Graduate Research Plan Statement

Hypothesis: The compositional evolution of crustal material (both felsic and mafic) following impact events can be simulated by heating and partially vaporizing such materials at high temperatures in containerless experiments. Varying the temperature (*T*), time (*t*), and oxygen fugacity (fO_2) in the experiments enables the creation of synthetic impact glass analogues. Comparing the textures and compositions of these analogues to those of natural glasses will inform how these materials evolve during the tektite formation process. Incorporating the results of partial vaporization experiments into mixing models of tektite formation will result in more realistic predictions of tektite parent materials and potentially explain why tektites do not form from mafic protoliths on Earth.

Background: There are currently 190 confirmed craters on Earth's surface[1], only four of which are in basaltic targets. Lonar crater, which formed in Deccan Trap basalt, is the only well-known and fully accessible of these. During impact events, shocked and melted material may be ejected from the site of impact. Material that is thrown more than 2.5 crater diameters away from the impact location is known as distal ejecta[2]. Glassy, chemically homogenous, and aerodynamically shaped distal ejecta are known as tektites. Only four of the 190 terrestrial craters have resulted in tektite distribution over wide geographic regions known as strewn fields, and all known tektites originate from target rock that is felsic, approximating rhyolitic compositions. This research will investigate why tektites have never formed from mafic (basaltic) target rock during a terrestrial impact event, and to seek to better understand the nature and evolution of the starting materials that formed tektites from the four major strewn fields. Existing mixing models[3–6] assume compositions of tektites represent idealized end-member mixtures of the melted target material, and most attempts to identify the parent materials involve general comparison among chemical components of tektites and predicted parent materials[5]. These models are overly simplistic as they do not account for the loss of chemical constituents to volatilization at high temperatures in the impact plume.

Research Plan: *(Research Goal 1: Tektite experiments)* I will synthesize glasses that replicate the geochemistry and textures of tektites and Lonar crater impact glass in an aerodynamic levitation laser furnace[7] (ALLF). Melting/vaporization experiments will vary *T*, *t*, and fO_2 to identify conditions that form Lonar glass analogues (Table 1).

Table 1. Experimental conditions based on previous experiments estimating tektite thermal histories[7]

Series	1	2	3	4	5	6	7	8	9
T(°C)	1800	1800	1800	2000	2000	2000	2200	2200	2200
t (s)	10-120	10-120	10-120	10-120	10-120	10-120	10-120	10-120	10-120
fO_2	Ar	O_2	$CO+CO_2$	Ar	O_2	$CO+CO_2$	Ar	O_2	$CO+CO_2$

Starting materials are Deccan Trap basalt, USGS basalt (BCR-2), and USGS rhyolite (RGM-2). Experimental methods will follow previous ALLF tektite experiments[7]. Approximately 10 mg of the starting material is heated with a CO_2 laser at low power to fuse the sample and form spheres suitable for levitation. The fused spheres are then levitated on a flow of gas (Ar, O_2, or $CO+CO_2$) while being heated with the laser for seconds to minutes. After heating to the desired *T-t*, laser power is cut, and the melt spheres cool quickly to form glass. The chemical, mineralogical, and textural characterization of synthesized and natural glasses will be completed via scanning electron microscopy with energy dispersive x-ray spectrometry (SEM/EDS) at Indiana University–Purdue University Indianapolis (IUPUI) and electron probe microanalysis (EPMA) at Washington University in St. Louis (WUSTL). These analyses will be compared to electron microprobe analyses of Lonar glass[8], and previous work on felsic material[7].

Exploratory experiments using the starting materials and methods described above resulted in dark colored, glassy spheres with little to no vesicles or mineral growth. SEM/EDS analyses of these preliminary experiments show preferential loss of Na and K from all melt compositions relative to non-alkali components. Further, heating basalts in an oxygen-rich environment results in more rapid and complete loss of K_2O (undetectable after 10 s at 2000 °C).

(*Research Goal 2: Mixing model calculations)* Tektites are not produced from a single, homogeneous source rock – thus, any explanation of tektite generation must involve a multi-component mixing model

involving likely upper crustal target rocks (sediments) as the major components[9]. Previous studies have estimated the contributions of possible target lithologies to final tektite geochemistry using mixing models. However, the assumptions and limitations of existing models may hinder their ability to realistically represent tektite formation. Previous mixing models assume that end-member compositions of likely protoliths are unchanged during tektite formation, i.e., they do not take into account the effects of evaporative fractionation[3] on the target materials as they are heated in the impact plume. I will address this by executing computationally intensive mixing models that properly account for fractionation due to vaporization and assess the extent of agreement between assumed target lithologies and tektite geochemistry. I will incorporate my experimentally derived volatilization rates into dynamic multi-component mixing calculations by modifying the GeoChemical Data toolkit (GCDkit) software to create a more realistic representation of the processes attending tektite formation, and to determine the relative contributions of each protolith to different tektite compositions. I will also compare my experimentally derived volatilization rates, and the results of my mixing models with predictions of compositional evolution of tektite melts from MAGMA code.

My ongoing research uses the R programming language to perform multivariate analyses and implement machine learning algorithms to investigate tektite compositional trends. I am creating an open-source web-based application to classify unknown tektites into their strewn fields and subgroups within strewn fields. This NSF Graduate Research Fellowship will afford me the opportunity to expand my programming and modeling portfolio to more computationally intensive applications.

Intellectual Merit: The modification of planetary surfaces through impact cratering is the most important surface modifying process on most rocky bodies in the Solar System[10], yet it remains underrepresented as a field of study. My research will improve both the understanding of the evolution of Earth's crust and the modeling of impact events. My mixing model calculations will be the first to properly account for the chemical modifications that occur in the impact plume. These calculations will produce a useful tool for the scientific community to analyze (or reanalyze) terrestrial impact products and target lithologies. My experimental data will also provide valuable insight into the volatilization behavior of felsic and mafic melts at conditions relevant to impact plumes. The results may shed light on the absence of mafic tektites.

Broader Impacts: The results of my research will have applications in a diverse set of fields such as high-temperature geochemistry, computational modeling of geochemical processes, and impact processes. I will disseminate the results in journals (e.g., Computers & Geosciences), at conferences (e.g., AGU, GSA), and to GK-12 students and the general public at outreach events (e.g., Pacers STEM Fest, Celebrate Science Indiana). As an NSF Graduate Fellow, I will continue working towards a more equitable and inclusive culture. Already as a new graduate student I became a founding member of IUPUI's Geology COmmunity for Racial Equity (GeoCORE). I also came up with the idea for the Mineral Eponym Crowdsourcing Initiative (MECI), an effort to facilitate an examination, analysis, and synthesis of the origins of mineral names, and the messages this historic naming system has created. This initiative is currently being led by members of the Mineralogical Society of America (MSA) Diversity Task Force (my advisor is a member) to seek funding for its execution. Most recently, I have been invited to participate in a project to create new curricular materials for the IUPUI Earth Sciences Department focusing on issues at the intersection of Earth sciences, ethics, and equity. My role in this project will be to analyze, quantitatively and qualitatively, the assessment results of teaching material effectiveness. The analytical and computational skills I will learn as an NSF Fellow will allow me to perform analyses that will directly impact the inclusivity, diversity, engagement, and retention of underrepresented groups within the geosciences.

References: [**1]** Earth Impact Database, PASSC [**2]** Glass, B. P. *et al. Elements* 8, 43–48 (2012) **[3]** Ackerman, L. *et al. Geochim et Cosmochim Ac* 276, 135–150 (2020) **[4]** Ferrière, L. *et al. Chem Geol* 275, 254–261 (2010) **[5]** Love, K. M. *et al.* 52, 2085–2090 (1988) **[6]** Meisel, T. *et al. Meteorit Planet Sci* 32, 493–502 (1997) **[7]** Macris, C. A. *et al. Geochim et Cosmochim Ac* 241, 69–94 (2018) **[8]** Ray, D. *et al. Earth Moon Planets* 114, 59–86 (2014) **[9]** Koeberl, C. *Tectonophysics* 171, 405–422 (1990) **[10]** Koeberl, C. in *Treatise on Geochemistry* 73–118 (Elsevier, 2014)