Geologic Adventures in Trieste, Italy

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This June, I had the privilege of embarking on a research internship at the University of Trieste in northeastern Italy in the pursuit of my master's degree at North Carolina Central University. Virtually surrounded by active faults, Italy's high seismic activity (on dramatic display this past August, October, and January) has fostered world-class expertise at the University of Trieste's Department of Mathematics and Geosciences. My department tapped this knowledge for collaboration in modeling seismic hazard for the Watts Bar Nuclear Power Plant in the understudied eastern Tennessee seismic zone. Those results are forthcoming in conference abstracts; for now, my task is to attempt to do justice, in limited space, to other highlights of the trip.

The geological history of Trieste and the region at large is every bit as fascinating as the human history, which, per *H. heidelbergensis* fossils, could reach back as far as 400,000 years. The name Trieste seems to stem from *Tergeste*, an ancient Indo-European word for "market." Evidence of human habitation appears about 2000 BC, and the Romans conquered the area around 177 BC; a few Roman artifacts still exist, including an amphitheater. Perennial tourist favorites include the Castle Miramare (once home of the short-lived and ill-fated Emperor Maximilian of Mexico) and its nature reserve, as well the Piazza Unità d'Italia, the largest open square on a sea. The unique rocks of the Karst and the vegetation they support give rise to local culinary specialties such as the much-recommended wines like *vitovska, malvasia*, and *terrano*.

Civico Orto Botanico: Geopaleontological Route

Returning to the geology, Trieste's Civico Orto Botanico offers an excellent introduction to the region's distinctive geological history. This public garden, which is free to visit, includes a Geopaleontological Route featuring the area's characteristic rocks with explanatory placards alongside the park's vibrant flowers. The numerically ordered placards walk the visitor from the past to the near-present, watching in the rocks as the region transforms from an ancient carbonate platform into modern Trieste.

As explained in the park, the word karst derives from the Indo-European word *kar* or *karra* meaning "rock," adopted into English to describe the landscape typical of carbonate regions. The *Classical Karst* proper refers to a limestone plateau covering 170 mi2 across northeastern Italy and southwestern Slovenia. One hundred million years ago, the Karst lay at a balmy 30 degrees latitude as a large undersea carbonate platform (today the Karst is at the much less reef-friendly latitude of 45 degrees north). The limestones range in age from 140 Ma to 47 Ma and are capped by *flysch*, a marine sedimentary sequence of sandstone and marl, laid down 47 to 40 Ma ago as the ongoing Alpine orogeny threw sediments into the sea. Now an eroded anticline trending northwest-southeast, the plateau emerged from the waters about 20 Ma ago.

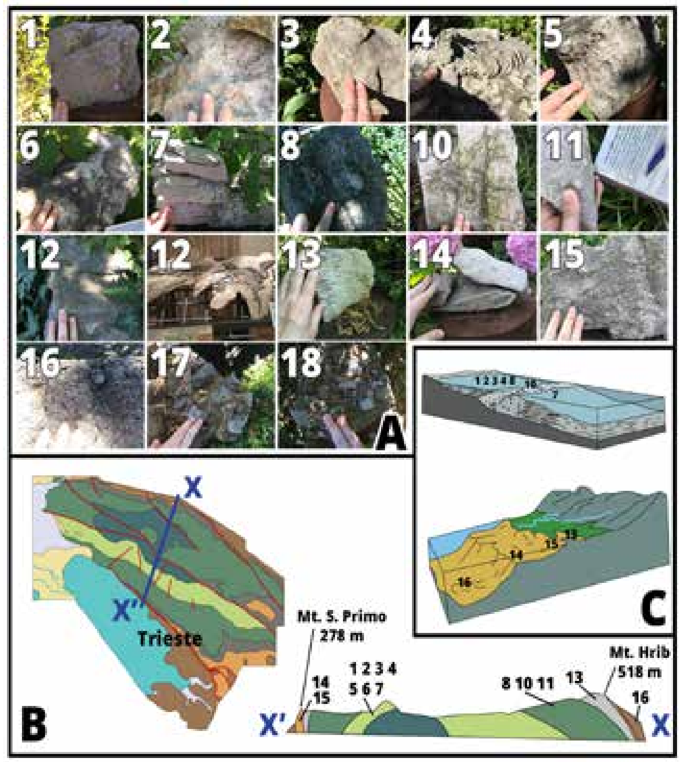

Figure 1- A) Rocks of the Karst Plateau as displayed at the Civico Orto Botanico in Trieste; see text for description. B) Map of Karst Plateau with cross section. Redrawn from the Civico Orto Botanico. C) Depositional environments of rocks shown in A. Redrawn from the Civico Orto Botanico.

Figure 1 shows most of the rocks displayed in the garden; I've followed the park's numbering as of June 2017, with descriptions after the Civico Orto Botanico.

1. Black limestone, Albian-Cenomanian (113–93.9 Ma). Mud-supported, fetid limestone with microscopic fossils. Deposited in a backreef lagoon in a reducing environment.

2. Calcareous dolostone, Albian (113–100 Ma). Black, fetid, and mud-supported limestone with Requienia fossils (rudists). Deposited in an oxygenated backreef with moderate to low sedimentation.

3. Calcareous dolostone, Albian-Cenomanian (113–93.9 Ma). Crystalline, fetid, compact, dark grey, and calcareous dolostone with irregular fractures.

4. Fossiliferous calcareous dolostone, Cenomanian 100.5–93.9 Ma. Crystalline, fetid, compact, dark grey, and calcareous dolostone with irregular fractures and Chondrodonta (molluscs) and rudist bioconstructions. Deposited in an inner carbonate platform.

5. "Sea flower" limestone, Cenomanian (100.5–93.9 Ma). Compact limestone rich in fragments of rudists, bivalves, and gastropods. Fine calcareous breccia of organic origin. Deposited in a dynamic shallow marine environment with a bioclastic sandy seabed.

6. Limestone with *Neithea*, Cenomanian (100.5–93.9 Ma). Fetid, compact, light grey limestone with organic fragments and valves of the bivalve *Neithea*. Deposited in a dynamic shallow marine environment with a bioclastic sandy seabed.

7. Laminated limestone ("Komen shale"). Repeated cyclically in the Upper Cretaceous: Cenomanian (100.5–93.9 Ma), Cenomanian-Turonian (94 Ma), and Santonian (86.3–83.6 Ma). Stratified, bituminous, fine-grained limestone with dark grey-black colors and fish and reptile fossils. Deposited in a shallow nearshore marine basin with an anoxic seabed.

8. Limestone with Acteonella, Turonian (93.9–89.8 Ma). Compact, light limestone with fossil fragments and complete *Trochactaeon* (gastropods with smooth, egg-shaped shells). Deposited in an inner carbonate platform backreef lagoon.

9. Limestone with flint nodules, Turonian-Santonian (93.5–85.3 Ma). Block limestone containing flint nodules used by Homo *heidelbergensis* (0.4–0.3 Ma) to build stone tools. Deposited in a backreef lagoon with stagnant, poorly oxygenated water. No photo.

10. Limestone with *Vaccinites*, Santonian-Campanian (86.3–72.1 Ma). Light and compact limestone with many fragments of organic materials and *Vaccinites*, a rudist with thick conical or cylindrical shells.

11. Limestone with *Keramosphaerina tergestina*, Upper Santonian (86.3–83.6 Ma). Fossiliferous, light grey limestone with fragments of organic materials and well-preserved *K. tergestina*, a large foraminifera (up to 19 cm in diameter). Deposited in a dynamic shallow marine environment with a bioclastic sandy seabed.

12. Laminites of Villaggio del Pescatore, Upper Campanian–Lower Maastrichtian (75–70 Ma). Thick laminated limestone with couplets of mm-thick dark organic rich lamina between thicker carbonate mud lamina. Contains fossils of crocodiles, fish, plants, and dinosaurs, the most famous being "Antonio," a hadrosauroid (*Tethyshadros insularis*) found in perfect anatomical alignment and now on display nearby at the Civico Museo di Storia Naturale. Deposited in an inner carbonate platform in a brackish water basin with an anoxic bed of carbonate muds.

13. Limestone with stromatolites, Danian (66–61.6 Ma). Fossiliferous, black, bituminous limestone with stromatolites. Deposited in a shallow restricted lagoon, inter and supratidal settings.

14. Limestone with *Nummlites*. Ilerdian (56–50 Ma). Compact, grey limestone with *Nummilites*, a large foraminifera 1–5 cm in diameter). Deposited in a continental shelf, less coastal than Alveolina.

15. Limestone with *Alveolina*. Ilerdian (55–50 Ma). Compact, grey limestone with many *Alveolina*, an elliptic foraminifera. Deposited in a continental shelf, more coastal than *Nummilites*.

16. Sandstone with vegetation remains, Middle Eocene (47.8–41.2 Ma). Turbidite sediments deposited at the base of the continental shelf.

17. Slivia ossiferous breccia, Pleistocene (0.9–0.8 Ma). Breccia with many mammal groups found. Deposited in an arid steppe-like environment with forests in humid areas.

18. Visogliano breccia, Pleistocene (0.45–0.30 Ma). Remains in the breccia include a tooth and jaw of Homo *heidelbergensis* and large (deer, horse, bison, rhinoceros, bear, fox, minks) and small (vole, dormouse) mammals. Deposited in a sinkhole.

Further information can be found in the park's booklet at http://www.ortobotanicotrieste.it/portfolio/percorso-geopleontologico/.

Below the Karst: Grotta Gigante

The carbonates of the Karst support many interesting caves and other hydrological phenomena hidden within the belly of the Karst. With a central cavern measuring 350 by 215 by 430 ft, the aptly named Grotta Gigante claims fame as the second largest cave in the world open to tourists (Fig. 2). The 10 million year old cave was first explored in 1840 by a spelunker hoping to find a water source at its bottom, but, alas, the river that carved the cave had left it 3 million years prior. This elusive "disappearing" Timavo River enters the ground near the mountains and exits near the sea, its underground course through the carbonates of the Karst Plateau still largely a mystery.

Figure 2. View of Grotta Gigante with its pendula visible on the right (two parallel vertical white lines).

Around two-thirds of the water in the Timavo stems from infiltration of precipitation through the carbonate rocks, to which the Grotta Gigante's magnificent speleothems testify. The water becomes acidic as it travels through the soil, dissolving carbonate minerals and carrying them in solution; as the water falls into the cave, the carbonates crystallize out. Studies in the cave show that its towering stalagmites, platy in shape due to their formation from the splashing of falling water drops, grow upwards from the ground at about 1 mm every 20 years. The stalactites, which hang from the ceiling, sport a more circular appearance as raindrops swirl down and around them. Although the limestone is originally white, the water, carrying iron leached from clay above, adds a red color.

The cave's size, constant temperature, and relative isolation from outside noise sources make it ideal for certain scientific instruments. It hosts two 330 ft pendula, thought to be the longest in the world, that measure the tiniest movements–fractions of a millimeter–of Earth's crust that result from solar and lunar tides and snow loads.

Figure 3. From top left to bottom right: Tre Cime di Lavaredo; entrance of trench/cave; Cortney inside the cave; gun port; exit of trench/cave.

For further information, see https://www.researchgate.net/publication/291147142_Grotta_Gigante.

Above the Karst: Tre Cime di Lavaredo

While the caves play coy, the Dolomite mountains which lend their name to the mineral, dominate the landscape for miles, otherworldly in their majesty as they seemingly spring suddenly from the earth. Indeed, the highlight of my experience in Italy was hiking around the Tre Cime di Lavaredo, three distinctive tower-like peaks glorying over a nature park named after them (Fig. 3). I won't belabor the park's beauty, leaving photographs to attempt it, even if they, too, fall short of that task, but I do want to mention that the park, which witnessedthe World War 1 front between Austria and Italy, provides a solemn testimony to the intersection of geology and warfare. Soldiers carved gun ports in the steep mountain walls and dug trenches and caves in the carbonate bedrock, all easily visible on a standard hike around the park (Fig. 3). Other war uses of the geology included tunneling and the use of explosions to trigger fatal rock slides. Further discussion of the military geology of the Dolomites can be found at https://blogs.scientificamerican.com/history-of-geology/accretionary-wedge-36war-geology/.

Making Connections

My beloved Appalachians are in many ways the spiritual ancestors of the Dolomites; visiting the Dolomites felt akin to glancing back at the Appalachians in their heyday and has enriched my understanding of them. A different academic experience saw me in Turks and Caicos, which allowed me to better envision the carbonate platform that was churned into the Karst Plateau and the Dolomites. As H. H. Read timelessly exhorted, "The best geologist is he who has seen the most rocks." Every trip continues to aid me in piecing together the picture not just of deep time and geology in general but also specifically of local geology. In closing, I would like to encourage undergraduates interested in this specific internship opportunity to contact the Department of Earth Science at North Carolina Central University—but of course, always keep your eyes out for other opportunities to travel and learn!

About the Author: *Cortney Cameron recently earned a master's degree in earth science from North Carolina Central University and accepted a position as a hydrogeologist in Florida.*