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Magnetostratigraphic potential of Longarm Formation (Lower Cretaceous) strata, Queen Charlotte Islands, British Columbia

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Abstract: A new magnetostratigraphic study of Cretaceous rocks of the Queen Charlotte Islands should improve the resolution of local and regional correlations and help assess possible latitudinal displacements. Preliminary sampling of Longarm Formation strata was done at three widely spaced localities in the islands (NTS 103C, F) to test the preserved magnetic signal. Biostratigraphic data suggest the sections include Hauterivian, Barremian, and Aptian strata.

All samples have magnetizations of moderate intensity and almost all reached stable endpoints during alternating field demagnetization. Stable endpoint inclinations are generally negative and commonly quite steep. Declinations are somewhat scattered but tend to fall in the southwest quadrant. Rock magnetic studies indicate that the principal magnetic carrier is very fine-grained magnetite. On the basis of this pilot study, we conclude that Longarm Formation strata contain a primary remanent magnetization suitable for magnetostratigraphic and tectonic studies.

Résumé : Une nouvelle étude magnétostratigraphique des roches crétacées des îles de la Reine-Charlotte devrait améliorer la précision des corrélations locales et régionales et faciliter l'évaluation des éventuels déplacements latitudinaux. Un échantillonnage préliminaire des strates de la Formation de Longarm a été exécuté dans trois localités largement espacées dans les îles (cartes 103 C, F du SNRC), afin de vérifier le signal magnétique préservé. Les données biostratigraphiques suggèrent que les coupes échantillonnées renferment des strates du Hauterivien, du Barrémien et de l'Aptien.

Tous les échantillons présentent des aimantations modérées et presque tous ont atteint des points extrêmes stables lors de la désaimantation du champ alternatif. Les inclinaisons des points extrêmes stables sont généralement négatives et souvent assez raides. Les déclinaisons affichent une certaine dispersion, mais elles ont tendance à chuter dans le quadrant sud-ouest. Les études magnétiques des roches indiquent que le principal porteur magnétique est une magnétite à grain très fin. À la lumière des résultats de cette étude pilote, les auteurs concluent que les strates de la Formation de Longarm renferment une aimantation rémanente primaire qui convient à des études magnétostratigraphiques et tectoniques.

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INTRODUCTION

Cretaceous rocks form a significant part of the Mesozoic succession of Queen Charlotte Islands, western British Columbia (Fig. 1). The basement to the Cretaceous rocks of Queen Charlotte Islands is the classic Wrangellia Terrane sequence (summarized in Thompson et al., 1991 and Lewis et al., 1991) and includes Triassic pillow basalts and massive flows of the Karmutsen Formation and a conformably overlying succession of marine carbonates and clastics of Late Triassic to Early Jurassic age. Subsequent Middle to Late Jurassic arc volcanism is reflected in widespread pluton emplacement, and coeval andesitic volcanic rocks and associated epiclastic strata (Anderson and Reichenbach, 1991; Cameron and Tipper, 1985; Haggart, 1992).

The latitudinal position of Wrangellia during the Cretaceous is unclear. Various workers, citing paleomagnetic data, have inferred that Wrangellia Terrane occupied a low paleolatitude during Cretaceous time (Monger et al., 1982; Cowan, 1993; Wynne and Irving, 1993). Others cite geological evidence to suggest that the terrane arrived at its approximate position relative to North America by Middle Jurassic time (Thompson et al., 1991; van der Heyden, 1992; McClelland et al., 1992). The present study may resolve the problem.

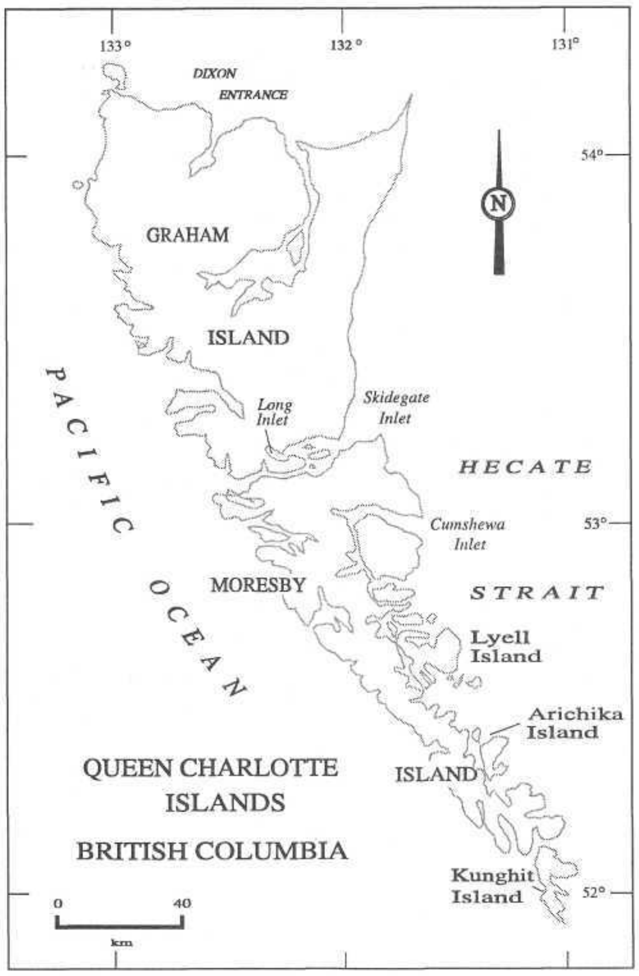

Figure 1. *Location map of Queen Charlotte Islands, British Columbia.*

The Cretaceous sequence of the islands records a history of essentially uninterrupted sedimentation through Cretaceous time. Strata of all stages are known with the exception of Berriasian and Maastrichtian, although there is a suggestion that at least the Berriasian may also be present (Haggart, 1991, 1992). Volcanic strata are uncommon in the Cretaceous succession and are known from only one geographically and temporally restricted Late Cretaceous locale. Most sections of Cretaceous strata exhibit an overall fining-upward trend and reflect initial transgression upon pre-Cretaceous basement and subsequent basin deepening. Stratigraphic analysis and paleocurrent and provenance studies indicate the basin was mostly open to the west (Yagishita, 1985; Haggart, 1991; Haggart and Carter, 1993; Gamba, 1993).

To date, correlation of Cretaceous strata of Queen Charlotte Islands has relied principally on molluscan biostratigraphy. However, difficulties exist in correlating poorly fossiliferous sections, especially in finer-grained facies. In addition, the endemic nature of much of the Cretaceous macrofauna of the islands restricts their utility in long distance, global correlations. Typically, microfauna are poorly preserved, although recent work suggests that some microfaunal groups may have promise in this area (e.g., Haggart and Carter, 1993).

As a potential correlation tool, we have initiated a magnetostratigraphic sampling program of Cretaceous strata of the Queen Charlotte Islands. The goals of this program are: 1) to improve the resolution of local stratigraphic correlations; 2) to increase the precision of regional and global correlations; 3) to integrate bio- and magnetostratigraphy for Cretaceous strata of the Northeast Pacific region; and 4) to assess various models of the Cretaceous tectonic history of the region.

PALEOMAGNETIC SAMPLING

To assess the suitability of Lower Cretaceous rocks for paleomagnetic studies, we sampled strata of the Valanginian to Aptian Longarm Formation in four sections at three widely separated localities in the islands: at Long Inlet in western Skidegate Inlet; at Cumshewa Inlet; and at Arichika Island (Fig. 1). The Longarm Formation at each of these localities consists of clastic sedimentary strata, variably rich in macrofossils. Although biostratigraphic control in each of the sections is limited, molluscan fossils indicate that the four sections include strata of at least Hauterivian-Barremian age (Fig. 2).

Section 89-1, in Cumshewa Inlet, was sampled using a portable, gasoline-powered diamond core drill. Three oriented cores were collected at each sample site. This section consists of medium- to coarse-grained, cross-stratified silty sandstone at the bottom, locally with pebble stringers. Several covered intervals characterize the lower part of the section and basalt sills, 0.5 to 3 m thick, are found near the base and top. The section fines upward into massive to cross-stratified, silty fine-grained sandstone and sandy siltstone. Fossils collected from Section 89-1 include *Inoceramus* cf. *paraketzovi* EFIMOVA and *Simbirskites* in the lower part, indicating the presence of Hauterivian strata (Jeletzky, 1970), and the ammonites *Shasticrioceras, Lytoceras,* and *Shastoceras* in the middle part, indicating the presence of Barremian and possibly Aptian as well (Anderson, 1938; Murphy, 1975). Nine sites were sampled from this section, for an average sample interval of 15 m.

Sections 89-2 and 89-3, both in Long Inlet, do not include the base of the Cretaceous section, although facies and age relationships suggest that our paleomagnetic sampling included strata near the base of the stratigraphic succession in this region. Section 89-2 dips gently (30°NE) while Section 89-3 dips vertically (also NE). Several 0.5 to 1 m thick sills were noted in the upper part of Section 89-3. Lower strata in Section 89-3 and all strata in Section 89-2 consist of strongly indurated, silty, fine- to medium-grained, cross-stratified sandstone to granule sandstone, of lithic-arenite composition. Higher strata in Section 89-3 are more massive and consist of fine-grained sandstone to sandy siltstone. Fossils from the middle of Section 89-3 include the bivalve *Inoceramus* cf. *paraketzovi*, suggesting a general Hauterivian age. Fossils from Section 89-2 include the ammonite *Simbirskites* spp., also indicating a Hauterivian age, probably early (Jeletzky, 1970). Paleomagnetic samples were collected from each section following the procedure outlined above. Two sites were sampled from Section 89-2, for an average sample interval of 20 m. Five sites were sampled from Section 89-3, for an average sample interval of 30 m.

On Arichika Island, the last sampled locality (Section 89-4), the section consists of a basal conglomerate that fines upward through coarse-grained sandstone to fine-grained sandstone in its upper limits. The bivalve *I.* cf. *paraketzovi* and small belemnites were collected from the lower part of the section, indicating a Hauterivian age for those beds. We collected four oriented hand samples from Section 89-4, for an average sample interval of 46 m (Fig. 2).

All samples were measured on a cryogenic magnetometer at the Paleomagnetics Laboratory, University of California, at Davis.

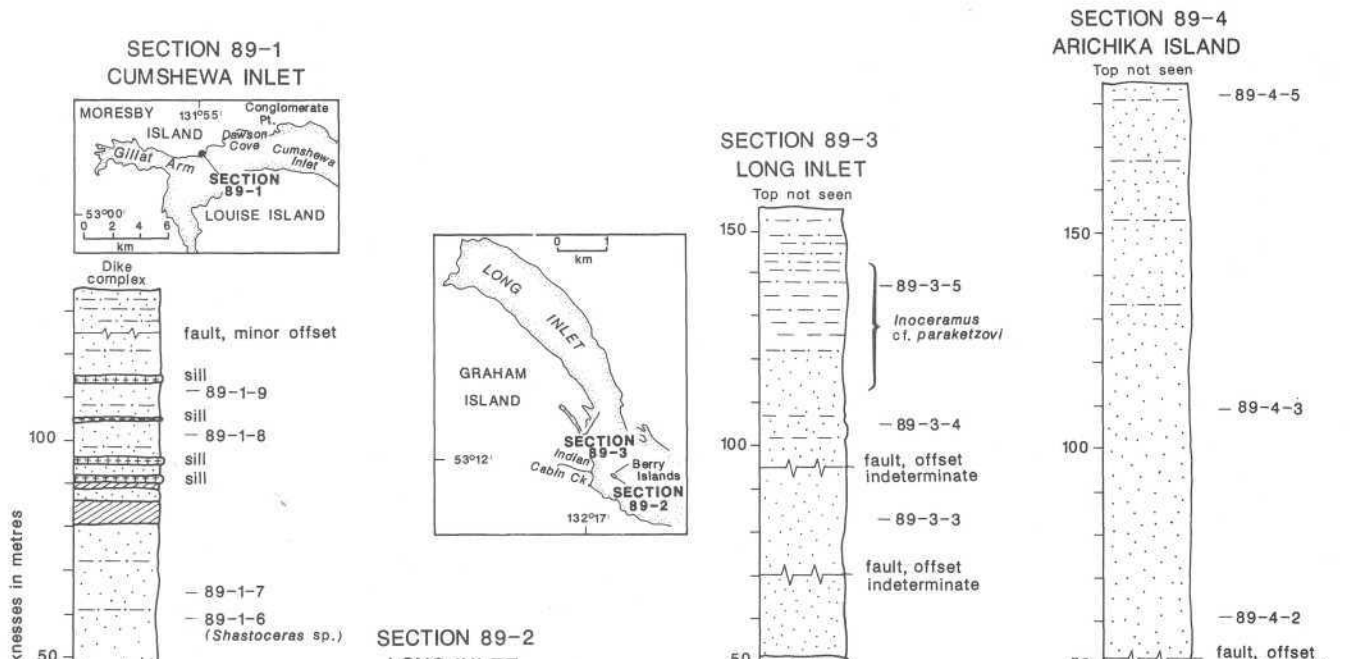

Figure 2. *Stratigraphy of sampled Longarm Formation sections, Queen Charlotte Islands. No correlation of sections implied.*

ROCK MAGNETIC ANALYSIS

We determined the nature of the magnetic carriers by studying the acquisition and demagnetization of anhysteretic remanent magnetization (ARM) and isothermal remanent magnetization (IRM). ARM is the magnetization acquired by a sample exposed to a weak direct field in the presence of a decreasing alternating magnetic field. IRM is the magnetization acquired in the presence of a strong direct field. Figure 3 shows typical curves for IRM acquisition. In these examples, the magnetization levels off and becomes saturated at about 100-200 milliTesla, which suggests that magnetite, rather than hematite, is the magnetic carrier.

Comparisons of alternating field demagnetization of the ARM and the saturated IRM (SIRM) of typical samples are shown in Figure 4. The SIRM curve is consistently below the ARM curve, which implies that the strata contain fine-grained magnetic carriers in either a single domain or pseudo-single domain state. Together with IRM acquisition data, these results indicate that the magnetic mineralogy of the Longarm Formation consists primarily of fine-grained magnetite.

PALEOMAGNETIC ANALYSIS

Samples from all four sections were subjected to both alternating field and thermal demagnetization. Figure 5 shows typical curves of the decrease in intensity during alternating field demagnetization. The curves have median destructive fields of about 20-35 milliTesla, which is consistent with our inference about the nature of the magnetic carriers. Figure 6 shows typical curves of directional changes during alternating field demagnetization of samples from Long Inlet. Closed squares are plotted on north-south and east-west axes, and represent the declinations at each demagnetization level. Open squares are plotted on vertical and horizontal axes, and represent the inclinations at each demagnetization level. The initial direction (zero demagnetization level) is shown by the enlarged box.

Paleomagnetic results from Arichika Island and the two sites on Long Inlet are quite promising. In each case, the alternating field demagnetization quickly removed any viscous secondary components and thereafter the magnetization decayed univectorially toward the origin. Thus, these samples appear to have stable primary directions with well-defined endpoints. The samples from Cumshewa Inlet are more difficult to interpret, and it is not always clear that a stable endpoint was reached in the demagnetization process.

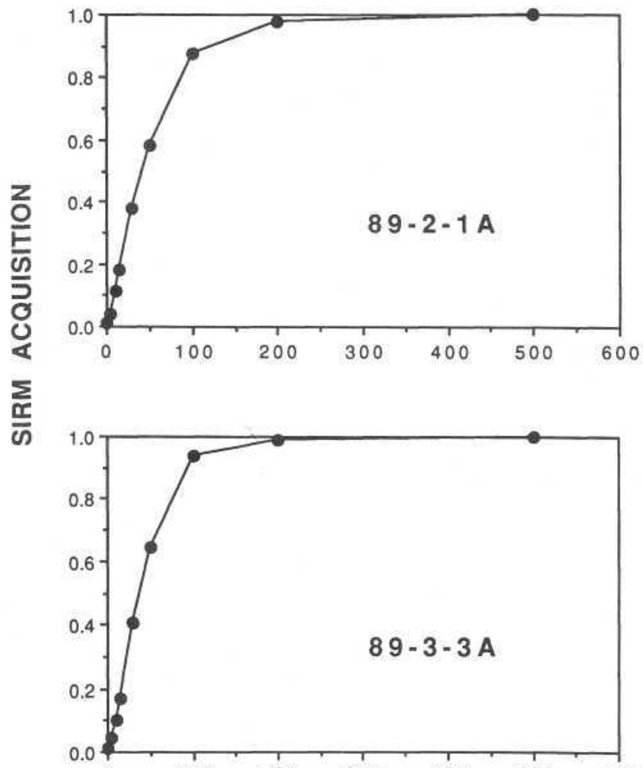

Figure 3. Typical SIRM acquisition curve obtained after demagnetization. Induced magnetization on the vertical axis and acquisition level (milliTesla) on the horizontal. The curve levels off, or becomes saturated, at ~100-200 milliTesla.

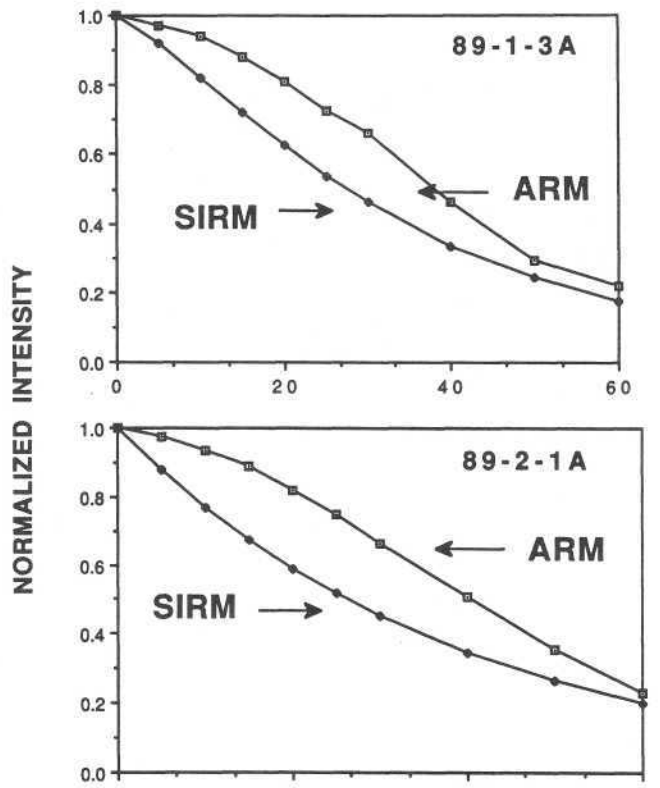

Figure 4. Typical ARM-SIRM curves.

The results of thermal demagnetizations are problematical. At about 400°C several of the samples showed large and erratic changes in direction, associated with moderate increases in magnetic susceptibility. We believe that these directional changes reflect chemical alteration of magnetic minerals caused by heating. Paleomagnetic data obtained below 400°C generally showed univectorial decay toward the origin and, more importantly, for paired samples there was very good agreement between the results obtained by alternating field demagnetization and those obtained by thermal demagnetization.

The alternating field or thermal demagnetization curve for each sample was analyzed using the least-squares approach of Kirschvinck (1980). For alternating field demagnetization, the 16 samples from Long Inlet and Cumshewa Inlet yielded 12 good directions. All of these directions had upward inclinations and southerly declinations that indicate a reversed magnetic polarity. These results are shown in Figure 7a. The four samples from Arichika Island yielded three good directions, all of which had the downward inclinations and northerly declinations of a normal magnetic polarity. As noted above, thermally demagnetized samples generally yielded directions that were consistent with directions obtained from paired samples that had been thermally demagnetized. The thermally demagnetized directions from samples from Long Inlet and Cumshewa Inlet are shown in Figure 7b.

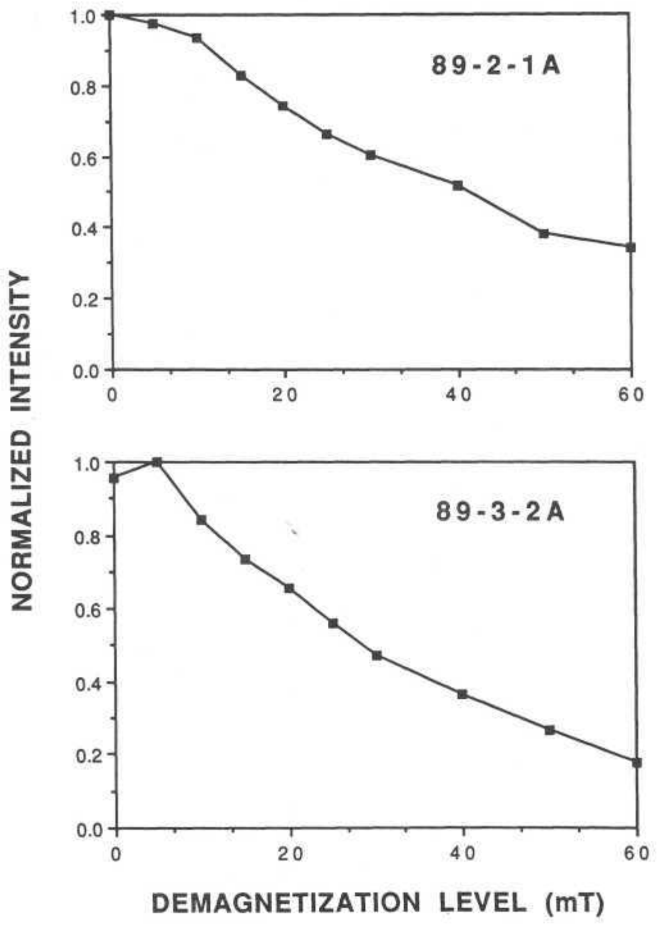

Figure 5. Typical curves of intensity decrease during demagnetization. The curves fall off with median destructive fields of about 30-35 milliTesla, consistent with our inferences about the nature of the magnetic carrier.

DISCUSSION

Subsequent remagnetization possibilities

Structural disruption of Mesozoic strata on Queen Charlotte Islands is concentrated in discrete zones (Thompson et al., 1991) and most rocks exhibit low metamorphic grade (Sutherland Brown, 1968). Most sections of Cretaceous rocks outside the principal deformation zones are flat lying to gently dipping, show minimal deformation and alteration, and, at a few sites, contain mollusc fossils that retain their original aragonite component (Haggart, 1991).

Conodont Colour Alteration work on Triassic rocks and organic maturation studies on Mesozoic strata indicate a systematic diagenetic alteration pattern across the islands, increasing towards the southern part of Queen Charlotte Islands and likely reflecting proximity to plutonism (Orchard and Forster, 1991; Vellutini and Bustin, 1991). Our sampled sections were selected to avoid as much as possible structural disruption and effects of intrusion. It appears that this strategy

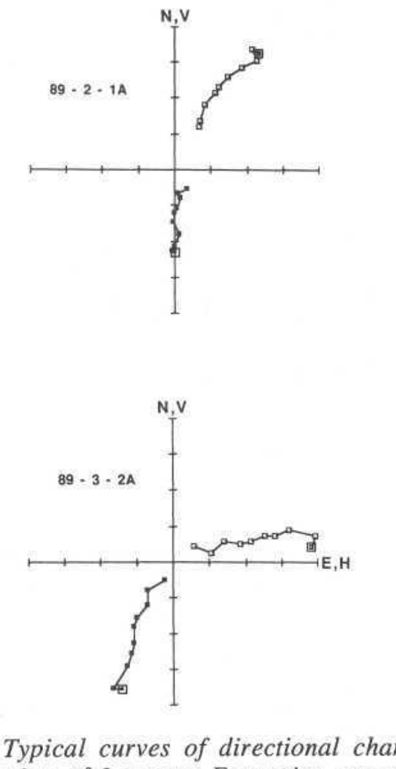

Figure 6. Typical curves of directional change during demagnetization of Longarm Formation samples. Closed squares refer to sample declination and are related to north and east axes. Open squares refer to vertical and horizontal axes and give sample's magnetic inclination. The start of each curve is shown by the enlarged boxes.

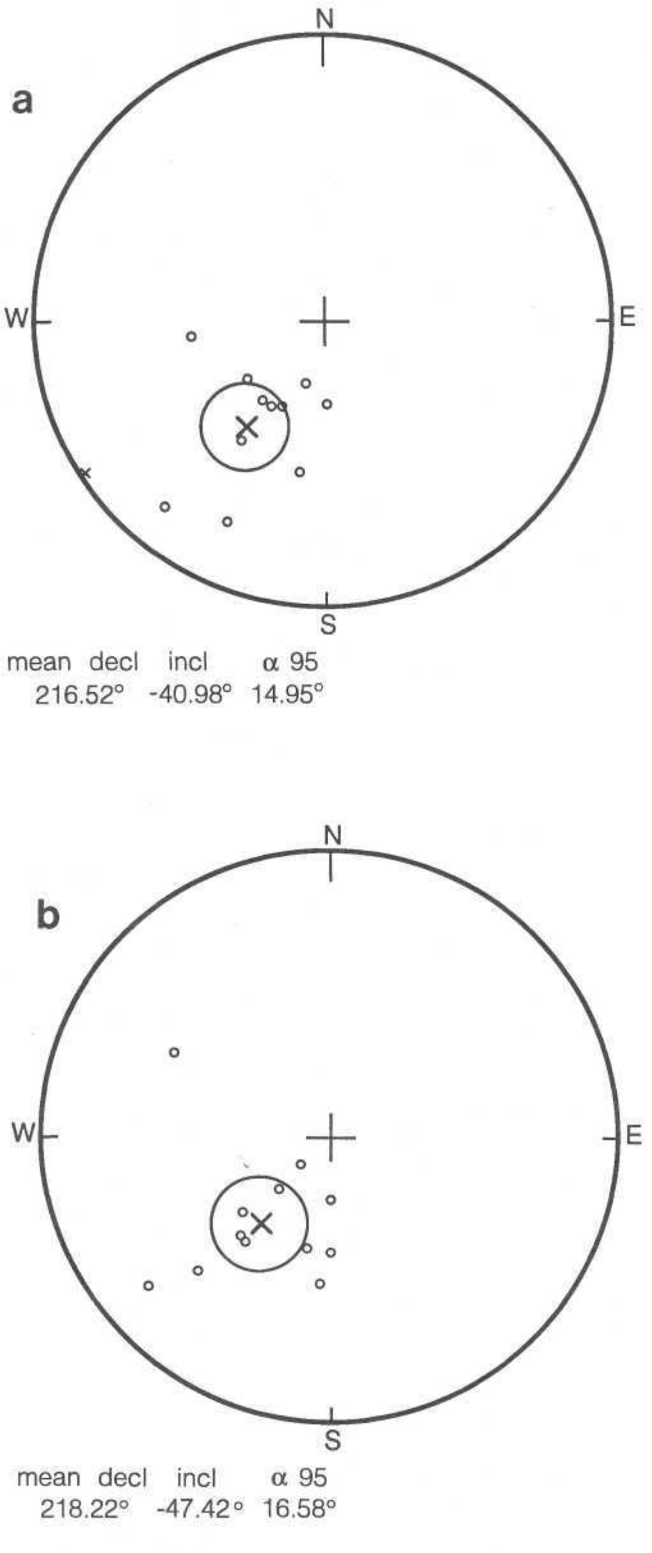

*Figure 7. Stereonet of final directions for the 12 samples with stable endpoints. (**a**) shows mean direction for alternating field demagnetized samples; (**b**) shows mean direction for thermally demagnetized samples.*

can guide us in future sampling. The fact that good magnetic signals were obtained from the vertically dipping Section 89-3 in Long Inlet suggests that structural disruption has affected the magnetic signature minimally or not at all.

The question of whether a normal overprint has been fully removed is relevant to magnetostratigraphic studies of the Longarm Formation. The recovery of almost antipodal normal and reversed directions is strong evidence that we are dealing with a primary detrital remanent magnetization that has not been subsequently remagnetized. In fact, the two most likely sources of remagnetization are the Recent and the Cretaceous Long Normal Intervals. The fact that most of the polarities measured are reversed is additional evidence against the remagnetization hypothesis.

Magnetostratigraphy

The magnetic polarity time scale for the Lower Cretaceous is shown in Figure 8. The Hauterivian-Aptian interval is a period characterized by both normal and reversed magnetic polarity zones of varying length. Above Chron M0, however,

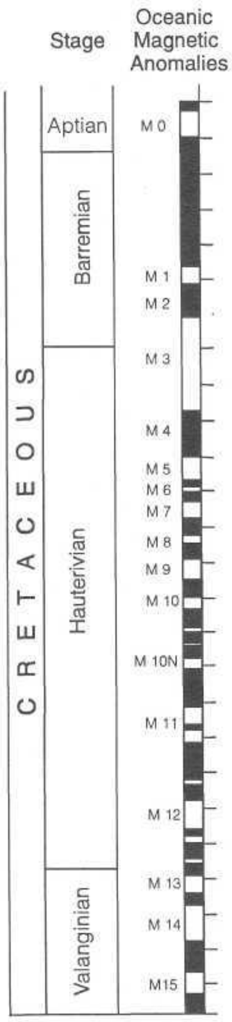

Figure 8. Lower Cretaceous magnetostratigraphic time scale (after Lowrie and Alvarez, 1984).

found within the lower part of the Aptian (Lowrie and Alvarez, 1984; Lowrie and Ogg, 1986), an extended period of normal polarity, termed the Cretaceous Long Normal Interval, characterizes the time scale until the lower Campanian.

The biostratigraphic data we have for our four sections suggest that Aptian strata are present only in the Cumshewa Inlet section (Section 89-1). This is based on the occurrence of the ammonite *Shastoceras* at several levels in this section. The genus *Shastoceras* is endemic to the western coast of North America, and was previously recognized in the lower Aptian of northern California (Anderson, 1938; Wright, 1957). Thus, we infer that all strata sampled in Section 89-1 in Cumshewa Inlet, spanning some 135 m, are contained within Chron M0 or below. It is interesting to note that to date, our sampling of this section has only detected reversed polarity zones. However, we consider this fortuitous and due to the sparse sampling density undertaken for our preliminary study. We also note that six of the sampled horizons in Section 89-1 are within the zone of *Shastoceras* and thus are likely within the lower Aptian reversed zone. Given that the absolute time represented by both normal and reversed polarity periods is approximately equal for the Hauterivian-lower Aptian interval (Lowrie and Ogg, 1986), it is not surprising that the three sampled horizons lower in the Cumshewa Inlet section are also of reversed polarity.

Unfortunately, with the low sampling density that characterizes our preliminary study it is not possible to confidently correlate the bulk of our sampled sections with the magnetic polarity time scale. We are confident, however, that a complete magnetostratigraphic study of the Longarm Formation, integrated with available biostratigraphic control, will ultimately allow us to make an unambiguous correlation with the time scale.

Displacement and rotation?

The mean direction for alternating field demagnetized samples in Figure 7a has an inclination of -41.0° and a declination of 216.5° with an α_{95} of 14.9°. For thermally demagnetized samples in Figure 7b the inclination is -47.4°, the declination is 218.2°, and the α_{95} is 16.6°. On first assessment, these data seem to suggest that strata of the Longarm Formation may have been deposited at a latitude of about 25°, and that they have been subsequently rotated clockwise about 15-20°.

Although tectonic rotations of parts of northern Queen Charlotte Islands have been inferred previously, based on paleomagnetic data (Yorath and Chase, 1981; Higgs, 1990), these interpretations have been questioned on the grounds of geologic evidence (Lewis et al., 1992). At present, we feel there are too few samples in our data set to allow us to draw any firm conclusions from the data regarding possible displacements or rotations. In addition, we note that the three good (normal) directions from Arichika Island are significantly steeper than the reversed directions shown in Figure 7. This suggests that we may not have removed all the normal overprint in the samples with reversed directions. Clearly, additional sampling and additional paleomagnetic and rock magnetic studies are needed before the questions of translation and rotation can be resolved. However, our preliminary results indicate that these studies are certainly worth pursuing.

CONCLUSIONS

We emphasize that our study to date has been preliminary in scope, with the goal of assessing the suitability of Cretaceous strata of Queen Charlotte Islands for detailed paleomagnetic study. We have found that the principal magnetic carrier appears to be fine-grained magnetite and that the rocks carry a strong and stable magnetic signal. Primary directions with stable endpoints have been recovered using both alternating field and thermal demagnetization methods, and these directions represent both normal and reversed polarities. With additional work, it should be possible to develop a detailed magnetostratigraphy of Cretaceous strata and possibly to determine the extent of tectonic translations and rotations.

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