A reconnaissance paleomagnetic study of cretaceous rocks from central Cuba

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Abstract. We applied thermal demagnetization to 12 sites of mid- and Upper Cretaceous volcanics and sediments of the Zaza terrane (central Cuba). Consistent directions of low- and/or high-temperature components were obtained from eight sites. The fold test performed on a short-wave fold in the Upper Cretaceous Arimao Formation is negative, as well as the conglomerate test on lava boulders from the same formation, whereas site-means for the entire data set are better grouped after tilt-correction. We conclude that the entire Cretaceous succession of the Zaza terrane was re-magnetized in the Campanian. The measured latitude is lower by 15°±6° with respect to the North American APWP indicating ca. 1600±600 km northward displacement of the Zaza terrane since the Campanian. Also discordant is the measured declination implying 37°±11° counterclockwise rotation of the Zaza terrane.

Geological setting and sampling

The tectonic structure of Cuba comprises many fault-bounded zones consisting of multiple thrusts and nappes. All tectonic zones can be combined into three domains (Fig. 1a) [e.g., Pushcharovsky et al., 1989]: 1) the northern zones comprising thick sedimentary piles without influx of volcanic material; 2) the central volcanic zones including both ophiolite and volcano-sedimentary island-arc complexes; 3) the southern zones where sedimentary and metasedimentary rocks prevail. All volcanic domains from different parts of Cuba were often united as a Zaza zone in spite of considerable lateral variations in structure, composition and probably in age. Two main complexes, namely ophiolites and 10 km-thick volcano-sedimentary pile of island-arc origin, are recognized here [Knopper, 1975; Somin and Millan, 1981]. The Zaza zone actually consists of remnants of different terranes juxtaposed during the Late Cretaceous and Eocene [e.g., Pushcharovsky et al., 1989]. Though against an important role of horizontal movements, contrasting views are expressed on the evolution of Cuba: for instance, the volcanic complex in west Cuba is thought to have been thrust northward [Fonseca et al., 1985; Mossakovskiy and Albear, 1978] or southward [Pushcharovsky et al., 1989].

In central Cuba, the Zaza zone comprises volcano-sedimentary rocks of the so-called Tobas series (Fig. 1b), [Mapa...R. 1985]. The rhyolite-basalt Los Pasos Formation at the section base is overlain by the thick pile of basalts, andesites and tuffs of the Matagua Formation of Aptian-Albian age [Renne et al., 1991].

The volcanics are overlain by carbonates and tuffs of the Latest Albian-Cenomanian Provincial Formation [Hatten et al., 1989]. Still above, tuffs and tuffaceous sandstones and siltstones of the Late Cretaceous Seibabo formation are in turn covered by massive dacites and rhyolites of the Bruja Formation. The approximate counterpart of the two latter formations is the Arimao formation in the west which consist of lavas, tuffs and conglomerates. With angular unconformity, the above succession is overlain by Maastrichtian and younger rocks. The Zaza zone is bounded in the north by a large fault, and its southern boundary passes along the contact of Lower Cretaceous lavas with Manicaragua granite intrusions and/or metamorphic rocks.

A collection of Cretaceous rocks was sampled from the Zaza zone during a three-day field trip in 1988. Bedding attitudes could be measured in Neocomian Los Pasos volcanics at one limited outcrop (site M1, Fig. 1b); even there, bedding varied considerably. The Matagua Formation was sampled from a number of small outcrops considered as one site M2. Limestones and calcareous tuffs of the Provincial Formation, volcano-sedimentary rocks of the Seibabo formation, and well exposed Bruja volcanics were sampled at sites M3 to M6, M7 to M8, and M9, respectively. Sites M1 to M7 are from the southern limb of the Seibabo syncline, whereas sites M8 and M9 are from its axial part. To the south-west, volcanics and volcano-sedimentary rocks of the Arimao Formation were studied at sites A1 and A3. Stratified rocks at site A1 are overlain by conglomerates composed of well-rounded lava boulders up to 15 cm in diameter immersed in volcanoclastic matrix visibly similar to that of stratified rocks; eight boulders were sampled (site A2). Still above, conglomerates are altered and cut by numerous quartz veins. In total, 72 hand-samples oriented with magnetic compass were taken from 12 sites. Samples were spaced over up to several tens meters at each site. Almost everywhere, rocks dip northwest to northeast at various angles, with the only exception of site M8 where rocks dip to the south. Also, a small fold was studied at site A1. No reliable bedding measurements could be made on the Bruja Formation at site M9.

Treatments and Results

Treatments. Two cubic specimens from each hand-sample were heated in up to 17 steps using Schonstedt TSD-1 demagnetizer in the Paleomagnetic laboratory of Rennes University. Measurements were made on either Schonstedt spinner with noise level about 2 x 10^-4 A/m or cryogenic magnetometer with the noise level about 2 x 10^-5 A/m. Components isolated from two specimens from a sample were used to calculate sample-means which were in turn used for computation of site-means.

Overview. Intensities of natural remanent magnetization, NRM, vary from 1 A/m in volcanics of the Matagua, Arimao and Bruja formations to 10^-2 A/m in tuffs of the Seibabo and Provincial Formations to below 10^-3 A/m in the Provincial carbonates. Demagnetization characteristic are also variable. In a few samples, a characteristic component, ChRM, was isolated above 350°-400°C (Fig. 2a), whereas in other ones the ChRM was evident only above 550° (Fig. cuba 2b). Still other samples
M7 yielded well defined and tightly clustered HTC directions. In contrast, a HTC was isolated from all samples from site M8; in addition, a LTC was isolated from four samples. Both components are consistent on the within-sample level, but have a planar distribution, the differences being mainly in declination. We suspect that the planarity results from strongly overlapping unblocking spectra of different NRM components which we failed to properly isolate. The fold test for this formation is inconclusive.

Bruja Formation. All specimens from four blocks of these volcanics revealed a well-defined component from 200° on. Unfortunately, sample-means are scattered in situ. Judging by demagnetization data, these rocks do carry a stable remanence but were deformed, probably folded. Since no beddings could be measured in the field, this results was rejected.

Arimao Formation. Though often heavily overprinted and displaying curved plots (Fig. 2c,d), these rocks yielded consistent HTC directions (Table 1). Boulders from intraformational conglomerate also responded well to thermal cleaning, usually revealing two components of magnetization (Fig. 2g). The scatter of the LTC is rather low, whereas the HTC is much more dispersed (Table 1, Fig. 3). Nevertheless, in both cases the length of vector-resultant much exceeds the 95% confidence level of the uniformity test (Mardia, 1972); in addition, low value of precision parameter for the high-temperature component is mainly due to data from two boulders.

Combined Results and Analysis

In total, a LTC was isolated from 7 sites and HTC from 8 sites out of 12; everywhere, these components are of normal polarity.

Figure 1. Tectonic zonation of Cuba (top) and schematic geological map of studied area (bottom). Legend to tectonic map: 1, tectonic zone of the North American shelf and continental slope; 2, central volcanic zone, including ophiolite complexes; 3, southern tectonic zone including metamorphic rocks of the Escambray massif; 4, Paleogene volcanics of southern Cuba; 5, undeformed cover (Oligocene and younger rocks). Legend to geological map: 1, serpentines; 2, metamorphic rocks of the Escambray massif and Manicaragua igneous rocks; 3, Neokomian Los Pasos Formation; 4, Aptian-Albian Matagua Formation; 5, Late Albian-Cenomanian Provincial Formation; 6, Turonian to Campanian rocks; 7, Maasthichtian-Paleogene rocks; Quaternary rocks. Sampling sites are shown as solid dots.

are strongly overprinted by an unstable remanence, but a well-defined ChRM could be recovered (Fig. 2c,d). Most samples displayed curved plots, and ChRM isolation was sometimes difficult (Fig. 2e,f). Different behavior could be displayed by samples from the same formation as illustrated for Matagua volcanics (Fig. 2a,f) and Provincial tuffs (Fig. 2b,e). Most samples were completely demagnetized at about 580° thus implying magnetite as the main carrier; in some samples, however, that hematite may also be a carrier (Fig. 2b,d).

Los Pasos Formation. Five hand-samples yielded a high-temperature component (HTC) consistent within samples but very scattered between samples, both in situ and after tilt correction. Bedding attitudes measured on sedimentary layers cannot be much in error. The origin of this dispersion remains an enigma, and this result was rejected, though tilt corrected site-mean agrees with the other data (Table 1).

Matagua Formation. All ten hand-samples of volcanics and sediments yielded interpretable results, though of different quality (Fig. 2a,f); both low-temperature component (LTC) and HTC were isolated (Table 1). Though beddings somewhat vary from sample to sample, the clustering of sample-means is the same in both coordinate systems, with just a 10-percent improvement of grouping during incremental unfolding.

Provincial Formation. Weakly magnetized micritic limestones from sites M3 and M4 did not yield consistent data. Tuffs from Matagua-Provincial transitional layers (site M5) revealed consistent HTC directions from only three samples (Table 1). Also, a LTC was isolated from weakly magnetized marls (site M5); here, no consistent component was found above 450°.

Seibabo Formation. Only three samples out of six from site M7 yielded well defined and tightly clustered HTC directions. In
formation. Solid (open) symbols are projections onto lower (upper) hemisphere.

Figure 3: Tilt-corrected directions of low-temperature (a) and high-temperature (b) components from boulders of the Arimao Formation. Solid (open) symbols are projections onto lower (upper) hemisphere.

We cannot estimate the within-sample scatter in each sample having studied just two specimens. However, we calculated vector-results for each pair of specimens and then averaged them. The mean length of the vector-resultant corresponds to precision parameter of about 300; thus implying a negligible noise on the within-sample level and reliable component isolation. In contrast, the between-sample dispersion is rather high (Table 1). In some cases, it may partly be due to imprecise determination of bedding in volcanics, but similar scatter is found in well-stratified rocks as well (site M8). We mainly blame this scatter on the complex nature of the NRM in these rocks.

Although many specimens displayed well-defined remagnetization circles during cleaning, the normals to remagnetization circles outline an almost isometrical rather tight cluster close to the stereonet center (not shown). The direction of the normal to the best-fitting plane [Halls, 1976] is D = 316°, I = 11°, close to the mean for direct observations (Table 1) but hardly reliable.

For the HTC in the Arimao formations, we selected 16 sites from the Matagua and three sites from the Provincial Formations [Renne et al., 1991]. In spite of close proximity of sampling sites, our results and reported data differ in several ways. First, our data are more scattered. Since it is not clear which stratigraphic interval was spanned by each site of Renne et al. [1991], it is difficult to speculate on this subject. Second, our isometric distribution of normals to remagnetization circles contrasts with their long band, but our cluster coincides with the maximum density of data within the band. Finally, our sites yield

Table 1. Paleomagnetic Results

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<th>S</th>
<th>FM</th>
<th>B</th>
<th>N</th>
<th>D°</th>
<th>I°</th>
<th>K</th>
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<tr>
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<td>19</td>
<td>17</td>
<td>10.8</td>
<td>300</td>
<td>17</td>
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</table>

Comments. S is the number of sites as in Figure 1b; FM is the studied formation: LP, Los Pasos; FM, Matagua; PV, Provincial; SB, Seibabo, AR, Arimao; B is the mean azimuth of dip/mean angle of dip (f is for the sites where a fold was studied); N is the number of hand samples studied/used; D is declination; I is inclination, K is precision parameter; a95 is radius of confidence circle [Fisher, 1953].

Interpretation and Discussion

The only paleomagnetic result from central Cuba was reported on two sites from the Matagua and three sites from the Provincial Formations [Renne et al., 1991]. In spite of close proximity of sampling sites, our results and reported data differ in several ways. First, our data are more scattered. Since it is not clear which stratigraphic interval was spanned by each site of Renne et al. [1991], it is difficult to speculate on this subject. Second, our isometric distribution of normals to remagnetization circles contrasts with their long band, but our cluster coincides with the maximum density of data within the band. Finally, our sites yield and the marginally negative fold test for the Arimao formation.

But it is true, there is no reason to believe that all other data are not also the result of a regional remagnetization. The entire Zaza zone has undergone low-grade metamorphism, especially the Los Pasos and Matagua Formations. This might account for the good agreement of mean directions for Middle and Upper Cretaceous rocks and conglomerates (Table 1). Improvement of clustering for the entire data set may be due to the multi-phase deformation; in other words, some deformation could postdate the initial folding, metamorphism and remagnetization.

Figure 4 Equal area projections of site-mean directions of the high-temperature components from the Zaza terrane in situ (a) and after tilt-correction (b). Dots are our sites, star and triangle are mean directions of the low-temperature and high-temperature components from boulders of the Arimao Formation, respectively. Squares are unscreened site-mean directions from Renne et al. [1991]. Solid (open) symbols are projections onto lower (upper) hemisphere.
a mean inclination of 11° which is about 27° less than expected, whereas Renne et al., [1991] reported a more concordant value of 26° (Fig. 4). Presently, we cannot account for this discrepancy and, since the general agreement of the two data sets is rather good, all results were pooled. Only two directions, those from sites M8 and 89.07 [Renne et al., 1991], appear to be somewhat anomalous (Fig. 4). The last result was discarded by its authors, whereas the deviating mean from site M8 fits our conclusion that the proper isolation of the NRM components is not achieved here (see above). Without these two sites, the overall mean direction for the Zaza terrane is rather well defined (Table 1).

Two main epochs of deformation are known in the Zaza zone. Campanian tectonism is restricted to this zone and is thought to be connected with the collision of this volcanic terrane with the Escambray terrane [Pushcharovsky et al., 1989]. In contrast, Eocene folding and thrusting which had affected the entire island is regarded as the result of the collision of the Zaza-Escambray block with the North American continental margin [ibid]. Afterwards, the territory of Cuba became a part of the North American plate, NAP.

Both in situ and tilt corrected mean inclinations are similar (Fig. 4, Table 1). The tilt-corrected overall mean inclination for ten sites, 17° ± 8° (Table 1), is lower by about 20° than the NAP reference values of the Aptian to Middle Eocene age [Besse and Courtillot, 1990]. Since the sampling sites are widespread (Fig. 1b), it is unlikely that this entire area was tilted by about 20° after magnetization acquisition; in any case we are unaware of any evidence for post-Cretaceous tilting of the Zaza terrane. It implies that remagnetization of Cretaceous rocks occurred at a much lower latitude than expected for the NAP. Thus an Eocene age of remagnetization can be discarded. The ubiquitous normal polarity both of our data and those from Renne et al., [1991] also fits better with the above assumption since a long normal polarity interval is known in the Campanian while reversals where much more frequent in the Eocene [Cande and Kent, 1992]. Therefore, an older age of remagnetization should be chosen. Between the Late Campanian to Middle Eocene, no major tectonic activity is known in central Cuba. It is tempting to assume that remagnetization occurred in the Campanian, by the time of collision. In this case, there is both enough time and space to account for observed discrepancy of 15° ± 6° between the reference and measured latitudes (80 Ma mean pole at 72°N, 195°E was used). This corresponds to ca. 1600 ± 600 km northward displacement of the Zaza terrane with respect to the NAP since the Campanian to Middle Eocene.

Our interpretation of paleomagnetic data from the Zaza terrane clearly differs from that of Renne et al., [1991] who reported much less latitudinal difference of 8° ± 6°. This misfit is almost independent of the timing of remanence acquisition (Campanian vs. Aptian-Albian) or reference poles used. With such a limited data set in hand it is difficult to say which interpretation is preferable. We just point that a negligible influx of volcanic material is found in carbonates of the northern domain which is often regarded as the North American shelf and continental slope. This better matches with the Zaza terrane being far away from North America. The Campanian age of remagnetization also accounts for the of the fold test: the initial folding could have predated metamorphism and remagnetization accounting for the negative fold test for the Arimao Formation, and postdated the Middle Eocene folding as evidenced by the improvement of grouping for the entire data set.

Mean declination from the Zaza terrane deviates by 37° ± 11° westward from the 80 Ma NAP reference direction, most probably as the result of counterclockwise rotation. This rotation is certainly pre-Middle Eocene in age, for central Cuba has been tectonically stable since that time [e.g., Knipper, 1975]; until new paleomagnetic data on post-Campanian-pre-Middle Eocene rocks are available, the age and mode of rotation cannot be constrained more precisely.

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