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Robin Riddihough

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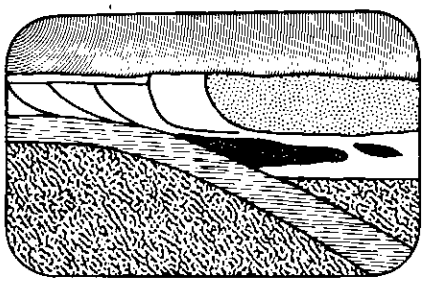

A Symposium on the Deep Structure of Southern Vancouver Island: Results of Lithoprobe Phase 1 — 19 April 1985

Robin Riddihough
Earth Physics Branch
Energy, Mines and Resources
Ottawa, Ontario K1A 0E8

Organised jointly by the Pacific Section of the Geological Association of Canada and the Canadian Geophysical Union, this one-day symposium brought together 150 scientists from Canada and the United States at the Pacific Geoscience Centre, Sidney, British Columbia. In their Foreword to the Programme, Ted Irving and Ron Clowes state "The results (of Phase 1) obtained so far are startling, and in many ways, unexpected, and there is no doubt they have revitalized discussion of the origin and evolution of Vancouver Island". Although it was less than 10 months since much of the field work had been carried out, the excitement and enthusiasm for the results and their implications was evident from the first few moments of the day. (In the following account only the person who presented each paper is named).

After a brief welcome from the ebullient Jane Wynne (President of the Pacific Section of GAC) and George Garland (Chairman of the Lithoprobe Steering Committee), Chairman Ron Smyth (B.C. Ministry of Energy, Mines and Petroleum Resources) introduced the first paper by Alan Green (Earth Physics Branch, EMR, Ottawa). This paper reviewed the reasons why Lithoprobe Phase 1 was located on Vancouver Island. The concept of a plate that was subducting beneath the island, gravity interpretations and the results of the 1981 seismic refraction experiment all suggested that a full-scale multi-fold reflection seismic survey might be capable of imaging the descending Juan de Fuca plate. Four lines were recorded, VISP 1 which crossed the Island from Bamfield to Georgia Strait, VISP 2 and 4 which crossed the Leech River and San Juan Fault Systems at the south end of the Island and VISP 3 which ran sub-parallel to VISP 1 across the centre of the Island. A combination of new technology, heavy vibrator trucks with feedback controlled ground coupling, and careful data analysis and processing have produced very high quality seismic sections that could even "convince an unbeliever". A number of NE-dipping horizons are visible on these and can be traced to surface faulting. It is possible to interpret the lowest of these horizons, dipping to the NE at 7-10 second two-way travel time, as the top of the subducting plate.

Atholl Sutherland Brown (Consultant, Pacific Geoscience Centre) reviewed the geological history of the Wrangellian Terrane. Three episodes of volcanism occurred from Late Paleozoic to Early Jurassic, the last being accompanied by the intrusion of the Island Intrusions. Uplift and flexing were then followed by Cretaceous basin development. Cenozoic underthrusting beneath and within this superstructure produced further deformation, thrusting and uplift. Geological mapping carried out under the Lithoprobe programme quickly lead to a radical re-interpretation of previously mapped geology. In particular, the previously strike-slip Beaufort Range Fault is now seen as an important thrust. Chris Yorath (Pacific Geoscience Centre) then presented a joint paper that provided a first level interpretation of the main reflection profiles across Vancouver Island (Figure 1). He noted that surface geological mapping was essential to tracing horizons and reflectors down into the seismic reflection data and that such units as the Buttle Lake Limestone may prove to be critical markers in this respect. He reiterated that in the authors' opinion, the dipping Juan de Fuca plate can be seen overlain by an underplated zone which may be an older section of oceanic crust and sediments similar to the core zone of the Olympic Mountains. The early to mid-Jurassic Island Intrusions appear as transparent areas with few reflectors. If this interpretation is correct, much of Wrangellia is underlain by these presumed granitic bodies. Assuming that Wrangellia had an original crustal thickness of 30-40 km and rested on a Paleozoic lithosphere, major tectonic erosion must have occurred during the underthrusting episodes.

Ron Clowes (University of British Columbia) then presented interpretations of the southern profiles which crossed the Leech River and San Juan Fault Systems. The Leech River Fault, which has been a source of much contention for a number of years, is clearly seen dipping northward at about 35° to depths of greater than 10 km. Beneath it is a zone interpreted as the Eocene Metchosin basalts. Underneath these is a layered sequence interpreted as the equivalent of the Olympic Core complex of marine sediments (although there are some high velocities in this sequence which are not yet understood). The lowest reflector (8-10 second two-way travel time) may correlate with the presently subducting Juan de Fuca plate. If so, it is possible to contour the upper surface of this plate and its possible warping as it descends beneath the Georgia Strait-Puget Sound region.

After a coffee break, Paul Hoffman (Geological Survey of Canada) gave his usual spirited account of a possible analogy of a deformed continental margin along the NW boundary of the Slave Province. The Eastern Wopmay Orogen shows all the characteristics of a convergent continental margin with accretionary prism and volcanic arc which has been compressed, thrust and metamorphosed. Variation in exposed structural level due to erosion allows one to "see" down to depths of 30 km in this orogen without using expensive vibrator trucks! It contains features such as an overthrust, rootless, plutonic complex which transmitted heat downward into an underlying, colder autochthon.

Jack Sweeney (Pacific Geoscience Centre) then presented new model sections based on new gravity data measured along the main Lithoprobe transect. Comparing the two main suites of previous models, he felt that both were valid interpretations but that gravity still demanded mantle density material at depths as shallow as 25-30 km beneath Vancouver Island. This could either be older, underthrust material overlying the present Juan de Fuca plate, a wedge of trapped asthenospheric material or the descending plate itself. In any case, there was no evidence for material of crustal density being carried below depths of 30 km on the subducting plate. John DeLaurier (Pacific Geoscience Centre) reviewed magnetotelluric data measured with Phoenix Geophysics equipment along the main Lithoprobe section during 1984. Results showed a strongly conductive zone dipping NE from 21-29 km which could be correlated with the deepest major seismic reflector. The conductivity measured provided constraints for porosity, saline solutions or magnetite content which may have important implications in understanding the metamorphic processes occurring at these depths. The last paper of the morning, given by W. Neinaber (University of Victoria) described the model tank experiments which have been carried out to provide a physical analogue with which to compare field geomagnetic observations on and around Vancouver Island. Discussion from the floor then centered on the gravity interpretations.

After lunch in the Institute of Ocean Science Cafeteria (Deli sandwiches and

beer!), Roy Hyndman (Director, Pacific Geoscience Centre) introduced a session on the broader tectonics of the West Coast. Ben Page (Stanford University) reviewed the history of the Salinian Block of the southern Coast Ranges of California. This block was originally formed as part of a plutonic belt in west-central Mexico and was sliced and transported northward as part of right-lateral strike-slip faulting along the North American Margin. The timetable of speed and direction of this block correlates well with calculations of Kula plate, Farallon plate and finally Pacific plate motions relative to North America. The style of slicing, transport and accretion is typical of many of the Cordilleran terranes and is probably applicable to at least parts of the British Columbia margin. Ted Irving (Pacific Geoscience Centre) then showed how in fact the "super-terrane" of Wrangellia, the Coast Plutonic Complex, the Stikine and Cache Creek terranes and Quesnellia (named Baja B.C.) was probably transported 2000 km northward since the mid-Cretaceous, travelling with the Kula plate. A key point of this interpretation is that the observed 60° clockwise rotation of the paleopoles of Baja B.C. is a consequence of its rotation with the Kula plate about an Euler pole near the present 44°N, 90°W and not a local "ball bearing" effect produced by the dextral strike-slip boundary. Motion in the early Tertiary would also be north-easterly in conformity with the NE-dipping faults observed. Mark Brandon (Pacific Geoscience Centre) then presented an interpretation of the Pacific North-West which hinged on a transcurrent truncation of western Vancouver Island in the 65-55 Ma period. This re-interpretation of the tectonics also included formation of the Washington-Oregon Coast Range basalts in a marginal basin environment similar to the present Gulf of California (rather than as a hot spot chain in an open ocean as previously suggested). He also identified Mesozoic rocks exposed west of, and structurally beneath, the Coast Range basalts.

Karl Muehlenbachs (University of Alberta) discussed data on the oxygen isotope geochemistry of the Island Intrusions and other igneous rocks along the Lithoprobe transect. He noted that they showed no evidence of interaction with meteoric water. This was in contrast with the Coast Plutonic Complex where results are consistent with meteoric water interaction during cooling. Dick Armstrong (University of British Columbia) reviewed the results of the age dating of igneous rocks on Vancouver Island. These results confirmed that the Sicker Group was Silurian-Devonian (420-330 Ma), and was metamorphosed in the Jurassic-Triassic. The West Coast Complex may contain rocks which were originally Paleozoic as well as plutons of Early to Middle Jurassic age which may be equivalent to the Island Intrusions. The latter gave dates in the 150-190 Ma range. Of interest are a suite of small high-level plutons (Catface Intrusions) of 32-50 Ma age which may mark a period of plutonism slightly younger than the widespread Early to Middle Eocene episode seen in mainland B.C.

Trevor Lewis (Pacific Geoscience Centre) showed heat flow values across Vancouver Island which demonstrated the characteristic low heat flux produced by the adsorption (heat-sink effect) of the downgoing plate. An abrupt transition to high heat flow occurs 30 km seaward of the Garibaldi Volcanic Belt. The steepness of this transition demands a source that is relatively shallow in the crust and which seems worthy of closer investigation. The heat flow data allowed preliminary calculation of temperatures along the line of the main Lithoprobe section. Calculated isotherms show a dip which is virtually coincident with the lower reflections interpreted as the Juan de Fuca plate and suggest that it is at temperatures of 400-500° C. Garry Rogers (Pacific Geoscience Centre) reviewed the detailed earthquake position and depth determina-

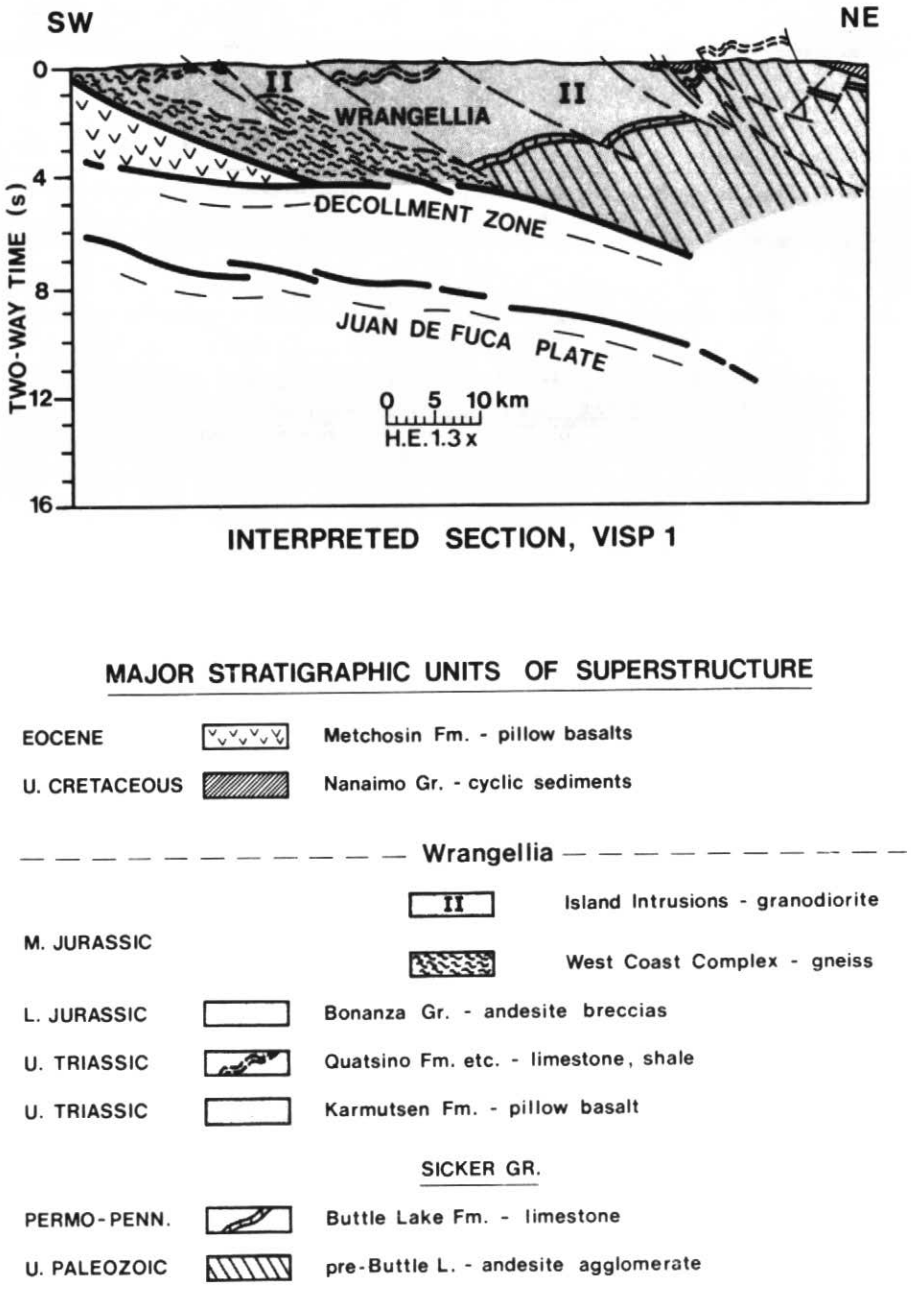

Figure 1 *Preliminary interpretation of VISP 1 seismic section by Chris Yorath and Atholl Sutherland Brown. (As printed in the Symposium Programme)*

tions that are now possible through an expanded seismometer network. In section, events have occurred in two suites, a shallow crustal suite beneath Georgia Strait and a deeper suite dipping to the east at about 18° at depths from about 25 km beneath the west coast of Vancouver Island to 60 km beneath the Strait of Georgia. This lower set of events must occur in brittle material at temperatures of less than 500° C. Fault plane solutions suggest that they occurred within the ocean crust and not between it and the overlying material. Thus the deepest reflectors in the seismic reflection record may **not** represent the downgoing plate but lie 2-5 km above it. These reflectors also apparently dip at a shallower angle than the earthquake zone.

Bill Fyfe (University of Western Ontario) had been sampling water and pore fluids associated with recent faulting on Vancouver Island. These fluids indicated the presence of minerals which could be associated with the subduction process. He felt that the dewatering of the downgoing plate was a critical process that had to be understood and documented in understanding subduction. Temperatures of 500° C in the plate as estimated from heat flux correlated very well with estimates of the origin of the water sampled in the faults.

In summing up the day's proceedings, George Garland called on four members of the audience to make some short comments. Darryl Cowan (University of Washington) said that he was particularly impressed with the evidence for underplating and the multi-disciplinary way that Lithoprobe had been conducted. Roy Hyndman also emphasized the interaction, interplay and advances that the multi-disciplinary approach had clearly made. Paul Hoffman voiced a warning that, exciting though the results from Vancouver Island were, a number of different areas will need to be looked at before we can begin to come to any conclusions about the subduction process. Bill Fyfe again stressed that Lithoprobe showed the value of trying to penetrate deeper into the crust and of combining a number of geophysical approaches to the same problem.

A general discussion ensued on the meaning of the high conductivity zones mapped, the danger of neglecting surface geological mapping (an essential component of such experiments as Lithoprobe), the plans for future seismic processing of the data and the need for geochemical studies in the Lithoprobe corridors. Roy Hyndman closed the meeting with the comment that he could see a new era of thin sheet, "flake" tectonics and that our recently developed ideas of slices of the earth's crust bounded by vertical faults may have to be modified in a new earth science revolution.

As a general comment from this observer, the Symposium left little doubt that this area of Vancouver Island is underlain by a complex series of north-east–dipping thrusts affecting rocks of all ages. There is also clear evidence for major underthrusting of younger material beneath Wrangellia. However, the exact identification of the lowest seismic reflectors will require a carefully balanced assessment of seismic velocity sections, conductivity, earthquake hypocentre distribution and gravity modelling. Although there was a wish to make an unequivocal correlation with the subducting Juan de Fuca plate by some speakers, others were more circumspect. To this observer, it seems probable that these reflectors do delineate some aspect of the downgoing plate. Whether it is the offscraped and overlying sediments, the ocean crust or even the underlying Moho, it may be too early to tell.