Better understanding the geology of central Cuba through stream sediment composition analysis using X-ray diffraction

Abstract

In a globalized world, where environmentally-impactful industrial agriculture is common, understanding the mechanisms and benefits of transitioning towards organic, conservation agricultural practices is vital to sustaining soil health, water quality, wildlife, and Earth's rapidly growing human population (Schmidt et al. 2016). Cuba is a unique place to study the landscape-altering effects of this transition due to its history of sugar-cane intensive industrial agriculture during the Soviet era (1959-1991) followed by conservation-based agriculture after the collapse of the USSR (1991-present). As agricultural impacts on the landscape are quantified, contextualizing these impacts with local rock type data is crucial to a comprehensive and mechanistic understanding of how human land use influences water quality, erosion rates, and overall landscape change. Rock types in Cuba are poorly documented, and my project will be the first detailed study of central Cuban geology and rock weathering processes, providing critical insight into how Cuban rocks weather into soil, thereby influencing water chemistry as well as soil and water quality in central Cuba.

Project description

Largely due to political reasons, there is not much data available to U.S. scientists on the geology of Cuba because of restricted access to the country, and thus our understanding of the local stream geochemistry, water quality, mineralogy, and complex rock formations is lacking (Iturralde-Vinent et al. 2016; Schmidt et al. 2016). However, considering the improving political situation, the US Department of Agriculture and the Cuban Ministry of Agriculture signed a Memorandum of understanding on March 21, 2016 which contains eight areas of cooperation, including “agricultural research and management techniques for soil and forest conservation.” (USDA, 2016). The research project I am part of (funded by the US National Science Foundation to UVM and Oberlin) in collaboration with other American universities and Centro de Estudios Avanzados de Cuba (CEAC) is focused on quantifying the effects of industrialized agriculture followed by country-wide soil conservation efforts. My specific project aims to better contextualize the work that the 2016 memorandum makes possible by providing a better understanding of the underlying geology of Cuba. Our study is the first of its kind in Cuba after nearly 60 years of isolation from U.S. scientists (Schmidt et al. 2016).

Previous Work

Geology –

Cuba’s emergence as an island occurred after the breakup of Pangea ~135 mya during the Cretaceous period as the North American Plate and NW Caribbean plate converged, forcing the North American Plate to dip under the Caribbean plate where it reached hot mantle and melted. Over millions of years, this process produced magma that rose to the surface, erupted, and solidified, forming Cuba as we know it today (Iturralde-Vinent et al. 2016). Due to its volcanic history, Cuba is largely composed of igneous rock with high silica content, but also contains igneous rock with high Mg and Fe content in some places as well (Pardo, 1975; French and Schenk, 2004; Iturralde-Vinent et al. 2016). Additionally, Cuba’s position in an ocean basin prior to its volcanic emergence has resulted in a prominence of marine sedimentary rock with high calcite content due to the deposition of $CaCO_3$ from shells and coral in an area with abundant coral reefs (Iturralde-Vinent et al. 2016; French and Schenk, 2004). Most of these rock types also exist in forms that have been altered by the heat and pressure caused by past volcanic processes and the faulting of Cuba's continually active plate boundary (Case and Holcombe, 1980). Cuba's bedrock geology is therefore a complex system of young volcanic rock, older marine sedimentary rock, younger sedimentary rock from the weathering of Cuban rocks, and metamorphic forms of most of these rock types (Case and Holcombe, 1980; Schmidt et al. 2016). Though the general geologic history of Cuba is mostly-established, the specifics of local rock formations are poorly understood, making a detailed analysis of local rock type and mineralogy necessary to properly contextualize in-depth landscape analyses related to land-use change.

Land Use –

Human impacts on erosion are a global issue as clearing slopes for agricultural use results in increased hillslope erosion, thus increasing sediment moving into streams. Such sediment impairs water quality and damages fisheries as well as burying tropical reefs in sediment (Bierman et al. 1997; Bilotta and Brazier, 2008; NSF AC-ERE, 2015). These impacts are expected to become more significant as human populations increase and steeper land must be cleared to produce enough timber and food to sustain a growing population (Schmidt et al. 2016). One suggested solution to this issue is conservation agriculture practices (Blaikie and Muldavin, 2004).

Significance

Cuba is a uniquely useful place to study the effects of conservation agriculture practices on erosion due to its history of industrial sugarcane agriculture before and during the Soviet era (1959-1991) followed by 25 years of small scale, organic conservation agriculture (1991-present); thus Cuba provides a model to test for the landscape scale results of implementing conservation agriculture practices (fig. 1; Schmidt et al. 2016). Such research is time-sensitive as agricultural imports and exports in Cuba have increased in the last decade and demand for local, sustainable agriculture has decreased (Zahniser et al. 2015). Because of this, data on the effects of conservation agriculture must be collected soon before industrial agriculture dominates Cuba again.

By determining the composition of river sediment samples, I will provide a comprehensive understanding of the rocks underlying all the basins we are studying in Cuba. My data will put into context the erosion rates, water chemistry, and water quality data from each basin, allowing for a more mechanistic understanding of these data as well as both human impacts and natural rock weathering processes. More specifically, my results of local rock type composition will improve our understanding of the impacts of conservation agriculture on erosion in post-Soviet Era Cuba through its control on the nature and rate of rock weathering and soil formation. These implications include what rock types are being weathered, how resistant these rock types are to erosion, and how the weathering of those rock types will influence water quality, soil health, and wildlife, therefore providing crucial insight into human impacts on Cuba's dynamic landscape. As worldwide erosion rates increase with the use of industrial agriculture, providing this mechanistic understanding of rock-weathering in Cuba is crucial as it could lead to more effective solutions mitigating the environmental impacts of agriculture on landscapes both locally and on a global scale.

Proposed Methodology

As part of an effort to better understand mass transfer from source to sink in collaboration with other American universities and Cuba's CEAC, stream sediment and water samples, each from a different watershed in Cuba are being analyzed for rates of erosion, water quality, and water chemistry (fig. 2; Acosta 2018). We are using rivers to indirectly sample landscapes that cannot be mapped directly.

For my work, I am using two types of geochemical analysis equipment. First and foremost, I am using X-Ray powder Diffractometry (XRD). XRD involves the scanning of powdered rock by scattering X-rays off that material at increasing angles and comparing the resulting output to a database with past scans of known minerals. Scanning samples under various conditions (washed and unwashed) as well as varying grain sizes allows for a more accurate and detailed picture of mineral content. I have already scanned 26 stream sediment samples, each from a different watershed, in two grain sizes (250-850µm and <63µm) both in raw form and after being washed for a total of 4 scans per sample (104 XRD scans overall so far). I have analyzed the graphs produced by these 104 scans for mineral content along with the percent content of each mineral where possible. I have already performed an initial interpretation of all 104 scans for mineral content over the past year and plan to continue refining these results by performing various tests such as running additional scans after heating samples at 400˚C to more accurately identify which minerals are present. If time allows, I will continue to perform scans on samples from 20 additional watersheds collected in June of 2019 as well as 6 samples to be collected during field work in November.

I will compare the data I produce to: 1. water chemistry and water quality data (collected by my advisor, P. Bierman), 2. the rock types present in each sample's watershed according to a published geologic map, and 3. X-Ray Fluorescence (XRF) bulk geochemistry data which uses X-rays like XRD but provides element-content data as opposed to mineral-type data (collected by

Cuban colleagues and myself). These comparisons will allow me to cross-check and contextualize my results as well as identify possible error in both my analyses and the existing map of local rock formations. I will also run XRF scans for element-content on any samples that have not already been scanned with XRF and will observe samples under optical and electron microscopes to further cross-check results.

I am currently preparing to present the results I have produced thus far at the annual Geological Society of America meeting in Phoenix, AZ (September 21-25) which will help me to hone my course of action as I discuss my project with the many geologists attending the conference. After the conference and for the rest of the fall semester I plan on refining the XRD results I already have through additional tests and comparison to XRF data, optical data, water chemistry data, and XRF data. I also plan on performing scans followed by a base analysis of the 20 (and 6 to-be collected) newly collected stream sediment samples as well as XRF scans on any samples that have not yet been scanned for elemental-content by the end of the fall semester. During the spring semester I plan on further refining my results, both from the already scanned samples and the samples yet to be scanned, and doing an in-depth comparison of XRD data to water quality data, geologic maps, XRF data, and erosion rates over varying time scales to interpret the impact of Cuban rock-weathering processes on the landscape under various conditions. In summary, I plan to use the fall semester to focus heavily on collecting, analyzing, and refining my data before using the spring semester to focus on the significance of what my data mean in the context of natural rock-weathering processes and how those processes are influenced by the overall shift from industrial agriculture practices to conservation agriculture practices in Cuba.

Figures

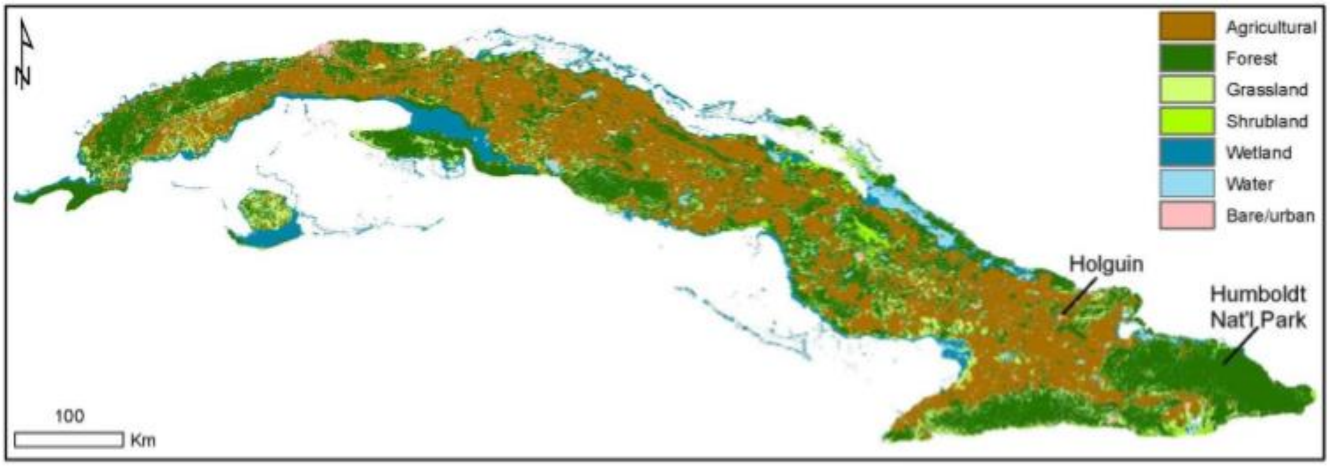

Figure 1A. Land use distribution in Cuba. Data from Chen et al. 2015, map is from Schmidt et al. 2016.

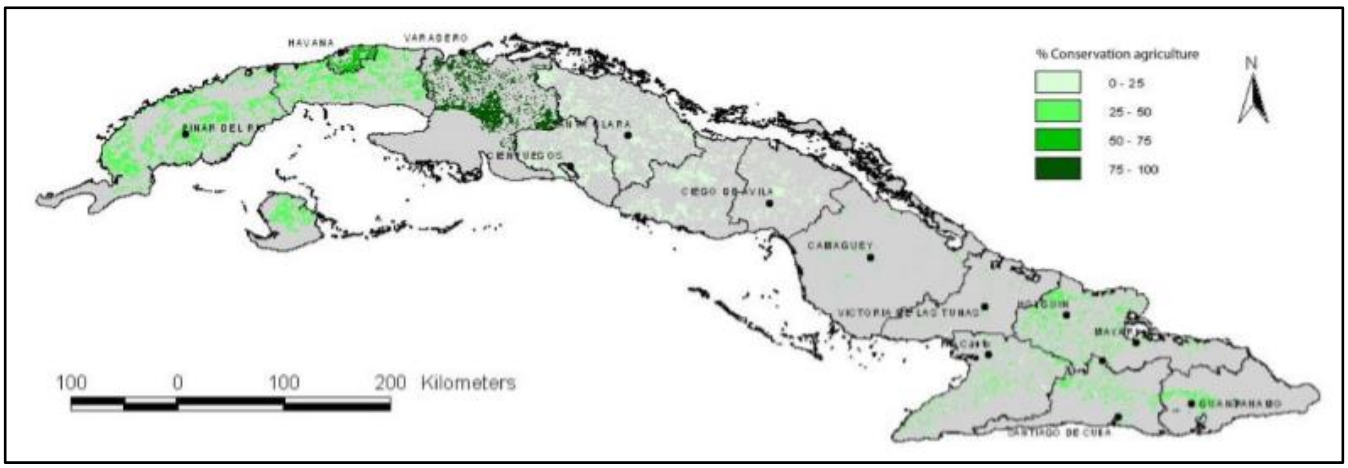

Figure 1B. Conservation agriculture land use distribution in Cuba (LADA, 2016).

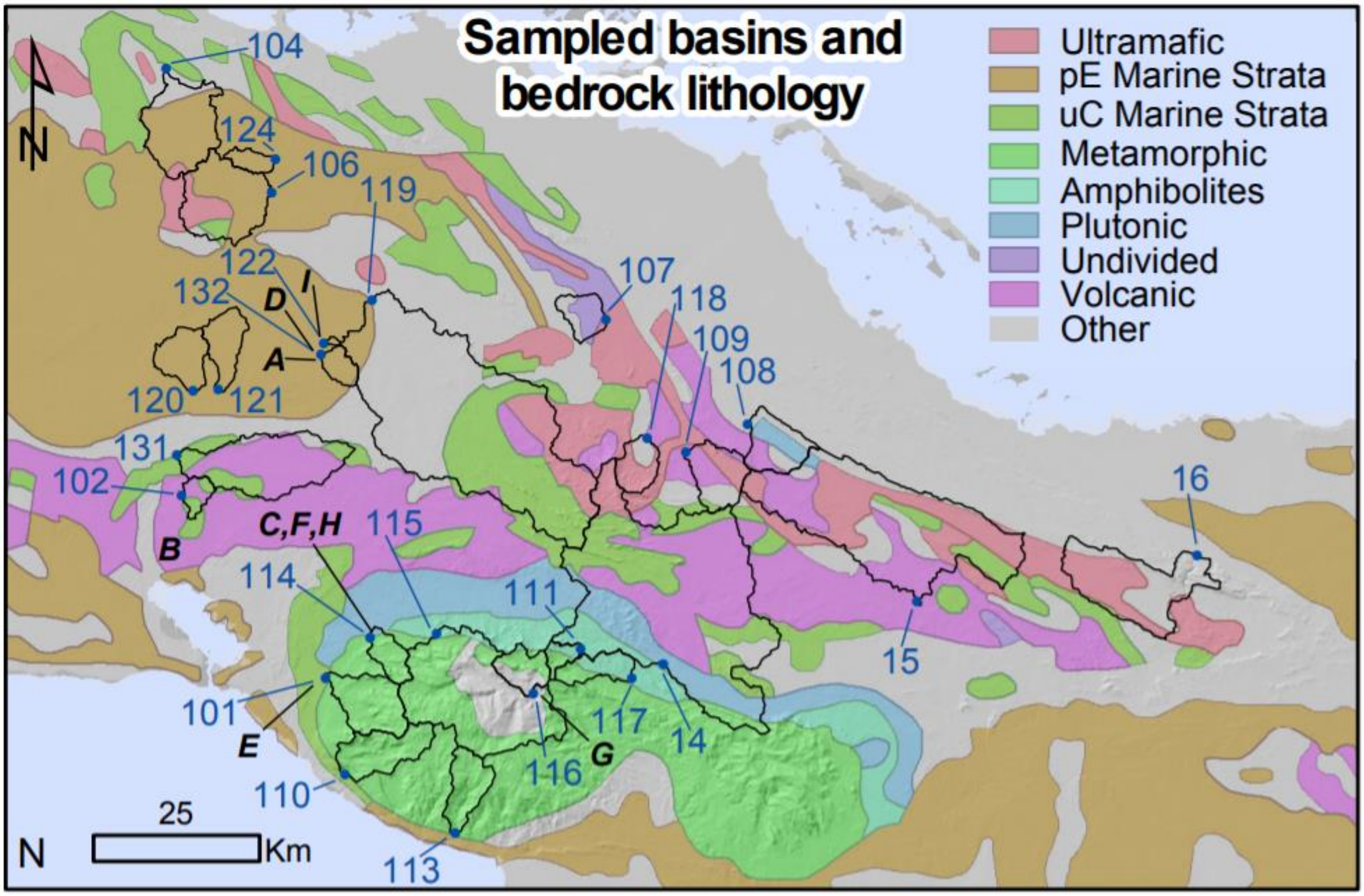

Figure 2A. Sampled basins overlain on generalized geological map (French and Schenk, 2004). Letters show location of photos in Figure 3. Dots represents outlets.

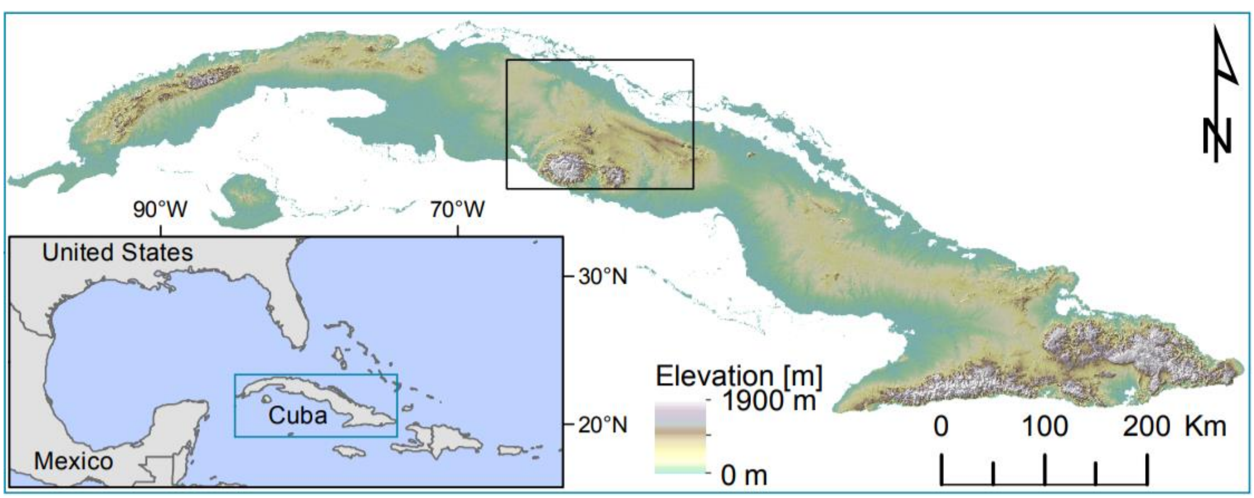

Figure 2B. Location map of Cuba showing elevation as color ramp. Black outline is area of samples and mapped in Figure 2A. Inset shows location of Cuba in relation to North America.

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