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REPLY

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Reply to the Comment on "Chronology of Vesuvius' activity from A.D. 79 to 1631 based on archeomagnetism of lavas and historical sources" by R. Lanza and E. Zanella

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We are grateful to our colleagues Lanza and Zanella for their emphasis on a part of our paper (Principe et al. 2004) that is indeed very important for volcanologists, i.e. the precision and accuracy that can be expected from archeomagnetic dating. We unfortunately failed to sufficiently explain this point in our Table 7 caption (archeomagnetic ages), although a reference was made in the text to our methodological article (Tanguy et al. 2003), where precision and accuracy are discussed in detail. We understand, of course, that readers might have been surprised by how such ages and restricted error bars were obtained. Here is our response. With regard to the errors and assumptions associated with archeomagnetic directions outlined by Lanza and Zanella, we fully acknowledge, and have already pointed out, the three main causes for "misalignment of the ChRM recorded by volcanic rocks with respect to the paleofield present when they formed." Let us consider, however, that these problems are sometimes exaggerated (Tanguy et al. 2005) and are largely overcome through careful collection of samples within an area of tens of meters (and not centimeters, as is the case for core-drilled sampling sites such as those both at Vesuvius and Etna). In fact, the present geomagnetic field was investigated through detailed instrumental measurements on 12 of our archeomagnetic sites distributed over the whole area of Mount Etna (Tanguy and Le Goff 2004). The results demonstrated that the average geomagnetic direction typically deviates by no more than 1.5° (at the 95% confidence level) from the regular field outside the volcano. From the same study, it does not appear that geomagnetic directions "have been regionally deflected by the magnetic anomaly caused by the whole volcanic edifice", since the average of the 12 sites is within 0.4° from the "true" field in Sicily. Of course, such a study is still lacking at Vesuvius, but the simple morphology of this volcano as compared to Mount Etna suggests that magnetic anomalies are not larger. Therefore, any magnetic anomalies in our Vesuvius study are unlikely to exceed the 2° uncertainty regarded as the upper limit we allowed in our rather stringent method. We believe indeed that magnetic anomalies are mainly responsible for the dispersion we observed at each archeomagnetic site, because as previously reported, our special method enabled us to reach a precision of a few tenths of a degree on each separate sample. Also, the large samples result in good control of potential small-scale heterogeneity in magnetization, and the large number of large samples (7 to 18 per site; Principe et al. 2004; Table 3) is a further advantage of our process. We insist that the lavas that we measured extend up to 7–8 km on Vesuvius' slopes, and they were sampled at sites tens (and in some cases, hundreds) of meters across. We carefully avoided fault zones and "limited outcrop conditions" that may have been affected by tilting.

Finally, we did not find any evidence for "the possible occurrence of a systematic deviation" of the geomagnetic direction. The "disagreement of a few degrees between the secular variation curve derived from historical direct measurements of the Earth's field and the lava flow remanence directions" does not apply in our high-accuracy large-sample method. In fact, our paleodirections agree with the historical measurement curve. Further, the results are not affected by the magnetic refraction effect due to the demagnetizing field of thick lava flow units, because our reference curve for the directional secular variation was defined using volcanic rocks (Tanguy et al. 2005). In one case only, at Mount Etna, our samples were collected within an area where the geomagnetic field was later shown to be subject to an unusual distortion of declination (Tanguy and Le Goff 2004), and the discrepancy disappeared after making the small correction of 2.6°, determined using our instrumental measurements.

The second part of Lanza and Zanella's comment concerns how the reference curve for archeomagnetic dating

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is achieved, and the difficulty of extrapolating an available curve to other locations because the Earth's magnetic field direction and intensity vary throughout the world at a given time. The starting point of our Italian "volcanic" curve was its close agreement with the French archeological curve relocated to Sicily for the last seven centuries (A.D. 1300 to the present), a period for which there is no major problem in age attribution of eruptive products (see Fig. 1 in Tanguy et al. 2003). When going backward into the past, an increasing number of sites may present results that disagree with their presumed ages, although the path of the curve is correctly traced. For calibrating this curve with time, we were thus forced to refer to ages from the French archeological curve. There is a close agreement, once more, between the latter and our "benchmarks" represented by unequivocal eruptions at Ischia in A.D. 1302, and at Vesuvius in A.D. 1139, 787, 472, and 79. This agreement is firm evidence for the validity of our curve, whatever the size of the approximation represented by "relocation" of the French curve to southern Italy (Tanguy et al., 2003). In this respect, it must be pointed out that the shape of the secular variation curve was found to be remarkably similar over most of Western Europe (Gallet et al. 2002).

The error bar of each single age is obtained by projecting on the reference curve the upper and lower limits of the 95% confidence circle. As indicated in Tanguy et al. (2003), we do not take into account the uncertainty of the reference curve itself, because it is virtually impossible to evaluate. However, for the reasons indicated above, this uncertainty must be very small for the period 800–1200 A.D., so that our conclusions stand. Even if the age calibration of the curve is slightly altered (by no more than 20–30 years), then the relative ages of single volcanic sites are consistent each other. Obviously, several sites the confidence circles of which are statistically indistinguishable could be attributed to the same eruption, and, conversely, a given site which encompasses several possible dates could be attributed to several eruptions. These uncertainties are indicated in Table 7 of Principe et al. (2004), where bold characters indicate the most probable attributed eruption as it appears from other data (mainly historical accounts).

We point out once more that these archeomagnetic results were independently checked wherever possible through other methods such as stratigraphy, 14C dating, etc. Their validity is supported by their perfect agreement with historical evidence (e.g., a lava overlain by a tower built in the 1500s cannot have erupted in 1631: in fact, we found it to be medieval), and there is no discrepancy with the numerous 14C data available, although the latter are usually much less precise.

We apologize again for an insufficient explanation of precision and accuracy in an already long paper and hope that Lanza and Zanella will appreciate our response. Certainly, "discussing the errors is much easier than finding a way to take them into account", but this conclusion could be extended to many other results, including those obtained in radiochronology.

References

Gallet Y, Genevey A, Le Goff M (2002) Three millennia of directional variation of the Earth's magnetic field in Western Europe as revealed by archeological artefacts. Phys Earth Planet Int 131:81–89

Principe C, Tanguy JC, Arrighi S, Paiotti A, Le Goff M, Zoppi U (2004) Chronology of Vesuvius' activity from A.D. 79 to 1631 based on archeomagnetism of lavas and historical sources. Bull Volcanol 66:703–724

Tanguy JC, Le Goff M, Principe C, Arrighi S, Chillemi V, Paiotti A, La Delfa S, Patane G (2003) Archeomagnetic dating of Mediterranean volcanics of the last 2100 years:validity and limits. Earth Planet Sci Lett 211:111–124

Tanguy JC, Le Goff M (2004) Distortion of the geomagnetic field in volcanic terrains: an experimental study on the Mount Etna stratovolcano. Phys Earth Planet Int 141 59–70

Tanguy JC, Principe C, Arrighi S (2005) Comment on "Historical measurements of the Earth's magnetic field compared with remanence directions from lava flows in Italy over the last four centuries" by R. Lanza, A. Meloni and E. Tema. Phys Earth Planet Int 152:116–120