IMPLICATIONS OF AN UPDATED VOLCANOLOGICAL CONCEPTUAL MODEL AT LOS HUMEROS FOR GEOTHERMAL EXPLORATION AND MODELING

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Previous volcanology-based thermal model

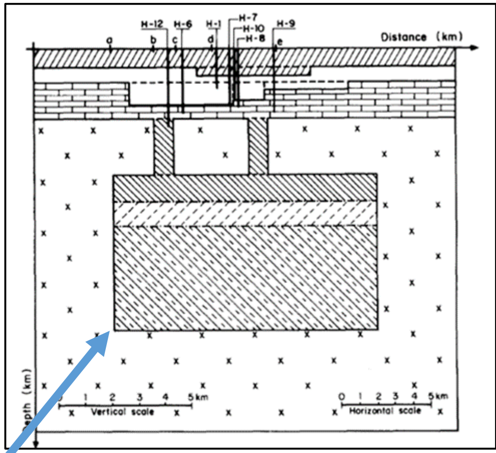
GEMex

Table 1. Some physical and chemical parameters of Los Humeros volcanic center (after Verma, 1985b)

Formation/flow	Magma erupted (km^3)	Age (My)	Temp. °C	SiO_2 %	Minerals left behind (km^3)*
Ol. basalt	0.25	<0.02	1070	49	—
Rhyodac.–dacites	10	0.03–0.02	910	59–69	70
El Xalapazco caldera					
Cuicuiltic tuff	0.1			69–72	1
Limón and other andesite	6	0.04–0.02	960	56–59	20
Llano andesite ignim.	0.1				
Xoxoctic tuff	0.6		890	65	2
Cueva Ahumada lavas	0.1	0.06			
Los Potreros caldera					
Zaragoza ignimbrite	10	0.10	880–920	54–71	64
Zaragoza basal fall	2.0		855	71	20
??????					
Faby tuff	10	0.24	875	69–73	100
Post-Xal. rhyolites	4.7	0.36–0.22		73–76	54
Los Humeros caldera					
Xaltipan ignimbrite	115	0.46	800–875	69–77	1200
Pre–Xal. rhyolites	0.1	0.47			
Teziutlán formation	60	3.5–1.6			

*The parameter "Minerals left behind (km^3)" refers to the volume of crystals separated and left behind in the magma chamber and is based on a fractional crystallization model of Verma (1984).

Verma et al. (1990)



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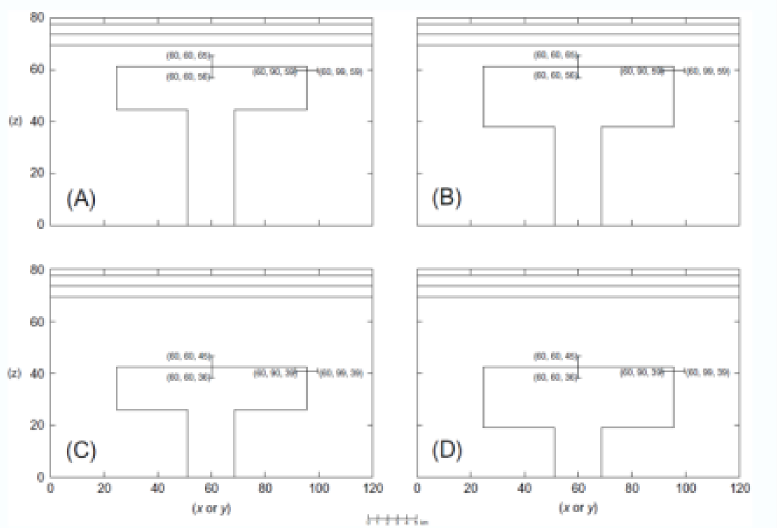
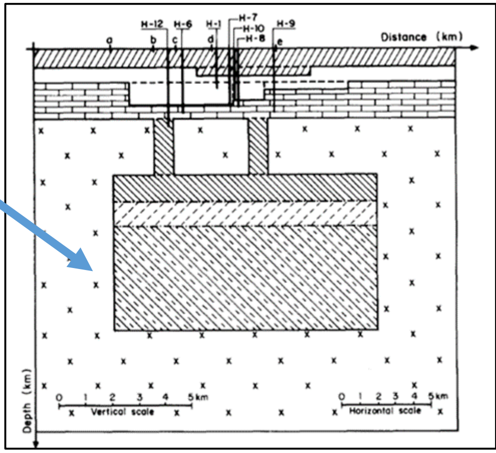
Previous volcanology-based thermal model

Table 2. Emplacement conditions for sensitivity evaluation of the Los Humeros geothermal field (LHC).

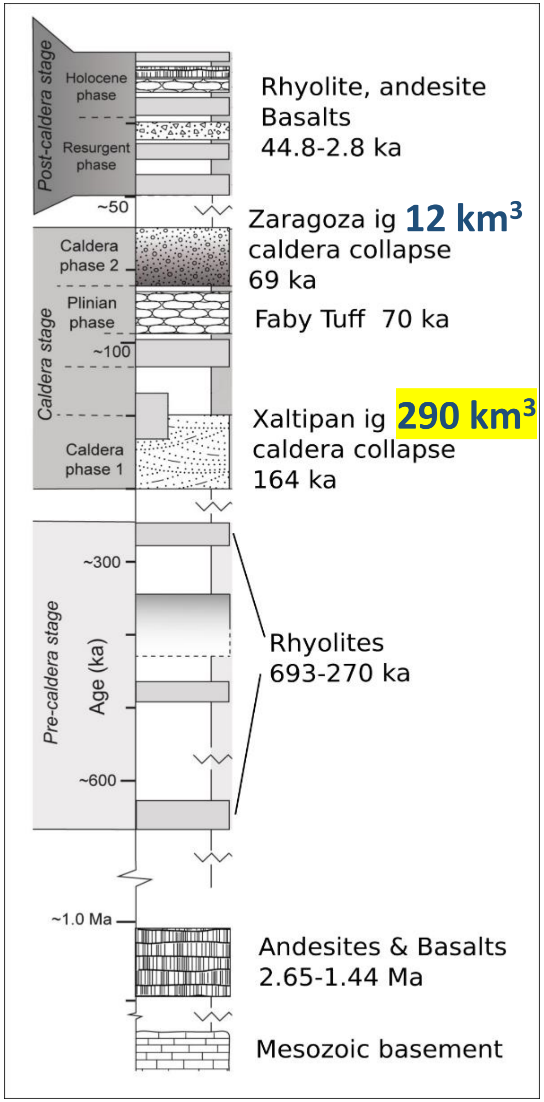
Physical property (units)	Emplacement of magma chamber
Depth of the top the chamber (d_{cham}) (km)	5–10
Volume (V_{cham}) (km^3)	1000–1400
Thickness (E_{cham}) (km)	4.5–6.5
Radius (r_{cham}) (km)	8.5
Magma emplacement temperature (T_{cham}) (°C)	1350

Verma et al. (2011) and Verma and Gomez-Arias (2013)





Longevity and volume of the deep magmatic heat source

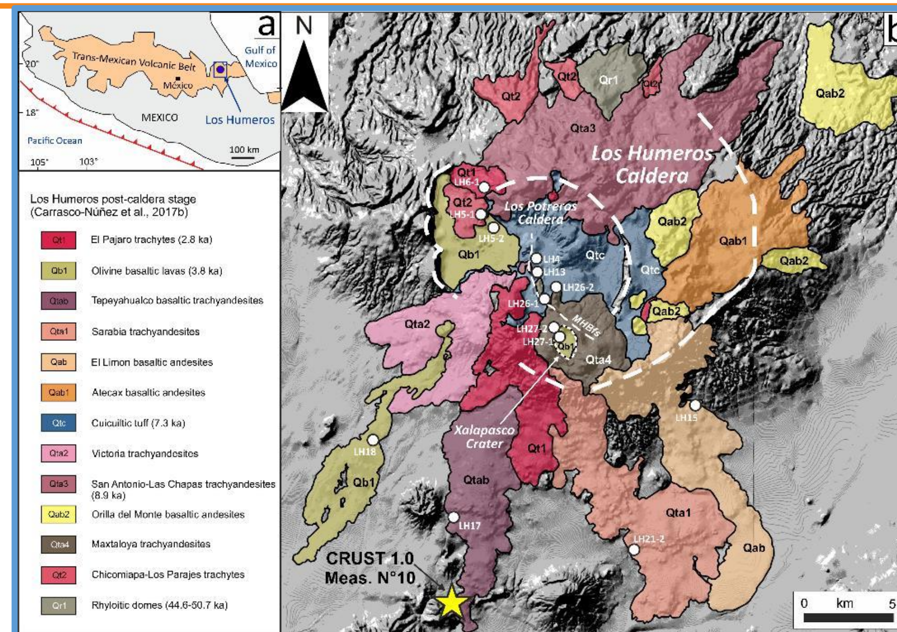


Post-peak phase (69 ka-present)
Bimodal magmatism/recharge

Peak phase (164-69 ka)
Largest reservoir of rhyolitic magma and its emptying

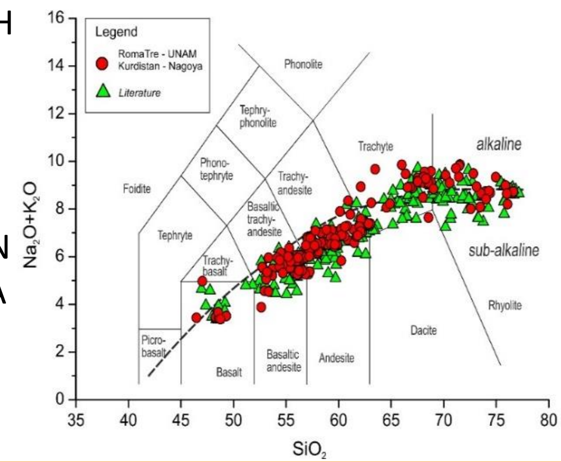
Build up phase (>693-164 ka)
Intrusion/Recharge /Differentiation

Carrasco-Núñez et al. (2018) G-Cubed
Cavazos & Carrasco-Núñez (2020) JVGR



Lucci et al. (2020) Solid Earth

RECHARGE RATES HAVE BEEN NOT HIGH ENOUGH TO PROMOTE LARGE INTERCONNECTION AND REHOMOGENIZATION TO A SINGLE MAGMA BODY



Petrological modeling of the LHPCS magmatic heat sources: a window into present plumbing system

GEMex

LH18 (Texcal lava) is characterized by textures typical of basalts erupted directly by the deep reservoir.

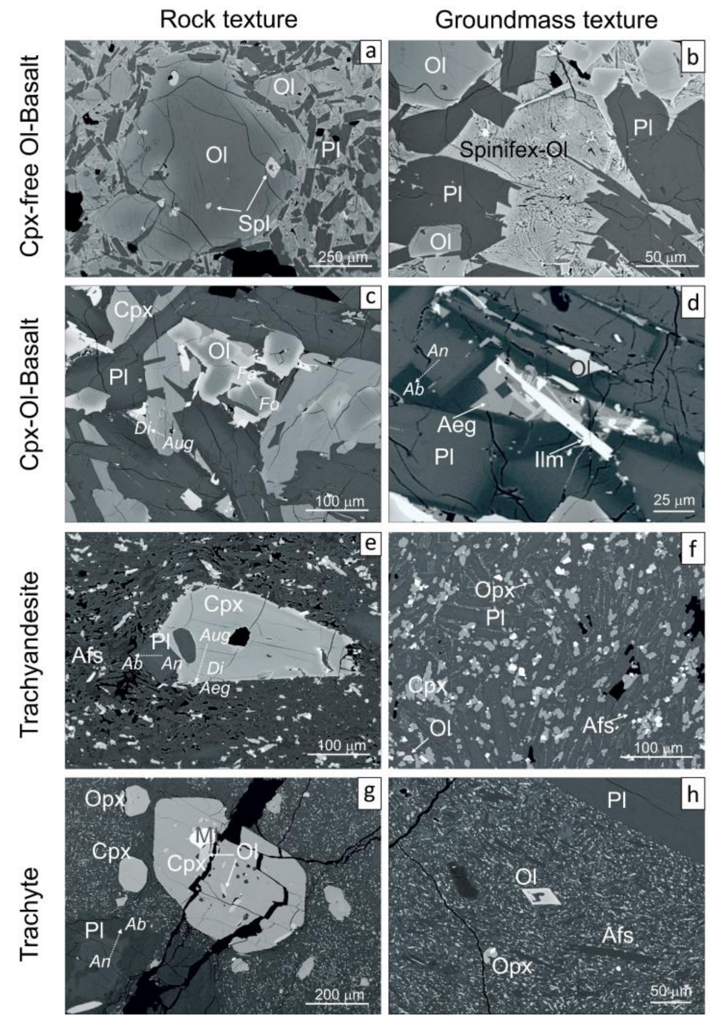
All LHPCS volcanic rocks do not show disequilibrium textures typical of assimilation and fractional crystallization (AFC) mixing processes.

The Rayleigh fractional crystallization (RFC) model

$$\sum r^2 = \sum_{i-1}^{n} (b_i' - b_i)^2$$

demonstrate that all LHPCS magmas, from basalts to trachytes, belong to the same line of descent and evolve through a progressive fractionation of the Pl + Cpx + Ol + Spl mineral assemblage.

Trachyandesites and trachytes represent different degrees of fractionation (RFC values in the range 45 %–74 %) starting from a Cpx-bearing basaltic source.



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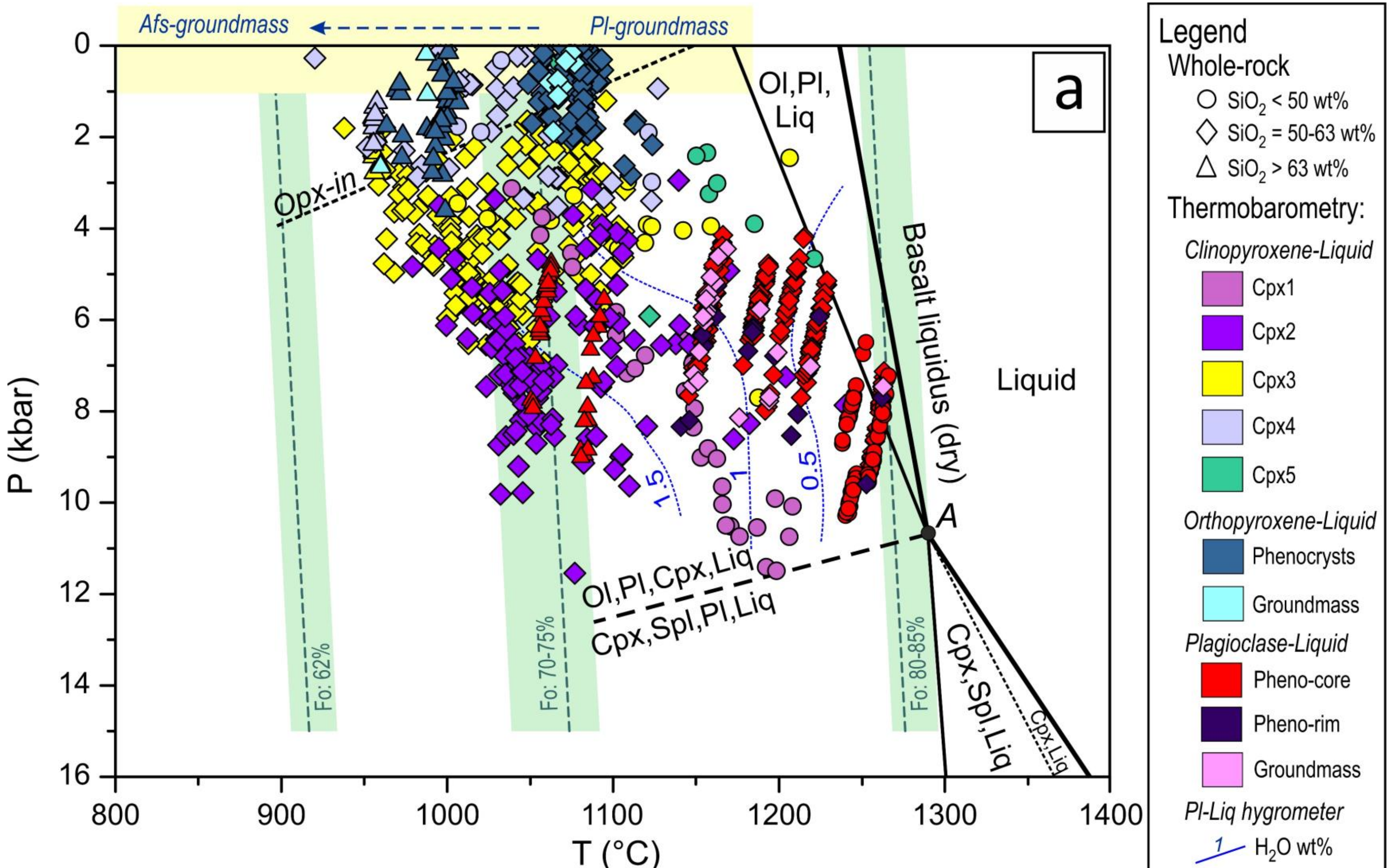
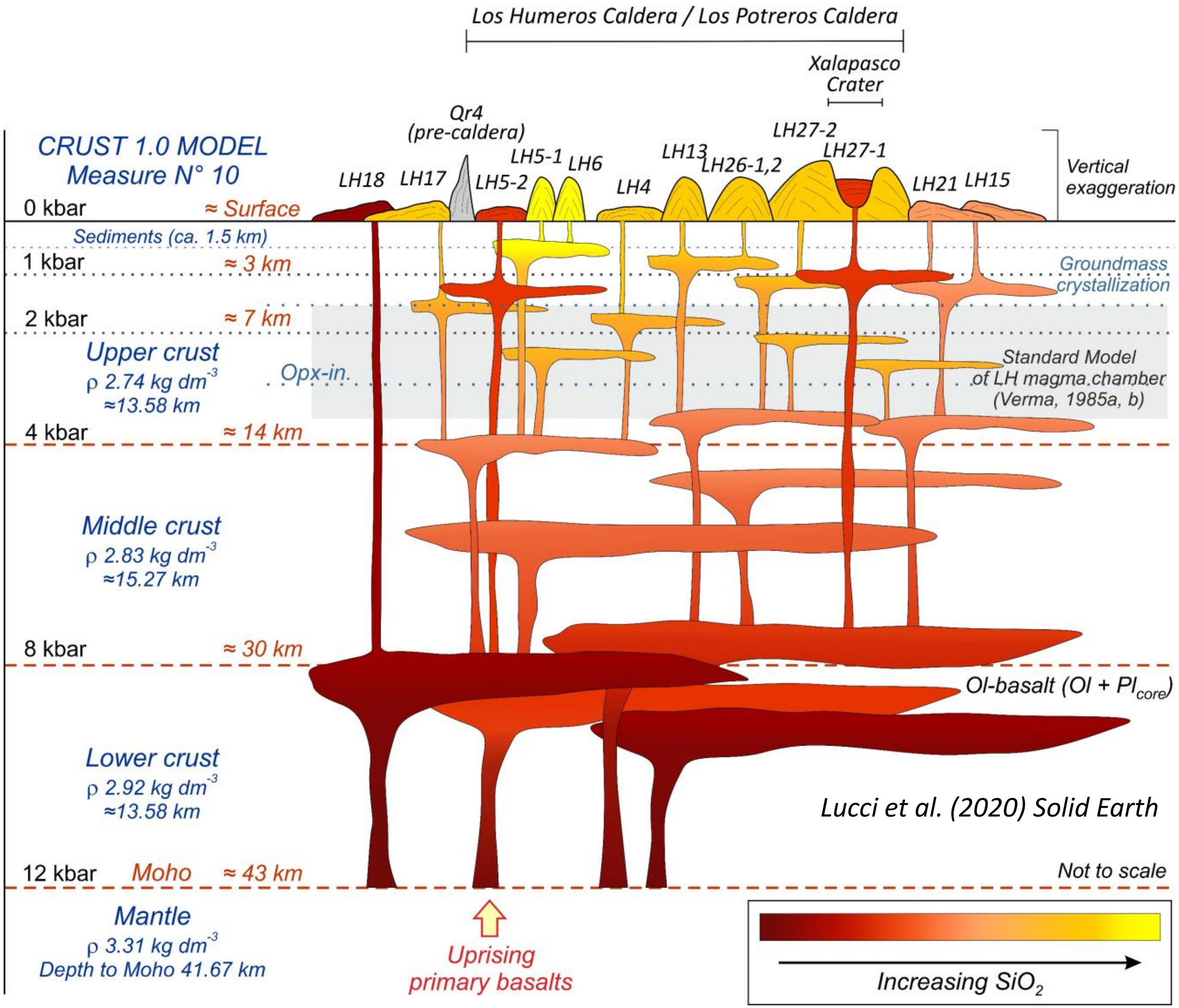
Geothermobarometry of the heat sources



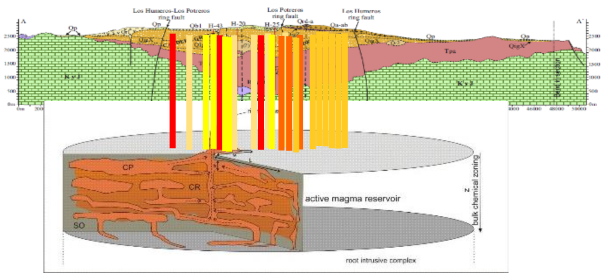
2400 EMPA spot - 1300 min-liq pairs

Lucci et al. (2020) Solid Earth

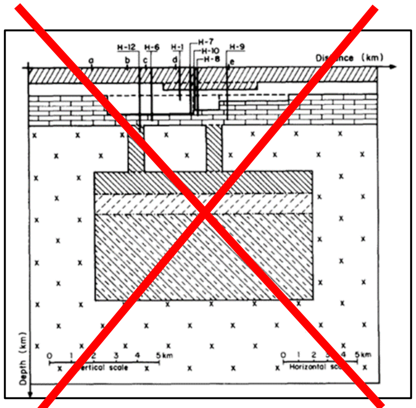
Step-change volcanological conceptual model of the heat sources



PRESENT Plumbing system



Modified from Cashman and Giordano, 2014, JVGR



Verma et al. 2011

Volcanological conceptual model of the heat sources

GEMex

	Xaltipan	Zaragoza	LH11,12	LH6°	LH27-2°	LH 17° (Tepeya)	LH15° (Limon)	LH5-2° (Los Potreros)	LH18 (Texcal)
Erupted Composition	high-silica rhyolite	rhyolite-andesite	rhyolite (obsidian)	Trachyte	Trachyandesite	Trachyandesite	Opx-free Trachyandesite	Ol-Basalt	Ol-Basalt
Eruptive temperature*° (°C)	790-890		800	950	1050	1050	1050	1150	1250
DRE Erupted Volume (km3)	290"	15	0.03	0.1	1	1	1	0.2	
Age of eruption (ka)^	164	69	7	2.8	>7	>2.8	?	3.8	
Residence time of differentiated magma in shallow reservoir	5ka^	ka	a	a	a	a	a	a	a
Amount of evacuation of shallow reservoir	complete*	complete*						?	
Residual volume >30 km (km3)	3600	161	0.3	0.2	1	1.2	1	0.02	
Residual volume 30-14 km (km3)	370	17	0.03	0.06	0.6	0.3			
Residual volume 14-7 km (km3)			0.05						
Residual volume <7 km (km3)	540	21	0.004	0.06	0.4			0.2	
Depth of top of shallowest transient reservoir° (km)	<=7	<=7	1 [H26]	3	<7	<7	>10	<= 3	
Depth of top of shallowest fractionated/intrusive resident reservoir° (km)	<=7	<=7		3			>10		
Temperature of shallowest fractionated/intrusive resident reservoir° (km)	1000	1000	1000	1000	1050	1050	1075	1150	
x-y area	200	100							
z-thickness	2.7	0.2							
Intrusion shape	cylinder	cylinder	sphere	sphere	sill	sill	sill	sill	sill

*Ferriz and Mahood 1986, J Petrol

°Lucci et al 2020, Solid Earth

"Cavazos & Carrasco Nunez 2020, JVGR

^Carrasco Nunez et al. 2018, G-Cubed

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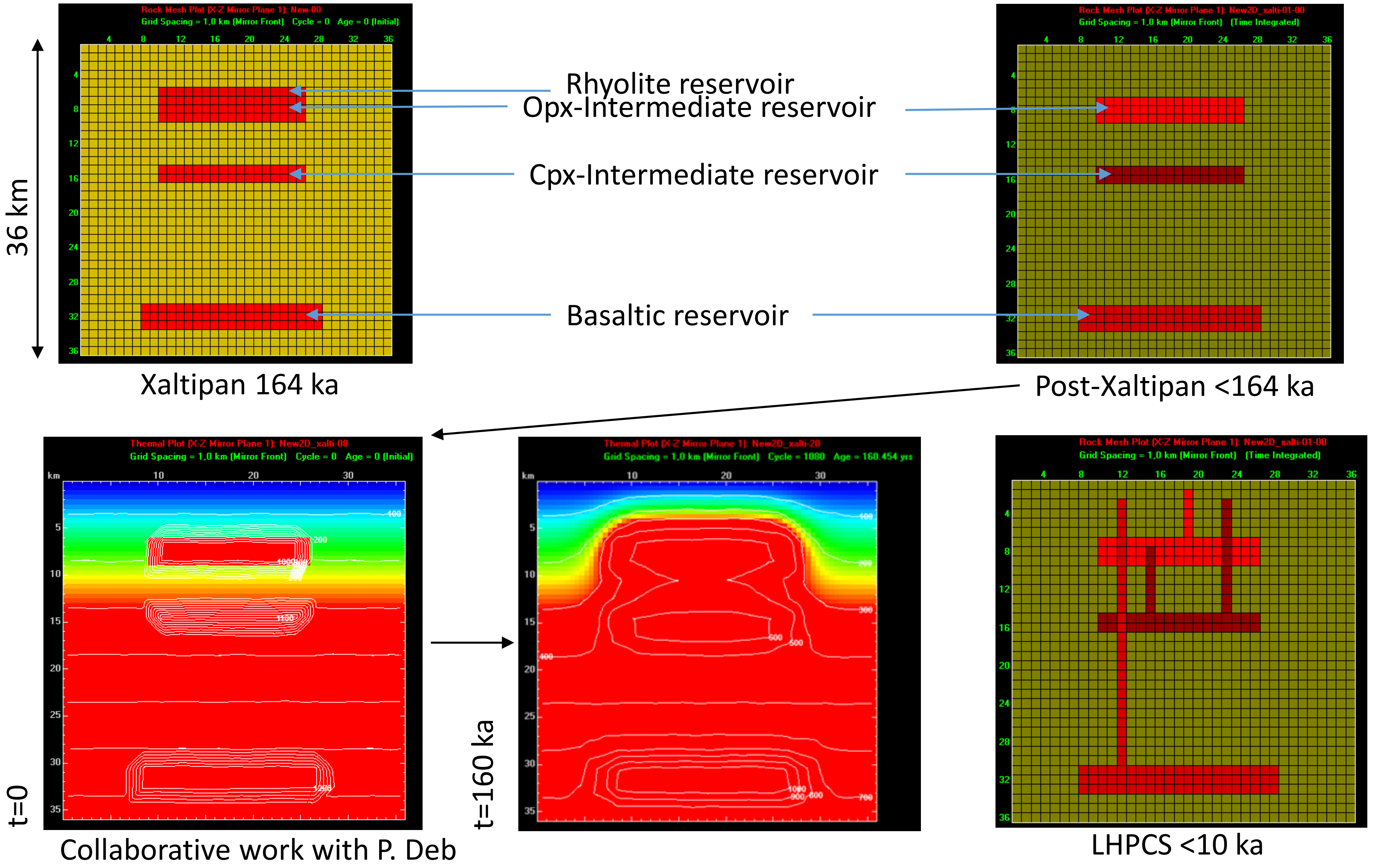
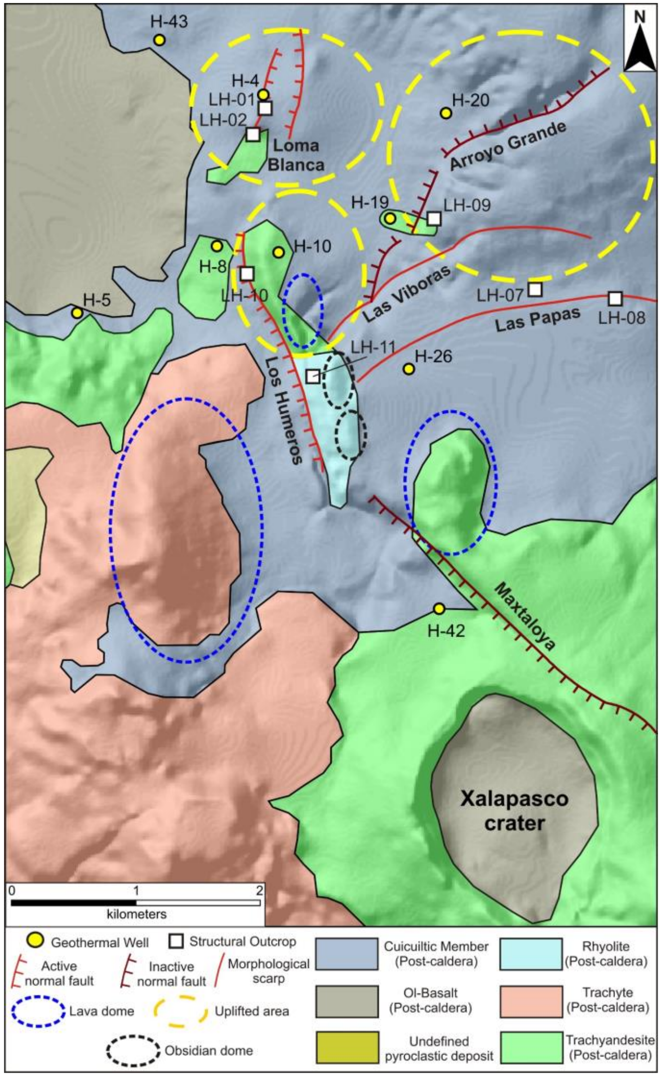
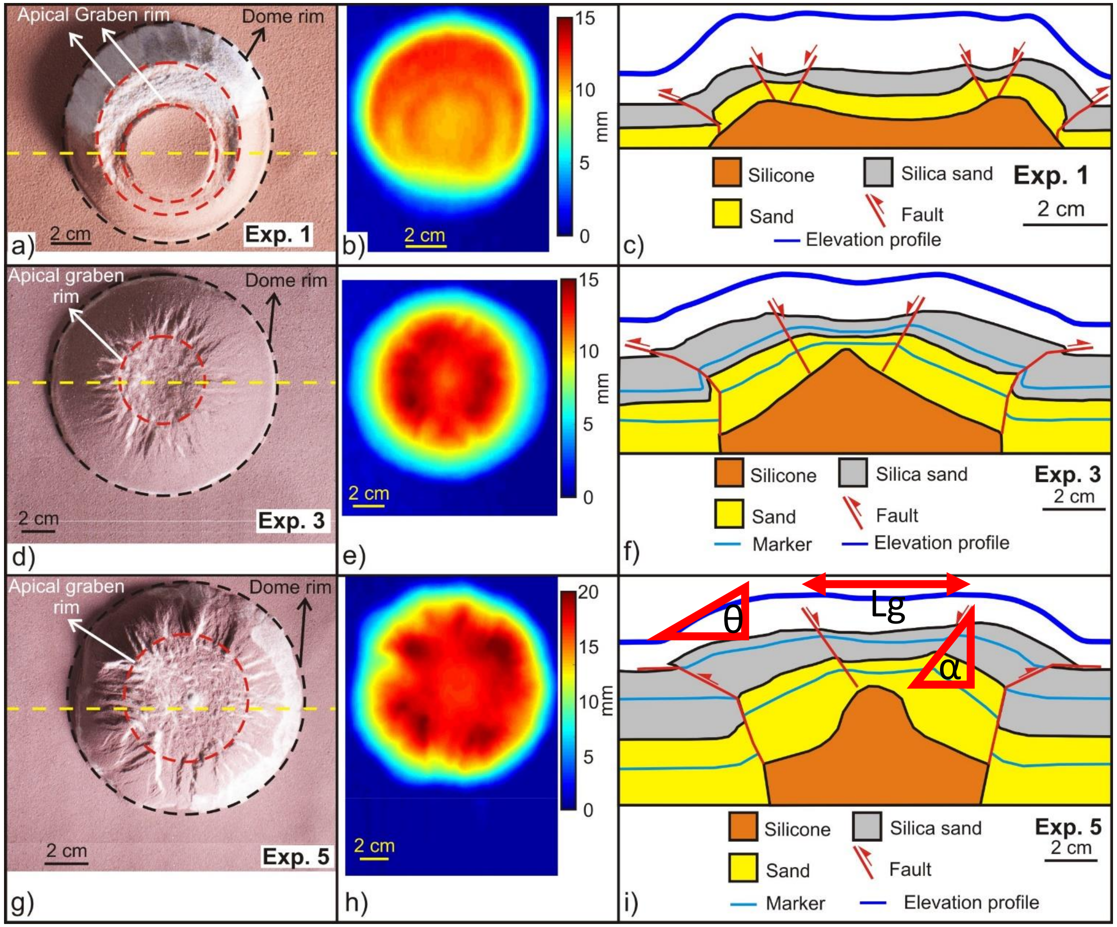
Implications for the heat sources



Implications for shallow structures



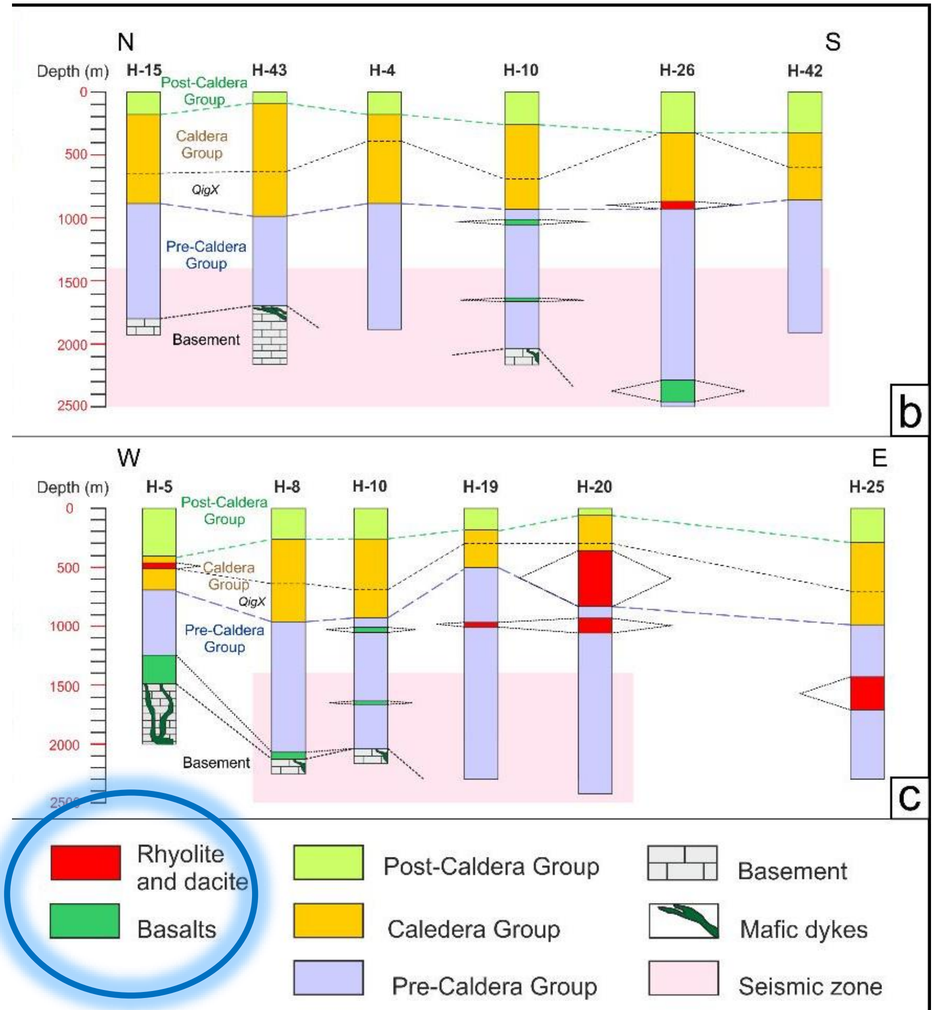
Urbani et al. (2020) Solid Earth

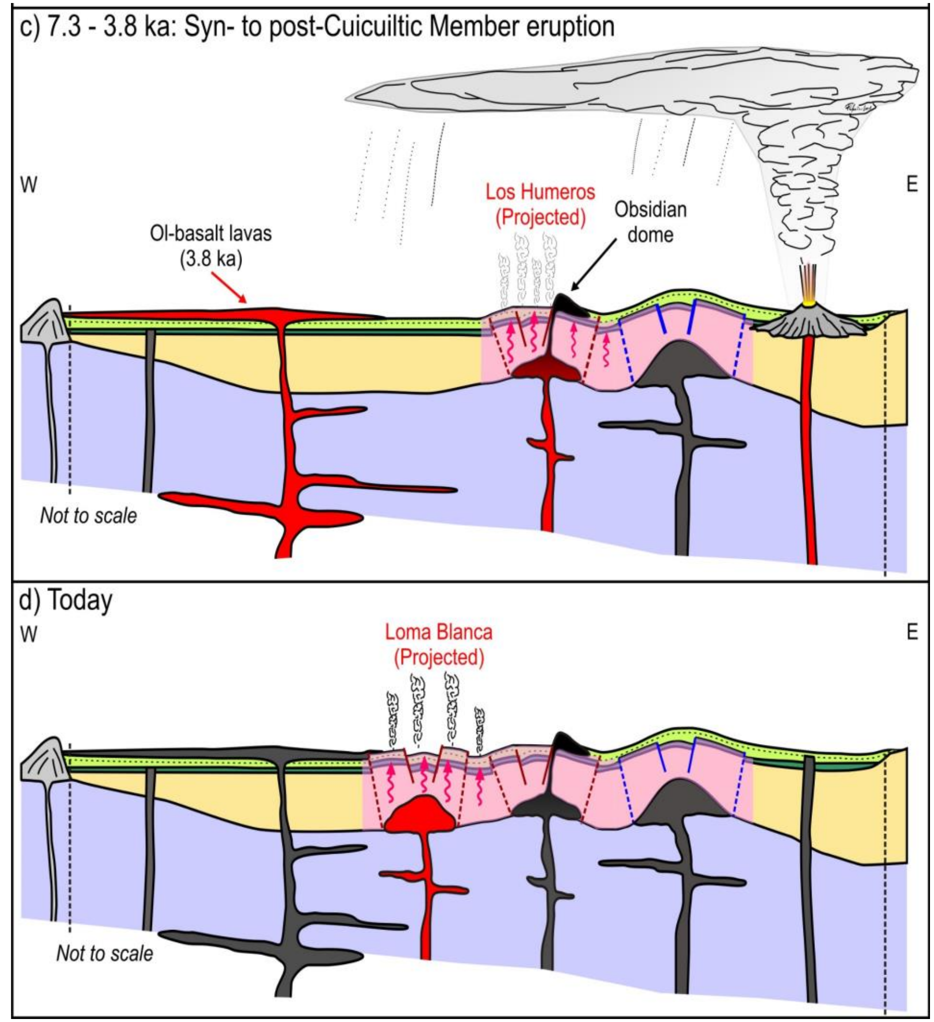


$$T_t = \frac{1}{2} L_g \times \frac{\sin(\theta+\alpha)}{\cos\theta}$$

e.g. Loma Blanca bulge depth of source of deformation:
T= 425 ± 170 m.

Implications for subsurface setting

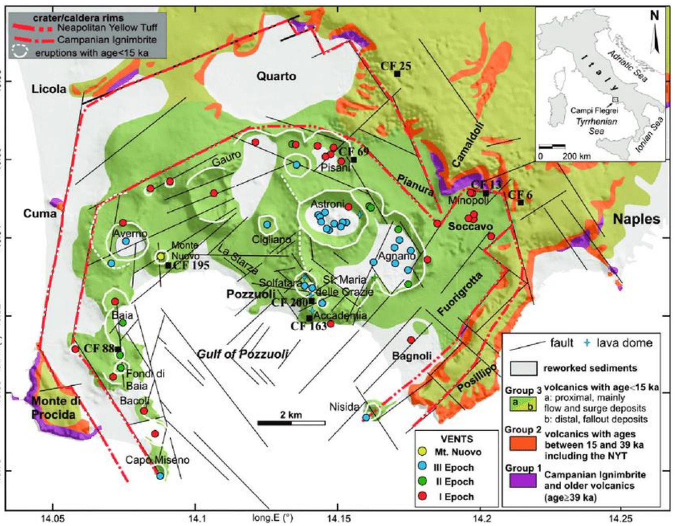




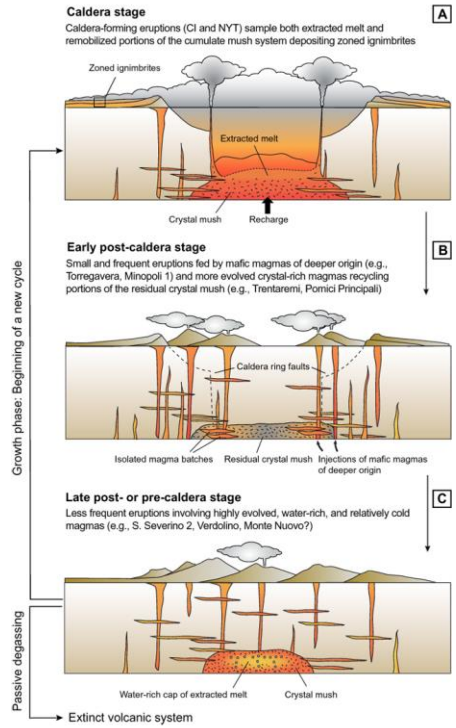
Urbani et al. (2020) Solid Earth

Analogue caldera – Campi Flegrei

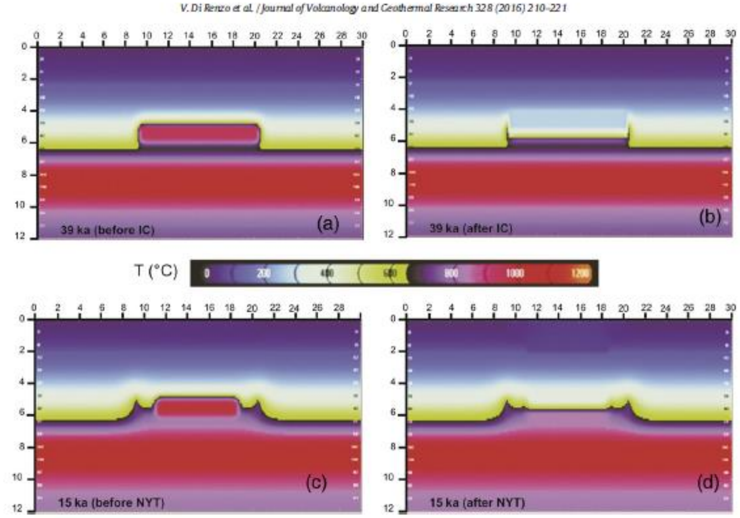
GEMex

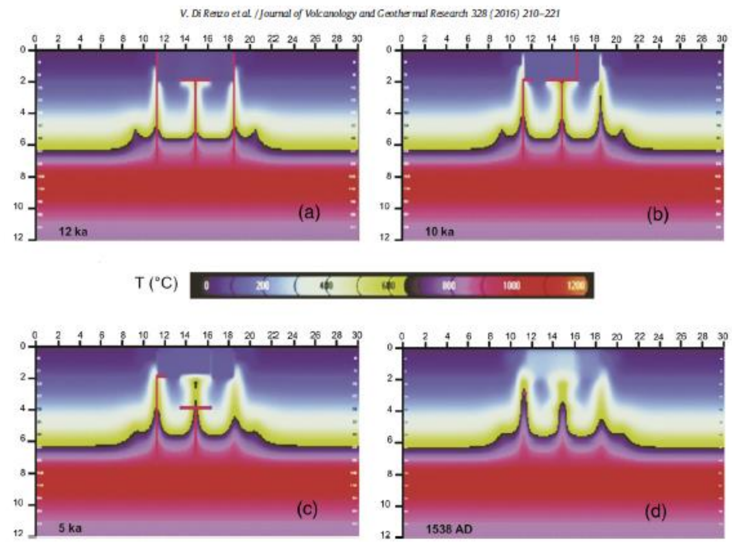


Isaia et al. (2016) GSAB

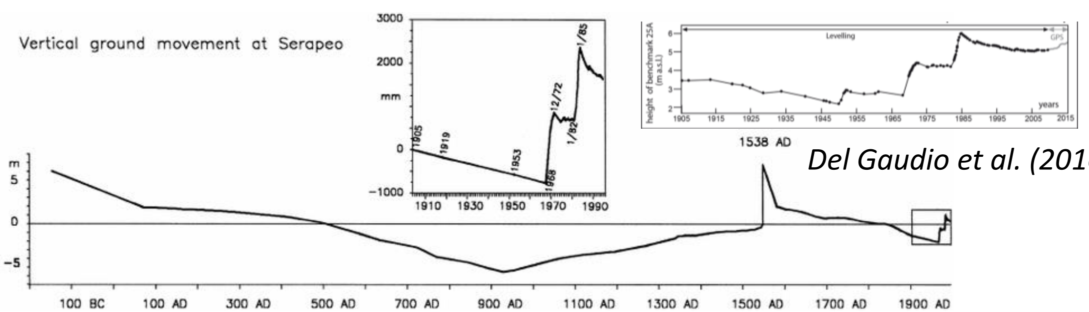


Forni et al. (2018) Sci Adv





Di Renzo et al. (2016) JVGR



Del Gaudio et al. (2010)

< Potsdam 2020 >
<Giordano et al.>

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TAKE HOME MESSAGES

- PETROLOGIC MODELING AT LH ALLOWED A STEP-CHANGE IN THE VOLCANOLOGIC CONCEPTUAL MODEL, FROM SINGLE MAGMA CHAMBER TO MULTILAYERED, TANSCRUSTAL RESERVOIRS

- UNPACKING AGE, VOLUME AND DEPTH OF THE MAGMATIC HEAT SOURCES IS THE FIRST ORDER NEED FOR GEOTHERMAL MODELING

- THERMAL MODELING OF HEAT CONDUCTION FROM THE MAGMA SOURCE MUST TAKE INTO ACCOUNT BOTH THE GEOMETRICAL CONSTRAINTS AND INCREMENTAL MASS BALANCES (RECHARGE vs WITHDRAWAL)

- THE CURRENT HEAT FLUX AT LH IS THE RESULT OF THE COMBINATION OF THE THERMAL RELAXATION OF THE XALTIPAN MAGMA CHAMBER + RECENT SHALLOWER INTRUSIONS + FRACTURE CONTROLLED FLUID ADVECTION

- MAGMATIC PRESSURE SOURCES THAT GENERATE BRITTLE DEFORMATION AND PERMEABILITY ARE POLYPHASED IN SPACE AND TIME

- DEVELOPMENT OF SHGS AT LH REQUIRES EFFORTS IN IMAGING THE VOLUME BETWEEN 7 AND 3 KM, WHERE MASS AND HEAT TRANFER HAVE OCCURRED DURING THE LAST 10 KA

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