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Magnetic links among lava flows, tuffs and the underground plumbing system in a monogenetic volcano, derived from magnetics and paleomagnetic studies

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Global MagIC Seminar

Feb. 18, 2014

Geoff Cromwell (SIO)

Overview

This study follows a series of investigations into the age and polarity of the Xalnene Ash in Central Mexico

- Background studies
  - Gonzalez et al., 2006; Renne et al., 2005; Goguitchaichvilli et al., 2009; Feinberg et al., 2009
  - Age and polarity discussions
  - Correlation of extrusive deposits to proximal volcano (Cerro Toluquilla)
- Urrutia-Fucugauchi et al., 2012
  - Modeling magnetic anomalies of the Cerro Toluquilla volcano

“Footprints” of the Valsequillo Basin

ELSEVIER

Quaternary Science Reviews 25 (2006) 201–222

QSR

Human footprints in Central Mexico older than 40,000 years

Silvia González[a,*], David Huddart[a], Matthew R. Bennett[b], Alberto González-Huesca[c]

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[b]*School of Conservation Sciences, Bournemouth University, Talbot Campus, Fern Barrow, Poole, Dorset BH12 5BB, UK*
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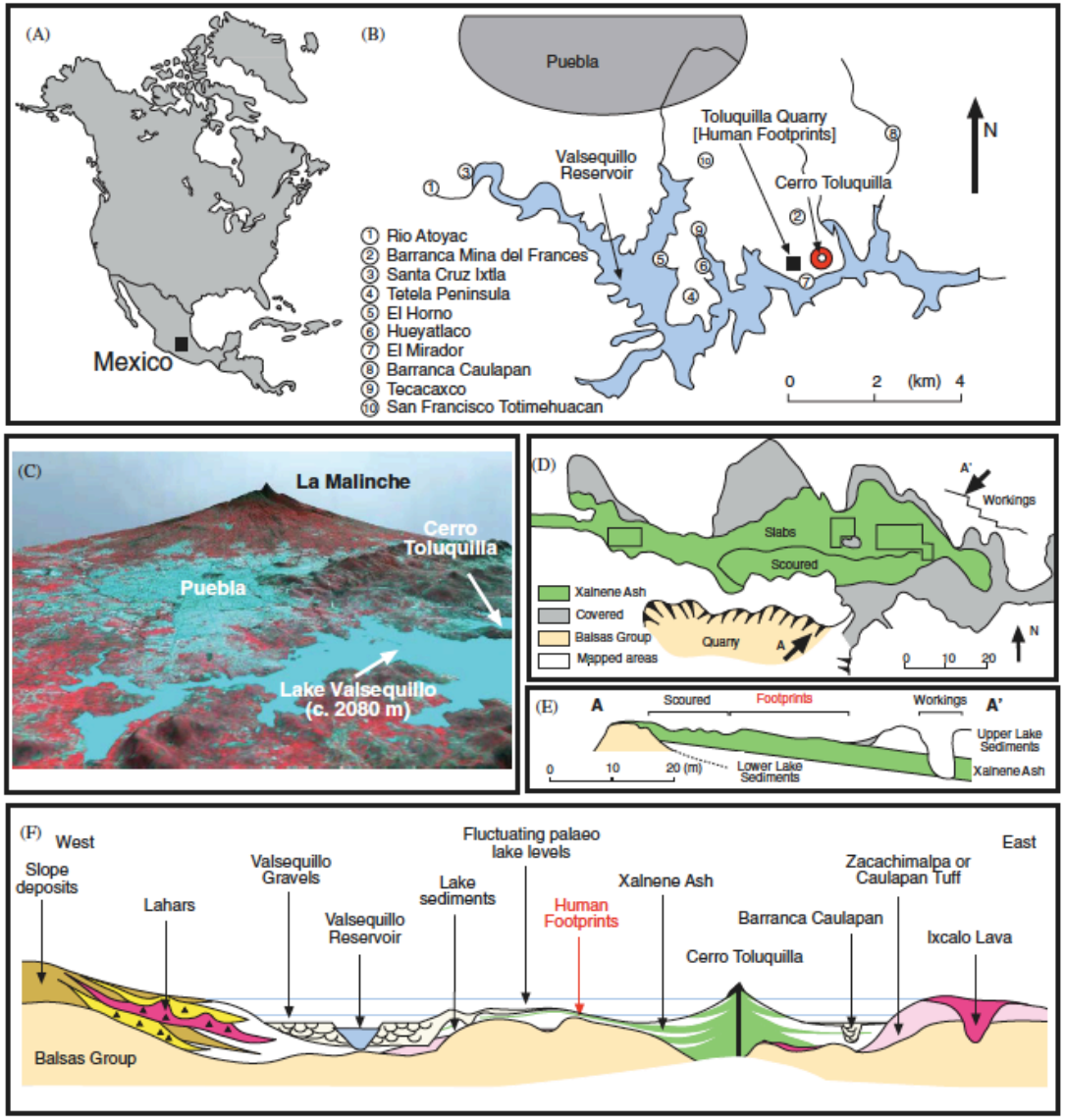
Received 28 April 2005; accepted 13 October 2005

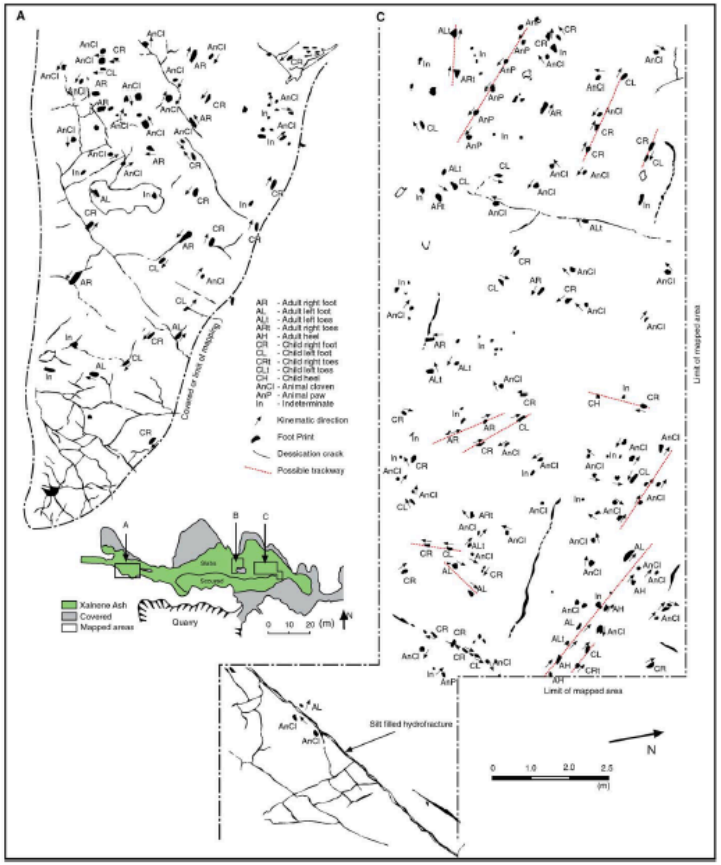
- Footprints in Xalnene Ash
- Optically Stimulated Luminescence (OSL)
  - 43 ka
- Pre-dates Clovis culture expansion and earliest dated humans in North America
  - 11.5 ka

Valsequillo Basin Geology



Gonzalez et al., 2006

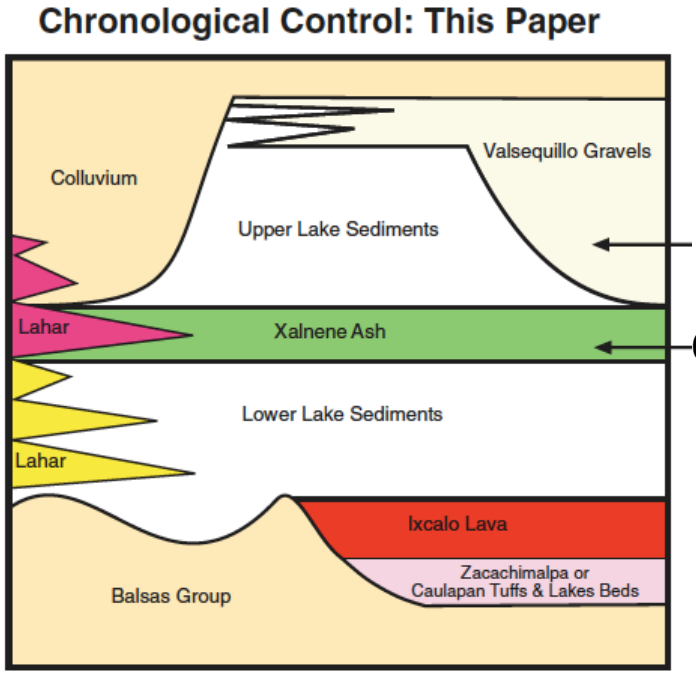
“Footprints”



Gonzalez et al., 2006

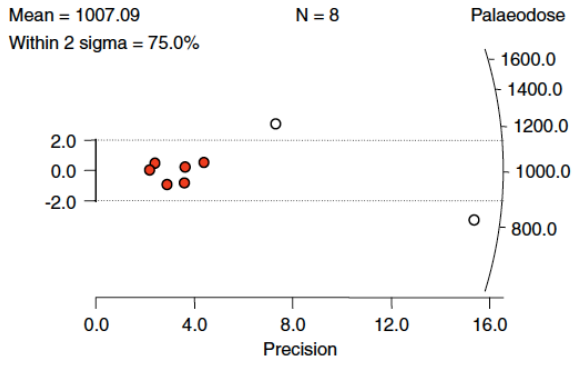
Geochronology

1. Radiocarbon dating Valsequillo gravels
   - Mollusc shells
   - 25-39 ka
2. Ar/Ar of Xalnene Ash
   - Lapilli fragments
   - 2.2-4.6 Ma
3. OSL of Xalnene Ash Horizon
   - Sandy xenolith, reworked limestone from underlying Balsas Group
   - 38 ± 85 ka



C14: 25-39 ka

OSL: 38 ± 85 ka



Gonzalez et al., 2006

Revised Geochronology

NATURE|Vol 438|1 December 2005 BRIEF COMMUNICATIONS ARISING

GEOCHRONOLOGY

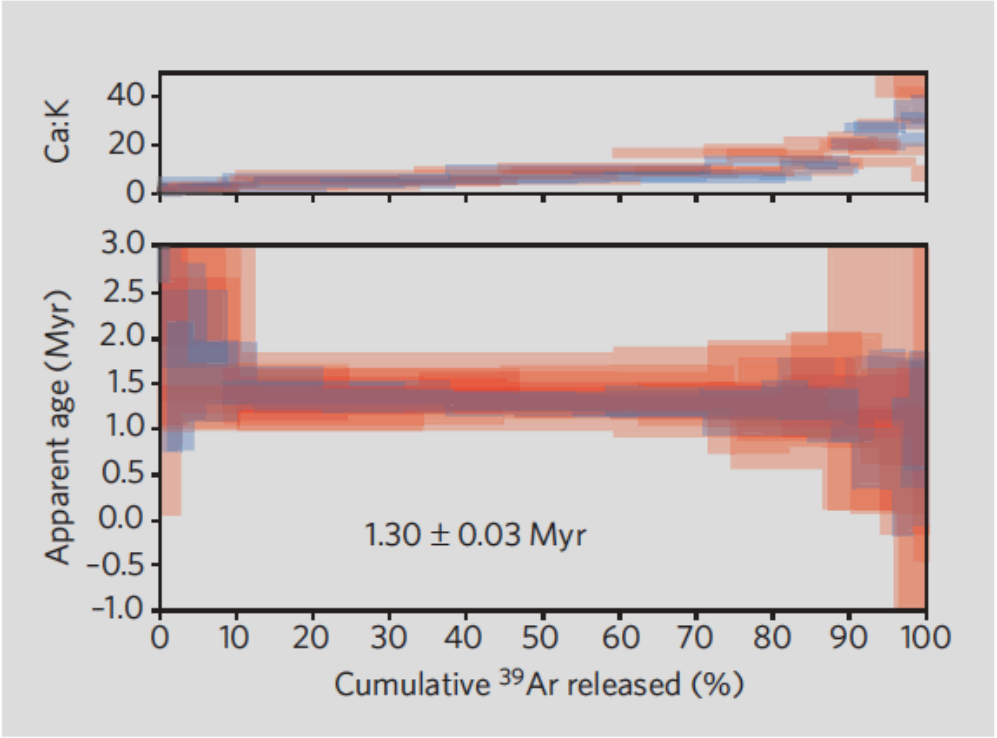
Age of Mexican ash with alleged 'footprints'

Arising from: R. Dalton *Nature* doi: 10.1038/news050704-4 (2005)

- Renne et al., 2005
  - Ar/Ar and paleodirections
  - Xalnene Ash Lapilli

Ar/Ar Ages of Xalnene Ash

- Incremental laser heating
- n=9
- Weighted mean:
  - 1.30 ± 0.03 Ma



Renne et al., 2005

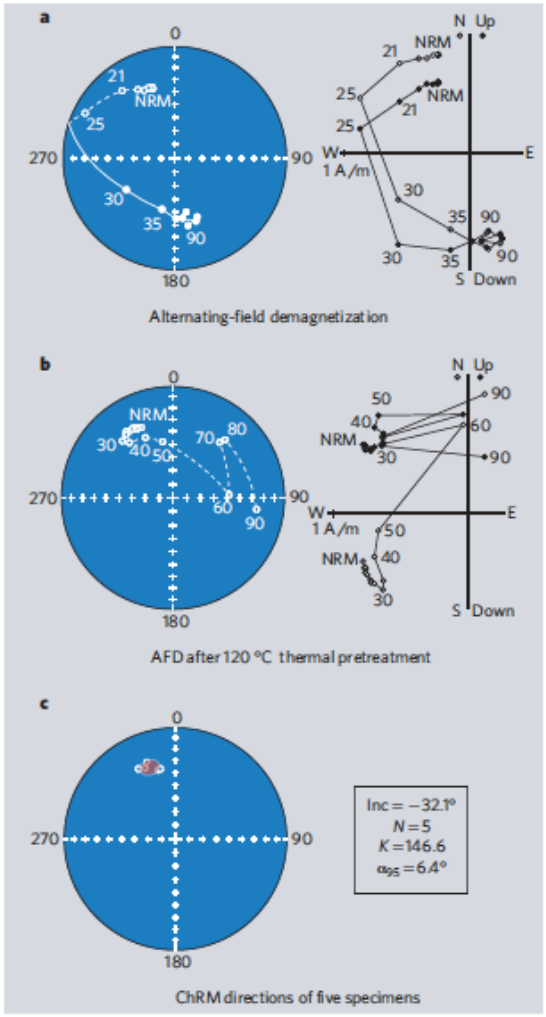
Paleodirections of Xalnene Ash

Up-Oriented lapilli samples
- Inclination Only

Two Components of Opposite Polarity
- Reverse Polarity magnetite, thermoremanence
- Secondary normal polarity from geothite

Average Inclination = -32.1°, n=5

Clustered directions indicate post-depositional cooling through blocking temperature



Renne et al., 2005

Transitional Volcanics?

Earth Planets Space, **61**, 205–211, 2009

Paleomagnetic and rock-magnetic study on volcanic units of the Valsequillo Basin: implications for early human occupation in central Mexico

Avto Goguitchaichvili[1], Ana Lillian Martin-Del Pozzo[2], Jose Luis Rocha-Fernandez[3], Jaime Urrutia-Fucugauchi[4], and Ana Maria Soler-Arechalde[4]

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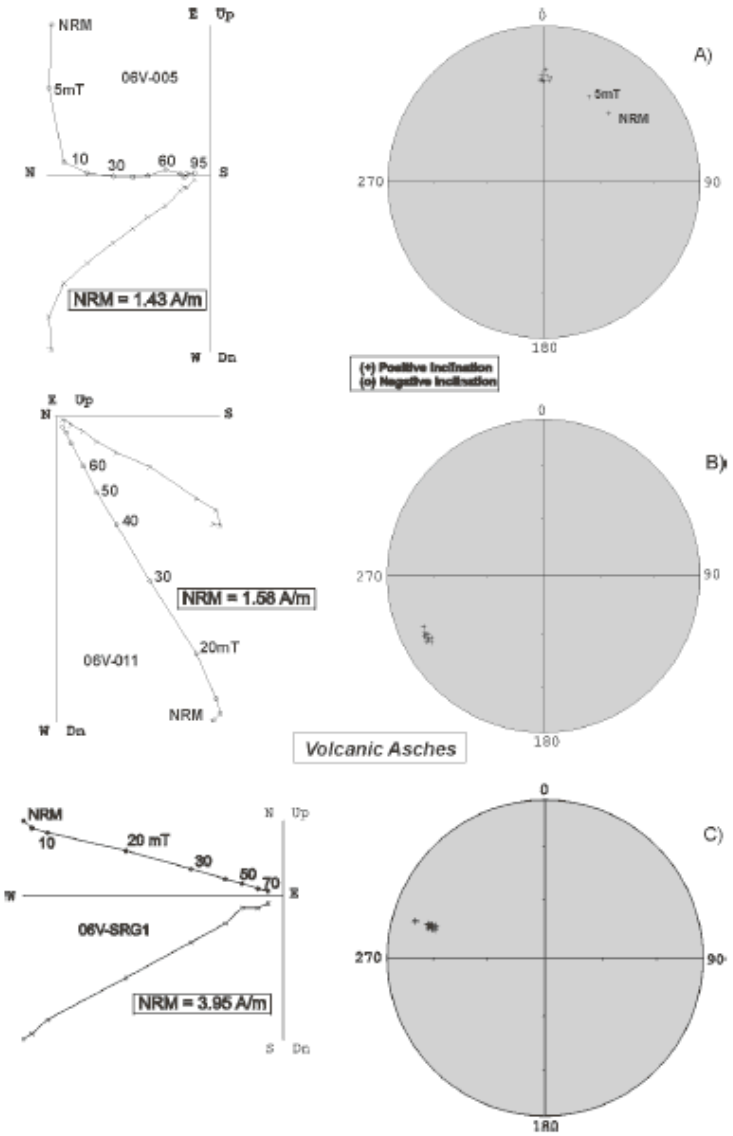
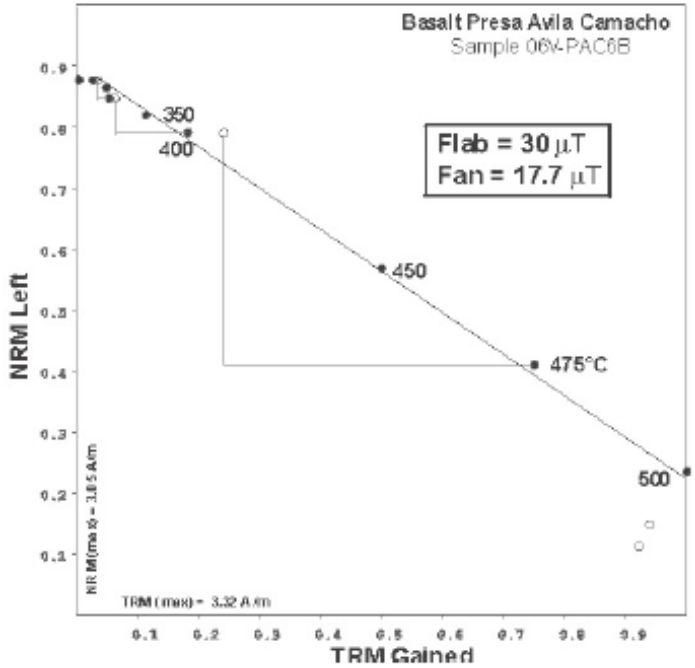
[2]*Departamento de Vulcanología, Instituto de Geofísica, Universidad Nacional Autónoma de México, Ciudad Universitaria s/n, 04510 México DF, Mexico*
[3]*Programa de Posgrado en Ciencias de la Tierra, Instituto de Geofísica, Universidad Nacional Autónoma de México, Ciudad Universitaria s/n, 04510 México DF, Mexico*
[4]*Laboratorio de Paleomagnetismo, Departamento de Geomagnetismo y Exploración Geofísica, Instituto de Geofísica, Universidad Nacional Autónoma de México, Ciudad Universitaria s/n, 04510 México DF, Mexico*

(Received October 19, 2007; Revised April 8, 2008; Accepted April 10, 2008; Online published January 23, 2009)

- Goguitchaichvilli et al., 2009
  - Transitional directions for Xalnene Ash
  - Low paleointensity from a nearby lava flow

Paleomagnetics





Goguitchaichvilli et al., 2009

Paleomagnetic Results

Directions

Site mean paleodirections from Valsequillo area

Site	Location	n/N	Inc (°)	Dec (°)	α_{95} (°)	k	Pol
White ashfall (1)	98°10′20.1″/18°55′05″	6/6	32.8	1.4	2.6	654	N
Blackish ash (2)	98°09′22.3″/18°55′24″	6/6	13.1	264.6	6.7	99	I
Xalnene ash (4)	98°09′21.5″/18°55′21″	10/10	17.8	280.8	6.8	52	I
Toluquilla volcano basalt (3)	98°09′06″/18°54′48.4″	8/8	−29.7	169.8	5.8	93	R
Avila Camacho basalt (5)	98°06′29.5″/18°54′37″	8/8	−36.4	189.5	2.2	891	R

Intensity

Paleointensity results from near Avila Camacho basalt

Sample	Inc	Dec	n	$T_{min} - T_{max}$	f	g	q	$F_E \pm \sigma(F_E)$	VDM	$F_E \pm$ s.d.	VDMe
06VPAC6B	−33.9	184.9	7	200–500	0.68	0.80	15.2	17.7 ± 0.6	4.01	17.7 ± 0.7	3.9 ± 0.2
06VPAC8B	−37.2	190.2	7	200–500	0.71	0.78	21.9	18.6 ± 0.5	4.10		
06VPAC4C	−35.8	190.4	6	200–475	0.52	0.74	9.4	17.8 ± 0.6	3.97		
06VPAC3A	−37.4	192.8	6	200–475	0.51	0.71	6.2	16.8 ± 0.9	3.69		

Goguitchaichvilli et al., 2009

Reverse Polarity Correlation

Geology

Age constraints on alleged "footprints" preserved in the Xalnene Tuff near Puebla, Mexico

Joshua M. Feinberg, Paul R. Renne, Joaquin Arroyo-Cabrales, Michael R. Waters, Patricia Ochoa-Castillo and Mario Perez-Campa

Geology 2009;37;267-270
doi: 10.1130/G24913A.1

- Feinberg et al., 2009
  - Paleomagnetics on Xalnene Ash and Cerro Toluquilla lava
  - Ar/Ar on Cerro Toluquilla lava

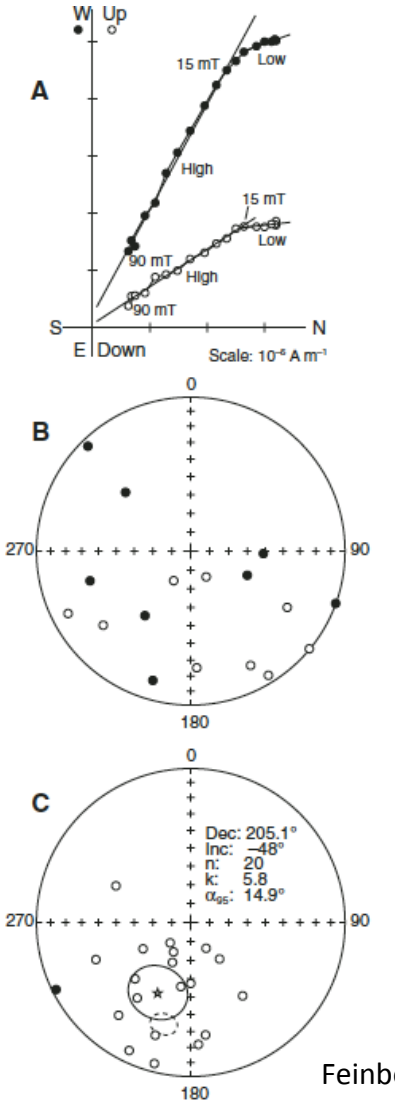
Individual Lapilli Directions

Remanence carried by cubic spinel, titanomagnetite composition

Two components of magnetization

- Reverse, low-coercivity removed at 15 mT
- Random, well defined high-coercivity

Reverse component acquired post-deposition (C)
High –coercivity component (B) acquired in flight



Feinberg et al., 2009

Cerro Toluquilla: Source Volcano

TABLE 1. SUMMARY OF PALEOMAGNETIC RESULTS

Site	Dec. (°)	Inc. (°)	N	K	α_{95} (°)	Polarity
Xalnene Ash						
Bulk Samples*	194†	–32.10	5	146.6	6.4	Reversed
Individual Lapilli	205.1	–48.00	20	5.8	14.9	Reversed
Cerro Toluquilla						
High-coercivity	176.3	–33.10	12	100.9	4.3	Reversed
Low-coercivity	354.0	–11.10	10	112.5	4.6	Reversed

*From Renne et al., 2005.

†These samples come from an azimuthally unoriented block. For the sake of comparison with the lapilli and Cerro Toluquilla samples, they have been rotated parallel to 194°, the orientation of a reversed polarity field relative to the modern declination at the field site.

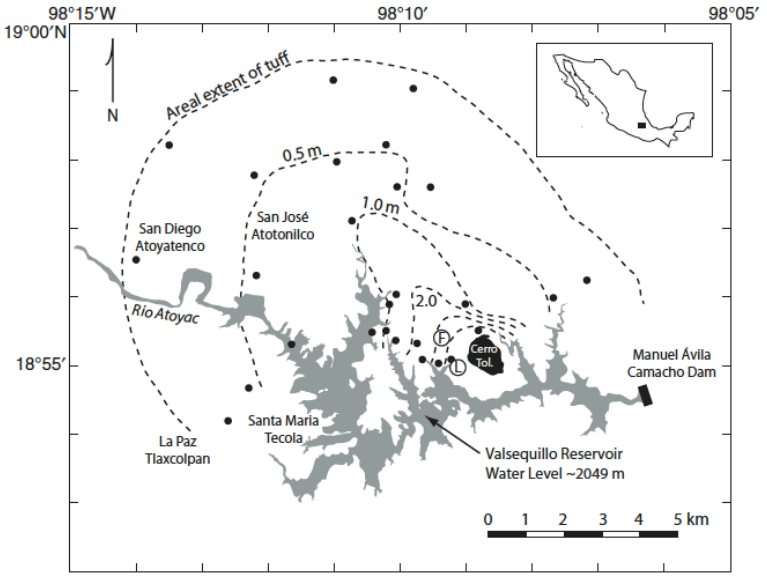
Feinberg et al., 2009

Directions similar for:

- Renne et al. bulk samples
- Individual lapilli
- Cerro Toluquilla

Ar/Ar for Cerro Toluquilla lava:

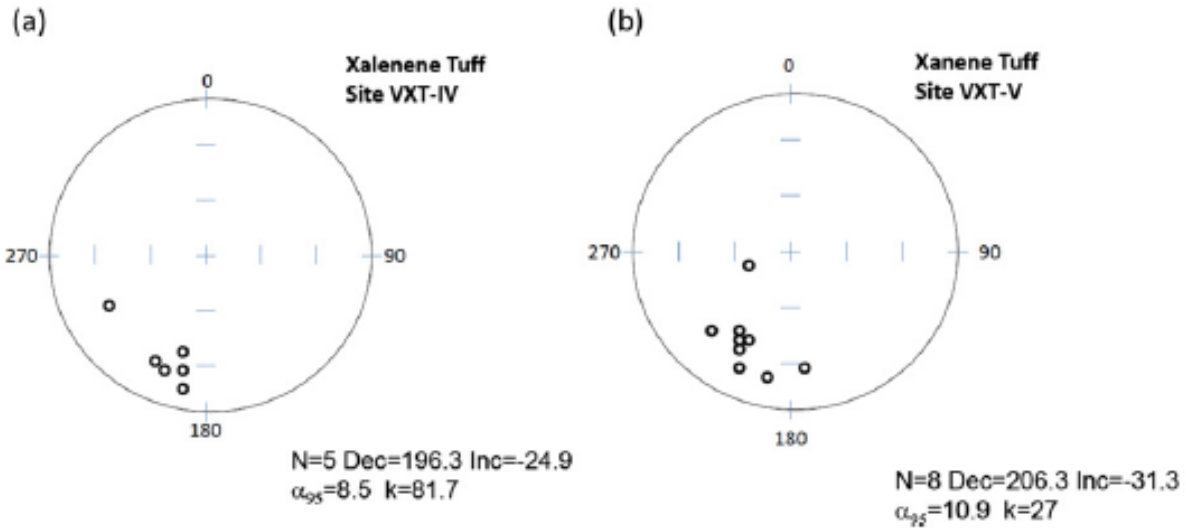
- 1.29 ± 0.02 Ma
- Identical to Renne et al., ash (1.30 ± 003 Ma)



New Paleodirections

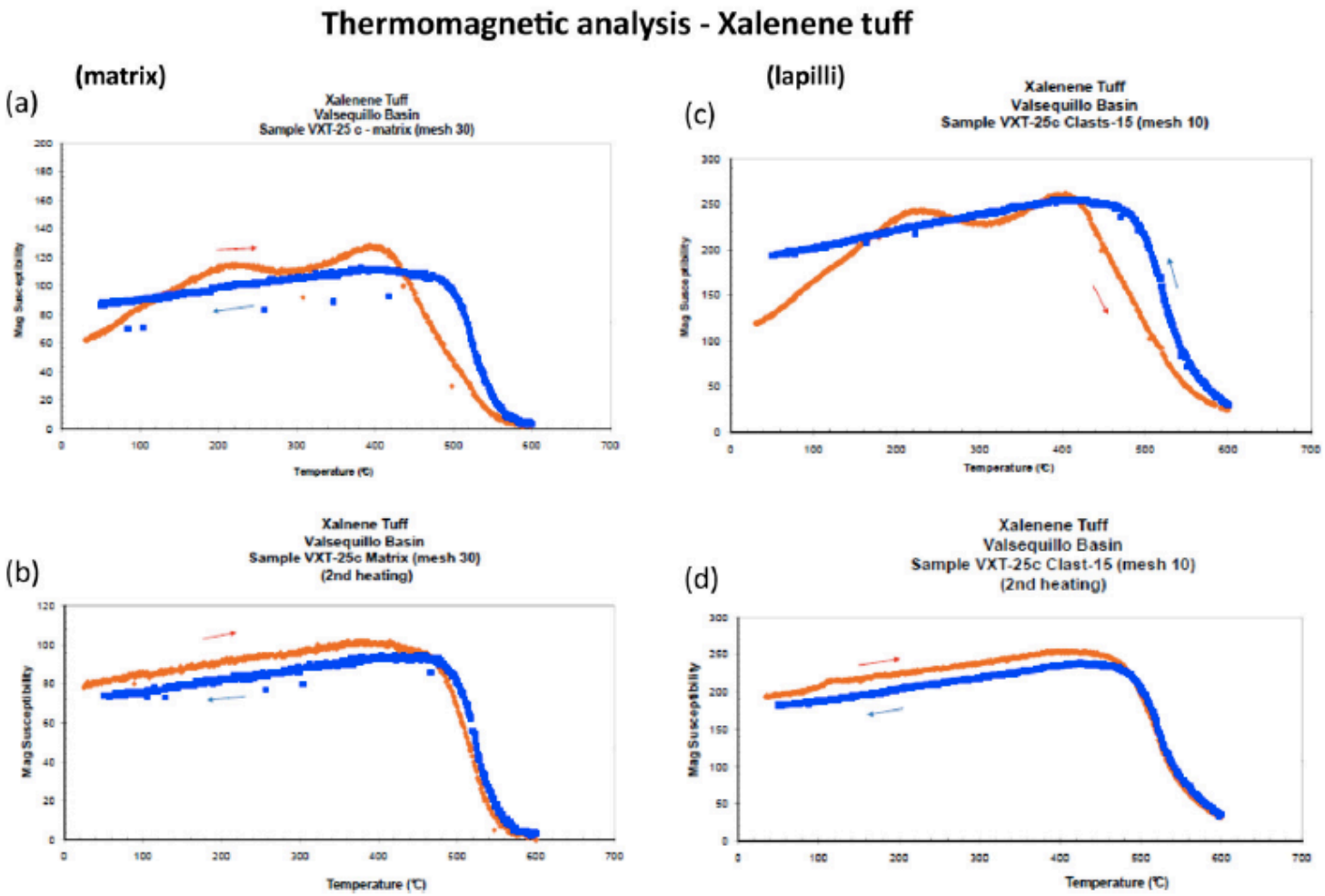
Urrutia-Fucugauchi et al., 2012

- Reverse Directions on Xalnene Tuff
- Two Sites
  - 196.3° / -24.9°
  - 206.3° / -31.3°
- Consistent with Feinberg et al. and Renne et al.



Urrutia-Fucugauchi et al., 2012

Ash Properties



Urrutia-Fucugauchi et al., 2012

Summary of Findings

Table 1
Summary of paleomagnetic results for Valsequillo basin.

Site	*n*	Dec (°)	Inc (°)	*k*	α_{95}	Polarity	Reference
Xalnene tuff							
Bulk samples	5	194*	−32.1	146.4	6.4	Reverse	1
Individual lapilli	20	205.1	−48.0	5.8	14.9	Reverse	2
Xalnene ash	10	280.8	17.8	52	6.8	Intermediate	3
Blackish ash	6	264.6	13.1	99	6.7	Intermediate	3
VXT-IV	5/8	196.3	−24.9	81.7	8.5	Reverse	4
VXT-V	8/9	206.3	−31.3	27.0	10.9	Reverse	4
Toluquilla lavas							
High-coercivity	12	176.3	−33.1	100.9	4.3	Reverse	2
Low-coercivity	10	354.0	−11.1	112.5	4.6	Intermediate	2
Toluquilla basalt	8	169.8	−29.7	93	5.8	Reverse	3

Notes: *Declinations have been rotated to a reference value of 194°, to allow comparison with data for the Toluquilla lavas and Xalnene tuff samples (Refs. 1 and 2).
References: (1) Renne et al. (2005); (2) Feinberg et al. (2009); (3) Goguitchaichvili et al. (2009); (4) this study.

Not in situ

Unknown

Urrutia-Fucugauchi et al., 2012

1. Laschamp age for Xalnene Ash
   - OSL age of Xalnene horizon xenolith (Gonzalez et al., 2006)
   - Transitional directions, low intensity (Goguitchaichvilli et al., 2009)

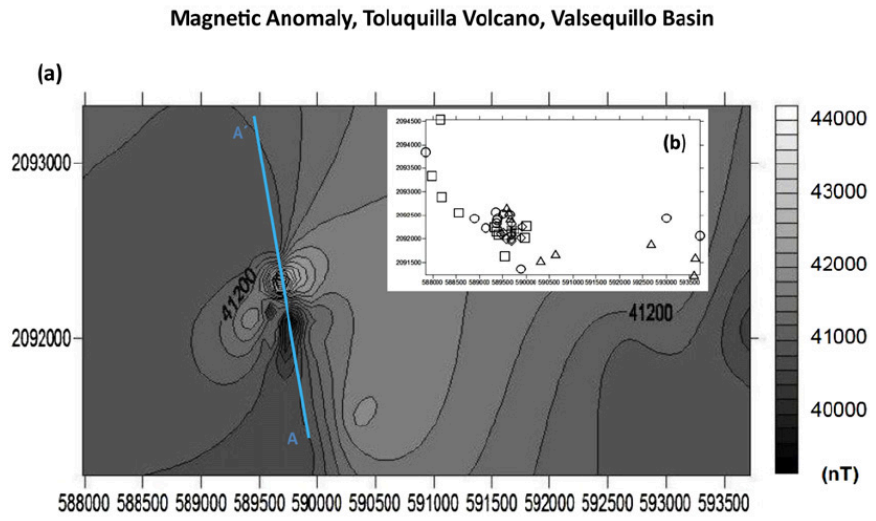
2. Xalnene Ash and Cerro Toluquilla Lava = 1.3 Ma
   - Ar/Ar ages (Renne et al., 2005; Feinberg et al., 2009)
   - Reverse polarity (Renne05; Feinberg09; Urrutia-Fucugauchi et al., 2012)

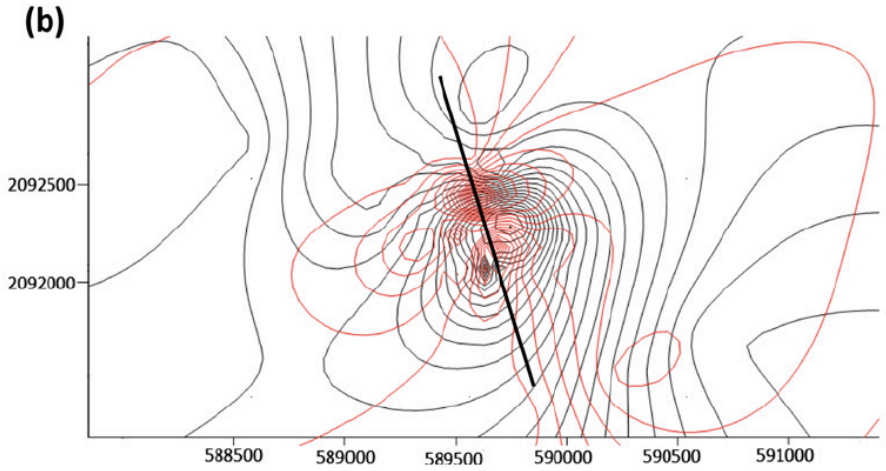
Modelling Cerro Toluquilla

Cerro Toluqiolla volcano erupted during a reverse magnetic polarity

Urrutia-Fucugauchi et al., 2012 use magnetic mapping to look into the guts of the volcano

Magnetic survey using Geometrics G-856 proton magnetometer (total field) and a GPS Trimble receiver





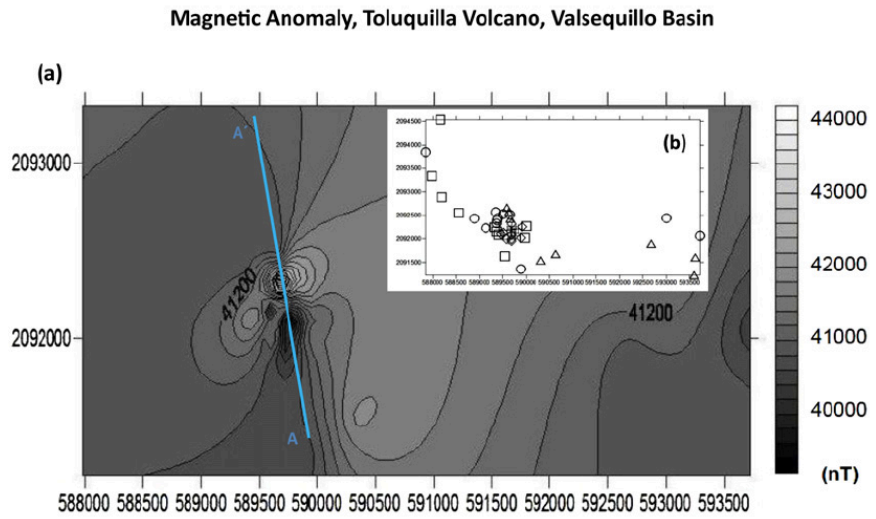
Urrutia-Fucugauchi et al., 2012

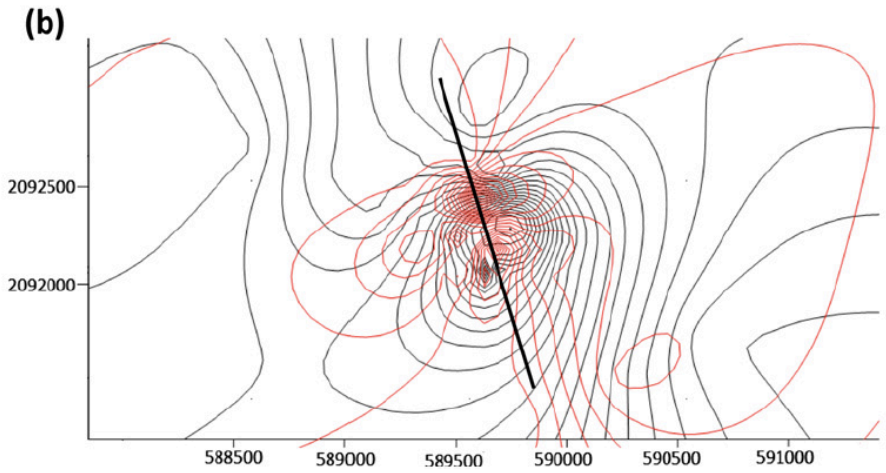
Modelling Cerro Toluquilla

Measurements corrected for diurnal effects

A first degree regional field of 41000 nT (from IGRF) removed to determine residual anomaly

Spline interpretation generates contour plots of magnetic anomaly



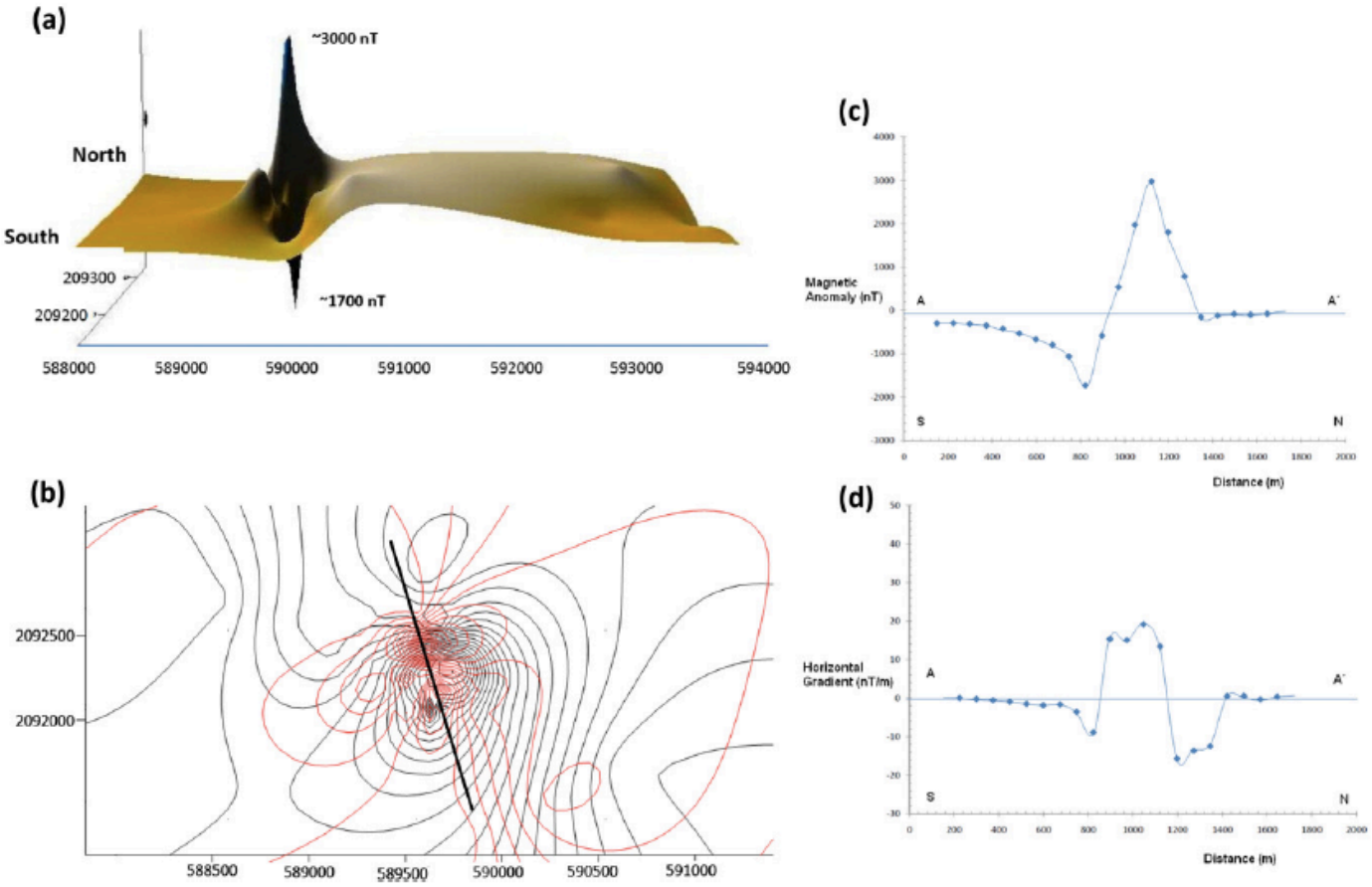


Urrutia-Fucugauchi et al., 2012

Remanent Magnetic Anomalies

Reverse polarity magnetization

Anomaly high in the north, low to the south of the cinder cone



Urrutia-Fucugauchi et al., 2012

Reproducing Magnetic Anomaly Map

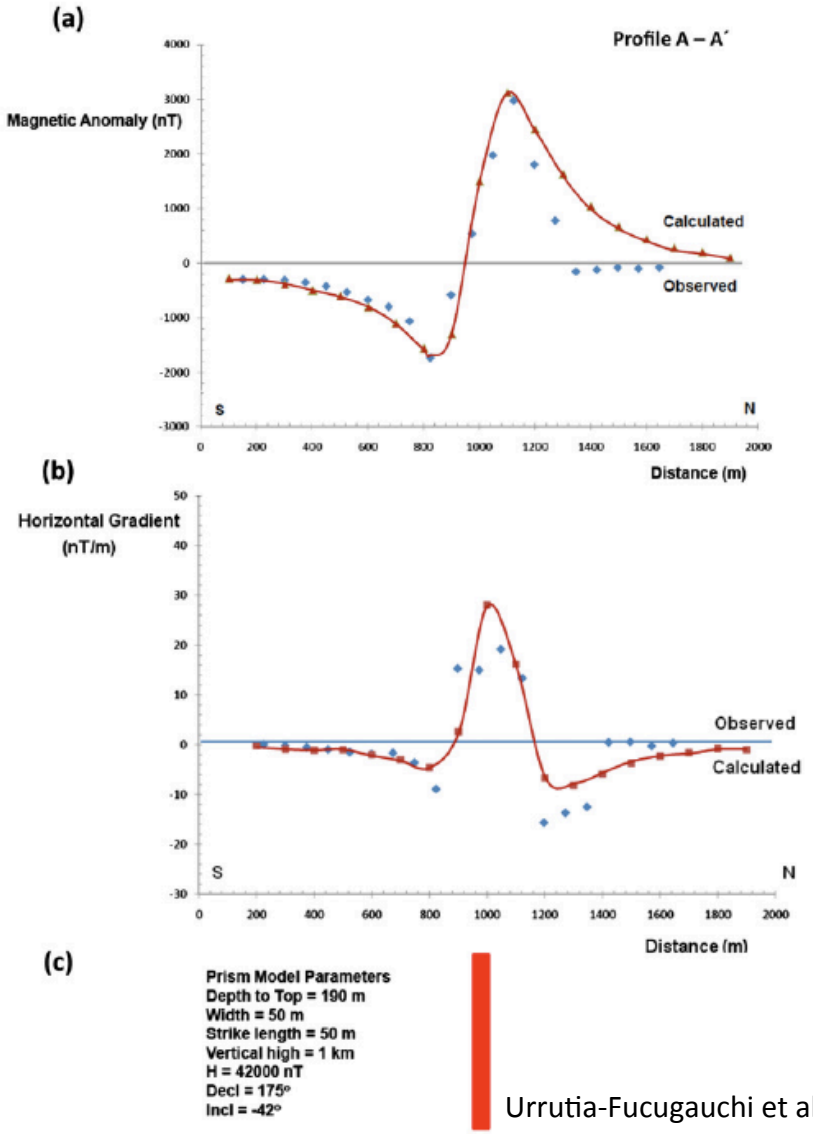
Qualitative magmatic body selection:

- Vertical prismatic body
- 50 m square
- 190 m depth below cone summit
- 1 km tall

Best-fit magnetic properties:

- 42000 nT
- Dec = 175°
- Inc = -42°

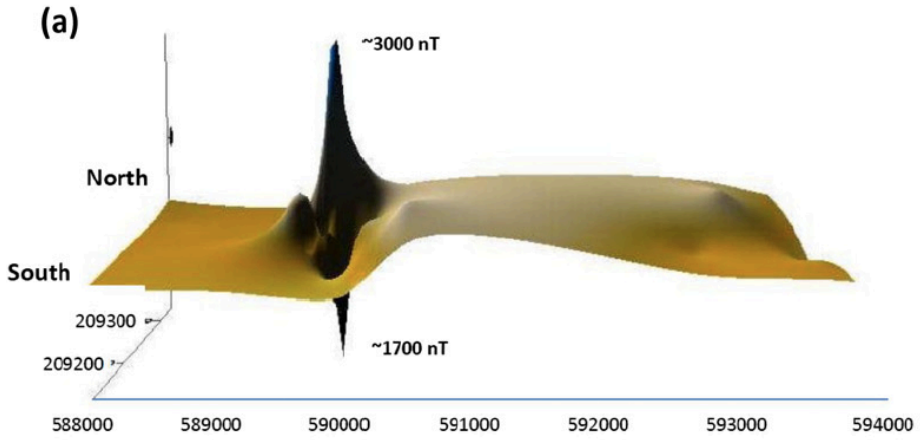
Inc. greater than lava estimates (-33°), but smaller than lapilli (-48°)



Urrutia-Fucugauchi et al., 2012

Interpreting the Model

Prism Model Parameters
Depth to Top = 190 m
Width = 50 m
Strike length = 50 m
Vertical high = 1 km
H = 42000 nT
Decl = 175°
Incl = -42°



Urrutia-Fucugauchi et al., 2012

Magmatic Body:
Authors present some evidence that the structure of the prism is reasonable, but volcano plumbing is inherently more complicated (e.g., small magnetic anomaly on southwestern flank)

Conduit geometry and depth of source bodies needs to be constrained.

Interpreting the Model

Temporal constraints:
Paleomagnetic data provides a time point, cooling of magmatic body over millions (?) of years

IF the Xalene ash eruption was in the Laschamp, could the magmatic body still record a reverse polarity anomaly?

Can a prismatic body of dimensions used in this model be expected to mirror paleomagnetic directional data?

Conclusions

- “Footprints” are likely older in age, 1.3 Ma and not human
- Reverse polarity for Xalnene Tuff and proximal Cerro Toluquilla lava
- Coincident ages for both volcanic bodies (1.3 Ma)
- Reverse polarity magnetic anomaly beneath Cerro Toluquilla volcano
- Anomaly modeled using directional information similar to paleomagnetic data