PRF# 54500-UNI8 Final Report
Project Title: Timing of Incision of the Ethiopian Plateau, East African Rift System: Integration of Apatite (U-Th)/He and $^{4}He/^{3}He$ Thermochronometry
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First of all, the PI greatly acknowledges the American Chemical Society for funding this high impact research on the Ethiopian Plateau, which has been a wonderful gateway to enhance the visibility of Western Kentucky University (WKU) as a leading university with student-centered research and active learning, and international reach research. This PRF funding facilitated the PI to endeavor successfully a major research initiative at WKU, a primarily undergraduate teaching institute as an early-career tenure-track faculty (now tenured). As part of this PRF funded project, the PI was able to successfully found the LeGo (Landscape Geodynamics) Lab research facility, the first of its kind at this university, to continue multi-year tectonics and geodynamics research, training and teaching involving undergraduate and graduate students and collaborators. In addition to this lab and research facility, the PI has developed long-term research collaboration with Arizona State University, Addis Ababa University, Oklahoma State University, ETH and Geoseps Services LLC.

The PI supervised a total of 10 students (six undergraduate and four graduate), who were recruited to participate in all aspects of this project starting from rock sample collection from the field sites in Ethiopia, preparation and processing, picking minerals, assisting and training in thermochronometric dating techniques at reputed and cutting-edge labs, and manuscript preparation for publications. All the undergraduate students were funded to engage in undergraduate research projects the outcome of which include 6 local and national conference presentations (undergraduate students as leading authors and presenter), several scholarships and awards (>$20,000), and three manuscripts for peer-reviewed journals. Undergraduate student Helen Flynn awarded several prestigious scholarships and awards, including U. S. Fulbright Alternative recognition. She also traveled to the Ethiopian Plateau for field data collection and completed B.Sc. degree with Summa Cum Laude. Deborah is now gearing up for launching into a graduate program in U.S. or Europe. Undergraduate student Brittiny Moore is now completing her MSc. Program in Texas State University, and Cody Meservy and Christopher Williams completed their B.Sc. degrees successfully and now employed in geological and environmental agencies. Kaily Scott, Jamin Lopez and another student are completing their B.Sc. degrees in geology. The PI was also the primary thesis advisor for six graduate students. Nathaniel Blackburn and Indu Bhattarai had successfully completed their Master's theses in thermochronology, and now full-time employees in geological companies. Shelby Bowden had conducted fieldwork in Ethiopia for data and sample collection. He is defending his Masters' thesis in thermochronology in fall 2018 and was already offered a Ph.D. position at a reputed U.S. university. Jacob Grigsby is completing his Master's thesis in thermochronology. All these graduate students generated two completed and two in progress Master's theses, four manuscripts (ready to be submitted in high impact peer-reviewed journals-see in the list below), 10 local and national conference abstracts and presentations, and received several grants, stipends, assistantships and scholarships including Geological Society of America Research Grant (>$40,000). Graduate students Michael Arthur and Adam Mattson, who are partially involved by this grant are also completing their Master's theses. The PI also presented six conference papers directly related to this project and published three papers (all included manner of acknowledgment required by ACS-PRF; Gani and Neupane, 2018; Liang et al., 2018; Gani, 2015) and a title paper (Gani, 2016) with undergraduate and graduate student coauthors, in reputed peer-reviewed journals. The PI has submitted two full proposals to NSF and obtained a few external and WKU internal grants including large amount software grants related to this project (~$12 M).

The Ethiopian Plateau in East Africa, one of the large igneous provinces, has been deeply incised by the Blue Nile River. The plateau has experienced extensive volcanisms at ~30 Ma linked to outpouring of the Afar mantle plume that accumulated average 1 km thick flood basalt. This event, along with later repetitive volcanisms in the region, has complicated (e.g., partial resetting of mineral cooling ages, abnormal geothermal gradients) the application of thermochronological modeling to constrain the Cenozoic unroofing and incision history of the plateau. The objective of this PRF-funded project is to decipher the incision on the Ethiopian Plateau by integrating apatite (U-Th)/He and $^{4}He/^{3}He$ thermochronometry to better understand the timeline and mode of the Blue Nile Canyon incision and the landscape geodynamics of the Ethiopian Plateau. This project mainly involves (1) rock sample collection from the Ethiopian Plateau, and preparation- rock samples were prepared and separated by using

standard mineral separation procedures at LeGo Lab, Isolation of single apatite minerals from each sample using binocular and petrographic microscopes, (3) thermochronologic dating of these apatites from Arizona State University and (4) Thermal modeling of apatite He dates using HeFTy and other thermochronology software. The main scientific findings of this PRF funded project suggest that the apatite cooling ages are comparatively older than that of previous thermochronological studies of the area. In this study, a cooling/thermal history is suggested by explaining the data dispersion by the radiation damage effect in the dated apatite grains, which is related to He retention with time. The apatite suite has been subjected to protracted cooling, the longer residence time in the He partial retention zone, and partial resetting due to Mesozoic rift-related burial and subsidence from the deposition of ~1.2 km thick sedimentary rocks, the extensive emplacement of ~1 km-thick flood basalt at 30 Ma, and differential incision. Thermal modeling of these cooling ages yields a young incision where the onset of rapid erosion started at late Miocene. Thus, this study brings fresh a perspective on the topographic evolution and the incision history of the Ethiopian Plateau.

This PRF-funded project sample analysis also leads to three other new projects the PI is now actively conducting. One of these projects involves zircon (U-Pb) geochronology and elemental geochemistry to investigate the petrogenesis and evolution of intrusive basement rocks in western Ethiopian Plateau. Samples from this region show three intrusive periods under distinct tectonic domains that represent an evolving convergent margin. The oldest granite formation is related to melting associated with continental arc subduction, followed by post-subduction related magmatic activity, whereas, the youngest granites are evidence of late stage, crustal thickening in the final stage of collision. These project results were presented at AAPG annual conference in 2018, and soon a paper was ready to submit in the journal Precambrian Research. The other project involves He depth profiling to understand the exhumation history of the Ethiopian Plateau. The PI and her research team already separated sample collected from the Ethiopian Plateau and sent those to ASU for this dating to further interpret. Another project investigates, for the first time, the timing of exhumation of the Blue Nile Rift from cooling ages deduced from apatite fission track thermochronology. The results from the fission track dates show a general trend of increasing cooling ages with elevations. The time-temperature simulations of the fission track dates illustrate a rapid cooling event between 80 and 70 Ma, followed by a slow cooling after 70 Ma and an accelerated cooling starting around 10 Ma. The Cretaceous rapid cooling event likely related to the flank uplift of the Blue Nile Rift and associated faulting, during which much of the exhumation likely occurred. Today, the Blue Nile Rift is buried under the thick cover of Mesozoic sedimentary rocks and Cenozoic volcanics. This result agrees well with the Cretaceous rapid cooling of the Anza rift located south of the Blue Nile Rift. These project results were presented at AGU annual conference in 2017. The PRF support also leads to expand the PI's research other parts of East African Rift System (e.g., Kenya Rift; Liang et al., 2017, Liang et al., in review) Below is a list of publications related to directly and partially related to the PRF funded project:

- Gani, N. D., Neupane, P. C. 2018. Understanding transient landscape of the Ethiopian Plateau in relation to mantle dynamics, Geological Journal. v. 53, p. 371–385. DOI: http://dx.doi.org/10.1002/gj.2903. PR.
- Liang, X., Alemu, T. Gani, N. D. and Abdelsalam, M. G. 2018. Spatial and Temporal Variability of Tectonic Uplift Rates in the Southeastern Ethiopian Plateau, East African Rift Systems from Morpho-tectonic Analysis, Geomorphology, v. 309, p. 98–111. DOI: https://doi.org/10.1016/j.geomorph.2018.02.025 PR (Peer-reviewed).
- Liang, X. Gani, N. D. and Abdelsalam, M. G. 2017. Geomorphologic Proxies for Bedrock Rivers: A Case Study from the Rwenzori Mountains, East African Rift System, Geomorphology, vol. 285, p. 374-398. DOI: http://doi.org/10.1016/j.geomorph.2017.01.009. PR.
- Gani, N. D. 2016. Dextral shear zone within the Blue Nile Canyon, the Ethiopian Plateau: Photograph of the month, Journal of Structural Geology, vol. 92, page iii. DOI: http://dx.doi.org/10.1016/S0191-8141(16)30166-3.
- Gani, N. D. 2015. Erosion history from incision modeling and river profile morphologies: example from the Tekeze River System, Ethiopian Plateau, East Africa. Arabian Journal of Geoscience, volume 8, Issue 12, p. 11293–11305. DOI: http://dx.doi.org/10.1007/s12517-015-1941-1. PR.
- Bhattarai, I., Gani, N. D., and Liang, X. Quantitative River Profile Analysis to Investigate Exhumation (soon to be submitted to Tectonophysics). PR.
- Bowden, S., Gani, N.D., vanSoest, M. Gani, M. R. Unroofing history of the northwestern Ethiopian Plateau: Insights from apatite (U-Th)/He thermocronology. (Ready to be submitted in Tectonics). PR.
- Bowden, S., Gani, N.D., Alemu, T., Abebe, B., Tadesse, K., and O'Sullivan, P. Age and origin of syn-tectonic intrusions from the Tulu Dimtu Belt, Western Ethiopian Shield. (Ready to be submitted in Precambrian Research). PR.
- Gani, N. D., Blackburn, N., VanSoest, M., Tadessa, K. Cenozoic thermal history of the Ethiopian Plateau (Soon to be submitted to the journal Tectonics). PR.
- Liang, X. Gani, N. D. and Abdelsalam, M. G. Drainage incision, tectonic uplift, and magmatism of the Kenya Rift, East African Rift System: A morpho-tectonic analysis approach, Journal of Geophysical Research-Earth Surface (in review). PR.