KECK GEOLOGY CONSORTIUM

PROCEEDINGS OF THE TWENTY-FOURTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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Dr. Robert J. Varga, Editor
Director, Keck Geology Consortium
Pomona College

Dr. Holli Frey
Symposium Convenor
Union College

Carol Morgan
Keck Geology Consortium Administrative Assistant

Diane Kadyk
Symposium Proceedings Layout & Design
Department of Earth & Environment
Franklin & Marshall College

Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

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Editor and Keck Director
Pomona College

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Diane Kadyk
Proceedings Layout & Design
Franklin & Marshall College

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Students: *SHANNON BRADY*, Union College. *LOGAN SCHUMACHER*, Pomona College, *HANNAH ZELLNER*, Trinity University.

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EOCENE TECTONIC EVOLUTION OF THE TETONS-ABSAROKA RANGES, WYOMING
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Keck Geology Consortium: Projects 2010-2011
Short Contributions— Volcán Barú, Panama

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Project Faculty: THOMAS GARDNER, Trinity University, KRISTIN MORELL, Penn State University

PETROLOGIC EVIDENCE FOR MAFIC RECHARGE AT VOLCÁN BARÚ, PANAMA
SHANNON BRADY, Union College
Research Advisor: Holli Frey

VOLUME CONSTRAINT AND POTENTIAL SECONDARY VOLUME INPUTS OF LATE PLEISTOCENE AGE SECTOR COLLAPSE, VOLCÁN BARÚ, PANAMA
LOGAN SCHUMACHER, Pomona College
Research Advisor: Eric Grosfils

VOLCÁN BARÚ DEBRIS AVALANCHE FACIES AND AGES
HANNAH ZELLNER, Trinity University
Research Advisor: Thomas Gardner

Keck Geology Consortium
Pomona College
185 E. 6th St., Claremont, CA 91711
Keckgeology.org

VOLUME CONSTRAINT AND POTENTIAL SECONDARY VOLUME INPUTS OF LATE PLEISTOCENE AGE SECTOR COLLAPSE, VOLCÁN BARÚ, PANAMA

LOGAN SCHUMACHER, Pomona College
Research Advisor: Eric Grosfils

ABSTRACT
The purpose of this project is to constrain the volume of a large sector collapse debris-flow deposit for Volcán Barú, Panama using GIS modeling of the assumed paleotopography prior to and following the event. These models are produced by reconstruction of modern day topography and interpolation of identified lower surface indicators respectively. This volcano is poorly understood, but represents one of the larger sector-collapse deposits clearly preserved in the modern rock record. Based on preliminary field observations I hypothesized that a calculated volume of the observed debris-flow deposit will show a significantly larger volume than those previously calculated using edifice reconstruction methods. GIS volume calculations of modeled paleotopography indicate a minimum debris flow of approximately 46.4km3 (38.6km3 before block expansion) greater than the calculated 20-30km3 edifice displacement volumes (Sherrod et al., 2007) necessitating an additional debris-flow volume source beyond that of the displaced edifice.

INTRODUCTION
Volcán Barú is an active calc-alkaline stratovolcano situated southeast of the Talamancas at the end of the Central American Volcanic Arc. In this region there is a convergence of three tectonic plates (Gardner. Fig 1 this volume), where the Cocos and Nazca subduct along semi-parallel trajectories beneath the Caribbean plate and the Panamanian continental shelf landmass. This convergence forms the Panama Triple Junction (Defant., 1992:, Drummond et al., 1995), to the south of which extends regional strike slip faulting known as the Panama Fracture Zone. Subduction of the oceanic crust, the PFZ and hotspot fed seamounts of the Cocos ridge helps feed adakite melt geochemistry (De Boer., 1988) and uplift of the Terraba formation in the region (Morell et al., 2008). Volcán Barú lies approximately 60 kilometers north of the Pacific coastline, and 35 kilometers east of Panama's western border (Gardner Fig. 2, this volume). The southern flanks of the edifice are primarily composed of prehistoric lahar fans which extend 60km to sea level. To the southwest is a large debris flow deposit composed of hummocky shattered blocks and interstitial lahar matrix, evidence of a late Pleistocene sector collapse of the western flank of the edifice. Radiometric dating puts the age of this event at approximately 10ka, (Sherrod et al., 2007:, Frels. 2009) which is supported by dating of organic clasts in lahar matrix collected during field work conducted in July of 2010 . The late Pleistocene sector collapse left behind a westward facing amphitheater approximately 3 km in diameter. The modern day Volcán Barú reaches an elevation of 3477 meters, but prior to collapse may have reached as much as 3800-4000 meters in elevation (Seibert et al., 2006). For a full regional overview refer to Gardner Figs. 1 and 2 this volume.

The goal of this project is to use GIS modeling to constrain the volume of the 10ka Late Pleistocene sector collapse event. Volume constraints for events of this scale may be accomplished by modeling a reconstructed edifice and finding the volume difference between the edifice and the post collapse topography. In the case of Volcán Barú a USGS open file report has constrained the volume of this event to between 20-30km^3 using this method. (Sherrod et al., 2007). However, field observations from July 2010 and following estimates based on surface extent and observed depths indicated that the debris flow volume was significantly greater than previously calculated. A disparity between normalized debris-flow volume and edifice reconstruction volume would indicate the need for an additional volume source, such as a concurrent eruption, debris flow from a neighboring edifice, deeply plunging slip-surface/ failure-plane, a cyclical pattern of Pleistocene sector collapse and dome reconstruction, or incorporation of volcanic materials along the flanks of the volcano away from the edifice proper.

MODELING METHODS

Constraining the volume of the sector collapse using GIS software requires 3 primary inputs, [1] a well-defined areal extent, [2] a model of the lower paleo-topography immediately prior to the event, and [3] a model of the upper paleo-topography immediately following the event. The extent has been well defined by Morell, and is adapted from geologic mapping of the region (Gardner, Fig 3 this volume: Morell et al., 2008:, Herrick,. 2009).

UPPER PALEO-TOPOGRAPHIC MODEL

The upper paleo-topographic model is constructed by modifying a modern day digital elevation model (DEM) of the region to account for erosional activity following the event. Fluvial erosion of the debris flow deposit has created river channels far deeper than the maximum observed channel depths of approximately 40m observed in the older, lower gradient lahar fans. Within the extent region all major river channels have had elevations raised to values representative of the likely elevation of the lahar fans

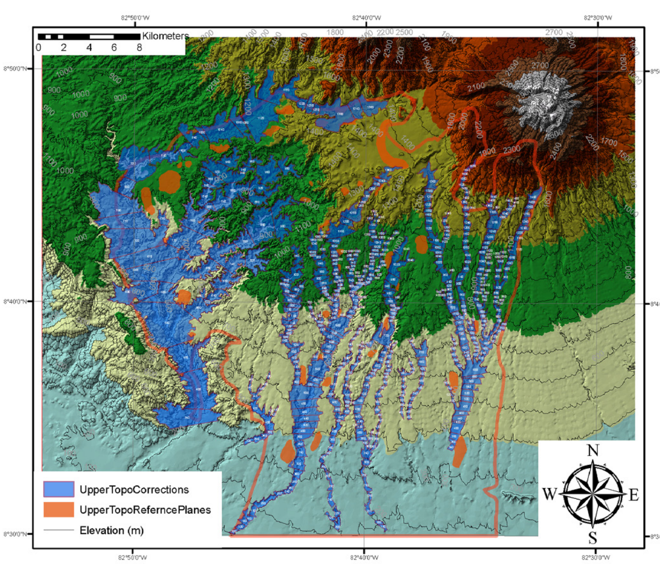

Figure 1, Upper Paleo-Topographic Surface Model Overview of the upper paleo-topographic model.   Blue regions indicate areas of modified elevation in order to fill in volume lost to 9,000-10,000 years of fluvial erosion.

prior to the effects of fluvial erosion. (Figure 2, blue regions) The DEM is converted to a 3D polygon model, and regions requiring modification have their elevations raised based either on known paleo-topographic indicator regions, or by reconstruction of interpreted lahar fan contours which curve outward in predictable patterns.

LOWER PALEOTOPOGRAPHIC MODEL

The lower paleo-topographic model is constructed by interpolating a raster, or grid image with associated pixel elevations. This interpolation is the product of all available inputs which indicate the topography prior to the sector collapse event. These inputs are [1] observed debris flow contacts and minimum debris flow elevations, [2] reconstructed edifice contours, [3] reconstructed contours of the Volcan Tisingal's edifice to the northwest, [4] the east dipping contact of the Terraba Formation thrust belt along the western extent, [5] separately calculated volume of the debris flow distal extent region based on southernmost observed exposures, [6] GPS and GIS derived gradient profiles for the >40 ka lahar fans south of Baru's edifice, and [7] eastern extent contacts of the older lahar flows (Figure 2) Each of these inputs is manually converted into points with associated elevation values, and the set of points is interpolated into a best fit raster using either Inverse Distance Weighted (IDW) and Spline 3D analyst GIS tools. Interpolations of varying weight, point sample size and type were calculated in order to assess possible error regions and to determine ideal interpolation settings.

RESULTS

Debris flow volume calculations are accomplished using the ArcGIS TIN Difference tool, using the defined extent as the area boundary. Results from the varying interpolation methods and input parameters are shown below (Table 1). IDW interpolations provide estimates of averaged depth and volume based on distance weighted calculation methods, and proved to have lower total calculated volumes than Spline interpolations. High and low power IDW interpolations exhibited poor resolution and polygonal ordering of elevations rather than smooth surfaces (Fig 3). In both cases this this led to large regions of negative

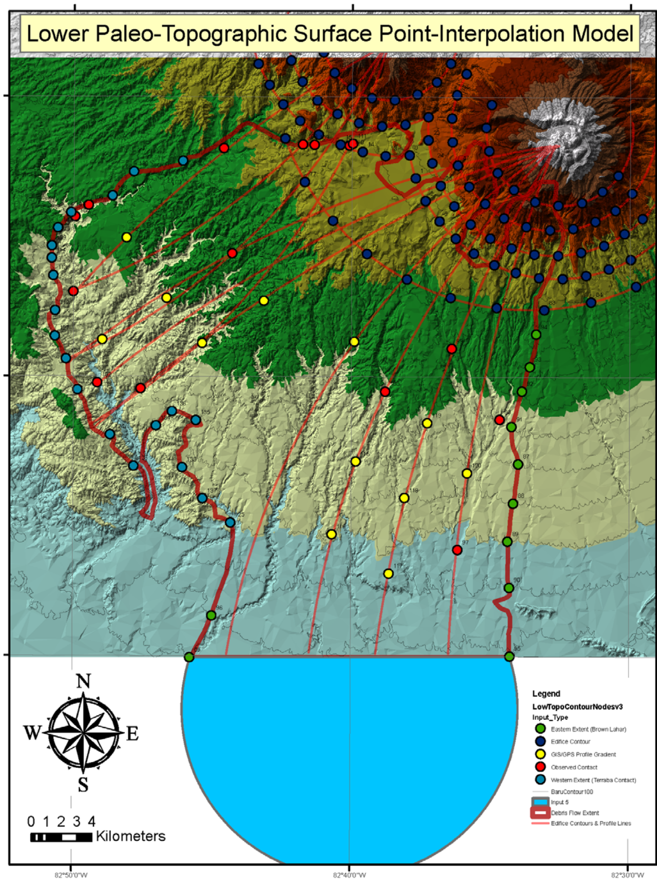

Figure 2, Lower Paleo-Topographic Surface Model Overview of the lower paleo-topographic model. Nodes are Sample points used in Interpolation of the lower surface. Node color corresponds to Input type. Input 5 shows size of estimated distal flow region. (DA3 in Morell, this volume)

Name	Interpolation Method	Sample Points #	Power(IDW) Weight(Spline)	Major Range(IDW) / Type (Spline)	10ka Debris Flow Deposit Volume
IDWp8Pm	IDW	8	Power = 2	No Major Range	49.3 km^3
IDWp8Pl	IDW	8	Power = 0.2	No Major Range	33.7 km^3
IDWp8Ph	IDW	8	Power = 20	No Major Range	60.6 km^3
IDWp12Pm	IDW	12	Power = 2	No Major Range	43.4 km^3
IDWp12Pl	IDW	12	Power = 0.2	No Major Range	18.6 km^3
IDWp12Ph	IDW	12	Power = 20	No Major Range	60.6 km^3
IDWp8MR10	IDW	8	Power = 2	Major Range = 10	50.4 km^3
IDWp8MR20	IDW	8	Power = 2	Major Range = 20	49.3 km^3
IDWp12MR10	IDW	12	Power = 2	Major Range = 10	46.6 km^3
IDWp12MR20	IDW	12	Power = 2	Major Range = 20	43.4 km^3
SPLp8WmR	Spline	8	Weight = 0.1	Regularized	75.5 km^3
SPLp8WhR	Spline	8	Weight = 1	Regularized	77.8 km^3
SPLp8WlR	Spline	8	Weight = 0.01	Regularized	73.2 km^3
SPLp12WmR	Spline	12	Weight = 0.1	Regularized	75.5 km^3
SPLp12WhR	Spline	12	Weight =1	Regularized	80.3 km^3
SPLp12WlR	Spline	12	Weight =0.01	Regularized	76.8 km^3
SPLp8WmT	Spline	8	Weight =0.1	Tension	73.8 km^3
SPLp8WhT	Spline	8	Weight =1	Tension	69.9 km^3
SPLp8WlT	Spline	8	Weight =0.01	Tension	71.2 km^3
SPLp12WmT	Spline	12	Weight =0.1	Tension	73.7 km^3
SPLp12WhT	Spline	12	Weight =1	Tension	72.4 km^3
SPLp12WlT	Spline	12	Weight =0.01	Tension	74.2 km^3

IDW = Inverse Distance Weighted, SPL = Spline, p = # Sample Points, P = Power, W = Weight, MR = Major Range (km), m = medium Weight/Power value (default), h = high Weight/Power value (default x 10), l = low Weight/Power value (default / 10)

Table 1, Interpolation Model Volume Calculations. Interpolation parameter settings and calculated volumes. Model names correspond to interpolation type and parameter settings. Medium weighted interpolations with no major range constraint were identified as the least error models. High and low power and weight interpolations were generally poor resolution, and frequently produced polygonal rather than smooth surfaces.

depth in the volume calculation (Fig 4b). Spline interpolations within determined point and weight parameters run generally had less negative space and smother profiles, but high influence of depth points leading to several low artificially low regions likely led to artificially large volume results. Variations between Regular Spline and Tension Spline interpolations were minimal, and average values were taken (Fig 4a).Volume estimates of the late Pleistocene deposit have been constrained to 46.4km³ and 75.5km³ based on respective IDW and Spline idealized input averages.

Before these volumes can be compared to volume estimates derived from edifice reconstruction (Sherrod et al., 2007), expansion of debris must be taken

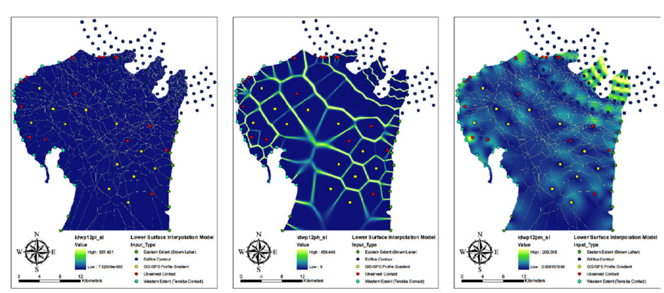

Figure 3, IDW Interpolation Slope Assessment. Calculated slope rasters of IDW interpolations at low, high, and medium power values. Low and high rasters show the sharp polygonal surfaces which form when weight distances is very large or small. Images 1 and 2 show muting of elevation and poor resolution due to single point over-influence.

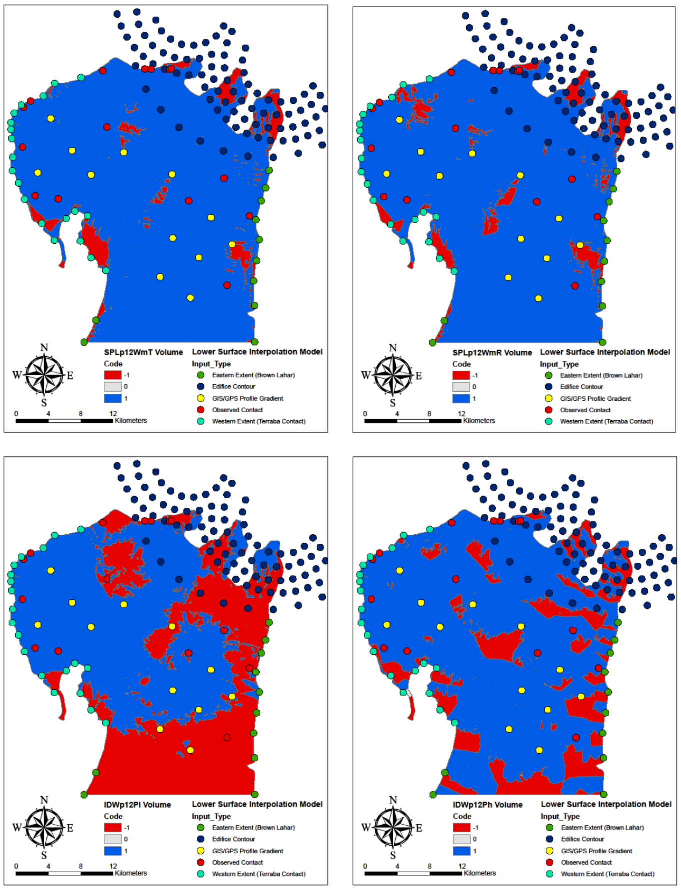

Figure 4, Interpolation Volume Rasters.
Volume rasters of IDW and spline interpolations. Blue zones indicate positive model depths, red zones indicate negative model depths. Red zones are known regions of error. Images 1 and 2 show the minimal variations observed. Images 3 and 4 show negative depth error due to high and low IDW power settings.

into account. Estimates of debris expansion based on density measurements of Mount St. Helens and other modern sector-collapse events indicate a volume expansion of the debris blocks of approximately 20 percent during the sliding (Glicken, 1991). This is mostly due to shattering and matrix formation within edifice blocks during their lateral displacement, a process that occurs primarily due to loss of strength and high pore pressure of saturated material (Voight et al, 1983). Accounting for this expected increase in volume during deposition is necessary for a comparison of debris-flow and missing edifice volumes. The determined minimum debris flow volume constraint normalized for expected volumetric expansion is 38.6km3.

DISCUSSION

A comparison between the missing-edifice maximum volume estimates (Sherrod et al., 2007) and GIS model derived debris flow minimum volume estimates shows a minimum volume disparity of approximately 8.6 km^3. One third greater than the missing edifice volume, this disparity is a clear indicator of an additional necessary volume source beyond that of the displaced edifice. There are several possible sources for this additional volume. A volcanic eruption occurring concurrently with the sector collapse event could provide additional volume as juvenile material integrated into the debris flow. So far no exposures have exhibited evidence of tephra or other volcanic beds associated with a proposed concurrent eruption however other work on this Keck Project has shown mineral textures indicating mafic recharge, a chemistry associated with eruptive events and a potential trigger for a large eruption. The possibility of a concurrent volcanic eruption indicated by debris flow mineralogy would fulfill the necessary additional volume source. A second possible solution to the volume disparity is an unexpectedly low sliding plane during flank collapse displacing portions of the edifice several kilometers from the center point, and deeper into the edifice structure than is shown by the modern day topography. 800-1000 years juvenile flows and erosional lahars could refill a deep amphitheater structure to mask this large volume in an edifice reconstruction calculation. This is a likely additional volume source in the case of Volcán Barú, where volume the poorly exposed in-amphitheater lava flows may have been easily underestimated by Sherrod. A third possibility is that this sector collapse event was followed and possibly preceded by a cycle of smaller debris flow events, possibly fueled by dome reconstruction and juvenile volcanics. This would not necessarily require multiple large collapse events, but rather a single large event of shattered block movement, with larger associated periods of primarily lahar activity. This hypothesis is supported by the radiometric dating, which indicates a period of 800-1000 years of lahar activity following the main event (Zellner, this volume, Sherrod et al., 2007). These solutions are not mutually exclusive, and the volume disparity is likely due to some degree of juvenile volcanics and lahar activity originating from Volcán Barú's edifice.

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