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21. Another implication of the trend of decreasing saturation pressure with increasing fractionation (higher K_2O) is that these eruptions were not fed by stable shallow crustal-level magma chambers. Instead, the magma was moving upward as it fractionated, and this movement probably prevented settling of MIs that were formed earlier (that is, MIs with high saturation pressures). Also, despite the systematic variation shown in Fig. 3, many MIs do not follow a simple paragenetic sequence, suggesting that the magma was transported by a network of dikes rather than a single dike.
22. The extinction coefficient for CO_3^{2-} (375 l/mol•cm) is from G. Fine and E. Stolper [*Earth Planet. Sci. Lett.* **76**, 263 (1986)]. The extinction coefficients for H species (0.62 at band 5200 cm^{-1} and 0.67 at band 4500 cm^{-1}) are from J. E. Dixon, E. M. Stolper, and J. R. Holloway [*J. Petrol.* **36**, 1607 (1995)]. The extinction coefficient for total water (63 at band 3550 cm^{-1}) is from J. E. Dixon, E. Stolper, and J. R. Delaney [*Earth Planet. Sci. Lett.* **90**, 87 (1988)]. Basalt glass density is assumed to be constant at 2800 g/liter. Wafer thickness was measured optically by viewing crystal edgewise.
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Measurements of the Cretaceous Paleolatitude of Vancouver Island: Consistent with the Baja–British Columbia Hypothesis

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A previously unsampled outcrop of gently dipping or flat-lying Upper Cretaceous sedimentary strata in the Vancouver Island region, which contains unaltered aragonitic mollusk fossils, yielded a stable remanent magnetization that is biostratigraphically consistent with Cretaceous magnetochrons 33R, 33N, and 32R. These results, characterized by shallow inclinations, indicate an Upper Cretaceous paleolatitude of about 25 ± 3 degrees north, which is equivalent to that of modern-day Baja California. These findings are consistent with the Baja–British Columbia hypothesis, which puts the Insular Superterrane well south of the Oregon-California border in the Late Cretaceous.

The Cordillera of western North America is composed of an amalgamation of tectonic terranes, which were accreted at various times onto the stable North American continent (Fig. 1). The accretional history of the Insular Superterrane (*1*), which is composed of the northern Cascades of Washington State, the Coast Ranges of western British Columbia, Vancouver Island, the Queen Charlotte Islands, and a large region extending from southeastern Alaska to the Wrangel Mountains in northern Alaska, is currently in dispute. Two conflicting and mutually exclusive hypotheses are favored (*2*). The first hypothesis suggests that the Insular Superterrane lay north of the Franciscan-Sierran convergent plate boundary in California during most, if not all, of the Cretaceous period (*3*). The second hypothesis is that all of the Insular Superterrane north of latitude 49°N and up to 58°N was situated at a minimum of 2400 km south of its present position relative to North America 90 million years ago (Ma) (*4*, *5*, *6*). In this model, the Intermontane Superterrane (Fig. 1) is also expected to be found at least 1000 km south of its modern-day position in the mid-Cretaceous (*2*). This latter hypothesis is called the Baja–British Columbia (BBC) hypothesis because it predicts that, 90 Ma, the Vancouver Island region would have been offshore of present-day Baja California (*2*, *4*).

Evidence that can be used to refute either or both of these hypotheses comes from two main sources: geological and paleomagnetic evidence. Geological evidence includes (i) provenance studies of sediments included within the Insular Superterrane, (ii) the correlation of features found within the Insular Superterrane with similar features found inboard of it, and (iii) features limiting the offset across transcurrent faults to values less than those proposed by the BBC hypothesis. Paleomagnetic evidence relies on the determination of paleolatitudes, which are derived from either igneous or sedimentary rocks. Bedded sedimentary rocks are preferred because the paleohorizontal can be readily observed, eliminating the problem of anomalously low paleolatitudes due to tilting and deformation.

Three sets of paleomagnetic data from the region (Fig. 1), for which tilt corrections have been performed (Mount Stuart batholith, Silverquick conglomerate and volcanics, and the Duke Island ultramafic complex), support the BBC hypothesis (*6*, *7*). Only the Duke Island Complex, however, comes from the Insular Superterrane; the others are from the Coast Mountains orogen and the Intermontane Superterrane. Furthermore, until now, no paleomagnetic data, from either superterrane, have come from well-bedded sedimentary rocks of Cretaceous age in which the original horizontality is unambiguous. Here we present paleomagnetic evidence from well-bedded sedimentary rocks of the Insular Superterrane south of Alaska that is consistent with the BBC hypothesis.

We sampled strata from the Upper Cretaceous Nanaimo Group of Vancouver Island, which had been considered unsuitable for paleomagnetic investigation, because all previous sampling efforts showed a pervasive remagnetization (*8*). However, we located previously unsampled outcrops along the eastern margin of the Nanaimo basin that contain ammonite and inoceramid bivalve fossils composed of unaltered aragonite containing organic macromolecules within concretionary mudstone and siltstone facies. It has been proposed that the presence of such unaltered fossil material is an indication that thermal and chemical remagnetization is minimal to absent (9) because (i) the conversion temperature of aragonite to calcite (~100°C) is lower than the blocking temperature of the fine-grained ferromagnetic particles (~400° to 580°C) that record the natural remanent magnetism (NRM) in many clastic sediments and (ii) the presence of organic macromolecules in the fossils indicates that little fluid has passed through the sediment after deposition, retarding di-

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agenetic changes occurring after deposition that can also affect primary magnetization. Thus, we believe that the degree of alteration of aragonite to calcite in fossils can be an indicator of the gradient between primary and overprinted magnetization of the Nanaimo Group (or other) strata.

Although the sampling of sedimentary rocks for paleomagnetic analyses offers the advantage of unambiguous bedding orientations, it has been argued that it may lead to anomalously low paleolatitudes because of "compaction shallowing" of paleomagnetic inclinations (*10*, *11*). Although compaction shallowing occurs in certain fine-grained sedimentary facies, the strata we sampled appeared to be free of such effects, because our samples were from bioturbated poorly sorted siltstones and mudrock containing abundant carbonate concretions that formed during the early stages of diagenesis, preserving undeformed fossils at their center. Recent studies of such concretions have indicated that the initial $CaCO_3$ cements were deposited at the contact between grain boundaries, immobilizing the particles from further grain rotation and preventing sediment compaction (*12*). In bioturbated sediments, this cementation may also lock in a postdepositional remanent magnetization. Thus, the Nanaimo sediments offer an additional method of testing the hypothesis of inclination error by comparison of the paleomagnetic results from concretions with the silty mudstones. We collected samples from Texada and Hornby islands, which are part of the eastern margin of the ~200-km-long Nanaimo basin. The Pender Formation on Texada Island, located at the northern margin of the basin is of early to middle Campanian (~83 to 78 Ma) age (*13*). The Spray Formation on Hornby Island, located in the northern half of the basin, is late Campanian and perhaps early Maastrichtian (~75 to 70 Ma) age (*13*). These sampled strata encompass the *Baculites chicoensis* through *Pachydiscus suciaensis* ammonite zones. Paleomagnetic samples were obtained with standard techniques. All samples were collected from freshly excavated strata, and, in all cases, sites exhibiting any signs of surface oxidation or degraded fossils were avoided.

The 131 cores collected from Texada and Hornby islands were analyzed on a two-axis superconducting quantum interference device magnetometer system housed in a shielded-metal room. The background noise of the instrument was less than 10^{-11} A·m^2. Alternating field (AF) demagnetization was performed with a computer-controlled three-axis coil system. Thermal demagnetization was performed in a magnetically shielded furnace. All samples were initially measured for NRM and then subjected to low AF demagnetization up to 10 mT at 1.25-mT steps to remove low-coercivity magnetizations. The samples were then treated with thermal demagnetizations from 100°C until they became unstable. The highest temperature attained was 400°C. AF demagnetization and then thermal steps up to 150°C were required to remove an observed trend toward viscous behavior in some samples (Fig. 2).

Results from the demagnetization experiments were similar to those from other studies of nearshore, drab-colored marine siltstones and limestones from Cretaceous sediments of the Cordillera (*9*, *14*) (Fig. 2).

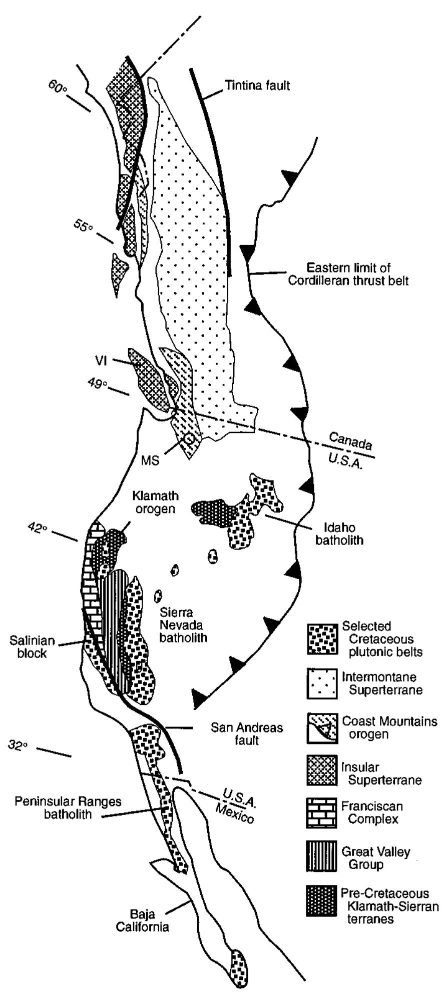

Fig. 1. Present geographic positions of major crustal and tectonic elements of the West Coast, including the Insular and Intermontane superterranes. The sampling sites from this study (Texada and Hornby islands) are located on the interior side of Vancouver Island (marked VI). MS refers to the position of the Mount Stuart batholith. Other tectonic elements are indicated in the key. Present-day latitudes are indicated. Modified from (*2*).

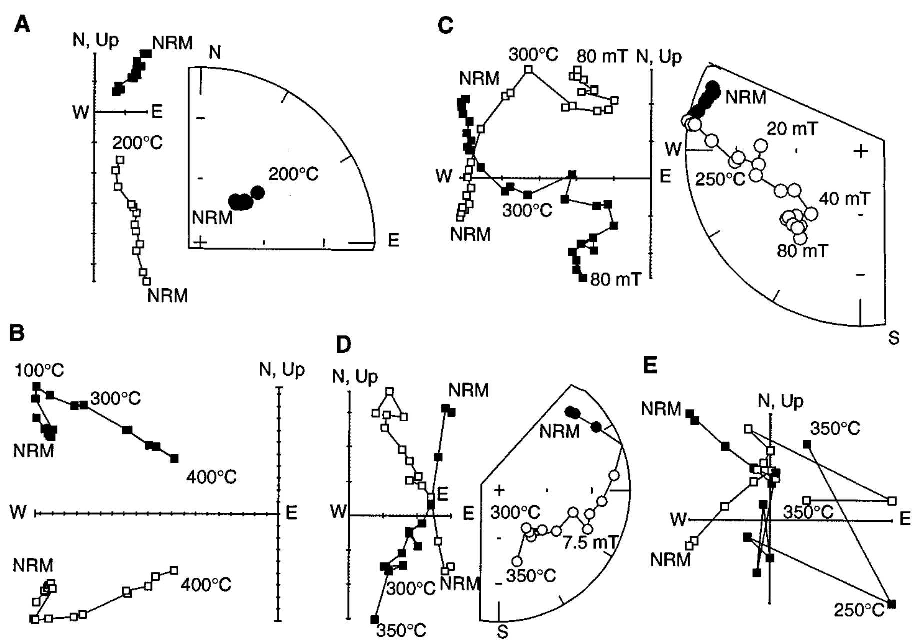

Fig. 2. Examples of representative demagnetization behavior of samples from Hornby and Texada islands. Solid symbols on the orthogonal diagrams show the projection of the demagnetization vector into the plane of the bedding, whereas the open symbols show the corresponding projection onto the north-south vertical plane. Each division is a magnetic moment of 10^{-9} A·m^2. On the equal-area projections, lower and upper hemisphere directions are indicated by solid and open symbols, respectively. (**A**) Hornby Island sample C-80 and (**B**) Texada Island sample G-16 yielded normal and reversed demagnetization line directions, respectively. (**C**) Texada Island sample H-151 and (**D**) Hornby Island sample F-213 yielded demagnetization planes (remagnetization circles). (**E**) Hornby Island sample A-7 became unstable before useful data could be obtained. (A) and (B) show convincing trajectories toward the origin on orthogonal projections.

The majority of samples (103 of 131) could be characterized as well-behaved, with either (i) a single component of magnetization that decayed linearly to the origin of the Zijderveld plot and clustered on the equal-area plot (Fig. 2, A and B) or (ii) intervals on the demagnetization path that were composed of two well-defined components that produced a planar subset of demagnetization data (Fig. 2, C and D). We analyzed the demagnetization data using principal component analysis to isolate stable components of magnetization (*15*) and to assess the polarity of samples with multiple components. Only demagnetization lines with maximum angular deviation values below 10° and planes below 15° were included in the statistical analysis (Table 1). The remaining samples displayed confusing results during demagnetization (Fig. 2E). Mean directions were obtained with Fisher statistics (*16*), and the method of McFadden and McElhinny (*17*) was used for combining demagnetization lines and planes. The reversals test and the test of mean directions followed those of McFadden and McElhinny (*18*).

Upon demagnetization, 76% (38 of 50) of the Texada and 80% (65 of 81) of the Hornby samples yielded usable directions. Normal and reversed directions can be detected in samples from Texada and Hornby islands (Fig. 3). Lower Campanian rocks on Texada are dominantly reversely magnetized, whereas normal polarity dominates the Hornby collection. Previous magnetostratigraphic investigation of Cretaceous strata from the Upper Cretaceous North Pacific Biotic Province has shown that the biostratigraphic zones sampled in our study areas correlate with magnetochrons 33R to 32R and that zones of normal and reversed polarity should be present (*14*, *19*). Our results yielded normal and reversed intervals at biostratigraphic levels that are consistent with previous paleomagnetic sampling of these biozones in the North Pacific

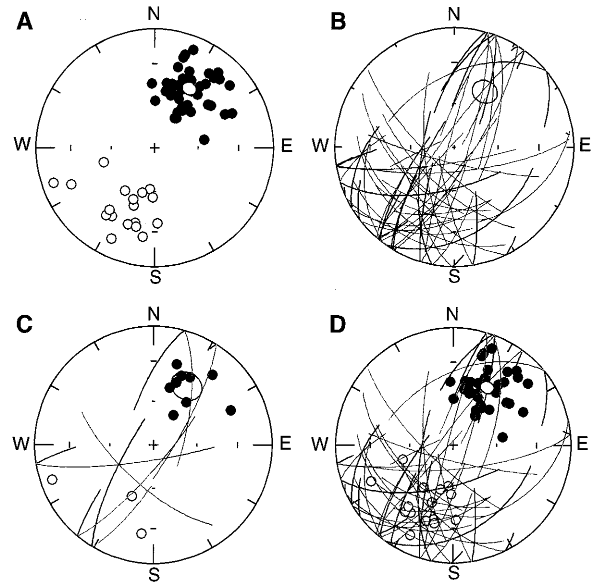

Fig. 3. Equal-area projections of the stable tilt-corrected directions from this study. For all diagrams, the solid dots and dark arcs are on the lower hemisphere, whereas the open symbols and light arcs are on the upper hemisphere. (**A**) All demagnetization lines. (**B**) All demagnetization planes, showing the arc constraints. (**C**) All line and plane directions from concretions and sandstones, which are the sedimentary rocks least likely to display inclination shallowing. (**D**) All line and plane directions from all siltsones and claystones.

Table 1. Paleomagnetic results from Upper Cretaceous sediments on Hornby and Texada islands. L, lines; P, planes; *N*, number of samples; Dec., declination; Inc., inclination; κ, Fisher's precision parameter; α_{95}, alpha 95 values; VGP lat., virtual geomagnetic pole latitude; VGP lon., VGP longitude.

Direction	*N*	Dec.	Inc.	κ	α_{95}	VGP lat. (°N)	VGP lon.
			Hornby Island				
L	41	32.2	50.5	20.8	5.0	59.8	9.5°W
		30.1*	42.2*	19.5*	4.6*	55.7*	1.2°E*
L and P	65	32.3	48.7	15.7	4.8	58.5	3.3°E
		29.4*	41.0*	14.4*	4.6*	58.6*	3.3°E*
			Texada Island				
L	19	32.4	41.7	10.4	11.0	54.1	0.9°W
		31.0*	40.7*	13.1*	9.6*	54.2*	1.6°E*
L and P	38	35.3	46.5	10.9	7.3	55.4	8.6°W
		31.6*	45.2*	11.6*	7.1*	56.5*	2.8°W*
			Combined results				
Normal L	42	33.6	50.9	19.9	5.1	59.2	11.8°W
		31.3*	42.1*	19.5*	5.1*	55.0*	0.3°W*
Reversed L	18	29.6	40.1	11.2	10.8	54.7	3.4°E
		28.3*	40.9*	12.9*	10.0*	55.8*	4.7°E*
All L	60	32.2	47.8	15.5	4.8	58.0	6.6°W
		30.4*	41.7*	17.2*	4.6*	55.2*	1.2°E*
All P	43	35.9	48.7	10.1	7.2	56.5	11.9°W
		28.8*	46.1*	7.9*	8.1*	58.8*	0.4°W*
All L and P	103	33.2	48.0	13.8	3.9	57.6	8.0°W
		30.1*	42.5*	13.3*	3.9*	55.9*	0.9°E*
			Inclination error test: Concretion and sandstones				
All L and P	18	32.9	47.5	11.0	10.9	57.4	7.2°W
		29.6*	42.5*	12.8*	10.1*	56.1*	1.7°E*
			Inclination error test: Siltstones				
All L and P	85	33.3	48.1	14.3	4.2	57.6	8.2°W
		30.2*	42.6*	13.2*	4.4*	55.8*	0.8°E*

*Values corrected for tilt of bedding.

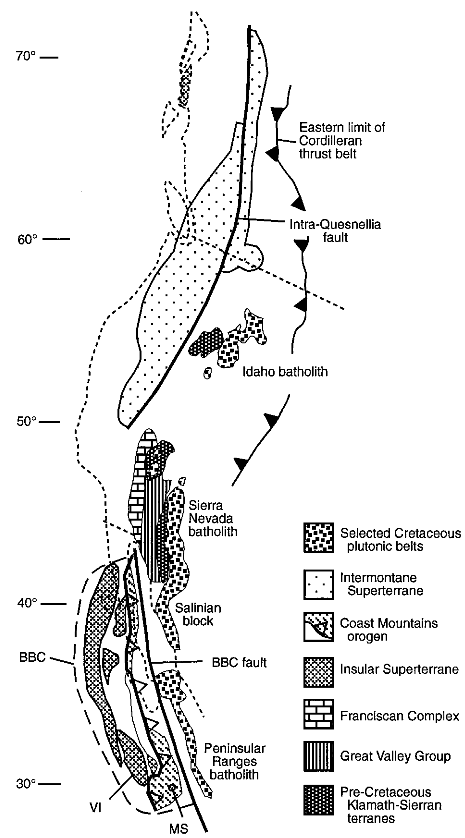

Fig. 4. Paleographic reconstruction for Late Cretaceous time (75 to 85 Ma) showing the hypothesized geographic position of BBC and the position of the hypothesized BBC fault. The paleolatitude for North America at this time is shown at the left of the diagram. Modified from (*2*).

Biotic Province and in the Tethyan region of Europe. This consistent stratigraphy is evidence for the presence of a stable original magnetization. Furthermore, we found no evidence for inclination shallowing, as magnetic directions from early diagenetic carbonate concretions are statistically indistinguishable from siltstones and claystones in the section (Table 1 and Fig. 3). We note that even if such inclination shallowing did exist in our samples, it would still not change our basic finding of large-scale terrane movement: although inclination errors on the order of 10° have been documented in some clay-rich sediments (*11*), this would change our paleolatitude estimate from 25°N to 33°N. This is not enough to explain the latitude discrepancy we have observed unless large-scale tectonic transport took place. Our results show a mean paleolatitude value for the lower Campanian Texada sites of 26.7° ± 5.7°N, whereas the upper Campanian Hornby sites yielded a mean value of 23.5° ± 3.5°N. Because these mean directions are not statistically distinct (Table 1), we infer that there was no measurable translation of the Insular Superterrane during Campanian time. Our results place Vancouver Island off the coast of Baja California between 70 and 80 Ma, with an inferred geographic displacement of about 3500 km (Fig. 4). Within the error limits, our data imply that the Insular Superterrane occupied latitudes similar to those of the present-day Rosario Formation of Baja California, Mexico.

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Fossilized Metazoan Embryos from the Earliest Cambrian

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Small globular fossils known as *Olivooides* and *Markuelia* from basal Cambrian rocks in China and Siberia, respectively, contain directly developing embryos of metazoans. Fossilization is due to early diagenetic phosphatization. A nearly full developmental sequence of *Olivooides* can be observed, from late embryonic stages still within an egg membrane, to hatched specimens belonging to several ontogenetic stages. Earlier cleavage stages also occur, but cannot be identified to taxon. *Olivooides* shows similarities to coronate scyphozoans and to their probable Paleozoic representatives, the conulariids. *Markuelia* eggs contain looped embryos of a segmented worm with short, conical processes covering the body.

Reports of fossilized eggs of marine invertebrates are rare. This may, however, largely be due to the difficulties of recognizing them. There is an abundance of small globular structures in the fossil record, including that of the Cambrian (*1*). Zhang and Pratt (*2*) reported Middle Cambrian spherical fossils, 0.3 mm in diameter, that under a smooth membrane preserved a polygonal pattern which the authors interpreted as remains of blastomeres belonging to 64- and 128-cell stages of arthropod embryos. In some other cases, at least a general resemblance to eggs has been noted. We report here that two such occurrences of globular fossils from basal Cambrian rocks are eggs containing identifiable embryos (*3*) of metazoans.

As the name implies, the Early Cambrian *Olivooides* Qian, 1977, has been compared to eggs, and Zhang and Pratt (*2*) mentioned this fossil as a possible further example of fossilized eggs. We have found that the globular fossils indeed contain developing embryos of the co-occurring fossil hitherto known as *Punctatus* He, 1980 (= *Pyrgites* Yue, 1984). The material (thousands of eggs and about 10 more or less complete hatched specimens) derives from limestones of an interbedded chert–limestone–phosphorite sequence in the upper part (beds 23 to 27) of the Dengying Formation in the Shizhonggou section, near Kuanchuanpu village, Ningqiang County, Shaanxi Province, China (*4*). The level is equivalent to the Kuanchuanpu Formation *sensu* Qian (*5*, *6*). Associated fossils, *Anabarites trisulcatus*, *Siphogonuchites triangularis*, and *Carinachites spinatus*, indicate that these are Lower Cambrian (Lower Meishucunian) rocks.

The hatched animal (Fig. 1, J and K) is conical, with rounded cross section and distinct transverse annulations. The largest specimen is 3.3 mm long. A characteristic surface pattern of star-shaped projections, stellae, in the apical part is replaced in the more apertural parts by fine longitudinal striae (*6*, *7*). Growth seems to have taken place by addition of striated tissue: Smaller specimens (Fig. 1J) are dominated by stellate tissue, whereas larger ones may have

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