Learning Science Through Research
Published by Keck Geology Consortium

Short Contributions
30th Annual Symposium Volume
29th April, 2017
ISBN: 1528-7491

OLIGOCENE TO RECENT VERTICAL TECTONISM ON SOUTHWESTERN VANCOUVER ISLAND REVEALED BY ANALYSIS OF THE CARMANAH GROUP SEDIMENTARY UNITS

CARLEE AKAM, University of Victoria
Research Advisor: Dr. Kristin Morell

INTRODUCTION

Vertical tectonism on Vancouver Island is hampered by a lack of sedimentary units younger than Cretaceous, but older than Quaternary in age. In this study, we use the distribution of Oligocene sediments to test for changes in vertical tectonism since the Oligocene by mapping and describing the Carmanah Group sediments along the southwest coast of Vancouver Island. We use field observations and mapping to determine that the Carmanah Group is more extensive and at higher elevations than previously thought in the vicinity of two major crustal faults, the Leech River and San Juan Faults. These results imply a significant amount of vertical tectonism since the Oligocene that requires a mechanism, whether by slip along local faults, net uplift associated with interseismic cycles of the Cascadia Subduction Zone, or orocline rotation of Vancouver Island.

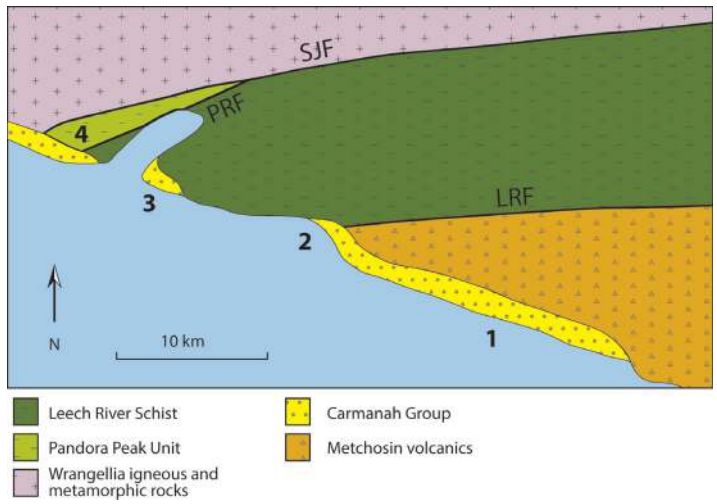

Figure 1. Geological map of southwestern Vancouver Island with study locations numbered: 1. China Beach, 2. Sombrio, 3. Botanical Bay, 4. San Juan Fault Region. SJF: San Juan Fault, PRF: Port Renfrew Fault, LRF: Leech River Fault. Modified from Rusmore and Cowan, 1985.

GEOLOGIC SETTING

Vancouver Island is made up of three allocthonous terranes: Wrangellia, Pacific Rim, and Crescent Terranes. The Pacific Rim Terrane was emplaced against Wrangellia in the early Eocene along the San Juan Fault (Fig. 1; Muller, 1977). The Pacific Rim Terrane is comprised of the Pandora Peak Unit and the Leech River Schist, separated from one another by the Port Renfrew Fault (Fig. 1). The Crescent terrane accreted to the North American margin in the middle to late Eocene along the Leech River Fault (Muller, 1977). The Crescent terrane is comprised of the Metchosin Igneous complex which is dominated by basalts at the surface. It is understood that the Pacific Rim and Crescent Terranes were thrust under the North American margin and the San Juan and Leech River faults are steeply north dipping thrusts. Recent lidar and field work analyses show that the Leech River Fault has been active in the late Holocene (Morell et al., 2017)

The Carmanah Group is a marine sedimentary unit deposited unconformably along the southwestern coast of Vancouver Island, draping the Wrangellia, Pacific Rim, and Crescent terranes. Fossil assemblage data constrain its deposition from latest Eocene to latest Oligocene (Cameron, 1980; Prothero, 2008). It generally covers no more than a kilometre inland and ranges in elevation from below sea level to less than 100 m. In rare locations it reaches up to 6 km inland and over 300 m elevation. Strata dip gently towards the southwest with increasingly older strata exposed towards the northwest. The Carmanah Group outcrops discontinuously along the coast, with the best exposures occurring at beaches, sea cliffs, and river mouths. The Carmanah Group consists of interbedded sandstone, conglomerate, and shale. Whole and fragmented fossils are common with some beds fossiliferous enough to be termed coquina. Frequent lenses and interfingering indicate rapid lateral facies changes and a high relief depositional environment. The depositional facies of the Carmanah Group range up section from bathyal to littoral (Clapp and Cooke, 1917; Jeletzky, 1954; Cameron, 1980). The overall succession describes a deepening Tertiary sea that retreats in the middle Oligocene (Jeletzky, 1973; Cameron, 1980).

An absence of faulting in the Carmanah Group where the Leech River and San Juan Faults are projected to intersect with the coast has led to the opinion that the San Juan and Leech River Faults have been inactive since the late Eocene to the middle Oligocene (Clapp and Cooke, 1917; MacLeod et al., 1977). The objective of this study is to map and describe the distribution of the Oligocene aged Carmanah Group sediments across the western extent of the Leech River and San Juan Faults to test for potential changes in vertical tectonism since the Oligocene on Vancouver Island.

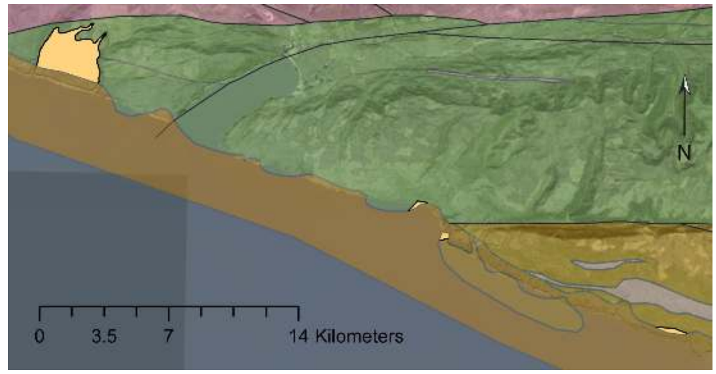

Figure 2. Map of the Carmanah Group produced from this study. Interpretation of the areal extent of the units is constrained by observed contacts and outcrops, and inferred from topography. The inferred contacts cover the minimum areal extent of the units. No contacts were observed in the north of the San Juan Fault Region and the northern extent of the unit is the least confident boundary. At Sombrio and China Beach, contacts were extended to the locations observed in this study. Modified from Massey et al. (2005).

OBSERVATIONS

The field work for this study covered an area from China Beach to south of the San Juan Fault (a distance of 40 km), and inland up to 5 km. Field observations are divided into 4 field locations: China Beach, Sombrio, Botanical Bay, and the San Juan Fault Region (Fig. 1).

China Beach

The Carmanah Group at China Beach forms sandstone cliffs with bedding that dips gently seaward. Occasional shells and 10 cm thick lenses of pebble conglomerate occur throughout the section. The unconformity with the underlying Metchosin Basalt can be seen intermittently. Grain size decreases and sorting increases up section, describing a transition to slightly more distal facies and an overall deepening sequence.

North of China Beach, alternating zones of unmapped conglomerate and basalt are exposed in road cuts at 160 m elevation (Fig. 2). The conglomerate exhibits poorly sorted, sub-rounded clasts of aphanitic basalt and, more rarely, crystalline granitoids of cobble to pebble size. The matrix is effervescent and sub-angular with very coarse to medium sand grain size. The conglomerate is occasionally interbedded with thinner layers of sand. Shell fragments are ubiquitous throughout the unit and oyster and gastropod fossils are present. One section of the conglomerate reaches 10 m in thickness and its lower contact with the basalt is visible at its base. Bedding dips 10° to the southeast.

Sombrio

The Carmanah Group at Sombrio is exposed as sea cliffs and wave cut platforms. It is composed of highly shelly, fine to coarse sandstone layers interbedded with boulder to cobble conglomerates (Fig. 3). Whole corals and bivalves are present as well as shell fragments. The conglomerate clasts mainly consist of the underlying bedrock (schist in the northwest,

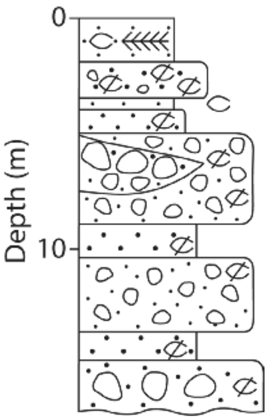

Figure 3. Stratigraphic column at Sombrio illustrating highly shelly interbedded sand and conglomerate units with occasional cross beds. Numerous lenses and broken shells indicate a high energy environment with rapid facies changes in the overall fining upwards sequence.

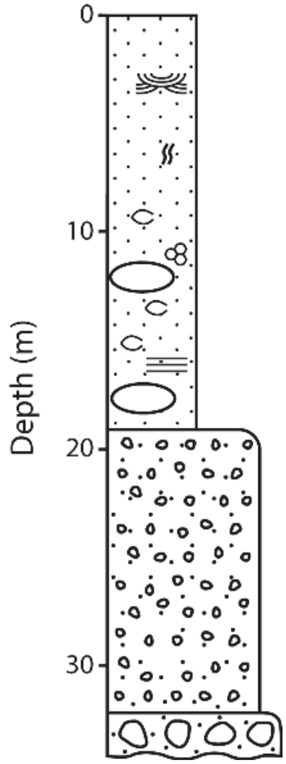

Figure 4. Stratigraphic column at Botanical Bay illustrating a fining upward sequence with sharp transitions from boulder and pebble conglomerate to medium to fine grained sands. Numerous sedimentary structures include planar bedding, trough cross beds, differential weathering, whole shells and corals, and bioturbation.

and basalt in the southeast). Well preserved ripples and trough cross beds are visible in the sand layers. Bedding dips 10° towards the south and southwest. The overall sequence describes a high energy marine environment with over 20 metres of relief and rapid lateral changes, similar to the headlands and bays of cobble and sand beach of the modern coastline.

The contact with the Leech River Schist is located to the northwest of the beach. Sombrio bay is overlain by a cobble beach and there are no outcrops of the Carmanah Group until the headlands to the southeast where the Carmanah Group unconformably overlies the Metchosin Basalt. Although both the schist and basalt are heavily sheared in this region, fault planes related to the Leech River Fault are not observed and the contact between the Pacific Rim and Crescent Terranes lies beneath the beach.

Botanical Bay

The Carmanah Group at Botanical Bay is a 34 m section with an overall fining upwards trend (Fig. 4). The contact with the steeply dipping Leech River Schist is sharp and unconformable. The base of the unit is a basal conglomerate containing boulder sized rip up clasts of schist. The boulder conglomerate grades into 15 m of schist quartz pebble conglomerate with carbonaceous cement. The upper unit is a well sorted, fine to medium grained lithic greywacke exhibiting planar bedding, trough cross beds, whole and fragmented shells, bioturbation, concretions, and differential weathering. This section is interpreted as shallow shelf marine deposits which have been uplifted to the beach and eroded into a wave cut notch and platform exposed above sea level.

San Juan Fault Region

In the San Juan Fault Region, previously unmapped sedimentary units were located at elevations ranging from over 360 m to fewer than 100 m (Fig. 2). Outcrops are typically no more than a few metres across, showing from beneath a till blanket or exposed in stream beds. A nonconformity with the underlying Pandora Peak Unit at the base of the section is visible at some outcrops. The sedimentary units in this region are grey, interbedded, fine to coarse grained lithic greywackes with occasional interfingered conglomerate beds. Clast types include quartz and lithic fragments of basalt and granitoids. Bedding is subhorizontal, dipping to the south or south east. Minor faults dip steeply to the north or northeast and often show a few centimetres of offset. At two

Figure 5. Fossilised leaf found in samples recovered from the sedimentary units in the San Juan Fault Region.

locations the sedimentary units are sheared parallel to, or truncated by, the faults. Spheroidal weathering and large scale trough cross bedding is observed. Samples taken from the San Juan Fault Region revealed a fossilized leaf (Fig. 5). Microscope analysis did not recover dynoflagellates or foraminifera, but identified charcoal fragments and grass cuticles. The sedimentary units outcrop intermittently, but continuously from the established Carmanah Group at the coast up to 360 m elevation and 3 km inland, indicating a continuous unit deposited across an area with high paleo relief.

DISCUSSION

The sedimentary units observed in this study are found to be consistent with the present knowledge on the Carmanah Group, but are more extensive and at higher elevations than previously recognized. Observations invariably describe a high relief coastline with rapid lateral facies changes similar to the modern coastline. The marine sediments consistently represent a deepening succession that is now located at more than 360 m above sea level. We interpret the previously unmapped sedimentary units observed at China Beach, Sombrio, and in the San Juan Fault Region as being marine sediments deposited as part of the Carmanah Group, and the geologic contacts in Figure 2 are extended to include these. Although it is possible that the sediments that we have described here are fluvial in origin, there are several observations that suggest they are instead marine. First, the lithology of the unmapped units described in this study is identical to the locally established Carmanah Group. Second, the distribution of the San Juan Fault Region sediments appears to be continuous from the coast up to 360 m elevation and reach 3 km inland. The distribution of the Carmanah Group sequences at Sombrio and Botanical Bay suggest that the Oligocene coastline was a rugged and rapidly alternating bay and headland configuration with high relief and the modern stream beds in the San Juan Fault Region are non-depositional, narrow, and deeply incised. Thus, a fluvial system in similar topography could not easily produce a 3 km wide fluvial plain implied by the areal extent of the San Juan Fault Region beds. Third, the consistently shallow dip of the bedding indicates a gently sloping, non-deltaic, near beach environment. Fourth, although the lack of marine microfossils supports fluvial deposition, charcoal, grass cuticles, and whole leaf fossils indicate a low energy, possibly stagnant environment. It is most likely that the San Juan Fault Region sedimentary units were deposited as marine units as part of the Carmanah Group and the inland extent of the deposit represents a bay or inlet. The lithology, gently dipping strata, and preserved leaf and charcoal fragments indicate a low energy estuary or lagoon depositional environment with limited circulation possibly explaining the lack of marine fossils.

This interpretation infers over 360 m of uplift since the deposition of the San Juan Fault Region beds in latest Eocene to Oligocene time. The implication of this study is that a mechanism is required to achieve this amount of uplift since the Oligocene. We suggest three possible explanations. One possible mechanism is net uplift of the Cascadia Subduction Zone. Interseismic deformation cycles that occur on the Cascadia Subduction Zone result from the subduction zone locking and the overriding plate to accumulating strain, bowing up and away from the overriding plate, until an earthquake rupture causes the overriding plate to subside suddenly (Clague et al., 1982; Atwater, 1987; Riddihough, 1988; Atwater and Yamaguchi, 1991; Hyndman and Wang, 1995). Models using the Cascadia convergence rate and the area of seismic zone predict the amount of interseismic deformation that will have accumulated since the last megathrust earthquake to be greater than what is observed. (Dragert et al., 1994; Leonard et al., 2004; Hu, 2011). The implication is that some of the stress must be relieved by permanent deformation and brittle faulting in the overriding plate resulting in net uplift of the Cascadia Subduction Zone.

A second possible mechanism is counter clockwise rotation of Vancouver Island and the Olympic Peninsula caused by subduction of the Crescent Terrane seamount chain during the Eocene (Johnston and Acton, 2005). Paleomagnetic evidence shows that the Carmanah Group has been rotated to a similar degree as the underlying terranes and that orocline continued activity into the Miocene (Irving and Massey, 1990; Prothero et al., 2008).

Finally, post Eocene slip along the Leech River and San Juan Faults may provide a mechanism for uplift. Recent studies offer evidence of post Eocene activity on the Leech River Fault (Morell et al, 2017). Motion on the Leech River or San Juan Faults may be independent or in response to strain due to net uplift of the Cascadia Subduction Zone or the Vancouver Island orocline being released along the existing fault planes.

CONCLUSION

The vertical tectonic history of Vancouver Island is obscured by a lack of sedimentary units positioned between the Eocene terranes and the Quaternary glacial deposits. The Carmanah Group is an Oligocene marine sedimentary unit deposited along the southwest coast of Vancouver Island. Newly mapped sediments in the San Juan Fault Region are determined to be part of the Carmanah Group based on lithology, areal extent, and dip of bedding. They are interpreted as a low energy, possibly stagnant bay or inlet that has subsequently been uplifted to over 360 m elevation. This attributes the Carmanah Group with a larger distribution and higher elevation than previously thought. The amount of uplift observed in this study requires a mechanism, or combination of mechanisms, that may include net uplift of the Cascadia Subduction Zone, counterclockwise rotation of the Vancouver Island orocline, and slip along the Leech River and San Juan Faults.

REFERENCES

Atwater, B.F., 1987, Evidence for great Holocene earthquakes along the outer coast of Washington state: Science, v. 236, p. 942–944.

Atwater, B.F., and Yamaguchi, D.K., 1991, Sudden, probably coseismic submergence of Holocene trees and grass in coastal Washington State: Geology, v. 19, p. 706–709.

Cameron, B.E.B., 1980, Biostratigraphy and depositional environment of the Escalante and Hesquiat formations (early Tertiary) of the Nootka Sound area, Vancouver Island, British Columbia, Geological Survey of Canada, Ottawa, Canada, 28 p.

Clague, J., Harper, J.R., Hebda, R.J., and Howes, D.E., 1982, Late Quaternary sea levels and crustal movements, coastal British Columbia: Canadian Journal of Earth Sciences, v. 19, p. 597–618.

Clapp. C.H., and Cooke, H.C., 1917, Sooke and Duncan map areas, Vancouver Island, Geological Survey of Canada, memoir 96, 445 p.

Dragert, H., Hyndman, R.D., Rogers, G.C., and Wang, K., 1994, Current deformation and the width of the seismogenic zone of the northern Cascadia subduction thrust: Journal of Geophysical Research, v. 99, p. 653–668.

Environmental Systesms Reasearch Institute (ESRI). 2016. ArcMap release 10.1. Digital Globe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDS, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, GIS user community.

Hu, Y., 2011, Deformation processes in great subduction zone earthquake cycles, PhD thesis, University of Victoria, Victoria, British Columbia, 195 p.

Hyndman, R.D., and Wang, K., 1995, The rupture zone of Cascadia great earthquakes from the current deformation and the thermal regime: Journal of Geophysical Research, v. 100, p. 22133–22154.

Irving, E., and Massey, N.W.D., 1990, Paleomagnetism of ocean layers 2 and 3: evidence from the Metchosin Complex, Vancouver Island: Physics of the Earth and Planetary Interiors, v. 64, p. 247-260.

Jeletzky, J.A., 1950, Stratigraphy of the west coast of Vancouver Island between Kyuquot Sound and Esperanza Inlet, British Columbia, Geological Survey of Canada, Paper 50-37, 52 p.

Jeletzky, J.A., 1954, Tertiary rocks of the Hesquiat-Nootka area, west coast of Vancouver Island, British Columbia, Geological Survey of Canada, Paper 53-17, 65 p.

Jeletzky, J.A., 1973, Age and depositional environments of Tertiary rocks of Nootka Island, British Columbia (92-E): mollusks versus foraminifers: Canadian Journal of Earth Sciences, v. 10, p. 331–365.

Johnston, S.T., and Acton, S., 2003, The Eocene Southern Vancouver Island Orocline—a response to seamount accretion and the cause of fold-and-thrust belt and extensional basin formation: Tectonophysics, v. 365, p. 165-183.

Leonard, L.J., Hyndman, R.D., and Mazzotti, S., 2004, Coseismic subsidence in the 1700 great Cascadia earthquake: Coastal estimates versus elastic dislocation models: Geological Society of America Bulletin, v. 116, p. 655–670.

MacLeod, N.S., Tiffin, D.L., Snavely Jr, P.D., and Currie, R.G., 1977, Geologic interpretation of magnetic and gravity anomalies in the Strait of Juan de Fuca, US-Canada: Canadian Journal of Earth Sciences, v. 14, p. 223–238.

Massey, N.W.D., MacIntyre, D.G., Desjardines, P.J., and Cooney, R.T., 2005, Geology of British Columbia, BC Ministry of Energy, Mines, and Petroleum Resources, Geosciences Map 2005-3, scale 1:1000000.

Morell, K.D., Regalla, C., Leonard, L.J., Amos, C., Levson, V., Mortimer, N., Campbell, H.J., Tulloch, A.J., King, P.R., Stagpoole, V.M., and Wood, R.A., 2017, Quaternary Rupture of a Crustal Fault beneath Victoria, British Columbia, Canada: GSA Today, v. 27.

Muller, J.E., 1977., Evolution of the Pacific margin, Vancouver Island, and adjacent regions: Canadian Journal of Earth Sciences, v. 14, p. 2062–2085.

Narayan, Y.R., Barnes, C.R., and Johns, M.J., 2005, Taxonomy and biostratigraphy of Cenozoic foraminifers from Shell Canada wells, Tofino Basin, offshore Vancouver Island, British Columbia: Micropaleontology, v. 51, p. 101.

Prothero, D.R., Draus, E., Cockburn, T.C., and Nesbitt, E.A., 2008, Paleomagnetism and counterclockwise tectonic rotation of the Upper Oligocene Sooke Formation, southern Vancouver Island, British Columbia: Canadian Journal of Earth Sciences, v. 45, p. 499–507.

Riddihough, R., 1988, The Northeast Pacific Ocean and Margin, in: Nairn, A.E.M., Stehli, F.G., and Uyeda, S. (eds.), The Ocean Basins and Margins, Springer, US, pp. 85–118.

Rusmore, M.E., and Cowan, D.S., 1985, Jurassic-Cretaceous rock units along the southern edge of the Wrangellia Terrane on Vancouver Island: Canadian Journal of Earth Sciences, v. 22, p. 1223–1232.

Shouldice, D.H., 1971, Geology of the western Canadian continental shelf: Bulletin of Canadian Petroleum Geology, v. 19, p. 405-436.

Tiffin, D.L., Cameron, B.E.B., and Murray, J.W., 1972, Tectonics and depositional history of the continental margin off Vancouver Island, British Columbia: Canadian Journal of Earth Sciences, v. 9, p. 280–296.