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GEOLOGICAL SURVEY

Seismic reflection records showing stable and unstable slopes near the shelf break, western Gulf of Alaska

by

Monty A. Hampton and Arnold H. Bouma

Open-File Report

77-702

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

Menlo Park, California

September, 1977

SEISMIC REFLECTION RECORDS SHOWING STABLE AND UNSTABLE SLOPES NEAR THE SHELF BREAK, WESTERN GULF OF ALASKA

by

Monty A. Hampton and Arnold H. Bouma

This Open-File Report supplements a publication by Hampton and Bouma (1977) that discusses slope instability on the uppermost continental slope off the Kodiak shelf in the western Gulf of Alaska (see Appendix). In that paper, only a few examples of seismic reflection records were shown, whereas all the records cited in that paper are included on the microfilm that accompanies the report (available from the U.S. Geological Survey library in Menlo Park, California). The locations of the profiling lines are given in figure 1. Xerographic copies of the seismic reflection records available on microfilm are included here as figures 2A-F.

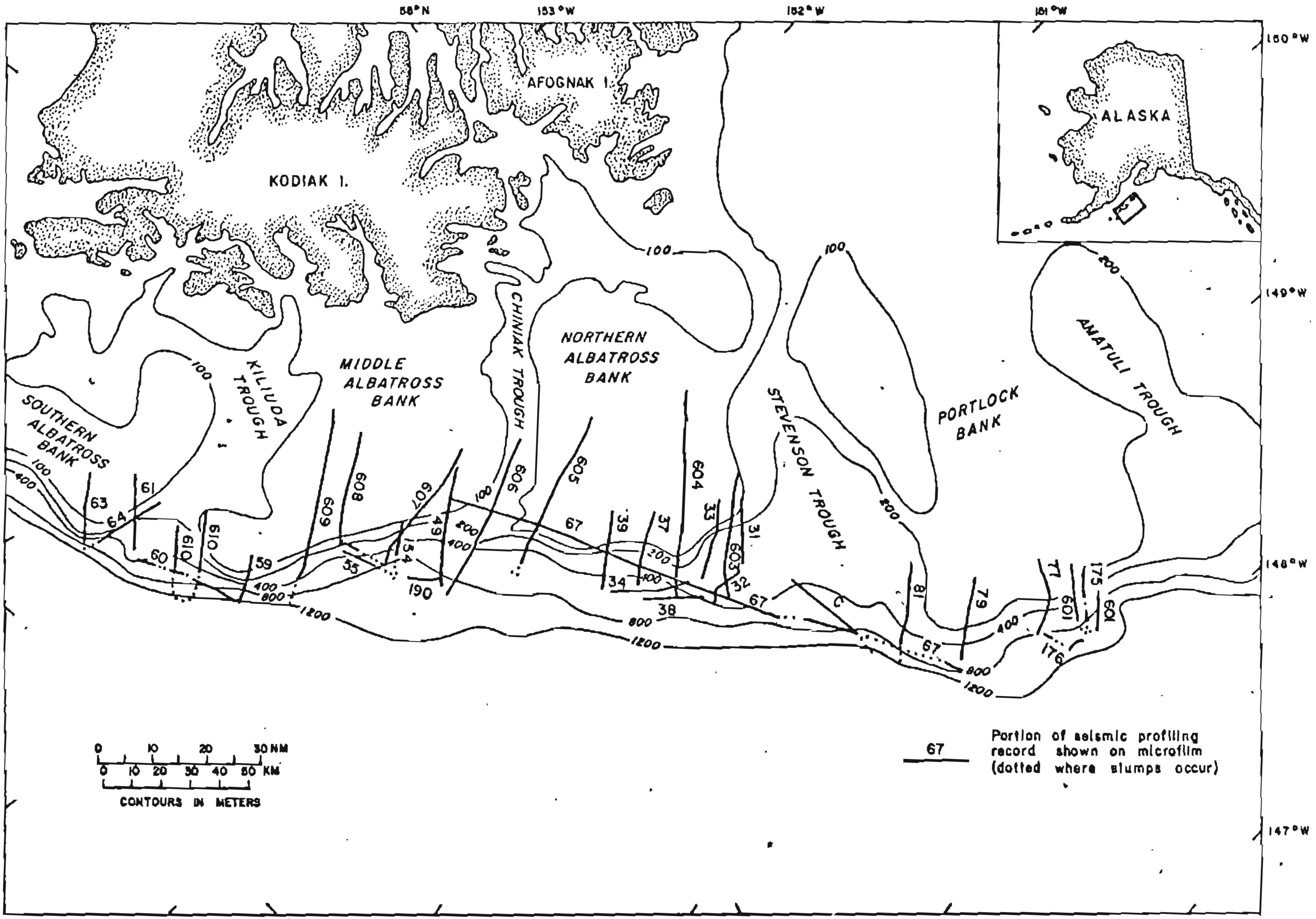
The seismic records were collected in June and July, 1976 aboard the R/V SEA SOUNDER (by A. H. Bouma and M. A. Hampton) and, for lines numbered greater than 600, aboard the R/V S.P. LEE (by R. von Huene). The seismic systems aboard each ship included 90 and 160 kilojoule sparker, uniboom, and 3.5 kilohertz systems.

Only sparker records and a few uniboom records are included in this report. The records from southern and middle Albatross Bank (lines 63 to 154, Fig. 1) show abundant evidence of sliding seaward of the shelf break. (Landslides are denoted by s on the seismic records; the shelf break by s.b.). Most of the slides appear to be large-scale rotational slumps, but the ones on lines 607-608 are relatively small and thin; apparently debris-slides (see the uniboom records of line 607-608).

Along northern Albatross Bank (lines 190 to 31, Fig. 1), only line 605 has evidence of slope instability, in the form of small debris slides (see the uniboom record for line 605). Slides are indicated on several of the seismic records off Stevenson Trough and Portlock Bank (lines C to 601, Fig. 1). Large rotational slides are common, but small debris slides occur on line 601 (see the uniboom record for this line).

REFERENCE

Hampton, M. A. and Bouma, A. H., 1977, Slope instability near the shelf break, western Gulf of Alaska: Marine Geotechnology, in press.



KODIAK I.
AFOGNAK I.
ALASKA
SOUTHERN ALBATROSS BANK
KILIUDA TROUGH
MIDDLE ALBATROSS BANK
CHINIAK TROUGH
NORTHERN ALBATROSS BANK
STEVENSON TROUGH
PORTLOCK BANK
ANATULI TROUGH
Portion of seismic profiling record shown on microfilm (dotted where slumps occur)
67
0 10 20 30 NM
0 10 20 30 40 50 KM
CONTOURS IN METERS

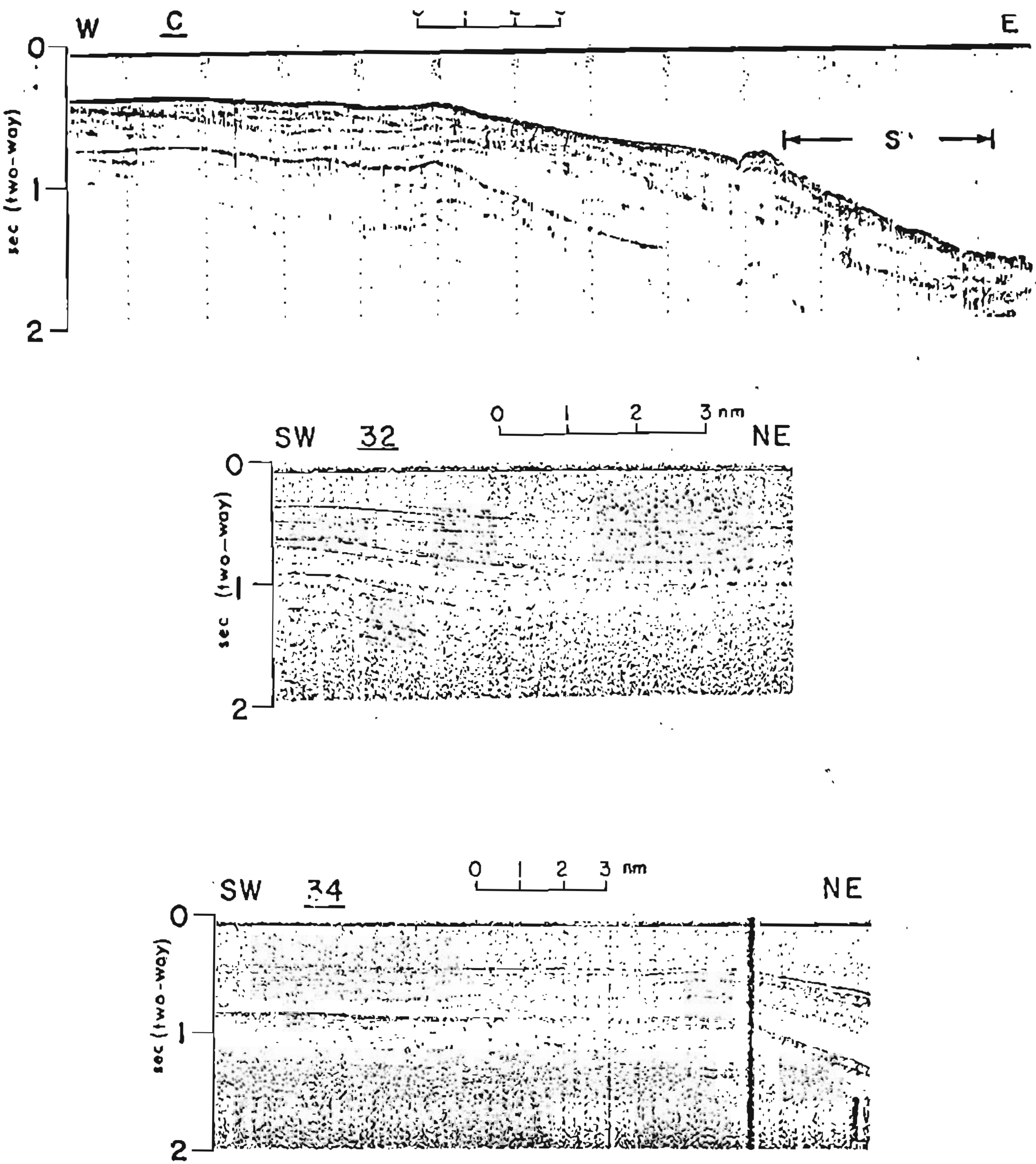

W
C
E
S
0
1
2
sec (two-way)
SW
32
NE
0
1
2
3 nm
sec (two-way)
SW
34
NE
0
1
2
3 nm
sec (two-way)

Fig. 2A

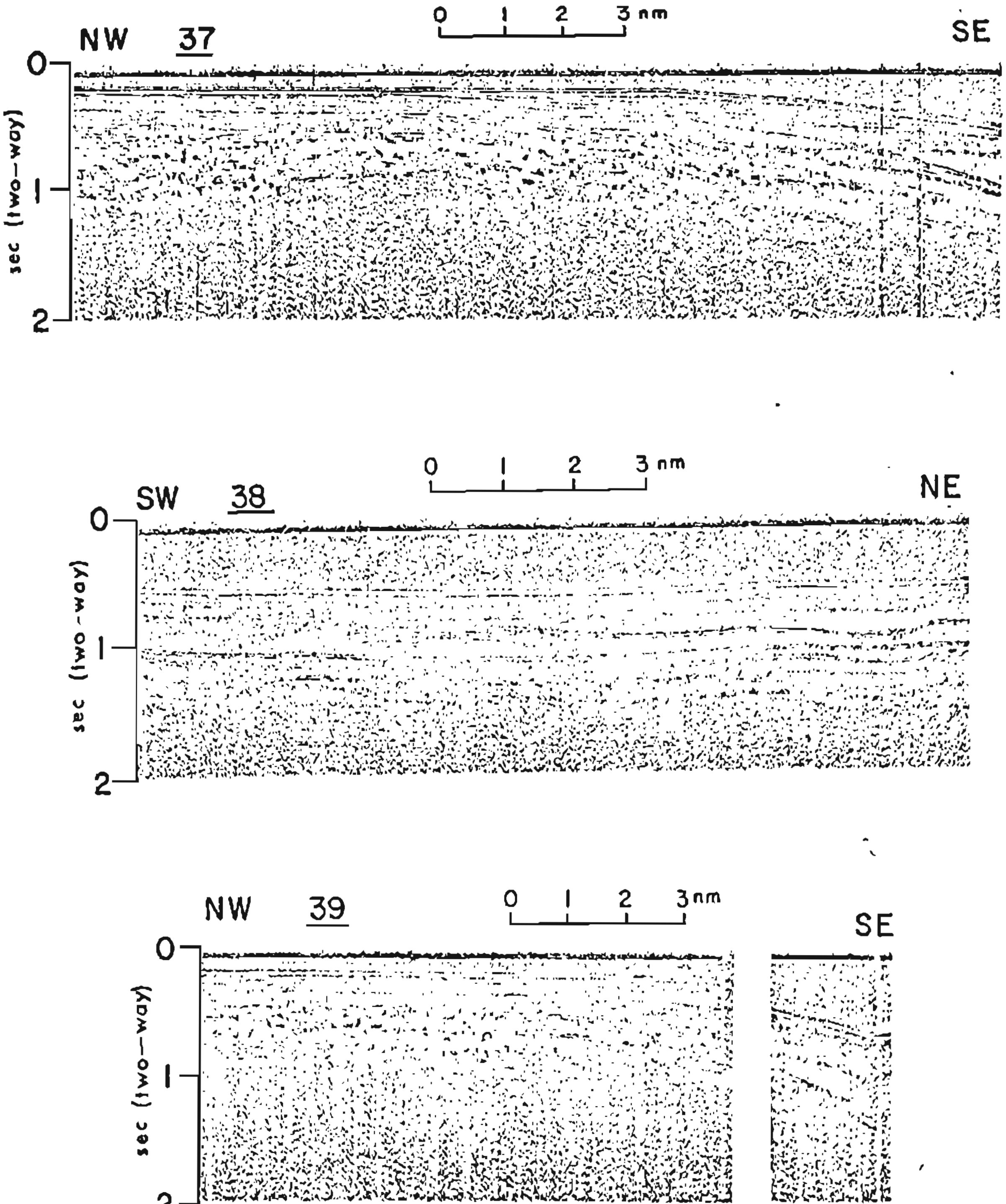

NW
37
SE
0 1 2 3 nm
sec (two-way)
0
1
2
SW
38
NE
0 1 2 3 nm
sec (two-way)
0
1
2
NW
39
SE
0 1 2 3 nm
sec (two-way)
0
1
2

Fig. 2B

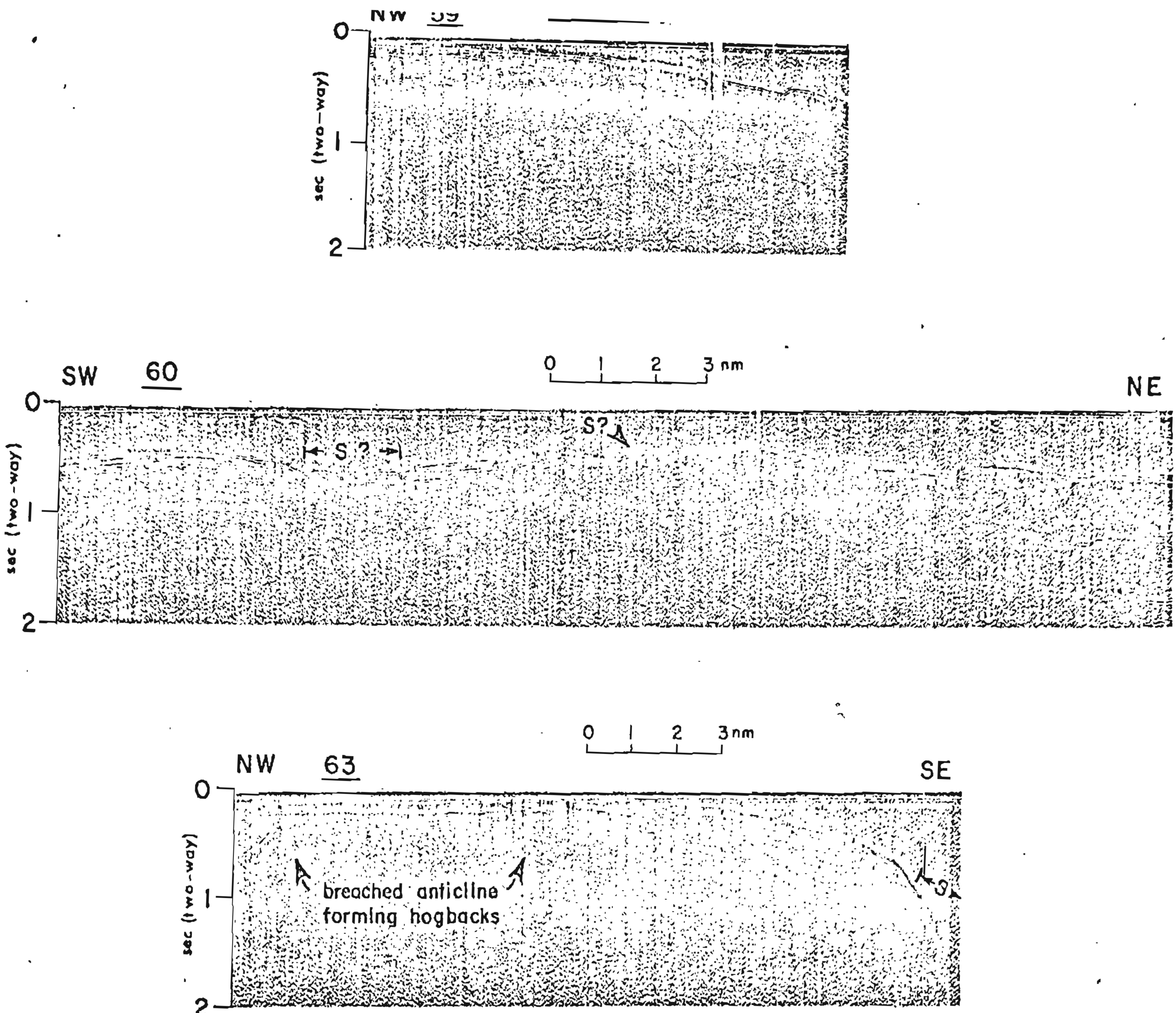
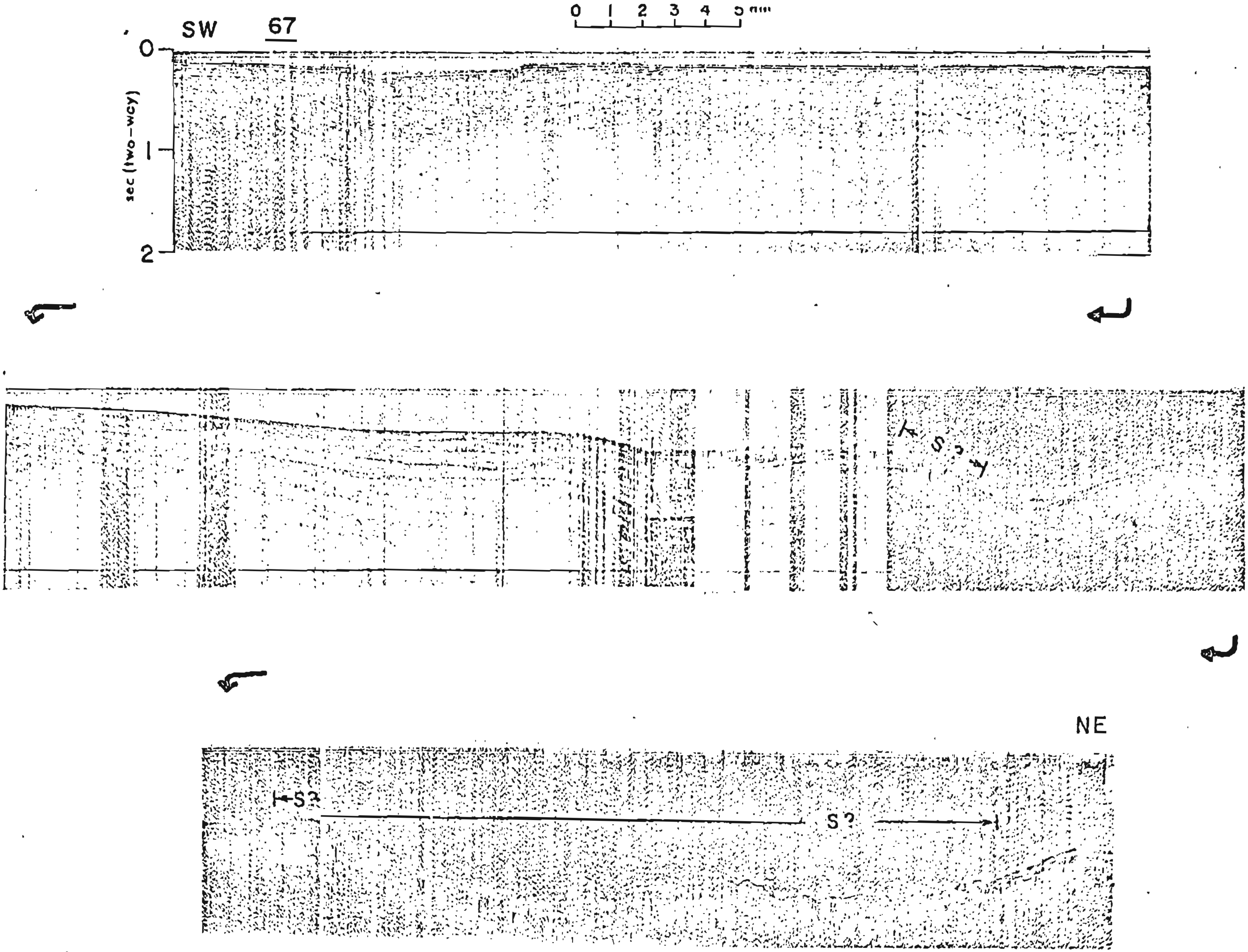

NW
sec (two-way)
0
1
2
SW
60
NE
0 1 2 3 nm
S ?
S?
63
SE
breached anticline
forming hogbacks
S

Fig. 2C



SW
67
0 1 2 3 4 5 nm
sec (two-way)
0
1
2
S?
S?
NE

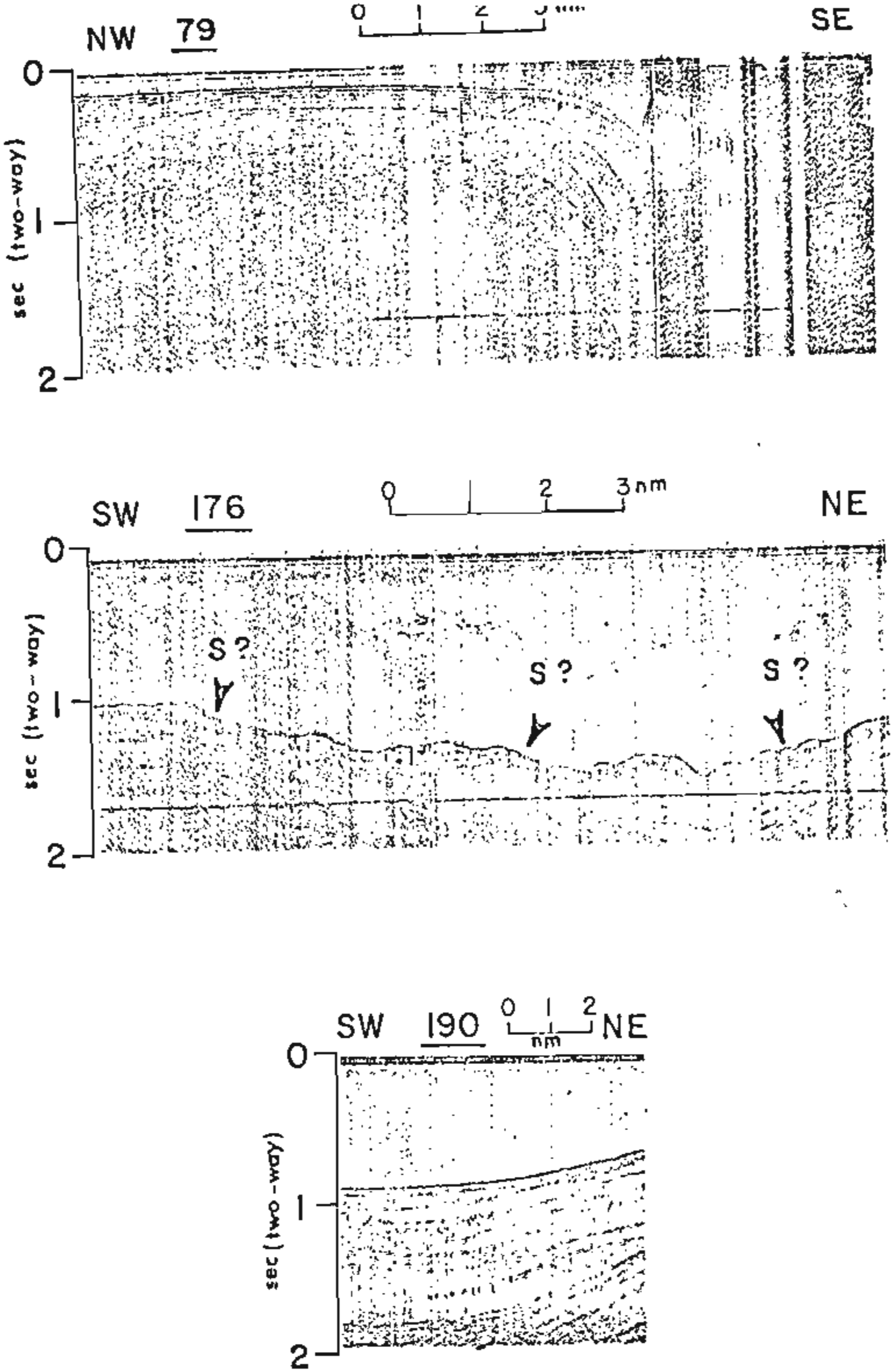

NW
79
SE
0 1 2
sec (two-way)
0
1
2
SW
176
NE
0 2 3nm
S ?
S ?
S ?
sec (two-way)
0
1
2
SW
190
0 1 2
nm
NE
sec (two-way)
0
1
2

Fig. 2E

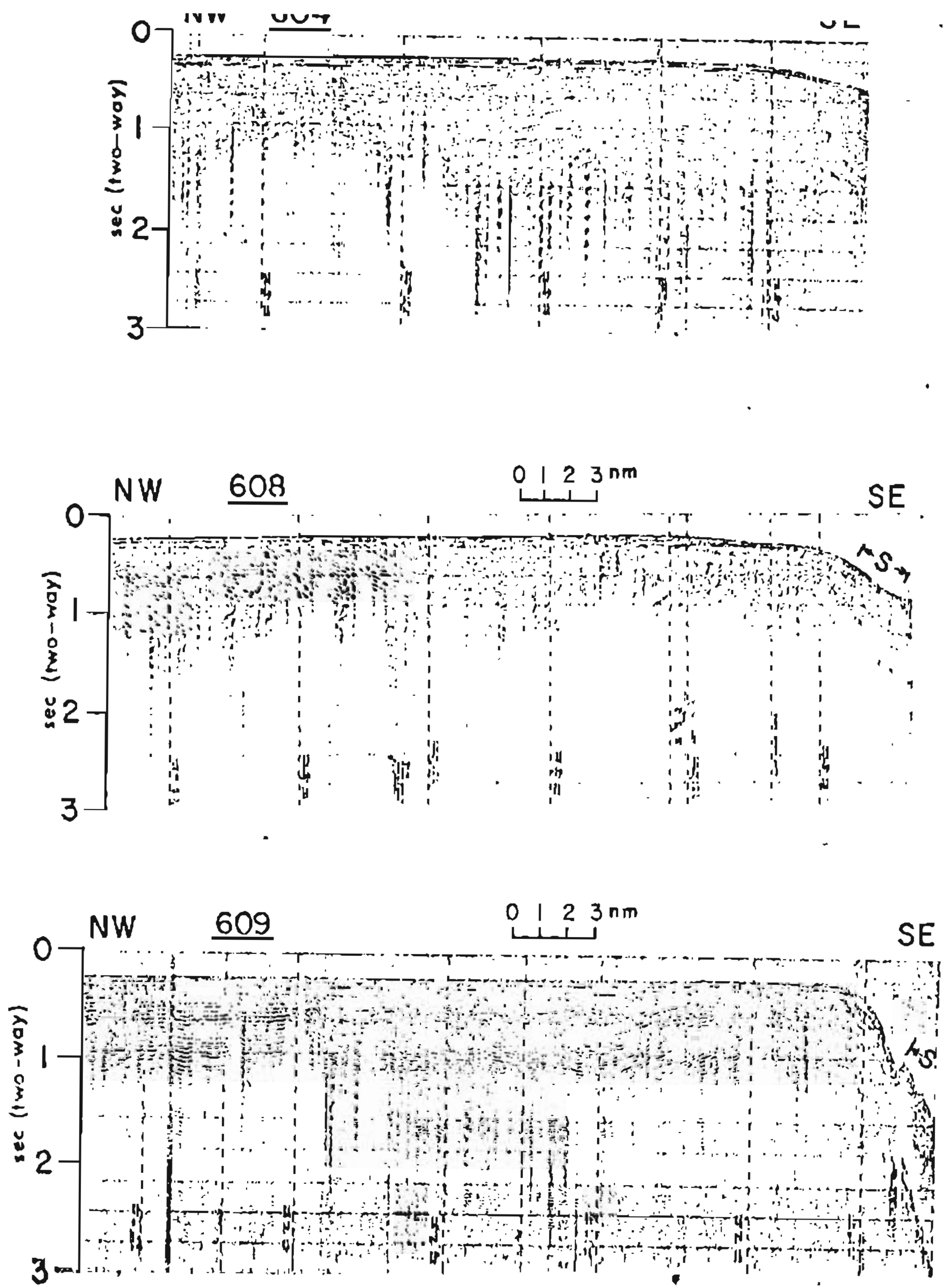


Fig. 2F

APPENDIX

SLOPE INSTABILITY NEAR THE SHELF BREAK, WESTERN GULF OF ALASKA

by

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Marine Geotechnolcgy

1977, volume 2, (in press)

SLOPE INSTABILITY NEAR THE SHELF BREAK, WESTERN GULF OF ALASKA

by

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ABSTRACT

The uppermost continental slope in the western Gulf of Alaska, from southern Albatross Bank to Portlock Bank, includes two broad areas where large submarine landslides occur and one intervening area where they are absent. The areas containing large slides show evidence for active near-surface folding and consequent slope steepening, which apparently is the ultimate control on this sliding. Evidence is absent for similar active steepening in the area containing no large slides, where slope gradients are relative gentle.

Relatively small, shallow slides, fundamentally different from the larger ones, occur in all three areas on slopes that are not necessarily actively steepening. These slides probably are stratigraphically controlled, with failure occurring along weak subsurface strata.

Strong earthquakes and the related accelerations probably are responsible for the actual triggering of many of the large and small slides. As long as the tectonic setting remains as it is today, future large-scale sliding should remain confined to the two broad areas in which it now exists. However, relatively small-scale and shallow slides might occur in any of the three areas.

INTRODUCTION

Slides and related forms of gravity-induced slope instability are widespread features of the continental slope. Seismic profiles of the slope reveal areas of hummocky surface geometry, abrupt scarps, deformed and discontinuous subbottom reflectors, rotated sedimentary units, and/or shallow extensional surface fractures. These areas are interpreted to have experienced slope instability.

The causative factors of instability seldom are evident on seismic reflection records. The relative steepness of the continental slope--an average of 4.17° according to Shepard (1973)--compared to other areas of the ocean floor, and the typically high rates of fine-grained sedimentation, probably are ultimately responsible for the abundance of sliding. Earthquakes and abnormally high pore pressures are thought to be common triggering mechanisms (see also Kelling and Stanley, 1976, p. 412-413).

Seismic reflection records gathered in June and July 1976 aboard the R/V Sea Sounder and R/V S.P. Lee show several areas of instability on the uppermost continental slope in the western Gulf of Alaska, off the Kodiak island group (Fig. 1). The survey lines, which had been designed mainly for an environmental geologic study of the continental shelf, did not extend far beyond the shelf break (Fig. 2) (Bouma and Hampton, 1976; Hampton and Bouma, 1976), but previous records show features interpreted as slides down to the junction of the continental slope with the Aleutian Trench (von Huene, 1972).

Inspection of our seismic reflection records allows identification of areas where slides are present on the uppermost slope and other areas where they are absent. Two fundamentally different types of slides have been distinguished and the habitats of each type defined. The records show ample evidence as to the major controls on instability.

Due to space and size limitations, seismic profiling records of all lines that cross the shelf break cannot be presented in this paper. Only a few representative records, illustrating important points, are shown. For the interested reader, copies of all of the records crossing the shelf break, as designated in Figure 2, are being published in the U. S. Geological Survey Open-File Report 77-xxx (Hampton and Bouma, in press).

METHODS

Continuous seismic reflection records were collected with intermediate-and high-frequency instruments including Teledyne 160 kilojoule and 90 kilojoule sparker, EG&G uniboom and Raytheon 3.5 kilohertz systems. Ship's speeds commonly were about 5 1/2 knots, but varied between 4 and 8 knots.

Navigation was by Magnavox and Marconi integrated satellite - Loran C systems. A Motorola Mini-Ranger unit, using land-based transponders, was the principal navigational tool where surveying was within 50 to 80 miles of the transponders.

Two grab samples and two gravity cores were collected beyond the shelf break, giving limited information as to the nature of the upper slope sediments.

GEOLOGIC SETTING

General

The western Gulf of Alaska continental margin is located on the edge of the North America plate near the zone of subduction associated with the Aleutian Trench. Active tectonism is demonstrated by frequent seismic and volcanic events in the general area.

The most recent major seismic activity to affect the western Gulf was the 1964 Alaska earthquake. A maximum uplift of about 7 m near the shelf break was computed from pre- and post-earthquake soundings by von Huene et al. (1972). Since the turn of the centruy, more than 80 earthquakes of greater than Richter magnitude 6.0 have occurred in the region from the tip of the Alaska Peninsula to Prince William Sound (von Huene et al., 1976; John Lahr, U.S. Geological Survey, unpublished data). Sixteen volcanoes in this same region have been active within the past 10,000 years.

Structure

The structure of the continental margin reflects major tectonic activity (von Huene and Shor, 1969; von Huene, 1972; von Huene et al., 1972). A zone of intense faulting and deformation occurs along and offshore of the Pacific Coast of the Kodiak islands. Seaward of this zone is a broad, gently deformed basin containing middle and upper Tertiary sediments. A broad arch, apparently is discontinuous at shallow to moderate depths, exists along the shelf break and forms the seaward flank of the basin. The arch is breached in several places, and a few rocks of Miocene and Pliocene age have been recovered by dredging (von Huene and Shor, 1969).

Seismic records suggest that the continental slope is composed of steeply dipping and folded sediments overlain by a blanket of terrigenous sediments (von Huene, 1972), but the structure is less well known than for the adjacent shelf.

Physiography

The surface physiography of the shelf off the Kodiak islands consists of several flat, relatively shallow areas cut by transverse valleys (Fig. 3). This physiography reflects the erosive action of glaciers and waves as well as some bedrock structural control. The shelf-break arch commonly forms a physiographic high, with a shallow trough behind it. Hogback ridges, reflecting breaching of the shelf-break arch occur at several places on the outer parts of the shallow banks. Surficial scarps, implying recent faulting, occur throughout the shelf area (Bouma and Hampton, 1976; Hampton and Bouma, 1976).

The continental slope can be divided into three broad physiographic areas: the relatively smooth upper slope, the benchlike middle slope, and the steep, rough lower slope (von Huene, 1972).

Sediments

Surficial sediments on the shallow banks of the shelf are sands that contain coarser material, ranging up to boulder size. They rarely contain significant quantities of silt and clay (Bouma and Hampton, 1976). Foraminifera tests and crushed shells of megafauna constitute major portions of these sediments. The surficial sediments in the transverse troughs typically are finer grained than those on the banks, and at a few places are composed almost entirely of silt- and clay-size material. Local occurrences of gravel and coarser clasts are common. Volcanic ash is an abundant constituent of most surficial trough sediments.

The two gravity cores collected on the uppermost continental slope, seaward of middle Albatross Bank (Figs. 2, 3) consist of silty mud with scattered pebbles. The cores came from an area of general sliding (Fig. 3). The two grab samples collected seaward of the mouth of a transverse valley, in an area that contains only minor evidence of slumping, are composed of pebbly sand with essentially no fine-grained material.

DESCRIPTIONS OF SEISMIC REFLECTION DATA

In the following discussion, the study area is divided into three distinct parts - southwestern, central, and northeastern. Each part is characterized by the types and abundance of sliding occurring within it.

In the southwestern part of the study area, which includes southern and middle Albatross Bank, most sparker records (lines 63 through 154, Fig. 2) show evidence of submarine sliding. Slides are not evident, or are questionable, on lines 61 (Fig. 4), 59, 60, and 608. Perhaps some of these lines did not extend far enough onto the continental slope to encounter slides. In the best examples, such as lines 64 and 610 (Fig. 4), the slides appear as high-relief hummocks that reach heights of about 60 m. These features have the general appearance of large rotational slumps (Varnes, 1958), having relatively small displacements relative to the size of the displaced units and generally curved slide planes, where visible. Truncation of strata at the headwall scarps is evident on lines 154, 610 (Fig. 4) and 63, but not on others such as 55 (Fig. 4).

A minimum thickness of 200 m of slumped material can be estimated on line 154 (Fig.4) by extending the 5 1/2° gradient of the upper slope above the headwall, out over the area of sliding and by measuring the distance down to the inferred slide plane. Estimates of thickness made on other lines are similar. The slide block visible in line 154 is about 95 m thick and has moved about 300 m downslope.

Complexly distorted bedding exists to great depths in some of the slide areas. Past the major course change marked on line 610, for example, deformation is evident below the surface for about 0.8 sec. of one-way travel time. About 0.38 sec. of deformed sediment is visible at the end of line 63, and about 0.18 sec. on line 55 (Fig. 4). Some irregular deformation also appears on line 60, which is parallel to the slope and crosses the trough between southern and middle Albatross Banks. The folding apparently is oblique to the main tectonic trend. The slope gradient normal to line 60 is about 6 1/2°.

The slides between lines 607-608 are subtle on the sparker records (Fig. 4) but show up well on the uniboom records (Fig. 5). They appear as a series of low-relief hummocks to about 5 m high. Continuous reflectors are visible below the slides, giving a limiting maximum thickness of about 30 m of displaced material. These slides appear to be debris slides or block glides (Varnes, 1958), involving movement of a few or several units along relatively planar slide surfaces.

The debris slides described above moved over a gradient of about 3°. In contrast, the larger slumps moved over generally steeper gradients of 3°-9°, averaging about 5-1/2°. Gradients on the upper continental slope where sliding is not observed range from about 2° to 4 1/2°, averaging about 3°.

The nature of the shelf break is highly variable along southern and middle Albatross Banks. On lines 610 (Fig. 4) and 609, for example, the shelf break is abrupt whereas it is broad on lines 154 (Fig. 4) and 59. The depth of the shelf break, measured at the first significant change in gradient, varies from about 45 m (line 59) to about 365 m (line 610). Part of the variation in depth is related to the presence of troughs between the banks. The shape and depth of the shelf break does not seem to vary consistently with the presence or absence of slides, except that all abrupt shelf breaks are followed by sliding on the adjacent upper slope.

The geologic structure in this part of the study area shows considerable evidence of recent tectonics. A large, breached anticline is present near the shelf break on most lines (e.g., line 61, Fig. 4). An apparent graben occurs near the large anticline on line 64 (Fig. 4), and may be present in a more subdued form on nearby line 63 and in part on line 61 (Fig. 4). The graben is probably related to extension above the general arching that seems to be taking place.

A smaller anticline appears seaward of the large one on some of the lines. For example, a small subsurface flexure that is draped by very slightly deformed slope sediments appears on line 61 (Fig. 4). Line 610, the next line to the northeast, shows a larger, but analogous anticline, one that has grown sufficiently to form a new shelf break beyond the landward one. The second crossing of the seaward anticline on line 610, past the major course change where the ship turned and headed back toward land, shows this anticline to be larger and forming a shallower shelf break (280 m versus 365 m) than on the previous crossing. The shelf break is a discontinuous, "en echelon" feature in this area, as depicted on Figures 2 and 3.

Ponded sediments occur between the two anticlines on lines 610 (Fig. 4). The increased dip of these sediments deeper in the section implies growth of at least the seaward anticline during deposition (von Huene, 1972).

The central part of the study area, along northern Albatross Bank (lines 190 to 31, Fig. 2), is devoid of slides on the uppermost continental slope, except for some relatively small features on lines 605-606 (Fig. 6). As seen on the uniboom record (Fig. 7), these slides are similar to the debris slides on lines 607-608. They occur on a slightly steeper gradient of about 4-1/2°, and appear to be about 25 m thick. Irregular subsurface deformation is apparent on lines 605-606 and 190 (Fig. 6) near the boundary with the southwestern part of the study area.

The gradient of the upper continental slope is gentle throughout most of the central area, in the range from 1/4° to 4 1/2°, averaging about 2°. The debris slides occur on the steepest slope observed (4-1/2°), where the shelf break is also most abrupt. The shelf break throughout the rest of the area ranges from sharp (e.g., line 34) to gradual (e.g., line 603). Its depth lies between 100 m and 175 m.

The geologic structure of the central region is in distinct contrast with that to the southwest. The shelf break anticline is present on most lines but is typically a broad feature with gently dipping limbs (e.g., lines 31, 34, 39, 604, Fig. 6). The seaward limb normally conforms to the gentle gradient of the upper slope, and seismic reflectors generally are planar under the slope (e.g. lines 32, 33, 37, and 38, Fig. 6). A tight, breached anticline is present on line 49 (Fig. 6), but it is well landward of the shelf break. A relatively small subsurface anticline occurs on line 606 but does not appear on adjacent lines.

Large-scale sliding resumes in the northeastern part of the study area, which encompasses Portlock Bank and the adjacent trough to the southeast (lines C to 601, Fig. 2). Large slumps are present on many of the track lines. On line 81 the slide plane is visible below the slide mass, which is about 175 m thick and has moved about 950 m downslope (Fig. 8). An older seismic record, nearly coincident with line 81 but extending to the base of the continental slope (line 6, Fig. 9), shows this same slide block in its entirety. It is about 3700 m long and is succeeded downslope by at least one more similar slide.

Debris slides, similar to those on lines 607-608, appear on line 601 near the shelf break (Fig. 10). The continuous reflectors below the slide blocks place a thickness of 70 m. as maximum. The gradient is 3°. The analogous location on the return crossing of the shelf break, beyond the major course change marked on line 601, shows no slide blocks.

In addition to the presence of large slumps, the northeastern area has many other similarities to the southwestern area. The shelf break is abrupt in some places and broad in others. Gradients of the upper slope are 2° to 9-1/2° and depths of the shelf break are 110 m to 510 m.

The geologic structure near the shelf break is similar to that of the southwestern area. Broad, breached anticlines appear on many lines (e.g. 77, Fig. 8, and 79), and a large graben is well shown on line 81 (Fig. 8). Irregular subsurface deformation also occurs (e.g. line 6, Fig. 9, and C, 67).

Multiple shelf breaks, reflecting a pattern similar to that on lines 61 and 610 (Fig. 4), appear on lines 77, 175 and 601 (Fig. 8). On line 77, a subsurface anticline is draped by slope sediments. This anticline deforms the sea floor to form a new shelf break on the next line to the northeast (line 601) and a shallower, more pronounced break on the next one (line 175). Large slumps are present on the steep slope beyond this shelf break.

DISCUSSION AND CONCLUSIONS

The occurrence of large slides in areas where there is evidence for active growth of structures on the shelf break and uppermost continental slope, and the absence of such slides where tectonic deformation is relatively minor, indicates a relationship between slope instability and tectonics. The upper continental slope is being tectonically steepened in places by growth of structural arches near the shelf break. The tectonic steepening probably is the ultimate control of the large slides in the study area, although earthquakes associated with the tectonism might actually be the triggering mechanism. Von Huene (1972) also has suggested a relationship between tectonic steepening and sliding in this area.

Active tectonic steepening is perhaps most convincingly demonstrated where multiple shelf breaks exist. The seaward shelf break represents the physiographic expression of a shallow anticlinal fold. As most clearly shown on lines 77, 601, and 175 (Fig. 8), the axis of the anticline is inclined gently toward the southwest. On line 77 the anticline apparently once existed as a physiographic high, with slope sediment onlapping it. Present-day slope sediments are unaffected by the anticline, suggesting that its growth at this location is now slow or nonexistent. On lines 601 and 175, the anticline has higher elevations on crossings successively to the northeast and appears from its physiographic expression to be active at present. A similar case can be constructed for the seaward anticline and shelf break on lines 61 and 610 (Fig. 4). Seismic reflection records of all crossings of multiple shelf breaks along the Kodiak shelf (lines 175, 601, and 610) show large slides on the actively steepening seaward flank of the outer anticline.

Irregular subsurface deformation is common in the general areas where large-scale slides occur. This deformation (e.g., line 60 on Fig. 4 and lines C, 67, 6, Fig. 9) undoubtedly represents buried slides in some places, but in others it may be produced by gravity folding, diapirism, or movements along deep slide planes. All of these processes could be basically controlled by tectonic slope steepening, and in this way the complex deformation might be genetically related to the large slides.

The debris slides occur in a different environment from the larger slides and generally are found on more gentle gradients. The debris slides most likely are not all principally controlled by slope steepening. On line 601 (Figs. 8, 10, for example, the slides occur near the landward shelf break, behind the seaward break and its associated rotational slumps. The gradient on which these smaller slides occur is probably decreasing with time, because the seaward shelf break is apparently being uplifted faster than the landward break, with sediments ponding in the interconnecting depression. Where small slides occur along line 605 (Figs. 6, 7), the gradient probably is not increasing significantly, because this line is located in the central region of gentle deformation. The small slides on line 607 (Figs. 4, 5) are near a zone of rotational slumps (see line 55, Fig. 4), and this is one instance where the local slope may be steepening. In all of these examples, the more-or-less planar geometry of the slide plane indicates ultimate stratigraphic of the instability, whereby sliding occurs along a weak layer of sediment. Failure of the weak layer might be triggered by accelerations and/or abnormal pressures related to earthquakes, and in this way tectonism probably does exert some influence.

According to the ideas developed in this paper, future large earthquakes and the related tectonic steepening will probably continue to generate large-scale slides in the two areas where they occur today (i.e., the upper slope off southern-middle Albatross Bank and off Portlock Bank). The third area, off northern Albatross Bank, which does not contain large-scale slides seems unlikely to experience such slope instability as long as tectonic steepening remains dormant. All three areas contain smaller, stratigraphically controlled debris slides and are therefore susceptible to shallow instability.

ACKNOWLEDGEMENTS

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REFERENCES

Bouma, A. H., and Hampton, M.A., 1976. Preliminary Report on the Surface and Shallow Subsurface Geology of Lower Cook Inlet and Kodiak Shelf, Alaska. U.S. Geological Survey Open-File Report 76-695, 36 pp. ,9 maps.

Hampton, M.A., and Bouma, A.H., 1976. Seismic Profiles of Lower Cook Inlet and Kodiak Shelf, R/V SEA SOUNDER, June-July 1976. U.S.Geological Survey Open-File Report 76-848, 36 pp., 9 rolls microfilm, 4 maps.

Shepard, F.P., 1973. Submarine Geology. New York, Harper and Row Publishers, 517 pp.

Varnes, D.J., 1958. Landslide types and processes. In Landslides and Engineering gePractice, Highway Research Board Special Report 29, National Research Council Pub. 544, pp. 20-47.

von Huene, R., 1972. Structure of the continental margin and tectonism of the eastern Aleutian Trench. Geological Society of America Bulletin, vol. 83, pp. 3613-3626.

von Huene, R , Bouma, A.H., Moore, G.W., Hampton, M.A., Smith, R., and Dolton, G., 1976. A Summary of Petroleum Potential, Environmental Geology, and the Technology, Time Frame, and Infrastructure for Exploration and Development of the Western Gulf of Alaska. U.S. Geological Survey Open-File Report 76-325, 92 pp.

von Huene, R., and Shor, G.G., Jr., 1969. The structure and tectonic history of the eastern Aleutian Trench. Geological Society of America Bulletin, vol. 80, pp. 1889-1902.

von Huene, R., Shor, G. G., Jr., and Malloy, R. J., 1972. Offshore tectonic features in the affected region. In The Great Alaska Earthquake of 1964, Oceanography and Coastal Engineering. Washington, D. C., National Research Council, National Academy of Sciences, pp. 266-289.

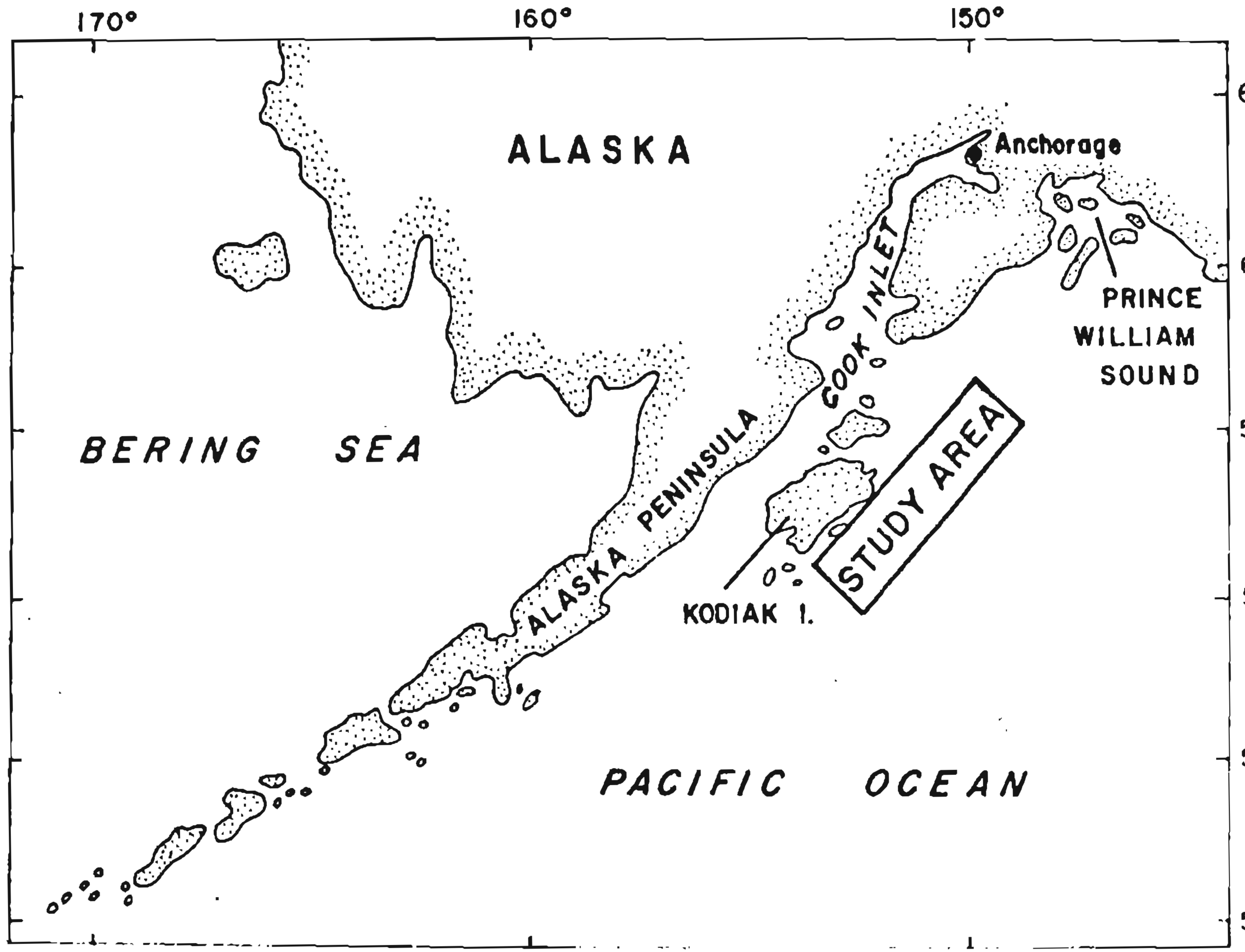

170°
160°
150°
62°
60°
58°
56°
54°
52°
ALASKA
BERING SEA
Anchorage
COOK INLET
ALASKA PENINSULA
PRINCE
WILLIAM
SOUND
STUDY AREA
KODIAK I.
PACIFIC OCEAN

FIG. 1

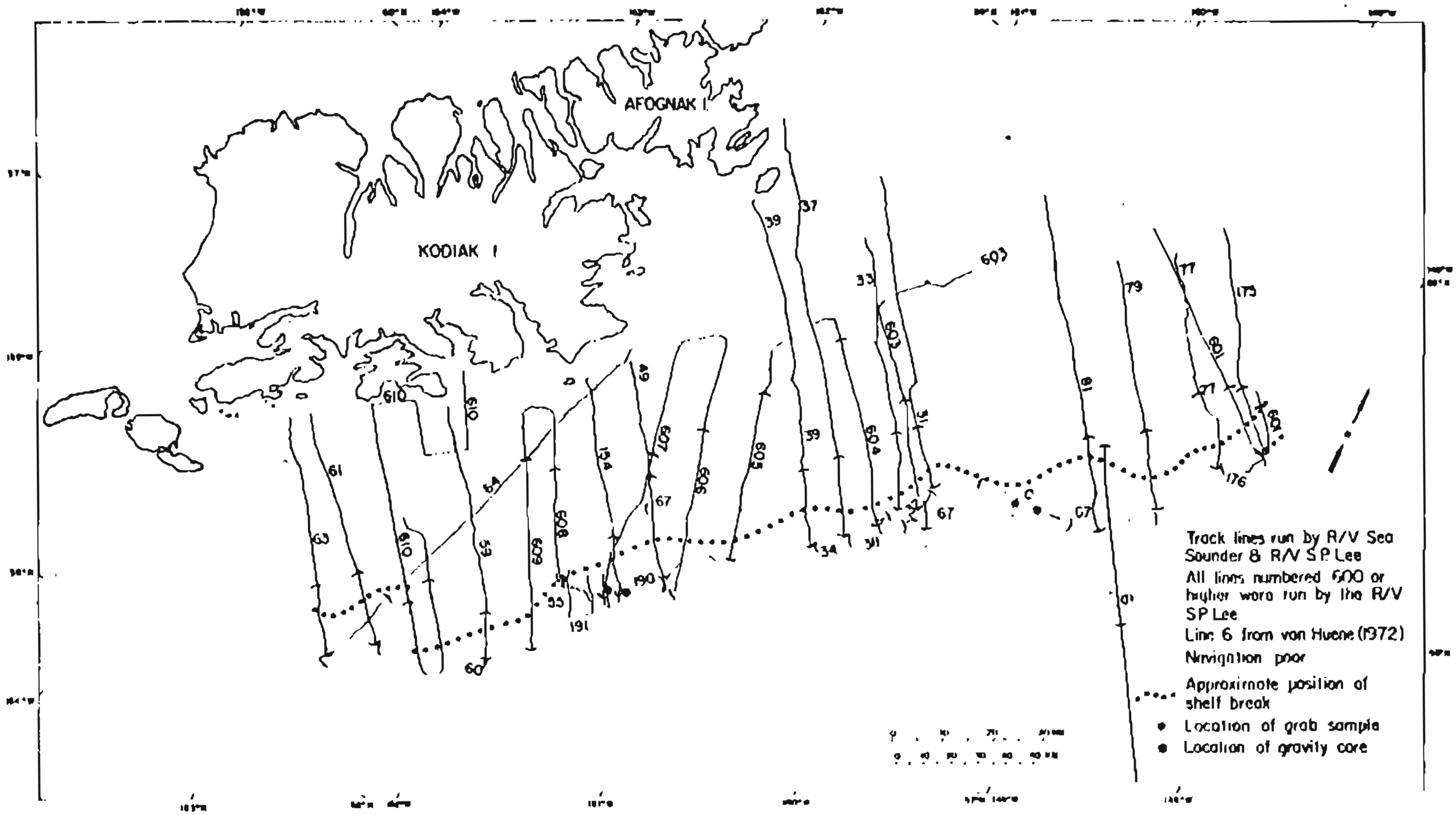
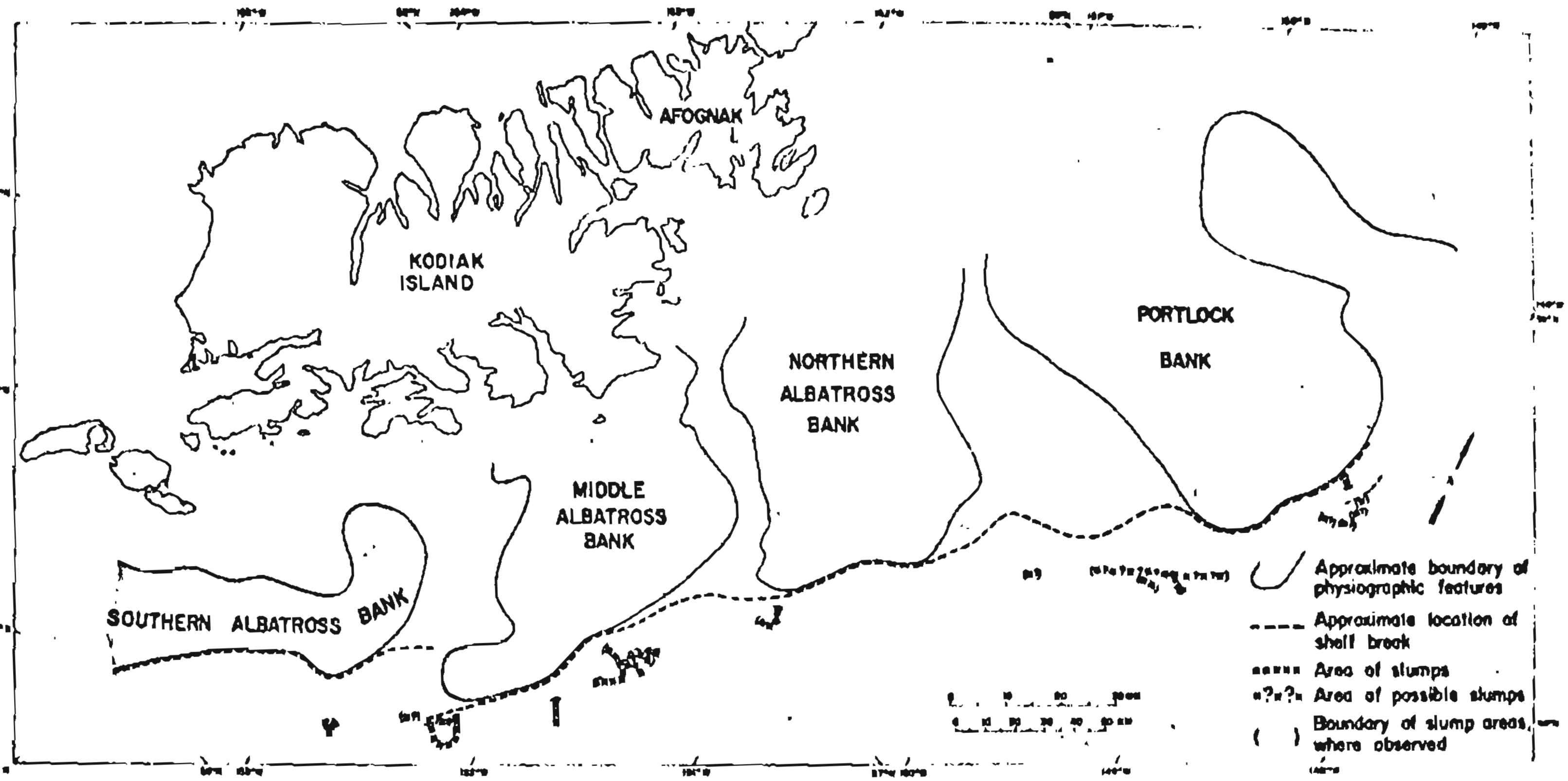
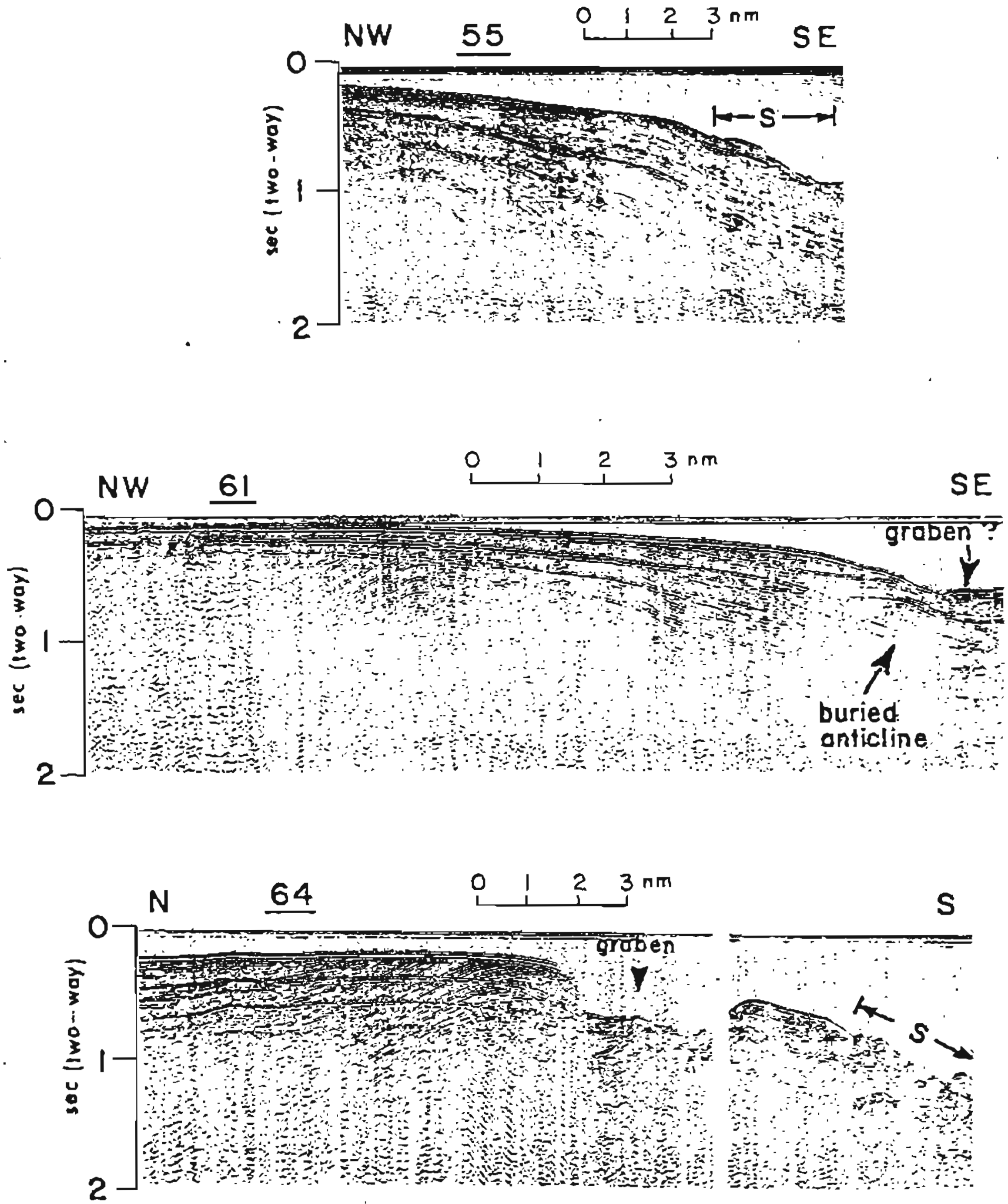

AFOGNAK I.
KODIAK I
Track lines run by R/V Sea Sounder & R/V S.P. Lee
All lines numbered 600 or higher were run by the R/V S.P. Lee
Line 6 from von Huene (1972)
Navigation poor
Approximate position of shelf break
Location of grab sample
Location of gravity core

FIG. 2



KODIAK
ISLAND
AFOGNAK
SOUTHERN ALBATROSS BANK
MIDDLE
ALBATROSS
BANK
NORTHERN
ALBATROSS
BANK
PORTLOCK
BANK
Approximate boundary of physiographic features
Approximate location of shelf break
Area of slumps
Area of possible slumps
Boundary of slump areas, where observed

FIG. 3



NW
55
0 1 2 3 nm
SE
S
0
1
2
sec (two-way)
NW
61
0 1 2 3 nm
SE
graben ?
buried anticline
0
1
2
sec (two-way)
N
64
0 1 2 3 nm
S
graben
S
0
1
2
sec (two-way)

FIG. 4 (1 of 2)

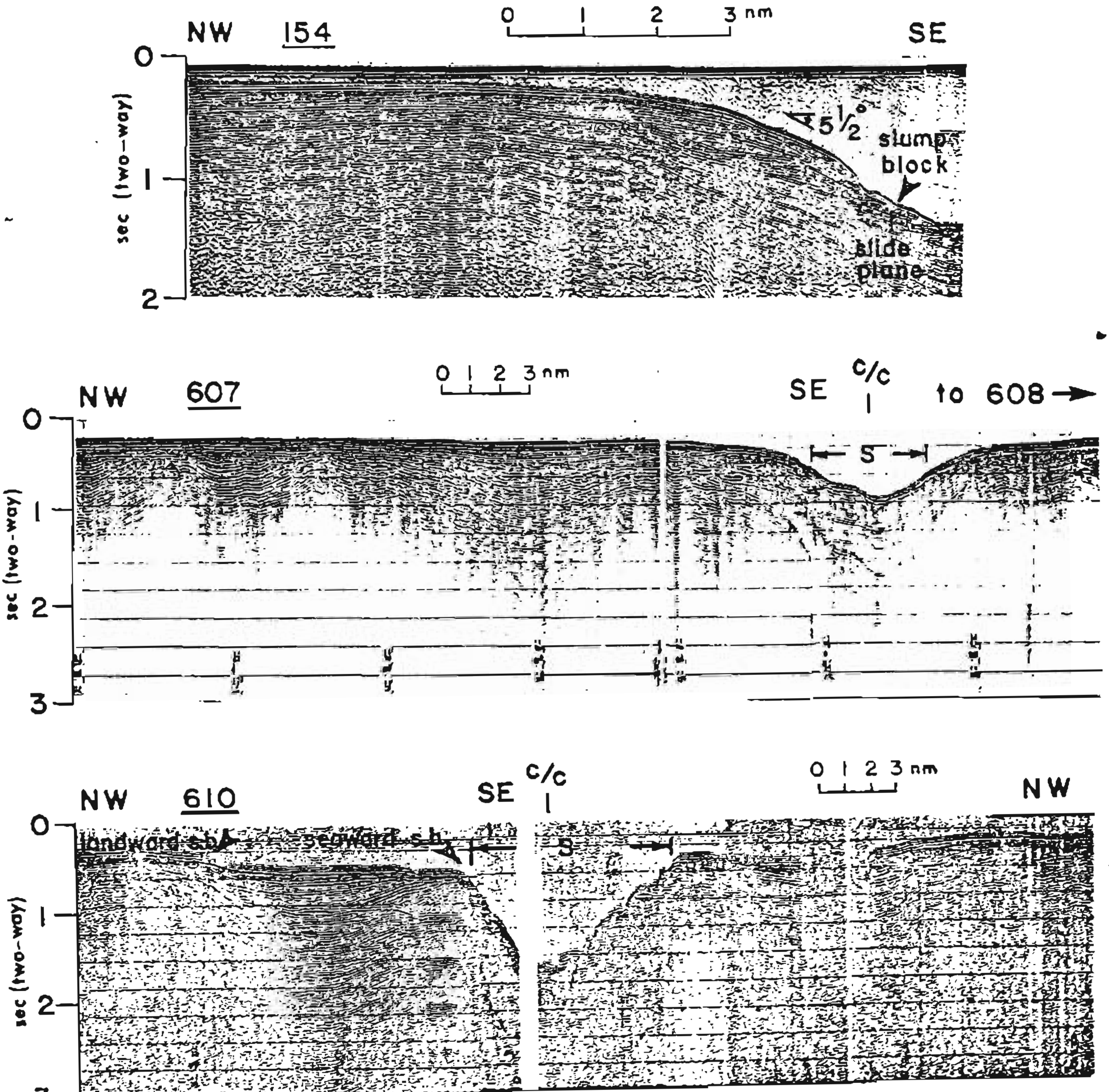

NW
154
0 1 2 3 nm
SE
0
1
2
sec (two-way)
5 1/2°
slump block
slide plane
NW
607
0 1 2 3 nm
SE
C/C
to 608 →
S
0
1
2
3
sec (two-way)
NW
610
SE
C/C
0 1 2 3 nm
NW
landward s.b.
seaward s.b.
S
0
1
2
3
sec (two-way)

FIG. 4 (2 of 2)

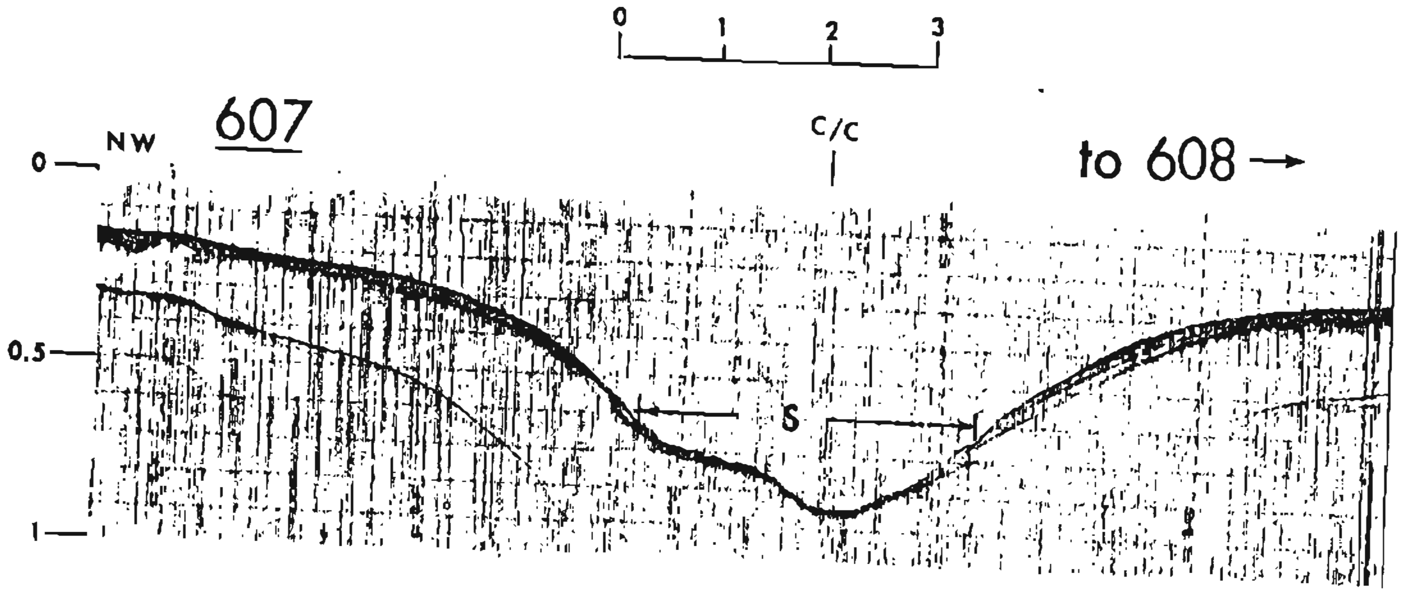


FIG. 5

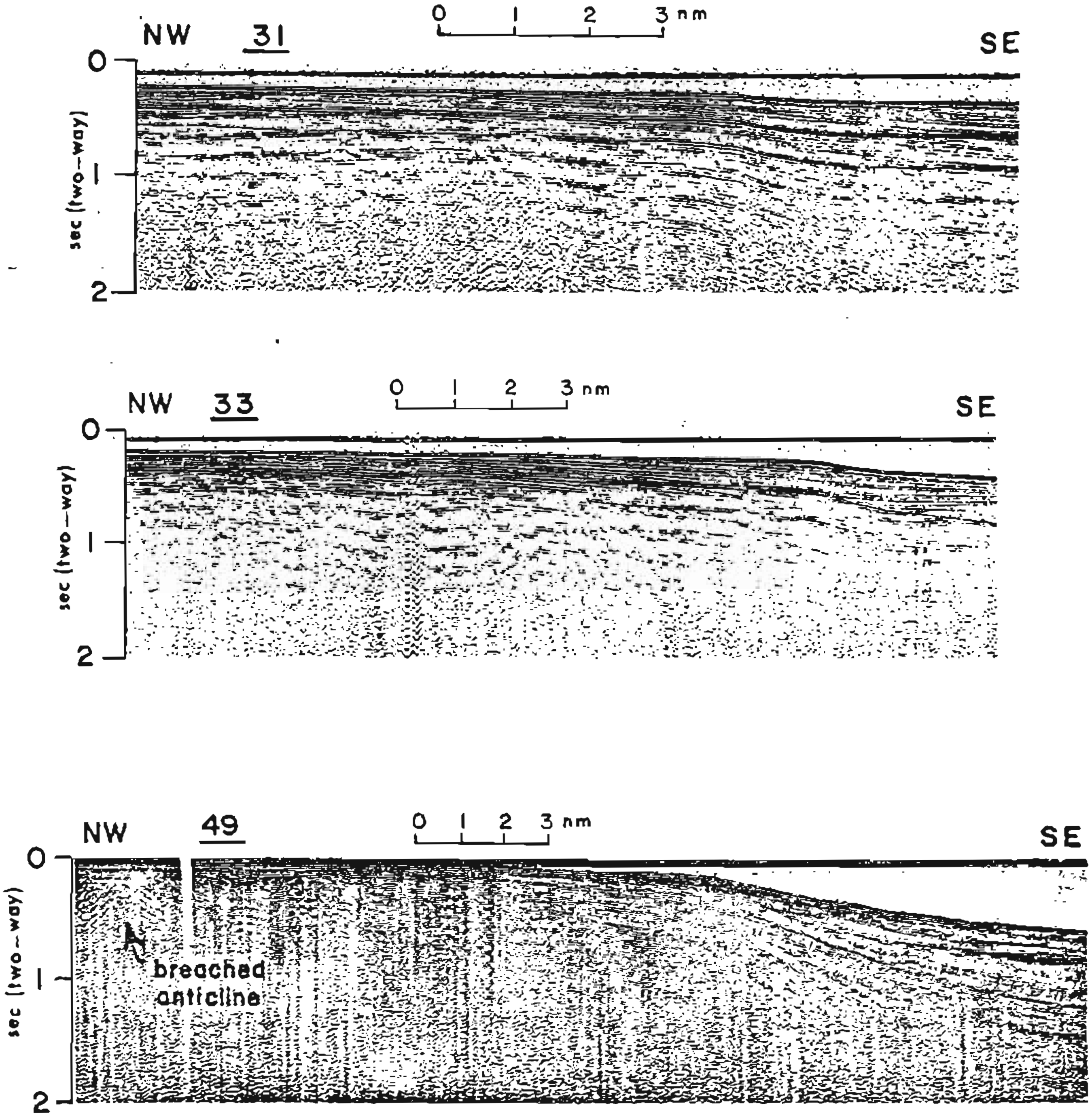
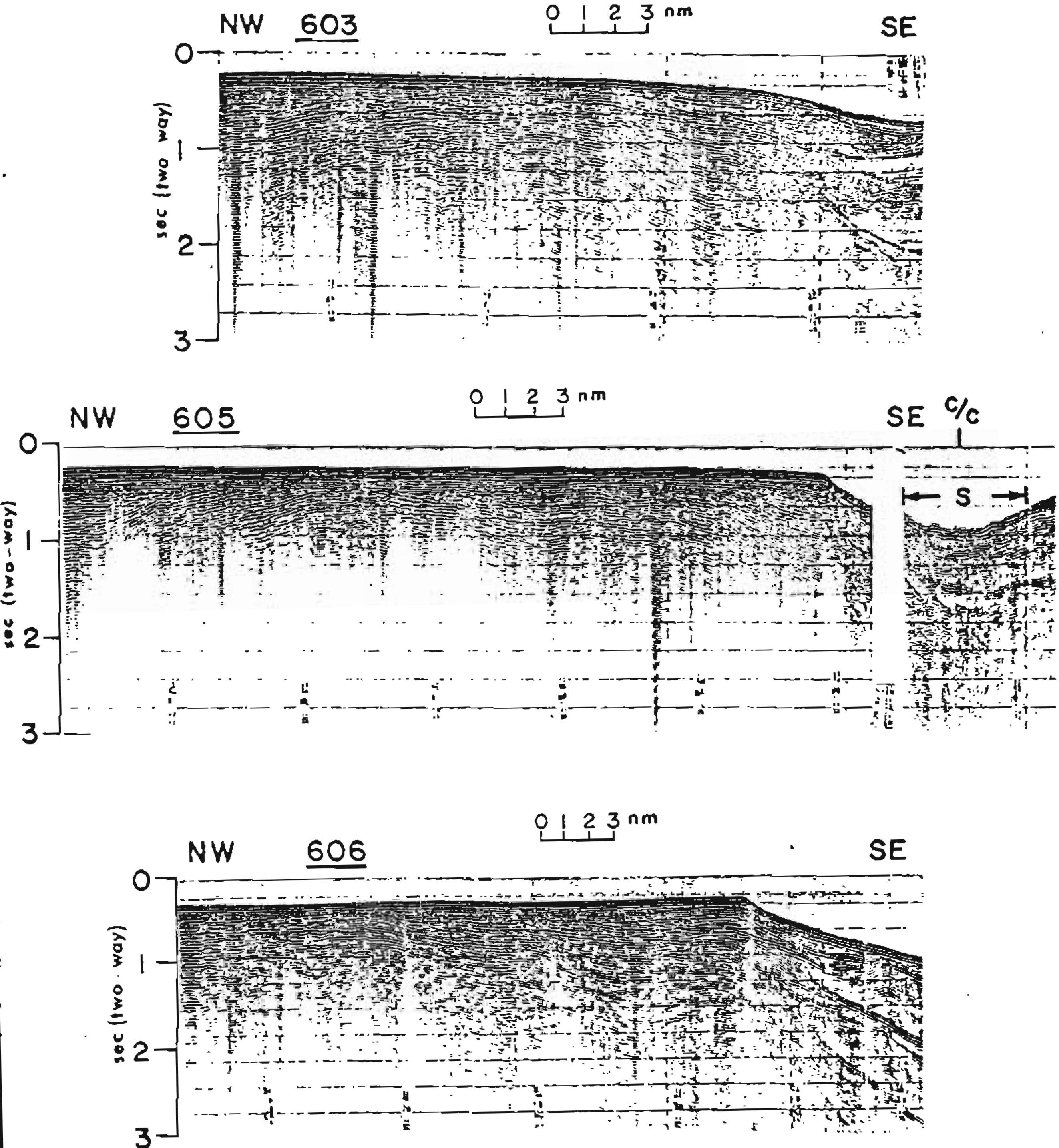

NW
31
0 1 2 3 nm
SE
0
1
2
sec (two-way)
NW
33
0 1 2 3 nm
SE
0
1
2
sec (two-way)
NW
49
0 1 2 3 nm
SE
0
1
2
sec (two-way)
breached anticline

FIG. 6 (1 of 2)



NW
603
0 1 2 3 nm
SE
sec (two way)
0
1
2
3
NW
605
0 1 2 3 nm
SE
C/C
S
sec (two-way)
0
1
2
3
NW
606
0 1 2 3 nm
SE
sec (two-way)
0
1
2
3

FIG. 6 (2 of 2)

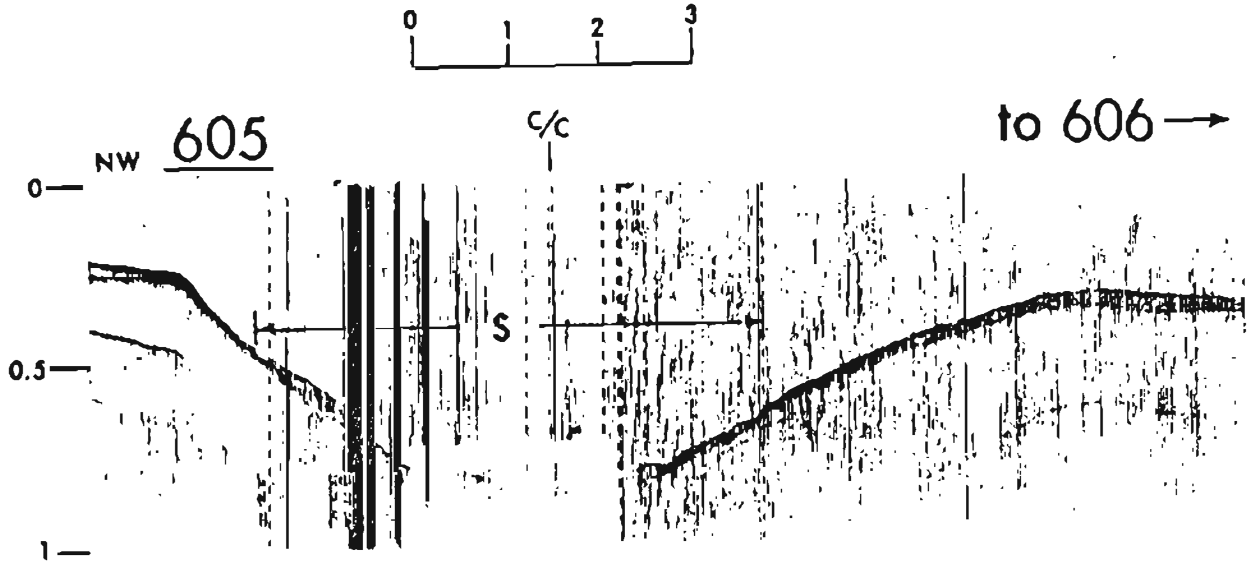
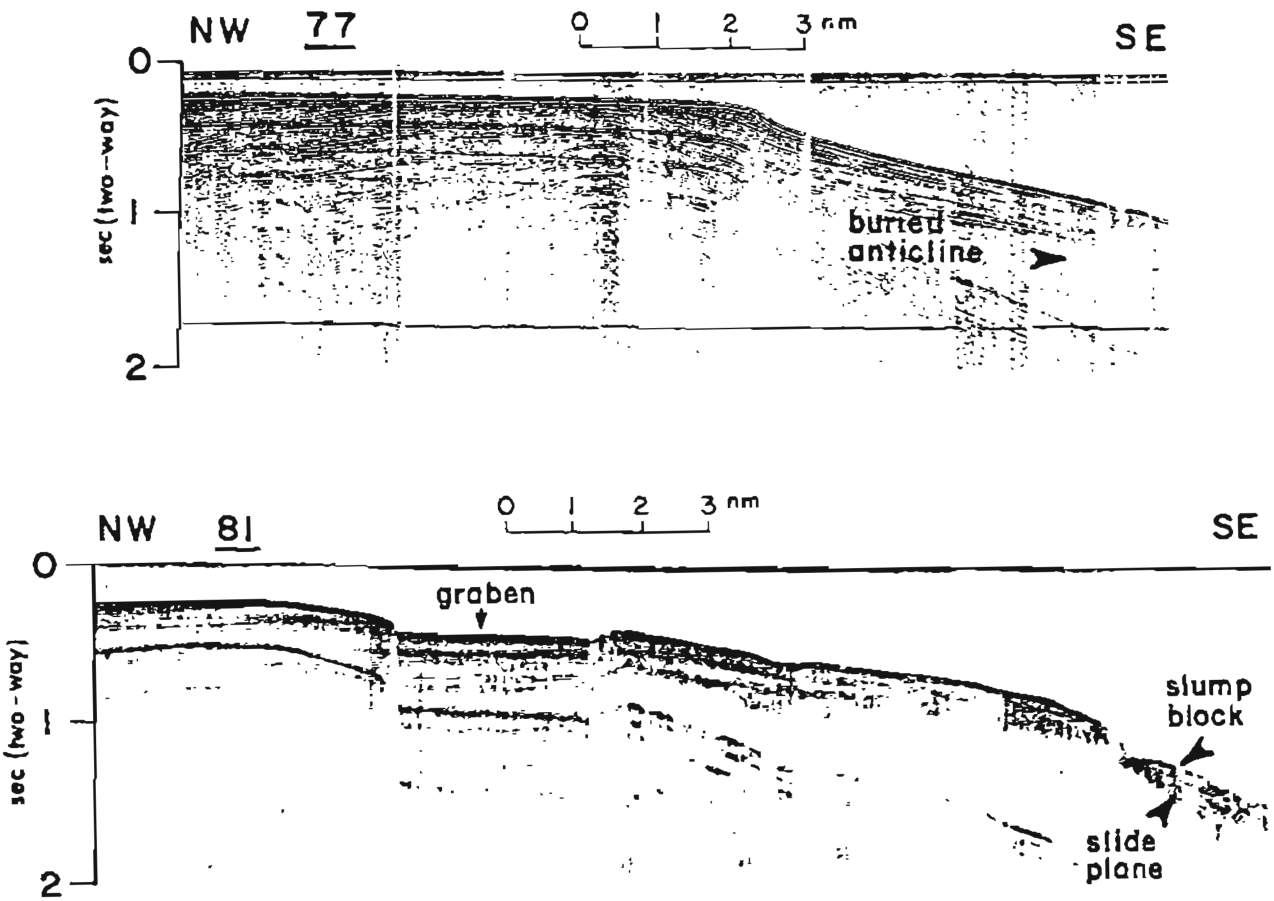


FIG. 7



NW
77
0 1 2 3 nm
SE
0
1
2
sec (two-way)
buried anticline
NW
81
0 1 2 3 nm
SE
0
1
2
sec (two-way)
graben
slump block
slide plane

FIG. 8 (1 of 2)

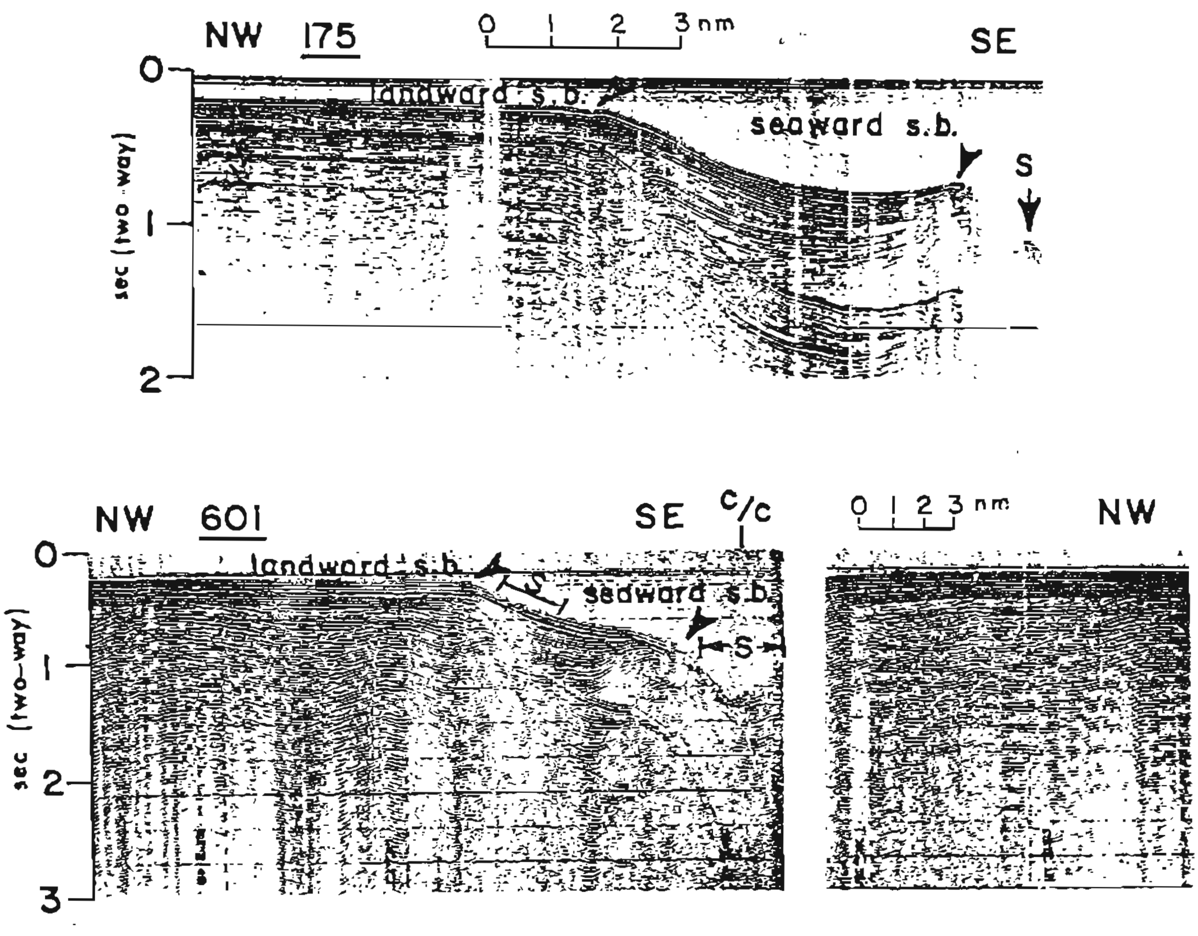

NW 175
0 1 2 3 nm
SE
landward s.b.
seaward s.b.
S
sec (two-way)
0
1
2
NW 601
SE
C/C
0 1 2 3 nm
NW
landward s.b.
seaward s.b.
S
S
sec (two-way)
0
1
2
3

FIG. 8 (2 of 2)

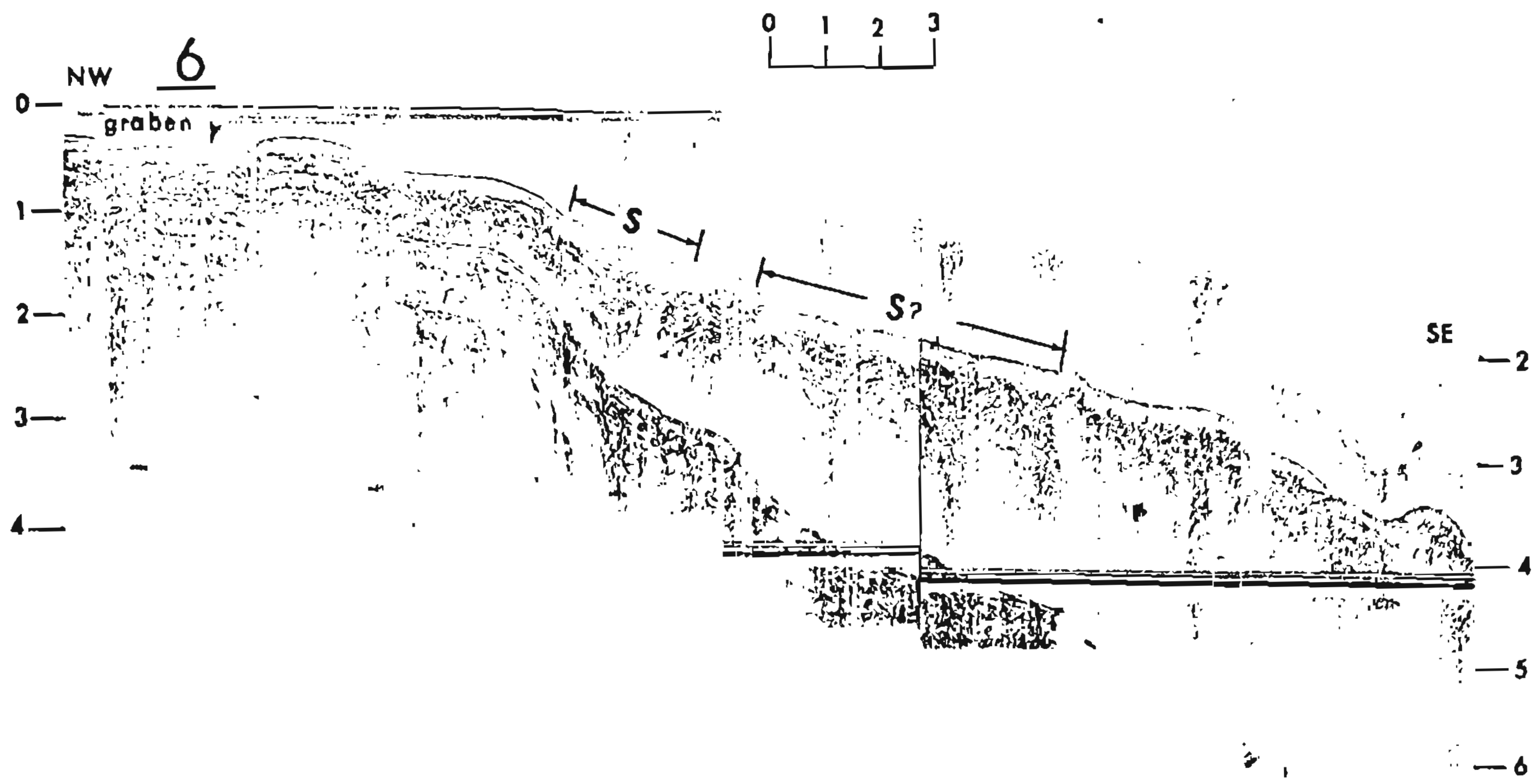


FIG. 9

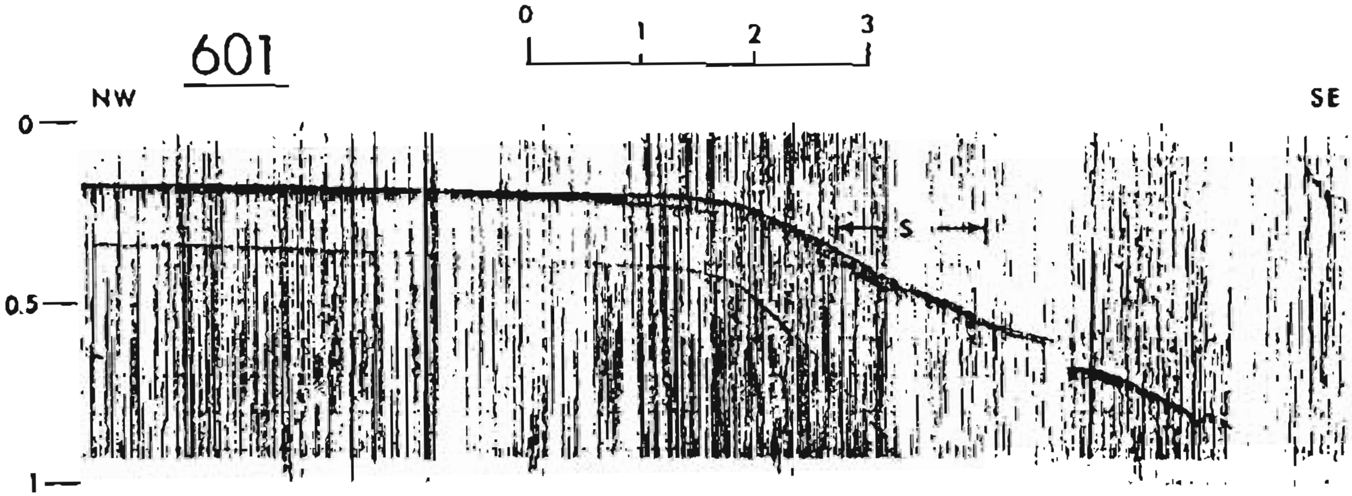


FIG. 10