ANATOMY OF A VOLCANIC CONE TRAVERSED BY A STRIKE-SLIP FAULT: AN EXAMPLE FROM ANCESTRAL MOUNT BAO, LEYTE, PHILIPPINES

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ABSTRACT

Ancestral Mount Bao (AMB) is an eroded stratovolcano in Leyfe, Philippines, directly overlying and offset by the active le??-lateral Philippine fault. This volcano was investigated to determine the deformation characteristics of a volcano traversed by a strike-slip fault. The deformation features recognized in the AMB include: a summit graben, sigmoidal surface features, cone elongation, normal faults, and reverse faults. Pronounced erosion is evident in the north-northwest and south-southeast flanks, regions of the AMB volcano above the Philippine fault. On these highly eroded volcanic flanks are widespread landslide deposits. The identified structures and related deformational features were compared with previous analogue sand cone models of volcanoes on top of strike-slip faults, models that describe a unique pattern of structural deformation. These features identified in the field and in satellite imagery of the AMB are identical to all the structures found in the analogue sand cone models.

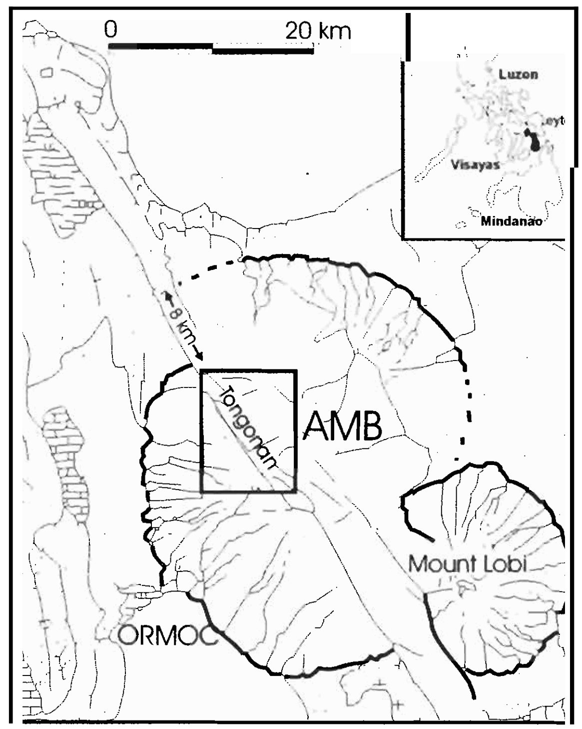

Figure 1. Map of Ancestral Mount Bao, Leyte (Dusquenoy, 1991). The map shows the outline of Ancestral Mount Bao (large circular outline) and a younger volcanic cone, Mount Lobi (small circular outline). Ancestral Mount Bao is traversed by the left-lateral Philippine fault.

1.0 INTRODUCTION

Analogue sand cone models are useful in interpreting the deformation of volcanic cones (Borgia, 1994, Merle 1995, Donnadieu 1998, Van Wyk de Vries 2000). Recent analogue sand cone modeling experiments have shown that volcanoes atop strike-slip faults deform in a peculiar fashion. A volcanic cone produces a complex set of fault structures and surface deformational features related to the orientation and sense of movement of an underlying active strike-slip fault (Lagmay et al. 2000). These deformational features found in the analogue experiments are compared with a natural example, the Ancestral Mount Bao (AMB). This volcano was displaced by about 8 km (Figure 1) by the left-lateral Philippine fault (Dusquenoy, 1991) over a minimum period of 340,000 years. The AMB offers a unique opportunity to study the structural anatomy of a volcano deformed by strike-slip movement. The strongly eroded nature of the flanks of the volcano, expose the internal structures of the volcanic edifice. These features are readily accessible due to the existence of a network of roads built for geothermal power plant operations in the Tongonan area.

2.0 ANALOGUE MODEL CHARACTERISTICS

Lagmay et al. (2000) described the structures found in an analogue volcanic cone deformed by an underlying strike-slip fault and its implications to generating structural instability in volcanoes. The observed deformation features include: a graben, surface sigmoids, cope elongation, reverse faults, and normal faults. The reverse and normal faults have oblique-slip motion. The analogue sand cone experiments are also observed to have "landslides" in flanks where structural deformation takes place. These areas are strongly eroded and are found approximately above the surface projection of the basal strike-slip fault.

3.0 ANATOMY OF ANCESTRAL MOUNT BAO

The surface deformation, fault characteristics, and erosional features within the **AMB** were studied through satellite image analysis and field investigation. The descriptions of the deformation structures and associated features found in the **AMB** were then compared to the anatomy of analogue sand cone models that were deformed by strike-slip movement. Each of the structures identified in the **AMB** is described and illustrated vis a vis with the scaled models of a volcanic cone traversed by a strike-slip fault.

3.1 Surface Deformation

The surface deformation features as seen from a Japan Earth Resources Satellite (JERS) image are the following: **A** lake at the summit of **AMB** called Lake Danao; a prominent sigmoid feature; and cone elongation of the **AMB** parallel to the strike of the Philippine fault (Figure 2).

3.2 Internal deformation

Fault analysis on the northern flank and summit of the **AMB** yield the following results: Reverse faults in the concave side of the sigmoid; normal faults at the upper mid-flank of the **AMB;** and en-echelon normal faults at the summit (Figure 3). These en-echelon normal faults form the graben at the summit of the **AMB.** The reverse and normal faults exhibit oblique-slip motion, a feature also observed in the analogue models. Cross-sections of the sand cones reveal faults that have combined horizontal- and vertical-slip motion (Figure 4).

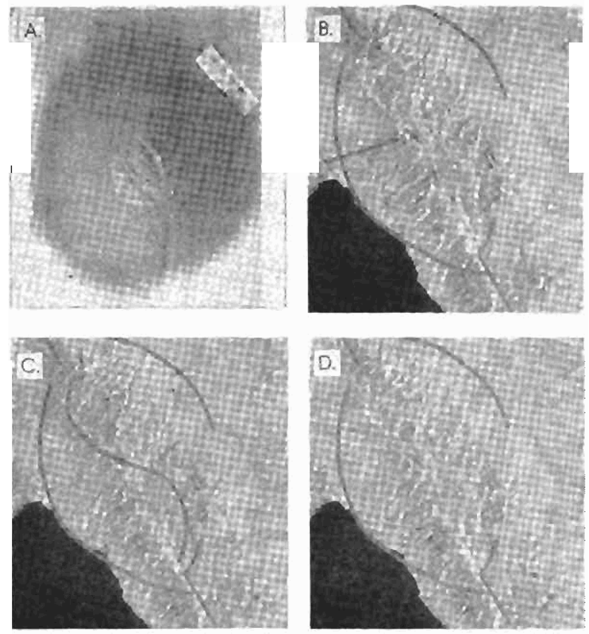

Figure 2. Comparison of the analogue model of a volcanic cone traversed by a strike-slip fault and a JERS **image of Ancestral Mount Bao. a.) Analogue sand cone model (plan view) after displacement by a left lateral strike-slip fault; b) Summit graben, c) Sigmoid, d) Cone elongation. Figures 2b-2c are from a** JERS **satellite image. The cone outline, the sigmoid, and the trace of the Philippine Fault are outlined in red. The features found in the analogue model are the same as those found in the** JERS **image of the AMB.**

3.3 Landslide deposits and erosion

As a consequence to the intense deformation above the Philippine fault, the northwest and southeast flanks of the **AMB** have been strongly eroded. In comparison, the west and east flanks are topographically smooth (Figure 5). In these areas where structural deformation is prevalent, landslide deposits are present. These landslide deposits are characterized by their widespread distribution at the northwest flanks and by brecciated clasts that exhibit jigsaw cracks (Figure 6). Preliminary results of field investigations conducted on the southwestern flanks of the **AMB** also show evidence for the presence of landslide deposits. However, the lateral extent of these landslide deposits in the southern flank of the **AMB** needs further investigation.

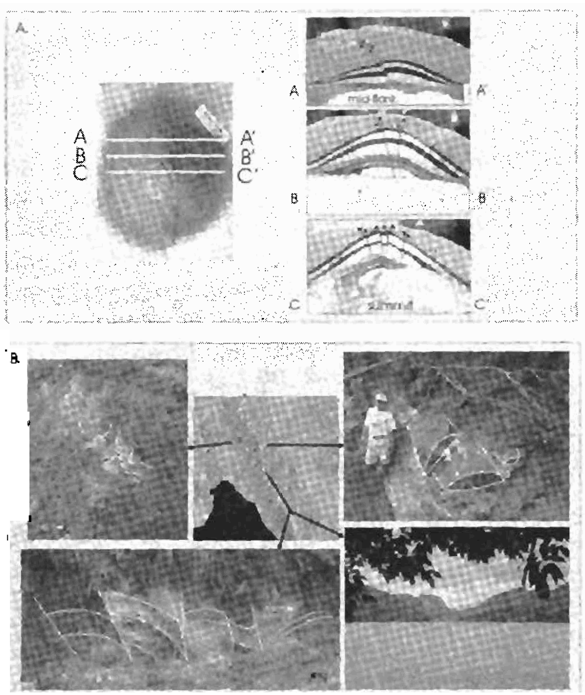

Figure **3.** Comparison of the intemal characteristics of the analogue sand cone models with the fiault structures of AMB. a) Vertical cross-sections of the experimental models cut perpendicular to the basal strike-slip fault. A reverse fault is present along section A-A'. Reverse and normal faults are present along section **B-B'**. En-echelon normal fiaults are present along section C-C'. b) Photographs of equivalent structures in Ancestral Mount Bao. A satellite photograph of AMB is inset for reference.

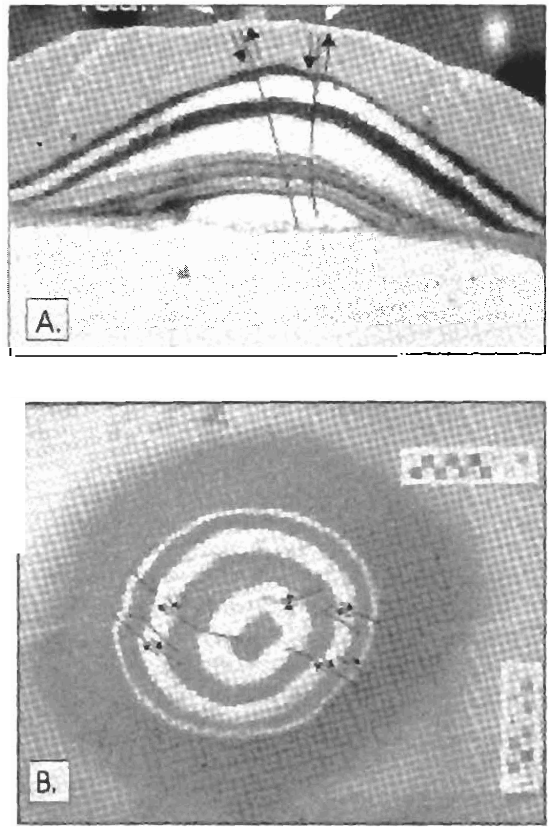

Figure 4. Photographs of horizontal and vertical cross-sections of the analogue sand-cone model. Cross sections show both horizontal- and vertical-slip movement. Oblique-slip movement of faults within the sand cone is inferred from the structures.

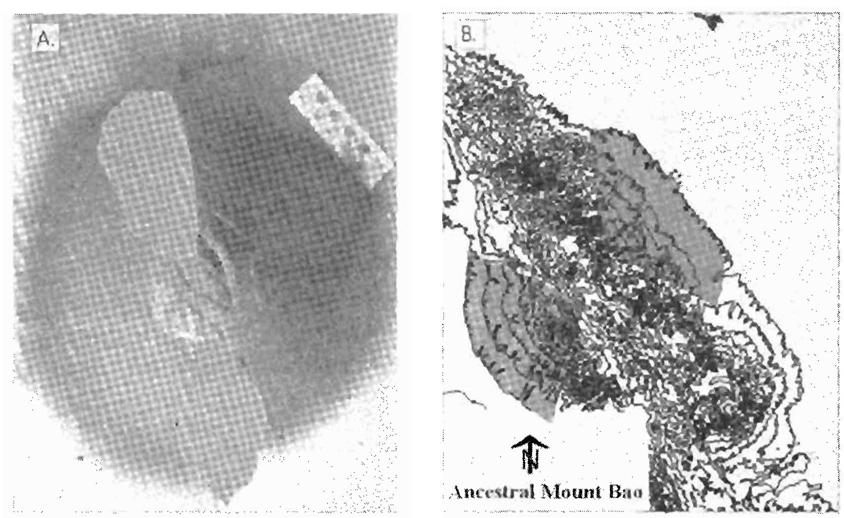

Figure 5. Comparison of the landslide and erosional features observed in the analogue model with Ancestral Mount Bao. a) Photograph of the analogue model and outline of observed locations where landslides occur during the laboratory experiment. b) Topographic map of the AMB volcano showing highly and poorly eroded areas. Highly eroded areas are in regions above the Philippine fault while the poorly eroded areas are outlined in orange.

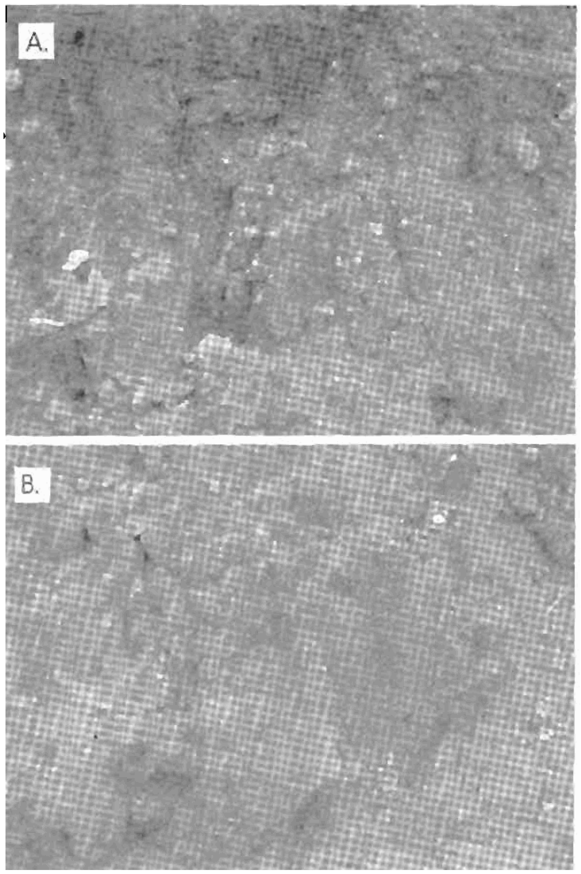

Figure 6. Photograph of a landslide deposit with characteristic jigsaw cracks. The clasts and matrix are dominantly composed of andesitic rocks. These landslide deposits are widespread in the north-northwest flank of AMB.

4.0 DISCUSSION

The structures found in the AMB volcano show striking similarities with the analogue models. With the aid of sand cone experiments, the occurrence of different deformation structures found in a volcano displaced by strike-slip movement is easily understood. The anatomy of the deformation is characterized in relation to the regional stress regime without resorting to several interpretations of the local occurrences of the structures. For example, the presence of reverse faults, normal faults, and a summit graben in a localized area such as a single volcano can be interpreted as the deformational response of a volcanic cone to the same stress regime responsible for the movement of the strike-slip fault underneath the volcano. In particular, the stress responsible for producing the unique deformation on the AMB volcano (e.g. reverse faults, graben, sigmoids) is the same stress acting on the Philippine fault in the region of North-Central Leyte. The type of interpretation given in this work is not possible with traditional structural models (Wilcox, et al., 1973, Woodcock, N.H., and Fischer, M., 1986. Woodcock, N.J., and Schubert, C., 1994) that do not consider the effect of morphology (i.e. cone geometry) on the propagation of faults.

The lines of evidence presented herein show that sand cone models mimic the development of surface and internal structures in volcanoes traversed by a strike-slip fault. Although volcanoes are by nature heterogeneous (i.e. layered), the structures identified in the homogeneous analogue sand cones are nonetheless strikingly similar to deformation of the AMB. It is therefore reasonable to conclude that the scale of the structures being modeled, are not significantly affected by inhomogeneities present in volcanoes.

5.0 SUMMARY

A natural example of analogue sand cone experiments of a volcanic cone displaced by basal strike-slip movement is presented. The structural anatomy of the AMB is described and follows the characteristics of the structures identified in analogue model experiments. This anatomy may be used as a guide for the description and interpretation of structures that may be identified in volcanoes found in similar tectonic settings as the AMB.

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REFERENCES

Borgia, A. (1994). The dynamic basis of volcanic spreading. Journal Geophysical Research, vol. 99, pp. 17791-17804.

Donnadieu, F. and Merle, O. **(1998).** Experiments on the indentation process during cryptodome intrusion: new insights into the Mount St. Helens deformation. Geology vol. **26,** pp. **79-82.**

Dusquenoy, Th., Barrier, E., Kasser, M., Aurelio, M., Gaulon, R., Punongbayan, R., Rangin, C. and the French-Filipino Cooperation Team. **(1994).** Detection of creep along the Philippine fault: first results of geodetic measurements on Leyte island, central Philippines. Geophysical Research Letters, vol. **21,** pp. **975-978.**

Merle, O. and Borgia, A. **(1996).** Scaled experiments of volcanic spreading. Journal of Geophysical Research, vol 101, pp **805-813.**

Merle, O. and Vendeville, B. **(1995).** Experimental modelling of skinned shortening around magmatic intrusions. Bulletin of Volcanology, vol 57 pp. **33-43.**

Lagmay, A.M.F., van Wyk de Vries, B., Kerle, N. and Pyle, D.M. **(2000).** Volcano instability induced by strike-slip faulting. Bulletin of Volcanology, vol. **62,** pp. **331-346.**

Van Wyk de Vries, B. and Matela, R.J. **(1998).** Style of volcano-induced deformation: numerical models of substratum flexure, spreading, and extrusion. Journal of Volcanology and Geothermal Research, vol **81,** pp. 1-1**8.**

Wilcox, R.E., Harding, T.P. and Seely, D.R., **(1973).** Basic wrench tectonics. American Association of Petroleum Geologists Bulletin, vol. 5**7,** pp. **74-96.**

Woodcock, N.H. and Fischer, M. **(1986).** Strike-slip duplexes. Journal of Structural Geology, vol. **8,** pp. **725-735.**

Woodcock, N.J. and Schubert, C. **(1994).** Continental strike-slip tectonic, in Hancock, P.L. (eds.). Continental deformation: Pergammon Press, New York.