Lithoprobe, southern Vancouver Island: Seismic reflection sees through Wrangellia to the Juan de Fuca plate

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ABSTRACT

Multichannel seismic reflection profiles obtained on Vancouver Island show that above a zone of decoupling between the North American and Juan de Fuca plates, Wrangellia is underplated by two accreted terranes of probable oceanic origin. Both the zone of decoupling and Wrangellia are disrupted by easterly dipping faults, some of which are thrusts. The crustal structure of Wrangellia comprises Paleozoic and Mesozoic volcanic and sedimentary rocks disposed as roof pendants upon, and large irregular masses within, a ubiquitous Jurassic plutonic and metamorphic complex.

INTRODUCTION

During the summer of 1984, multichannel seismic reflection surveys and supporting geologic and geophysical studies were undertaken on southern Vancouver Island as part of the initial phase of a project known as Lithoprobe. The objective of this work was multifold and included the delineation of the Juan de Fuca plate beneath the island and the nature of the crust underlying Wrangellia. We describe here the results obtained from Line 1, which crosses south-central Vancouver Island (Fig. 1). For further details on the history of development of the project, see Fyfe and Rust (1981), CANDEL (1981), and Clowes (1984).

REGIONAL GEOLOGIC AND TECTONIC SETTING

Vancouver Island (Fig. 1) is made up of Paleozoic, Mesozoic, and Cenozoic volcanic, plutonic, sedimentary, and metamorphic rocks, upon which is impressed a dominant northwesterly structural grain (Sutherland Brown and Yorath, 1985; Muller, 1977; Fyles, 1955). The main stratigraphic and structural unit is the Karmutsen Formation, a thick, relatively uniform ferrotholeiitic pillow lava sequence of Late Triassic age that separates middle and upper Paleozoic from Jurassic and younger volcanic and sedimentary rocks, most of which have been intruded by Lower Jurassic plutons. Along its axis and eastern margin, northwesterly aligned structural culminations expose the island's oldest rocks, the Sicker Group, in the Buttle Lake, Cowichan Lake, and Nanoose uplifts (A, B, C, respectively, of Fig. 1). On the west coast and beneath the continental margin, an apron of Cenozoic clastic rocks (Carmanah Group) overlies complexly deformed Upper Triassic to Cretaceous slope and trench deposits (Pacific Rim Complex) and Eocene oceanic basalts (Shouldice, 1971; MacLeod et al., 1977; Yorath, 1980). The volcanics represent the structurally highest slice within the subduction complex. On the east coast the Nanaimo Group of Late Cretaceous age comprises cyclical graded sequences of conglomerate, sandstone, and shale that developed within a successor basin on Wrangellia.

The primary crustal architecture of Vancouver Island is believed to comprise an underthrusting oceanic plate overlain by an amalgam of accreted terranes, plutonic complexes, and successor basins. During the past several years, many workers have identified the island as part of Wrangellia, a terrane known to be allochthonous by virtue of paleomagnetic studies on Triassic and Jurassic volcanics (Yole and Irving, 1980; Irving and Yole, 1983). The manner of assembly of this and other adjacent terranes and their accretion to the ancient continental margin is largely unknown. However, a reasonable model has recently been proposed by Monger et al. (1985) which shows the various terranes of the Cordillera as having underthrust one another during accretion such that they are now vertically juxtaposed, one above the other. Beneath these ancient terranes, the modern Juan de Fuca plate is thought to descend beneath the margin, first at a relatively shallow angle beneath the continental shelf and then more steeply beneath the island (Riddihough, 1979; Ellis et al., 1983; Spence et al., 1985). This phase of Lithoprobe was designed to test the proposed terrane accretion and subduction model with the aid of a velocity structure determined from recent refraction studies (Ellis et al., 1983; Spence et al., 1985).

LITHOPROBE PROFILE, LINE 1

Line 1 shows clear, coherent reflectors at three main levels in the section (Fig. 2). It is noteworthy that on all four profiles the middle and lower zones are equally well represented. Toward the northeastern end of Line 1 the uppermost prominent band of reflectors is laterally discontinuous and is bounded above and below by generally acoustically transparent sections.

A preliminary interpretation of Line 1 is described in Clowes et al. (1985), Green et al. (1985), and Yorath et al. (1985). The interpretation illustrated in Figure 3 incorporates surface geologic data where reflection quality is poor but where stratigraphic and structural information is of sufficient density and quality to allow reasonable projections to be made. In Figure 3 the lowermost reflector zone (A) is considered to represent a zone of decoupling between the North American and Juan de Fuca plates, comprising a sequence (about 3 km thick) of interdigitated materials of probable sedimentary and volcanic origin which we suggest is being accreted to the base of the continental plate. The overall dip of the zone is northeasterly at between 10° and 12° from about 24 km near the coast to about 31 km beneath central Vancouver Island beyond which resolution is lost (average velocity = 6.9 km/s). Within the zone, reflector discontinuities suggest the presence of easterly dipping faults. Whether the faults penetrate the underlying oceanic crust or become listric within this zone is unknown. At the southwestern end of the profile, structural relationships are complex and require an offshore extension of the line for their resolution; such has recently been obtained and is currently being processed. The depth to the top of the zone is close to or

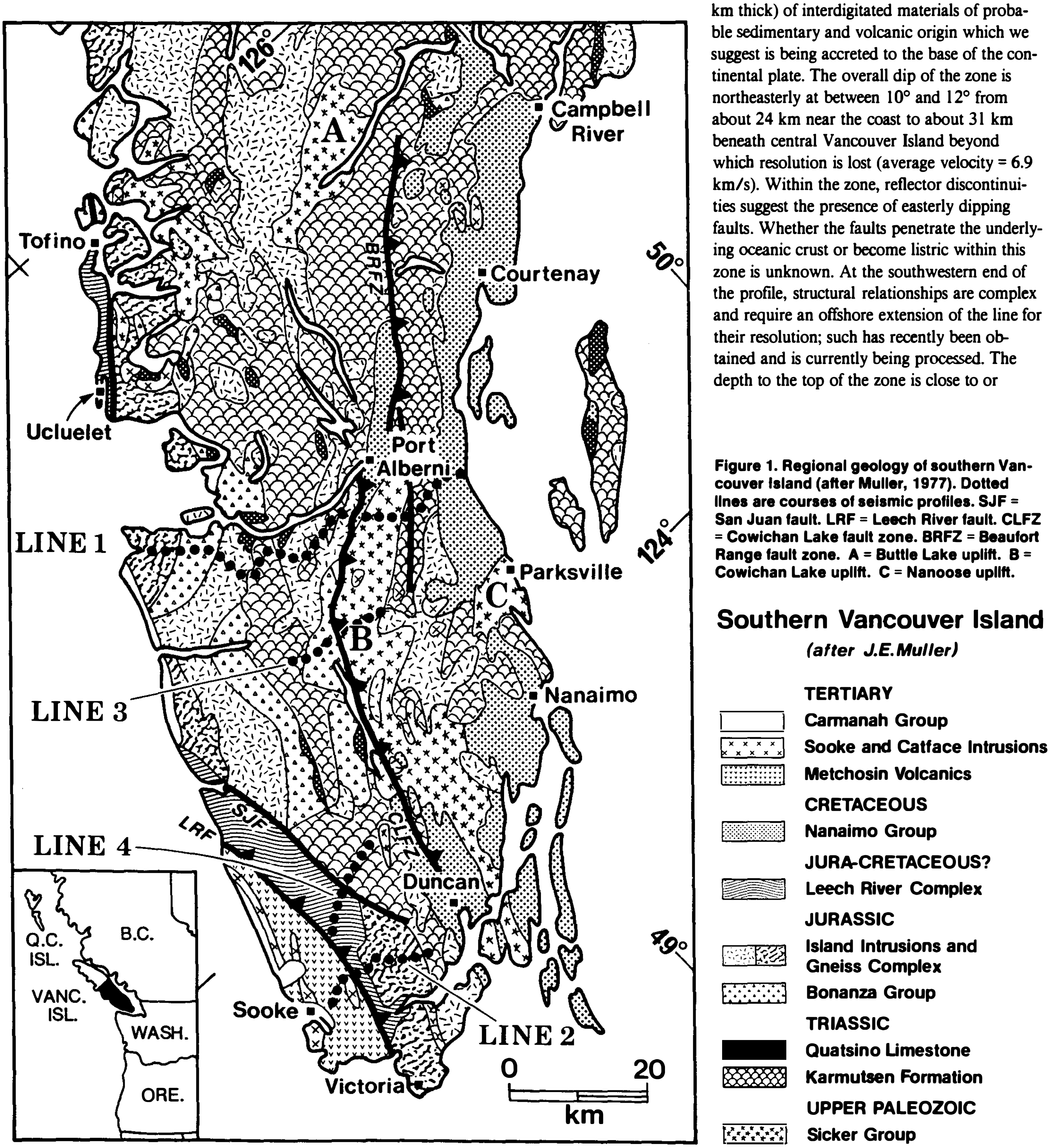

Figure 1. Regional geology of southern Vancouver Island (after Muller, 1977). Dotted lines are courses of seismic profiles. SJF = San Juan fault. LRF = Leech River fault. CLFZ = Cowichan Lake fault zone. BRFZ = Beaufort Range fault zone. A = Buttle Lake uplift. B = Cowichan Lake uplift. C = Nanoose uplift.

slightly shallower than that postulated in previous models for the top of the underthrusting oceanic crust (e.g., Riddihough, 1979; Spence et al., 1985). The reflectors show some evidence of an increase in dip toward the eastern end of the line near where continuity is lost. At about this location previous models have shown a change in dip from 10° to about 30°.

Above zone A is a thick interval with fewer, less coherent, discontinuous and discordant reflectors. This "underplated zone" (B) may represent accreted oceanic materials, comprising either slices of oceanic crust or imbricated oceanic sediments such as are found in the core rocks of the Olympic Mountains. Several faults that dislocate the lowest reflector zone appear to extend upward into the underplated zone. A post-Eocene age for underplating is supported by the probable early Eocene age of the wedge of basalt identified as the Metchosin volcanics at the western end of the profile. This is discussed below. A corollary to this interpretation is the necessary removal of some tens of kilometres of lithosphere that was originally a part of and beneath Wrangellia as a consequence of, or prior to, the emplacement of the underplated zone.

Between the 3.5- and 5-s interval and extending eastward across 75% of the record is another layered horizon which is interpreted as a decollement zone (C) at or beneath the base of Wrangellia. Like the lower layered interval, this zone shows numerous reflectors, the lateral continuity of which is interrupted by easterly dipping surfaces, some of which are listric within the zone and others of which appear to penetrate into the underlying underplated zone. Most of these faults that arise from the de-

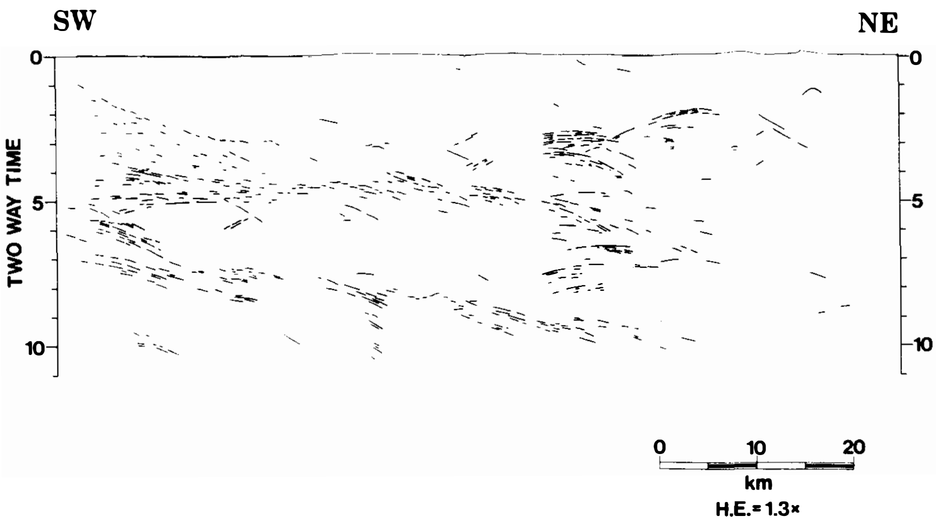

Figure 2. Reflector geometry of Line 1, south-central Vancouver Island (unmigrated).

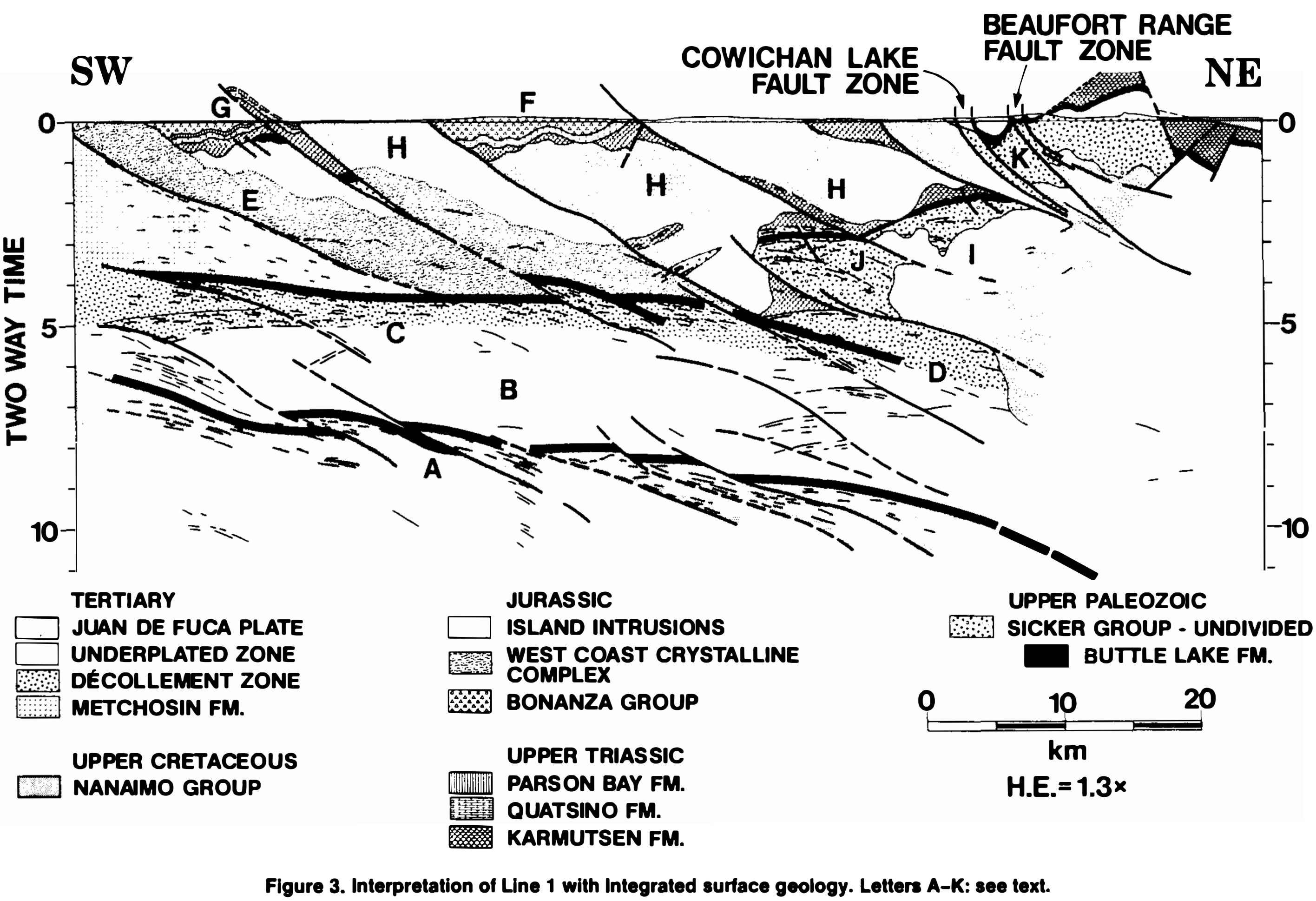

Figure 3. Interpretation of Line 1 with integrated surface geology. Letters A–K: see text.

collement zone, although not evident in the shallower part of the record section, can be projected to the surface where they coincide with the positions of mapped faults or plutonic contacts. At the eastern end of the zone (D) structural relationships are complex; discrimination between the underplated and decollement zone becomes difficult.

Like the lower layered sequence, the decollement zone may represent interdigitated materials of sedimentary and volcanic origin that overlay and were emplaced with the underplated zone. At the western end of the profile a wedge-shaped area of short, discontinuous reflectors (below E) is thought to represent the volcanics that were penetrated by exploratory wells (Shouldice, 1971; Yorath, 1980), which have been mapped magnetically as the Prometheus anomaly by MacLeod et al. (1977) and which are equivalent to the lower Eocene Metchosin volcanics of southern Vancouver Island and the Crescent Formation of northwestern Washington. The upper bounding surface of the wedge is the Tofino fault (E) which probably is coplanar with the Leech River fault of southernmost Vancouver Island (Fig. 1). The Leech River fault is believed to have been active during the late Eocene (Brandon, 1984, 1985). This wedge of volcanics is an important accreted element in the architecture of the continental margin and is further illustrated in reflection profiles on southern Vancouver Island (R. M. Clowes et al., in prep.).

The several other faults that displace parts of the decollement zone appear to control the structural level of Lower Jurassic granitic rocks. Some show thrust separation, which may explain the uplift of central and western Vancouver Island that resulted in the exposure of the Island Intrusions and the associated metamorphic rocks of the West Coast Crystalline Complex. This may have taken place in post-Eocene time as a consequence of the emplacement of the wedge of Eocene volcanics (Metchosin volcanics) and the underplated zone. Mesozoic stratified rocks (F, G), preserved between thrust traces, are thus roof pendants above a regionally ubiquitous Lower Jurassic granitic and metamorphic complex.

The acoustically transparent areas (H, I) are interpreted to represent Lower Jurassic plutonic rocks which, toward the northeastern end of the profile, are believed to enclose rocks of the middle to upper Paleozoic Sicker Group (J) and parts of the Triassic Karmutsen Formation. Above this zone, easterly dipping thrust faults (K) juxtapose Upper Triassic volcanics against Jurassic granite, and Paleozoic volcaniclastic and carbonate rocks against Upper Cretaceous sandstone, conglomerate, and shale. These relationships are known almost entirely from surface geologic data; corroborating reflections are absent except at the easternmost end of the profile where downthrown upper Paleozoic carbonate can readily be identified through down-plunge surface projections.

CONCLUSIONS

1. The lowermost reflector interval represents a zone of decoupling between the North American and Juan de Fuca plates. This layered sequence possibly comprises oceanic materials that are currently being underplated to the continental plate.

2. Beneath Wrangellia two accreted crustal sections occur, the lower of possible post-Eocene age and the upper of probable early Eocene age. Between these two terranes, a layered sequence, like the lowermost zone, and probably related to the underplated zone, has acted as a zone of detachment for easterly dipping faults, some with thrust separation, which extend into the upper crust and project to mapped faults and intrusive contacts at the surface.

3. The dominant structural style of Vancouver Island is one of shortening due to easterly dipping thrust faults and westerly directed folds. The faults that originate at deeper crustal levels partition Middle to Upper Jurassic plutonic rocks that were exhumed in post-Eocene time. These granitic rocks enclose large volumes of late Paleozoic and younger rocks, which, at the surface, appear as roof pendants above the fault-bounded plutons. At the eastern end of the profile, westerly directed high-level thrust faults juxtapose older against younger sequences.

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