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BIOSTRATIGRAPHIC RESULTS OF DART-CORING IN THE WESTERN GULF OF ALASKA, AND THEIR TECTONIC IMPLICATIONS

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ABSTRACT

Age determinations are reported for microfossils from 56 dart-cores collected in 1978 from the Kodiak shelf. The ages suggest that rocks cropping out along Albatross Bank, at the shelf edge, are as old as middle or late Miocene, and that the anticline forming Albatross Bank, previously defined with multi- and single-channel seismic records, plunges northeastward in the sampled area. Foraminiferal paleobathymetry further suggests that major tectonic activity has occurred on the Kodiak shelf since the early or middle Pliocene, including two episodes of vertical movement--first subsidence on the order of 2000 m, then uplift of at least 3000 m. Microfossil ages and paleobathymetric determinations indicate an average uplift rate of 1000-3000 m/m.y. for the seaward edge of the Kodiak shelf during the Quaternary.

INTRODUCTION

This report summarizes the results of biostratigraphic analyses of dart-cores collected near Kodiak Island, in the western Gulf of Alaska. These results include ages of diatoms (J. A. Barron), foraminifers (R. E. Arnal), radiolarians (S. A. Kling) and coccoliths (D. Bukry), and are summarized in Table 1. The cores were collected on the Kodiak shelf during a sampling cruise of the R/V SEA SOUNDER in 1978. The purpose of the sampling was to determine the age and lithology of rocks that crop out near the seaward edge of the shelf along a bathymetric high named Albatross Bank (fig.1). This bank forms the shelf-break locally, and is at the axis of an anticline trending approximately parallel to the Aleutian trench. Analysis of a multichannel seismic line (509), which crosses the shelf-break, indicates that the anticline has risen at least 3 km perhaps since the late Miocene (Fisher and von Huene, in press). Ages determined from cores collected along line 509, and along two adjacent seismic lines that also cross the shelf-break (sparker lines 509B and 509C, fig. 1), should help to establish a lower limit on the time of uplift of the shelf-break anticline.

The Aleutian trench has been postulated (Atwater, 1970) to be a zone of convergence between the North American and Pacific plates. The deformed sedimentary sequence under the Kodiak shelf, therefore, may contain a record of tectonic events related to subduction. If so, the biostratigraphic results presented in this report may provide evidence of the timing of these events.

Most of the dart-cores obtained during the cruise were collected on the continental shelf in an area 40 to 75 km east of Sitkinak Island and 55 to 90 km south of Kodiak Island. Along Albatross Bank, near the crest of the shelf-break anticline, hogbacks of bedrock provided the most suitable dart-coring targets. Water depths over most of the coring sites ranged from 26 to 152 m. Two dart cores (samples 09001 and 09002) were collected in water 875 and 925 m deep, respectively, on the upper continental slope, in the southeastern corner of the sampled area (station 2; Figure 2). Frequent conditions of rough seas and impenetrable bottom sediments limited coring success to 56 sample recoveries out of 107 attempts at 38 stations along sparker lines 509, 509B and 509C (figs. 2 and 3A-C).

Presented below are (1) the methods of data collection, (2) the results of the biostratigraphic analyses, (3) a consolidation and interpretation of the results, and (4) a discussion of the results.

We thank Stanley A. Kling and David Bukry for their paleontologic and biostratigraphic determinations. We also thank them and Paula Quinterno for their helpful critical reviews of this paper. Sparker records reproduced in this report were photoprocessed by Jeffrey Young (USGS, Menlo Park) using the CONTRAPTION at the Branch of Pacific-Arctic Marine Geology.

METHODS

Dart-cores were collected using a free-fall sampling device consisting of a detachable steel sample barrel (60.5 cm long, 4.8 cm inside diameter and 6.3 mm wall thickness), bolted to a 907 kg lead weight. A 3.5 kHz bathymetry system was used to locate target outcrops, and NAVSAT and Loran C navigation systems were used to determine the positions of coring stations. The number of coring attempts made at each station varied from 1 to 8. After each core was extruded from the sample barrel, the core was split longitudinally; described preliminarily in terms of lithology, structure and color; and subsampled for paleontologic analysis. Sample barrels that contained cores were not reused during the cruise to minimize the chance of microfossil contamination. Because of a faulty onboard extruder, 20 cores (specified in Table 1) could not be removed from the sample barrels. These unextruded cores were subsampled from the bottom of the core. After being subsampled, each core-half (or unextruded whole core) was wrapped in plastic and refrigerated. The cores are presently in the marine-sample refrigerator of the USGS Branch of Pacific-Arctic Marine Geology, at the Deer Creek facility in Palo Alto, California. The subsamples were analyzed for microfossils after the cruise.

RESULTS

Results of biostratigraphic analyses of siliceous and calcareous microfossils in the 56 cores are listed in Table 1, together with water depth and position of each sample site, and shipboard description of core lithology. Among the 56 samples, microfossils are present in all but seven (09003, 09008, 09019, 09021, 09B14, 09B15 and 09B24). In 21 of the samples only one microfossil group (either diatoms or foraminifers) provided the age. In the remaining 28 samples, two or more of the four analyzed microfossil groups are present and yielded ages.

The diatom and foraminiferal determinations independently indicate a possible late Miocene or early Pliocene age for rocks near the axis of the shelf-break anticline. Diatom ages indicate that rocks along the axis of the anticline may be as old as middle Miocene (i.e., at stations 25 and 27). Sample ages tend to decrease away from the axis landward along lines 509B and 509C, and landward and seaward along line 509.

Of the microfossil groups analyzed for age, foraminifers (mostly benthics) are the best represented, being present in 70% of the total of 56 samples. Diatoms were found in 55% of the samples, and coccoliths in only 7%. Thirty-eight samples, those collected near the axis of the shelf-break anticline, were analyzed for radiolarians. Of these 38 samples, 45% were found to contain radiolarians.

Except for the foraminifers, microfossils in the samples tend to be sparse and poorly preserved, and the groups present tend to be taxonomically nondiverse. Siliceous microfossils, except diatoms in the Quaternary assemblages, are commonly broken and in many cases were probably reworked from older Tertiary source terranes. The radiolarian species present are not diagnostic of an age more precise than Neogene. Although two radiolarian species occur at frequencies greater than "rare", these species range in age from at least early Miocene to the present (Kling, 1979, written comm.). Calcareous microfossils are either well preserved and abundant (foraminifers) or moderately well preserved and extremely rare (coccoliths). Only two coccolith assemblages (in 09002 and 09B01) contain indigenous populations, and specimens in these assemblages are of Quaternary age and are sparse and slightly etched (Bukry, 1979, written comm.). The remaining nannofloras (in 09B03 and 09C38) each contain a single species of Cenozoic coccoliths, specimens of which are either reworked or contaminants. Listed beside each station in Figure 4 are the ages of the samples determined on the bases of diatoms and foraminifers, which are the most age-diagnostic fossil groups present.

Seven samples (09001, 09002, 09011, 09024, 09C29, 09C34, and 09C41) from the 1978 cruise were analyzed (R. E. Arnal) for paleobathymetry, based on the paleocologies of the foraminiferal assemblages. These samples are the oldest from the Kodiak shelf, based on the foraminifers, and were selected for this analysis to determine the depth of deposition of the sediments in the cores. All of the above samples, except 09C34, contain foraminiferal assemblages typical of the outer continental shelf and upper continental slope (between about 200 and 500 m). Sample 09C34 (station 24; early Pliocene?) contains cold- and deep-water types of foraminifers that lived at depths from outer neritic (about 200 m) to 2000 m.

CONSOLIDATION AND INTERPRETATION OF RESULTS

Microfossil ages listed for many samples in Table 1 are inconsistent. This is most notable between diatom and foraminiferal ages. In some cases, ages of these fossil groups in a given sample differ by as much as two epochs (e.g., Miocene diatoms ages vs. Pleistocene foraminiferal ages). Possible reasons for the discordant determinations are:

(1) Quaternary fossils may have been displaced by the core barrel into older sediment during penetration (although only the inner part of each core was subsampled to minimize the possibility of such contamination);

(2) bioturbation (observed in 7 samples, noted in Table 1) may have mixed modern and older assemblages;

(3) reworking of sediment may have suspended and redeposited older microfossils with younger assemblages;

(4) sample contamination (recognized and corrected for one sample, 09C25) may have occurred during sample preparation.

(5) precise correlation between the ordinal biostratigraphic scales of the cold-water planktic and benthic microfossil groups has not been completely established.

In many cases these inconsistencies have been resolved according to the following rationales:

(I) Overlapping age ranges: If, for a given sample, a general age determination (i.e. an age range) based on one fossil group includes all or part of the range of another group, the restricted age defined by the interval of range-overlap becomes the basis of a refined estimate of sample age.

(II) Constraint of superposition: In most parts of the sampled area, the structure and relative ages of strata beneath the Kodiak shelf may be inferred from the sparker records (figs. 3A-C). The inferred superposition provides a check on the biostratigraphic determinations for the coring stations along the sample lines.

Age estimates refined according to the above rationales are listed beside each station in Figures 3A-C along the sparker records of lines 509, 509B and 509C. Where discrepancies between ages determined for a given sample, or between sample ages determined for a given station, cannot be resolved, each discordant determination is noted in Figures 3A-C.

Several of the discordant age-sets may be resolved. In one instance (station 18; figs. 3C and 4), the discordance between the middle Pliocene diatom and Quaternary foraminifer determinations for sample 09C10 is resolved by the constraint of superposition as observed in the seismic stratigraphy. Rocks cored at station 18 are part of a basinal sequence shown, in part, by the landward portions of the sparker profiles in Figures 3A-C. The stratigraphic position of station 18 is above strata elsewhere in the basin that are established as Quaternary by concordant microfossil ages. In the absence of evidence of major faulting in the sampled part of the basin, the superpositional evidence indicates a Quaternary age for rocks at station 18. The Pliocene diatoms from this station are attributed to reworking from older terranes, and the Quaternary age is accepted.

At station 23, the consistent discordance between the late Miocene or Pliocene diatom ages and the Quaternary foraminiferal ages is due in part to very low taxonomic and numerical representation of microfossils in assemblages from this station. However, the consistent absence of diatoms younger than Pliocene from this station, in combination with diatom and foraminiferal evidence of late Miocene or Pliocene rocks at stations 22 and 24, indicates a late Miocene or Pliocene age for station 23. The conflicting ages assigned to station 24 are resolved to late Miocene or early Pliocene. This age is based on the concordant ages of diatoms (in sample 09C36) and foraminifers (in sample 09C34) from this station.

Station 26 is located seaward and on top of the hanging-wall block of a normal fault. The discordant ages assigned to this station may have resulted from reworking of the early to middle Pliocene diatoms into younger sediment that has accumulated on the surface of the hanging-wall block.

The numerous Quaternary ages assigned to stations 27 to 30 suggest that bedrock was not penetrated. These stations are near the core of the shelf-break anticline. Bedrock at these stations therefore should be older, as inferred from superposition in the sparker record, than lower to middle Pliocene rocks at station 31. If penetration did occur, the middle and late Miocene determination at station 27 (sample 09B03, of questionable age due to poor diatom preservation) may represent rocks _in situ_ that are roughly equivalent in age to upper Miocene rocks sampled near the anticlinal axis along adjacent line 509C.

DISCUSSION

Despite the several inconsistent biostratigraphic determinations noted above, the following general observations may be made. First, along lines 509B and 509C, the oldest samples tend to occur near the seaward ends of the lines. On line 509B the oldest dated foraminiferal and diatom assemblages were found at station 27. On line 509C the oldest foraminiferal assemblage occurred at station 24, and the oldest diatom flora at station 25. These oldest assemblages are most probably middle to late Miocene in age. Those from stations landward of approximately station 30 (on line 509B) and station 23 (on line 509C) are probably Pliocene and Quaternary in age.

Second, along line 509 the oldest diatom flora (early to middle Pliocene) was found at station 9. Except for sample 09001 (station 2), microfossils collected landward and seaward of station 9 are all probably late Pliocene and Quaternary in age. The late Miocene or early Pliocene(?) foraminifers in sample 09001 suggest that rocks of this age crop out on the continental slope. These rocks may represent a deep portion of the sequence sampled on the shelf that has been truncated and exposed on the slope by faulting or submarine erosion (see fig. 3A, below station 2).

The position of station 9 is approximately coincident with the geophysically determined axis of the shelf-break anticline. The westward continuation of this axis passes some distance seaward of the south ends of lines 509B and 509C. Multichannel seismic data (Fisher and von Huene, in press) establish that this anticline is a major feature in the regional structure beneath the Kodiak shelf. These seismic data and the foregoing biostratigraphic results indicate that this anticline plunges northeastward (fig. 5) in the sampled area.

Results of the paleobathymetric analyses of the selected foraminiferal assemblages indicate that major vertical tectonic activity has occurred in the vicinity of Albatross Bank since at least as long ago as the early or middle Pliocene. This activity included an early episode of subsidence of about 2000 m followed by a later episode of uplift of over 3000 m. These estimated amounts of vertical movement are based on the following observations. The oldest sample along line 509 (09016, station 9) is early or middle Pliocene in age, based on diatoms. However this sample yielded no foraminifers for paleobathymetric analysis. Analyses of foraminifers from stations 6 and 14 indicate that rocks from these stations were deposited no deeper than on the upper continental slope (< 500 m). Rocks at station 9 were probably also deposited near this paleodepth. Assuming this initial depth in the early or middle Pliocene (3 to 5 m.y. ago), rocks at station 9 subsequently subsided and were buried by about 2000 m of sediment (fig. 6) until the late Pliocene or Quaternary (probably 1 to 3 m.y. ago). The average rate of subsidence was, therefore, 2000 m over probably not more than 4 nor less than 1 m.y., or 500-2000 m/m.y. During the late Pliocene or Quaternary (probably 1 to 3 m.y. ago), rocks on Albatross Bank, 4 km seaward of station 9 at the core of the shelf-break anticline, were uplifted over 3000 m (Fisher and von Huene, in press). The average rate of uplift of the anticline is, therefore, 1000-3000 m/m.y.

Because the depth distribution of living foraminifers in the Gulf of Alaska is poorly known, the preceding paleobathymetric results are based on analogy of the fossil foraminiferal assemblages from the Kodiak shelf to living assemblages off the California coast, where a depth zonation has been established (Bandy, 1953; Bandy and Arnal, 1957, 1960; Ingle, 1967; Arnal and Vedder, 1976). The application of the depth zonation of living foraminifers off California to our high-latitude, Neogene fossil assemblages, therefore, requires two assumptions: (1) that there has been little or no physiological evolution, with respect to bathymetric tolerances, in the histories of the analogous fossil and Holocene foraminifer species--an assumption basic to all uniformistic approaches to paleoecology, and (2) that the development and fluctuation in the late Tertiary trans-latitudinal, oceanographic temperature gradients did not affect the depth distribution of high-latitude foraminifers independently of foraminifer distribution off the California coast. The validity of the second assumption is presently being investigated at the U. S. Geological Survey through a study of modern foraminifer ecology in a series of Soutar-van Veen grab-samples recently collected in the Gulf of Alaska.

CONCLUSION

The results of micropaleontologic and biostratigraphic analyses of dart-cores collected in 1978 indicate that the shelf-break structure beneath Albatross Bank on the Kodiak shelf is a northeast-plunging anticline with middle to upper Miocene rocks exposed at its axis on the seafloor. Paleobathymetric analyses of foraminifers suggest that most (2000 m) of the 3 km of uplift recognized along Albatross Bank by Fisher and von Huene (in press) has occurred since the middle Pliocene, at an average rate probably of 1000-3000 m/m.y.

Table 1. Biostratigraphic and lithologic data for dart-core samples from the Kodiak shelf, western Gulf of Alaska. (Samples listed in order of station number.)

Abbreviations: "B" = sample barren of fossils.

"N/A" = sample not analyzed for radiolarians.

* = core lodged in dart-barrel.

Epoch subdivisions:

L = late
M = middle
E = early

Complete sample-number sequence is 09001-09030, 09C01-09C42, 09B01-09B35. Unlisted sample numbers were non-recoveries.

Table 1. Biostratigraphic and lithologic data for dart-core samples from the Kodiak shelf, western Gulf of Alaska.

LINE 509 SAMPLES						FOSSIL-AGE DETERMINATIONS			
Station	Sample	Latitude (N)	Longitude (W)	Water Depth (in m)	Lithology	Diatoms (Barron)	Foraminifers (Arnal)	Radiolarians (Kling)	Coccoliths (Bukry)
2	09001	56° 15.96'	152° 43.69'	875	silty claystone	L. Pliocene or E. Quaternary, prob. E. Quat.	L. Miocene or E. ? Pliocene undiff.	E. Miocene to Quaternary	B
2	09002	56° 15.96'	152° 43.69'	925	greenish mud w/erratic pebbles	L. Quaternary	L. Pliocene to Holocene	E. Miocene to Quaternary	Quaternary
3	09003	56° 21.31'	152° 50.77'	94	claystone	B	B	B	B
3	09004	56° 21.27'	152° 50.96'	92	claystone	Miocene to Quaternary	B	B	B
4	09005	56° 21.79'	152° 51.35'	73	silty claystone	B	Quaternary	B	B
5	09006	56° 22.36'	152° 52.61'	58	clay	B	Prob. Quaternary	B	B
5	09008	56° 22.28'	152° 52.45'	54	claystone	B	B	B	B
6	09010	56° 22.38'	152° 52.65'	47	silty claystone w/erratic pebbles	Miocene to Quaternary	Prob. Quaternary	B	B
6	09011	56° 22.30'	152° 52.81'	53	silty clay	B	L. Pliocene to Holocene	B	B
7	09012	56° 22.51'	152° 53.14'	50	claystone w/erratic pebbles	B	Prob. Quaternary	B	B
7	09013	56° 22.51'	152° 53.18'	55	claystone	B	Prob. Quaternary	B	B
8	09014	56° 22.68'	152° 53.57'	47	claystone	B	Quaternary	B	B
8	09015	56° 22.74'	152° 53.69'	45	bioturbated claystone	B	Quaternary	E. Miocene to Quaternary	B
9	09016	56° 22.99'	152° 54.54'	46	clayey limestone	E. or M. Pliocene	B	E. Miocene to Quaternary	B
10	09018	56° 23.02'	152° 55.02'	58	silty claystone	B	Quaternary	N/A	B
11	09019	56° 23.12'	152° 55.30'	46	silty clay bioturbated	B	B	N/A	B
12	09021	56° 23.04'	152° 55.63'	46	clay, bioturbated	B	B	N/A	B
13	09022	56° 23.92'	152° 54.54'	49	claystone	B	Prob. Quaternary	N/A	B
14	09024	56° 25.42'	152° 56.76'	53	claystone w/erratic pebbles	Prob. L. Quaternary	Prob. L. Pliocene to Holocene	N/A	B
14	09025	56° 25.22'	152° 56.90'	52	claystone*	Cenozoic	Prob. Quaternary	N/A	B

Table 1 (cont.)

						FOSSIL-AGE DETRMINATIONS			
LINE 509B SAMPLES									
Station	Sample	Latitude (N)	Longitude (W)	Water Depth (in m)	Lithology	Diatoms (Barron)	Foraminifers (Arnal)	Radiolarians (Kling)	Coccoliths (Bukry)
27	09B01	56° 19.73'	153° 08.18'	126	sand	L. Quaternary	L. Plio. to Holocene Poss. L. Pliocene or E. Pleistocene	N/A	Quaternary
27	09B03	56° 19.60'	153° 07.76'	130	silty claystone*	M. Miocene? or E.L. Miocene?	Prob. Holocene	E. Miocene to Quaternary	Tertiary or Quaternary
29	09B06	56° 20.33'	153° 07.82'	71	silty claystone	B	Prob. Holocene	B	B
30	09B08	56° 20.67'	153° 08.40'	53	silty, fine-grained sandstone	B	Prob. Holcene	B	B
30	09B09	56° 20.54'	153° 08.38'	56	silty, very fine-grained sand	B	Prob. Holocene	B	B
31	09B10	56° 21.09'	153° 08.69'	46	silty clay	L.L. Miocene or Pliocene	B	B	B
31	09B12	56° 20.94'	153° 08.76'	44	silty clay bioturbated	E. or M. Pliocene	B	E. Miocene to Quaternary	B
32	09B14	56° 22.14'	153° 08.77'	35	silty claystone	B	B	B	B
32	09B15	56° 22.11'	153° 08.72'	35	silty claystone	B	B	B	B
33	09B17	56° 22.73'	153o 09.01'	26	clayey siltstone w/erratic granules*	E. Quaternary	Quaternary	N/A	B
33	09B18	56° 22.69'	153° 09.01'	26	silty claystone w/erratic pebbles	L. Pliocene or Quat. Pre-latest Quaternary	Quat. prob. Holocene	N/A	B
34	09B20	56° 23.38'	153° 09.51'	29	sandy claystone*	B	Quat. prob. Holocene	N/A	B
34	0921	56° 23.31'	153° 09.68'	29	silty, very fine-grained sand	Cenozoic	B	N/A	B
35	09B24	56° 23.87'	153° 09.68'	29	pebbly claystone	B	B	N/A	B
36	09B25	56° 24.43'	153° 09.55'	29	silty claystone w/erratic pebbles*	B	Quaternary	N/A	B
37	09B26	56° 25.07'	153° 09.67'	28	silty claystone w/erratic pebbles	Latest Miocene to Quaterneary, pre-latest Quaternary	Quaternary	N/A	B
38	09B29	56° 25.27'	153° 09.83'	28	silty claystone w/erratic pebbles*	L. Pliocene or Quaternary	Quaternary	N/A	B
39	09B33	56° 25.66'	153° 09.56'	26	sandy claystone w/erratic granules*	L. Miocene to Quaternary	Quat., prob. Holocene	N/A	B

Table 1 (cont.)

LINE 509C SAMPLES						FOSSIL-AGE DETERMINATIONS			
Station	Sample	Latitude (N)	Longitude (W)	Water Depth (in m)	Lithology	Diatoms (Barron)	Foraminifers (Arnal)	Radiolarians (Kling)	Coccoliths (Bukry)
18	09C10	56° 23.75'	153° 18.91'	39	silty claystone, bioturbated	M. Pliocene	Quaternary	N/A	B
19	09C13	56° 22.75'	153° 16.91'	37	clay w/erratic pebbles	B	Quat., prob. Holocene	N/A	B
21	09C25	56° 20.45'	153° 15.23'	43	silty claystone	B	Quaternary	B	B
21	09C26	56° 20.27'	153 15.28'	43	claystone*	B	Quat., prob. Holocene	B	B
22	09C27	56° 19.90'	153° 14.91'	54	silty claystone*	L.L. Miocene or Pliocene	B	E. Miocene to Quaternary	B
22	09C28	56° 19.92'	153° 14.84'	54	claystone, bioturbated	L.L. Miocene or Pliocene	B	E. Miocene to Quaternary	B
23	09C29	56° 19.55'	153° 14.38'	55	silty claystone*	L.L. Miocene or Pliocene	L. Pliocene to Holocene	E. Miocene to Quaternary	B
23	09C30	56° 19.61'	153° 14.30	56	silty claystone*	L.L. Miocene or pliocene w/re-worked M. Miocene	Quaternary	E. Miocene to Quaternary	B
23	09C31	56° 19.65'	153° 14.14'	57	silty claystone*	L.L. Miocene or Pliocene	B	E. Miocene to Quaternary	B
23	09C32	56° 19.65'	153° 14.11'	58	silty claystone w/erratic granules, bioturbated	L.L. Miocene or Pliocene	Quaternary	E. Miocene to Quaternary	B
23	09C33	56° 19.64'	153° 14.25'	56	silty claystone*	B	Quaternary	B	B
24	09C34	56° 19.29'	153° 13.87'	63	silty claystone*	Post-Eocene	L. Miocene or E.? Pliocene, undiff.	E. Miocene to Quaternary	B
24	09C35	56° 19.31'	153° 13.90'	65	silty claystone*	B	Quaternary	B	B
24	09C36	56° 19.30'	153° 13.72'	67	claystone	L.L. Miocene or Pliocene	Quaternary	E. Miocene to Quaternary	B
25	09C37	56° 18.80'	153° 13.47'	86	silty claystone*	Miocene to Quat.	B	B	B
25	09C38	56° 18.78'	153° 13.33'	91	claystone*	L.M. Miocene? or E.L. Miocene?	B	E. Miocene to Quaternary	Tertiary or Quaternary
26	09C40	56° 18.50'	153° 12.96'	140	claystone	E. or M. Pliocene	Prob. Quaternary	E. Miocene to Quaternary	B
26	09C41	56° 18.53'	153° 12.81'	152	clayey sand	Latest Pliocene or Quat., prob. Lt. Quaternary	L. Pliocene to Holocene, most likely L. Plio. or E. Pleist.	E. Miocene to Quaternary	B

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F I G U R E S

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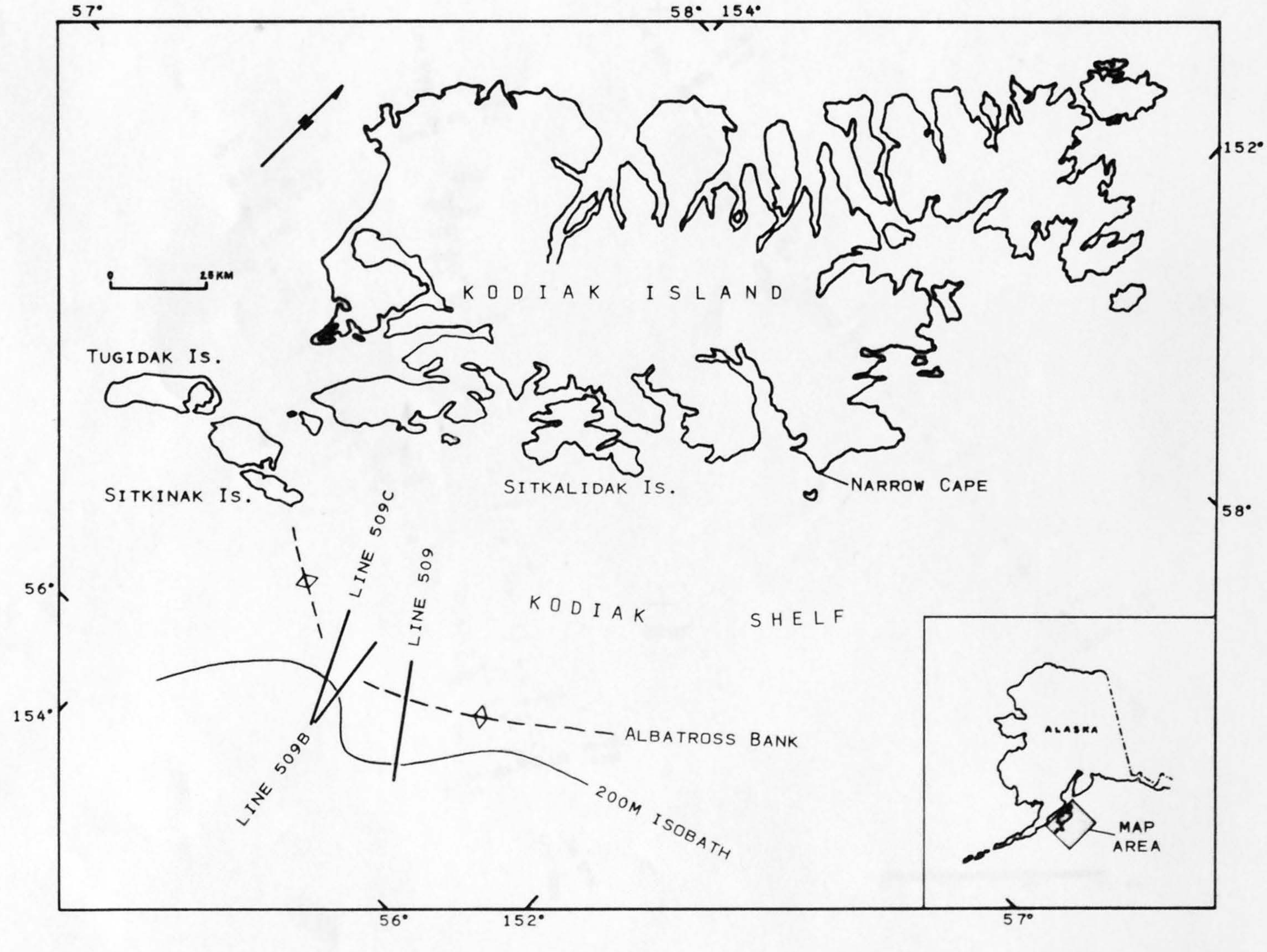

Figure 1. Location of sparker lines 509, 509B and 509C on the Kodiak shelf, western Gulf of Alaska.

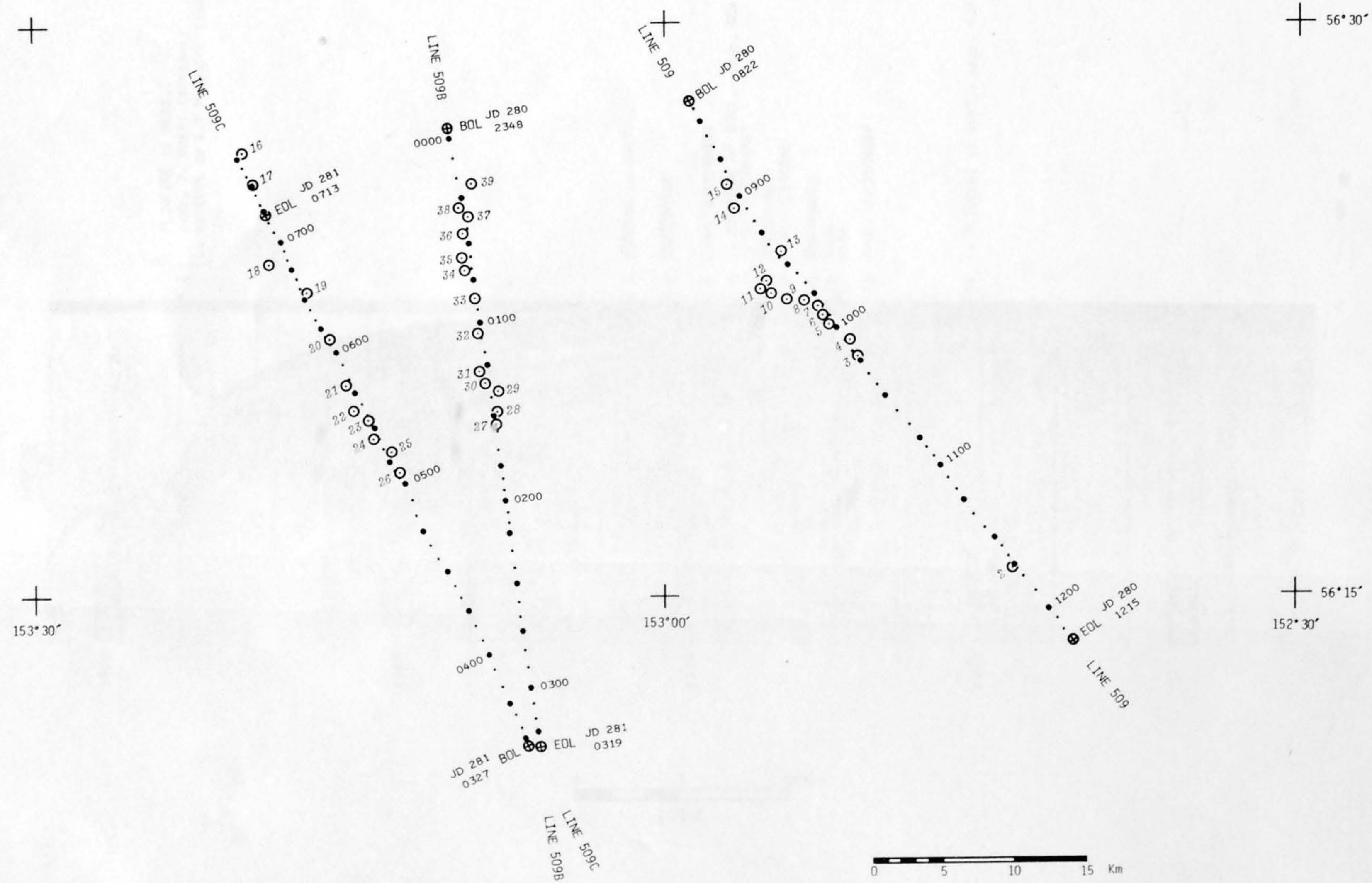

Figure 2. Sparker lines 509, 509B and 509C showing positions of dart-coring stations relative to time-marks on corresponding sparker profiles in Figures 3A, 3B and 3C.

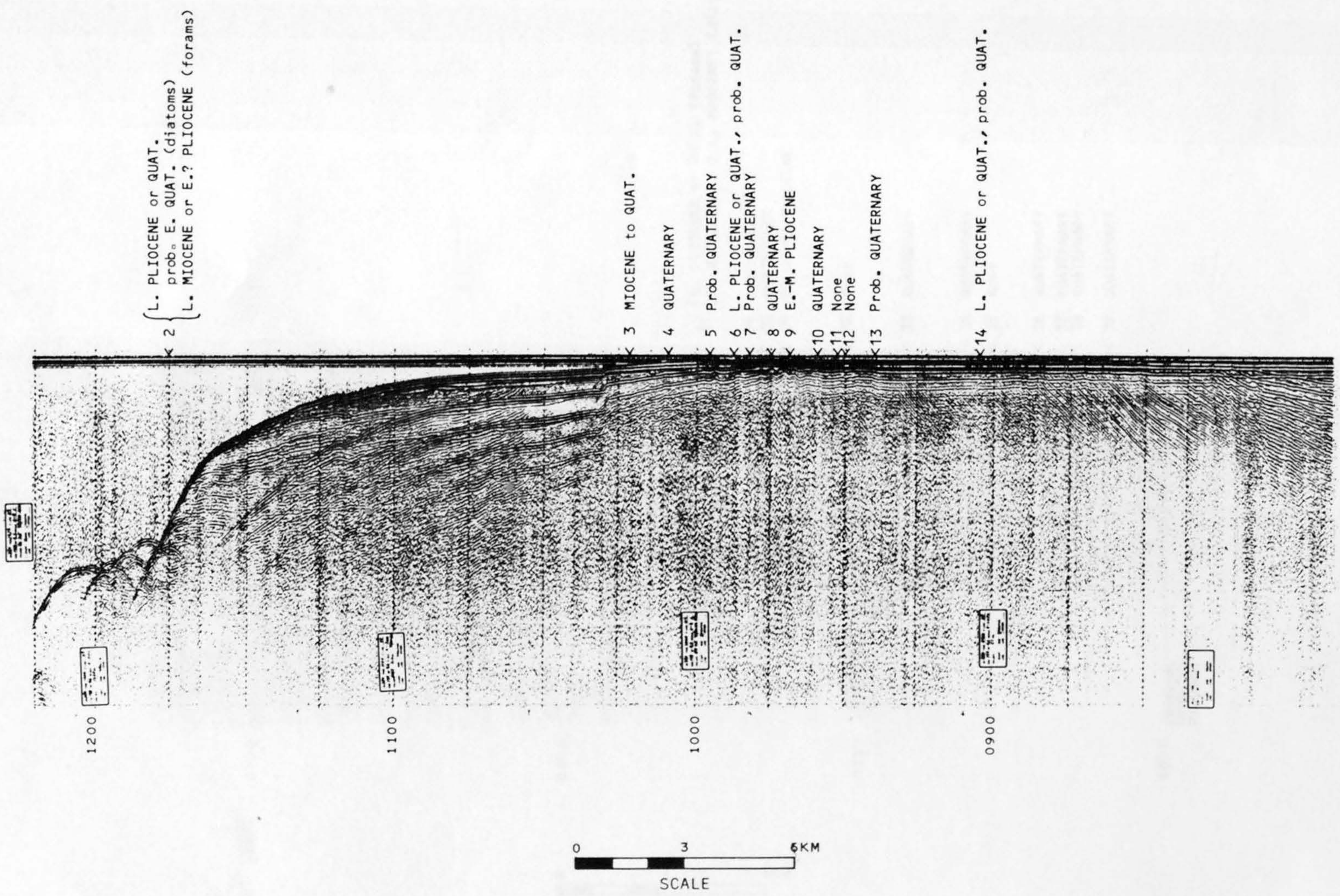

Figure 3A. Composite biostratigraphic ages of microfossil assemblages collected at stations 2 through 14 along sparker record of line 509.

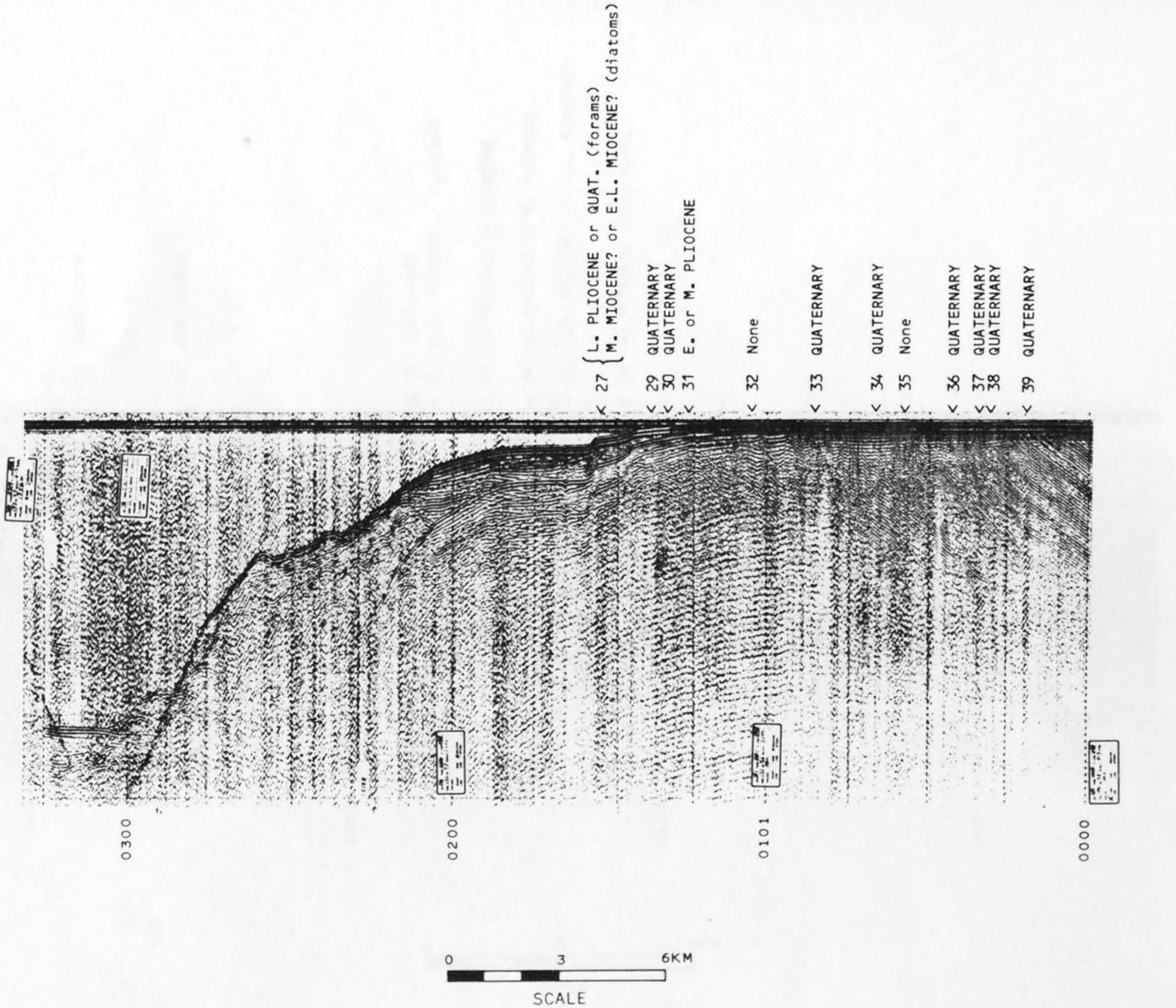

Figure 3B. Composite biostratigraphic ages of microfossil assemblage collected at stations 27 through 39 along sparker record of line 509B.

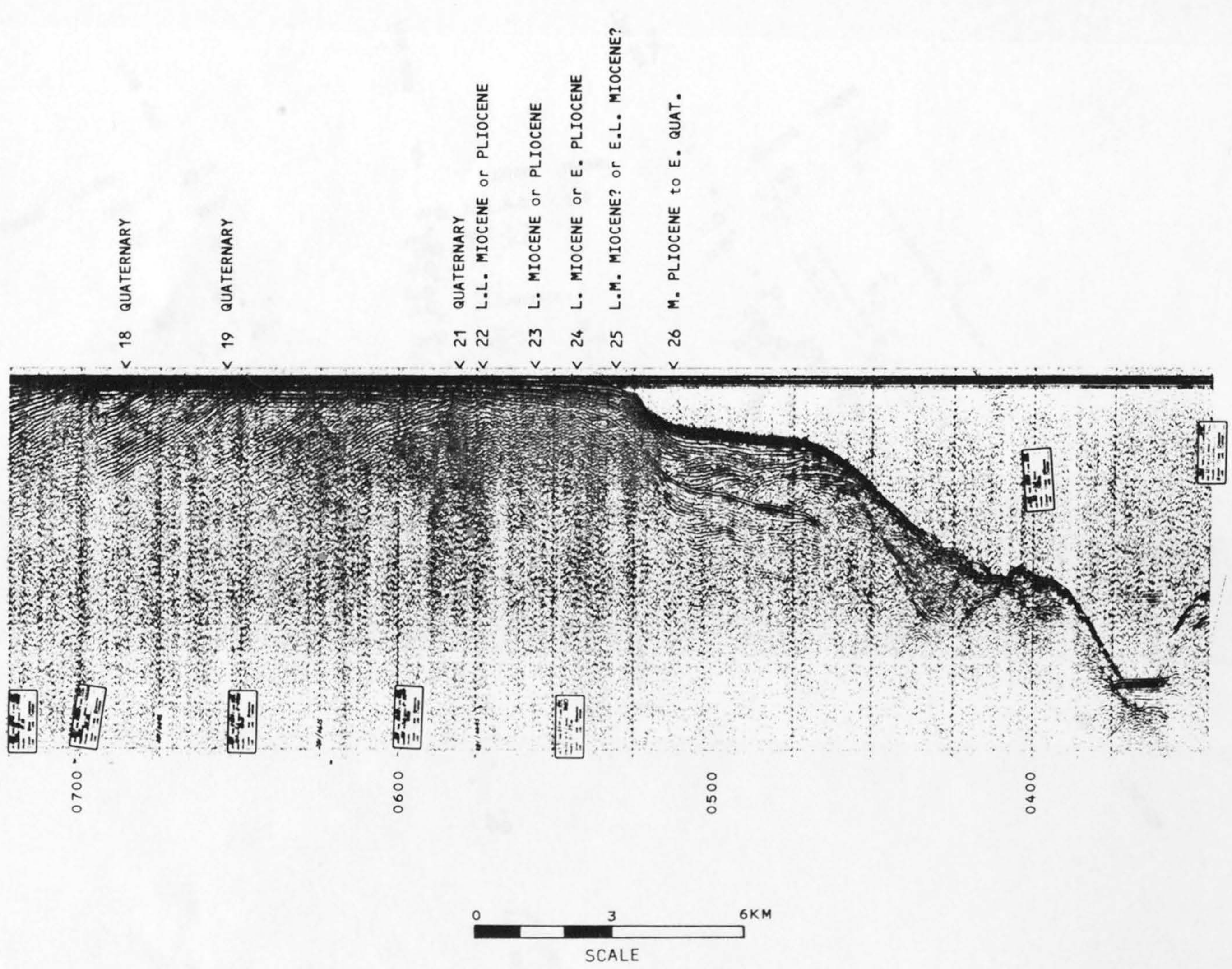

Figure 3C. Composite biostratigraphic ages of microfossil assemblages collected at stations 18 through 26 along sparker record of line 509C.

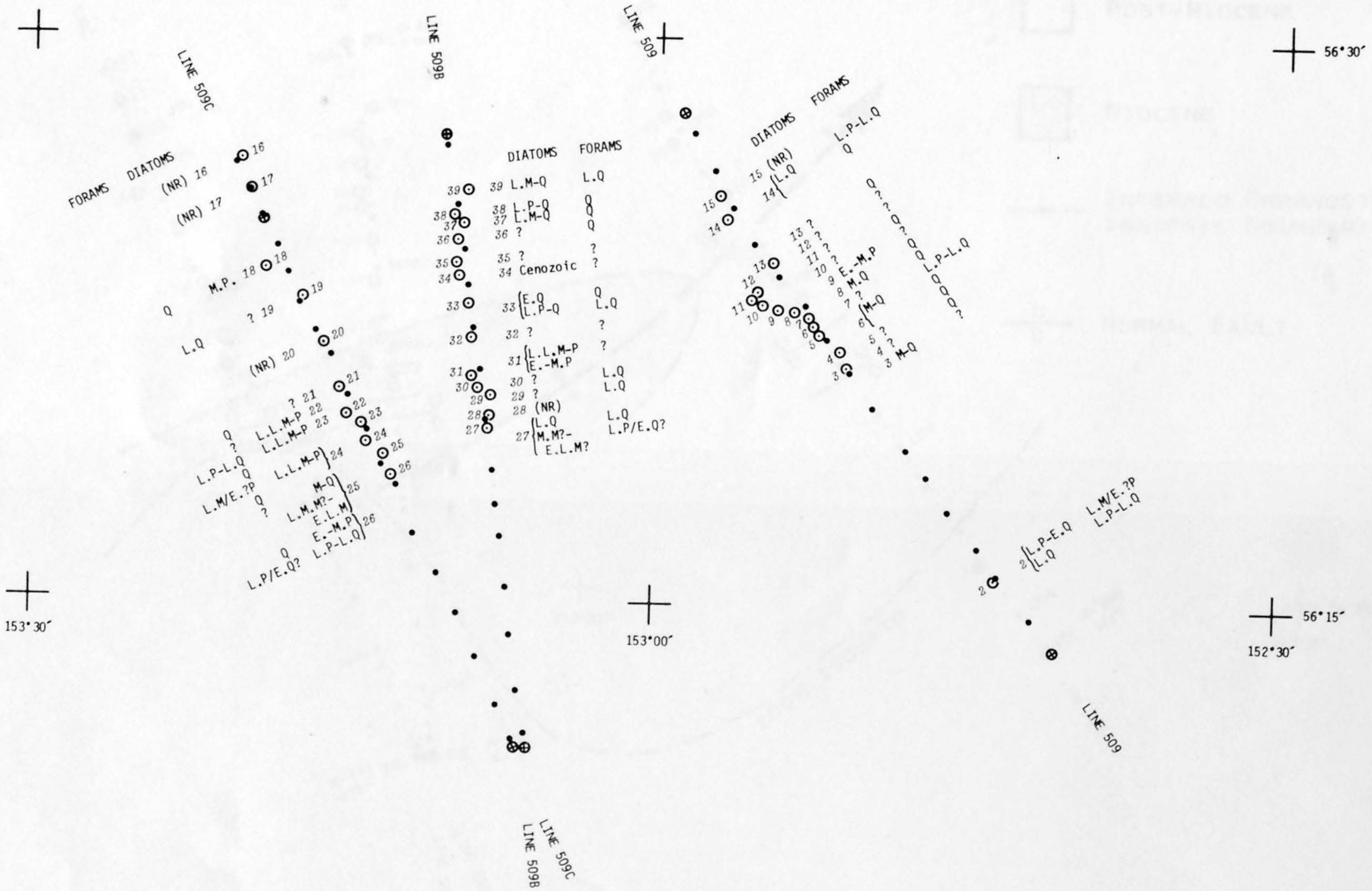

Figure 4. Areal distribution of diatom and foraminifer ages determined for dart-cores collected along sparker lines 509, 509B and 509C.

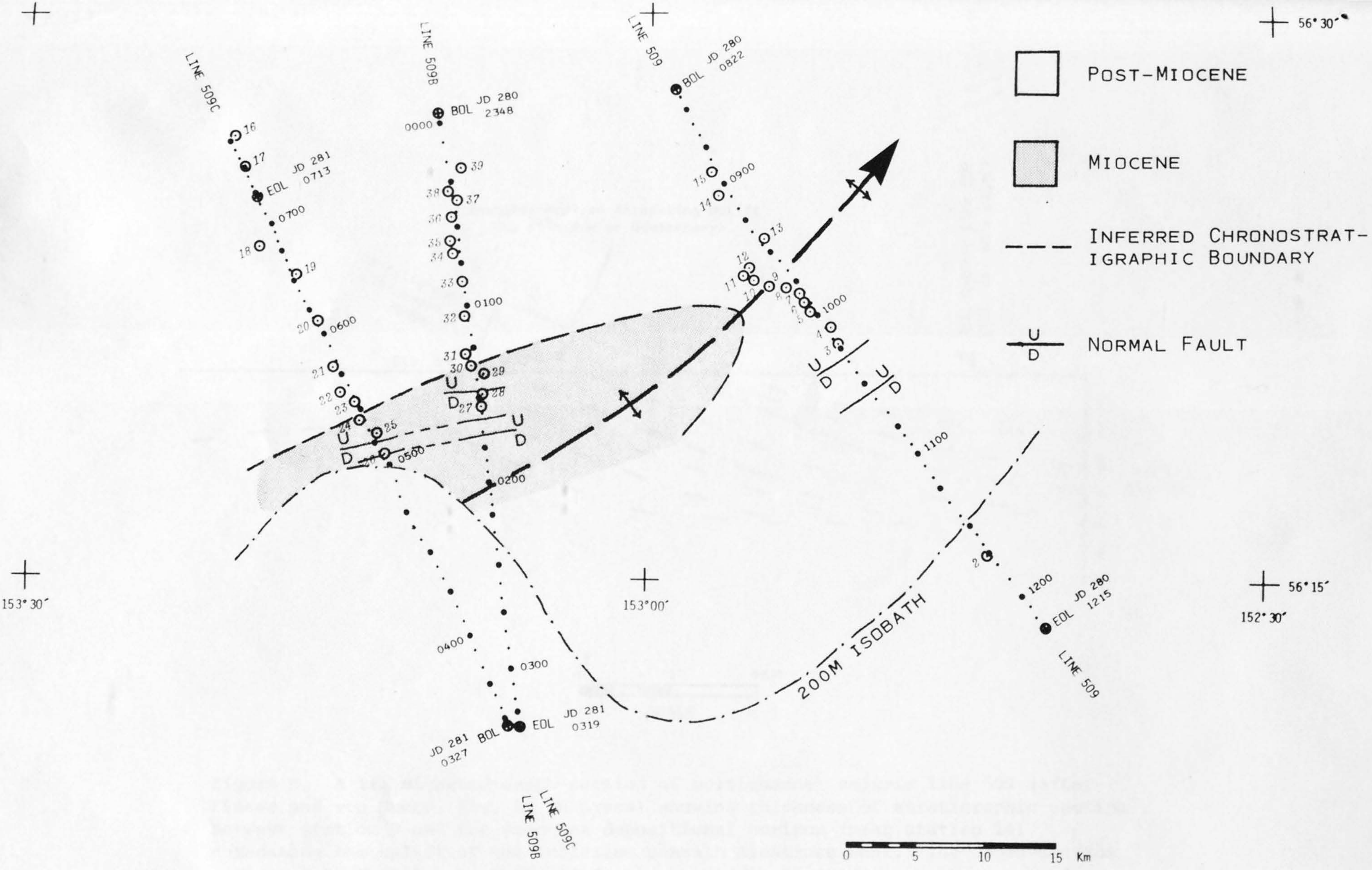

Figure 5. Geology of sampled portion of the Kodiak shelf, as inferred from microfossil biostratigraphy and seismic stratigraphy.

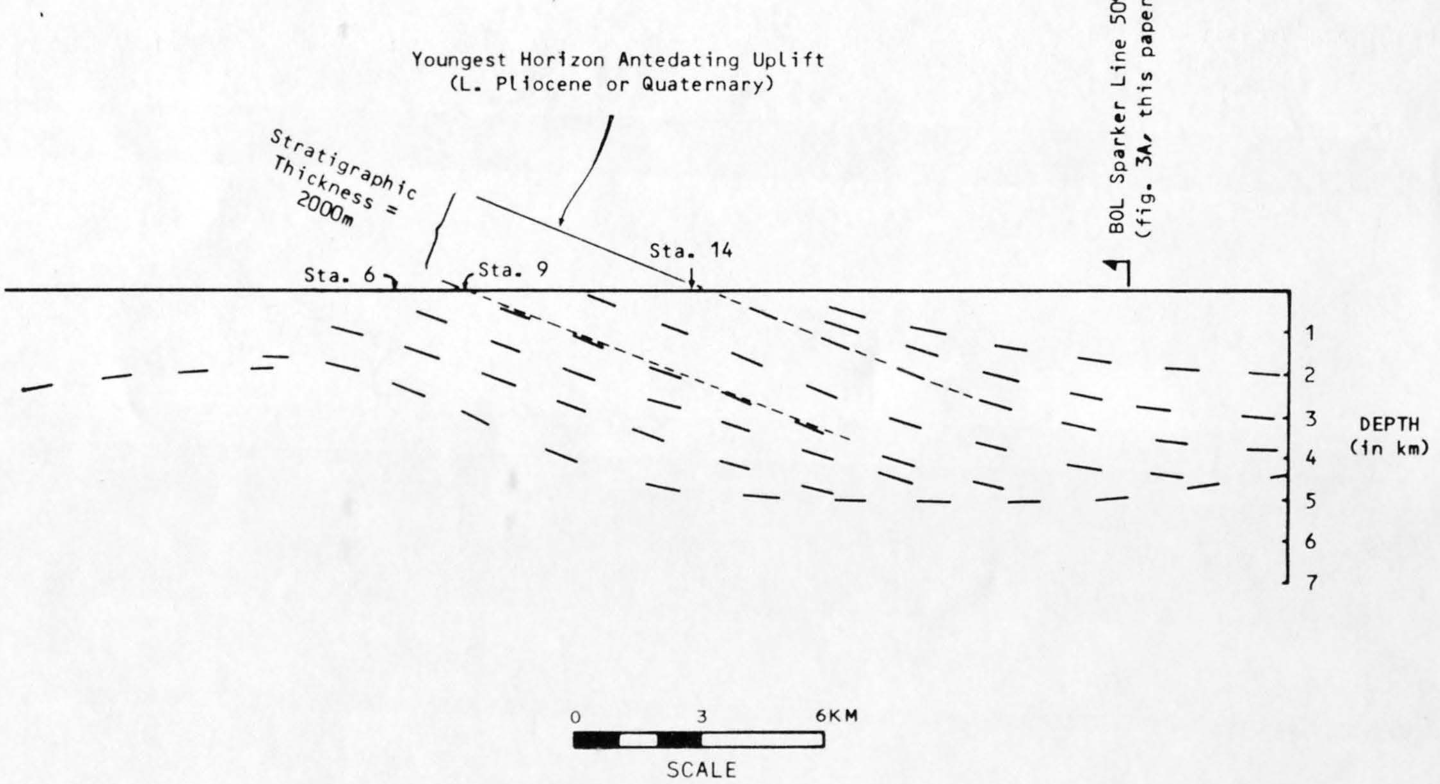

Figure 6. A 1:1 migrated depth-section of multichannel seismic line 509 (after Fisher and von Huene, fig. 5, in press) showing thickness of stratigraphic section between station 9 and the youngest depositional horizon (near station 14) antedating the uplift of the anticline beneath Albatross Bank. The cross-section indicates that rocks at station 9 (early or middle Pliocene in age) were buried to a depth of about 2.0 km before they were uplifted at least 3 km (estimated by Fisher and von Huene, in press) during the development of the anticline.