The Effect of Shock on the Amorphous Component in Altered Basalt

Scott A. Eckley*, Shawn P. Wright, Elizabeth B. Rampe, and Paul B. Niles

*Jackson School of Geological Sciences, University of Texas at Austin, 78712 (seckley@utexas.edu)

Introduction

- The Martian surface contains a large proportion (up to 50 wt. %) of amorphous material whose nature and origin is not fully understood [1,2,3,4].
- Mass-balance equations have been employed to constrain the geochemistry of the amorphous component [1,2,3,4].
- Multiple hypotheses, most involving various aqueous processes, have been proposed to explain its origin [1,2,3,4,5,6].
- Shock-metamorphism deserves further consideration when trying to unravel the nature of the amorphous component.
- Teasing out the effect of shock will further constrain the contribution of aqueous alteration to the amorphous geochemistry, expanding our knowledge of the history of water on the Martian surface.

Project Goals

1. Constrain the contribution of shock-induced amorphous phases on Mars by understanding the nature and origin of amorphous phases produced in a shock-metamorphosed and chemically weathered basalt
2. Distinguish these shock-induced amorphous phases from other phases using the instruments onboard the *Curiosity* rover

Approach and Methodology

Using the same methods that were used for Gale Crater materials, we calculated the amorphous geochemistry of shock-metamorphosed basalt with various degrees of pre- and post-impact chemical weathering. The samples were collected from Lonar Crater (Figure 1) and found along the crater walls and in the ~1 m thick suevite matrix surrounding the crater. Their bulk and amorphous geochemistry were calculated and plotted on ternary diagrams to infer the origin of the amorphous phases.

Bulk Geochemistry – *Crystalline Geochemistry* = *Amorphous Geochemistry*

Figure 2: Example of mass balance calculations for the amorphous component in LC09-327

LC09-327 (Class 3)

Phases	Formula	Quantity (wt. %)
Augite	$(Mg_{1.0}Ca_{0.8}Fe_{0.2})Si_2O_6$	26.6
Pigeonite	$(Fe_{1.0}Mg_{0.9}Ca_{0.1})Si_2O_6$	10.9
Calcite	$CaCO_3$	6.7
Andesine	$Na_{0.6}Ca_{0.4}Al_{1.4}Si_2O_6$	2.1
Ilmenite	$FeTiO_3$	2.1
Ferrosilite	$FeMgSi_2O_6$	0.9
Magnetite	Fe_3O_4	0.5
Quartz	SiO_2	0.3
Amorphous		49.9

Table 1

Table 1: Crystalline phases and abundances determined using powder XRD at NASA's Johnson Space Center.

Oxide	Moles of Oxide	Mol. Wt. of each oxide (g/mol)	Grams of oxide	Wt. % (normalized to 100%)	Wt. % (normalized to crystalline quantity)
MgO	1.0	40.32	40.32	18.35	4.88
CaO	0.8	56.08	44.86	20.42	5.43
FeO	0.2	71.85	14.37	6.54	1.74
SiO_2	2.0	60.09	120.18	54.69	14.55
		Sum	219.73	100.00	26.60

Table 2

Table 2: Elemental abundance (in wt. % oxide) of augite in LC09-327

Oxides	Bulk	Crystalline	Amorphous	Crystalline Normalized to 100 %	Amorphous Normalized to 100 %
SiO_2	48.61	18.33	30.28	46.94	49.69
TiO_2	2.37	0.92	1.46	2.34	2.39
Al_2O_3	13.31	0.46	12.84	1.18	21.07
FeO_T	13.67	5.68	7.99	14.55	13.11
MnO	0.21	0.00	0.21	0.00	0.35
MgO	5.57	5.57	0.00	14.27	0.00
CaO	13.78	7.97	5.81	20.40	9.54
Na_2O	2.05	0.12	1.93	0.31	3.17
K_2O	0.21	0.00	0.21	0.00	0.35
P_2O_5	0.20	0.00	0.20	0.00	0.33
Total	100.00	39.05	60.95	100.00	100.00

Table 3

Table 3: Amorphous geochemistry calculated by subtracting the combined elemental abundances for each mineral from the bulk geochemistry (bulk geochemistry acquired at the XRF lab at Franklin and Marshall). Corrections were made for negative amorphous values and results are reported in wt. % oxide.

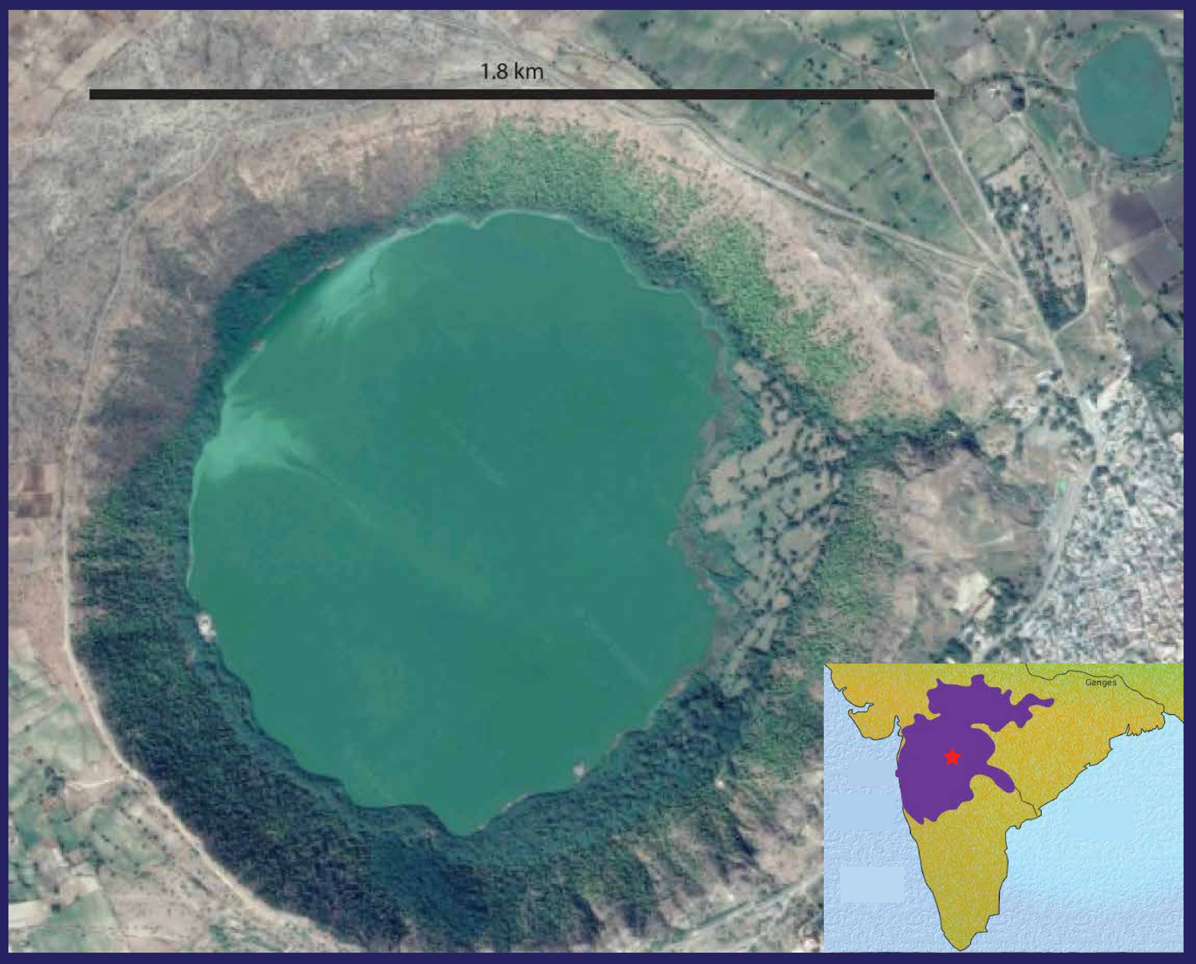


Figure 1: Lonar Crater, located on the Deccan Traps in India, is a well-preserved impact crater into a basaltic target. Because of this, it is a valuable analog for studying the Martian surface [7].

Discussion

A shock-metamorphosed amorphous component could be an integral part of the global Martian dust

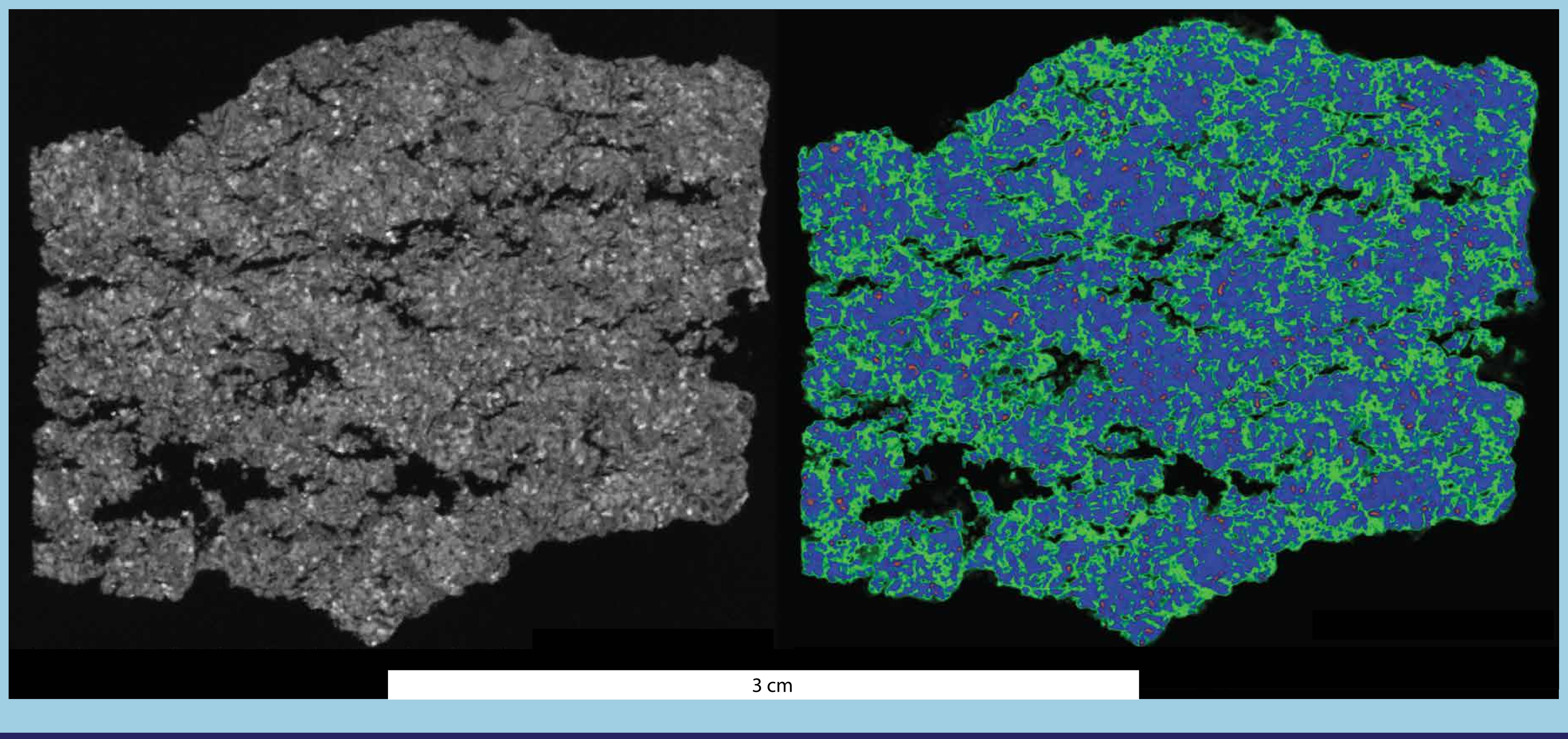
- Plagioclase becomes relatively enriched in an impact breccia through preferential comminution from the target-rock during an impact [9].
- Relatively recent impacts (< 1 Ga) could produce significant amounts of plagioclase-glass/bulk rock composition amorphous material within the ejecta with subsequent global distribution through aeolian homogenization [10,11].
- We hypothesize that the Rocknest sand shadow amorphous component could be a physical mixture of no more than 31 wt. % (constrained by the Al_2O_3 apex) of a shock-induced plagioclase-glass/bulk rock combination (LC09-327 Amor.) and another amorphous weathering product.

Figure 4: X-ray CT slice of LC15-452 (Class 3) shocked basalt. Having undergone 40-60 GPa of shock pressure [7], it has been heavily fractured and partially melted and represents the type of rock that would undergo preferential comminution of plagioclase during an impact event. Data were acquired at the University of Texas at Austin CT lab.

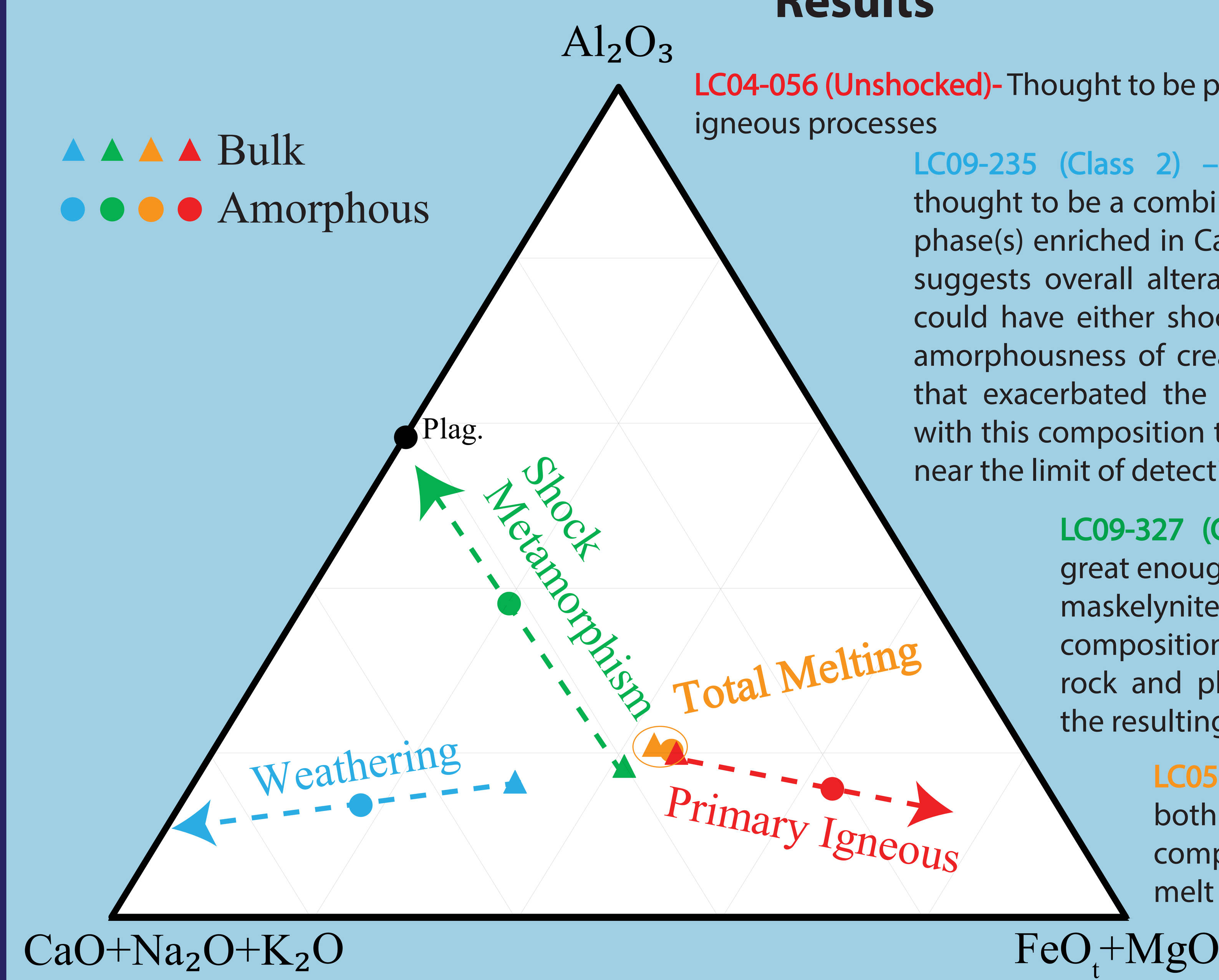
Left: Highly fractured with decompression cracks [8] running across the sample. Dark gray areas are flowing glass of plagioclase and matrix composition and brighter specks are fractured augite [personal correspondence with Dr. Shawn Wright]

Right: X-ray CT volume slice. Colors were assigned based off CT number [12]

- Flowing glass of plag. and matix composition
- Heavily fractured matrix/bulk rock
- Fractured augite



Results



LC04-056 (Unshocked)- Thought to be primary glass formed during natural igneous processes

LC09-235 (Class 2) – The amorphous component is thought to be a combination of maskelynite and another phase(s) enriched in Ca, Na, and K. Its bulk geochemistry suggests overall alteration. Therefore, the impact event could have either shocked these secondary minerals to amorphousness of created micro-conduits [8] (Figure 4) that exacerbated the formation of secondary minerals with this composition that are either poorly crystalline or near the limit of detection for our XRD analysis.

LC09-327 (Class 3) – Shock pressures were great enough to transform plagioclase beyond maskelynite into a flowing glass of identical composition. Therefore, a mixture of the bulk rock and plagioclase compositions comprise the resulting amorphous component.

LC05-Melt (Class 5)- Homogenization of both the amorphous and crystalline components expected with an impact melt

Figure 3: Bulk and calculated amorphous geochemistry (molar %) for the samples with the best fit XRD refinement patterns. This diagram illustrates mixing and weathering of primary igenous phases. Arrows represent the hypothesized processes by which the amorphous components were derived.

Conclusions

- Using our mass balance methods, different geologic processes can be identified for shocked basalt.
- It is likely that amorphous material on Mars consists of a mixture of different components produced by different processes including shock-metamorphism and low-temperature weathering.
- If the plagioclase/bulk rock amorphous phase (LC09-327) is part of the Rocknest amorphous component, then the remaining amorphous material would be composed of Si, Fe, Mg, Ca, Na, K and volatiles (S and Cl). One possible mechanism for the formation of amorphous material with this composition is by incipient weathering of basalt at low pH [13].

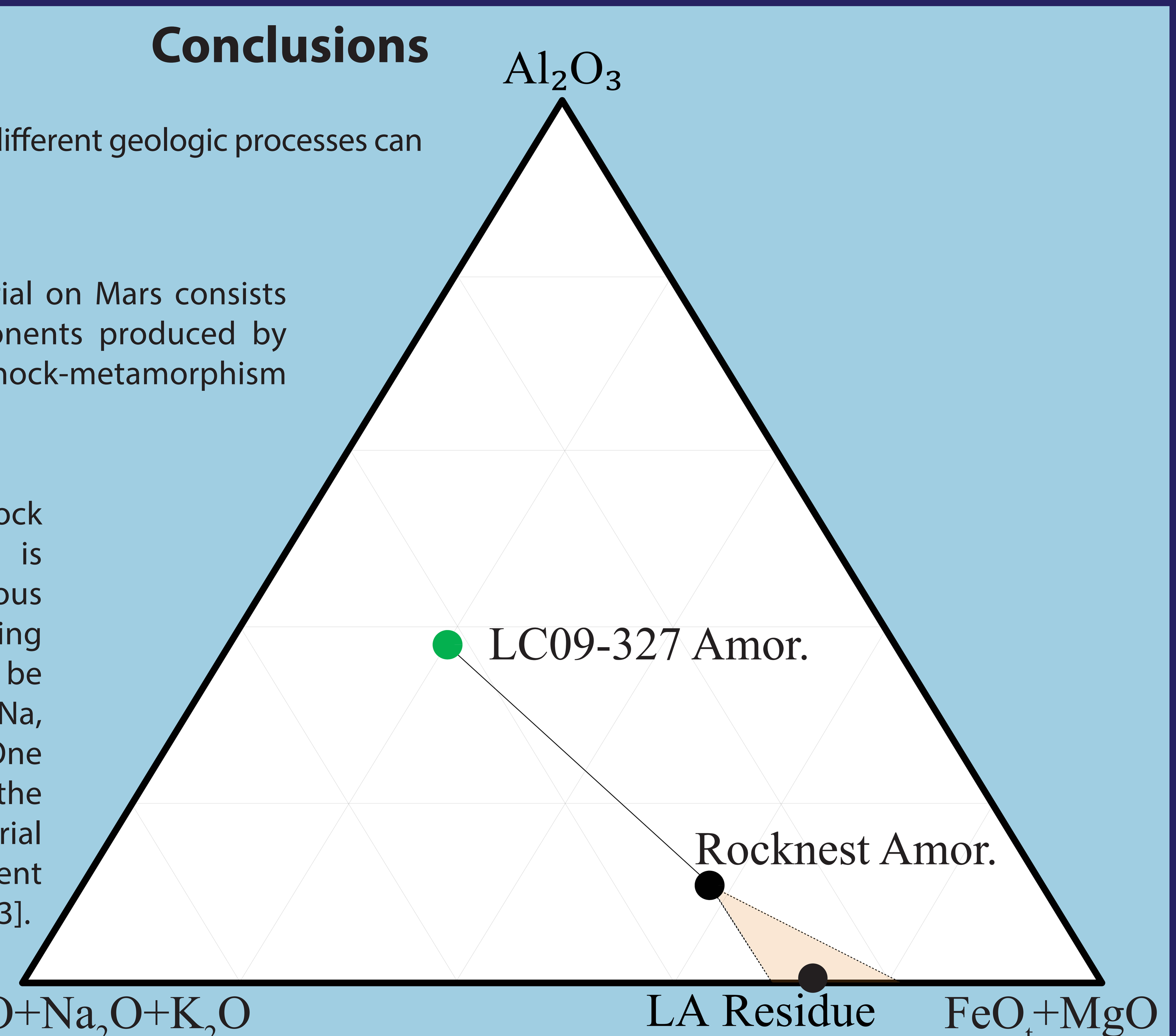


Figure 5: The Rocknest amorphous component represented as a physical mixture between a shock-induced amorphous component (LC09-327 Amor.) and a complementary amorphous phase(s) derived from weathering of basalt. LA Residue (an acidic weathering residue [5 wt. % FeTi-oxides added in]) [13] is a possible candidate.

References: [1] Bish D. L. et al. (2013) *Science*, 341.6153 [2] Morris R. V. et al. (2014) *LPSC 45* #1319 [3] Dehouck E. et al. (2014) *JGR* 119, 2640-2657 [4] Vaniman D.T. et al. (2014) *Science* 343.6169 [5] Blake D. F. et al. (2013) *Science* 341.6153 [6] Morris R. V. et al. (2013) *LPSC 44* #1653 [7] Kieffer S. W. et al. (1976) *LPSC 7*, 1391-1412 [8] Wright S. P (2013) *LPSC 44* #1010 [9] Reagan et al. (1996), *GSA* 302, 235-243 [10] McSween H. Y and Keil K. (2000) *GCA*, 64, 2155-2166 [11] Burns R. G. (1993) *GCA*, 57, 4555-4574 [12] Ketcham R. A. and Carlson W. D. (2001) *C&G*, 27, 381-400 [13] Hurowitz J. A. et al. (2006) *JGR* 111, E2