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TWO NEWLY DISCOVERED SUBMARINE CANYONS ON ALASKAN CONTINENTAL MARGIN OF BERING SEA

by

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INTRODUCTION

The search for new energy resources by the U. S. Geological Survey has focused increasing attention on the Alaskan continental margin in the Bering Sea, sometimes called the Beringian margin. Although there has been emphasis on the Aleutian Islands and the Bering Strait, partly due to their strategic locations, there has been limited oceanographic and geologic coverage of the Beringian margin until the last decade. The bathymetric and geophysical track line coverage across the northern part of the margin was, until 1980, very sparse. However, regional studies by Marlow and others (1976; in press) and Scholl and others (1976), resulted in the discovery of large basins filled with thick sequences of sedimentary material of Cenozoic and perhaps Mesozoic age. These thick sedimentary sequences have become the targets of several petroleum lease sales planned for the next few years. In preparation for the scheduled sales, we collected the first publicly available, detailed, bathymetric and high-resolution geophysical data over the northern Beringian margin in the summer of 1980 (Carlson and Karl, 1981). From these data, we developed a better understanding of the margin, and in particular the three large submarine canyons, Navarinsky, Pervenets, and Zhemchug Canyons (Plate 1 and Carlson and others, 1981). The data collected in 1980 also suggested the presence of another moderate-size canyon between Pervenets and Zhemchug Canyons. A second cruise, conducted in 1981 (Carlson and Karl, 1982) provided additional data on the northern Beringean margin that showed two canyon systems to be present between Pervenets and Zhemchug Canyons (Fischer and others, 1982).

The purpose of this paper is to describe, delineate and compare these newly-discovered submarine canyons. Included in the report are a detailed bathymetric map of the two canyon systems and sketches of seismic profiles showing the canyons and the subbottom units into which they were carved. We also speculate briefly on the mode and time of formation of these canyons.

Data Collection

Data used to develop "smooth sheets" are taken primarily from 3.5 kHz transducer records complimented by simultaneously collected airgun seismic profiles collected in 1980 and 1981 (Carlson and Karl, 1981, 1982). These data are supplemented by depth data from several other cruises (Marlow and Cooper, 1979, 1980; Scholl, Buffington, and Marlow, 1976; Scholl and Marlow, 1970). Navigational control was obtained from Loran C updated with satellite positions. Water depths for the Navarin study area were digitized assuming 1500 km/sec for speed of sound in water. Records were corrected for the hull-depth of transponder systems but no other corrections were made of the depth data.

MORPHOLOGY OF THE BERINGIAN CONTINENTAL MARGIN

Three physiographic provinces make up the Beringian continental margin. These are the flat, wide, continental shelf, the steep, rugged continental slope, and the gently sloping continental rise that extends from the base of the slope to the 3600-m isobath. Large submarine canyons deeply dissect the outer shelf and slope. Coalescing fans at the mouths of these canyons form part of the wedge of sediment of the continental rise. The continental shelf, one of the widest and flattest in the world, is about 450 km wide and has a gradient of 0.02° seaward of the Yukon River delta. By comparison, Shepard (1963) reported a world-wide average continental-shelf gradient of 0.12°. The continental slope begins at about the 150-m isobath and extends to a depth of about 2800 m. The width of the continental slope is about 50 km. The gradients of the Navarin slope range from 3° to 8° and even steeper gradients exist locally (Fischer and others, 1982). These slopes compare fairly well with the world-wide average gradient for continental slopes of about 4.3° (Shepard, 1963). The continental rise begins at the base of the slope at a depth of about 2800 m and extends to the 3600-m isobath that appears to mark the beginning of the abyssal plain. The average width of the rise is about 75 km and the gradients across the rise range from 0.5° to 1.8° (Fischer and others, 1982). Deep-sea channels cross the rise in the area of the canyon mouths and apparently are connected to the submarine canyons.

Descriptions of Newly Discovered Canyons

The Beringian continental slope between the Aleutian Island chain to the southeast and Cape Navarin, U.S.S.R. to the northwest, is dissected by seven large submarine canyon systems. They are from north to south Navarinsky, Pervenets, St. Matthew, Middle, Zhemchug, Pribilof and Bering Canyons (Plate 1). Five of these canyons have been known for at least 17 yrs (Kotenev, 1965). The names St. Matthew and Middle Canyons are proposed for the two canyons that have just been discovered.

The name St. Matthew Canyon is taken from St. Matthew Island located about 300 km northeast of the canyon head. Middle Canyon is the name proposed for the other canyon system for two reasons: (1) it is the middle-most canyon of the seven large slope canyons and (2) it is located at a midway point on the continental slope between the Aleutian Islands to the southeast and the U.S.S.R., to the northwest.

A. St. Matthew Canyon system

This complex dendritic canyon system, consisting of two main branches, heads near the shelf break in about 140 m of water (Plate 1). The west thalweg trends southeast obliquely across the continental slope for about 65 km where it bends to the south and continues another 12 km where the canyon debouches onto a deep-sea fan at a depth of 3200 m. St. Matthew Canyon west has an average thalweg gradient of 2.5° and reaches a gradient of 3.3° over the steepest part of the canyon (Fig. 1; Table 1). Below 3200 m, as the canyon morphology changes to that of a deep-sea fan channel, the gradient changes to 0.4° and the channel extends at least another 55 km across the fan. Selected cross-canyon profiles show a V-shaped canyon that has maximum relief of 2200 m on the northeast wall and 1250 m on the southwest wall

(Fig. 2a). The walls of the canyon have average declivities of 8.1°, ranging from as steep as 16° (profile G-H, northeast wall) to as gentle as 2° (profile O-P, east wall; Table 2a). The western branch of St. Matthew Canyon has at least nine tributaries (Fig. 3) that average 23 km in length and 5.2° in gradient, ranging in length from 6 to 42 km and in gradient from 8.5° to 2.9° (Table 3a).

The eastern branch of the St. Matthew Canyon system begins at a water depth of about 150 m and trends south-southwest for a distance of about 34 km where the canyon discharges onto a deep-sea fan at 3000 m (Plate 1). The average axial gradient of the eastern branch is about 5° and reaches a gradient of 7.6° over the steepest part of the canyon (Fig. 1; Table 1). The deep-sea channel that extends from the east branch canyon about 64 km across the fan to the 3600 m isobath, has a gradient of 0.4°. The eastern and western branches of the St. Matthew Canyon system merge on the fan at a depth of about 3600 m.

Selected cross-canyon profiles of the eastern branch of St. Matthew Canyon are much less V-shaped than those of the west branch and show maximum wall relief of 1100 m (Fig. 2b; Table 2b). The walls have average declivities of 8.2°, ranging from as steep as 16.7° (profile C-D, west wall) to as gentle as 1.1° (profile I-J, west wall). The east branch of St. Matthew Canyon has three good-sized tributaries that range in length from 26.5 to 30 km and in axial gradient from 2.3 to 4.8° (Table 3b).

B. Middle Canyon system

This complex canyon system consisting of two main branches and numerous tributaries (Plate 1), has a dendritic pattern similar to the St. Matthew system, but has approximately twice the areal extent. (St. Matthew = 3290 km^2 and Middle Canyon = 6620 km^2). The west branch of Middle Canyon, has cut a shallow valley about 20 km into the shelf. The west branch heads in 130 m of water and trends southerly across the slope about 40 km where it debouches onto a deep-sea fan at a water depth of 3000 m. The average thalweg gradient of the west branch of Middle Canyon is 4.1° and this thalweg attains a gradient of 6.4° over the steepest part of the canyon (Fig. 1; Table 1). The contiguous deep-sea fan channel extends at least 67 km across the fan at a gradient of 0.5°. Selected cross-canyon profiles are V-shaped on the slope and open up dramatically to broad channels (12-20 km wide) on the deep-sea fan (Fig. 4a). The canyon has a maximum relief of 1100 m on the west wall and 650 m on the east wall (Table 4a). The walls of the west branch canyon attain an apparent maximum steepness of 20.6° (east wall, profile C-D, Fig. 4a; Table 4a) and as low a gradient as 1.6° on the fan channel east wall (profile K-L). The walls have an average slope of 9.3°. The west branch of Middle Canyon has seven tributaries that join the canyon above a depth of 3200 m and four that merge with the fan channel between 3200 and 3600 m (Fig. 3). The longest of these eleven valleys measures 79 km (32 km above 3000 m) and the shortest is about 6 km in length (Table 5a). The gradients range from 11.3° for a slope tributary to 0.8° for a fan valley.

The east branch of the Middle Canyon system is about the same size as the west branch and also has a complex dendritic "drainage" (Plate 1). The east branch begins at a water depth of 140 m and winds across the slope in a south-southeasterly direction for 60 km where it debouches onto a deep-sea fan at a depth of 3200 m. The east branch of Middle Canyon has an average axial gradient of 2.9° and reaches a gradient of at least 4.3° in the steepest part of the canyon (Fig. 1; Table 1). At 3200 m the axial gradient becomes greatly reduced resulting in an average gradient of 0.4° for the 60 km of channel to a depth of 3600 m. The east branch merges with the west branch of Middle Canyon at a depth of about 3600 m.

Transverse profiles of the east branch of Middle Canyon are less V-shaped than those of the west branch, coming closer in profile to the east branch of the St. Matthew Canyon system (compare Figs. 2b and 4b). The walls of the east branch of Middle Canyon show maximum relief of 850 m and range in steepness from 19.9° (profile C-D, east wall) to 1.2° (profile I-J, southeast wall of fan channel). The walls have an average slope of 6.5° (Table 4b). The east branch of Middle Canyon has six tributaries that join the main thalweg at about 3000 m and nine that join the east branch deep-sea channel between 3200 and 3600 m (Fig. 3). These tributaries have an average length of about 30 km and an average gradient of 3.7° (Table 5b). The six canyon tributaries range in length from 7 to 35 km and in gradient from 4.1° to 6.1°. The nine tributaries, that join the east branch of Middle Canyon below 3200 m, range in length from 12.5 to 84 km and in gradient from 1.2° to 5.5° (Table 5b). The gradients of these tributary valleys across the upper part of the deep-sea fan vary from 0.3° to 1.0°.

GEOPHYSICAL PROFILES AND SEAFLOOR SAMPLES

Several seismic reflection profiles (sound source: 2 - 40 in^3 airguns) were shot across the newly-discovered canyon systems (Carlson and Karl, 1981, 82). Rocks were dredged from the walls of the two canyons (Jones and others, 1981; Marlow, oral commun., 1982) and a total of 17 gravity cores (8.0 cm diameter) were collected from the two canyons and adjacent fans, six from the St. Matthew Canyon system and eleven from the Middle Canyon system (Karl and Carlson, 1982). Locations of these airgun profiles, dredges and gravity cores are shown in figure 5.

Seismic-reflection profiles across both the St. Matthew and Middle Canyon systems show V-shaped gorges cut in layered sedimentary rocks. The reflectors that characterize the layered sedimentary sequences are sharply truncated at the canyon walls (Fig. 6). Hummocky, broken reflectors are present on some of the canyon walls and in some parts of the floor (Fig. 7).

A diapir-like feature has been found near the shelf-break adjacent to the southwest wall of St. Matthew Canyon (Fig. 8). A magnetometer record collected across this feature shows a 100 mgal anomally suggesting that the feature could be related to some type of igneous intrusive. The affect of this diapir-like mass on the overlying 200 + meters of sedimentary material is a slight amount of doming of the strata. This diapiric feature does not appear to have had a noticeable affect on the west branch of St. Matthew Canyon.

Several of the airgun profiles that were shot across the east and west branchs of St. Matthew and the west branch of Middle Canyon (Fig. 9) show walls devoid of reflectors. In Middle Canyon, the opposite wall shows well-developed reflectors truncated by the canyon (Fig. 9). A dredge haul from the reflectorless wall of the east branch of St. Matthew Canyon (Fig. 10) yielded several pieces of basalt, one of which was dated by K-Ar methods to be at least as old as Eocene (Jones and others, 1981). A recent cruise of the R/V S.P. Lee (L-9-82) produced a dredge haul from the northeastern wall of the west branch of St. Matthew Canyon that yielded several igneous rocks ranging in type from basalt to dacite (M. Marlow, oral commun., 1982). Other basalts and some tuffs were dredged from other areas on the Beringian margin (Jones and others, 1981).

Burrowed, moderately indurated mudstones dredged from the wall of the west branch of Middle Canyon, that contains well-bedded reflectors, were dated as Eocene using silicoflagellates and foraminifers (Jones and others, 1981). Other sedimentary rocks, principally burrowed mudstones and a few sandstones, dredged from the Beringian margin have ranged in age from Jurassic to Quaternary (Jones and others, 1981).

Gravity cores collected on the walls of the two canyon systems contain sediment that is primarily clayey silt and ranges in age from Pliocene to Holocene (Baldauf, 1981). This sediment is in many places draped over the older Tertiary mudstones.

Air-gun profiles across the fan channels show broad (10-15 km wide), flat valleys at the present seafloor underlain by buried channels that contain as much as 400 m of sedimentary fill (Fig. 11). Some of the deep-sea fan channel walls contain flat-lying reflectors and in other places the walls are characterized by jumbled and broken reflectors and hummocky morphology. Gravity cores (3-5 m length) collected from the floor of St. Matthew and other Navarin margin canyons and channels contain occasional thin sand or silt layers interlayered with the diatom-rich, clayey silt that pervades the Navarin margin (Baldauf, 1981). Some of these coarse layers are graded and many contain benthic foraminifers that are typically thought to be diagnostic of much shallower water (Quinterno, 1981; Carlson and others, 1982). Some of the canyon cores also contain sections of pebbly, sandy, mud and disrupted, contorted sediment that is primarily Quaternary in age (Bauldauf, 1981).

DISCUSSION

Similarities in the two canyon systems

St. Matthew and Middle Canyon systems, although smaller than the five large canyons of the Beringian margin, are comparable in size to most of the submarine canyons that cut into the continental margin of the east coast of the United States, and are considerably larger than the canyons off southern California (Table 6).

The large Beringian margin canyons are cut back further into the shelf than are the St. Matthew and Middle Canyons and as a result have considerably lower axial gradients (Table 6). The very steep gradient of the east branch of St. Matthew Canyon, 5.1° (Table 1), is steeper than most of the submarine canyons reported by Shepard and Dill (1966) and even steeper than the world wide average gradient of continental slopes (4.3°, Shepard, 1963). The east branch is cut into a slope that has an average gradient of about 6°. The west branch of Middle Canyon (thalweg gradient 4.1°) is also steeper than most of the world's submarine canyons. There are other similarities between St. Matthew and Middle Canyons in addition to their size and steepness. The west branch of each canyon makes an oblique traverse across the slope and the west branch of each is more V-shaped than the east branch. The two canyon systems apparently contribute to the build-up of one deep-sea fan; the fan channels appear to merge on the fan beyond the 3600 m isobath (Plate 1).

Both canyons are cut into Tertiary strata that ranges in age from Eocene to Pliocene. The principal rock type is a burrowed, moderately indurated mudstone. In many places throughout the Navarin province, this Tertiary mudstone is covered, probably disconformably, by several tens of meters of Pleistocene-Holocene unconsolidated sediment.

Sediment from the floor of both St. Matthew and Middle Canyon-fan-channel systems contains fine sand and silt layers interbedded with the normal diatom-rich mud. Many of these coarse layers are graded and many contain benthic foraminifers that are more typical of shallow water environments, suggesting emplacement by turbidity currents. The young ages of the sediment suggest that some turbidity current activity occurs from time to time even today. Several of the gravity cores also contain pebbly, sandy mud layers and some contain highly contorted, disrupted layers that indicate this material has slumped or slid to its present locality. The submarine sliding that is indicated by these coarse and contorted sediments very likely generates the turbidity currents. Both sliding and turbidity current activity can also be inferred from the seismic-reflection profiles we have obtained from these canyon-fan systems.

Differences between the two canyon systems

There are also several differences between the two canyons. Middle Canyon has the larger "drainage" area, has more tributaries, and has longer fan channels, whereas St. Matthew Canyon has the longest and shortest principal canyons.

Stratigraphically, the biggest difference between the canyons is the presence of an outcrop of Eocene basalt that forms part of the east wall of the east branch of St. Matthew Canyon. Basalt also has been dredged from the west branch of St. Matthew Canyon. In comparison, only sedimentary rocks have been dredged from the walls of Middle Canyon; however, additional dredging may show that the reflectorless wall of Middle Canyon (Fig. 9) also contains basalt outcrops.

Genesis of the canyon systems

We subscribe to the hypothesis of Scholl and others (1970), that the large canyons of the Beringian margin were cut when lowered sea level exposed the Bering shelf to a depth of about 150 m and allowed large rivers such as the Yukon and Anadyr to carry large amounts of sediment to the shelf edge. The most likely canyon-cutting agents were slumps and resulting turbidity currents supplemented by bioturbation of canyon walls and by erosional effects of canyon-focused waves and currents (Carlson and others, 1982).

We have deduced from seismic-reflection profiles and sediment-samples that similar processes appear to have been responsible for the carving of the St. Matthew and Middle Canyon systems. At question, however, is the reason for the much larger size of Navarinsky, Pervenets, and Zhemchug Canyons compared to St. Matthew and Middle Canyons. Perhaps the position of the canyons with respect to the major rivers (Anadyr and Yukon) that meandered across the flat Bering Shelf during Pleistocene and earlier low-stands of sea level was a key factor. If we look at a map of the Bering shelf (Plate 1 inset), we see that St. Matthew Island lies directly in line between the Yukon Delta and the heads of the St. Matthew and Middle Canyon systems. According to Patton and others (1976), St. Matthew Island is made up of some 500 m of subaerial volcanic rocks intruded by an early Tertiary age granodiorite. They suggest that the island is a southeastward extension of the Cretaceous-Early Tertiary volcanic arc that borders the Siberian Pacific margin. Perhaps this resistant island platform served as a deflector of the Yukon River as it meandered seaward across the broad shelf, thus inhibiting initiation of St. Matthew and Middle Canyons perhaps until the Pleistocene. Also the western edge of the large Navarin Basin, beneath the outer shelf and upper slope, is bordered by a northwestward trending basement high buried by 0.5 - 1.0 km of Cenozoic sediment (Marlow and others, 1976). This basement ridge would also result in restricted access of the large rivers to much of the area of the present continental slope until the basin was nearly full of sediment. Just as with any ridge system, the water gap is determined not only by low spots in the ridge but also by the presence of less-resistant or more faulted and fractured segments of the barrier. Compounding the problem, is the presence of basalt on the walls of at least St. Matthew Canyon and perhaps Middle Canyon. If this igneous rock is present as an elongate ridge parallel to the shelf-break, the cutting of these two-smaller canyons would indeed be retarded. However, igneous rocks also have been dredged from the walls of Zhemchug and Pervenets Canyons (Jones and others, 1981). Without further dredging we cannot assess the relative importance of the igneous rocks as to their influence on the rates of canyon cutting in any of the four canyons.

Our model of canyon development suggests that the large canyons began forming much earlier than did the St. Matthew and Middle Canyon systems. During low stands of sea level perhaps in the late Tertiary, the ancestral Yukon and Anadyr Rivers contributed to the development of the three large canyons. Geographically the Anadyr River seems most likely to have contributed to the formation of Navarinsky Canyon and the Yukon to Zhemchug Canyon. Pervenets Canyon could have been influenced by distributaries from either of the two major rivers. Proximity would suggest that distributaries of the Yukon River would be the most likely contributors to the St. Matthew and Middle Canyon systems.

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Table 1. Principal Canyons and Fan Channels of the St. Matthew and Middle Systems

Canyon	Length(km)	Head(m)	Mouth(m)	Gradient	Steepest Gradient
St. Matthew					
West Branch	70	150	3000	2.5°	3.3°
East Branch	34	150	3000	5.1°	7.6°
Middle					
West Branch	40	130	3000	4.1°	6.4°
East Branch	60	140	3200	2.9°	4.3°
Fan Channel					
St. Matthew					
West Branch	55	3200	3600*	0.4°	
East Branch	64	3200	3600*	0.4°	
Middle					
West Branch	67	3000	3600*	0.5°	
East Branch	60	3200	3600*	0.4°	

* Marks extent of deepest contour; channel extends further onto fan. See Figure 3 for location of canyon systems.

Table 2a. West Branch, St. Matthew Canyon wall gradients

Section*	Length(km)	Relief(m)	Gradient
A	5.1	650	7.3°
B	6.0	1050	10.0°
C	4.0	800	11.3°
D	8.2	1800	12.4°
E	5.0	1250	14.1°
F	8.3	2200	14.8°
G	7.6	400	3.0°
H	7.6	2200	16.1°
I	6.7	340	2.9°
J	9.5	1600	9.6°
K	7.0	1025	8.3°
L	12.3	1300	6.0°
M	8.0	800	5.7°
N	9.5	550	3.3°
O	9.0	450	2.9°
P	8.0	300	2.2°

Table 2b. East Branch, St. Matthew Canyon wall gradients

Section*	Length(km)	Relief(m)	Gradient
A'	1.5	100	3.8°
B'	1.5	100	3.8°
C'	1	300	16.7°
D'	2	300	8.5°
E'	3	650	12.2°
F'	3	500	9.5°
G'	2	400	11.3°
H'	5.5	1000	10.3°
I'	6.5	125	1.1°
J'	12	1100	5.2°

*Side of transverse profile from top of wall to thalweg of canyon. (See Fig. 3 for profile locations).

Table 3a. Tributaries of the west branch of St. Matthews Canyon system

West branch Tributararies	Length(km)	Head(m)	Mouth(m)	Gradient
1	6	200	1100	8.5°
2	8	800	1500	5.0°
3	42	140	2300	2.9°
4	22	140	2500	6.1°
5	20	140	2700	7.3°
6	16	2000	3200	4.3°
7	34	750	3200	4.1°
8	13	2200	3300	4.8°
9	14	2200	3350	4.7°
10	48	200	3500	3.9°
avg.	23.2			5.2°

Fan Channel	Length(km)	Head(m)	Mouth(m)	Gradient
8	3	3200	3300	1.9°
9	8	3200	3500	2.1°

Table 3b. Tributaries of the east branch of St. Matthew Canyon system

East branch Tributaries*	Length(km)	Head(m)	Mouth(m)	Gradient
1	29	600	3050	4.8°
2	26.5	2200	3250	2.3°
3	30	1600	3250	3.2°
avg.	28.5			3.4°

*See Figure 3 for locations of tributaries.

Table 4a. Wall gradients of the west branch of Middle Canyon

Section*	Length(km)	Relief(m)	Gradient
A	2	500	14.0°
B	2	500	14.0°
C	3	500	9.5°
D	1.2	450	20.6°
E	4	1100	15.4°
F	2	500	14.0°
G	6	850	8.1°
H	14	650	2.7°
I	8	1050	7.5°
J	16	450	1.6°
K	13	650	2.9°
L	10	300	1.7°
M	14.5	725	2.9°
N	12	350	1.7°

Table 4b. Wall gradients of the east branch of Middle Canyon

A'	3	125	2.4°
B'	5	125	2.0°
C'	2.5	125	2.9°
D'	3.5	125	2.0°
E'	3.5	150	2.5°
F'	3	125	2.4°
G'	3	450	8.5°
H'	2	725	19.9°
I'	4.5	450	5.7°
J'	7	850	6.9°
K'	5.5	700	7.3°
L'	6	450	4.3°
M'	10	500	2.9°
N'	7.5	300	2.3°
O'	3.5	125	2.0°
P'	6.0	125	1.2°

* Side of transverse profile from top of wall to thalweg of canyon. (See Fig. 3 for profile locations).

Table 5a. Tributaries of the west branch of Middle Canyon

West branch Tributaries*	Length (Length to 300 m)	Head(m)	Mouth(m)	Gradient
1	6	800	1700	8.5°
2	6	1100	2300	11.3°
3	26	140	2650	5.5°
4	22	600	3025	6.3°
5	12	2200	3100	4.3 (7.6°)
6	33 (26)	200	3100	5.0 (6.2°)
7	26 (16)	1400	3200	4.0 (5.7°)
8	36 (26)	600	3200	4.1 (5.3°)
9	79 (32)	200	3425	2.3 (5.0°)
10	26 (9)	2200	3450	2.8 (5.1°)
11	17 (8)	2400	3400	3.4 (4.3°)
12	58 (4)	2800	3575	0.8 (2.9°)
avg.	29			4.9°

Fan Channels*	Length(km)	Head(m)	Mouth(m)	Gradient
5	6	3000	3100	1.0°
6	7	3000	3100	0.8°
7	10	3000	3200	1.1°
8	10	3000	3200	1.1°
9	47	3000	3425	0.5°
10	17	3000	3450	1.5°
11	9	3000	3400	2.5°
12	54	3000	3575	0.6°
avg.	15.1			1.2°

* See Figure 3 for location of tributaries and fan channels.

Table 5b. Tributaries of the east branch of Middle Canyon

Tributaries*	Length km (length to 3000 m)	Head(m)	Mouth(m)	Gradient
1	52	150	2900	3.2°
2	22	200	2100	4.9°
3	24	600	2700	5.0°
4	11	1400	2300	4.7°
5	8	2000	2850	6.1°
6	7	2400	2900	4.1°
7	23	1200	3050	4.6°
8	19	1200	3025	5.5°
9	32 (28)	1400	3225	3.3° (3.7°)
10	12.5	2700	3200	2.3°
11	77 (37)	1000	3450	2.5° (3.4°)
12	31	1200	3200	3.7°
13	84 (30)	1200	3475	1.6° (3.8°)
14	23 (19)	2000	3225	3.1° (3.6°)
15	40 (17)	2800	3600	1.2° (1.4°)
ave.	31			3.7°

Fan Channels	Length(km)	Head(m)	Mouth(m)	Gradient
9	4	3200	3225	0.4°
11	40	3200	3450	0.4°
13	54	3200	3475	0.3°
14	4	3200	3225	0.4°
15	23	3200	3600	1.0°
avg.	25			0.5°

* See Figure 3 For locations of the tributaries and fan channels.

Table 6. Comparison of canyons of the Beringian continental margin with canyons of the east and west coasts of the U.S. (Data for east and west coast canyons from Shepard and Dill, 1966)

East Coast Canyons	length (km)	gradient
Corsair	26	3.4°
Lydonia	30	2.3°
Gilbert	37	3.4°
Oceanographer	32	3.6°
Welker	50	2.1°
Hydrographer	50	2.1°
Hudson	92	1.3°
Wilmington	43	2.7°
Baltimore	52	1.9°
Washington	52	2.1°
Norfolk	70	2.0°
West Coast Canyons		
Astoria	115	1.0°
Eel	50	2.9°
Monterey	111	1.5°
Mugu	15	2.8°
Dume	5.6	5.5°
Redondo	15	2.2°
Scripps	2.7	5.5°
La Jolla	14	2.3°
Coronado	15	3.3°
Beringian Margin Canyons		
Navarinsky	270	0.5°
Pervenets	160	1.3°
St. Matthew	70	2.5°
Middle	40	4.1°
Zhemchug	125	0.8°
Pribilof	90	1.2°
Bering	875	0.2°

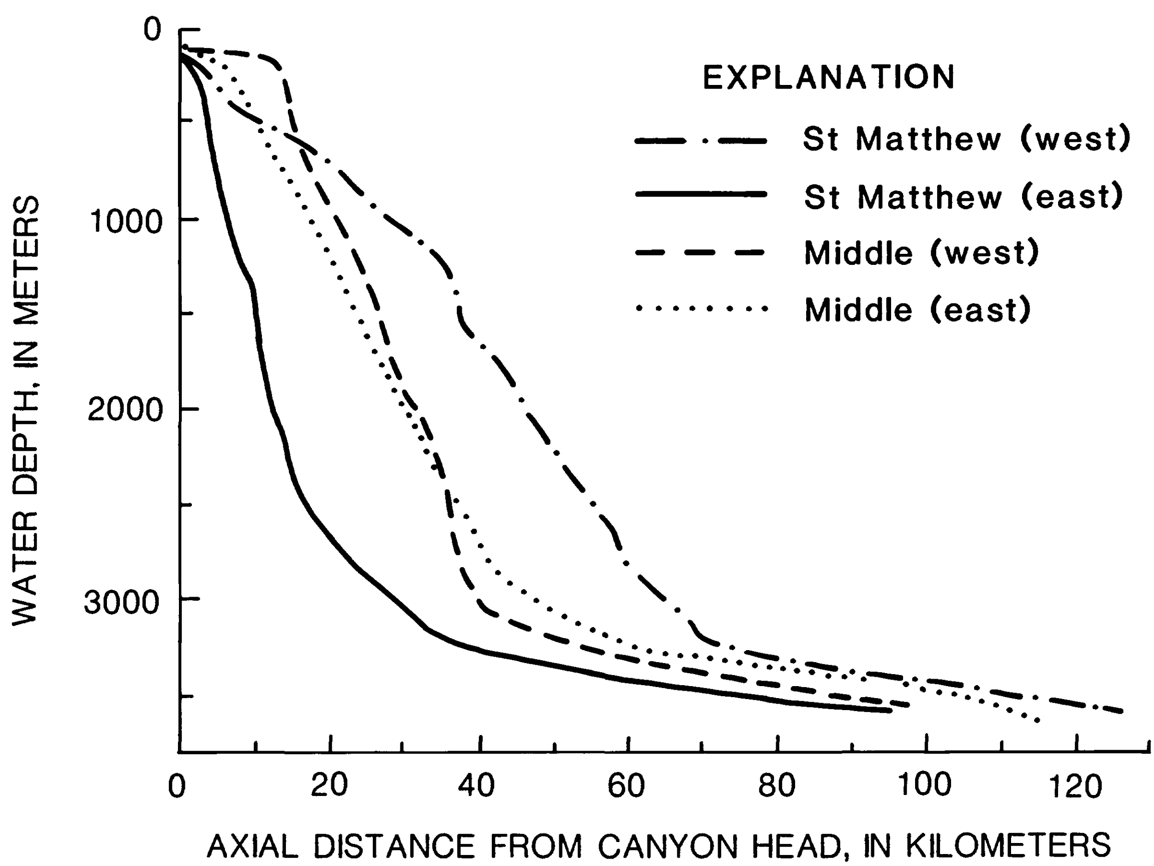

Figure 1. Thalweg profiles of main branches of St. Matthew and Middle Canyons.

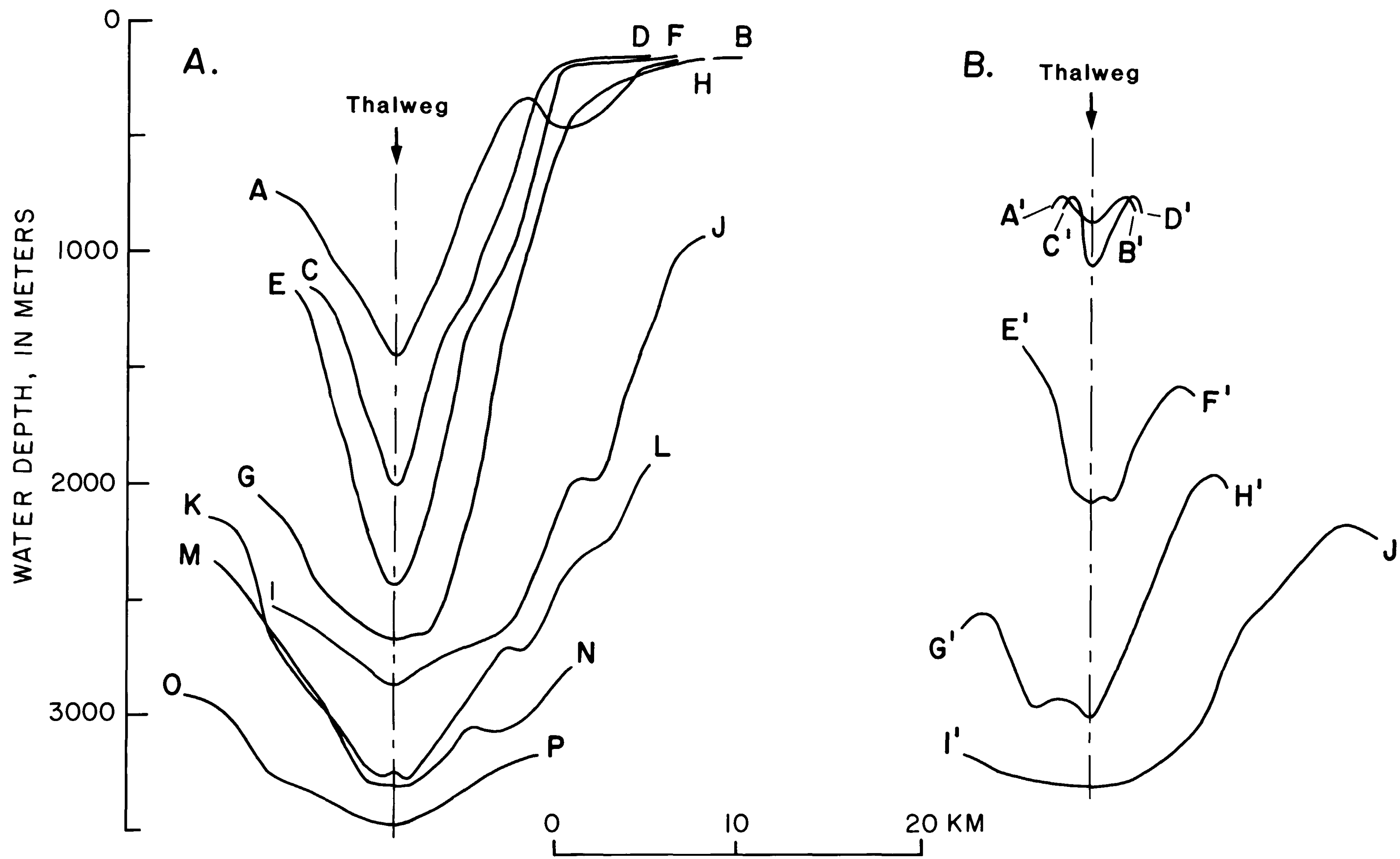

Figure 2. Transverse profiles of west (a) and east (b) branches of St. Matthew Canyon (see Fig. 3 for traverse locations).

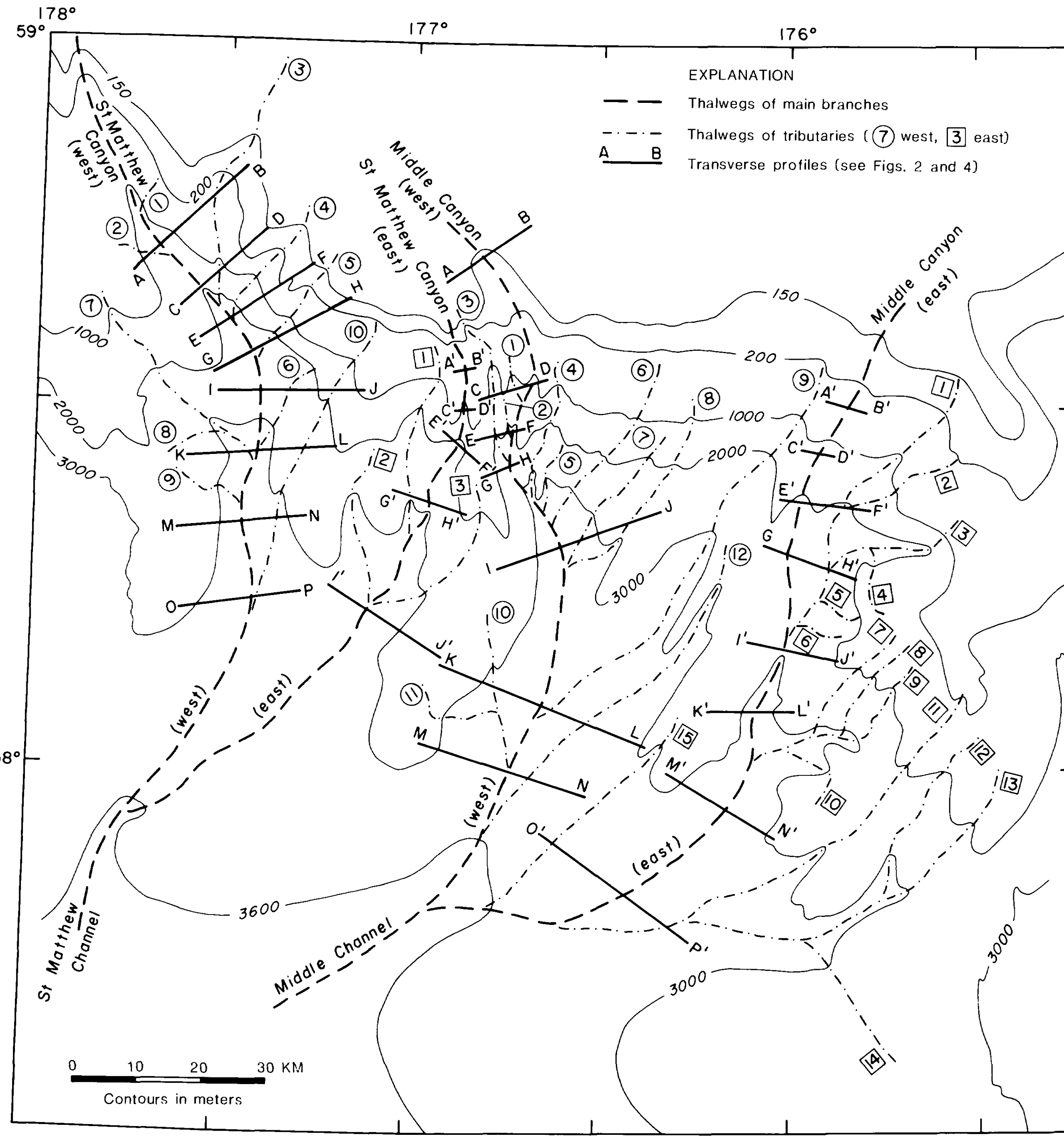

Figure 3. Map of St. Matthew and Middle Canyon systems, showing thalwegs of main branches and tributaries and locations of transverse profiles illustrated in Figures 2 and 4.

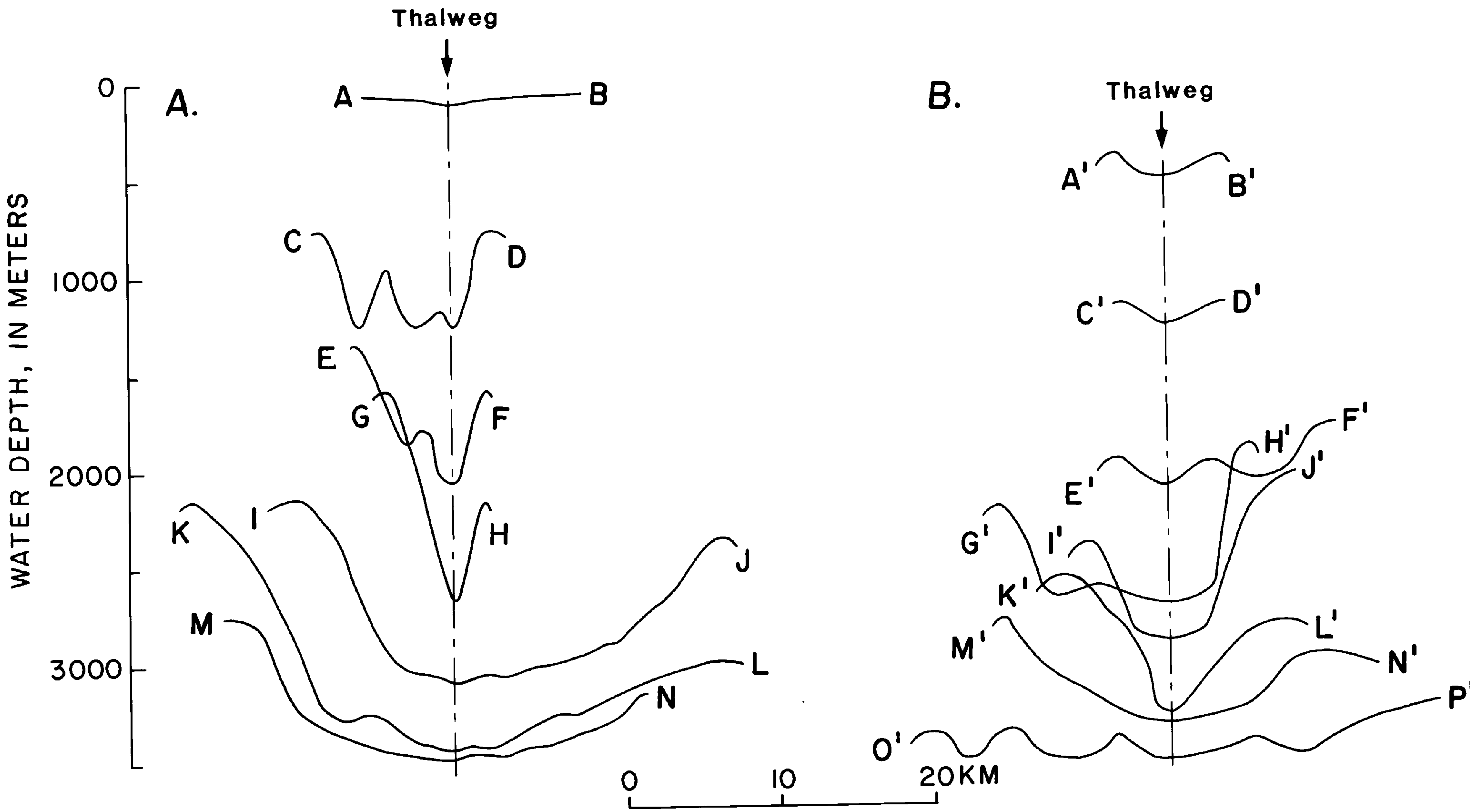

Figure 4. Transverse profiles of west (a) and east (b) branches of Middle Canyon (see Fig. 3 for locations of transverse profiles).

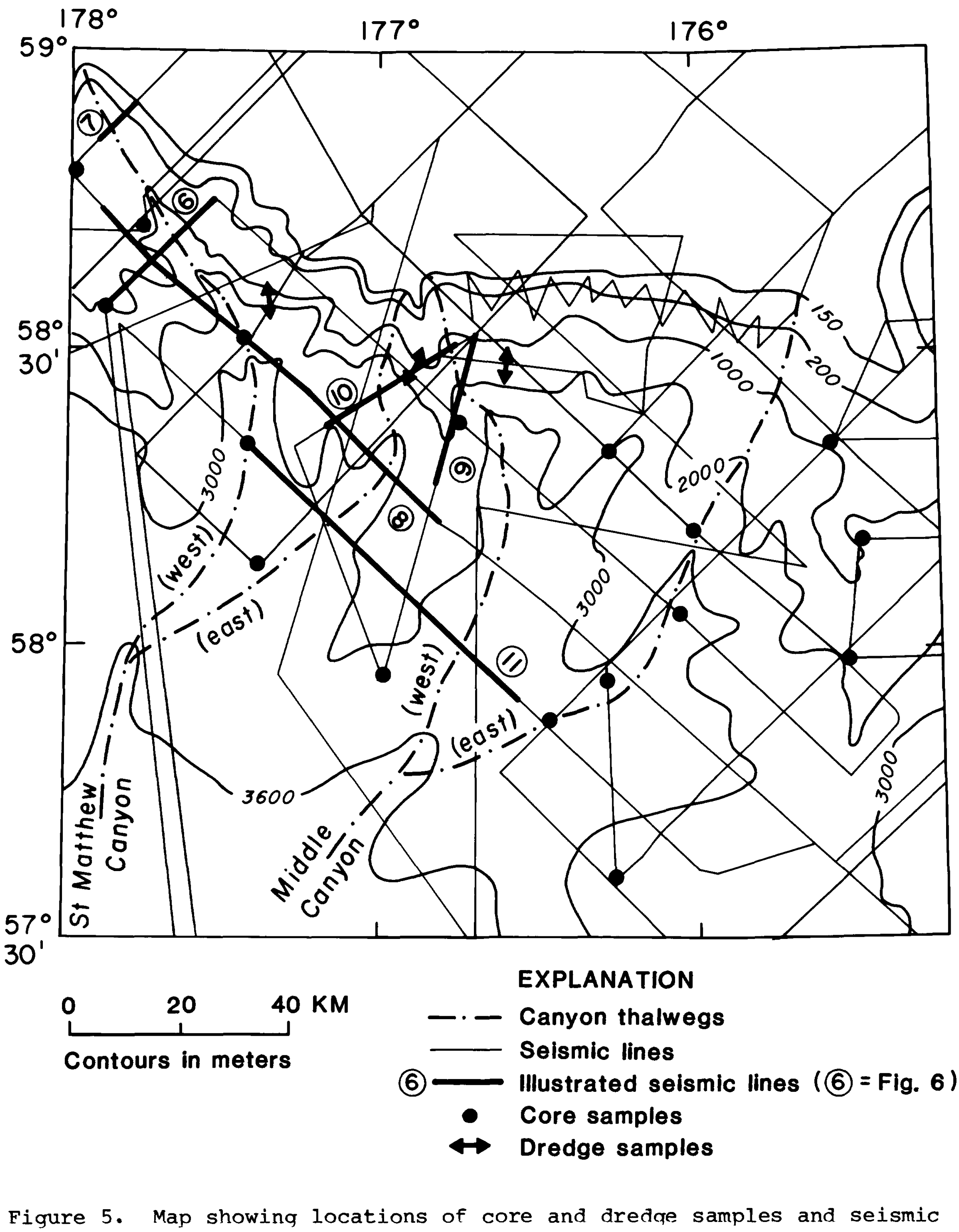

Figure 5. Map showing locations of core and dredge samples and seismic profiles, including illustrated line drawings.

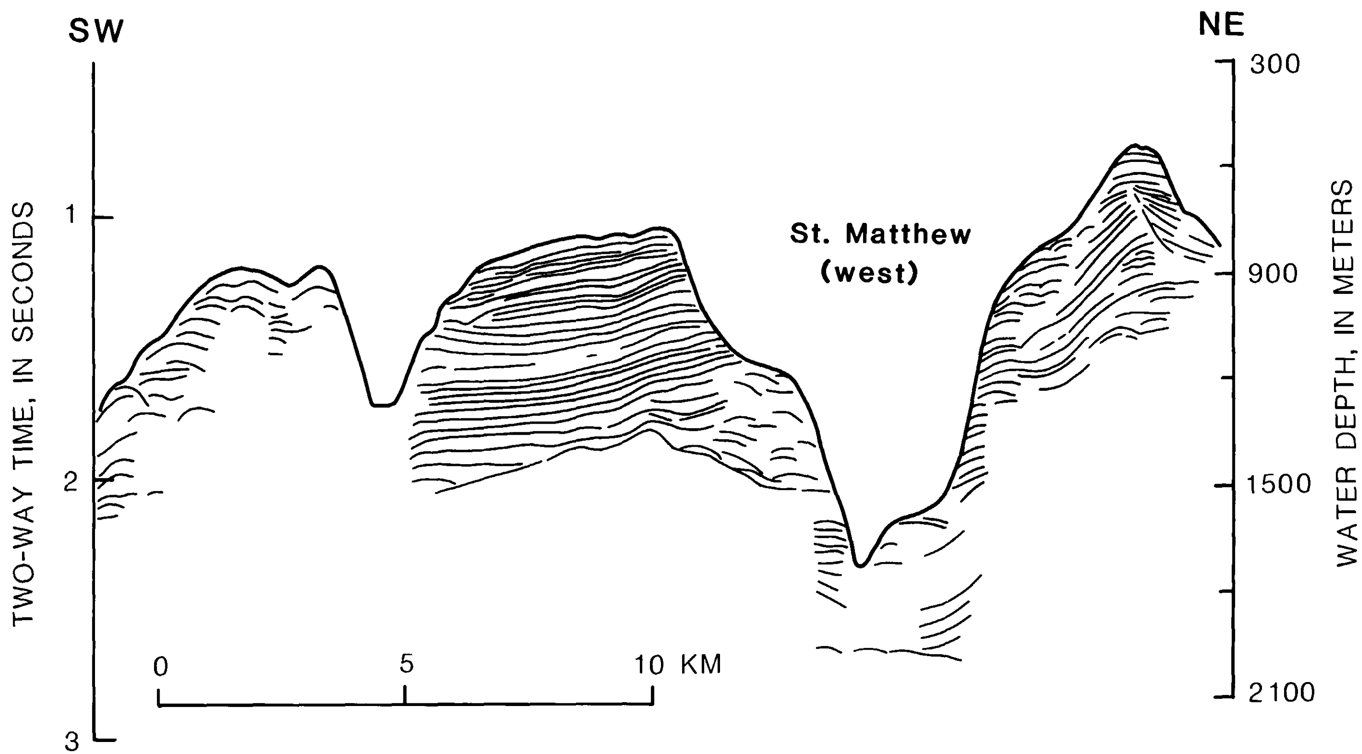

Figure 6. Interpretive line drawing of air-gun profile across west branch of St. Matthew Canyon (see Fig. 5 for location), (Vertical exaggeration (V.E.) ~x7).

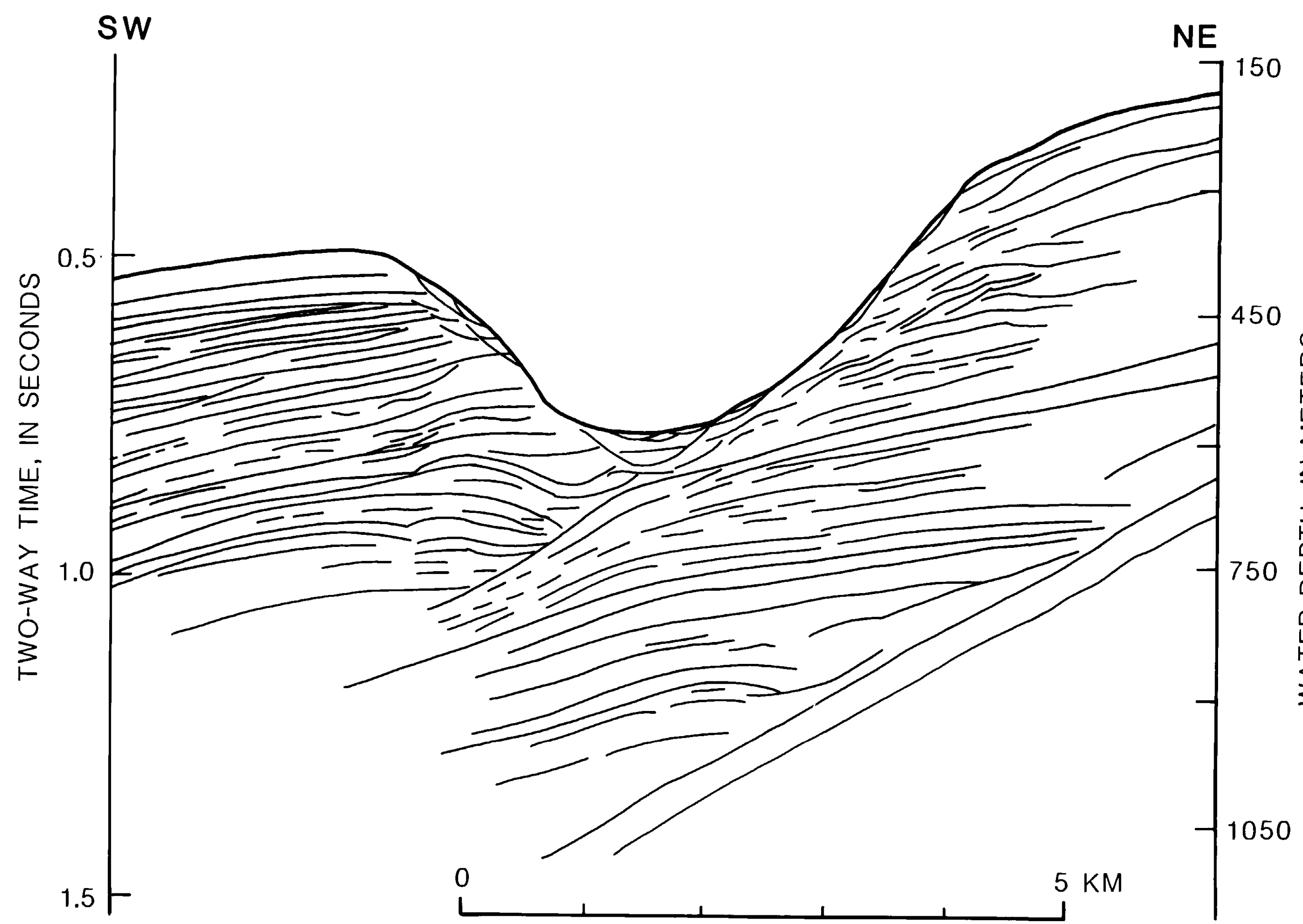

Figure 7. Interpretive line drawing of air-gun profile across west branch of St. Matthew Canyon (see Fig. 5 for location). (V.E. ~x7).

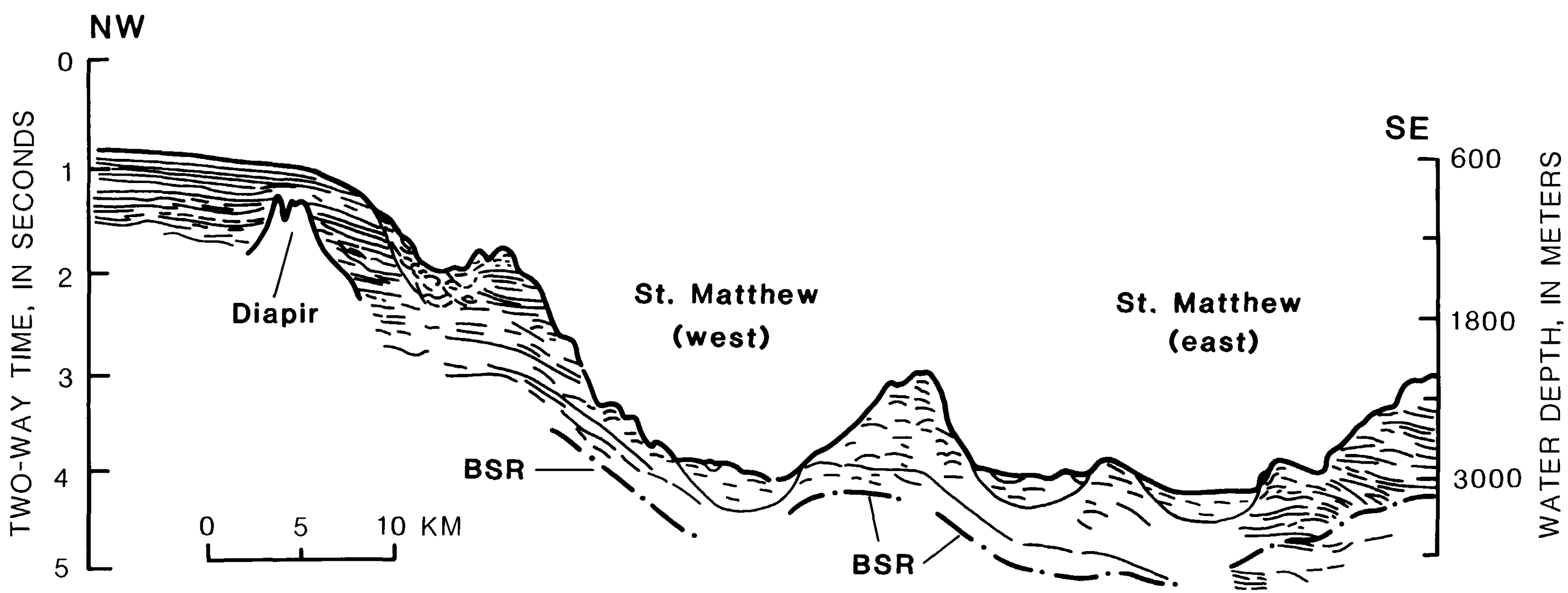

Figure 8. Interpretive line drawing of air-gun profile across the St. Matthew Canyon system (see Fig. 5 for location). (V.E. ~x7).

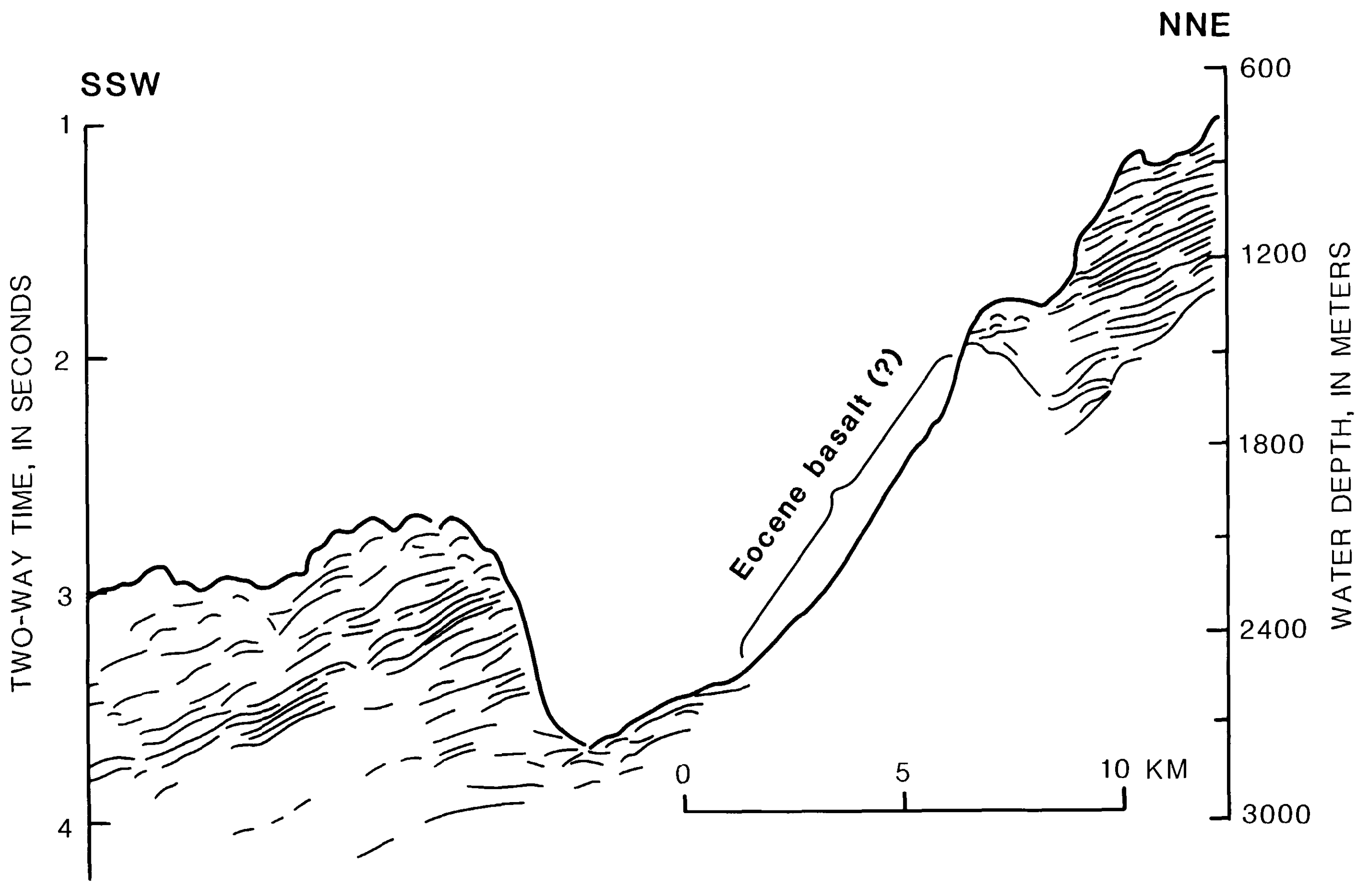

Figure 9. Interpretive line drawing of air-gun profile across west branch of Middle Canyon (see Fig. 5 for locations). (V.E. ~x7).

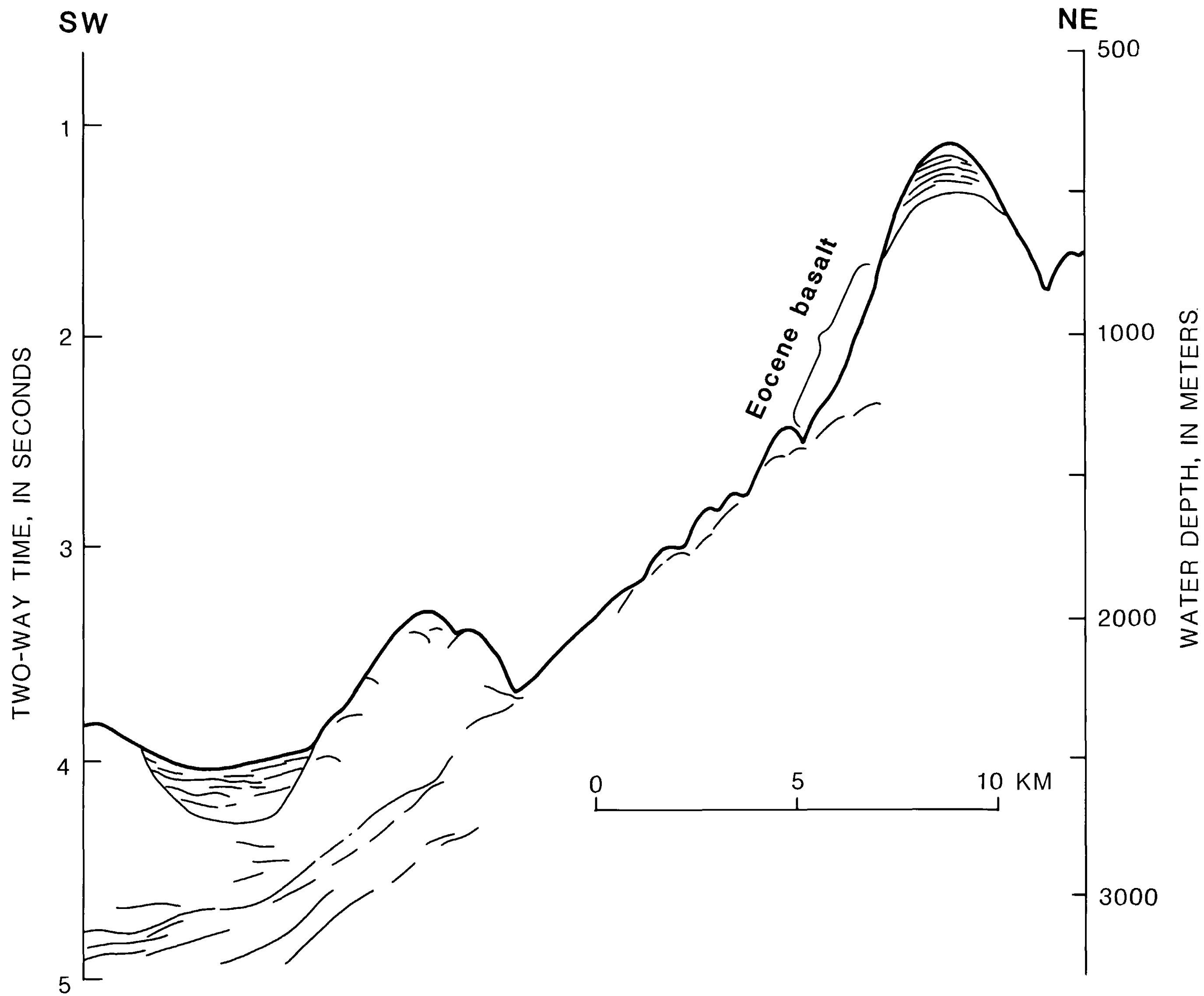

Figure 10. Interpretive line drawing of airgun profile across east branch of St. Matthew Canyon (see Fig. 5 for location). (V.E. ~x7).

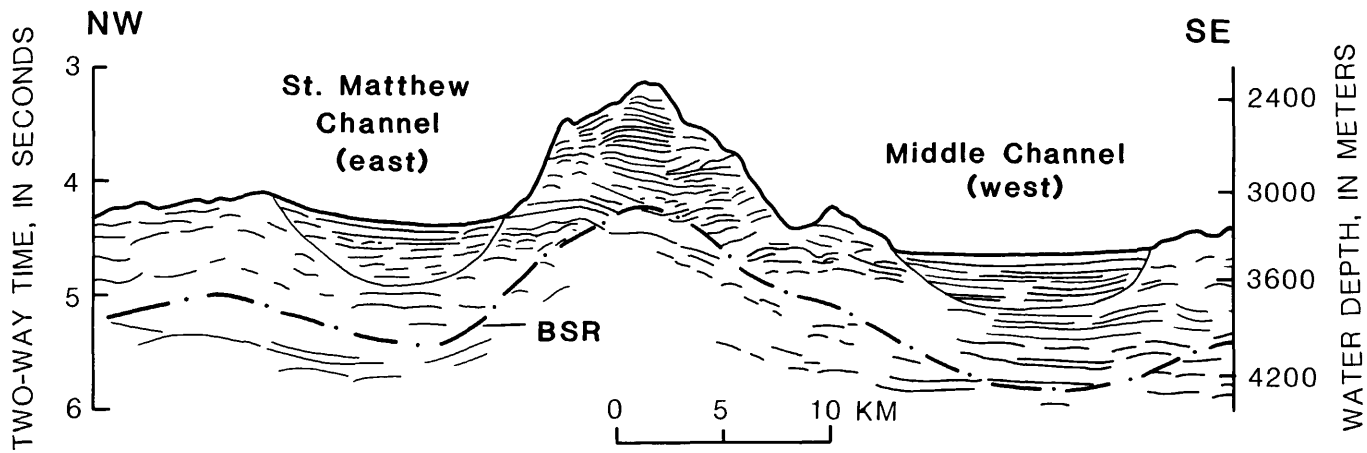

Figure 11. Interpretive line drawing of air-gun profile across St. Matthew and Middle Fan channels (see Fig. 5 for location). (V.E. ~x7). (BSR = Bottom simulating reflector).