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Supporting Information for

Volcano Monitoring with Magnetic Measurements: A Simulation of Eruptions at Axial Seamount, Kīlauea, Bárðarbunga, and Mount Saint Helens

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Noddy .his files for Tables S1 to S2 are available at https://doi.org/10.5281/zenodo.7015052

Introduction

This Supporting Information file contains tables and text listing all of the parameters in the .his Noddy files, a brief overview of how to get started with Noddy, and a brief discussion of monitoring strategies.

Text S1. Model Notes

Noddy is a 3D geologic and geophysical modeling software package, that is used for both teaching and research (Jessell and Valenta, 1996; Jessell, 2001; Wellmann et al., 2016; Guo et al., 2021; Jessell et al., 2022). There is a stand-alone version of Noddy for windows (https://tectonique.net/noddy/) and a python version (https://github.com/cgre-aachen/pynoddy). Noddy is not the most powerful nor feature-rich aeromagnetic modeling package, but it is free to use and has a relatively shallow learning curve. It is more than sufficient for the goals of this study. Tutorials and a manual for the software package are available here: https://tectonique.net/noddy/. The .his files available here (https://doi.org/10.5281/zenodo.7015052) contain all of the information presented in Tables S1 and S2, and are the same files that we used to create the models in Figures 1-4.

Mount Saint Helens
Susceptibility from Finn et al. (2018)
Remanence intensity from Dzurisin et al. (1990)
Magma geometry from Ulberg et al. (2020), Tilling et al. (1990), Pallister et al. (1992)
See Sections 2.1 and 4.1 for additional model details.

Axial Volcano
Susceptibility and remanence intensity from Johnson and Tivey (1995)
Magma geometry from Chadwick et al. (2022), Arnulf et al. (2018)
See Sections 2.2 and 4.2 for additional model details.

Kīlauea
Susceptibility from Decker (1963)
Remanence intensity from Decker (1963)
Magma geometry from Neal et al. (2019), Feng et al. (2020), Wieser et al. (2021)
Dikes have unconstrained length and height in Noddy. To create the correct geometry shown in Figure 3, several faults and unconformities were used. See the .his file and Sections 2.3 and 4.3 for additional details.

Bárðarbunga
Susceptibility from Oliva-Urcia et al. (2011)
Remanence intensity from Oliva-Urcia et al. (2011)
Magma geometry from Sigmundsson et al. (2015), Ágústsdóttir et al. (2019), Gudmundsson et al. (2016)
Note that we included the ice cap and thicker ice within the caldera area in our model. Dikes have unconstrained length and height in Noddy. To create the correct geometry shown in Figure 4, several faults and unconformities were used. See the .his file and Sections 2.4 and 4.4 for additional details. We could not find susceptibility and

remanence intensity data from Bárðarbunga itself. Data from nearby Krafla volcano was used instead.

Text S2. Model Notes

The number of magnetometers needed to monitor a volcanic system will vary widely depending on the needs of the monitoring program. The difference maps presented in Figures 1-4 assume a dense array of magnetometers are in use. In reality, ground-based magnetometers will probably not be plentiful and widely distributed on a volcano of interest. When using a limited number of ground-based magnetometers, they are most effective when placed in areas of higher activity such as rift zones and summit calderas. Volcanic systems with more distributed vents or more complex morphologies will require more magnetometers to be effectively monitored.

Additionally, at least one (but preferably several) magnetometers must be placed away from the areas of probably activity, where changes to the magmatic system will not affect their measured signals. These magnetometers will serve as a control group, providing background measurements of the field that can then be subtracted from the signal measured by magnetometers on the volcano itself. This is a straightforward way to account for the variations in the field from environmental noise such as diurnal variations and geomagnetic storms (see Section 5.1).

Depending on the number of stationary magnetometers that are needed, it may be more economical to replace them with one or more drone-based magnetometer systems (e.g. Koyama et al., 2021). These platforms are becoming increasingly common and could fly regularly to monitor a large area.

Table S1.

Table S1: Model Settings in Noddy

Model Name	Model Dimensions (m)			Model Origin (m)			Magnetic Field			Cube Size (m)	
	Length	Width	Height	X	Y	Z	Int. (nT)*	Decl.	Incl.	Geology	Geophys.
Mt. St. Helens	10000	10000	8000	0	0	8000	52450	0	90	50	50
Axial	13300	18700	10000	0	0	10000	53300	30	90	50	50
Kilauea	40000	20000	10000	0	0	20000	34500	18	90	25	25
Bardarbunga	50000	20000	15000	0	0	15000	52300	45	90	25	25

*Intensity from the International Geomagnetic Reference Field (Thébault et al. 2015)

Table S2.

Table S2: Parameters for Individual Rock Units in Noddy

Geologic Unit	Suscept. (SI)	Remanence			Unit				Unit Position*			Unit Orientation		
		Int. (A/m)	Decl.	Incl.	Shape	Length	Width	Height	X	Y	Z	Direction	Dip	Pitch
Mount Saint Helens														
Surface	0.005	2	0	90	flat layer	--	--	variable	--	--	variable	0	0	0
Bulge Magma	0	0	--	--	ellipsoid	300	300	300	5300	6000	7650	90	90	0
Connector	0	0	--	--	ellipsoid	100	100	550	5150	5500	7450	285	0	20
Conduit	0	0	--	--	cylinder	--	100	variable	5000	5000	4000	90	90	0
Deep Source	0	0	--	--	sphere	4500	3000	3000	5000	5000	-2500	90	90	0
Middle	0.005	2	0	90	flat layer	--	--	variable	--	--	3000	0	0	0
Base	0.005	1	0	90	flat layer	--	--	3000	--	--	--	0	0	0
Axial Seamount														
Top Layer	0.0012	15	30	90	flat layer	--	--	1000	--	--	9000	0	0	0
Middle Layer	0.0012	10	30	90	flat layer	--	--	1000	--	--	8000	0	0	0
Lower Layer	0.0012	5	30	90	flat layer	--	--	2000	--	--	6000	0	0	0
Base Layer	0.0001	0	--	--	flat layer	--	--	6000	--	--	0	0	0	0
2015														
Magma Body N	0	0	--	--	ellipsoid	2000	4900	500	7150	11650	8000	95	10	90
Magma Body S	0	0	--	--	ellipsoid	1750	3900	800	6650	5350	8050	80	0	90
Alteration Zone N	0	0	--	--	ellipsoid	2000	4900	500	7550	11650	8750	95	10	90
Alteration Zone S	0	0	--	--	ellipsoid	1750	3900	800	6650	5350	8550	80	0	90
2020														
Magma Body N	0.05	0	--	--	ellipsoid	2000	4900	500	7150	11650	8000	95	10	90
Magma Body S	0	0	--	--	ellipsoid	1750	3900	800	6650	5350	8050	80	0	90
Alteration Zone S	0.0002	0	--	--	ellipsoid	1750	3900	800	7650	2350	8650	80	0	90
Kilauea														
All Wall Rocks	0.137	10	18	90	flat layers	--	--	--	--	--	variable	0	0	0
Upper Reservoir	0	0	--	--	ellipsoid	600	800	600	0	17000	18000	0	0	0
Lower Reservoir	0	0	--	--	ellipsoid	1000	800	1000	0	17000	16000	0	0	0
Little Pipe	0	0	--	--	ellipsoid	200	2000	200	0	17000	17700	0	0	0
Big Pipe	0	0	--	--	cylindrical	--	200	--	0	17000	20000	90	90	0
Dyke	0	0	--	--	dike	c. 5000	25	variable	25000	5000	15000	0	90	0
Dyke segment 2	0	0	--	--	dike	c. 8000	50	variable	0	17000	15000	245	90	0
Dyke segment 3	0	0	--	--	dike	c. 30000	50	variable	0	12000	15000	212	90	0
Rift	0	0	--	--	ellipsoid	50	4000	1000	35000	5000	18500	0	0	0
Bardarbunga														
Wall Rock	0.02	4	45	90	flat layer	--	--	--	--	--	variable	0	0	0
Ice Cap	0.0001	0	--	--	tilted layer	--	--	variable	25000	20000	15000	214	1.2	0
Caldera Ice	0.0001	0	--	--	ellipsoid	700	3000	5000	5700	15300	15000	35	90	0
Melt Lens	0	0	--	--	ellipsoid	5500	3500	50	5700	15300	2000	125	0	90
Deep Source	0	0	--	--	ellipsoid	2000	3000	5000	5700	15300	0	35	90	0
Dyke	0	0	--	--	dike	c. 8000	25	variable	8950	4700	5000	87	90	0
Dyke segment 2	0	0	--	--	dike	c. 11000	25	variable	8950	4700	5000	191	90	0
Dyke segment 3	0	0	--	--	dike	c. 8000	25	variable	29900	2400	5000	180	90	0
Dyke segment 4	0	0	--	--	dike	c. 6000	25	variable	29900	2400	5000	135	90	0
Dyke segment 5	0	0	--	--	dike	c. 14000	25	variable	46800	11600	15000	157	90	10

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