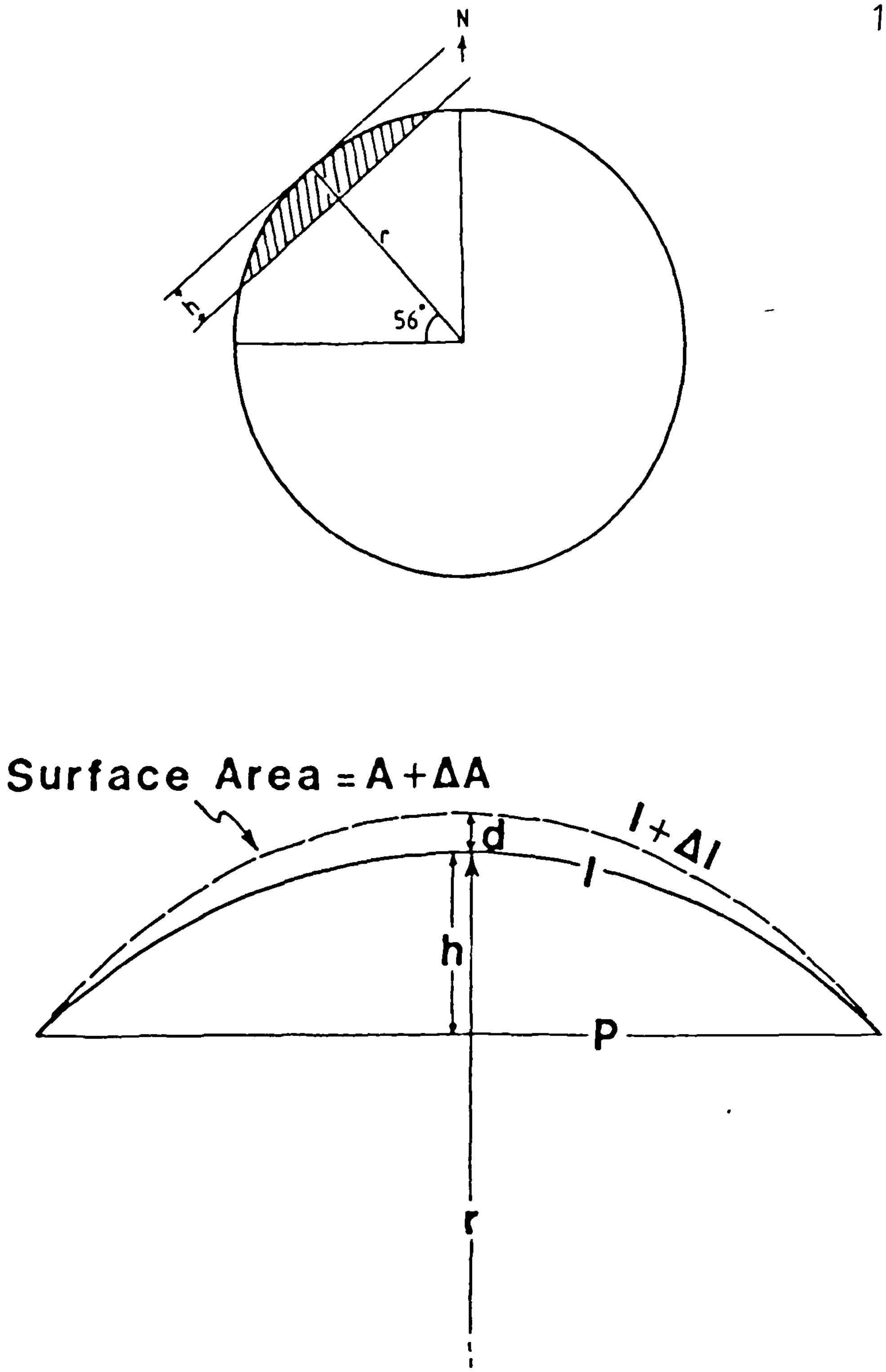
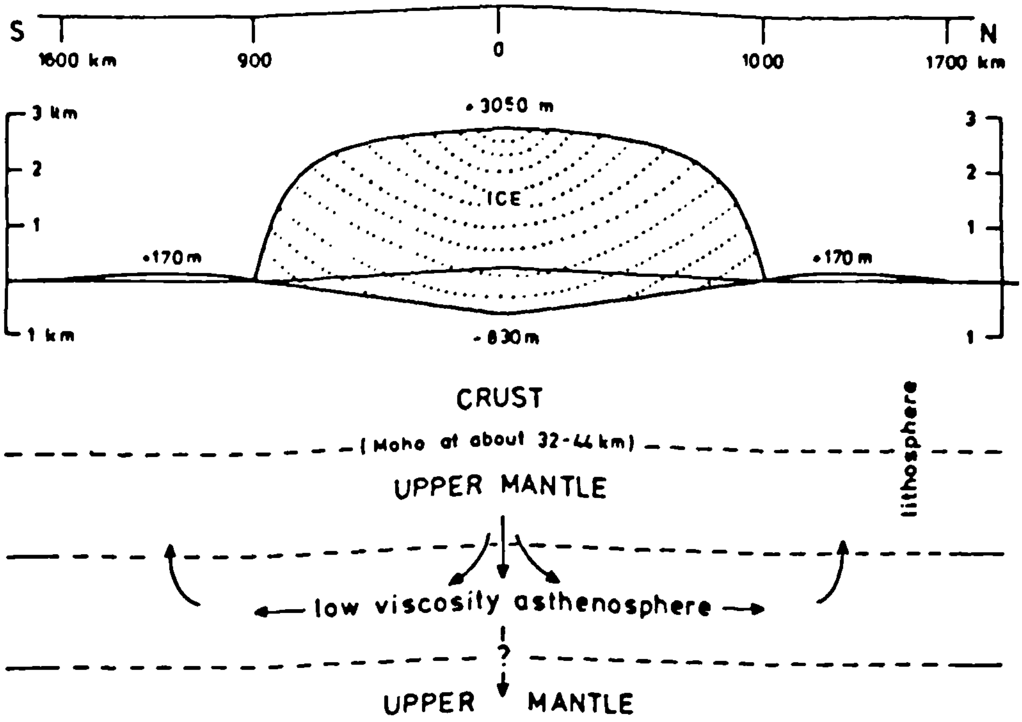


Fig.17-11. Sketches of the geometry employed in modelling the changes in curvature of a spherical segment (shaded area at a latitude of 56 degrees.
h = thickness of spherical segment,
A = surface area of spherical segment,
l = length of arc through centre of segment,
P = length of cord through centre of segment.
A change in curvature by displacement of the centre by distance d results in a new arc length $l+\Delta l$ and area $A+\Delta A$.

A



B

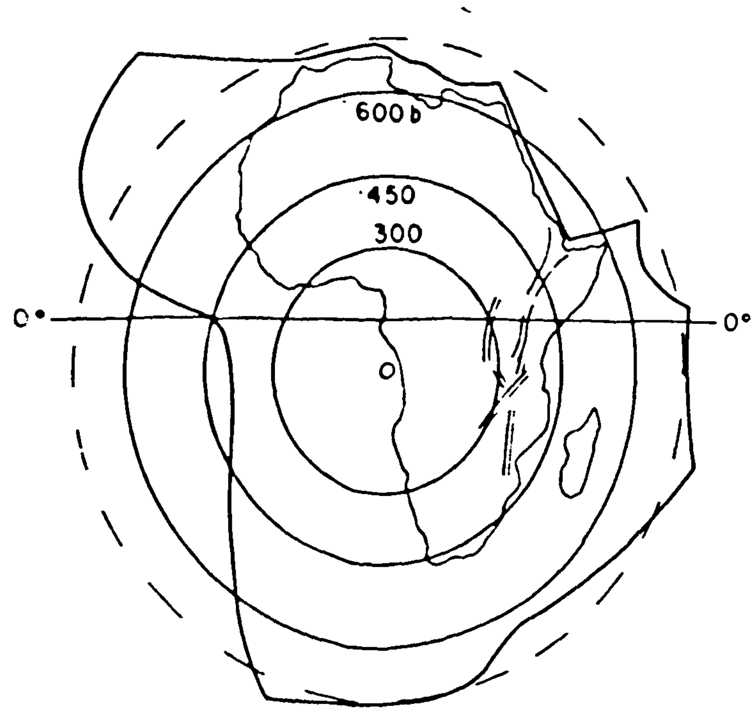


Fig.17-12. A. Morner's 1981 model of displacements related to the Fennoscandian ice.
B. Stress contours (in bars for the continent of Africa calculated by Turcotte & Oxburgh (1976) as resulting from the change in curvature caused by the northward drift of the continent by 20 degrees of latitude in the last 100 Ma.

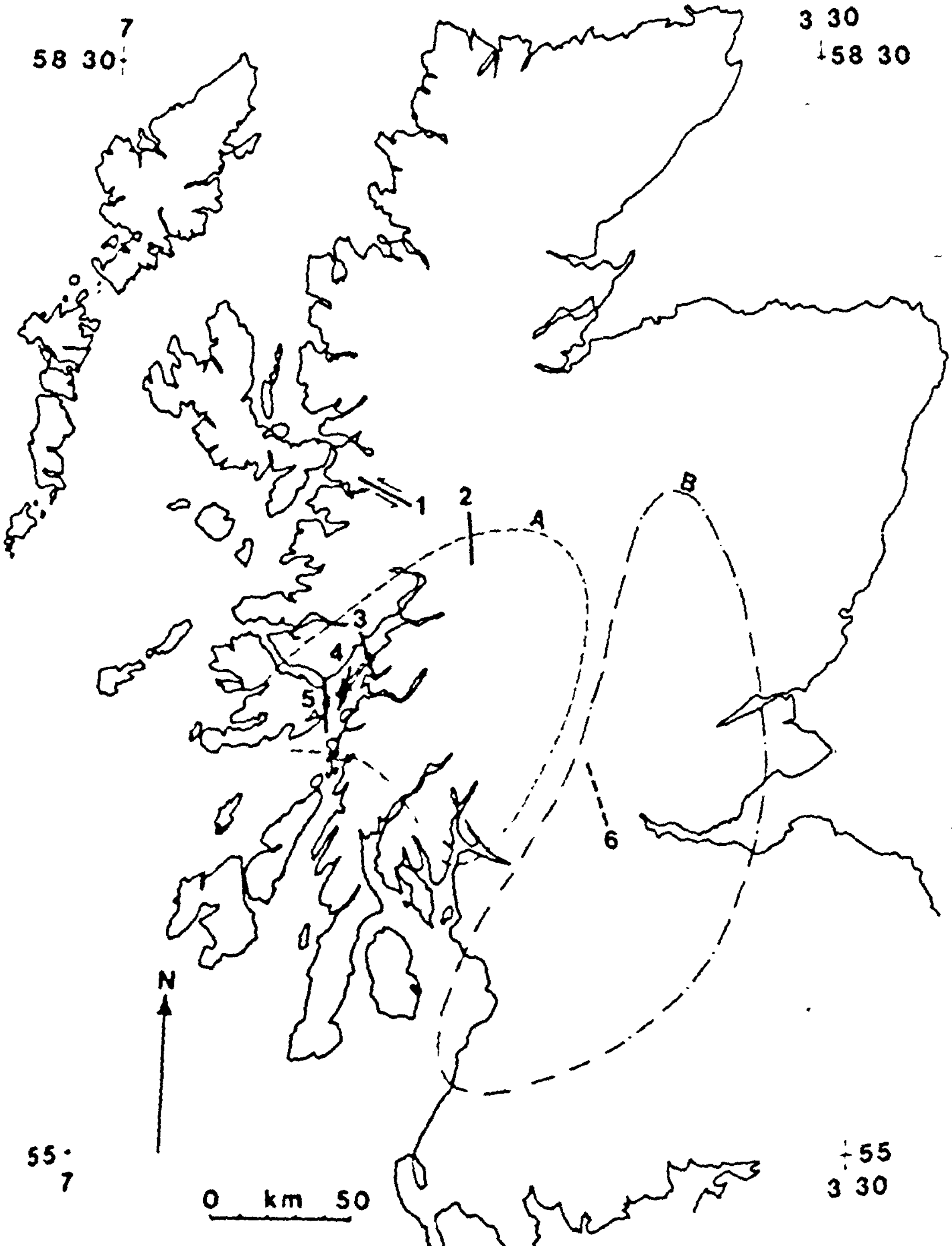
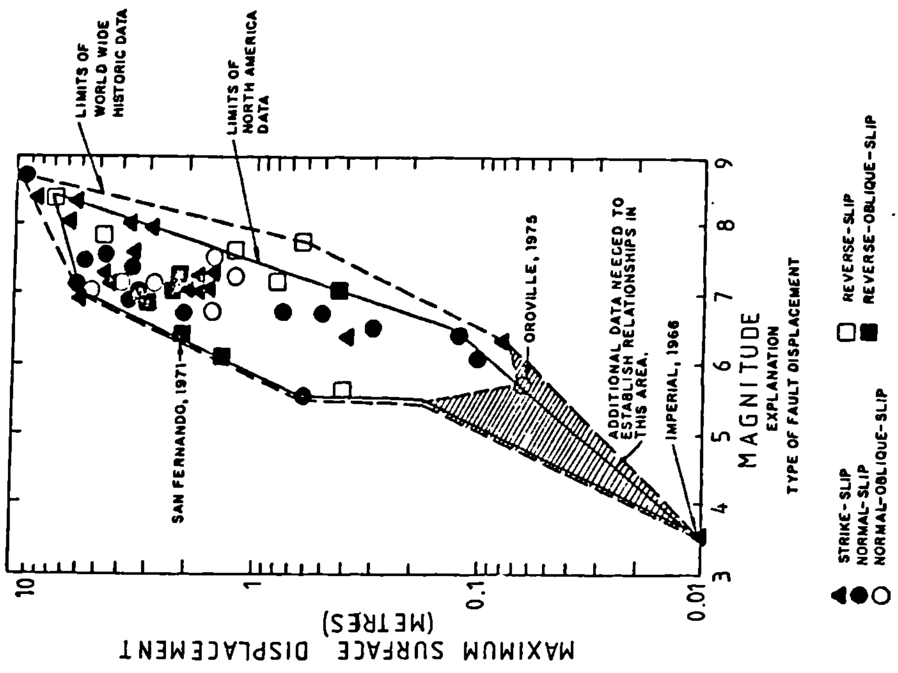


Fig.17-13. Post-glacial faults documented in this thesis, 1-Kinloch Hourn, 2-Glen Roy, 3-Shuna, 4-Lismore, 5-Port Donain, Mull; and 6 - the displacements reported by Sissons 1972). The fault for this last displacement has not been identified but a lineament of the orientation shown is suspected from field and remote sensing study (Davenport & Ringrose 1987b).

B.



A.

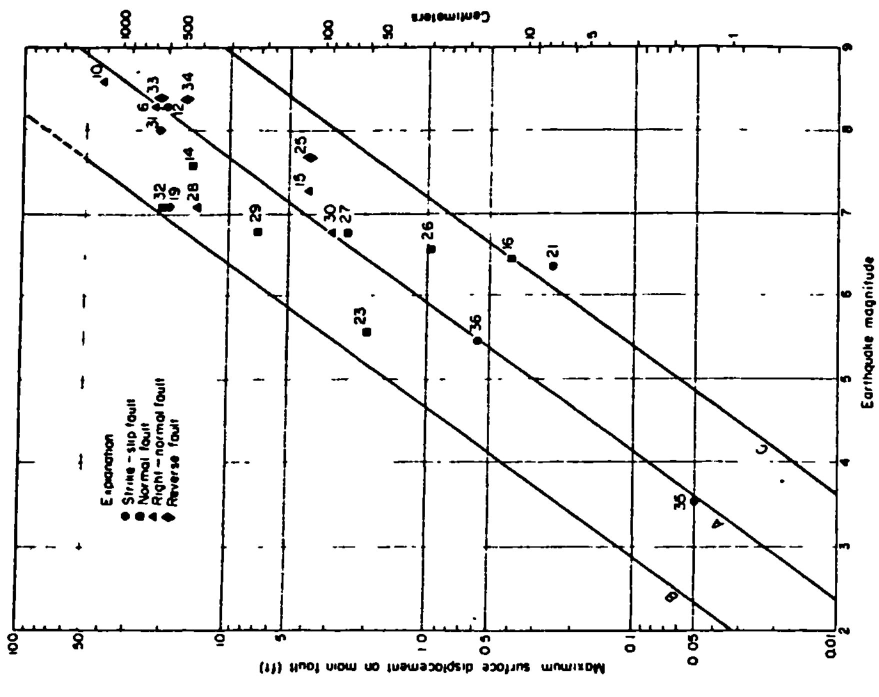


Fig.19-1. A. Bonilla's (1970) relationship for earthquake magnitude and maximum surface fault displacement based on North American faults. Line 'A' is the best-fit for the data (the relationship is given in Table.19-1).
B. Maximum surface displacement and earthquake magnitude for a world-wide database (after Bonilla & Buchanan 1970).

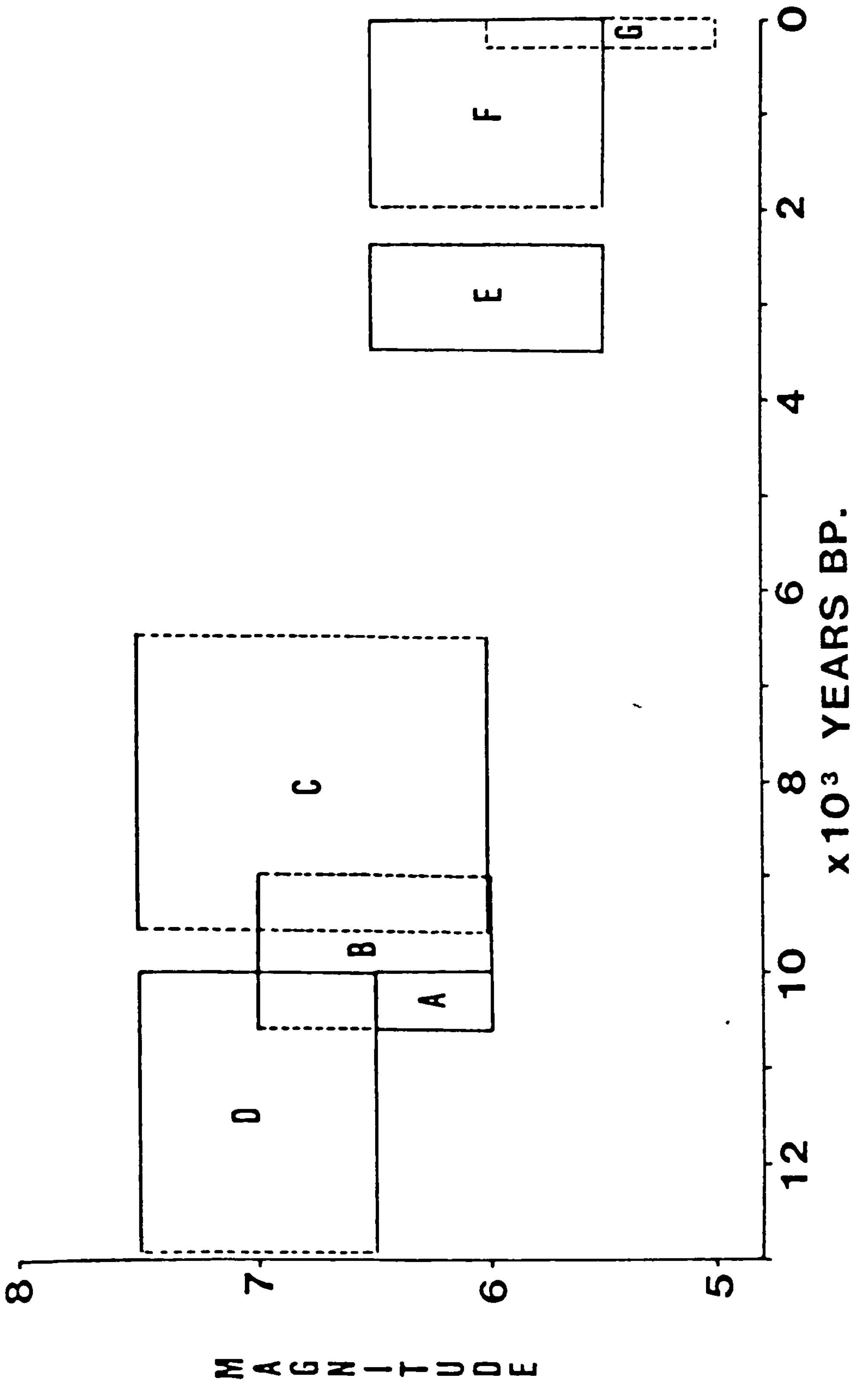


Fig.19-2. Scottish palaeoseismic events (for explanation see Table.19-2).

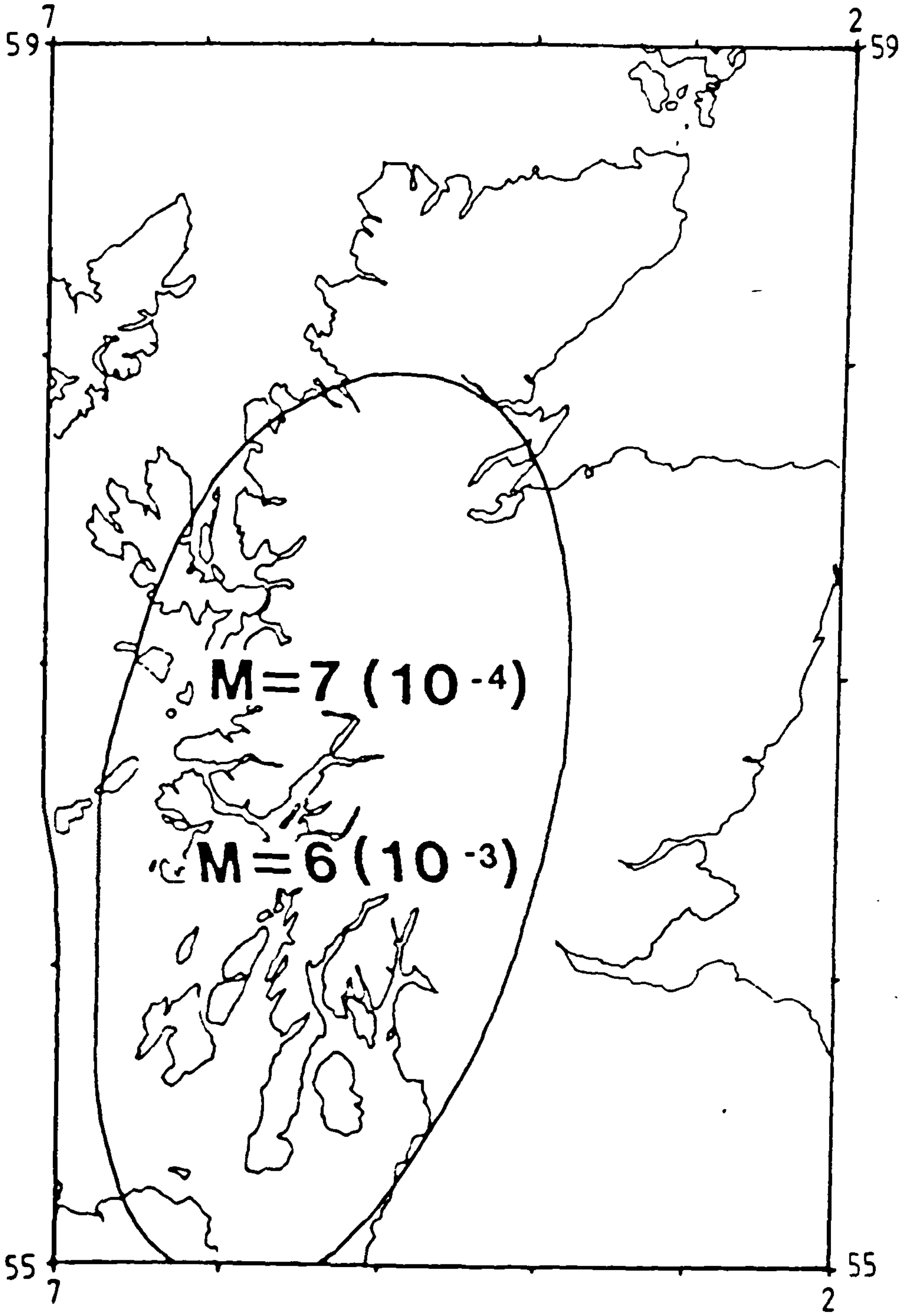


Fig.20-1. The proposed western, central Scotland seismotectonic zone with the suggested annual probabilities of occurrence for large events (i.e. one magnitude-6 event per 1000 years).

Appendices

APPENDIX 1

LISMORE FIELD NOTES

This appendix outlines field observations on faulting observed in the south of Lismore island, Firth of Lorne. The field notes are described with reference to Figs.9-3 and 9-4. More detailed field study was made along one section - the Miller's Port Fracture Zone. Field notes referring to this section are tabulated first, with reference to fracture identification numbers, 1 to 26 (displayed in Fig.9-4). Following this, field localities from the rest of the area studied are described with reference to locality numbers, 27 to 100 (displayed in Fig.9-3).

Notes and abbreviations used

Miller's Port Fault Zone:

Fracture Identification Number (I.D.): referring to fractures illustrated in Fig.9-4.

Orientation: of fracture plane, given by strike direction / angle of dip.

Feature offset: identified by: A,B,C or D = dykes shown in Fig.9-4.
Morph. = a morphological feature.
20 = a fracture (I.D. number).

Offset and Sense: amount of offset diplayed by the feature (with estimated error in brackets) and the sense of displacement indicated by:
S = sinistral
D = dextral
T = thrust.

General:

Locality: locality number shown in Fig.9-3.

Orientation data: the attitude of various features, given by strike direction / angle of dip. Features indicated by:
l.f. = limestone foliation
d = dyke
f = fracture plane
f.t. = fracture surface trace.

Some terms used in the field notes

Emplacement offset: an offset (or step) in a dyke which is clearly a feature of the initial intrusion of the dyke.

Hydrothermal: this term is used descriptively for alteration features and allochthonous deposits within a fracture, thought to result from hydrothermal activity.

Rubble texture: alteration of an igneous intrusion such that it froms a tightly-packed 'gravel' (c. cm-sized clasts), having lost the primary fabric.

Onion-skin texture: spheroidal weathering of intrusive rock, thought to have a hydrothermal origin.

Crofter's dyke: man-made wall - a field boundary constructed of stones and turf (usually much less than a metre high and wide).

Head-dyke: Large crofter's dyke at the limit of farmed land.

LISMORE FIELD NOTES: MILLER'S PORT FRACTURE ZONE.
[N.B. in localities 1-26 (at Miller's Port) 'A,B,C,D' refer to four dykes. Each of these dykes has a fairly variable thickness, but mostly in the range of 1-2m thick.]

Fracture I.D.Number	Orientation (degrees)	Feature offset	Offset & sense (metres(error))	Notes
1.	025/35W	B	? - S	Could be a sinistral displacement of 1-2m, however change in orientation of dyke from 042/vert (south) to 080/60S (north) suggests an emplacement offset, if any. Exposure not good.
2.	024/38E	B	? - D	Could be a dextral displacement of 10m or so, as inferred by dyke trend - speculative.
3.	030/64W	C	? - S	Sharp fracture, looking very similar to other dyke offset fractures. Dyke is submerged by seawater at fracture but morphology suggests sinistral offset.
4.	020/86W	C	2.1(0.1) - S	Dyke orientation around 060/vert.
		B+A	?	Not sufficiently exposed.
5.	016/42W	a) C	1.0(0.3) - S	Displacement is difficult to measure because of very low angle of intersection with dyke (057/74S on north side). Fracture bends to follow along east side of dyke (032/52W) before running into sea.
		b) Morph.	0.9(0.2) - S	Freshly exposed surface of limestone on footwall, not etched like all surrounding rock, is consistant with this displacement. However, the removal of a block of rock could possibly explain the freshly exposed surface.
	037/46W	c) C	0.8(0.1) - S	Dyke C outcrops as an en eschelon emplacement jump such that this fracture cuts the dyke twice.

LISMORE FIELD NOTES: MILLER'S PORT FRACTURE ZONE.

Fracture I.D.Number	Orientation (degrees)	Feature offset	Offset & sense (metres(error))	Notes
6.	178/63W	Morph.	0.50(0.05)-S	White patch on freshly exposed surface of limestone matches neighbouring rock profile very closely on restoration of this displacement.
	"	a) clay	-	2mm thick clay, exposed manually, reveals a lineation (slickenlines/shearing?) pitching 17 degrees south on the fault plane - 178/63W.
	"	Morph.	0.49(0.02)-S	Offset indicated by distinctive foliation surfaces either side of the white patch (a).
	"	b) Morph.	0.47(0.02)-S	Offset indicated by distinctive foliation surfaces and by a bevelled calcite vein on a protruding block.
	"	c) C	0.5(0.1) - S	Dyke orientation: 052/82S (north) and 068/80S (south).
	025/?	d) Morph.	0.55(0.05)-S	Pale, smooth and relatively unetched patch on limestone restores moderately well with adjacent rock and grass profile.
	"	e) Morph.	0.5(0.2) - S	Limestone morphology and lithology.
	"	f) Morph.	0.5(0.2) - S	Darker, smoother surface on limestone with absence of lichen and etching of fractures. Restores well with adjacent slope profile.
		A&B	?	Not sufficiently exposed.

LISMORE FIELD NOTES: MILLER'S PORT FRACTURE ZONE.

Fracture I.D.Number	Orientation (degrees)	Feature offset	Offset & sense (metres(error))	Notes
7.	032/50W	C	20.0(0.5) S	Dyke orientation: 050/vert.(south) and 065/80S (north).
	060/34N	B	4.7(0.3) - S	Dyke orientation: 100/70S (between fractures 7 and 7a.).
	"	A	?	Not sufficiently exposed, but an en echelon jump of some kind would need to be inferred.
7a.	000/64W	B	9(2) - S	Estimated by extrapolation only; very poor exposure.
8.	026/vert.	C	6.5(0.5) - S	Limited exposure.
	030/?	B	15(1.0) - S	Poorly exposed.
		A	?	As for fracture 7 (above).
8a.	032/77E	C	19.5(0.5) -S	Dyke orientation: 085/75S (between fractures 7 & 8).
9.	000/50W	B	?	Not seen - below seawater.
	"	A	1.1(0.1) - D	Moderately exposed; cannot rule out emplacement offset.
10.	154/38W	A	1.9(0.1) - D	Dyke orientation: 042/vert. (north).
11.		A	? - D	Dyke trends either side of bay suggest a dextral offset of several metres - speculative.
12.	018/75W	B	1.8(0.1) - S	Dyke orientation: 043/vert.(south).
		A		Not sufficiently exposed.
13. (W)	115/18N	B	3.9(0.1) - T	Shallow dipping fracture bounded by fractures 12 and 14, Displays slickenlines on calcite plunging 14 degrees west.
(Y)	084/24N	B	2.2(0.1) - T	Shallow dipping fracture bounded by 12 and 14.

LISMORE FIELD NOTES: MILLER'S PORT FRACTURE ZONE.

Fracture I.D.Number	Orientation (degrees)	Feature offset	Offset & sense (metres(error))	Notes
14.	175/40W	B	2.6(0.1) - S	
		A	3.0(1.0) - S	Poorly exposed.
15.		B	3.0(1.0) - D	More probably an emplacement offset. Poorly exposed.
		A	? - D	Could be displaced by 1-3 metres - speculative.
16.		B	1.0(0.5) - S	Poorly exposed - speculative.
		A	?	Dyke very poorly exposed; fracture trace conjectural.
17.	033/vert.	-	-	Slightly sinuous, sharp fracture; contains limestone and calcite breccias and extensive veining.
18.	020/80E			Sharp eroded fracture.
19.		C&D		Very prominent fracture; abundant calcite veining; No offsets apparent, but no direct exposure at dykes.
20.	030/vert.	D	0.6(0.1) - S	Sharp but closed fracture with few mm of calcite.
21.	122/56S	20	0.11(0.01)-D	Sharp, mostly open fracture offsetting fracture 20.
22.	142/vert.	20	0.6(0.1) - D	" " "
23.	107/81S	20	0.08(0.01)-D	" " "
24.		D	1.1(0.1) - D	Not exposed immediately adjacent to fault; could be an emplacement offset.
25.		-	-	Poorly exposed fracture.
26.		C	40(10) - S	Exposure very poor, but morphology strongly suggests this offset.

LISMORE FIELD NOTES: GENERAL.

Locality	Orientation data	Notes
27	020/vert.(f)	A set of four fractures, only one of which has displaced the 2m-thick dyke which shows a 0.4±0.2m sinistral offset. The fractures are infilled by calcite and possibly thin films of clay.
28	042/72E(l.f.) 055/88S(d)	0.75m-thick dyke following the limestone foliation; several emplacement offsets across the foliation are seen; no fault offsets.
29	-	Fracture with orange hydrothermal alteration infilling.
30	-	1m-thick dyke, pinching out to the north; unaltered, unfaulted.
31	165/vert.(f)	Fracture offsetting dyke by 1.6±0.1m dextrally. No evidence of hydrothermal alteration along fracture, however, offset dyke does show alteration, indicating post-hydrothermal faulting.
32	-	2m-thick dyke; variable trend with several en-eschelon emplacement offsets, as well as the faulted offset on fracture 31.
33	100/50N(d)	1m-thick, hydrothermally altered dyke.
34	-	2-3m-thick dyke, slightly altered with rubble-texture; curved surface trace inland - if exposed trends are extraploated c.100m of sinistral offset is implied on the extrapolation of the Miller's Port Fracture zone.
35	038/?(f.t.)	Strike-parallel fracture, with some alteration and brecciation within it; 0.5m-thick dyke pinches out landwards; its intersection with the fracture is not exposed.
36	-	2m-thick, near-vertical dyke; very variable emplacement trend.
37	-	1m-thick dyke.

LISMORE FIELD NOTES: GENERAL.

Locality	Orientation data	Notes
38	-	Fairly sharp linear; possibly an unexposed dyke; evidence for offsets on two historical features searched for - not offset.
39	-	Sharp straight linear; not a dyke; continues right up to Miller's Port fracture zone and possibly through it.
40	-	1-2m thick dyke: variable trend, mostly vertical; many emplacement offsets.
41	-	Straight 2-3m thick near vertical dyke.
42	106/32S(d) 066/55S(l.f.)	Moderately well exposed fracture running alongside and to the north of a 1-2m thick dyke.
43	043/68S & 045/55E(l.f.) 142/54E & 136/66E(f)	0.20(0.05)m sinistral offset in lithology and morphology of limestone. Fracture is sharp and clean; no clays seen.
44	142/22N(f)	Clean, sharp, shallow fracture; contains some calcite veining (1-2cm thick), but mostly an open fracure; small rock fall beneath fracture; no displacement apparent.
45	-	Excavation of crofter's dyke across probable line of fault; no displacement apparent; 20 cm would be unresolvable (cf. locality 48).
46	-	Excavation in crofter's head dyke (1-2m wide, 0.5-1m high, with several large stones (up to 0.5m)); initial excavation strongly suggested a sinistral displacement of 20-30 cm close to probable fault trace; subsequent excavation to foundations indicated no clear displacement; wall has probably just fallen down. Limestone outcrops along probable fault trace seem to suggest a systematic offset of between 0.4 and 0.9m sinistrally, however exposure is poor and this observation remains speculative.

LISMORE FIELD NOTES: GENERAL.

Locality	Orientation data	Notes
47	045 & 070(f.t.) 024/80W(d)	0.5m-thick dyke sinistrally offset in two places, 3m apart, along fault trace (apparent by greener grass lines); offsets of 0.75(0.1) and 0.60(0.1)m perpendicular to dyke trend, or by 0.9(0.1) and 1.0(0.2)m if measured along fault trace; inspection of excavations at both offsets strongly favours displacement over emplacement.
48	030(f.t.)	0.2(0.05)m sinistral offset in a 0.3-0.4m wide crofter's dyke; dyke (trending 120) runs down steep slope; offset was initially apparent in the grass ridge morphology; removal of grass and soil revealed a narrow line of stones displaying the offset; subsequent excavation revealed a confused distribution of wall stones at greater depths, where offsets were impossible to define.
49	050(f.t.)	2m wide dyke with 6.5m dextral offset; probably an emplacement offset, but cannot rule out some displacement; exposure poor.
50	133/vert.(d)	2m thick dyke.
51	094/60N(f)	Fracture with net-veined calcite, heavily stained with oxides; some orange and pink hydrothermal(?) deposits. Two dykes: northern one - 1m thick, negative relief, very weathered (hydrothermal?); southern one 0.5m thick, positive relief, not heavily weathered.
52	060/60S(f)	Fracture, clean and open with some calcite veining and limestone breccia; could be some lithological clay - masked by beach sand.
53	140/vert.(d)	1m thick dyke with thinner near horizontal offshoots on either side.
54	168/42E(f)	Exposure of fracture at the side of 4m thick dyke; contains fresh micro-breccia and clay alongside calcite veining in a 3cm-wide fracture; rubble-texture weathering and negative relief suggest hydrothermal action; large rock-fall on raised beach near fracture.
55	104/40S(f)	1m-thick, very altered dyke, sporadically exposed in a fracture containing pink-orange hydrothermal deposit.
56	-	Hydrothermal deposit in fracture containing remnants of weathered dyke (30cm thick).
57	-	1m wide rubble filled fracture; no exposure of fracture contents.

LISMORE FIELD NOTES: GENERAL.

Locality	Orientation data	Notes
58	118/72S(f)	Very sharp fracture with up to 30cm of hydrothermal breccia; cliff morphology suggests 2-3m of sinistral displacement? - speculative.
59	128/vert.(f)	1m-thick fracture zone with hydrothermal material and purple staining in veins.
60	146/vert.(f)	10cm thick calcite-filled fracture; no hydrothermal material.
61	-	5m thick dyke; calcite veining and greater weathering on one side of dyke suggest some hydrothermal activity.
62	-	1-2m thick dyke displaying emplacement offsets.
63	-	Thin calcite-filled fracture; no hydrothermal material.
64	-	Two dykes - 0.5m-thick (south) and 1m-thick(north); the northern one contains 4-5cm of orange hydrothermal material alongside some calcite hydrothermal material alongside some calcite veining; both appear to be offset by a similar amount to the dykes of localities 66 and 67, however exposure is below low-water mark.
65	040/vert.(f)	1m wide fracture zone of sheared limestone; roughly parallel to foliation; sinistral displacement of 4.7(0.3)m is confirmed by similar offsets on three dykes (66&67) and less clearly on two others (64).
66	-	2m thick dyke sinistrally offset by 4.8(0.2)m on fracture 65; another sinistral offset of several metres is apparent across a poorly exposed fracture a few metres inland; this could well be an emplacement offset, however.
67	140/vert.(d) 102/vert.(d) 030/vert.(l.f.)	Two dykes (0.5 and 1m thick) intersecting at fracture where they are sinistrally offset by 4.5(0.1)m; thicker dyke contains hydrothermal mineral deposits very similar to that of locality 85; the hydrothermal vein is offset with the dyke and is not observed within the offsetting fracture zone; both dykes show evidence of hydrothermal alteration.

LISMORE FIELD NOTES: GENERAL.

Locality	Orientation data	Notes
68	-	Rubble-filled fracture; no hydrothermal material.
69	124/74S(f) 036/vert.(l.f.)	Fairly sharp fracture with calcite and hydrothermal infill; emplacement offset of dyke is associated with brecciation and thicker hydrothermal alteration; the associations here suggest that dyke emplacement was followed very soon after by hydrothermal activity.
70	-	Discontinuous calcite veins in rough fracture; limestone forms scarp along fracture; 0.5-1m dyke exposed only one side of this fracture.
71	139/61S(f)	Fracture clean and sharp with 1-2cm crumbly calcite infill.
72	-	0.5m dyke not offset; no hydrothermal material.
73	-	1-2m dyke; no hydrothermal deposit or alteration.
74	-	Very strong linear; broad open fracture with rubbly infill.
75	102/63N(f)	Cluster of several fractures of similar orientation; thin calcite infills; stepped topography suggests sinistral displacements of tens of centimetres.
76	206/59W(f) 046/76S(l.f.)	Slickenside, plunging 25 degrees south, in calcite; visable over portions of 10m of fracture surface.
77	124/?(f) 142/75W(f)	Fracture containing 0.3-0.5m thick hydrothermal material. Fracture with slickenside, plunging 62 degrees south; slickenside is very weathered but fracture is exposed for 30m.
78	-	Fracture with brecciated calcite veins in a zone 10-50cm wide.
79	-	Fracture with 0.5m wide zone of veining and brecciated limestone.
80	242/77W(f)	Thin fracture with clean calcite; roughly parallel to foliation.
81	126/40W(f)	Fractures containing 0.1m of calcite and brecciated limestone. No offset or movement apparent.

LISMORE FIELD NOTES: GENERAL.

Locality	Orientation data	Notes
82	157/88E(f)	Sharp fracture; calcite veining; topography suggests c.0.2m sinistral movement and 0.5m downthrow to the north.
83	-	Strike-parallel topographic features; no clear exposures of fracture.
84	021/?(f)	Broken and sheared fracture; very little calcite; strong topographic feature.
85	149/?(d)	4m-thick dyke; very weathered out and showing a variety of hydrothermal alteration. Running through the dyke is a dolomite/siderite vein which appears to have acted as the locus of alteration. Limestone country rock foliation - 143/vert.. This dyke appears to be sinistrally offset by 50-100m across fracture 84, on the basis of trend extrapolation. The alteration fabric is very similar to that of locality 67. Both localities are thought to be on the same dyke.
86	-	Three dykes: from south to north - 1m, sinuous, intrusion, inclined 120/225; 0.5m dyke similar to the first; 3m-thick vertical dyke, strike 155. No offsets of these dykes on the several fractures present.
87	-	0.5m dyke; very variable trend; no offset across the strike-parallel fracture it crosses.
88	-	Oblique intersection of hydrothermal fracture zone with 4m-thick dyke; at their intersection the dyke is heavily altered and sheared; no displacement can be inferred.
89	-	4m dyke, poorly exposed; showing shattered and sheared limestone on its southern side where slickenside in calcite is seen plunging 15 degress towards 337.
90	138/vert.(d)	2m-thick dyke showing 1.5m emplacement offset with clear chilled margins.
91	110/verts(d)	0.5m dyke; unaltered, not faulted.
92	135/55N(d)	4m-thick dyke; pinkish hydrothermal alteration at one side.

LISMORE FIELD NOTES: GENERAL.

Locality	Orientation data	Notes
93	-	1m-thick dyke, unaltered, prominant positive topographic feature; no offsets apparent; dyke cannot be seen in the coastal exposure.
94	134/33N(d)	1m-thick dyke exposed in foreshore, unaltered; cannot be seen inland; could perhaps correspond the dyke of locality 93 - a large emplacement offset perhaps?
95	052/?(f.t.) 048/85E(l.f.)	Prominent topographic gulley in the foreshore, parallel to foliation; comprising a zone, up to 2m wide, of stained, calcite veins and sheared limestone; often bounded on both sides by tight clean fractures.
96	-	1-2m wide zone of brecciated limestone with hydrothermal alteration.
97	-	0.5m dyke, very variable attitude and sinuous trace; unaltered.
98	109/vert.(f)	Very prominent, straight fracture; 0.1-0.3m thick fault breccia with dirty yellow and pink alteration; no clean calcite veins.
99	142/80E(d)	1.5m-thick altered dyke; onion-skin texture developed; negative topographic expression.
100	132/?(d)	2m-thick dyke; unaltered; positive topographic expression.

APPENDIX 2

RAISED SHORELINE LEVELLING SURVEY DATA

CONTENTS

A2.1 SURVEY PROCEDURE

A2.1.1 Description of sites

Shoreline levelling surveys were carried out at two sites:

a) The Isle of Shuna, Loch Linnhe, western Scotland.
b) Port Donain on the east coast of the island of Mull, western Scotland.

At both sites fault displacements of the 'Main Rock Platform' raised shoreline were suspected from the previous work of Gray (1974). Details of the sites are outlined in section A2.4.

A2.1.2 Objectives of survey:

1) Intensive survey of rock surface and soil surface heights within grids (approximately 30m by 30m) laid out on suitable portions of the raised beach with a view to acertaining the presence or absence of an identifiable shoreline level.

2) The 'levelling in' of intensive survey grids to measure relative heights of shoreline levels, where discernable, with a view to resolving vertical displacements on suspected faults.

3) The recording of relative heights and positions of permanent reference points as accurately as possible in order that re-levelling in the future may detect any current movement of the land surface.

A2.1.3 Methods:

Three kinds of levelling survey were carried out:

a) **Intensive survey grids:** Suitable portions of the 'Main rock platform' raised beach were located in the areas of interest by photographic and field survey; a 'suitable portion' being a sufficiently wide (greater than 10m) platform, relatively free from rockfall, vegetation and man-made cover. Permanent reference points were then emplaced as concrete pillars on freshly exposed bedrock surfaces (Plate-1). The instrument and tripod were placed vertically above each reference point using a plumb bob. The height of the instrument telescope above the reference point was measured with a metric tape. The instrument was positioned in this manner with an accuracy of less than ±10mm vertically and horizontally. A grid was then laid out using 30-metre tapes and ranging rods, with a general format of 4 lines running perpendicular to the shoreline spaced at 10m intervals. Along each line measurements of the height of the surface and of the bedrock were made every 3m (occasionally every 2-5m where necessary). The bedrock surface was located by boring through the soil cover with a peat bore or screw auger until no further penetration could be achieved. Soil thicknesses greater than 1m were not penetrated with the equipment used. The sound and 'feel' of the descending bore, and the material retrieved from it were useful indicators of whether bedrock, subsurface boulders or very stiff soil were the cause of 'no further pentration'. The vertices (corners) of each grid were surveyed in by measuring distances (by instrument stadia lines) and azimuths relative to one of the vertices to which a compass bearing was taken using a Brunton compass. The largest error in recording the grid location is the compass bearing:- ± 0.5°, which when siting over 50m would give an error of ±0.5m in position. Positioning of points relative to vertices is certainly less than ±0.5m and probably ±0.1m. Thus it should be possible to re-locate any point on a grid with an accuracy of less than 1m.

b) **Traverse lines:** Two such lines were surveyed at Port Donain in an attempt to locate the position of a suspected fault between grids. The survey method was similar to that above but along lines between two reference points and using instrument substations where necessary. Measurements were made every 5m typically in this case.

c) **Linking traverses:** That is, a levelling traverse made solely to measure relative heights between reference points, and having no 'interest' in the ground in between. Measurements were taken of staff heights viewed 30-60m from instrument substations. The linking traverses at Port Donain were made with the instrument set above the reference points, whereas at Shuna the staff was placed on the reference points; the later is the better and more accurate method. (This difference in procedure accounts for the slightly different data tabulation in these surveys.)

A2.2 SURVEYING INSTRUMENT DATA

Instrument: NI 050 Builder's Automatic Level - CARL ZEISS / JENA.
Measuring accuracy: Mean square error per 1 km double levelling = ± 5 mm.
Telescope: Magnification = x18
Field of view = 2° 24'
Level compensator: Working range = 60'

Mean setting accuracy = ± 1"

Graduated circle (for azimuth): Graduation interval = 1°
Reading by estimation to 0.1

Distance measurement by stadia lines (after Reichenbach):

horizontal distance (metres) = staff section x 100 + 0.1 (constant).

A2.3 TERMINOLOGY

A2.3.1 Explanation of abbreviations and terminology used in survey data tables

Azimuth: -angle measured in a horizontal plane from arbitary 'zero azimuth'.
Backsight: -sighting from instrument to staff backwards from the traverse direction.
Backslope or backing cliff: -raised cliff or steep slope occurring on the landward side of the raised beach platform.
Bore: -the height of the top of the peat bore or screw auger (1 metre) against the levelling staff at the bore's maximum penetration.
B-1: -bore height minus one metre, giving the thickness of soil cover.
Bottom: -height reading of the lower instrument stadial line.
Closing error: -the mis-match in level on completing a traverse circuit.
Diff.: -difference in height of the top and bottom stadial lines.
Distance: -distance measured according to the stadia line method.
Edge or lip of platform: -seaward edge of raised beach platform.
Foresight: -sighting from instrument to staff in the direction of traverse.
Instrument height (inst.hgt.): -height of centre of instrument telescope above reference point.
Knick (point): -marked change in slope at the landward edge of raised beach.
Level: -height of central stadial line on staff (i.e. the height of the instrument level above the ground surface) measured from a referenced station.
L+(B-1): -sum of height-above-surface and thickness-of-soil (i.e. the height of the instrument level above the rock surface).
Peat/sand/rock etc.: -soil stratigraphy - rock surface with sand and then peat ontop.
Position (posn.): -plan position of a survey point in a grid measured in metres along survey lines.
Raised beach (r.b.): -platform formed by former sealevel.
Reference (Ref.): -permanent reference point (concrete pillar).
Station: -referenced and mapped position of the levelling instrument.
Substation (Substn.): -unreferenced position of the levelling instrument.
Substation level (S.L.): -height of central stadial line on staff measured from a substation.
Top: -height reading of the upper instrument stadial line.

Traverse distance: -distance between the two end points of a traverse measured along the path of the traverse.

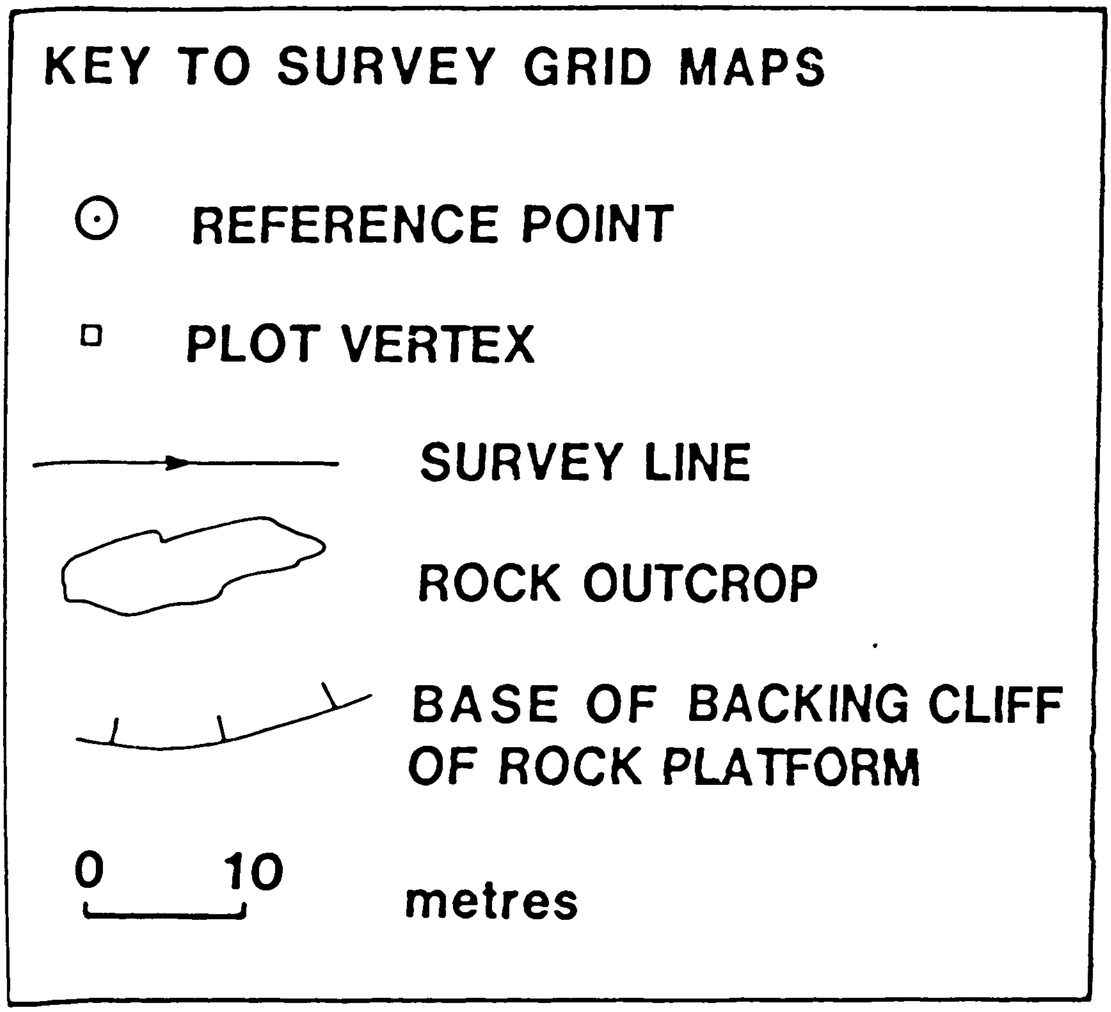
Vertex: -corner point of a surveyed grid.

A2.3.2 Units

All heights in metres (positive=upwards).
All distances in metres (or km where specified).
All angles in decimal degrees (measured clockwise from reference azimuth or true north).

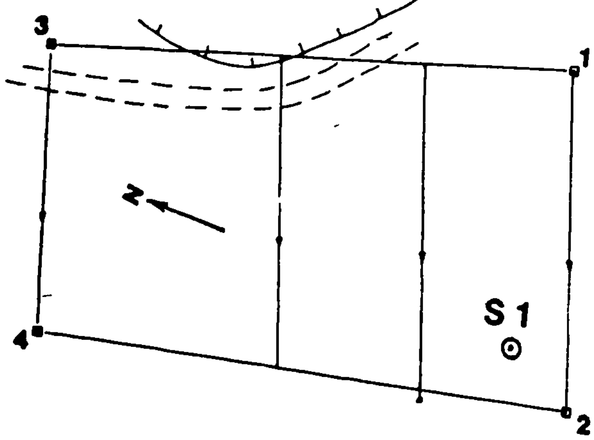
A2.4 MAPS OF SURVEY GRIDS

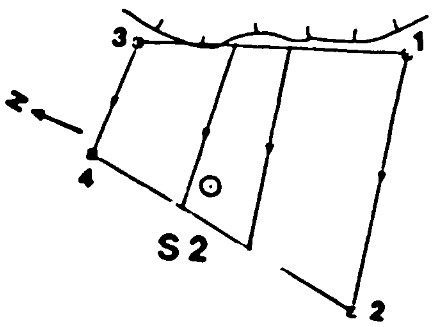
The maps below show the locations of the levelling survey grids: seven on the isle of Shuna and six at Port Donain, Mull. The grid location 'maps' are uncorrected, air photo interpretations with the locations of the survey grids and a simplified solid geology superimposed. The maps of the individual survey grids show the locations of the survey lines and are constructed, relative to each reference point, from the data tabulated in section A2.5.

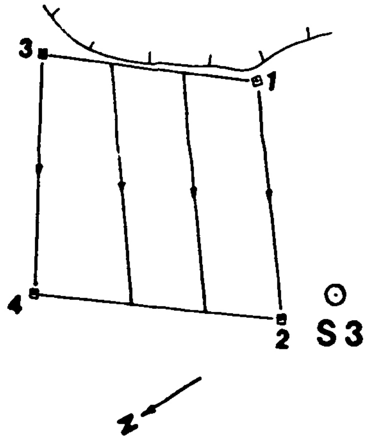


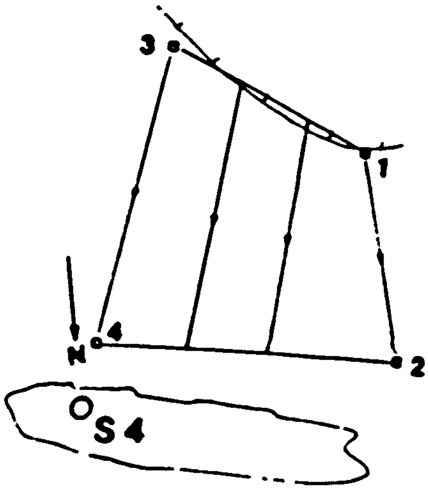
SHUNA SURVEY GRID MAPS

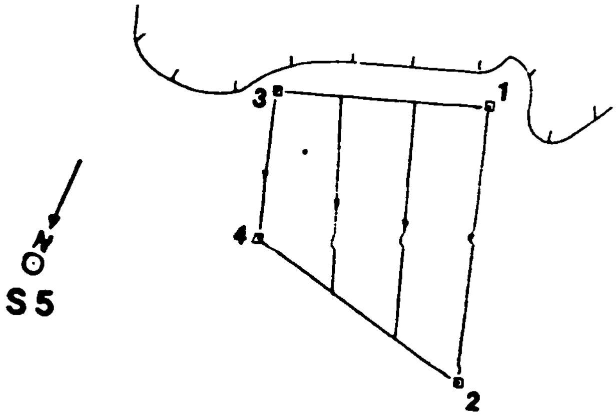
0 10 metres

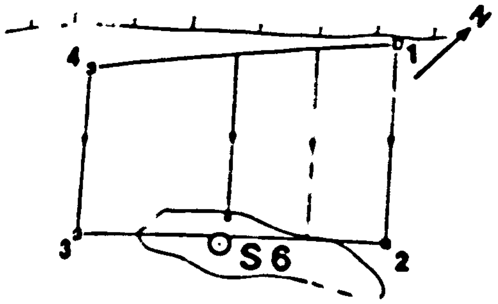


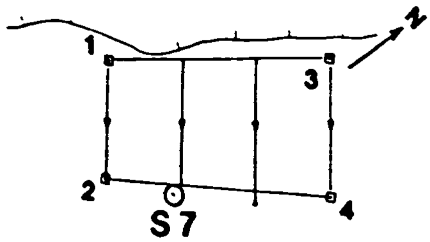








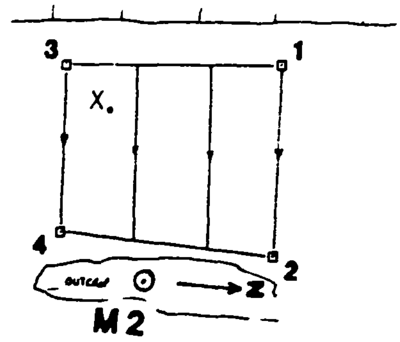


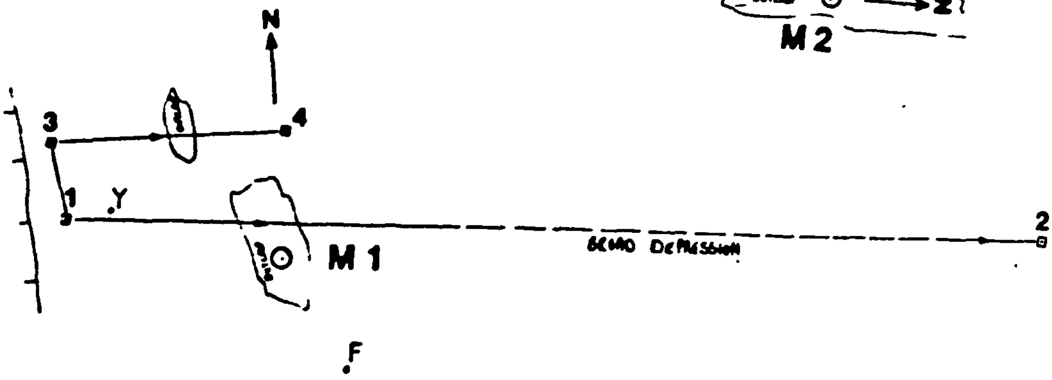


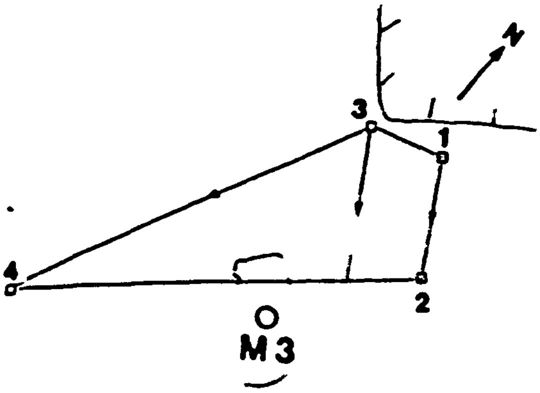
MULL SURVEY GRID MAPS

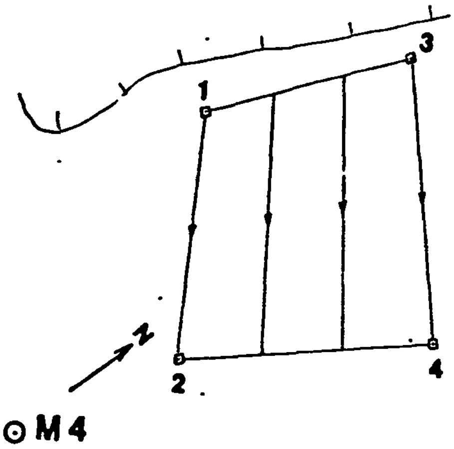
0 10 metres

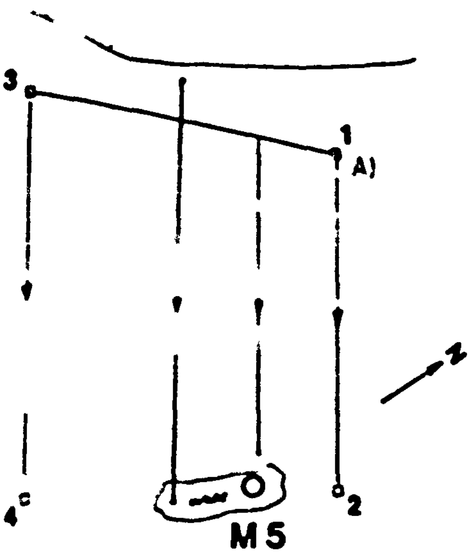
POINTS 'XYA & F ARE TRAVERSE END-POINTS

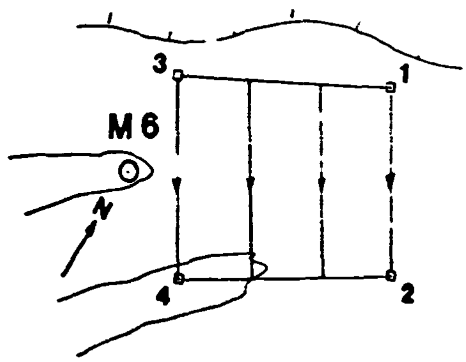


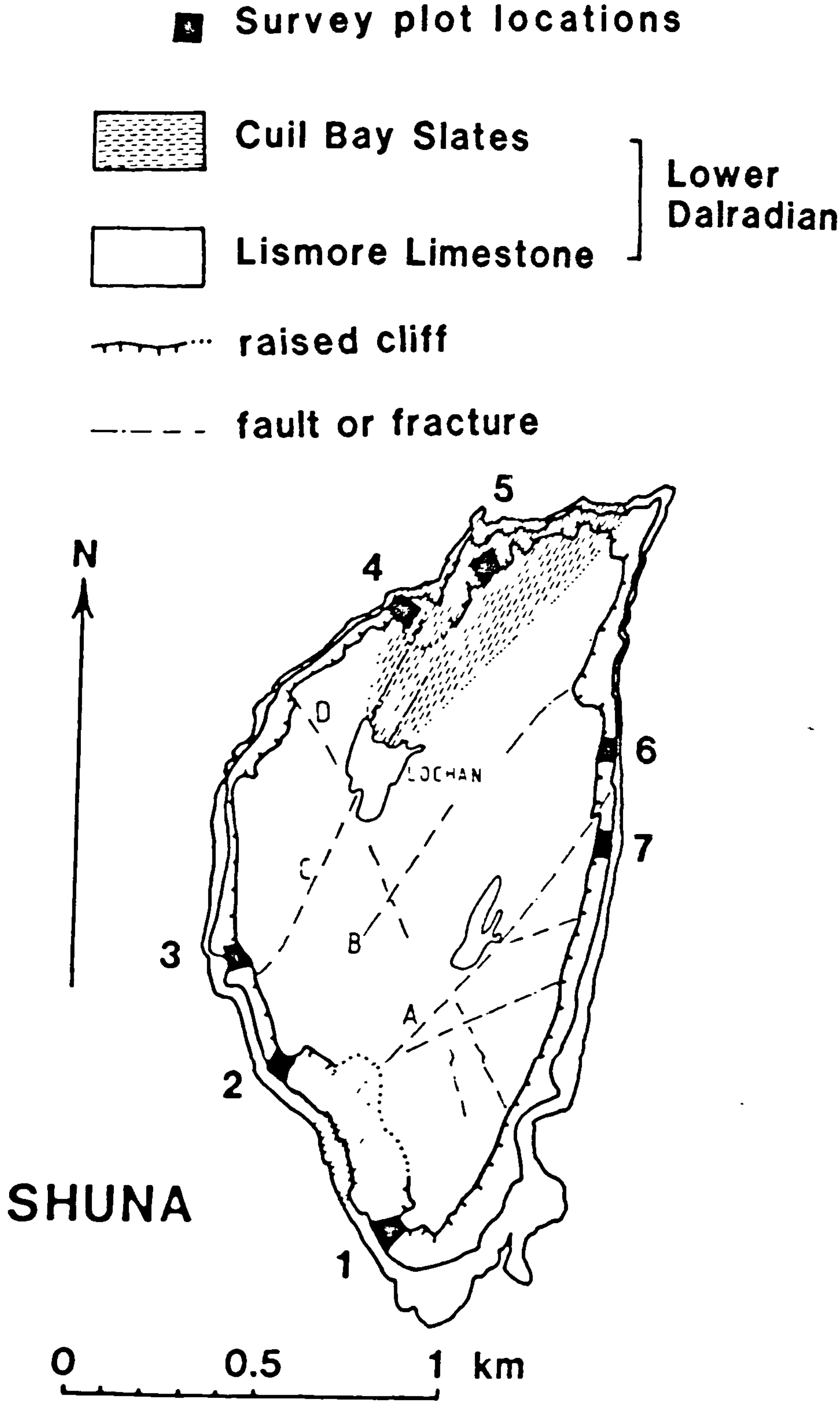


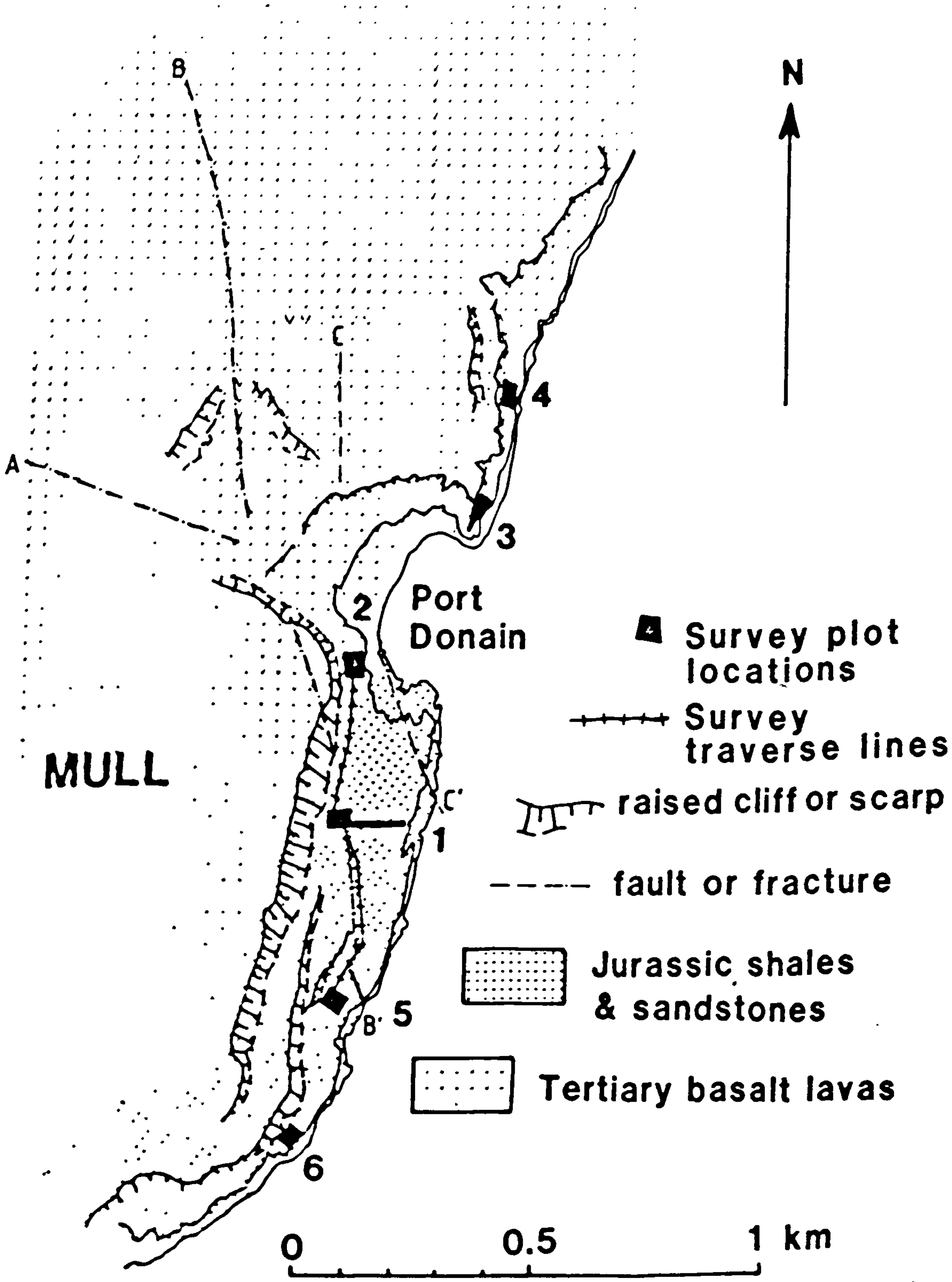









Survey plot locations
Cuil Bay Slates
Lismore Limestone
Lower Dalradian
raised cliff
fault or fracture
N
5
4
D
LOCHAN
6
7
C
B
3
A
2
SHUNA
1
0
0.5
1 km


N
B
C
A
MULL
Port Donain
1
2
3
4
5
6
B'
C'
Survey plot locations
Survey traverse lines
raised cliff or scarp
fault or fracture
Jurassic shales & sandstones
Tertiary basalt lavas
0
0.5
1 km

A2.5 SURVEY DATA TABLES

SHUNA LEVELLING SURVEY - August 1984.

PLOT ONE:

Instrument height above reference = 1.02

Zero Azimuth = Vertex 4 ; Compass Bearing = 342

Vertex	Azimuth	Top	Bottom	Diff.	Distance
1	102.0	1.658	1.301	0.357	35.8
2	224.4	-	-	-	10.6(by tape)
3	030.0	1.765	1.035	0.730	73.1
4	000	2.575	1.932	0.643	64.4

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 1	1.489	0.80	0.20	1.69	
3	1.522	0.21	0.79	2.31	stiff clayey peat - screw auger
6	1.573	0.45	0.55	2.12	(and for all PLOT 1)
9	1.694	0.465	0.635	2.63	
12	1.634	0.30	0.70	2.33	
15	1.678	0.47	0.53	2.21	
18	1.688	0.87	0.13	1.81	
21	1.817	0.48	0.52	2.34	
24	1.953	0.48	0.52	2.47	
27	1.936	0.975	0.025	1.96	
30	1.809	0.73	0.27	2.08	
33	1.885	0.90	0.10	1.99	
36	1.891	0.54	0.46	2.35	
38	1.702	0.89	0.11	1.81	
40=vertex 2	1.443	0.91	0.09	1.53	

Line 20 metres towards vertices 3 + 4 .

0(on line 1-3)	1.426	0.67	0.33	1.76
3	1.428	0.455	0.545	1.97
6	1.544	0.375	0.625	2.17
9	1.407	0.64	0.36	1.77
12	1.692	0.69	0.31	2.00
15	1.773	0.86	0.14	1.91
18	1.933	0.535	0.465	2.40
21	1.972	0.61	0.39	2.36
24	2.062	0.435	0.565	2.63
27	2.237	0.72	0.28	2.52
30	2.390	0.395	0.605	3.00
33	2.445	0.585	0.415	2.86
36	2.553	0.78	0.22	2.77
41(on line 2-4)	2.693	0.84	0.16	2.85

SHUNA LEVELLING SURVEY - August 1984.

PLOT ONE Continued:

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
Line 20 metres towards vertices 3 + 4.					
0(on line 1-3)	0.675	0.835	0.165	0.84	on backslope
3	1.224	0.815	0.185	1.41	
6	-	-	-	-	on track
8	1.375	0.755	0.245	1.62	
12	1.600	0.610	0.390	1.99	
15	1.775	0.555	0.445	2.22	
18	1.865	0.715	0.285	2.15	
21	1.884	0.840	0.160	2.04	
24	1.968	0.540	0.460	2.43	
27	1.955	0.795	0.205	2.16	
30	1.700	0.960	0.040	1.74	
33	1.874	0.770	0.230	2.10	
36	1.491	1.000	0.000	1.49	outcrop
40(on line 2-4)	2.129	0.875	0.125	2.25	
Line 34 metres to vertex 4,29 metres to vertex 3.					
0=vertex 3	1.399	0.870	0.130	1.53	
3	1.515	0.230	0.770	2.29	
6	1.495	0.560	0.440	1.94	
9	-	-	-	-	on track
12	-	-	-	-	boulder
13	1.785	0.835	0.165	1.95	
15	1.755	0.415	0.585	2.34	
18	1.880	0.330	0.670	2.55	
21	1.995	0.885	0.115	2.11	
24	2.115	0.885	0.115	2.23	
27	1.980	0.920	0.080	2.06	boulder ridge
30	2.315	0.930	0.070	2.39	
33	2.193	0.935	0.065	2.26	
36	2.170	0.820	0.180	2.35	
39=vertex 4	2.255	0.890	0.110	2.37	

SHUNA LEVELLING SURVEY - August 1984.

PLOT TWO:
Instrument height above reference = 1.30
Zero Azimuth = Vertex 1 ; Compass Bearing to Vertex 4 = 353

Vertex	Azimuth	Top	Bottom	Diff.	Distance
1	000	0.721	0.425	0.296	29.7
2	74.0	2.680	2.443	0.237	23.8
3	277.3	1.070	0.865	0.205	20.6
4	230.3	1.930	1.775	0.155	15.6

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 1	0.574	0.880	0.120	0.69	backslope?
3	1.272	0.801	0.109	1.38	backslope?
6	1.362	0.780	0.220	1.58	platform?
9	1.293	0.530	0.470	1.76	
12	1.755	0.860	0.140	1.90	
15	2.052	0.845	0.155	2.21	
18	2.488	0.515	0.485	2.97	sandy bottom
21	2.598	0.670	0.330	2.93	
24	2.621	0.685	0.315	2.94	
27	2.882	0.720	0.280	3.16	
30=vertex 2	2.550	0.860	0.140	2.69	lip of platform

Line 15 metres towards vertices 3 + 4.

0 on line 1-3)	1.102	0.881	0.119	1.22	recent fallen blocks upslope
3	1.341	0.765	0.235	1.58	surface boulder adjacent
6	1.388	0.400	0.600	1.99	platform?
9	1.428	0.760	0.240	1.67	
12	1.456	0.355	0.645	2.10	
15	1.428	0.805	0.195	1.62	edge of platform
18	2.158	0.895	0.105	2.26	just beyond rock outcrop ledge
21	2.411	0.863	0.137	2.55	downslope
25 on line 2-4)	3.139	1.000	0.000	3.14	outcrop

Line 10 metres towards vertices 3 + 4.

0 on line 1-3)	1.200	0.874	0.126	1.33	knick point?
3	1.515	0.805	0.195	1.71	subsurface boulders impassable
6	1.495	0.500	0.500	2.00	boulders?
9	1.372	0.710	0.290	1.66	
12	1.701	0.450	0.550	2.25	
15	1.660	0.580	0.420	2.08	edge of platform
18	2.378	0.930	0.070	2.45	
20 on line 2-4)	2.400	0.855	0.145	2.55	

Line 14 metres to vertex 4, 14.5 metres to vertex 3.

0=vertex 3	0.965	0.663	0.337	1.30	downslope from cliff boulders
3	1.593	0.597	0.403	2.00	onto platform
6	1.739	0.763	0.237	1.98	
9	1.711	0.870	0.130	1.84	knobly platform edge
12=vertex 4	1.850	1.000	0.000	1.85	outcrop

SHUNA LEVELLING SURVEY - August 1984.

PLOT THREE:

Instrument height above reference = 0.960

Zero Azimuth = Vertex 1 ; Compass bearing = 098

Vertex	Azimuth	Top	Bottom	Diff.	Distance
1	000	0.408	0.119	0.289	29.0
2	271.2	1.561	1.483	0.078	7.9
3	out of range - no measurement				
4	292.1	2.491	2.091	0.400	40.1

POSTION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 1	0.263	0.872	0.128	0.39	
3	0.918	0.615	0.385	1.30	knick point?
6	1.213	0.836	0.164	1.38	
9	1.470	0.773	0.227	1.70	
12	1.620	0.850	0.150	1.77	
15	1.791	0.890	0.110	1.90	
18	1.971	0.916	0.084	2.06	
21	2.139	0.836	0.164	2.30	
24	2.267	0.735	0.265	2.53	
27	2.223	0.896	0.104	2.33	
30.5=vertex 2	1.522	1.000	0.000	1.52	outcrop of outer ridge

line 10 metres towards vertices 3 + 4.

0 on line 1-3)	0.081	0.770	0.230	0.31	just above knick point
3	0.631	0.660	0.340	0.97	knick point
6	0.875	0.560	0.440	1.32	
9	1.092	0.260	0.740	1.83	peat/sand/rock
12	1.253	0.000	1.000	2.25	soil/peat
15	1.379	0.350	0.650	2.03	
18	1.468	0.450	0.550	2.02	
21	1.191	>1.0	-	>2.2	even though among rock outcrop
24	1.209	1.000	0.000	1.21	outcrop at edge of platform
30	2.698	0.855	0.145	2.84	downslope
32 on line 2-4)	out of range - no measurement				

line 10 metres towards vertices 3 + 4.

0 on line 1-3)	out of range - no measurement				
1.4	0.050	0.515	0.485	0.54	upslope
5	0.655	0.460	0.540	1.20	knick point
9	1.053	0.213	0.787	1.84	
12	1.228	0.210	0.790	2.02	
15	1.325	0.240	0.760	2.09	
18	1.478	0.390	0.610	2.09	
21	1.587	0.210	0.790	2.38	edge of platform
24	1.821	0.204	0.796	2.62	
30	2.538	0.354	0.646	3.18	downslope
33 on line 2-4)	out of range - no measurement				

SHUNA LEVELLING SURVEY - August 1984.

PLOT THREE Continued:

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 3	out of range - no measurement				
3	0.150	0.750	0.250	0.40	upslope
6	0.778	>1.0	-	>1.8	passed through sand
9	1.025	0.170	0.830	1.86	knick point,or just upslope of?
12	1.208	0.000	1.000	2.21	just hit rock?
15	1.350	0.250	0.750	2.10	definitely rock
18	1.553	0.495	0.505	2.06	edge of shelf?
21	1.620	0.460	0.540	2.16	grey clay then rock
24	1.959	0.710	0.290	2.25	
30=vertex 4	2.291	0.826	0.174	2.47	edge of platform - outcrop nearby

SHUNA LEVELLING SURVEY - August 1984.

PLOT FOUR:
Instrument height above reference = 1.31
Zero Azimuth = Vertex 1 ; Compass Bearing = 234

Vertex	Azimuth	Top	Bottom	Diff.	Distance
1	000	0.910	0.430	0.480	48.1
2	34.2	2.980	2.599	0.391	39.2
3	325.5	1.262	0.802	0.460	46.1
4	323.8	1.998	1.918	0.080	8.1(8.1 by tape)

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 1	0.670	0.927	0.073	0.74	
3	1.275	0.686	0.314	1.59	knick point?
6	1.625	0.855	0.145	1.77	
9	1.773	0.795	0.205	1.98	
12	1.989	0.895	0.105	2.09	edge of platform?
15	2.473	0.320	0.680	3.15	
18	2.928	0.562	0.438	3.37	
21	3.127	0.955	0.045	3.17	
23=vertex 2	2.791	1.000	0.000	2.79	outcrop on rocky edge

line 10 metres to vertex 3 , 15 metres to vertex 4.

0 on line 1-3)	0.373	0.240	0.760	1.13	
3	1.071	0.616	0.384	1.46	
6	1.612	0.802	0.198	1.81	knick point?
9	1.592	>1.0	-	>2.6	passed through sand
12	2.039	0.783	0.217	2.26	
15	2.278	0.884	0.116	2.39	edge rocky outcrop
18	3.018	0.270	0.730	3.75	near deep gulley
21	out of range - no measurement				gulley 2 metres wide approx.
24	2.244	0.733	0.267	2.31	
25.5 line 2-4)	3.051	1.000	0.000	3.05	outcrop on rocky edge.

SHUNA LEVELLING SURVEY - AUGUST 1984.

PLOT FOUR Continued:

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
Line 10 metres towards vertices 3 + 4 .					
0(on line 1-3)	0.698	0.280	0.720	1.42	
3	1.339	0.573	0.427	1.77	knick point just upslope?
6	1.572	0.603	0.397	1.97	gravelly,then rock
9	1.713	0.560	0.440	2.15	gulley?
12	1.669	0.647	0.353	2.02	
15	1.574	0.472	0.528	2.10	
18	1.625	0.600	0.400	2.03	bouldery base
21	2.222	0.705	0.295	2.52	half m. beyond outcrop ridge
24	2.161	0.432	0.568	2.73	
27	2.198	0.539	0.461	2.66	
30	2.114	0.488	0.512	2.63	
35	-	-	-	-	rock outcrop ridge
0=vertex 3	1.023	0.596	0.404	1.43	upslope from knick
3	1.462	0.680	0.320	1.78	peat then gravel
6	1.475	0.742	0.258	1.73	peat then rock
9	1.684	0.514	0.486	2.17	soily peat then rock
12	1.645	0.250	0.750	2.40	peat/sand/rock
15	1.524	0.607	0.393	1.92	peat then rock
18	1.562	0.369	0.631	2.19	
21	1.462	0.621	0.379	1.84	
24	1.486	0.714	0.286	1.77	peat then rock
27	1.451	0.810	0.190	1.64	
30	1.386	1.000	0.000	1.38	outcrop - small isolated ridge
33	1.723	0.696	0.304	2.03	
38=vertex 4	1.956	0.525	0.475	2.43	

SHUNA LEVELLING SURVEY - August 1984.

PLOT FIVE:

Instrument height above reference = 1.00

Zero Azimuth = Vertex 1 ; Compass Bearing = 227

Vertex	Azimuth	Top	Bottom	Diff.	Distance
1	000	0.799	0.157	0.642	64.3
2	032	2.670	2.085	0.585	58.6
3	343.9	0.968	0.579	0.389	39.0
4	011.7	2.735	2.432	0.303	30.4

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 1	0.475	0.620	0.380	0.86	near large surface boulder
3	0.985	0.788	0.212	1.20	soft peat then rock
6	1.265	0.820	0.180	1.45	" "
9	1.648	0.665	0.335	1.98	
12	1.788	0.761	0.239	2.03	
15	2.163	0.667	0.333	2.50	
18	2.377	0.430	0.570	2.95	peat/sand/rock
21	2.535	0.313	0.687	3.22	" " "
24	2.635	0.644	0.356	2.99	peat/rock
27	2.503	0.745	0.255	2.76	soily peat then rock
30.5=vertex 2	2.375	1.000	0.000	2.38	rock outcrop on ridge
Line 10 metres towards vertices 3 + 4 .					
0.on line 1-3)	0.253	1.000	0.000	0.25	rocky outcrop/backing cliff
3	1.035	0.603	0.397	1.43	peat/rock ; at knick
6	1.282	0.210	0.790	2.07	peat/soil/rock
9	1.383	0.035	0.965	2.35	soft peat/rock
12	1.858	0.340	0.660	2.52	" "
15	2.142	0.292	0.708	2.85	" "
18	2.395	0.719	0.281	2.68	
19	2.044	1.000	0.000	2.04	rock outcrop
21	2.902	0.665	0.335	3.24	peat/rock
24	3.312	0.480	0.520	3.83	peat/sand/rock
27 on line 2-4)	2.698	1.000	0.000	2.70	rock outcrop ridge

SHUNA LEVELLING SURVEY - August 1984.

PLOT FIVE Continued:

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
Line 10 metres towards vertices 3 + 4 .					
0(on line 1-3)	0.253	1.000	0.000	0.37	rock outcrop/backing cliff
1	0.825	0.523	0.477	1.30	peat/rock ; knick point
3	1.023	0.564	0.436	1.46	" "
6	1.355	0.646	0.354	1.71	" "
9	1.672	0.432	0.568	2.24	peat/sand/rock
12	1.993	0.628	0.372	2.37	" " "
15	2.180	0.600	0.400	2.58	peat/rock
18	2.512	0.865	0.135	2.65	" "
21	3.151	1.000	0.000	3.15	downslope of outcrop ridge
0=vertex 3	0.772	0.730	0.270	1.04	peat/sand/rock; knick point
3	1.082	0.750	0.250	1.33	peat/rock
6	1.575	0.510	0.490	2.07	peat/soil/rock
9	1.847	0.870	0.130	1.98	peat/rock
10.5	1.677	1.000	0.000	1.68	rock ridge
12	2.152	0.685	0.315	2.47	peat/rock
15	2.292	0.647	0.353	2.65	" "
19=vertex 4	2.583	1.000	0.000	2.58	edge of rock ridge

SHUNA LEVELLING SURVEY - August 1984.

PLOT SIX:

Instrument height above reference = 1.12

Zero Azimuth = Vertex 1 ; Compass Bearing = 352.5

Vertex	Azimuth	Top	Bottom	Diff.	Distance
1	000	0.748	0.421	0.327	32.8
2	049	3.771	3.568	0.203	20.4
3	283.2	0.433	0.155	0.278	27.9
4	235	2.547	2.365	0.182	18.3

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 1	0.585	0.895	0.105	0.69	base of cliff
2	1.158	0.520	0.480	1.64	v.stiff soil
4	1.664	0.035	0.965	2.63	peat/sand/rock
6	1.975	0.475	0.525	2.50	
9	2.223	0.654	0.346	2.57	stiff soil
12	2.563	0.673	0.327	2.89	subsurface boulders present
15	3.221	0.754	0.246	3.47	steeper slope - off platform?
18	3.885	0.612	0.388	4.27	
21	4.031	0.750	0.250	4.28	
25	3.668	1.000	0.000	3.67	rock outcrop ridge

Line 10 metres towards vertices 3 + 4 .

0 on line 1-3)	0.338	0.241	0.759	1.10	
2	1.002	0.863	0.137	1.14	knick?
4	1.378	0.674	0.326	1.70	stiff soil
6	1.572	>1.0	-	>2.6	soil
9	1.982	0.358	0.642	2.62	soil/sand/rock
12.3	2.079	1.000	0.000	2.08	rock outcrop
15	2.724	0.737	0.263	2.99	stiff soil
18	2.891	0.482	0.518	3.41	
21	2.931	0.505	0.495	3.43	soil/gravel/rock
24 on line 2-4)	2.302	1.000	0.000	2.30	rock outcrop ridge

Line 10 metres towards vertices 3 + 4 .

0 on line 1-3)	0.275	0.055	0.945	1.22	
2	0.715	>1.0	-	>1.7	
4	1.235	0.645	0.355	1.59	subsurface boulder?
6	1.541	0.287	0.713	2.25	definitely rock
9	2.018	0.700	0.300	2.32	rock
12	2.309	0.624	0.376	2.69	"
15	2.379	0.830	0.170	2.55	
18	2.125	1.000	0.000	2.13	rock outcrop
20 on line 2-4)	1.474	1.000	0.000	1.47	" "

Line 3-4 = 20 metres on from last line

0=vertex 3	0.297	>1.0	-	>1.3	went through sand
3	0.998	>1.0	-	>2.0	" " "
6	1.353	0.000	1.000	2.35	? /rock
9	1.723	0.220	0.780	2.50	? /rock
12	2.120	0.299	0.701	2.82	soil/rock
15	2.298	0.645	0.355	2.65	peat/sand/rock
18	1.835	1.000	0.000	1.84	rock outcrop ridge
21=vertex 4	2.457	0.660	0.340	2.80	

SHUNA LEVELLING SURVEY - August 1984.

PLOT SEVEN:

Instrument Height above reference = 1.34

Zero Azimuth = Vertex 1 ; Compass Bearing = 276

Vertex	Azimuth	Top	Bottom	Diff.	Distance
1	000	0.285	0.095	0.190	19.1
2	312	1.161	1.068	0.093	9.4
3	078.2	0.799	0.532	0.267	26.8
4	118.7	2.809	2.601	0.208	20.9

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 1	0.190	0.346	0.654	0.84	gravel on rock
2	0.474	0.320	0.680	1.15	peat/rock
4	0.677	0.688	0.312	0.99	" "
6	0.835	0.794	0.206	1.04	" "
9	1.112	0.727	0.273	1.39	
12	1.287	0.782	0.218	1.51	
15	1.113	1.000	0.000	1.11	rocky ridge

Line 10 metres towards vertices 3 + 4 .

0(on line 1-3)	0.472	0.893	0.107	0.58	subsurface boulder?
2	0.785	0.503	0.497	1.28	peat/sand/rock
4	0.999	0.567	0.433	1.43	" " "
6	1.215	0.520	0.480	1.70	" " "
9	1.405	0.840	0.160	1.57	peat/rock
12	1.510	0.584	0.416	1.93	" "
14	1.485	0.838	0.162	1.65	" "
16 on line 2-4	1.554	0.831	0.169	1.72	" "

line 10 metres towards vertices 3 + 4 .

0 on line 1-3)	0.713	>1.0	-	>1.7	
2	0.955	>1.0	-	>2.0	
4	1.244	0.202	0.798	1.75	peat/sandy soil/rock
6	1.479	0.550	0.450	1.93	" " "
9	1.635	0.418	0.582	2.22	peat/sand/rock
12	1.975	0.410	0.590	2.57	" " "
15	2.213	0.055	0.945	3.16	" " "
18	2.602	1.000	0.000	2.60	rock outcrop ridge

line 3-4 = 10 metres on from last line

vertex 3	0.665	0.771	0.229	0.894	
2	0.941	>1.0	-	>1.9	sandy soil
4	1.210	0.630	0.370	1.58	soil/sand/rock
6	1.489	0.692	0.308	1.80	" " "
9	1.763	0.597	0.403	2.17	" " "
12	2.205	0.370	0.630	2.84	" " "
15	2.545	0.790	0.210	2.76	soil/rock
vertex 4	2.705	>1.0	-	>3.7	sandy soil

SHUNA LEVELLING SURVEY - July 1985.

Linking traverse between Plots 1,2,3,4,5,6 and 7:

(Single circuit traverse around island.)

Staff at:	Backsight	Foresight	Difference	Reference at:
Ref.1	0.808	-	+0.808	0.000
1	0.429	0.882	-0.453	
2	0.298	3.994	-3.696	
3	3.870	2.126	+1.744	
4	4.119	3.498	+0.621	
5	2.512	0.623	+1.889	
6	0.517	1.059	-0.542	
Ref.2	2.400	0.877	+1.523	+1.017
7	1.912	2.772	-0.860	
8	0.703	1.140	-0.437	
Ref.3	1.953	0.800	+1.153	+0.950
9	2.465	3.616	-1.151	
10	3.090	3.387	-0.297	
11	3.103	0.421	+2.682	
12	2.991	4.223	-1.232	
13	2.672	2.063	+0.609	
14	0.347	1.736	-1.389	
15	2.223	1.263	+0.960	
16	0.654	1.990	-1.336	
17	2.837	1.467	+1.370	
Ref.4	0.668	0.800	-0.132	+1.034
18	0.117	2.569	-2.452	
19	4.084	1.867	+2.217	
Ref.5	0.498	0.376	+0.122	+1.345
20	3.003	2.080	+0.923	
21	1.956	2.824	-0.868	
22	1.233	1.858	-0.625	
23	0.988	0.783	-0.205	
24	1.401	1.010	+0.391	
25	2.107	1.432	+0.675	
26	1.991	3.498	-1.507	
27	3.481	1.610	+1.871	
Ref.6	1.810	1.811	-0.001	+0.974

SHUNA LEVELLING SURVEY - July 1985.

Linking traverse between Plots 1,2,3,4,5,6 and 7 cont.:

28	0.971	2.221	-1.250	
Ref.7	2.017	1.264	+0.753	+1.024
29	1.622	2.460	-0.838	
30	0.377	1.378	-1.001	
31	2.906	1.501	+1.405	
32	0.908	0.707	+0.201	
33	0.956	3.250	-2.294	
34	0.905	3.335	-2.430	
35	1.418	4.054	-2.636	
36	3.325	1.898	+1.427	
37	4.202	1.132	+3.070	
38	2.831	0.730	+2.101	
39	0.652	1.033	-0.381	
Ref.1	-	0.912	-0.912	0.000

Closing error .... 0.000metres.

Circuit length = 5 km ; Closing error per km = 0.000 m.
Documented mean square error for 2.5 km double levelling = 0.013 m.

PORT DONAIN LEVELLING SURVEY - August 1984.

PLOT ONE:

Instrument height above reference = 0.92

Zero azimuth = vertex 1 ; Compass Bearing = 285

Vertex	Azimuth	Top	Bottom	Diff.	Distance
1	000	0.418	0.145	0.273	27.4
2	167.5	4.28-	3.272	1.01-	101
3	006.4	0.559	0.230	0.329	33.0
4	079.3	3.344	3.184	0.160	16.1

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 1	0.275	0.780	0.220	0.495	
2	0.698	0.960	0.040	0.738	
4	1.019	0.950	0.050	1.069	v. thin peat cover
6	1.205	0.945	0.055	1.260	
8	1.319	0.840	0.160	1.479	
10	1.368	0.893	0.107	1.475	
12	1.539	0.910	0.090	1.629	
15	1.799	0.817	0.183	1.982	
18	1.918	0.797	0.203	2.121	
21	2.155	0.800	0.200	2.355	
24	2.432	0.827	0.173	2.605	
27	2.523	0.668	0.332	2.855	
30	2.473	1.000	0.000	2.473	rock outcrop
33	2.681	0.910	0.090	2.771	
36	3.523	0.685	0.315	3.838	
39	3.946	0.691	0.309	4.255	
42	4.082	0.560	0.440	4.522	
45	4.126	0.776	0.224	4.350	
50	4.223	0.773	0.227	4.450	
-	-	-	-	-	broad depression,beyond limit
-	-	-	-	-	of staff(4.3)
120	4.256	0.470	0.530	4.786	beginning of gentle rise
125	4.179	0.597	0.403	4.582	
130	3.928	0.726	0.274	4.202	
135=vertex 2	3.783	0.768	0.232	4.015	top of rise;drops sharply seaward
Line 10 metres on					
0=vertex 3	0.394	1.000	0.000	0.394	on rocks and boulders
2	0.718	0.975	0.025	0.743	
4	0.867	0.900	0.100	0.967	
6	1.101	0.894	0.106	1.207	
8	1.245	0.870	0.130	1.375	
10	1.401	1.000	0.000	1.401	rock outcrop
12	1.542	0.816	0.184	1.726	
15	1.395	0.893	0.107	1.502	
17	0.652	0.715	0.285	1.367	rocky knoll
21	2.389	0.794	0.206	3.183	
24	2.599	0.795	0.205	3.394	
27	2.978	0.555	0.445	3.533	
30=vertex 4	3.263	0.375	0.625	3.888	

PORT DONAIN LEVELLING SURVEY - August 1984.

PLOT TWO:

Instrument height above reference = 1.405

Zero azimuth = vertex 1 ; Compass bearing = 299

Vertex	Azimuth	Top	Bottom	Diff.	Distance
1	000	0.600	0.277	0.323	32.4
2	46.1	1.903	1.728	0.175	17.6
3	304.3	0.421	0.129	0.292	29.3
4	265.2	1.219	1.090	0.129	13.0

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 1	0.439	0.733	0.267	0.706	
2	0.690	1.000	0.000	0.690	
4	0.925	0.854	0.146	1.071	
6	1.210	0.940	0.060	1.270	gravelly road;could be few cm high
9	1.272	0.880	0.120	1.392	
12	1.553	0.849	0.151	1.704	
15	1.519	0.790	0.210	1.729	
18	1.641	0.806	0.194	1.835	
21	1.728	0.832	0.168	1.896	
23	1.456	0.861	0.139	1.595	top of rocky knoll
24=vertex 2	1.815	0.855	0.145	1.960	
Line 10 metres towards vertices 3 and 4					
0(on line 1-3)	0.583	0.736	0.264	0.847	rocky knoll; backslope
2	1.125	1.000	0.000	1.125	rock outcrop
4	1.349	0.892	0.108	1.457	
6	1.185	0.715	0.285	1.470	
8	1.388	0.746	0.254	1.642	
10	1.465	0.710	0.290	1.755	
12	1.599	0.720	0.280	1.879	
15	1.734	0.637	0.363	2.097	
18	2.192	0.780	0.220	2.412	
21	2.659	0.648	0.352	3.011	
24	2.611	1.000	0.000	2.611	rock outcrop;
27 on line 2-4)	1.768	1.000	0.000	1.768	" " then down to shore

PORT DONAIN LEVELLING SURVEY - August 1984.

PLOT TWO cont.:

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
Line 10 metres on towards vertices 3 and 4					
0(on line 1-3)	0.309	0.790	0.210	0.519	rocky backslope
2	0.835	1.000	0.000	0.835	rock outcrop
4	1.293	0.911	0.089	1.382	
6	1.295	0.973	0.027	1.322	
8	1.325	1.000	0.000	1.325	rock outcrop
10	1.611	0.821	0.179	1.790	
12	1.760	0.881	0.119	1.879	
15	2.000	0.817	0.183	2.183	
18	2.052	0.720	0.280	2.332	
21	2.220	0.589	0.411	2.631	
24	2.198	0.540	0.460	2.658	
26(on line 2-4)	1.800	1.000	0.000	1.800	rocky edge
Line 10 metres on					
0=vertex 3	0.279	0.812	0.188	0.467	
2	0.535	0.852	0.148	0.683	
4	0.798	0.691	0.309	1.107	
6	1.221	1.000	0.000	1.221	rock outcrop
9	1.465	0.936	0.064	1.529	
12	1.748	0.746	0.254	2.002	
15	2.049	0.716	0.284	2.333	
18	2.080	0.635	0.365	2.715	
21	2.040	0.937	0.063	2.103	
23=vertex 4	1.155	1.000	0.000	1.155	rocky edge

PORT DONAIN LEVELLING SURVEY - August 1984.

PLOT THREE:

Instrument height above reference = 1.295

Zero azimuth = vertex 1 ; Compass bearing = 007

Vertex	Azimuth	Top	Bottom	Diff.	Distance
1	000	0.873	0.570	0.303	30.4
2	027.9	1.177	0.965	0.212	21.3
3	340.3	0.728	0.455	0.273	27.4
4	230.2	1.857	1.531	0.326	32.7

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 1	0.720	0.921	0.079	0.799	
2	1.311	0.933	0.067	1.378	just up from knick point
4	1.483	0.757	0.243	1.726	
6	1.644	0.583	0.417	2.061	
8	1.581	0.407	0.593	2.174	
10	1.492	0.736	0.264	1.756	
12	1.350	0.492	0.508	1.858	
14	1.170	0.887	0.113	1.283	
15.5=vertex 2	1.070	1.000	0.000	1.070	

Line 10 metres on towards vertex 4

0=vertex 3	0.591	0.928	0.092	1.519	
2	0.813	0.955	0.045	0.858	
4	1.440	0.916	0.084	1.524	
6	1.712	0.900	0.100	1.812	knick point
8	1.775	0.963	0.037	1.812	
10	1.830	0.540	0.460	2.290	
12	1.830	0.941	0.059	1.910	
14	2.059	0.638	0.362	2.421	
16	1.955	0.860	0.140	2.095	
17.5 line 2-4)	1.764	1.000	0.000	1.764	rocky edge

0=vertex 3	0.591	0.928	*0.092*	*1.519*	
2	1.051	1.000	0.000	1.051	rock outcrop
4	1.593	0.837	0.163	1.756	knick?
6	1.629	0.791	0.209	1.838	
8	1.670	0.908	0.092	1.762	
10	1.845	0.901	0.099	1.944	
12	1.984	0.767	0.233	2.217	another knick?
15	2.038	0.476	0.524	2.562	
18	2.165	0.574	0.426	2.591	
21	1.692	1.000	0.000	1.692	rock outcrop
24	2.320	0.744	0.256	2.576	
27	1.753	0.831	0.169	1.922	
30	1.879	0.612	0.388	2.267	
33	2.215	0.490	0.510	2.725	
36	2.256	0.438	0.562	2.818	
39	2.284	0.565	0.435	2.719	
42	2.230	0.689	0.311	2.541	
45	2.193	1.000	0.000	2.193	rock outcrop
48	1.965	0.635	0.365	2.330	
50=vertex 4	1.693	1.000	0.000	1.693	rock outcrop

PORT DONAIN LEVELLING SURVEY - August 1984.

PLOT FOUR:

Instrument height above reference = 1.11

Zero azimuth = vertex 1 ; Compass bearing = 337

Vertex	Azimuth	Top	Bottom	Diff.	Distance
1	000	1.035	0.560	0.475	47.6
2	035.0	2.432	2.194	0.238	23.9
3	016.8	1.265	0.548	0.717	71.8
4	047.0	2.770	2.190	0.580	58.1

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 1	0.802	1.000	0.000	0.802	rockfall/boulder zone
2	1.115	0.872	0.128	1.243	knick?
4	1.275	0.562	0.438	1.713	
6	1.382	0.435	0.565	1.947	
9	1.513	0.360	0.640	2.153	
12	1.609	0.270	0.730	2.339	
15	1.601	0.244	0.756	2.357	
18	1.600	0.620	0.380	1.980	
21	1.632	0.436	0.564	2.196	
24	1.947	0.870	0.130	2.077	
27	2.425	0.246	0.754	3.179	
30	2.288	1.000	0.000	2.288	edge of present cliff

Line 10 metres towards vertices 3 and 4

0(on line 1-3)	0.928	1.000	0.000	0.928	rockfall zone
2	1.125	0.750	0.250	1.375	" " " again?
4	1.400	0.678	0.322	1.722	
6	1.505	0.336	0.664	2.169	
8	1.540	0.584	0.416	1.956	
10	1.521	0.160	0.840	2.361	
12	1.562	0.058	0.942	2.504	
15	1.621	0.362	0.638	2.259	
18	1.675	0.585	0.415	2.090	
21	1.775	>1.0	-	>2.8	
24	2.145	0.750	0.250	2.395	
27	2.391	0.200	0.800	3.191	
30	2.510	0.732	0.268	2.778	
31	2.543	1.000	0.000	2.543	edge of cliff

PORT DONAIN LEVELLING SURVEY - August 1984.

PLOT FOUR cont.:

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
Line 10 metres on towards vertices 3 and 4					
0(on line 1-3)	0.535	1.000	0.000	0.535	
2	1.198	0.925	0.075	1.273	knick?
4	1.452	0.816	0.184	1.636	
6	1.505	0.858	0.142	1.647	
9	1.642	0.485	0.515	2.157	
12	1.850	0.227	0.773	2.623	
15	1.920	0.227	0.773	2.693	
18	1.975	0.383	0.617	2.592	
21	2.050	0.356	0.644	2.694	
24	2.091	0.250	0.750	2.841	
27	2.255	0.476	0.524	2.779	
30	2.373	>1.0	-	>3.4	
32	2.421	0.841	0.159	2.580	
Line 10 metres on					
0=vertex 3	0.905	0.770	0.230	1.135	boulder?
2	1.209	0.785	0.215	1.424	small boulders around
4	1.485	0.294	0.706	2.191	
6	1.535	0.162	0.838	2.373	
8	1.628	0.247	0.753	2.381	
10	1.548	>1.0	-	>2.6	
12	1.657	0.278	0.722	2.379	
15	1.603	0.551	0.449	2.052	
18	1.759	0.277	0.723	2.482	
21	1.825	0.141	0.859	2.684	
24	1.927	0.070	0.930	2.857	
27	1.900	0.174	0.826	2.726	
30	2.171	0.730	0.270	2.441	
33	2.325	0.480	0.520	2.845	
35	2.392	1.000	0.000	2.392	rock outcrop
37	2.478	1.000	0.000	2.478	edge of cliff

PORT DONAIN LEVELLING SURVEY - July 1985.

PLOT FIVE:

Instrument height above reference = 1.20

Zero azimuth = vertex 1 ; Compass Bearing = 317

Vertex	Azimuth	Top	Bottom	Diff.	Distance
1	000	0.585	0.162	0.423	42.4
2	077.6	2.740	2.630	0.110	11.1
3	316.0	0.772	-	-	-
4	254.2	3.067	2.780	0.287	28.8

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 1	0.375	0.817	0.183	0.558	4m from cliff with boulders and
3	0.655	0.785	0.215	0.870	track inbetween
6	1.009	0.845	0.155	1.164	
9	1.090	0.260	0.740	1.830	soft peat on rock
12	1.197	0.170	0.830	2.027	peat/rock
15	1.264	0.573	0.427	1.691	peat/sand/rock
18	1.488	0.500	0.500	1.988	peat/rock
21	1.494	0.436	0.564	2.058	"
24	1.411	0.050	0.950	2.361	"
27	1.548	0.192	0.808	2.356	"
30	1.708	>1.0	-	>2.7	"
33	1.825	>1.0	-	>2.8	"
36	2.714	0.750	0.250	2.964	peat/rock close to rock ridge
39	2.877	0.520	0.480	3.357	" "
41=vertex 2	2.685	0.697	0.303	2.988	

line 10m on towards vertices 3 + 4.

0 on line 1-3)	0.503	0.372	0.628	1.131	peat/rock (for all of this line)
3	0.506	>1.0	-	-	
6	0.577	"	"	"	
9	0.711	"	"	"	
12	0.755	"	"	"	
15	0.955	"	"	"	
18	1.160	"	"	"	
21	1.123	"	"	"	
24	1.534	"	"	"	
27	1.723	0.060	0.940	2.663	
30	1.874	0.300	0.700	2.574	
33	2.059	0.396	0.604	2.663	
36	2.132	0.473	0.527	2.659	
39	2.391	0.634	0.366	2.757	

PORT DONAIN LEVELLING SURVEY - July 1985.

PLOT FIVE cont.:

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
Line 10m on towards vertices 3 + 4.					
O(on line 1-3)	0.885	0.470	0.530	1.415	peat/rock
-3	0.655	0.665	0.335	0.990	peat/sandy gravel/rock
-5	0.379	0.838	0.162	0.541	sandy soil/rock
3	0.958	0.204	0.796	1.754	peat/rock
6	0.932	>1.0	-	-	peat (for rest of this line)
9	0.915	"	"	"	
12	1.041	"	"	"	
15	1.172	"	"	"	
18	1.519	"	"	"	deep gulley with stream
25	1.598	"	"	"	
30	1.788	"	"	"	
33	2.032	"	"	"	
36	2.053	"	"	"	
40	2.098	"	"	"	
47	1.598	1.000	0.000	1.598	rock ridge
Line 20m on at vertices 3 + 4.					
0=vertex 3	0.488	0.394	0.606	1.094	peat/rock (for all of this line)
-2	0.470	0.435	0.565	1.035	
-4	0.335	0.642	0.358	0.693	
-6	-	-	-	-	base of cliff exposure just out of range
3	0.518	0.220	0.780	1.298	
5	0.500	0.254	0.745	1.246	
6	0.500	>1.0	-	-	
10	0.594	"	"	"	
15	0.745	"	"	"	
20	0.930	"	"	"	
25	1.265	"	"	"	
30	1.621	"	"	"	
35	2.050	"	"	"	
40	2.379	"	"	"	
45	2.819	0.120	0.880	3.699	
48	2.838	0.190	0.810	3.648	
51	2.025	0.491	0.509	3.434	

PORT DONAIN LEVELLING SURVEY - July 1985.

PLOT SIX:

Instrument height above reference = 1.265

Zero azimuth = vertex 1 ; Compass bearing = 041

Vertex	Azimuth	Top	Bottom	Diff.	Distance
1	000	0.497	0.130?	0.367	37?
2	036.2	2.095	1.170	0.388	38.9
3	314.4	1.004	0.867	0.137	13.8
4	078.3	1.750	1.600	0.150	15.1

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=vertex 1	0.310	0.808	0.192	0.502	sandy; many boulders around
2	0.376	0.860	0.140	0.516	peat
4	0.614	0.791	0.209	0.823	peat
6	0.800	0.763	0.237	1.037	grass on rock (or boulder?)
9	1.013	0.540	0.460	1.473	peat/rock
12	1.197	0.420	0.580	1.777	peat/rock
15	1.250	0.288	0.712	1.962	peat/sand/rock
18	1.386	0.234	0.766	2.152	peat/sand/rock
21	1.637	0.470	0.530	2.167	peat/rock
24=vertex 2	1.901	0.575	0.425	2.326	peat/rock

Line 10m on towards vertices 3 + 4.

0(on line 1-3)	0.218	0.587	0.413	0.631	peat/rock (for all of this line)
2	0.410	0.655	0.345	0.755	
4	0.648	0.706	0.294	0.942	
6	0.814	0.685	0.315	1.129	
9	1.070	0.651	0.349	1.419	
12	1.199	0.593	0.407	1.606	
15	1.393	0.530	0.470	1.863	
18	1.513	0.527	0.473	1.986	
21	1.696	0.641	0.359	2.055	
24 on line 2-4)	1.877	0.696	0.304	2.181	

PORT DONAIN LEVELLING SURVEY - July 1985.

PLOT SIX cont.:

POSITION	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
Line 10m on towards vertices 3 + 4.					
0(on line 1-3)	0.501	0.872	0.128	0.629	boulders immediately upslope
2	0.672	0.406	0.594	1.266	peat/rock (for all of this line)
4	0.912	0.502	0.498	1.410	
6	1.019	0.499	0.501	1.520	
9	1.228	0.678	0.322	1.550	
12	1.496	0.753	0.247	1.743	
15	1.735	0.783	0.217	1.952	
18	1.864	0.910	0.090	1.954	
21	1.762	0.830	0.170	1.932	boulders around
23	0.887	1.000	0.000	0.887	rock outcrop ridge
Line 10m on at vertices 3 + 4.					
0=vertex 3	0.935	0.510	0.490	1.425	peat/rock
-0.5	0.758	1.000	0.000	0.758	rock outcrop
2	0.983	0.676	0.324	1.307	peat/rock (for all of this line)
4	1.221	0.760	0.240	1.461	
6	1.433	0.654	0.346	1.779	
9	1.569	0.829	0.171	1.740	
12	1.632	0.437	0.563	2.195	
15	1.923	0.633	0.367	2.290	
18	2.127	0.810	0.190	2.930	
21	2.172	0.846	0.154	2.326	grass/sandy soil/rock
24	2.115	0.900	0.100	2.215	
26	1.675	1.000	0.000	1.675	rock outcrop ridge

PORT DONAIN LEVELLING SURVEY - August 1984.

Line traverse between plots 1 and 2:

Line from 'X' in plot 2 to 'Y' in plot 1, keeping roughly 5 metres from cliff base
Distances measured by tape.
Instrument height at reference 2 = 1.075
Instrument height at reference 1 = 0.845

Instrument	Vertex	Azimuth	Compass	Top	Bottom	Diff.	Distance
at Ref.2	X	000	261	0.953	0.738	0.215	21.6
at Ref.1	Y	249.1	-	1.000	0.783	0.217	21.8
at Ref.1	X	000	-	-	-	-	-

POSN.	S.L.	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=X		0.845	0.680	0.320	1.165	Reading from Ref.2
5		0.883	0.626	0.374	1.257	
10		0.918	0.914	0.086	1.004	
15		1.071	0.783	0.217	1.288	
20		0.923	0.876	0.164	1.087	
25		0.977	1.000	0.000	0.977	rock outcrop; ridge running
30		0.748	1.000	0.000	0.748	diagonally across r.b. from ref.2
35		1.415	0.900	0.100	1.515	
40		1.485	0.970	0.030	1.515	
45		1.631	0.914	0.086	1.717	
50		1.752	0.770	0.230	1.982	
55		1.918	0.726	0.274	2.192	
60		2.027	0.728	0.272	2.299	
60	2.083		"	"		Reading from substation 1
	-0.056					difference
65	2.287	2.231	0.831	0.169	2.400	
70	2.159	2.103	0.716	0.284	2.387	
75	2.027	1.971	0.893	0.107	2.078	
80	1.865	1.809	1.000	0.000	1.809	rock outcrop
85	1.670	1.614	0.897	0.103	1.717	
90	1.428	1.372	0.813	0.187	1.559	
95	1.707	1.651	0.850	0.150	1.801	
100	1.573	1.517	1.000	0.000	1.517	rock outcrop
105	1.636	1.580	0.890	0.110	1.690	
110	1.587	1.531	0.878	0.122	1.653	
115	1.550	1.494	0.848	0.152	1.646	

PORT DONAIN LEVELLING SURVEY - August 1984.

Line traverse between plots 1 and 2 cont.:

POSN.	S.L.	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
120	1.440	1.384	0.875	0.125	1.509	
120	2.272		"	"		reading from substation 2
	-0.832					difference
	-0.056					
	-0.888					cumulate difference
125	2.130	1.242	0.931	0.069	1.311	
130	2.010	1.122	1.000	0.000	1.122	rock outcrop
135	1.960	1.072	1.000	0.000	1.072	" "
140	1.943	1.055	0.867	0.133	1.188	
145	1.885	0.997	0.937	0.063	1.060	
150	1.917	1.029	0.793	0.207	1.236	
155	1.819	0.931	0.450	0.550	1.481	stiffer peat; sandy?
160	1.510	0.622	0.350	0.650	1.272	" " "
165	1.374	0.486	0.523	0.477	0.963	definite sand on rock
170	1.470	0.582	0.531	0.469	1.051	" " "
175	1.712	0.824	0.700	0.300	1.124	less sand
180	1.435	0.547	0.479	0.521	1.068	peat only
185	1.624	0.736	0.727	0.273	1.009	peat/gravel/rock
190	1.315	0.427	0.660	0.340	0.767	peat/rock
195	1.137	0.249	0.705	0.295	0.544	
200	0.918	0.030	0.760	0.240	0.270	
205	0.981	0.093	0.875	0.125	0.218	
210	1.053	0.165	0.833	0.167	0.332	
210	2.974		"	"		reading from substation 3
	-1.921					difference
	-0.888					
	-2.809					cumulate difference
215	3.108	0.299	0.737	0.263	0.562	
220	3.186	0.377	0.766	0.234	0.611	
225	3.316	0.507	0.846	0.254	0.761	stream with boulders
230	2.735	-0.074	0.640	0.360	0.286	
235	2.460	-0.349	0.714	0.286	-0.063	
240	2.450	-0.359	0.973	0.027	-0.332	
245	2.234	-0.575	0.752	0.248	-0.327	
250	2.325	-0.484	0.898	0.102	-0.382	
255	2.373	-0.436	0.881	0.119	-0.317	
260	2.440	-0.369	0.928	0.072	-0.297	thin, stiff peat cover
265	2.565	-0.244	0.874	0.126	-0.118	" " " "

PORT DONAIN LEVELLING SURVEY - August 1984.

Line traverse between plots 1 and 2 cont.:

POSN.	S.L.	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
270	2.325	-0.484	0.894	0.106	-0.378	thin, stiff peat cover
270	2.506		"	"		reading from ref.1
	-0.181					difference
	-2.809					
	-2.990					cumulate difference
275	2.406	-0.584	0.716	0.284	-0.300	sandy peat/rock
280	2.371	-0.619	0.955	0.045	-0.574	
285	2.294	-0.696	0.853	0.147	-0.549	
290	2.153	-0.837	0.965	0.035	-0.802	
295	1.820	-1.170	0.850	0.150	-1.020	thin sandy soil
300	1.781	-1.209	0.850	0.150	-1.059	" " "
305	1.591	-1.399	0.853	0.147	-1.252	" " "
310	1.373	-1.617	0.842	0.158	-1.459	" " "
315	1.440	-1.550	0.894	0.106	-1.444	
320	1.195	-1.795	0.942	0.058	-1.737	
325	0.971	-2.019	0.859	0.141	-1.878	
330=Y	0.891	-2.099	0.863	0.137	-1.962	

Back traverse for closing error:

Station	Backsight	Foresight	Difference
Ref.1	0.845(inst.hgt)	3.178	-2.333
Substn.	1.29(3)	2.628	-1.335
Ref.2	1.591	1.135(inst.hgt)	+0.456
			-3.212 (i.e. Ref.1,3.212 above 2)

Cumulate difference for traverse = -2.990
Instrument height of Ref.2 = -1.075
-4.066
Instrument height of Ref.1 = +0.845
-3.221.......-3.221
Closing error....................................-0.009 metres.

Traverse distance = 0.32 km ; Closing error per km = 0.028 m.

PORT DONAIN LEVELLING SURVEY - July 1985.

Line traverse between plots 5 and 1:

Line from 'A' (vertex 1) in plot 5 to 'F' in plot 1, roughly along break of slope.
Distances paced and not measured between vertices.
Instrument height at reference 5 = 1.220
Instrument height at reference 1 = 0.950

Instrument	Vertex	Azimuth	Compass	Top	Bottom	Diff.	Distance
at Ref.5	A	000	317	0.585	0.162	0.423	42.4
at Ref.5	B	052.2	-	2.213	1.567	0.646	64.7
at Ref.5	D	064.3	022	-	-	-	-
at Substn.Z	B	293.8	-	2.088	1.365	0.763	76.4
at Substn.Z	C	278.0	-	2.345	2.118	0.227	22.8
at Substn.Z	D	000	286	1.328	1.226	0.102	10.3
at Substn.Z	E	067.6	-	2.775	2.175	0.600	60.1
at Ref.1	D	000	169	-	-	-	-
at Ref.1	E	048.9	-	3.774	3.054	0.720	72.1
at Ref.1	F	346.3	-	2.872	2.716	0.156	15.7

PORT DONAIN LEVELLING SURVEY - July 1985.

Line traverse between plots 5 and 1 cont.:

POSN.	AZIMUTH	S.L.	LEVEL	BORE	B-1	L+(B-1)	COMMENTS
0=A	000		0.375	0.817	0.183	0.558	Reading from Ref.5
10	015.0		0.413	0.746	0.236	0.649	
20	027.7		1.149	0.721	0.279	1.428	peat/rock for most of
30	038.0		1.098	0.562	0.438	1.536	traverse
40	046.1		1.713	0.385	0.615	2.328	
50=B	052.2		1.890	0.286	0.714	2.604	
50=B	293.8	1.729		"	"		Reading from substn.Z
		+0.161					difference
60	292.5	2.067	2.228	0.600	0.400	2.628	keeping roughly 5m from
70	290.2	2.014	2.175	0.240	0.760	2.935	low cliff
80	286.5	2.048	2.209	0.075	0.925	3.134	
90	283.2	2.296	2.457	0.374	0.626	3.083	
100=C	278.0	2.233	2.394	0.130	0.870	3.264	change in line direction
110	295.2	1.800	1.961	>1.0	-	-	peat bank abutting adja-
123=D	000	1.275	1.436	"	-	-	-cent higher platform
133	032.0	1.012	1.173	"	-	-	"
140	042.0	1.073	1.234	"	-	-	"
150	048.0	1.010	1.171	"	-	-	"
160	053.8	1.150	1.311	"	-	-	"
170	058.6	1.615	1.776	"	-	-	last of peat bank sites
182=E	067.6	2.478	2.639	0.071	0.929	3.568	just off peat bank
182=E	048.9	3.416					Reading from Ref.1
		-0.938					difference
		+0.161					
		-0.777					cumulate difference
194	348.9	3.975	3.198	0.358	0.642	3.840	change in direction
204	348.1	3.495	2.718	>1.0	-	-	
215	346.0	3.179	2.402	"	-	-	
227	347.6	3.029	2.252	"	-	-	
237=F	346.3	2.798	2.021	"	-	-	stiff soily peat

PORT DONAIN LEVELLING SURVEY - July 1985.

Line traverse between plots 5 and 1 cont.:

Back traverse for closing error:

Station	Backsight	Foresight	Difference
Ref.1	0.950(inst.hgt)	3.653	-2.703
Substn.	2.729	1.570	+1.159
Ref.5	1.677	1.175(inst.hgt)	+0.502
			-1.042 (i.e. Ref.1,1.175 above 5)

Cumulate difference for traverse = -0.777
Instrument height of Ref.1 = -1.220
-1.997
Instrument height of Ref.5 = +0.950
-1.047......-1.047
Closing error.................................-0.005 metres

Traverse distance = 0.43 km ; Closing error per km = 0.012 m.

PORT DONAIN LEVELLING SURVEY - July 1985.

Linking traverse between References 1,2,3,4 and 5:

Station	Instr. Height	Backsight	Foresight	Level change
Outward traverse (intercepting each Reference station):-				
Ref.5	1.175	-	1.273	+1.175
Substn.1	-	1.047	2.241	-0.226
Ref.1	0.875	3.210	3.457	+0.969
Substn.2	-	1.989	3.014	-1.468
Ref.2	1.168	1.547	2.718	-1.467
Substn.3	-	0.725	2.995	-1.993
Substn.4	-	3.545	1.229	+0.550
Substn.5	-	3.470	1.659	+2.241
Ref.3	1.380	2.074	1.009	+0.415
Substn.6	-	1.187	1.033	+0.178
Return traverse:-		Staff on Ref.4		
Substn.6		1.033	1.187	0.000
Substn.7		1.054	2.123	-0.133
Substn.8		1.441	4.188	-0.682
Substn.9		2.632	3.865	-1.556
Substn.10		1.934	2.013	-1.931
Substn.11		4.244	0.439	+2.231
Substn.12		1.813	2.686	+1.374
Substn.13		2.563	3.814	-0.123
Substn.14		4.120	1.013	+0.306
Substn.15		2.267	1.777	+0.521
Substn.16		2.298	1.482	-1.482
		Staff on Ref.5		

Closing error..+0.153 metres.

Traverse distance = 1.7 km ; Closing error per km = 0.090 m.

Reference heights relative to Ref.5 ....1) +1.043
2) -2.185
3) -1.184
4) -0.659

PORT DONAIN LEVELLING SURVEY - July 1985.

Linking traverse between References 5 and 6:

Station	Inst. Height	Backsight	Foresight	Level change
Ref.6	1.265	-	0.417	+1.265
Substn.1	-	2.511	2.069	+2.094
Substn.2	-	2.190	1.605	+0.121
Substn.3	-	0.613	0.680	-0.992
Substn.4	-	2.002	2.022	+1.322
Return traverse:-		Staff on Ref.5		
Substn.4	-	2.022	2.237	0.000
Substn.5	-	2.099	1.278	-0.228
Substn.6	-	1.036	1.507	-0.242
Substn.7	-	1.271	2.243	-0.236
Substn.8	-	1.573	2.415	-0.670
		Staff on Ref.6		

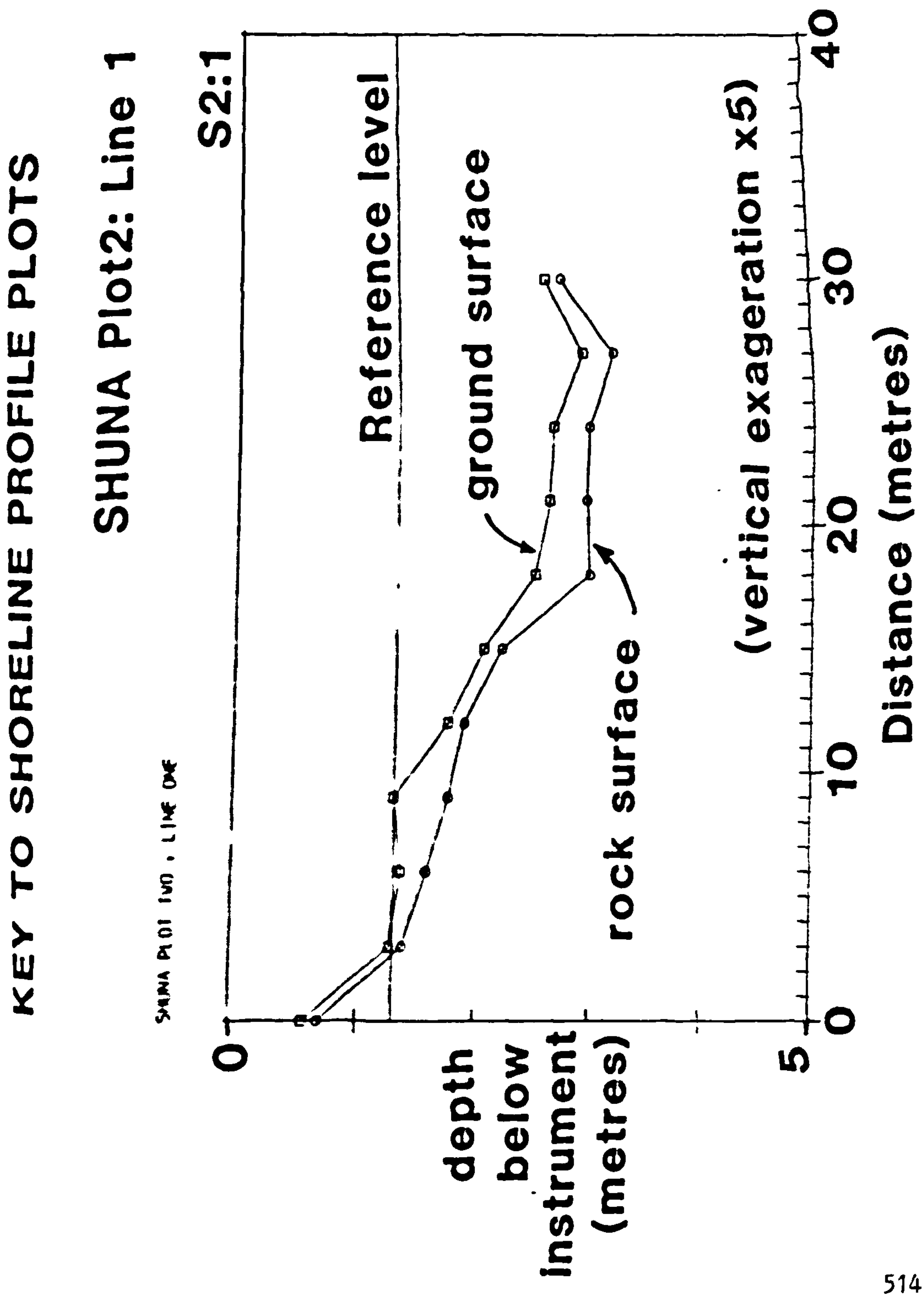
Closing error.. +0.019

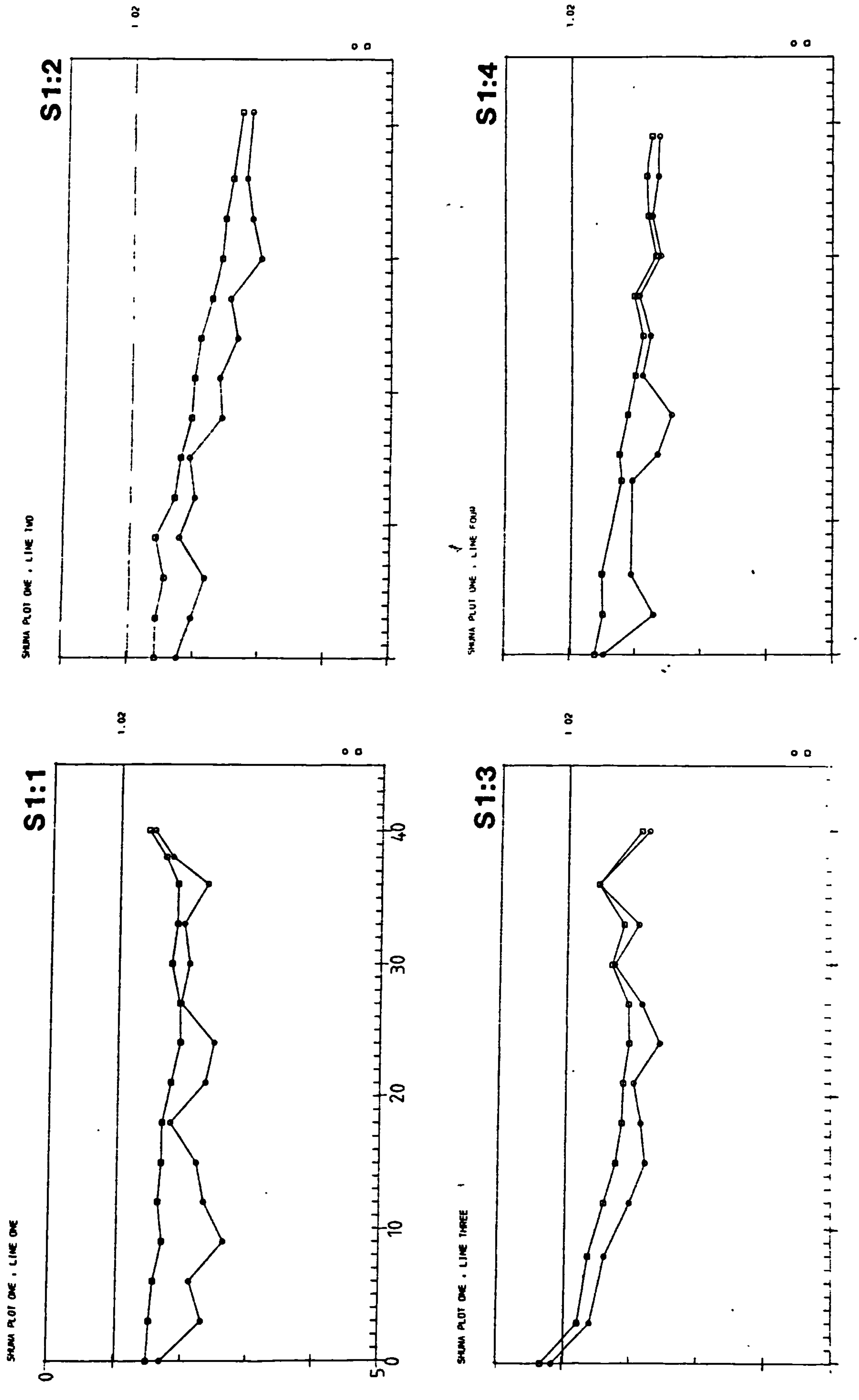
Traverse distance = 0.30 km ; Closing error per km = 0.063 m.

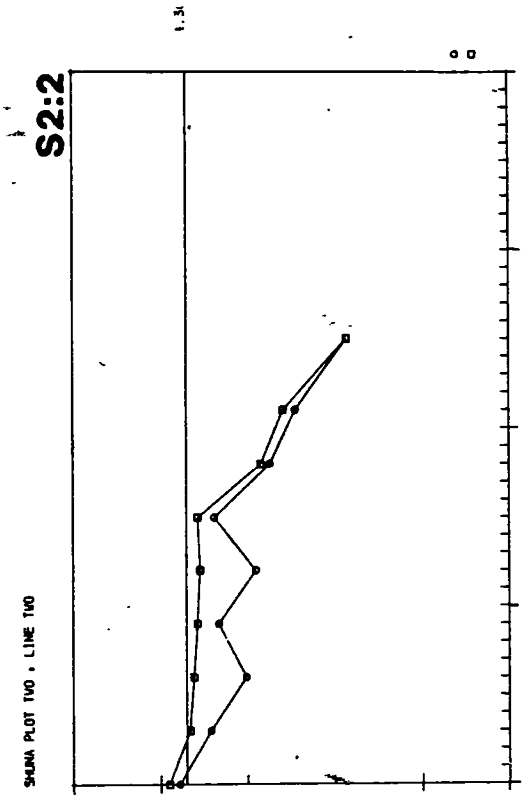
Reference heights relative to Ref.5 ....6) -1.788

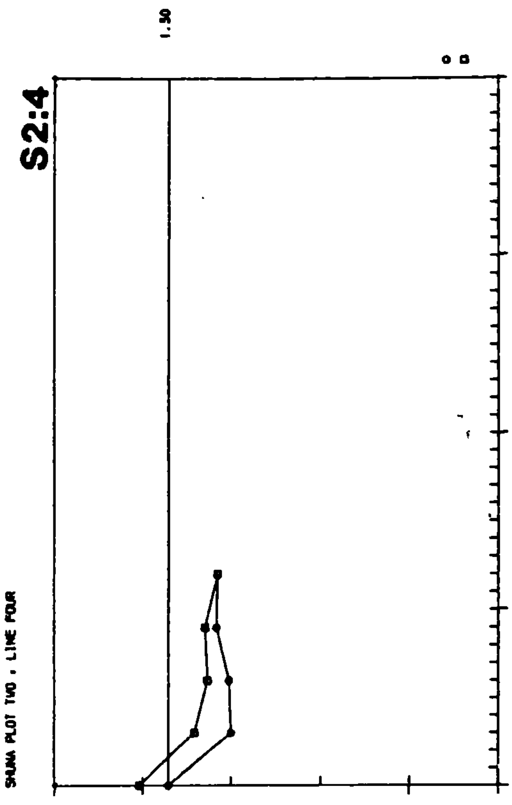
A2.6 RAISED SHORELINE PROFILES

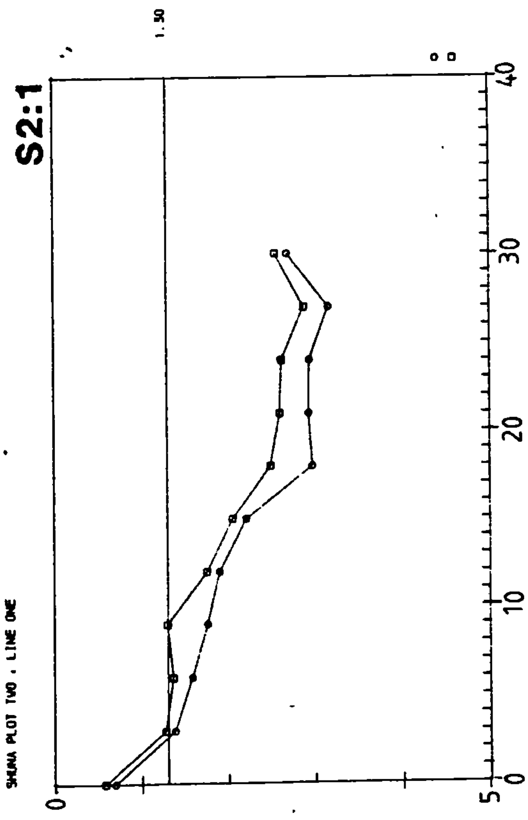
Each survey line, tabulated in section A2.5 has been plotted below to give a graphic representation of the data. [The VAX/SIMULA programme 'JTD' used to generate these plots was developed by Dr. G. Bowes, Dept. Applied Geology, University of Strathclyde.] The graphs show the elevations of the ground surface and the underlying rock surface relative to the reference level. The 'elevations' are plotted with respect to depth below the levelling instrument (i.e. the value read on the survey staff). The elevation of the reference point at each grid is indicated by a horizontal line across the graph. The measured points are connected by straight lines, not representing the true surface.

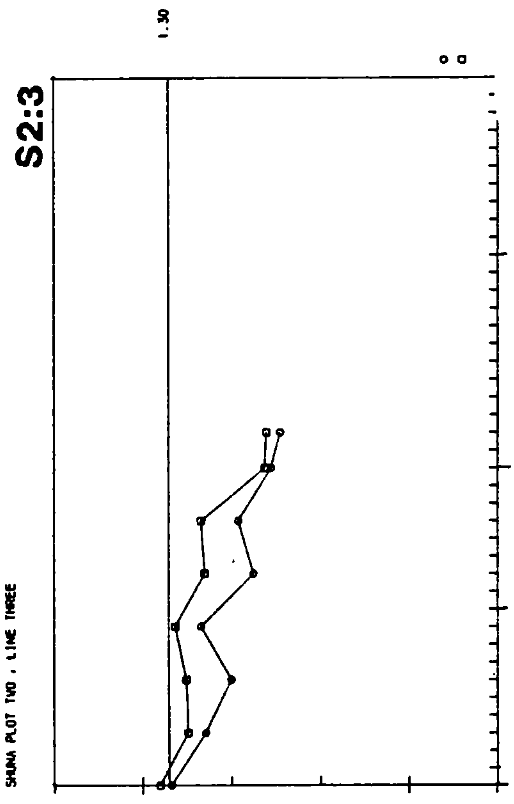


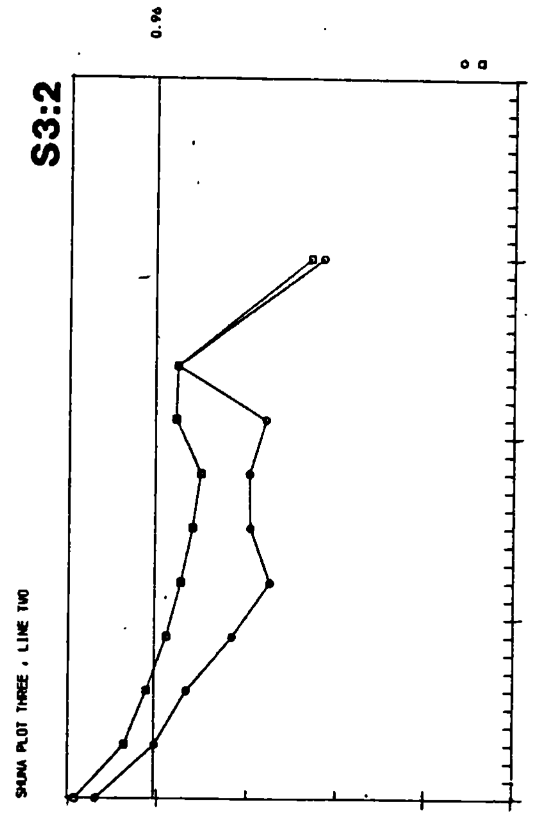

S1:2
SHUNA PLOT ONE , LINE TWO
1.02
S1:4
SHUNA PLOT ONE , LINE FOUR
1.02
S1:1
SHUNA PLOT ONE , LINE ONE
1.02
0
5
10
20
30
40
S1:3
SHUNA PLOT ONE , LINE THREE
1.02

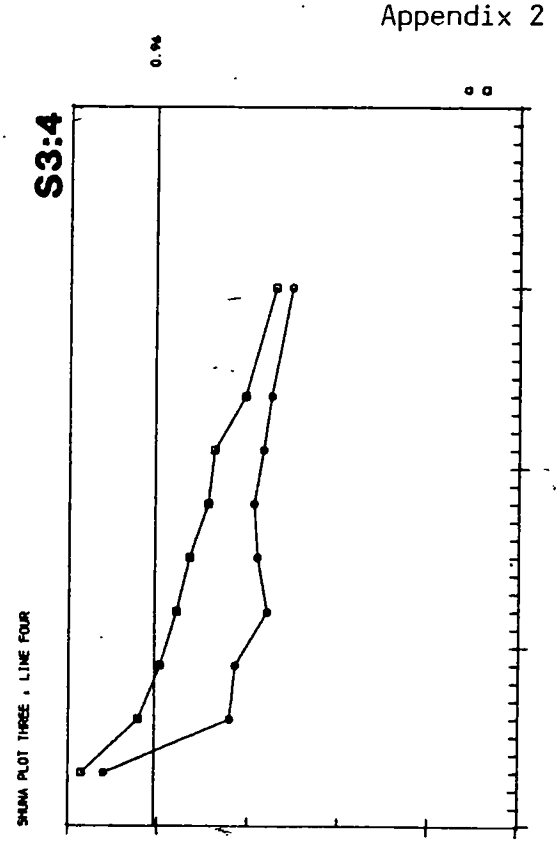

S2:2
SHUNA PLOT TWO , LINE TWO

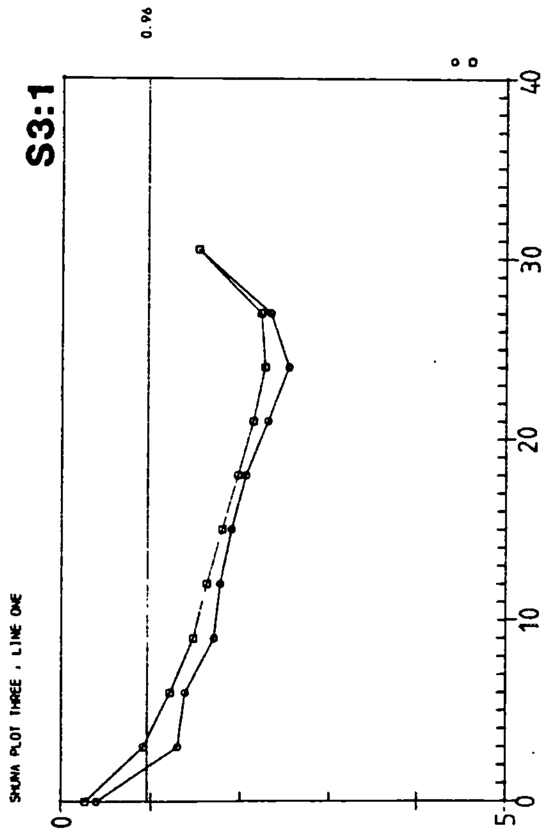

S2:4
SHUNA PLOT TWO , LINE FOUR
1.30

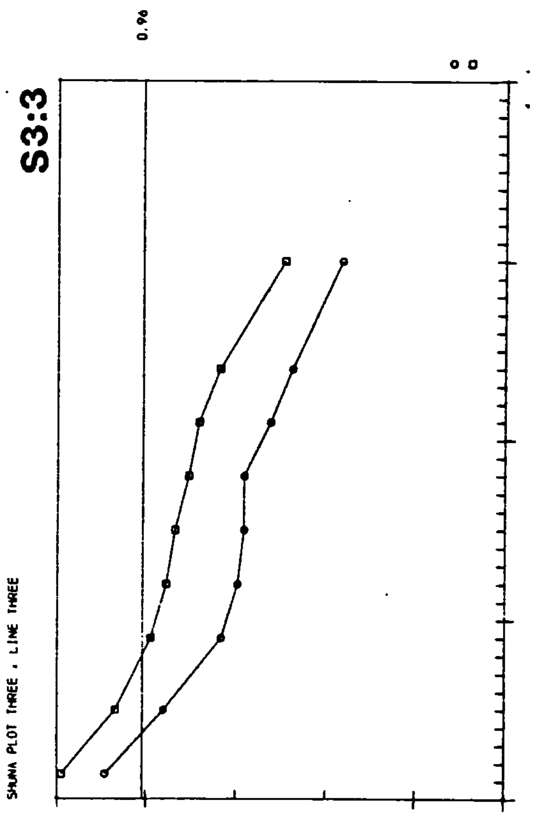

S2:1
SHUNA PLOT TWO , LINE ONE
1.50
0
5
0
10
20
30
40

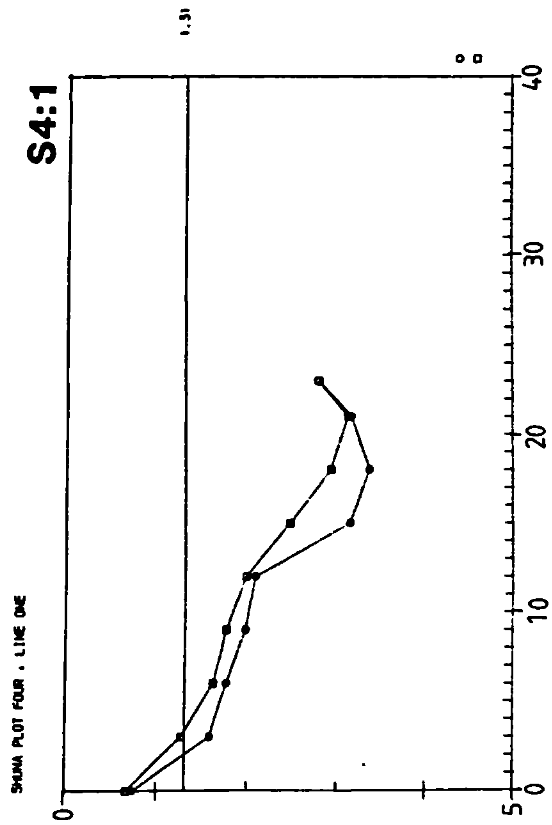

S2:3
SHUNA PLOT TWO , LINE THREE
1.30

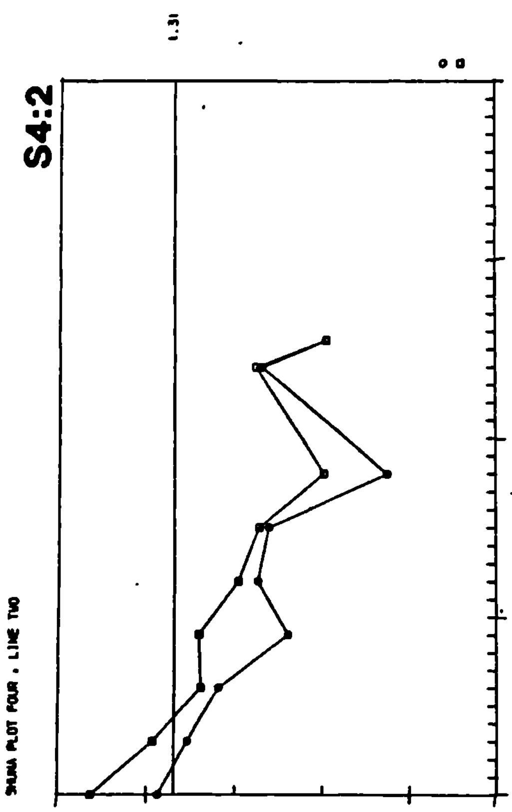

S3:2
SHUNA PLOT THREE , LINE TWO
0.96

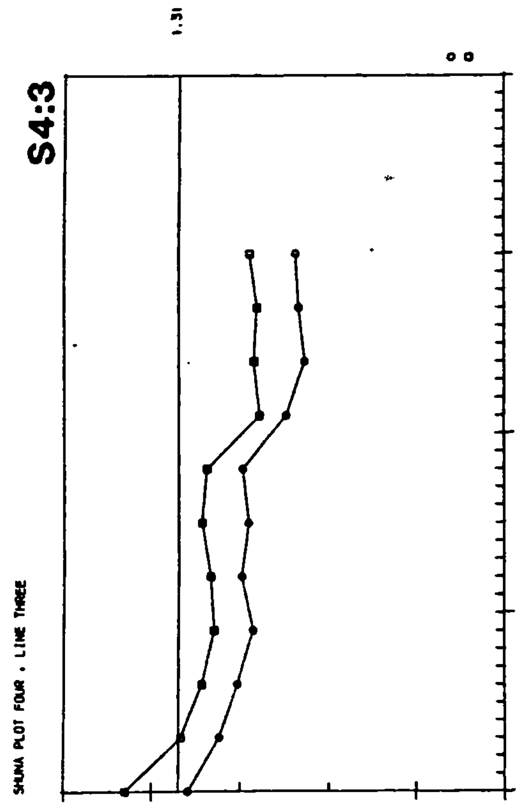

S3:4
SHUNA PLOT THREE , LINE FOUR
0.96

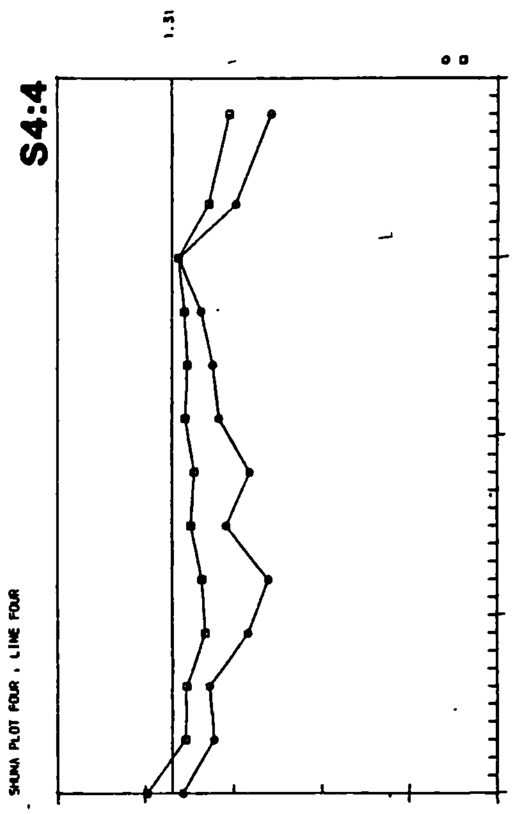

S3:1
SHUNA PLOT THREE , LINE ONE
0.96
0
10
20
30
40
0
5

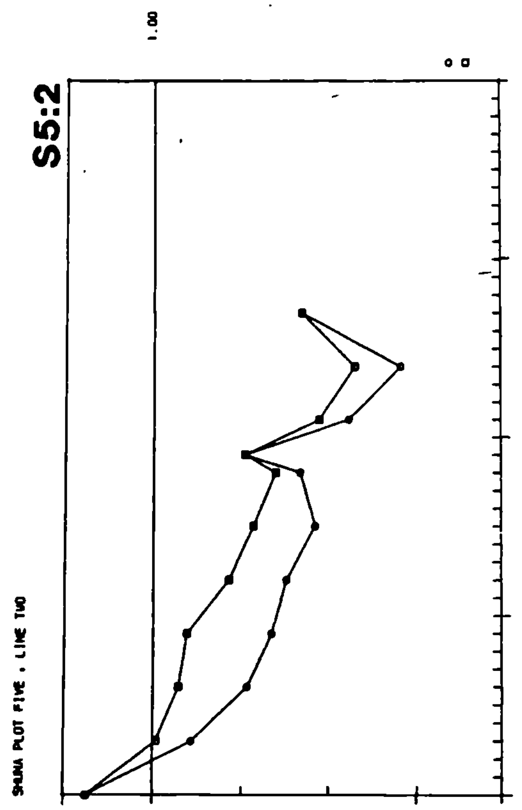

S3:3
SHUNA PLOT THREE , LINE THREE
0.96

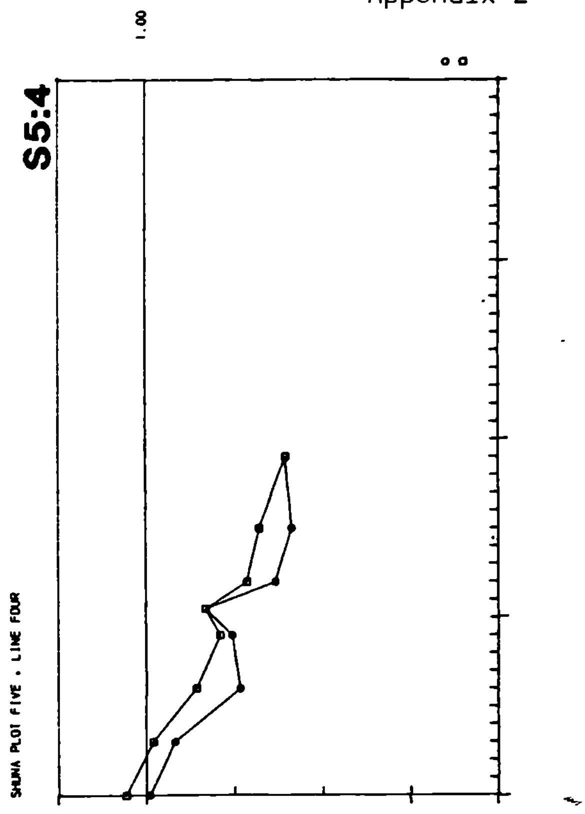

S4:1
SHUNA PLOT FOUR . LINE ONE
1.31
0
5
10
20
30
40

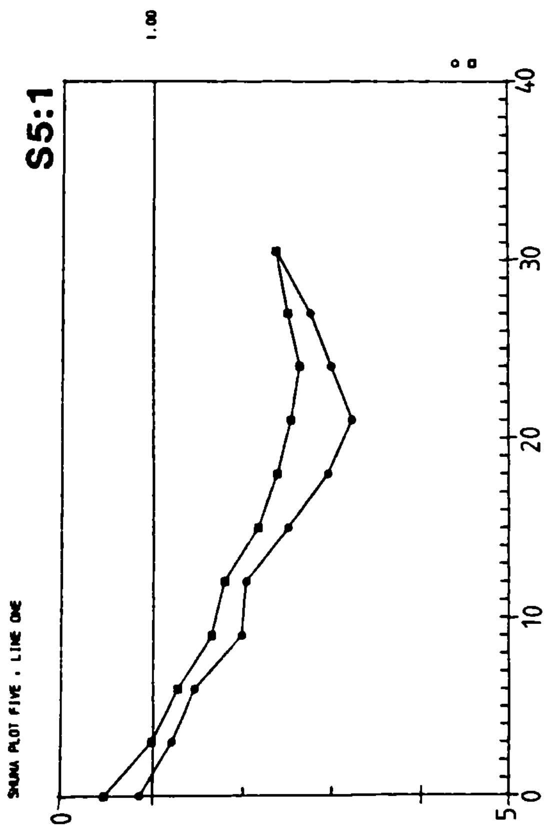

S4:2
SHUNA PLOT FOUR . LINE TWO
1.31

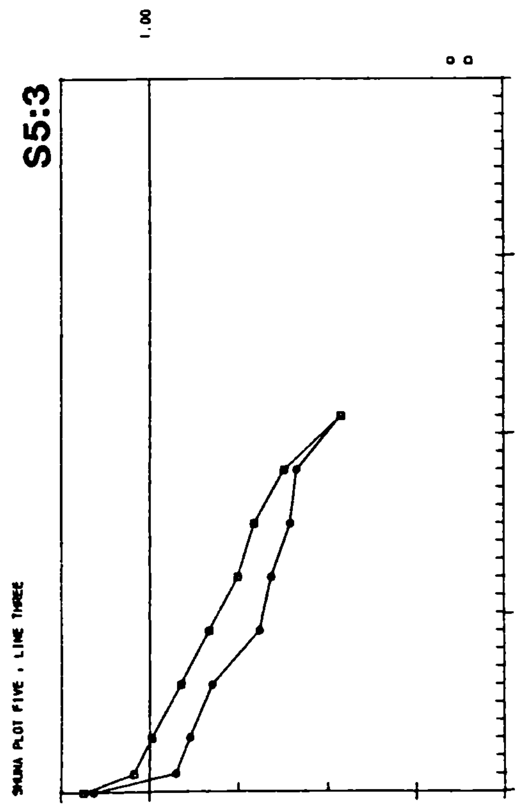

S4:3
SHUNA PLOT FOUR . LINE THREE
1.31

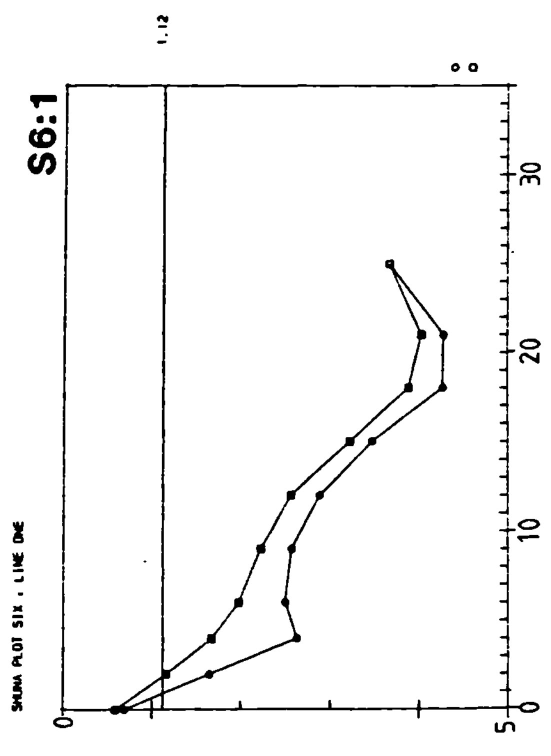

S4:4
SHUNA PLOT FOUR . LINE FOUR
1.31

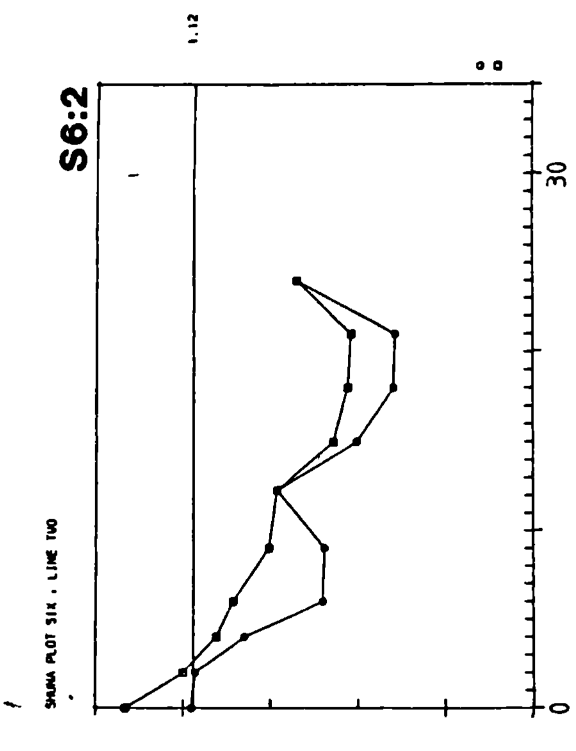

S5:2
SHUNA PLOT FIVE . LINE TWO
1.00

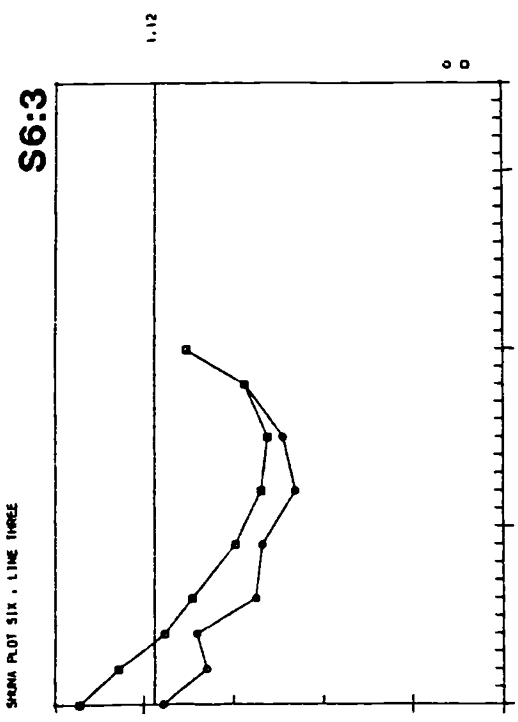

S5:4
SHUNA PLOT FIVE . LINE FOUR
1.00

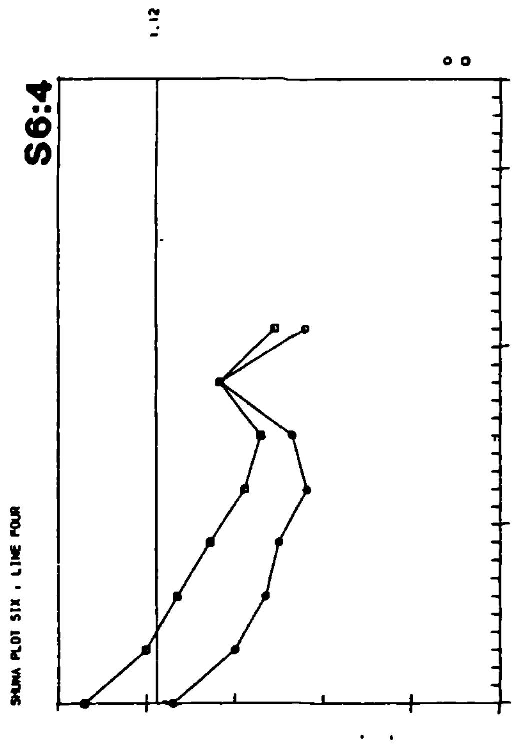

S5:1
SHUNA PLOT FIVE . LINE ONE
1.00
0
5
0
10
20
30
40

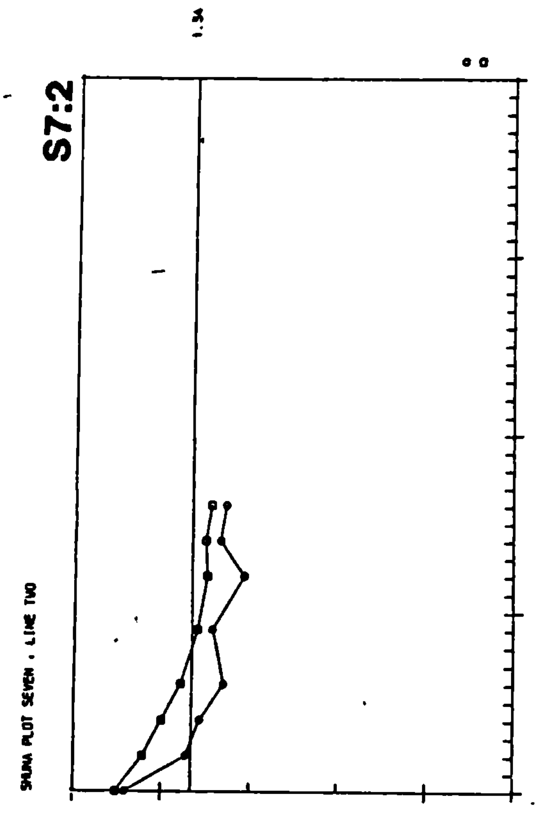

S5:3
SHUNA PLOT FIVE . LINE THREE
1.00

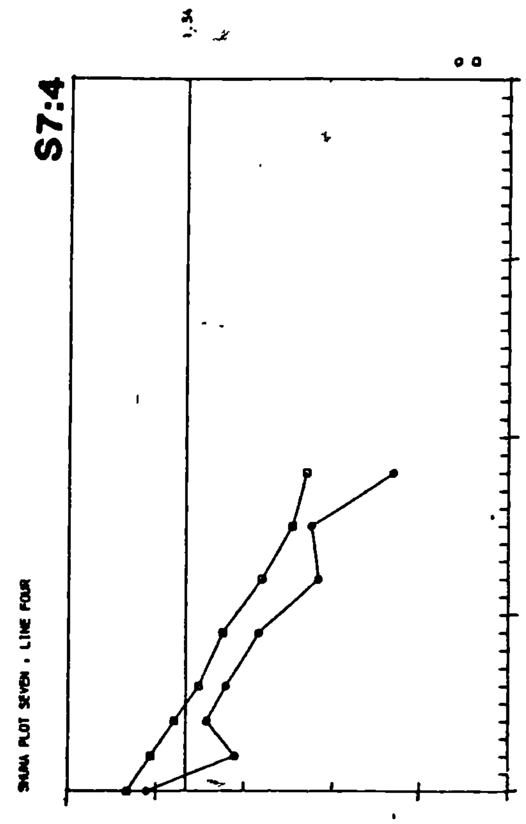

S6:1
SHUNA PLOT SIX , LINE ONE
0
5
0
10
20
30

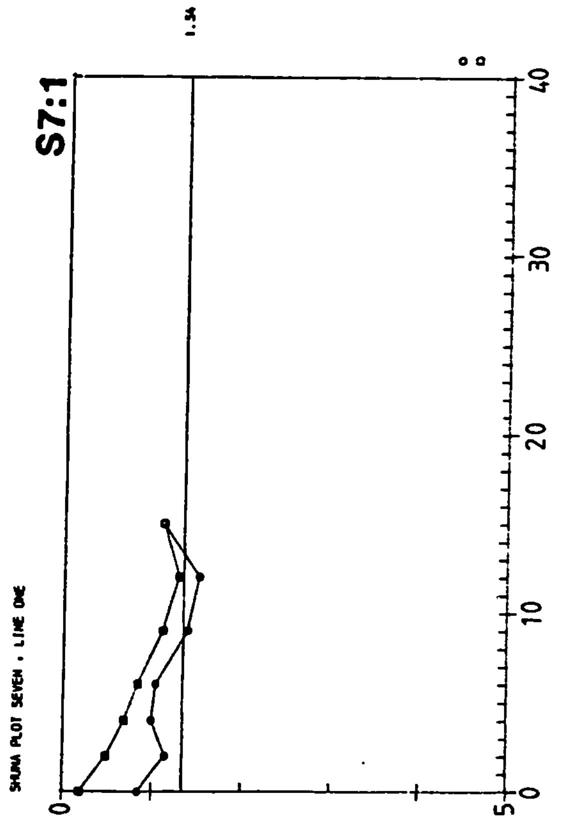

S6:2
SHUNA PLOT SIX , LINE TWO
0
30

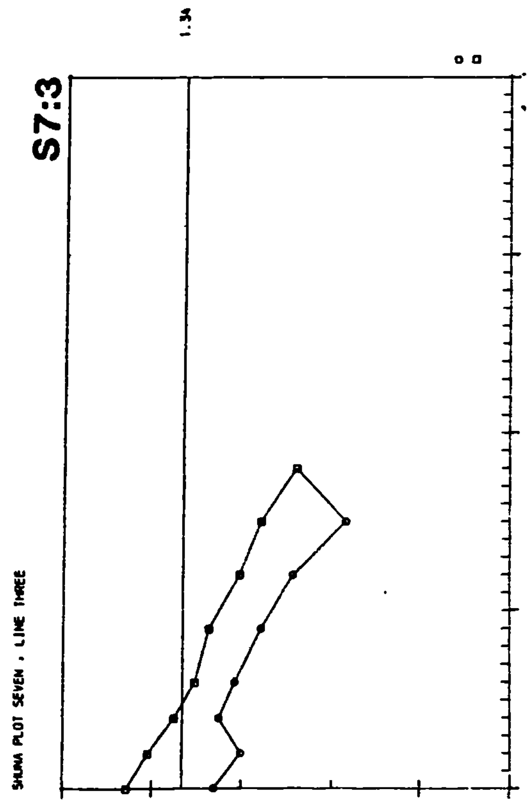

S6:3
SHUNA PLOT SIX , LINE THREE

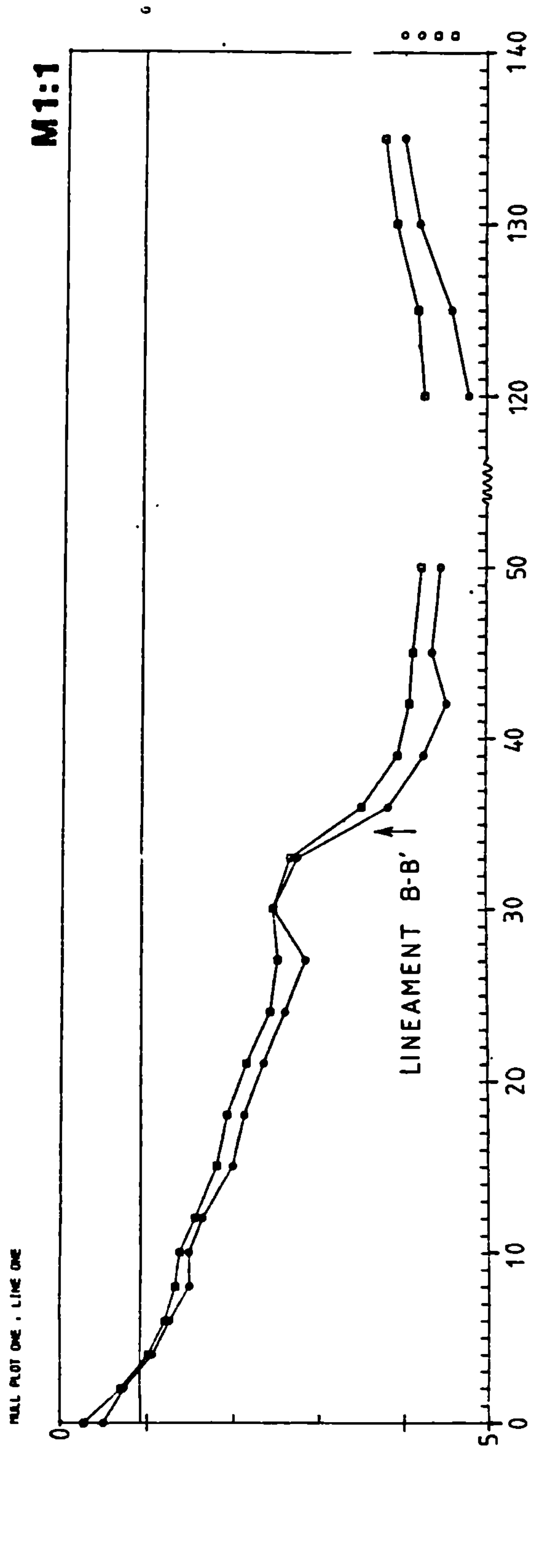

S6:4
SHUNA PLOT SIX , LINE FOUR

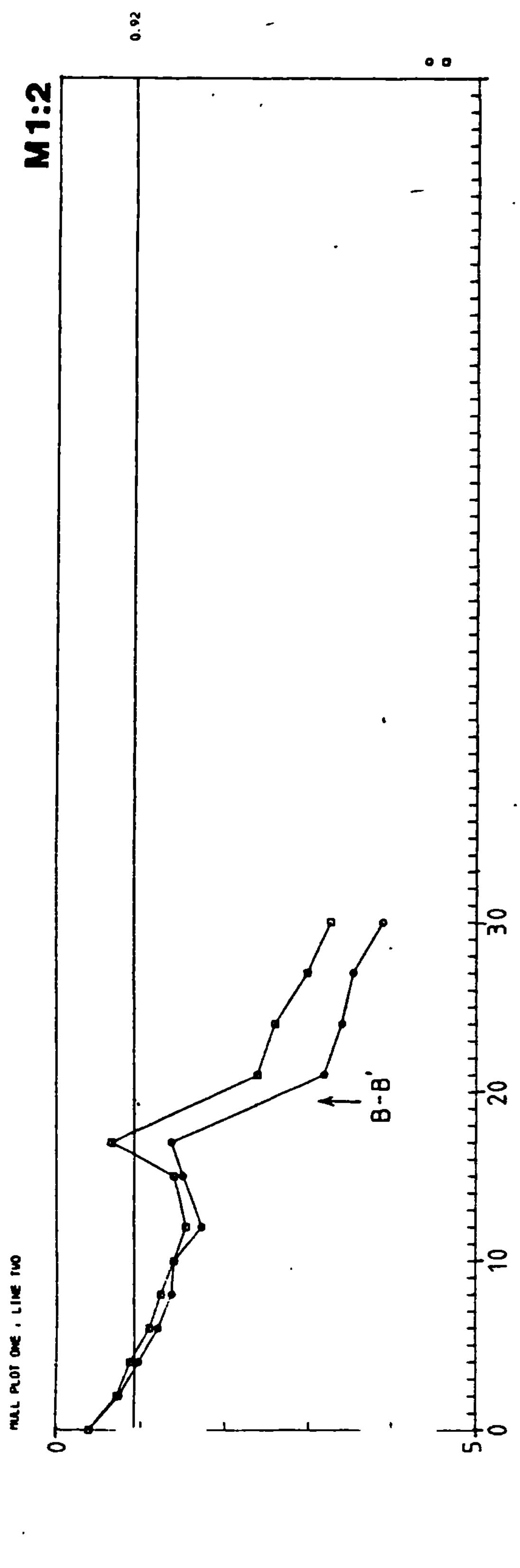

S7:2
SHUNA PLOT SEVEN . LINE TWO
1.34

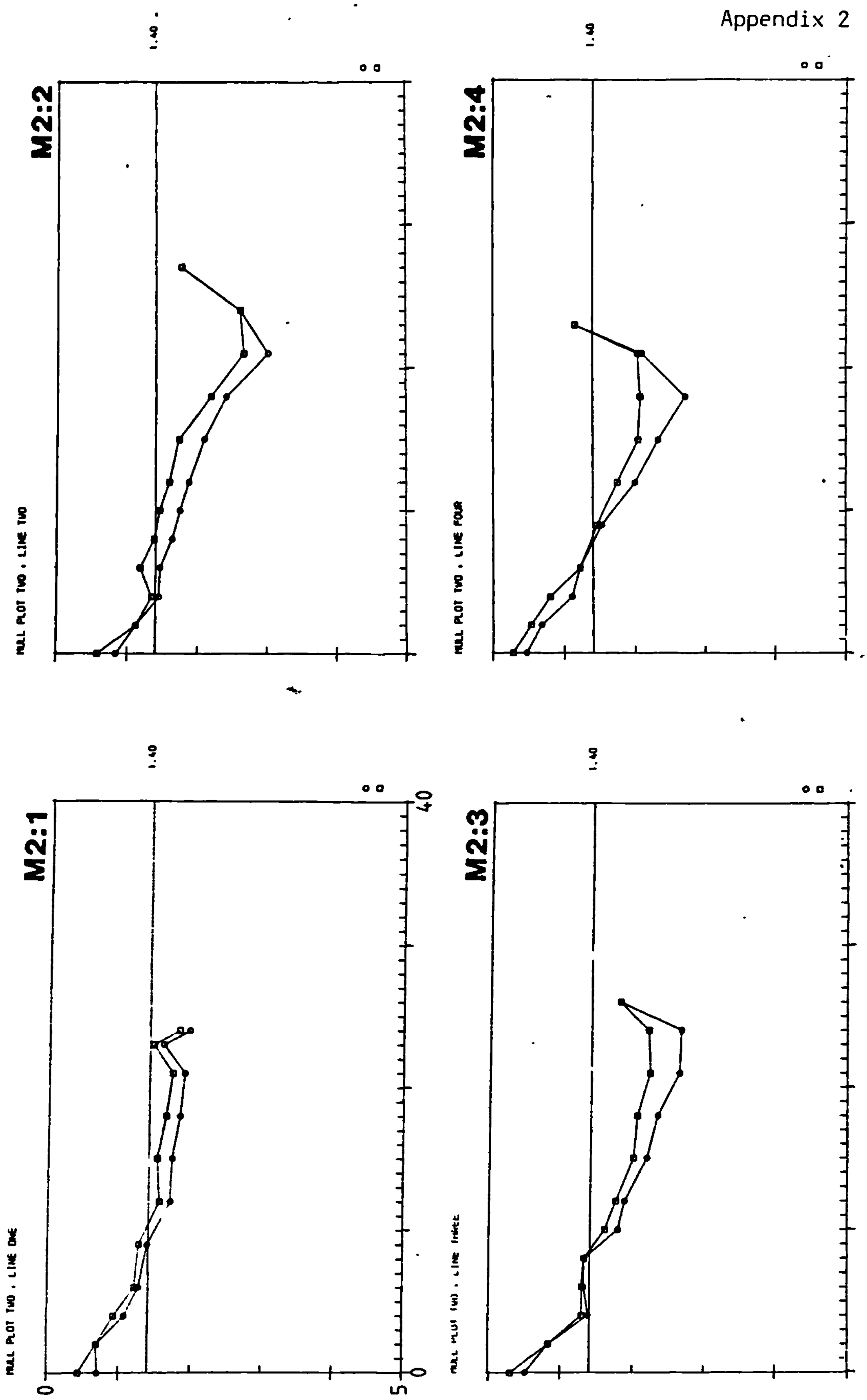

S7:4
SHUNA PLOT SEVEN . LINE FOUR
1.34

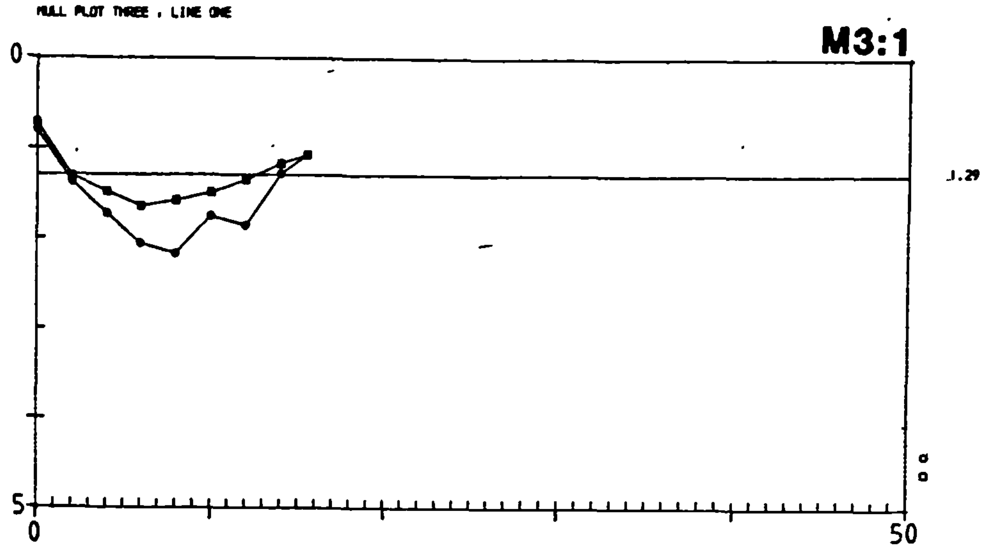

S7:1
SHUNA PLOT SEVEN . LINE ONE
1.34
0
5
0
10
20
30
40

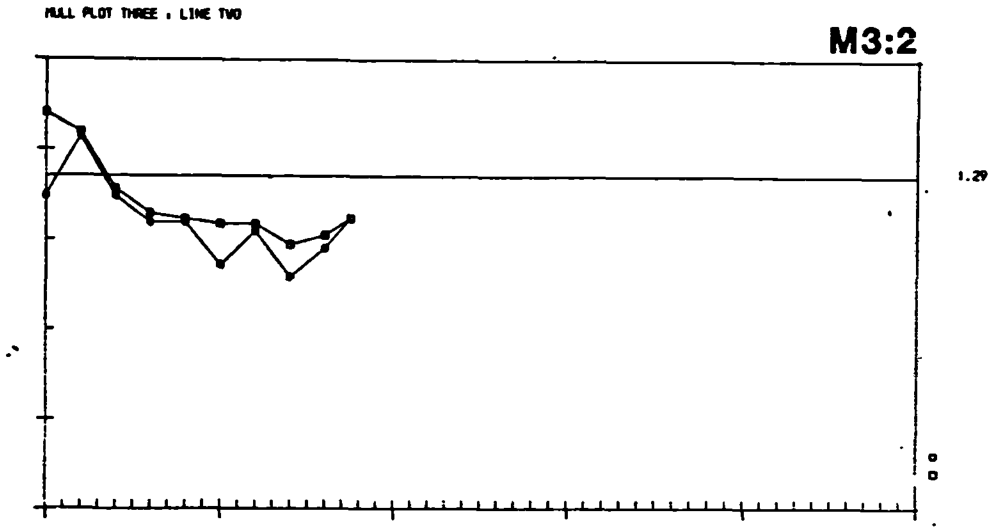

S7:3
SHUNA PLOT SEVEN . LINE THREE
1.34

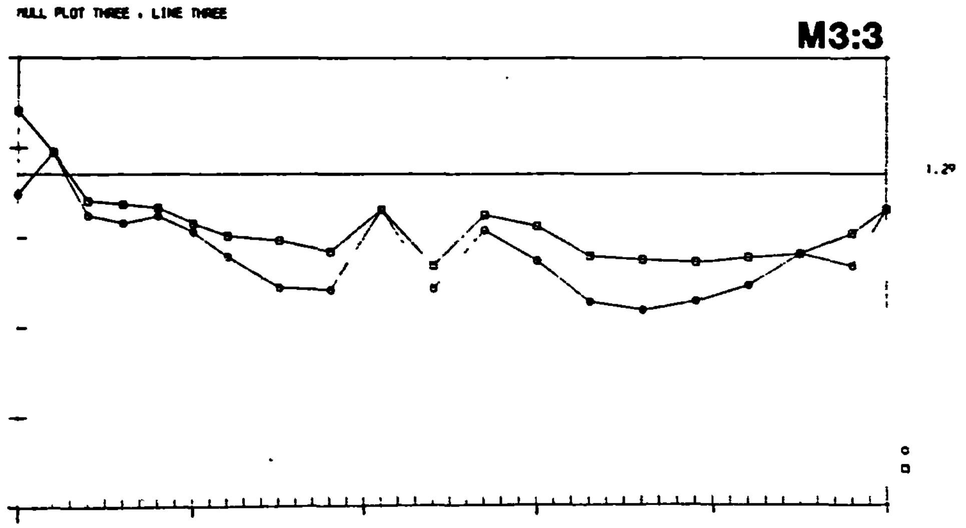

M1:1
NULL PLOT ONE , LINE ONE
LINEAMENT B-B'
0
5
0
10
20
30
40
50
120
130
140

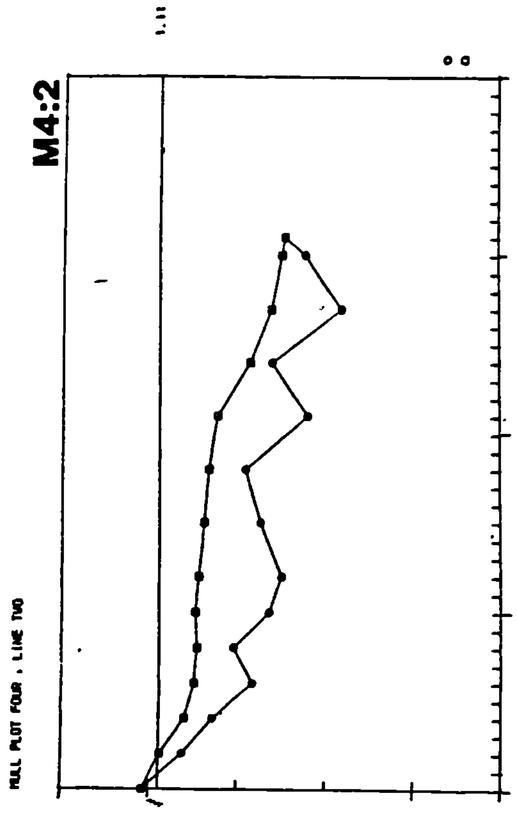

M1:2
NULL PLOT ONE , LINE TWO
0.92
B-B'
0
5
0
10
20
30

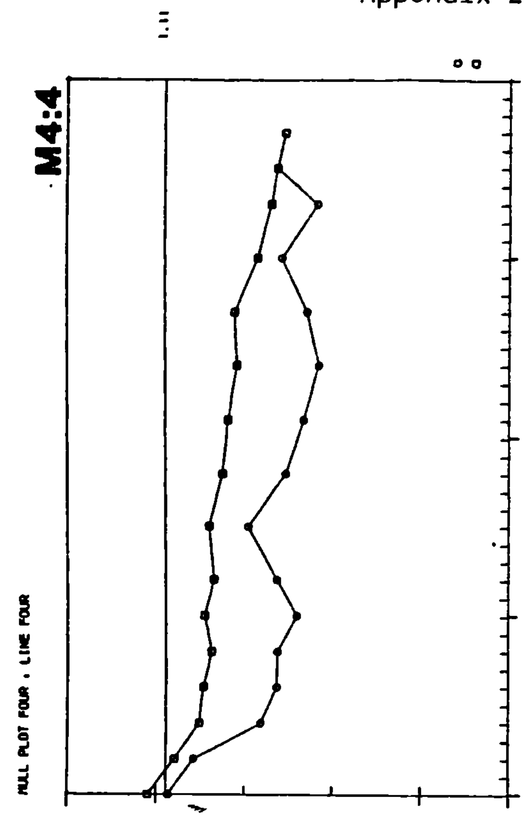

M2:1
M2:2
M2:3
M2:4

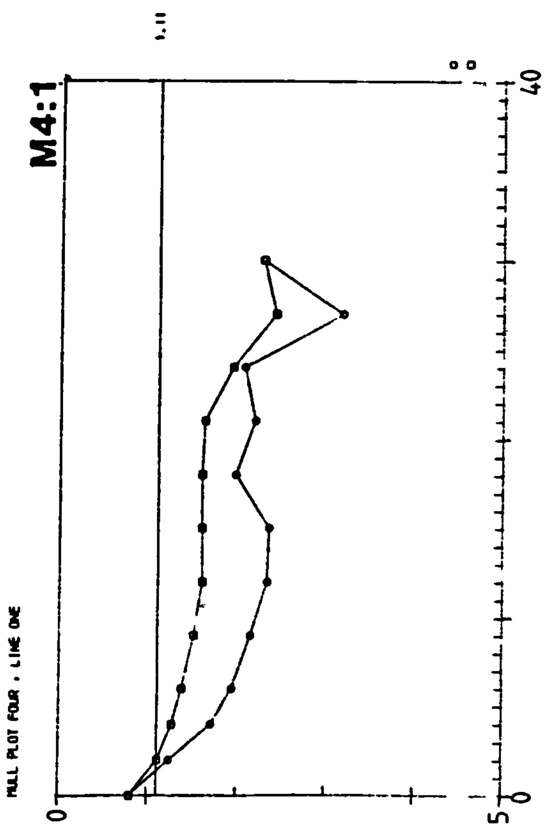

HULL PLOT THREE , LINE ONE
M3:1
0
5
0
50
1.29

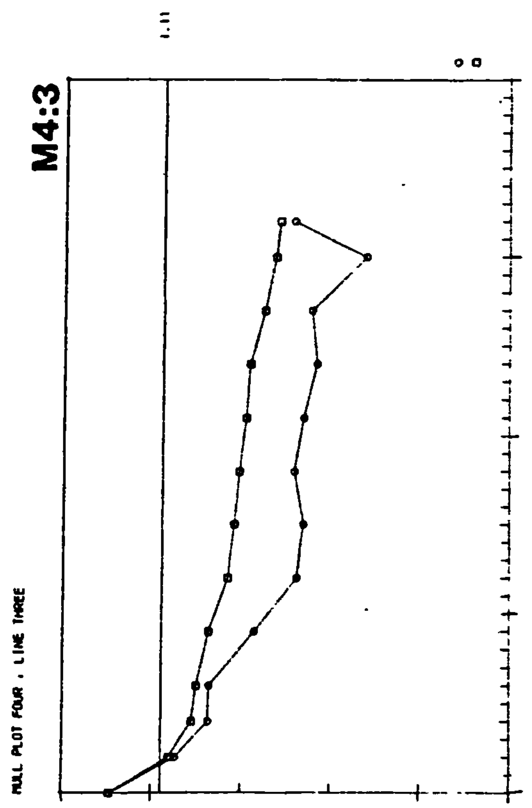

HULL PLOT THREE , LINE TWO
M3:2
1.29


HULL PLOT THREE , LINE THREE
M3:3
1.29


M4:2

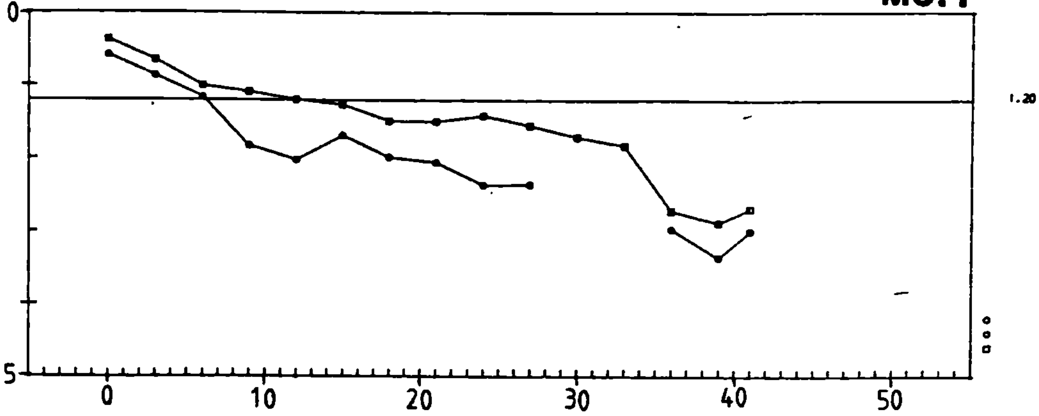

M4:4


M4:1
0
5
0
40


M4:3

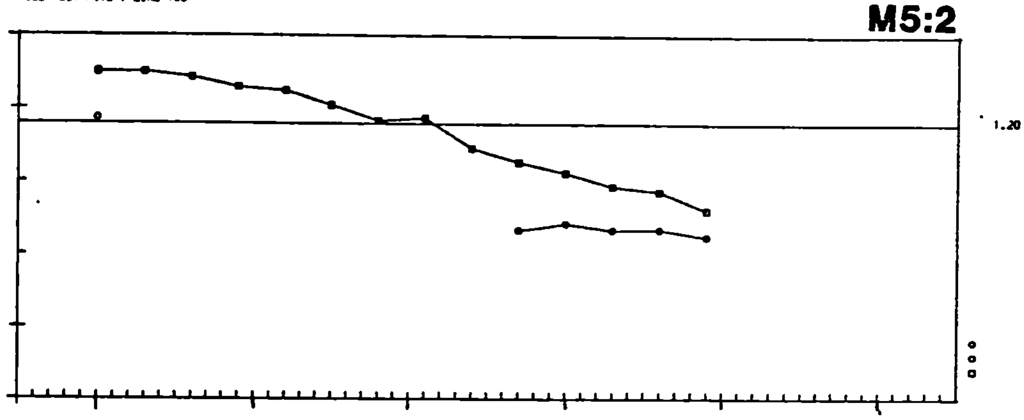
HULL PLOT FIVE , LINE ONE

M5:1



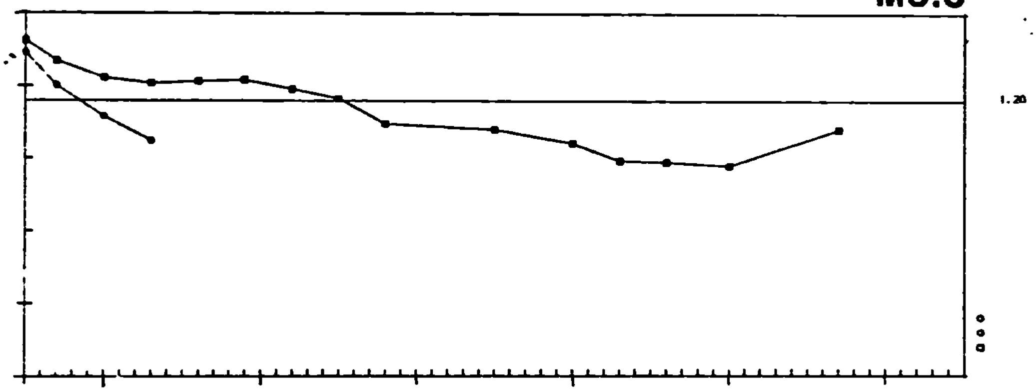
HULL PLOT FIVE , LINE TWO

M5:2



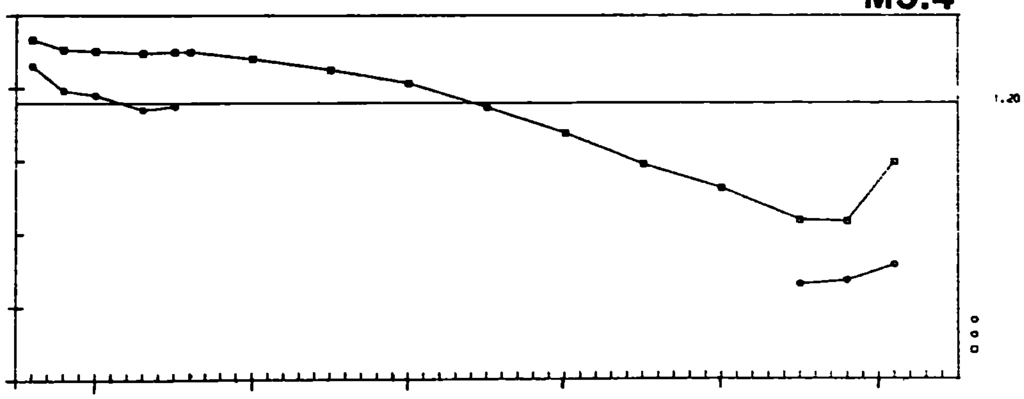
HULL PLOT FIVE , LINE THREE

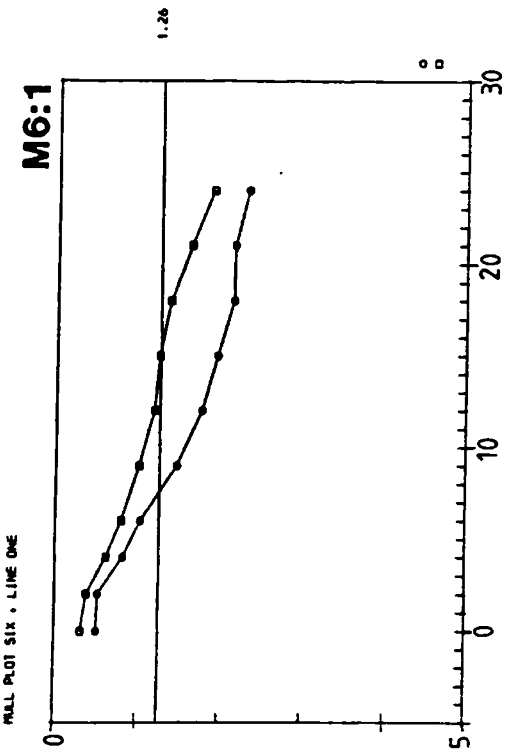
M5:3

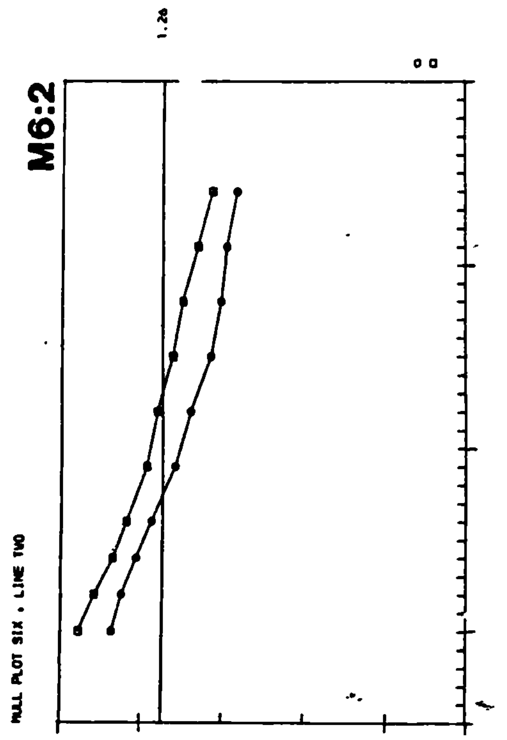


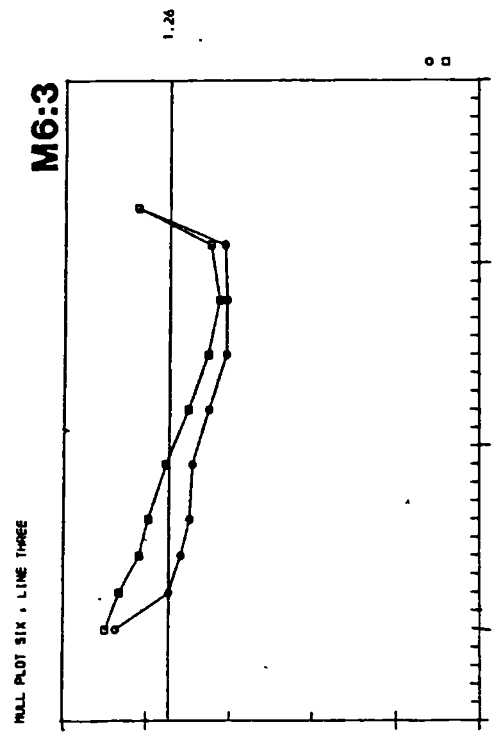
HULL PLOT FIVE , LINE FOUR

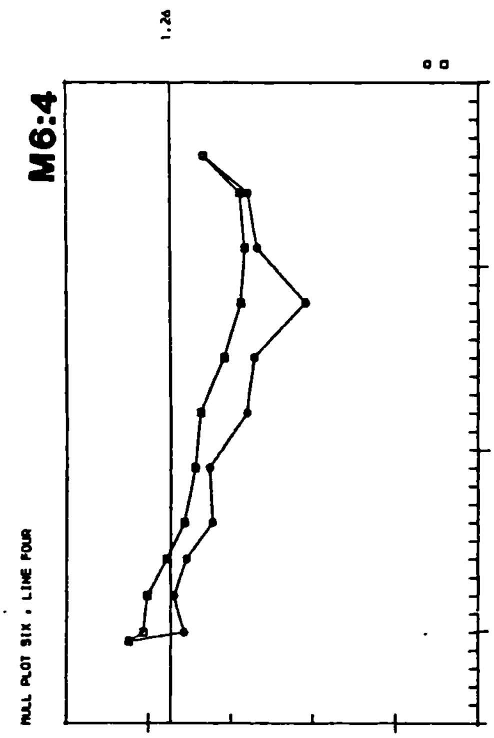
M5:4

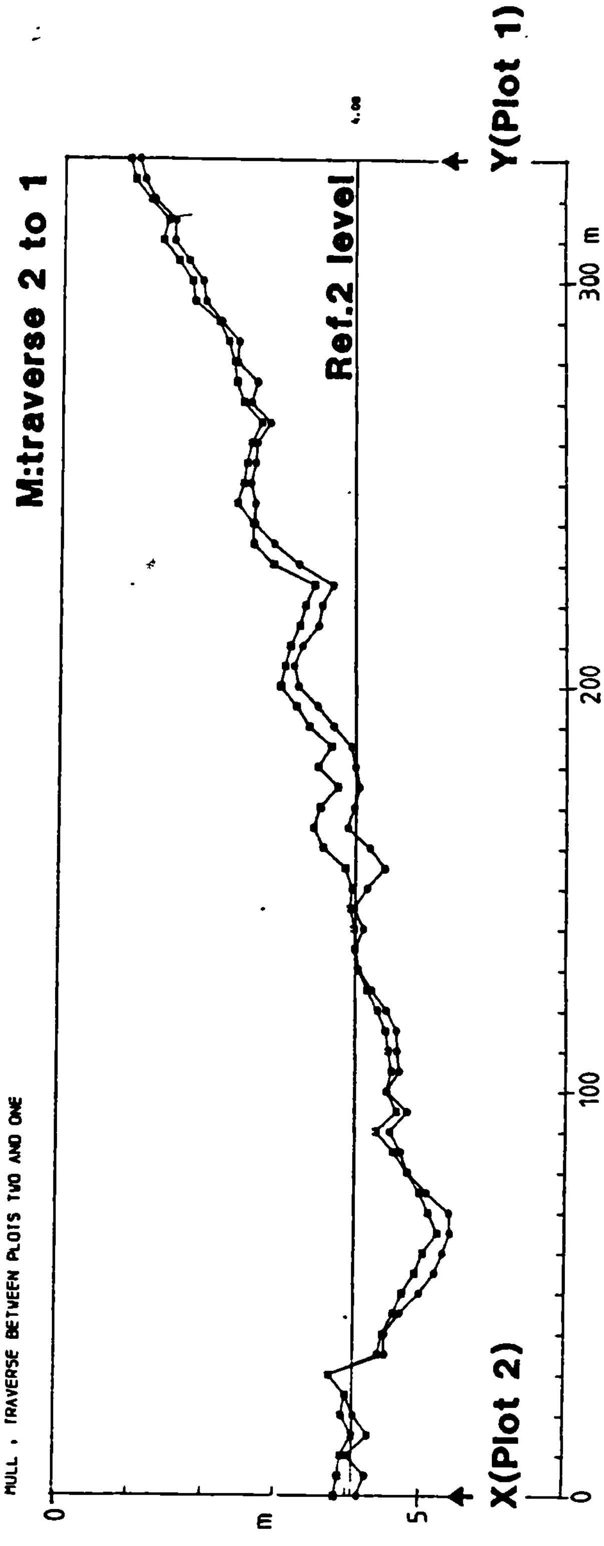


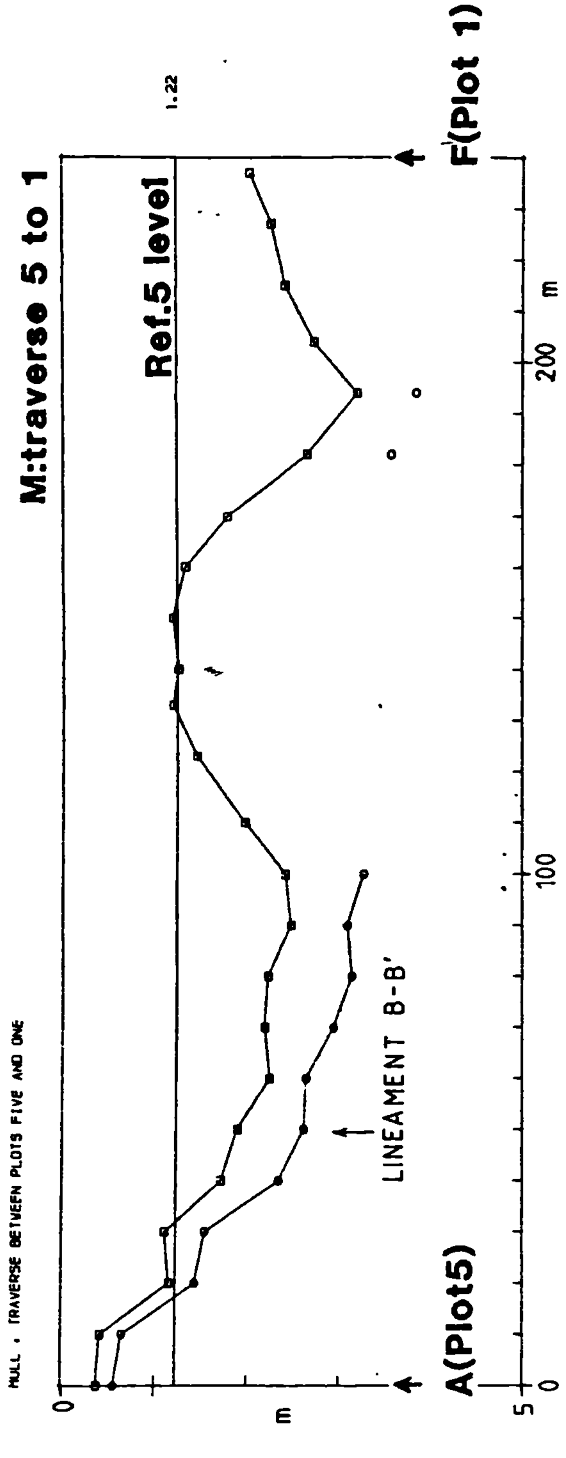

M6:1
MULL PLOT SIX , LINE ONE
1.26
0
10
20
30
0
5


M6:2
MULL PLOT SIX , LINE TWO
1.26


M6:3
MULL PLOT SIX , LINE THREE
1.26


M6:4
MULL PLOT SIX , LINE FOUR
1.26


M:traverse 2 to 1
Ref.2 level
Y(Plot 1)
X(Plot 2)
MULL . TRAVERSE BETWEEN PLOTS TWO AND ONE
0
100
200
300 m
0
m
5


M:traverse 5 to 1
Ref.5 level
F(Plot 1)
A(Plot5)
LINEAMENT B-B'
MULL . TRAVERSE BETWEEN PLOTS FIVE AND ONE
1.22
0
100
200
m
0
m
5

APPENDIX 3

LANDSAT LINEAMENT STUDY

A3.1 Introduction

This appendix outlines details of the LANDSAT imagery used and the techniques involved in a study of lineaments in portions of the Highlands of Scotland. The main database consists of c.250 colour transparency photographs of images seen on the GEMS image processing system. The image processing and photography was carried out at ERSAC, Livingston, Scotland, and was funded by NERC. Four LANDSAT images were processed and studied:

LANDSAT MSS, 23 APRIL 1984, ARGYLL SCENE.
LANDSAT MSS, 23 APRIL 1984, GREAT GLEN SCENE.
LANDSAT MSS, 24 AUGUST 1976, GREAT GLEN SCENE.
LANDSAT THEMATIC MAPPER, 08 MAY 1984, HIGHLANDS SCENE.

Specific details of the images and processing techniques are tabulated in A3.3, below. Only a selection of the images have been referred to in the thesis (chapters 11 & 12), however the whole database is documented here for reference. The colour transparency images are contained in an external file, in the possession of the author.

A3.2 Study procedure

Aims: This study was aimed at identifying and studying lineaments corresponding to surface fault features identified in the field, examining their regional context in terms of lineament distribution, and comparing seismic epicentre distribution with the lineaments identified.

Procedure:

1)Suitable cloud-free images of the Highlands of Scotland were selected from the database at ERSAC, and loaded onto the GEMS image processing system.

2) The images were then processed according to the following procedure:
- Apply an appropriate 'stretch' to the contrast range of the input image.
- Edge enhance the image.
- Apply principal component analysis to the input bands to create new images.
- Ratio the bands to create synthetic variable images (TM only).
- Apply principal component analysis to the synthetic variables (TM only).
- Combine different images to create colour composites.

3) Photographs, onto colour transparencies, were taken of each successful image, concentrating on extracts around field localities, especially around Kinloch Hourn and Glen Roy. The colour transparencies were then projected for study; observed lineaments were drawn on overlays of the projected image. These overlays were then super-imposed in order to produce composite overlays containing lineaments found on more-than-one image. These composite overlays together with the individual overlays were then studied with regard to the significance of the lineaments, making comparisons with field observations, known regional geology, and seismicity.

A3.3 CATALOGUE OF LANDSAT IMAGES

Tabulated below are details of each image photographed onto colour transparency.

Abbreviations used:

Scene: LANDSAT scene identification number.

Band: LANDSAT input bands:-

Recorder	Band	wavelength range	description	spatial resolution
MSS	4	0.5-0.6µm	green	80m
MSS	5	0.6-0.7µm	red-orange	80m
MSS	7	0.8-1.1µm	infra-red	80m
TM	2	0.52-0.60µm	green	30m
TM	3	0.63-0.69µm	red	30m
TM	4	0.76-0.90µm	near infra-red	30m
TM	5	1.55-1.75µm	middle infra-red	30m
TM	7	2.08-2.35µm	infra-red	30m

Stretch: description of the contrast stretch applied:-
manual: adjusted manually to be visually acceptable.
auto 2: a standard gaussian distribution applied by the GEMS software.
(whole/extract): stretch applied to whole image / extract of the image.

Operation: process applied to the image:-
EE16 = Edge enhance with a 16x16 pixel matrix.
PC1 = 1st principal component.
SV1 = 1st synthetic variable.
neg. = a negative image.
mean to median = shift the mean of the input contrast range to the median of the output range.

Colour guns: allocation of input bands to the colour guns of the monitor.
R=red, G=green, B=blue.

Magnification: zoom 2 = 2x magnification etc.

CATALOGUE OF LANDSAT IMAGES (cont.) MSS - 1.

Scene: 8072 206:20 23APR84 C57-32N 004-47W 150 43 104810 L4 ARGYLL B4,5&7.

Image	Band	Stretch	Operation	Colour guns	Magnification	Comments
1/1,2	457	auto 2	none	R7,G5,B4	zoom 2 on 1 by 1 pixel extract over Lismore	
1/3,4	457	manual linear	"	"	zoom 1	Lismore
1/5,6	457	"	"	"	zoom 2	Lismore
1/7,8	7	"	"	all	zoom 1	Lismore
1/9	7	"	"	"	zoom 4	south end of Lismore
1/10	7	"	"	"	"	Port Donain, Mull
1/12,13	457	auto 2	"	R7,G5,B4	whole scene	

CATALOGUE OF LANDSAT IMAGES (cont.)

MSS - 2.

Scene: 8073 206:21 23APR84 C55-55N 003-90W 149 44 104810 L4 GREAT GLEN B4,5&7.

Image	Band	Stretch	Operation	Colour guns	Magnification	Comments
1/14,15	457	auto 2	none	R7,G5,B4	whole scene	
1/16	457	"	histogram	"	whole scene	
1/17,18	457	"	none	"	2 by 2 pixel	extract over Kintail
1/21/22	457	manual linear	"	"	1 by 1 pixel	and for rest of this scene
1/23	457	"	histogram	"	"	
1/24,25	457	"	EE16/PC1	all	"	
1/27	457	"	" /PC2	"	"	
1/28	457	"	" /PC3	"	"	
1/29,30	457	"	" /PC1&2	R1,G2,B1	"	
1/32	457	"	" "	R2,G1,B2	"	
1/33,34	457	"	negate "	"	"	
1/35	457	man. non-linear	negate "	"	"	
1/37,38	457	"	"	"	zoom 2	arrow marking fault
2/1	457	"	histogram	R1,G2,B3	1 by 1 pixel	
2/2,4	457	"	EE32/PC1 neg	all	"	
2/5,6	457	"	" /PC2 neg	"	"	
2/7,8	457	"	" /PC3 neg	"	"	
2/9,10	457	"	" /PC1&2 neg	R1,G2,B1	"	
2/11,12	457	"	" " neg	R2,G1,B2	"	
2/13,14	457	"	" /PC1	all	"	
2/15,16	457	"	" /PC2	"	"	
2/17,18	457	"	" /PC1&2	R1,G2,B1	"	
2/19,20	457	"	" "	R2,G1,B2	"	

CATALOGUE OF LANDSAT IMAGES (cont.)

MSS - 3.

Scene: 8034 222:20 24AUG76 C57-14N 004-17W 134 35 100500 L1 GREAT GLEN B4,5&7.

Image	Band	Stretch	Operation	Colour guns	Magnification	Comments
2/21,22	457	manual 2 part	linear/none	R4,G5,B7	whole scene	
2/23,24	457	"	histogram	"	"	
2/25,26	457	auto 2	none	"	"	
2/27,28	457	"	"	"	1 by 1 pixel	showing extract position extract over Glen Roy and for rest of this scene
2/29,30	457	"	PC1	all	"	
2/31,32	457	"	"	"	zoom 2	
2/33,34	457	"	PC2	"	zoom 1	
2/35,36	457	"	"	"	zoom 2	
2/37,38	457	"	PC3	"	zoom 1	
3/1,2	457	"	"	"	zoom 2	
3/3,4	457	"	PC1&3	R1,G3,B1	zoom 1	
3/5,6	457	"	"	R1,G1,B3	"	
3/9,10	457	"	"	"	zoom 2	
3/26,27	457	"	EE16/PC1,2&3	R1,G2,B3	zoom 1	
3/28,29	457	"	" /PC3	all	"	
3/30,31	457	"	" "	"	zoom 2	
3/32,33	457	"	EE32/PC1,2&3	R1,G2,B3	zoom 1	
3/35	-	-	GEMS menu	-		
3/36	-	-	GEMS menu - Histograms etc.			
3/37	-	-	GEMS menu - Maths operations.			
3/38	-	-	GEMS menu - Copy image etc.			

CATALOGUE OF LANDSAT IMAGES (cont.)

THEMATIC MAPPER - 1.

Scene: TM.5 6920 5760 1 L5 TM. 207.20 08 MAY 84 HIGHLANDS B2,3,4,5&7.

Image	Band	Stretch	Operation	Colour guns	Magnification	Comments
4/9	-	manuel	histograms	all	of whole scene	unidentified
4/11	5	auto 2 (whole)	none	all	whole scene	poor image
4/12,13	345	auto 2 (extr.)	"	R5,G4,B3	whole scene	
4/14,15	345	"	"	"	zoom 2	
4/19,20	7	"	"	All	whole scene	
4/21,22	237	"	"	R2,G3,B7	whole scene	coastline clear
4/23,24	457	"	"	R7,G4,B5	whole scene	dull
4/25,26	457	"	"	R5,G4,B7	whole scene	spurious extract shown
4/27,28	5	none	histogram	all	of whole scene	
4/29,30	235	manual	mean to median	R5,G3,B2	1 by 1 pixel	extract over Glen Roy
4/31,32	235	"	"	R3,G5,B2	"	
4/34,35	235	"	negate	"	"	
4/36	235	"	negate	"	zoom 4	over Glen Roy landslip
4/37,38	235	"	negate	"	zoom 2	

CATALOGUE OF LANDSAT IMAGES (cont.) THEMATIC MAPPER - 2.

Scene: TM.5 6920 5760 1 L5 TM. 207.20 08 MAY 84 HIGHLANDS B2,3,4,5&7.

Image	Band	Stretch	Operation	Colour guns	Magnification	Comments
5/2,3	234	auto 2 (extr.)	none	R4,G3,B2	2 by 2 pixels	extract over Glen Roy
5/4,5	345	"	"	R4,G5,B3	ditto	and for rest of TM images
5/6,7	"	"	"	"	zoom 2	
5/8,9	5	"	negate	all	"	
5/10,11	4	"	negate	"	"	
5/12,13	3	"	not neg	"	"	
5/14,15	2	"	"	"	"	
5/16,17	23457	"	PC1	"	"	
5/18	"	"	PC1 neg	"	"	
5/19,20	"	"	PC2	"	"	
5/21,22	"	"	PC2 neg	"	"	
5/23,24	"	"	PC3	"	"	
5/25,26	"	"	PC3 neg	"	"	
5/27,28	"	"	PC4 neg	"	"	
5/29,30	"	"	PC4	"	"	
5/31,32	"	"	PC5	"	"	
5/33,34	"	"	PC5 neg	"	"	
5/35	"	"	histogram PC1	"	-	
5/36	"	"	" PC2	"	-	
5/37	"	"	" PC3	"	-	
6/1	"	"	" PC4	"	-	
6/2,3	"	"	" PC5	"	-	

CATALOGUE OF LANDSAT IMAGES (cont.) THEMATIC MAPPER - 3.

Scene: TM.5 6920 5760 1 L5 TM. 207.20 08 MAY 84 HIGHLANDS B2,3,4,5&7.

Image	Band	Stretch	Operation	Colour guns	Magnification	Comments
6/4,5	23457	auto 2 (extr.)	PC's 1,2&5	R5,G2,B1	whole extract	
6/6,7	"	"	"	"	zoom 2	
6/8,9	345	"	histogram	R3,G4,B5	-	
6/10,11	3	manual	mean to median	all	zoom 2	
6/12,13	4	"	"	"	"	
6/14,15	5	"	"	"	"	
6/16,17	7	"	"	"	"	
6/18,19	345	"	histogram	R3,G4,B5	-	
6/20,21	3/5	"	SV1 (ratio 3/5)	all	whole extract	
6/22,23	"	"	"	"	zoom 2	
6/24,25	4/7	"	SV2 (ratio 4/7)	all	whole extract	
6/26,27	"	"	"	"	zoom 2	
6/28,29	SV1&2	"	none	R1,G&B-2	"	
6/30,31	"	"	"	"	whole extract	
6/32,33	SV1	"	negate	all	"	
6/34,35	"	"	negate	"	zoom 2	
6/36	SV2	"	negate	"	"	
7/2,3	SV1234	"	PC1	all	whole scene	
7/4,5	"	"	"	"	zoom 2	
7/6,7	"	"	PC1 neg	"	"	
7/8,9	"	"	"	"	zoom 4	top of Glen Gloy
7/10,11	"	"	PC2	"	zoom 2	
7/12,13	"	"	PC3	"	"	
7/14,15	"	"	PC4	"	"	

Appendix 3

A3.4 DETAILS OF PRINCIPAL COMPONENT ANALYSIS AND THE CREATION OF SYNTHETIC VARIABLES ON AN EXTRACT OVER GLEN ROY OF THE THEMATIC MAPPER IMAGE.

Scene: TM 5 6920 5760 1 L5 TM 207:20 08MAY84 HIGHLANDS B2,3,4,5&7.

Extract co-ordinates: TL 5160 3170
Extract size: 2 by 2 pixels.

Derivation of Principal Components:

Input Bands	2	3	4	5	7
Mean of input bands	37.9	43.6	63.7	84.3	35.2
Standard Dev. of input bands	17.7	19.6	19.1	27.0	17.4
S.D. of P.C.s before storing	41.0	18.0	7.7	5.8	1.2

Eigenvalues (scaled to sum = 1) 0.80152 0.15368 0.02808 0.01599 0.00074

Principal Components as combinations of original bands:

PC1	0.3677	0.4253	0.4333	0.5805	0.3989
PC2	0.5106	0.4683	0.1399	-0.7015	-0.0967
PC3	0.1848	0.1472	-0.8049	0.0018	0.5443
PC4	-0.0142	-0.5037	0.3689	-0.3699	0.6878
PC5	0.7548	-0.5695	-0.0990	0.1843	-0.2493

Creation of Synthetic Variables:

TM Bands	3	4	5	7
Median/mean	3	2	1.44	3.48

(i.e. multiplication factor used to distribute band data normally about median)

Synthetic Variable	SV1	SV2	SV3	SV4
Band ratio	3/5	4/7	3/4	5/7
ratio of adjusted means	1.057	1.055	1.007	1.006
median/ratio of means	120	120	126	126

(i.e. multiplication factor used to distribute ratio data normally about median)

Derivation of Principal Components for adjusted bands and synthetic variables 3 and 4:

Input bands	3	4	5	7	SV3	SV4
Means of input bands	127.2	126.3	120.4	119.7	129.2	119.6
Standard Dev. of input bands	32.6	29.8	33.6	37.4	26.3	9.9
S.D. of P.C.s before storing	62.9	30.6	21.8	8.4	5.7	2.0

Eigenvalues (scaled to sum = 1) 0.72307 0.17080 0.08652 0.01297 0.00592 0.00072

Principal Components as combinations of original bands:

PC1	0.4403	0.4027	0.5613	0.5701	-0.0624	0.0001
PC2	0.3297	-0.3585	-0.0433	0.1192	0.8420	-0.2275
PC3	0.6169	0.5122	-0.4096	-0.4335	0.0141	0.0346
PC4	0.0488	-0.0903	-0.3854	-0.3279	0.2334	0.8240
PC5	-0.5486	0.6599	0.1241	-0.1135	0.4672	-0.1307
PC6	-0.1164	0.1316	-0.5928	0.5937	0.1194	0.5011

APPENDIX 4

GLEN ROY SEDIMENT LOGS

(Note: The locations of the sediment logs are given in Fig.13-3)

Notes and abbreviations used in this table:

Log abbreviations: GG= Glen Gloy, GR= Glen Roy, RR= Roy road, BR= Bohennie road, GS= Glen Spean, LL= Loch Laggan, CL= Caol Lairig, SB= Spean Bridge, LPR= lower parallel 'road'.

Heights: in metres above mean sea level, to nearest ten metres. (+ or - sign indicates above or below relevant shoreline)

Grid References: all in block 'NN' of U.K. national grid; prefixed by '2' and '7' (e.g. (2)261 (7)895).

Excavation depths: in metres. '*' indicates the exposure of a complete lacustrine stratigraphy.

Sediment type: L= lacustrine; O= outwash; R= river terrace deposits. Descriptions listed in order of volumetric proportion with largest first.

No. of events: minimum number of events needed to describe observed deformation.

Styles of deformation:

S.L.D.=	surface-layer deformation without significant mass-flow.
P.Slump=	plastic surface mass-flow maintaining layering.
B.slump=	broken mass-flow of local sediment.
Debris flow=	mass flow containing polymict allochthonous material.
F.G.=	fault-grading stratigraphy; I.F.G.= incipient F.G. stratigraphy.
C.L.D.=	confined (sub-surface) layer deformation; I.C.L.D.= incipient C.L.D..
Fissuring=	predominantly fluid injection.
Injection=	predominantly sediment injection.
B & P.=	ball and pillow structures.

/cont.

GLEN ROY SEDIMENT LOGS

Thickness of Deformation: in metres, i.e. the thickness of sediment involved in soft-sediment deformation.

Classification of deformation style: (i.e. relating to the first deformation event only)

A= fault-grading, ball-and-pillow structures.
B= confined-layer deformation, surface-layer deformation, incipient fault-grading, incomplete pillow-loading.
C= incipient-confined-layer deformation, injection.
D= flaming and fissuring only.
N= no fissuring or injection, i.e. undeformed.
S= section comprises slumped material only.

<u>Sample Number:</u>

Total number of excavations (Logs)	=	90
Number containing lacustrine sediment	=	68
" " outwash sands	=	14
" " river terrace	=	6
" with sediment of uncertain origin	=	5

GLEN ROY SEDIMENT LOGS

Log	Height	Grid Ref.	Excavn. Depth	Sediment type	No. of Events	Styles of deformation	Thickness of Deformation	Deformation Class
GG1	230	261 895	0.4	L: sand & silt	1	flaming, faulting and fissuring	0.3	D
GG2	280	271 905	0.4	L: silty varves	1	very slight rucking	-	N
GG3	280	277 911	1.3	L: silty & sandy varves	1	fissuring/P.slump/injection	0.2	C
GG4	280	227 911	2.1 •	L: silty varves & sand	1	P.Slump	1.0	S
GG5	280	278 912	1.7	O: sand	1	faulting	-	
GG6	270	284 920	2.0	L: silt varves & sand	1	I.F.G./P.Slump	1.0	B
GG7	300	292 929	1.5	L: sand, silt & gravel	2	1st: C.L.D. and faulting	0.2	B
						2nd: debris flow and slump	0.4	
GG8	330	302 934	0.5	L: clay varves	1	P.slump/S.L.D.(?)	0.2	S
GG9	330	307 933	0.7	L: clay varves & sand	1	sand and clay balls/injection	0.6	A
GG10	300	294 932	1.1	L: sandy & silty varves	1	C.L.D./injection/S.L.D.	0.2/-/0.3	B
GG10A	"	"	1.0	L: silt, clay & gravel	1	massive gravel injection	1.0	
GR1	270	322 896	0.3	?: angular gravel	1	debris flow (?)	-	
GR2	250	320 894	0.4	L: clay & silt varves	1	fissuring/flaming	-	D
GR3	220	318 894	0.6	L: silt varves	1	severe fissuring and injection	-	C
GR4	240	333 908	-	?: stoney silt	-	-	-	
GR5	240	331 907	0.5	L: silt varves	1	sand injection and boudinage	-	C
GR6	210	333 908	1.5	R: boulders	-	-	-	
GR7	250	338 919	0.6	L: silt varves & sand	1	severe fissuring and injection, C.L.D.	0.4	B
GR8	250	340 922	0.6	L: sand & silt varves	1	faulting and flaming	-	D
GR9	260(-)	334 928	0.7 *	?: sand, peat & gravel	1	flaming/C.L.D./sand balls	0.3	B
GR10	260(+)	333 930	2.0	O: sand	-	undisturbed	-	

GLEN ROY SEDIMENT LOGS

Log	Height	Grid Ref.	Excavn. Depth	Sediment type	No. of Events	Styles of deformation	Thickness of Deformation	Deformation Class
GR11	330	331 944	0.6	?: sand & gravel	1	faulting	-	
GR12	300	332 940	-	L: stoney silt varves	1	P.slump	-	S
GR13	260(+)	340 925	-	L: stoney silt varves	1	B.slump	-	S
GR14	250	346 924	1.0	L: silt varves & sand	1	C.L.D./faulting & fissuring	0.1	B
GR15	270	356 927	0.3	L: sandy varves	1	I.C.L.D./fissuring	0.1	C
GR16	270	356 927	0.7	L: stoney silt & sand	1	B.slump	0.7	S
GR17	260(+)	358 924	0.6	L: sand & silt	1	flaming	0.2	D
GR18	320	373 925	0.7	L: silt varves & sand	1	I.C.L.D./faulting	0.1	C
GR19	340	398 941	0.6	L: stoney sands & silts	1	I.C.L.D.	0.1	C
GR20	320	399 937	0.6 *	L: silty varves & clay	1	I.C.L.D.	0.1	C
GR21	320	398 935	1.5 *	L: silt &clay varves & sand	2	1st: I.C.L.D./faulting/S.L.D. 2nd: I.C.L.D.	0.1/-/0.2 0.1	C
GR22	320	397 934	0.6	L: silty varves & sand	1	I.C.L.D./injection	0.2	C
SB1	70	220 818	2.5	L: clay & silt varves	2	1st: S.L.D.(cryoturbation?) 2nd: very minor faulting	0.4 -	N
CL1	280	284 860	1.2	L: silt varves, sand & gravel	2	1st: C.L.D./F.G. 2nd: P.slump	0.3/0.3 0.4	A
CL2	270	281 858	0.8	L: silt varves, sand & gravel	2	1st: faulting/S.L.D./injection 2nd: B&P/S.L.D./P.slump	0.1 0.6	B
LPR1	250	302 866	0.5	L: sand, clay & gravel	1	P.slump/sand balls	0.3	B

GLEN ROY SEDIMENT LOGS

Log	Height	Grid Ref.	Excavn. Depth	Sediment type	No. of Events	Styles of deformation	Thickness of Deformation	Deformation Class
RR1	120	281 822	1.2	L: silt varves & sand	1	faulting and I.C.L.D.	0.2	C
RR2	190	294 844	1.0	L: silt varves,sand & clay	1	faulting/clay balls/injection	0.6	B
RR3	200	295 847	1.8	L: sands & silts	1	faulting and flaming	-	D
RR4	210	297 850	1.0	L: sand & gravel	1	loading/clay balls	-	C
RR5	200	297 851	1.7	L: sands and silts	1	B.slump	1.7	S
RR6	220	298 853	0.7	O: sand and gravel	1	faulting	-	
RR7	230	296 858	1.0 *	L: silt, sand & gravel	2	1st: C.L.D./ruck folding	0.2	B
						2nd: slumping	0.3	B
RR8	190	296 872	2.5	L: silty varves	2	1st: C.L.D./S.L.D. and clay balls	0.2/0.3	B
						2nd: faulting,fissuring,S.L.D./P.slump	0.3/0.4	
RR9	190	298 875	3.7	L: silt varves	2	1st: F.G./clay balls/ruck fold/S.L.D.	0.6	A
						2nd: B.slump/debris flow	1.0	
RR10	220	312 894	0.9 *	L: sands & gravels	2	1st: C.L.D./S.L.D./clay balls	0.2	B
						2nd: debris	0.2	B
RR11	210	313 894	0.7	L: silt varves and sand	1	C.L.D./faulting	0.2	B
RR12	200	317 896	5	R/O: boulders/sand & grav.	1	O: faulting and loading	3	
RR13	120	278 821	2	O: sand	-	undeformed	-	
RR14	110	274 817	1.5 *	L: silt varves & sand	1	I.C.L.D.(?)	-	N
RR15	110	272 816	0.8	L: silt varves	1	faulting	-	N
RR16	220	309 892	3.0	L: silt varves & sand	1	F.G./clay injection/B&P/P.slump	3.0	A
RR16A	"	"	1.5	O: sand & gravel	6/7	6 cryoturbation horizons/3 fault zones	1.5	
RR17	230	296 858	0.8	L: sand, silt & gravel	1	C.L.D./sand balls,S.L.D./debris flow	0.1/0.4/0.2	B
RR18	220	297 856	1.3	L: silt varves, sand & gravel	2	1st: I.F.G./sand balls	0.3	B
						2nd: S.L.D./B.slump	0.2/0.2	

GLEN ROY SEDIMENT LOGS

Log	Height	Grid Ref.	Excavn. Depth	Sediment type	No. of Events	Styles of deformation	Thickness of Deformation	Deformation Class
BR1	130	291 826	0.5	L: stoney clay	1	slump	0.5	S
BR2	140	295 830	-	?: sand	-	undeformed	-	
BR3	230	303 841	0.5 *	L: sand & gravel	1	I.C.L.D.(?)	-	C
BR4	240	305 841	0.5	L: sand & gravel	-	undeformed	-	N
BR5	250	306 841	0.5	L: stoney sand	-	undeformed	-	N
BR6	260(-)	318 843	0.8 *	L: silt varves,sand & clay	1	C.L.D./injection	0.3	B
BR7	220	323 845	3.0	L: silt varves,sand & clay	1	C.L.D./S.L.D./B.slump	0.1/0.3/2	B
BR8	220	321 845	3.0 *	L: clay, silt varves, sand & gravel	2	1st: C.L.D./S.L.D. 2nd: S.L.D./injection/debris flow	0.2/0.1 0.5/-/0.2	B
BR9	290	328 853	3.5	L: clay in gravels	?	slight deformation (?)	-	?
				Morraine: gravels	-	-	-	
BR10	180	296 836	0.8	L: sand, silt varves & gravel	2	1st: C.L.D./faulting/S.L.D. 2nd: faulting/P.slump	0.2 0.1	B
BR11	200	298 838	0.5	L: silt varves & sand	1	C.L.D./P.slump	0.1/0.2	B
GS1A	110	264 802	0.8	O: sands	1	gently faulted	-	
GS1B	110	"	0.7	O/L: sand/sand & gravel	1	L: loading/injection	0.2	C
GS2	220	267 795	0.7	O: sand & gravel	1	faulting and over-steepened cross-beds	-	
GS3	200	305 811	0.5	O: sand & silt	1	gentle faulting	-	
GS4	190	306 812	0.7	L: clayey varves	1	boudinage and fissuring	-	D
GS5	190	332 809	1.2 *	L: silt varves & sands	2	1st: F.G./C.L.D./B&P 2nd: faulting and debris flow	0.8 0.4	A

GLEN ROY SEDIMENT LOGS

Log	Height	Grid Ref.	Excavn. Depth	Sediment type	No. of Events	Styles of deformation	Thickness of Deformation	Deformation Class
GS6	210	341 796	0.5	L: sandy varves	2	1st: C.L.D./faulting	0.1	B
						2nd: debris flow	0.2	
GS7	240	350 786	0.7	O: sand	1	faulting	-	
GS8	260(-)	376 811	4.0	O: sand & gravel	1	faulting	-	
GS9	260(-)	387 817	1.6	L: sand and silt varves & gravel	1	fissuring/faulting	-	C
GS10	80	227 815	1.5	L: sand and silt varves & gravel	2	1st: C.L.D./loading/injection/S.L.D.	0.5	B
						2nd: P.slump	0.2	
GS11	90	233 815	1.5	L: stoney clay	1	B.slump	1.5	S
GS12	230	257 786	1.6	L: silt varves, sand & gravel	1	I.C.L.D./injection/faulting	0.3	C
LL1	250	546 895	1.7	R: silt,sand & wood	-	undeformed	-	
LL2	250	546 894	1.5	R: sand/silt,sand & wood	1	L: S.L.D. in channel	0.4	
LL3	250	538 896	1.2	R: sand/sand & silt	1	L: slight S.L.D in channel	0.1	
LL4	250	501 874	0.5	L: clay varves	-	undeformed	-	N
LL5	250	482 869	1.5 *	O/L: sand & gravel/ peat & sand	-	slight flaming (?)	-	N
LL6	250	438 832	1.4	R: sand & peat	1	flaming and injection	-	
LL6A	"	"	5.0	O: sand & gravel	-	undeformed	-	
LL7	260(-)	425 828	0.8	L: silty clay varves	1	I.C.L.D./faulting	0.2	C
LL8	250	416 823	0.8	L: silt varves & sand	1	C.L.D./massive injection	0.1	B
LL9	250	407 817	2.0 *	L: silt varves & sand	2	?: gentle faulting and erosion	-	
						1st: C.L.D./S.L.D./P.slump	0.3/0.3	B

APPENDIX 5

LEVELLING DATA FOR SEDIMENT EXCAVATIONS AT:

- ARRAT'S MILL (Grid Ref: NO 3645 7588)
- MEIKLEOUR (Grid Ref: NO 3151 7393)
- KINLOCH HOURN: Arnisdale (Grid Ref: NG 1901 8097)

  Coire Shubh (Grid Ref: NG 1960 8054)

* In the tables below are listed the results of small levelling exercises which were done in order to find the relative heights of sediment logs at each site.

* Details of the surveying equipment and the survey methods have been outlined in Appendix 2.

* Maps of the survey sites at Arrat's Mill and Arnisdale are shown in Figs.14-1 and 16-1. The main stratigraphic-log diagrams for each site are:

  - Arrat's Mill: Figs.14-4&7.
  - Meikleour: Figs.15-2&3.
  - Arnisdale: Fig.16-2.
  - Coire Shubh: Fig.16-3.

* Each sediment log was referenced by placing the metric survey-staff alongside the cut section and then recording staff-height relative to the reference-station level. The heights of key horizons, given under 'Comments', are with respect to the survey staff - they do not directly correspond to the heights shown on stratigraphic-log diagrams, since these have been adjusted to give reference level = zero.

ARRAT'S MILL SEDIMENT LOGS 1 TO 13 - HEIGHTS AND AZIMUTHS (Metres/Degrees)

Readings from Reference A - Zero Azimuth = lamp post by waste crusher unit
- Staff at lamp post : height = 1.93
  :top = 2.40; bottom = 1.46; diff=0.94
  : distance = 94.1
- Bench reference(top of concrete platform behind lamp post) =3.67
- Staff at Log 2 : height = 0.788
  : top = 0.919; bottom = 0.656; diff = 0.263
  : distance = 26.4
- Compass reading to zero azimuth = 078
- Compass reading to Logs 1 and 2 = 283
- Staff at Log 13 : height = 1.999
  : top = 2.186; bottom = 1.813; diff = 0.373
  : distance = 37.4

LOG	HEIGHT	AZIMUTH	COMMENTS
1	0.233	205.1	BRH deformed in flame
2	0.788	205.1	BRH at 0.50
3	1.201	212.0	BRH at 0.55; deformation immediately above BRH
4	1.734	217.1	BRH at 0.80
5	2.197	223.3	BRH at 0.85 beginning to separate; truncation at 0.75; BDL at 1.2-1.4
6	2.448	232.2	BRH at 0.65; BDL at 1.25; deformation above 1.45
7	2.590	242.8	BRH at 0.55; BDL's at 0.65-0.75, 1.4-1.45, 1.7?; SL at 1.5; deformation above 1.7
8	2.857	252.7	BRH at 0.60; BDL's at 0.8, 1.3, 1.85; deformation between 2.0-2.2; truncation at 0.4
9	2.697	261.7	BRH at 0.3; contortions at 0.85; BDL at 0.95; slumping at 1.1-1.25; SL at 1.35; trunc. at 1.05
10	2.683	268.6	BRH at 0.2; truncations at 0.9 and 1.0?; BDL's at 1.1, 1.25; SL at 1.35 (faulted)
11	2.844	303.5	No BRH;channel fill, conglomeratic base at 1.6; MCH at 1.9; 'broken bank' at 1.4-1.6; BDL's at 0.95, 0.75, 0.55, 0.45, 0.20
12	1.825	315.9	MCH at 0.65
13	1.999	324.6	MCH at 0.75

BRH = Basal Reference Horizon (clay 'seal' layer).
BDL = Bounded Deformation layer (i.e. thin deformed layer with top and bottom).
SL = Sand Layer.
MCH = Marker Clay Horizon.

ARRAT'S MILL SEDIMENT LOGS 14 TO 20 - HEIGHTS AND AZIMUTHS (Metres/Degrees)

Readings from Reference B - set in approx. same location as Ref. A
- Zero Azimuth on same lamp post
- Azimuth to Logs 1 and 2 = 205.5 (c.f. 205.1 from A)
- Staff replaced at Log 2: height = 0.577
  : top = 0.721; bottom = 0.432
  : diff = 0.289
  : distance = 29.0
- BRH at 0.54 on replaced staff

LOG	HEIGHT	AZIMUTH	COMMENTS
14	0.272	233.8	Top of main section (above Log 6)
15	0.815	259.1	Top of main section (above and between Logs 9+10)

Readings from Substation 1 - Zero Azimuth to same lamp post
- Azimuth to Log 2 = 259.7
- Azimuth to Reference Azimuth Marker = 123.0
- Reading on interval staff:
  -from Ref. B = 2.093
  -from Subst 1= 1.144
  therefore Substation 1= 0.949 below Ref. B

LOG	HEIGHT	AZIMUTH	DIST (to St.2)	COMMENTS
16	4.168	121.8	9.7	liquefn. in channel with truncation top at 1.20

Readings from Substation 2 - Zero Azimuth to Reference Azimuth Marker
- Azimith of lamp post = 237.0
- Azimuth of Log 16 = 247.6
- Reading on interval staff:
  -from Subst 1 = 3.230
  -from Subst 2 = 0.618
  therefore Substation 2 = 2.612 below Subst 1
  and Subst 2 = 0.949 + 2.612 = 3.561 below Ref. B

LOG	HEIGHT	AZIMUTH	DIST (to St.2)	COMMENTS
17	2.340	310.0	23.0	truncated BDL at 0.4
18	1.595	316.9	18.8	truncation
19	1.850	328.7	16.5	top and bottom not visible
20	1.130	343.0	19.4	truncation

MEIKLEOUR - LEVELLING TRAVERSE BETWEEN FOREST PIT AND MAIN FACE (Metres)

Note: the traverse was not closed so that the closing error is unknown.

STATION	FORESIGHT	BACKSIGHT	DIFFERENCE	CUMULATE
1 to Main Face		0.392 on log tape		
		(Hor L at 5.0 : Hor L is 4.608 above level 1)		
1 to Main Face	3.591	1.040(staff)	-2.551	-2.551
2	2.089	2.543	+0.454	-2.097
3	1.582	1.032	-0.550	-2.647
4	0.823	2.633	+1.810	-0.837
5	3.098	1.071	-2.027	-2.864
6	1.658	4.215	+2.557	-0.307
7	0.687	3.520	+2.833	+2.526
8	0.359	2.776	+2.416	+4.942
9	1.735	1.612	-0.123	+4.819

9 to Forest pit Horizon T is 0.225 above level 9

level 9 is 4.819 higher than level 1
Horizon L is 4.819 - 4.608 - 1.040 + 0.225 + 1.735 = 1.131 below Horizon T.

ARNISDALE LOGS 1 TO 12 - HEIGHTS AND AZIMUTHS (Metres/Degrees)

Readings from single Reference - Zero Azimuth = small tree
- Compass reading to zero azimuth = 016.5
- Azimuth of pylon = 038
- Compass reading to pylon = 054.5
(pylon is first one to the S.E. of stream gulley seen of far side of Kinloch Hourn Fault)

LOG	AZIMUTH	HEIGHT	TOP	BOTTOM	DIFF.	DIST	COMMENT
1	341.8	1.753	2.160	1.348	0.812	81.3	LS at 03.5
2	334.2	1.564	1.920	1.209	0.711	71.2	
3	314.9	2.112	2.285	1.939	0.346	34.7	LS at 0.4
4	306.1	1.963	2.098	1.829	0.269	27.0	LS at 0.25; gravel at 0.1
5	297.3	2.162	2.274	2.052	0.222	22.3	LS at 0.4
6	289.4	2.177	2.279	2.077	0.212	21.3	LS at 0.55; T at 0.58
7	266.4	2.147	2.236	2.066	0.170	17.1	LS at 0.5; T at 0.55
8	215.2	2.020	2.174	1.869	0.305	30.6	LS at 0.25; sand at 0.73
9	206.8	1.892	2.151	1.634	0.517	51.8	sand at 0.55
10	189.0	2.498	2.839	2.160	0.679	68.0	sands at 0.5, 0.9
11	191.3	2.218	2.585	1.854	0.731	73.2	sands at 0.3, 0.4
12	198.3	2.225	2.734	1.717	1.017	101.8	sands at 0.2, 0.35

LS = Loaded Sand Horizon
T = Top of Deformation

COIRE SHUBH LOGS 1 TO 3 - HEIGHTS AND AZIMUTHS (Metres/Degrees)

Readings from single Reference - Zero Azimuth = monkey puzzle tree
- Compass reading to zero azimuth = 012.5
- Azimuth of cottage reference = 282.0
- Compass reading to cottage reference = 295.0
(cottage reference = front corner of cottage on bridge side)

LOG	AZIMUTH	HEIGHT	TOP	BOTTOM	DIFF.	DIST.	COMMENTS
1	123.5	1.962	2.055	1.870	0.185	18.6	USB at 0.63; T at 0.5
2	157.2	1.906	1.986	1.836	0.150	15.1	USB at 0.9; T at 0.8; BPL at 0.35
3	224.2	1.496	1.627	1.377	0.250	25.1	USB at 0.85; T at 0.65

USB = Upper Sand - Base
T = Top of deformation
BPL = Black peat layer

APPENDIX 6

PARTICLE-SIZE ANALYSIS

This appendix outlines the methods and results of particle-size measurement carried out in order to characterize the sediments which have undergone soft-sediment deformation.

The bulk of the treatment concerns wet-sieving of unconsolidated samples from the Quaternary sediment sequences, but a comparison with Devonian ball-and-pillow horizons is made by estimating particle-size distributions from thin sections.

The contents are as follows:

A6.1 DESCRIPTIONS OF PARTICLE-SIZE SAMPLES

Samples were taken by inserting 2.5cm diameter, 10cm long, brass tubes into the layers of interest within the cut section. The tubes were sealed with fitted nylon caps.

Section: GLEN ROY - RR9(E) (i.e. re-cut of section RR9). In most deformed area. Section shows fault-grading stratigraphy.

RR9-1 clayey basal varves, with sandy and organic layers.
RR9-2 poorly laminated silt between varve units.
RR9-3 organic varves.
RR9-4 clay/silt varves.
RR9-5 homogeneous silt around clay balls within fault-grading zone.
RR9-6 homogeneous silt.
RR9-7 homogeneous silt.
RR9-8 intact, silty varves.
RR9-14 deformed clayey layer.
RR9-9 slumped silt.
RR9-10 grey sand ontop of slumped silt.
RR9-11 undisturbed clayey varves.
RR9-12 red silt.
RR9-13 silty portion of heterogeneous slump deposit.

Section: GLEN ROY - RR16. In most deformed area.

RR16-1 clay diapir (but peripheral silt also within sample).
RR16-2 homogenized silt.
RR16-3 sand ball.
RR16-4 faulted silt and sand layers.
RR16-5 silt.
RR16-6 homogenized silt.
RR16-7 clay and gravel 'ribbon'.
RR16-8 structureless silt.
RR16-9 brown, undeformed sand overlying red silt.

Section: ARRAT'S MILL - Section S (not surveyed in with other logs). Section through the periphery of the deformed lens.

BP1 undeformed, massive sand at top of section (aeolian).
BP2 undeformed, laminated sands.
BP3 undeformed, silty sand.
BP4 homogenized silt.
BP5 deformed unit, silts and sands.
BP6 clayey layers below deformed unit.
BP7 undeformed silts and sands.
BP8 thin (freeze-thaw?) deformed horizon.
BP9 undeformed sandy silts.

(A6.1 cont.) DESCRIPTIONS OF PARTICLE SIZE SAMPLES

Section: ARRAT'S MILL - Log-4. Main portion of deformed lens.

B1	sand layer in basal cross-bedded sands.
B2	sandy silt.
B3	silty clay.
B4	Basal Reference horizon - clay layer at base of deformation.
B5	homogeneous silt beneath large pillow.
B6	silt layer at side of large pillow.
B7	silt layers within pillow, lower zone.
B8	silt layers within pillow, upper zone.
B9	'clayey' base to pillow.
B10	homogeneous silt within dish zone.

Section: ARRAT'S MILL - Section T. (not surveyed in with other logs). Section through top of deformation, a little back from the main face, and approximately above Log-4.

BC1	laminated silts immediately above deformed zone.
BC2	massive silts and sands (aeolian).
BC3B	" " " "
BC3T	" " " "

Section: MEIKLEOUR - Main vertical section.
Samples M1-7 are not illustrated since they are superceded by samples MP1-12 which were taken from the same section.

M1	laminated sands above horizon L.
M2	homogeneous silt below horizon L.
M3	sand pillows within the the horizon M layer.
M4	homogeneous silt below horizon M.
M5	clayey silts, lower section.
M6	homogeneous silts, lower section.
M7	clayey injection/diapir at base of section.

MP1	homogeneous material above sand volcano.
MP2	injected material at top of sand volcano.
MP3	laminated sands above horizon L.
MP4	injected material at base of sand volcano.
MP5	horizon L sand layer.
MP6	homogeneous silt below horizon L.
MP7	deformed material within pillow.
MP8	sandy pillow of horizon M layer.
MP9	homogeneous silt below horizon M.
MP10	sandy pillow.
MP11	sandy pillow.
MP12	homogeneous silt.
MPCB	clay base of pillow.

Section: MEIKLEOUR - Forest Pit.

MF1	the two, fault-terminating, clayey silt layers
MF2	laminated silts below fault-terminating suface
MF3	cross-bedded sands above faulted portion

A6.2 EXPERIMENTAL PROCEDURE

A combination of wet sieving and vacuum filtration was used to make particle size measurement. The proceedure followed was adapted from Wanogho (1985) and was as follows:

1) Weigh 3 grams of sample, taken from the bulk field sample, air-dried at 80°C.
2) Place weighed sample in 25ml of 10%, 100vol hydrogen peroxide, and leave overnight (in order to remove organics and break down organic bonds).
3) Boil off peroxide (for roughly 2 hours).
4) Add 25ml of 0.02 molar hydrochloric acid.
5) Place in ultrasonic bath for 1 hour (in order to disaggregate the grains).
6) Run sample through wet sieving apparatus with 500ml of water, collecting the flow-through water and suspension.
7) Dry sieves in oven at 100°C (for roughly 20mins).
8) Collect dried samples from sieves, weigh each fraction.
9) Pass water-suspended fines through a pre-weighed 5-micron cellulose filter, under a vacuum, and the filtrate from this through a pre-weighed 0.45-micron filter, under vacuum.
10) Dry filters overnight, at room temperature, and weigh.

The sieve stack consisted of Endecotts, British Standard sieves with phi-scale mesh sizes:

1mm (phi=0), 0.5mm (1), 0.25mm (2), 0.125mm (3), and 0.063mm (4).

The sample was vibrated through the stack for 10 minutes, with a water spray applied for the first two minutes at a flow rate of 250ml/min. The seives were washed between runs using a jet spray of cold water, and were placed in the stack in a wet condition to avoid adhesion of grains to the sieve walls.

The filtrations were made by placing the 5-micron filter (5cm in diameter) in a Buchner funnel, placed in a Buchner flask. A vacuum was applied using a tap-water aspirator. The 500ml sample usually passed through in less than 10 minutes. The filtrate from this was then passed through the 0.45-micron filter, in a similar assembly.

A6.3 PRELIMINARY TESTS AND ERROR ESTIMATES

Sedimentation: 3 grams of samples M5 (Meikleour) and B8 (Arrat's Mill) were sedimented for 6 hours in order to separate the clay (<2micron) fraction. A deflocculant agent (Calgon) was added to each and found to have negligible effect on the amount retained in suspension, so sedimentations were done without it. The 6-hour suspension was removed and centrifuged, dried and weighed. This is not a quantative method, but indicates that M5 contains about 10% clay and B8 about 6%. Sedimentations were also done on sample RR9-1, RR9-11 and RR9-14 (Glen Roy). RR9-1 was found to be clear after 2 hours (ie. all >5microns), RR9-11 was clear after 6hrs (ie. all >2microns), however RR9-14 had some suspension after 6 hours which was centrifuged and analysed. This would indicate very little clay in the Glen Roy samples (none in RR9-1), but at least some in the RR9-14 sample.

XRD spectrometric analysis of the centrifuged suspensions showed the samples to contain (in order of abundance):

M5 - kaolin, mica, and chlorite/smectite.
B8 - mica, chlorite/smectite, and kaolin.
RR9-14 - mica, chlorite, and kaolin.

Weighing: 1) Variation in the oven-dry weight of a 3 gram sample, due to moisture fluctuations was found to be not more than 1mg (0.03%).

2) Weight loss after peroxide treatment was between 0.4% and 0.7% (i.e.10-20mg) for the samples M1-7 (Meikleour). Since the Meikleour samples had the most vigorous reaction with peroxide, the weight loss for the other samples is likely to be less.

3) Weight loss after sieving and filtration was mostly 5 or 6%, or less, occasionally up to 10%, the highest being 12.1% (B7). These losses are attributed to grains retained in the sieve or fallen through during oven drying. Note that the weight percent fractions given in the tables below are percents of the fractional sum, and not the total, pre-sieving weight.

Variability of sampling: The 3-gram sample was removed from a petri dish containing a well-mixed, bulk sample, by taking several small scoops from all around the dish with a spatula. Three samples of B9 were taken and each run through a sieve apparatus (having a 90micron sieve instead of the 125 sieve). the results were as follows:

Sieve (microns)	1000	500	250	90	63	remainder
B9(1)	0%	0.06%	0.30%	41.8%	26.6%	31.2%
B9(2)	0%	0.07%	0.27%	38.1%	28.0%	33.6%
B9(3)	0.08%	0.09%	0.19%	40.1%	27.5%	32.0%
Variabilty	-	0.03%	0.11%	3.7%	1.4%	2.4%

These variations are probably largely due to sampling, but errors due to weighing of samples and washing of sieves would also be included. It is therefore inferred that the variabilities in fraction-percent are not in excess of 5% and usually around 1-2%.

Filtration: The 5-micron filter was chosen in order to collect the silt-sized fraction, which on the phi-scale would be >3.9microns (5microns was the nearest available size). However it was found that this filter collected the clay as well as silt fractions, thus in the table below it represents the 'fines' in total. The 0.45-micron filter collected very little material. Only a few runs collected significant amounts of material; some were due to known leakage through the 5-micron filter (BC2 & BC3-T) but sample RR9-11 definitely contained very fine dusty material which was not retained in the 5-micron filter. Thus, the 0.45-micron filter, acted both to detect losses and to pick up any very fine material.

Interpreting the results: The tables below give fraction-percents of phi-scale sand sizes and a value for 'fines' (silt and clay). Sample variability can be up to 4%, but usually around 1 or 2%. The graphical representation of the data (Figs. A6-1to3) gives a suitable account of the distribution in the light of the experimental errors.

A6.4 PARTICLE-SIZE ANALYSIS - DATA: GLEN ROY

Sample	Particle sizes (Percent of total)							Comments
	>0	1	2	3	4	<5	-	Phi scale
	1000	500	250	125	63	5	0.45	Mesh size (microns)
RR9-1	-	-	-	0.1	1.5	98.3	-	
RR9-2	-	-	-	0.1	4.4	95.5	-	
RR9-3	-	-	0.1	1.1	5.7	93.2	-	
RR9-4	-	-	-	-	0.1	99.8	-	
RR9-5	-	-	-	-	1.3	98.7	-	
RR9-6	-	-	-	-	2.0	98.0	-	
RR9-7	-	-	-	-	4.4	95.4	-	
RR9-8	-	-	-	0.1	0.7	99.0	0.2	
RR9-9	-	-	-	-	1.4	98.5	-	Cloudy, 5-micron filtrate - i.e. very fine
RR9-10	-	-	-	0.1	4.1	95.7	0.1	'dusty' material. Micro-rootlets and other
RR9-11	-	-	-	0.1	0.9	98.6	0.4	organic matter present.
RR9-12	0.1*	0.2*	0.2	5.2	54.4	39.9	0.1	*:aggregates of smaller particles in an
RR9-13	-	-	-	0.2	1.1	98.7	-	organic matrix present as 'larger particles'.
RR9-14	-	-	-	-	-	99.9	-	
RR16-1	-	-	0.1	2.2	26.9	70.8	-	
RR16-2	-	-	-	1.0	31.5	67.4	-	
RR16-3	1.5	4.3	9.9	27.3	37.8	19.2	-	
RR16-4	0.2	0.2	0.9	18.5	52.1	28.0	-	
RR16-5	-	-	0.3	13.4	38.4	47.8	0.1	
RR16-6	-	-	0.4	12.6	37.9	49.0	0.1	
RR16-7	14.1*	2.9	2.4	4.3	18.0	58.4	-	*: gravel (up to 5mm) included in this sample.
RR16-8	0.2	0.2	0.5	1.9	25.1	71.9	0.1	
RR16-9	0.7	0.1	2.5	39.4	39.7	17.6	-	

(A6.4 cont.) PARTICLE-SIZE ANALYSIS - DATA: ARRAT'S MILL

Sample	Particle sizes (Percent of total)							Comments
	>0	1	2	3	4	<5	-	Phi scale
	1000	500	250	125	63	5	0.45	Mesh size (microns)
B1	-	1.2	39.3	46.2	9.4	3.8	-	
B2	-	-	1.2	32.5	37.5	28.7	0.1	
B3	-	1.1	2.4	2.5	32.2	61.8	-	
B4	-	-	1.2	6.5	24.3	68.0	-	
B5	-	-	0.1	8.8	58.5	32.6	0.1	
B6	-	-	0.1	6.5	64.0	29.3	0.1	
B7	-	-	0.2	11.2	59.4	29.1	0.1	
B8	-	-	0.1	8.4	54.7	36.7	0.1	
B9	-	0.1	0.1	11.3	58.3	30.1	-	
B10	0.1*	0.2*	0.1	7.1	48.1	44.5	-	*:aggregates of smaller particles.
B11	-	0.1	2.3	14.5	22.1	61.0	-	
B12	-	0.2	2.6	14.2	21.0	62.0	-	
BC1	-	-	-	0.9	58.5	42.5	-	
BC2	-	-	0.4	44.2	45.2	9.8	0.4*	*:some leakage of 5 micron filter -
BC3-B	-	-	2.6	36.7	47.8	12.9	0.1	hence high 0.45 values.
BC3-T	-	-	0.1	3.7	40.7	51.5	4.0*	
BP1	-	-	0.7	62.6	28.3	8.4	-	
BP2	-	-	1.1	50.8	39.5	8.6	-	
BP3	-	-	0.2	27.9	58.1	13.8	-	
BP4	-	-	0.1	8.5	54.3	37.0	0.1	
BP5	-	-	3.8	31.9	39.7	24.5	-	
BP6	-	-	0.2	1.6	33.5	64.8	-	
BP7	-	0.2	3.5	34.7	46.9	15.5	-	
BP8	-	-	0.1	1.4	27.9	70.6	-	
BP9	-	-	4.3	62.5	21.4	11.8	0.1	

(A6.4 cont.) PARTICLE-SIZE ANALYSIS - DATA: MEIKLEOUR

Sample	Particle sizes (Percent of total)							Comments
	>0	1	2	3	4	<5	-	Phi scale
	1000	500	250	125	63	5	0.45	Mesh size (microns)
M1	0.8	1.6	6.1	37.8	32.7	14.2	-	
M2	-	-	1.1	12.3	44.7	41.8	-	
M3	-	0.1	4.1	48.0	25.8	22.0	0.1	
M4*	-	0.1	1.1	10.8	25.5	62.4	-	*:especially vigorous reaction with peroxide.
M5*	-	0.2	3.3	17.6	24.8	54.0	0.1	
M6	-	-	1.0	14.9	43.5	40.6	-	
M7*	0.8	0.2	1.9	23.7	19.4	53.9	0.1	
MP1	-	-	0.4	15.6	45.5	34.7	0.1	
MP2	1.1	3.1	4.8	40.7	31.8	18.5	-	
MP3	1.3	4.9	8.7	37.3	27.5	20.3	-	
MP4	-	0.1	0.3	19.1	39.6	40.9	-	
MP5	-	-	0.4	26.9	61.2	11.5	-	
MP6*	-	0.4	1.5	15.0	44.2	39.0	-	
MP7	-	-	0.1	1.6	31.2	67.0	-	
MP8	-	0.7	7.2	50.8	23.1	18.2	-	
MP9*	-	0.1	0.6	12.3	44.2	42.8	0.1	
MP10*	0.1	0.3	0.7	23.1	61.3	14.4	0.1	small concretions possibly present.
MP11*	-	-	2.8	18.3	28.9	49.9	0.1	
MP12*	-	0.1	2.9	14.7	28.7	53.5	0.1	
MPCB*	-	-	0.1	2.3	22.5	75.1	-	
MF1	-	-	-	0.4	12.4	87.0	-	
MF2	-	-	0.1	0.5	16.1	83.3	-	
MF3	-	-	0.1	1.9	60.1	37.8	-	

A6.5 PARTICLE SIZE FROM THIN SECTION STUDY

In order to make comparison of the (lithified) Devonian ball-and-pillow structures with the (unconsolidated) Quaternary examples, estimates of particle-size distributions in thin section were made. In each case 500 points were counted, using an automatic point counter. At each point the longest dimension of the thin section of the grain was estimated according to the microscope graticule. Each grain was also classified 'round' or 'elongate' (long-axis more than twice the short axis). In the absence of a 'grain' the presence of mica or amorphous/interstitial material was recorded. Study was also made of a thin section through a calcite concretion at Meikleour and of oil-immersed grain-mounts of loose, dry sediment samples from Meikleour and Arrat's Mill.

Comparative interpretation: Because of the difference in technique a direct comparison of particle-size distributions estimated from thin section and wet-sieving is not possible. The long-axis was measured in thin section, whereas smallest cross-sectional area is recorded in sieving. Thus the thin-section study will tend to show a bias to the larger grain-size end of the distribution. Nevertheless, general comparisons can be made, although it is safest to compare rock-thin section data to grain-mount data and to treat the sieving data as a separate database.

A6.6 DESCRIPTIONS OF THIN SECTIONS

(Refer to Fig.15-11 and section 15.6)

Fowlis:

FOW1 cross-bedded sands and silts below the ball-and-pillow horizon

FOW2 from a pillow in the deformed horizon

FOW3 planar bedded silts above the deformed horizon

Aberlermo:

AB1 from a pillow within the deformed horizon

AB2 from the structureless matrix around the pillows

AB3 from the top of the deformed bed - structureless silt

Meikleour:

MC1 concretion found in a pillow in the lower portion of Meikleour, main face; calcite has lithified the grains, enabling a thin section to be made.

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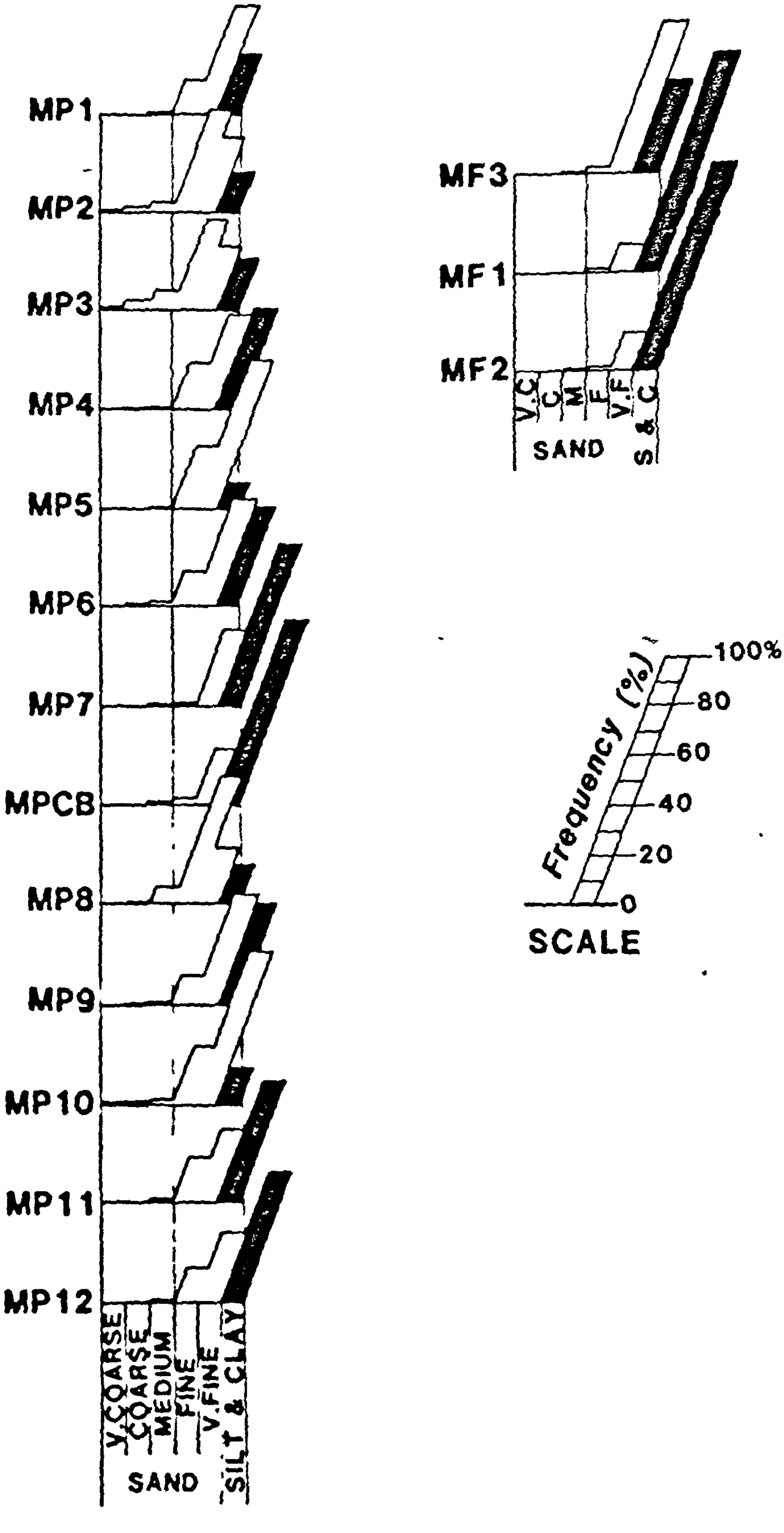
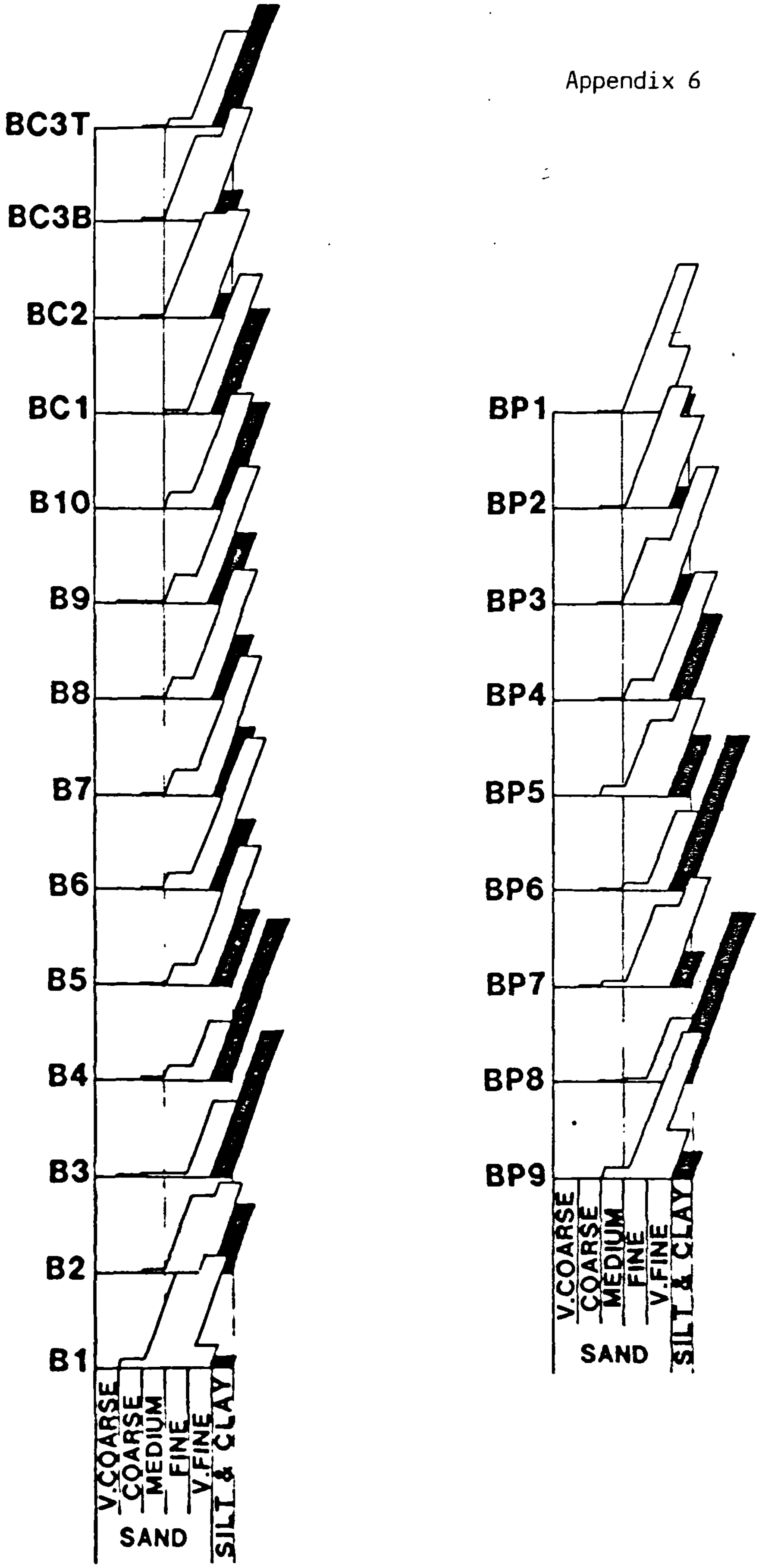
A6.7 ESTIMATES OF PARTICLE-SIZE DISTRIBUTIONS FROM THIN SECTION - DATA

Sample				Particle sizes (percent of total grains)						Comments
				<0.01	<0.05	<0.1	<0.25	<0.5	<1.0	long axis in millimetres
	%E	%mica	%P	7-8	5-6	4	3	2	1	approximate Phi-scale equivalent
FOW1	26.0	19.4	30.8	5.0	25.8	**41.6**	27.5	0	0	
FOW2	22.1	7.6	21.2	12.8	**43.7**	32.0	11.5	0	0	
FOW3	26.2	16.9	22.0	15.1	**38.6**	30.6	15.0	0	0	
AB1	21.9	27.5	33.2	8.7	12.8	33.0	**43.8**	1.6	0	
AB2	-	18.5	24.2	14.9	**64.7**	16.8	3.5	0	0	
AB3	16.6	21.0	25.4	10.5	23.1	23.8	**39.7**	2.7	0.3	
MC1	15.6	8.0	34.0	3.8	11.4	29.5	**51.0**	3.7	0.3	interstitial material is mostly calcite
M1	21.8	19.2	-	8.9	10.9	26.2	**38.9**	12.6	4.2	a few >1mm grains were not measured
M3	12.8	6.4	-	1.9	12.0	25.2	**52.8**	7.9	0.6	
M4	9.3	5.2	-	11.6	**35.0**	28.1	21.1	3.8	0.4	
B6	6.0	3.4	-	3.1	13.7	**44.5**	38.7	0	0	
B7	9.0	19.8	-	1.2	10.5	**50.8**	37.1	0.2	0	
B9	10.0	9.0	-	3.1	15.2	**45.1**	36.8	0	0	
B10	6.6	9.4	-	4.0	22.7	**45.5**	27.2	0.4	0	

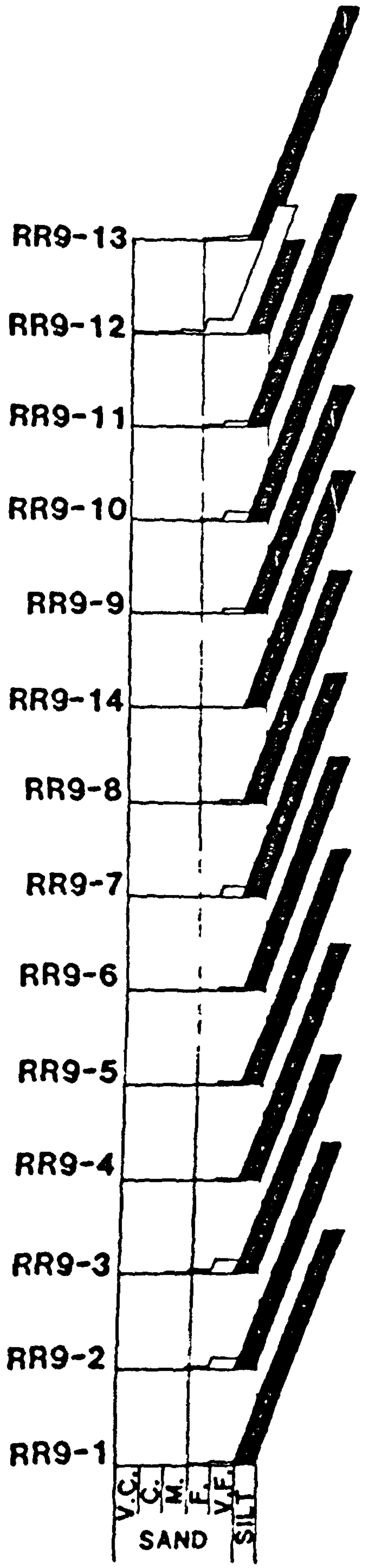
Notes:
1) '%E' gives the percent of elongate grains (long axis more than twice short axis) in the grain total, not including the mica grains.
2) '%mica' gives the percent of mica flakes relative to grains+mica.
3) '%P' is the amount of undifferentiated interstitial material including very fine material and diagenetic minerals. It gives an approximate porosity of the grain fabric. Only in the Meikleour concretion (MC1) could the porosity of the Quaternary sequences be estimated.
4) The modes of the grain size distributions are shown in bold type.

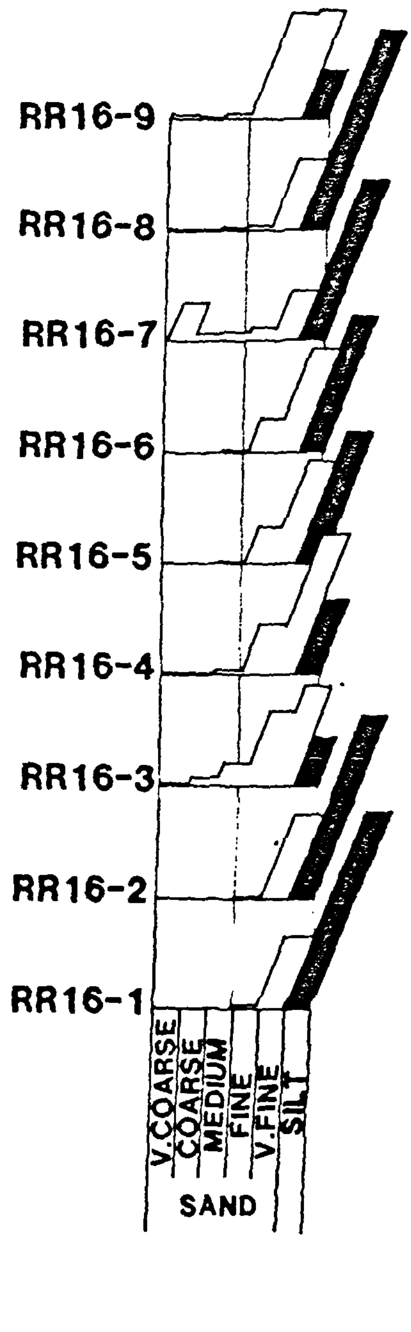


A6.8. Histograms of the particle-size distributions at Meikleour.



A6.8 (cont.) Histograms of the particle - size distributions at Arrat's Mill.





A6.8 (cont.) Histograms of the particle-size distributions in Glen Roy.

APPENDIX 7

RADIO-CARBON DATING ANALYSIS

This appendix outlines the results of radio-carbon dating analysis carried out in conjunction with the thesis study. The dating was done at 'The NERC Radiocarbon laboratory, East Kilbride, and was funded by NERC. The analysis was supervised by Dr. D. D. Harkness, who also advised on the interpretation of the dates. The principal investigator for the analysis was Mr. C. A. Davenport, University of Strathclyde. Seven samples were dated in the analysis. Each sample is named and described below together with details of the dating analysis and comments on the significance of the date. The dates are given in ^{14}Carbon years BP., with the error indicating the ± one standard deviation level for overall analytical confidence.

General summary of results:

Two of the samples dated comprised peaty soil from the Kinloch Hourn area. The dates calculated for these samples had good analytical confidence (±50 years - 2%) and were consistent with known stratigraphy. The dates were successful in resolving a deformation event and allowed the inference of a surface fault movement and an earthquake event in the area between 3500 and 2400 years BP.

Four samples from the two lateglacial sites on the east coast (Arrat's Mill and Meikleour) provided inconsistent dates, being mostly too young. The carbon content in these samples was low and of undetermined nature; the dates had low analytical confidence (±110 to 230 years - upto 4%). The target of dating these deposits and the deformation events involved was not acheived.

A reliable date was obtained for the seventh sample - a fragment of wood from Glen Spean. The wood was much younger than expected (2500 years BP) indicating the host sediment to be post- Loch Lomond Readvance. Thus no date for the deformation of the ice-dammed lake sediment was achieved (an attempt at dating a sample of varves failed since the sample contained too little carbon).

ONE: SRR-2853, KINLOCH HOURN FAULT (KF5).
(Sample collected on 20/7/84).

Location of site: A wedge of peaty soil within the Kinloch Hourn fault zone, Western Highlands. Grid Reference: NG 947 075.

Stratigraphy of sample: The wedge of peaty soil is in a fracture within the fault zone. The wedge is deeply incised (several metres) and is thought to have infilled a crack opened by fault activity. Two phases of fault gouge pass through the soil wedge (c.f. §12.2.4).

Relevant information: The site was exposed in 1983/4 by the Hydro Board with heavy equipment exposing a fresh cut into the rock around the fault fissure, revealing the soil wedge. Subsequent excavation by hand (summer 1984), removing at least 5cm of surface material, was made before removing the sample.

Significance of date: In order to establish when the soil infilled the fracture and, by inference, to date the fault rupture event. Also to indicate any correlation with the deformed sediment nearby (site of sample KFC, 3km away).

Radiocarbon date: 2400±50 years BP. ($d^{13}C = -28.6^{0}/oo$).

Analytical treatment: Hot digestion in 2M HCL, followed by washing to neutral pH. 1.6% carbon in the <1mm fraction.

Comment: Since the sample comes from an isolated wedge of soil, correlation is difficult. The date is later than the commencement of peat accumulation implied in the KLC (SRR-2853) date, as would be expected. The supposition that the soil wedge infills a fracture opened by fault movement associated with an earthquake event which also produced the deformation of sediment at Arnisdale (KLC) is supported by these dates. An earthquake event between 3500 and 2400 years BP is implied.

TWO: SRR-2854, ARNISDALE, KINLOCH HOURN (KLC).
(Sample collected on 17/7/84).

Location of site: Deformed sand and peat sequence at Arnisdale, Kinloch Hourn, Western Highlands, in glacial sands and post-glacial peats occurring in isolated pockets in valley floors. Grid Reference: NG-898 097.

Stratigraphy of sample: The sample was taken from a layer of intermixed sand and peat at the top of a 1-2m deformed sequence, and immediately below a truncation horizon, above which lie undeformed peats of present peat-formation times. The thickness of peat involved in deformation is only a few centimetres, such that the deformation event occurred very soon after commencement of peat accumulation. It therefore has great potential as a high resolution date.

Relevant information: The sample could contain more recent plant roots (it is 0.5-1.0m below surface). The water table was half a metre below the sample when removed in the summer of 1984; the winter water table is almost certainly above sample level.

Significance of date: In order to date the truncation horizon / deformation event and also the age of this isolated sediment pocket.

Radiocarbon date: 3490$\pm$50 years BP. ($d^{13}C = -29.2^{o}/oo$).

Analytical treatment: Hot digestion in 2M HCL, followed by washing to neutral pH. 21.6% carbon in the <1mm fraction.

Comment: The date is reasonable. The sample occurs at the edge of currently accumulating peat. Other areas in the NW Highlands (Pennington 1972) show peat accumulation beginning 6000-5000 BP. Therefore in a regional context this date appears too young. However, local peat accumulation may well have been late at this site.

THREE: SRR-2855, MEIKLEOUR (MFC).
(Sample collected on 4/7/84).

Location of site: Excavation on Meikleour Estate in sands and silts of the Meikleour Outwash Terrace, Perthshire. Grid Reference: NO-153 388.

Stratigraphy of sample: The sample was taken from a 3cm silt/clay layer exposed in the 'forest pit' excavation at Meikleour (see §15.3.2). The silt/clay layer comprises a truncation horizon below which faulting and deformation occur and above which no deformation is seen.

Relevant Information: Some modern roots were growing through the sample when collected. The sample was removed from about 30cm below the organic soil litter at the surface.

Significance of sample for dating: The silt/clay layer is considered to mark the top of the deformation observed in the Meikleour Terrace such that a date for it would indicate a minimum age for the deformation.

Radiocarbon date: 2500$\pm$110 years BP. ($d^{13}C = -24.5^{o}/oo$).

Analytical treatment: Hot digestion in 2M HCL; sieved (<1mm) organic detritus. 0.12% carbon in the <1mm fraction.

Comment: This date is much younger than expected. The Meikleour Terrace would be expected to date from the lateglacial, at around 13,000 years BP (Paterson pers. comm.). In view of the fact that the sample was taken from not far below the present day organic soil and contained rootlets, the most reasonable explanation for this young date is that modern rootlets (<1mm in size) have masked the true date.

FOUR: SRR-2856, ARRAT'S MILL (L12-CM).
(Sample collected on 5/7/84).

Location of site: Arrat's Mill waste disposal site (former sand and gravel works) in outwash sands and gravels located east of Brechin, North Angus. Grid Reference: NO 646 586.

Stratigraphy of sample: Sticky organic lacustrine clay/silt layer, 2-5cm thick, occurring stratigraphically above the deformed sequence within fluvio-lacustrine silts and sands (i.e. layer MCH in §14.3 and Fig.14-4).

Relevant Information: The clay layer contains gravel. Alteration and oxidation markings suggest that this layer has acted as a barrier to water flow. It is presently above the water table. Sample was removed from 30-50cm below the surface.

Significance of date: A date for the whole deposit, and especially the deformed sequence is needed both independently and relative to the Meikleour Terrace. Being stratigraphically above the deformed sequence the sample should provide a minimum age.

Radiocarbon date: 9410±130 years BP. ($d^{13}C = -20.9^{0}/oo$).

Analytical treatment: Hot digestion in 2M HCL; (<1mm) organic detritus. 0.18% carbon in the <1mm fraction.

FIVE: SRR-2857, ARRAT'S MILL (L12-CMC).
(Sample collected on 22/4/85).

Location of site: Arrat's Mill waste disposal site (former sand and gravel works) in outwash sands and gravels located east of Brechin, North Angus. Grid Reference: NO 646 586.

Stratigraphy of sample: Sticky organic lacustrine clay/silt layer, 2-5cm thick, occurring stratigraphically above the deformed sequence within fluvio-lacustrine silts and sands (i.e. layer MCH in §14.3 and Fig.14-4).

Relevant Information: Same clay layer as L12-CM. This sample was collected on a subsequent visit as a back-up to the L12-CM sample.

Significance of date: As with L12-CM above. Preliminary analysis (Radiocarbon Lab) indicated low carbon content such that this second sample was deemed necessary.

Radiocarbon date: 13,440±170 years BP. ($d^{13}C = -19.0^{0}/oo$).

Analytical treatment: No pretreatment.

SIX: SRR-2858, ARRAT'S MILL (S1-OC).
(Sample collected on 26/6/84).

Location of site: Arrat's Mill waste disposal site (former sand and gravel works) in outwash sands and gravels located east of Brechin, North Angus. Grid Reference: NO 646 586.

Stratigraphy of sample: The sample comprises disseminated organic blebs collected from the lens of deformed sediment (log-4, §14.4.3). The organics consist of thin coatings on sand and silt grains occurring as blebs throughout the sequence. These blebs are thought to have risen, during liquefaction, from layers in the lower parts of the deformed unit.

Relevant information: The sample was collected from an excavated face (log-4) from which at least a metre of sediment was removed immediately prior to sampling. The organic blebs were cut out of the face wherever they occurred in greatest abundance and from an area of about 1 square metre.

Significance of the date: Since the material comes from sediment which has suffered deformation, it should predate the deformation, and thus provide a maximum date for the deformation event.

Radiocarbon date: 6410±230 years BP. ($d^{13}C = -22.8^{0}/oo$).

Analytical treatment: No pretreatment (preliminary attempts at pretreatment indicated an unacceptable loss of acid soluble material.

Comment (samples 4,5&6): The Arrat's Mill deposit should have a lateglacial age (around 15,000 years BP, Paterson pers. comm.). Stratigraphically S1-OC should be older than L12-CM & L12-CMC. Therefore it must be concluded that some of these samples have been corrupted by the inclusion of younger carbon (especially S1-OC). In considering the range in these three ages, Dr. Harkness postulates the presence of fractions of considerably different age in the organic content of the samples. Surprisingly, the most acceptable date is the untreated L12-CMC.

Explanations for the stratigraphically anomalous sequence and youth of these dates include:

a) Humic acid from the soil above may well have contaminated the sample, and would not have been removed by pretreatment (the cuttings from which samples were taken had been the residence of a colony of birds (sand martins).
b) The nature of the carbon components in these samples are not known, largely because of the insufficient amounts of carbon in the samples. (Large standard deviations for these three samples reflect the poor analytical confidence associated with these small amounts of carbon).

SEVEN: SRR-2979, KINLOCH LAGGAN, GLEN SPEAN (LL2-W).
(Sample collected on 3/7/85).

Location of site: River Pattack, Kinloch Laggan, Glen Spean, Lochaber. Natural stream-bank cut into laminated grey, fluvio-lacustrine silts. Grid Reference: NN 546 896.

Stratigraphy of sample: A roughly 10cm diameter trunk of wood occurring at the base of a channel deposit in laminated silts and sands (Log-LL3). The tree trunk lies roughly horizontally within sediment which shows deformation structures at the channel base. Undeformed fluvio-lacustrine sediment lies beneath and undeformed aeolian sand above. Several fragments of wood are seen in the deposit at roughly the same horizon (i.e. within the fluvio-lacustrine sediment). The fragments are generally large (trunks up to several metres long and 30cm in diameter) though finer woody material is seen. No tree or plant material is observed in a 'life' or upright position - all appear to be broken, flat-lying fragments.

Relevant information: No evidence for modern plant roots. The sample was taken from 2m below the grass-turf surface. The site is one of c.100 excavations made during study of deformation structures seen in the lake sediments of the Glen Roy/Spean ice-dammed lake of Loch Lomond Advance times.

Significance of date: The wood has been washed into the sediment, possibly at or just before the time of deformation in the deposit. A date for this sample would clarify the age of the fluvio-lacustrine sediment at this site and could provide a date for the liquefaction event.

Radiocarbon date: 2480±50 years BP. ($d^{13}C = -27.0^{o}/oo$).

Analytical treatment: Cellulose extraction.

Comment: The date is younger that expected. A Loch Lomond Readvance age had been expected in view of the glacial appearance and location of the deposit (clean, light-grey silts, within the Glen Spean ice-dammed lake basin). The tree trunk fragment is very clearly syn-sedimentary and therefore it must be concluded that the sediments are post- 2480 years BP, fluvial deposits, incorporating reworked glacial material. These are therefore most likely to be alluvial deposits of the River Laggan.