Land of Opportunity

Setting the Stage for Updating the Geologic Maps of Yellowstone National Park

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WHO DOESN'T LOVE YELLOWSTONE?

What American landscape is more iconic than Yellowstone National Park? Towering peaks, boiling pools, rainbow geysers, and plentiful wildlife name just a few of the many attractions. Of course, none of these attractions would be there for our viewing pleasure without the expansive and living geology of the region. This unique aspect of Yellowstone was first recognized by the Tuka Dika people, also known as the Sheepeater tribe, who made a home in the area for centuries. Later on, during western migration, the gold rush, and colonization of the American West, multiple geologic surveys were conducted in the greater Yellowstone ecosystem. The breathtaking landscape and rugged terrain played a quintessential role in the push to designate Yellowstone as the first national park in the United States in 1872. As with many expeditions of the time, multiple maps and paintings were created to document this vast region, with geologic study continuing in the park over the following decades. However, as the park is about the size of Puerto Rico, a larger and more directed effort was eventually required. As the 100th anniversary of the park neared, the United States Geological Survey enlisted twelve geologists to map the entirety of the park in detail **(Fig. 1)**. The first version of this map was published in 1972 at a 1:125,000 scale, along with thirteen 1:62,500 scale maps within the park boundaries. An updated version of the 1:125,000 scale map was published in 2001.

But let's take a step back. What is the importance of a geologic map and why should the public care that their national and state lands are mapped accurately? Geologic maps provide a foundation for understanding a landscape. Yellowstone's distinction as a supervolcano came from early geologic maps that recorded the extent of the pyroclastic deposits, their thicknesses and stratigraphic sequence. Geologic maps are indispensable tools for geoscientists working in the park and can be used to locate desired rock units for analysis, understand the lateral extent of a lava flow, or gauge the structural features that control a mountain range or a deep canyon, just to name a few uses. However, these maps are not just important to scientists. Geologic maps also help keep the public safe. Road construction relies heavily on accurate understanding of the geology and the National Parks Service keeps tabs on hazards such as landslides and thermal features that have been mapped.

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So in 2019, with Yellowstone's 150th anniversary approaching in 2022, park geoscientists began to imagine what they could do to commemorate the rich geology and leave visitors with a souvenir of their time in the park. They decided that a higher resolution geologic map would be an excellent contribution, especially considering the previous maps' release on the 100th anniversary. Thus, multiple institutions began working together to ascertain funding and compile existing maps for this undertaking.

As the current geologic maps of Yellowstone (both published and unpublished) were compiled, the organizations began to notice a common issue cropping up across the park: many of the geologic maps did not agree along their shared boundaries **(Fig. 2)** This is not an uncommon or unexpected

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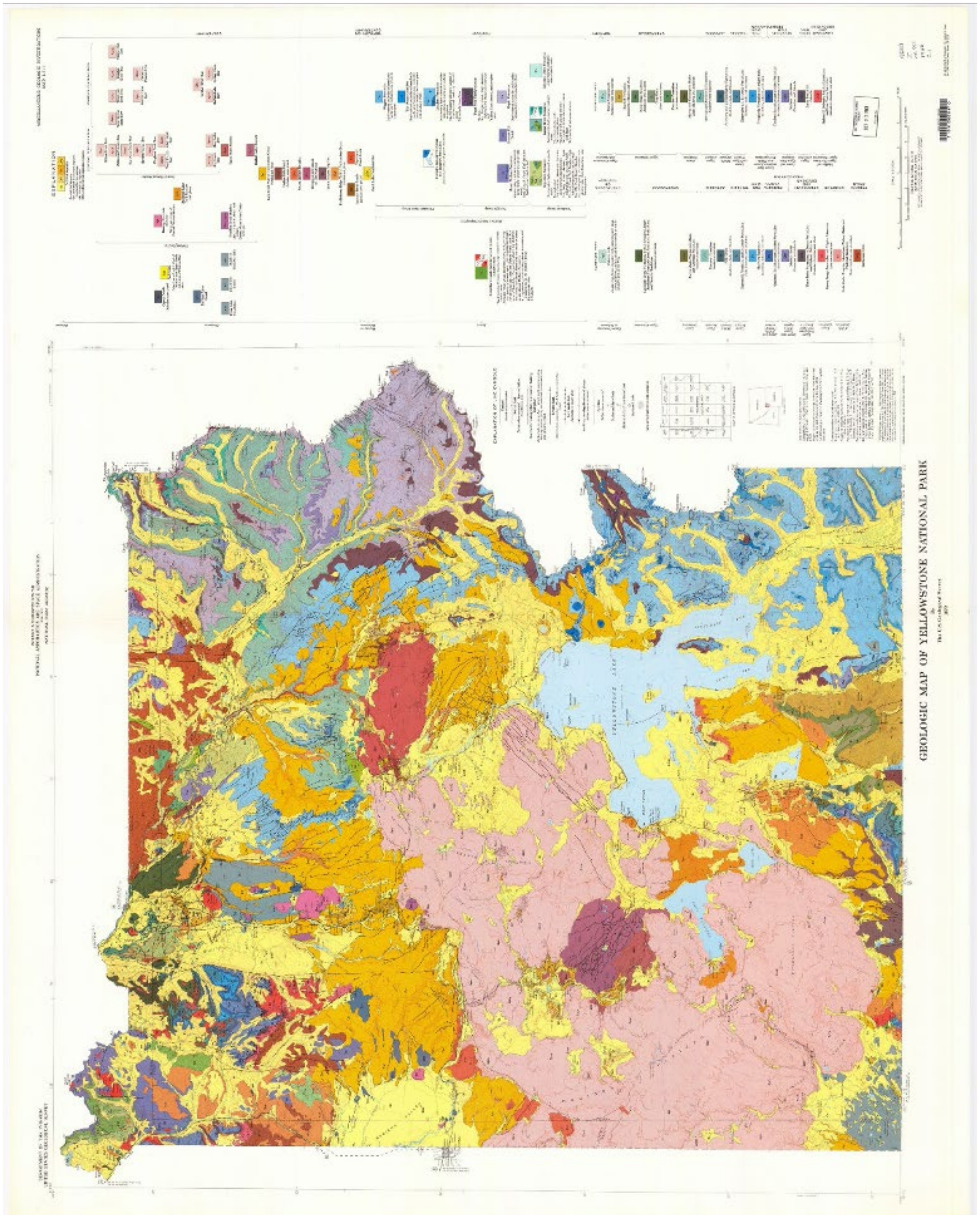

FIGURE 1: 1:125,000 geologic map of Yellowstone National Park, published in 1972. Image taken from the USGS and AASG National Geologic Map Database.

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occurrence, as compiling maps made by different authors with varying mapping objectives is bound to result in some disagreements. However, to publish a cohesive map, the broad Yellowstone team devised a plan to involve local resources to help resolve these issues. That's where Montana State University came in. And oh, what a journey it became…

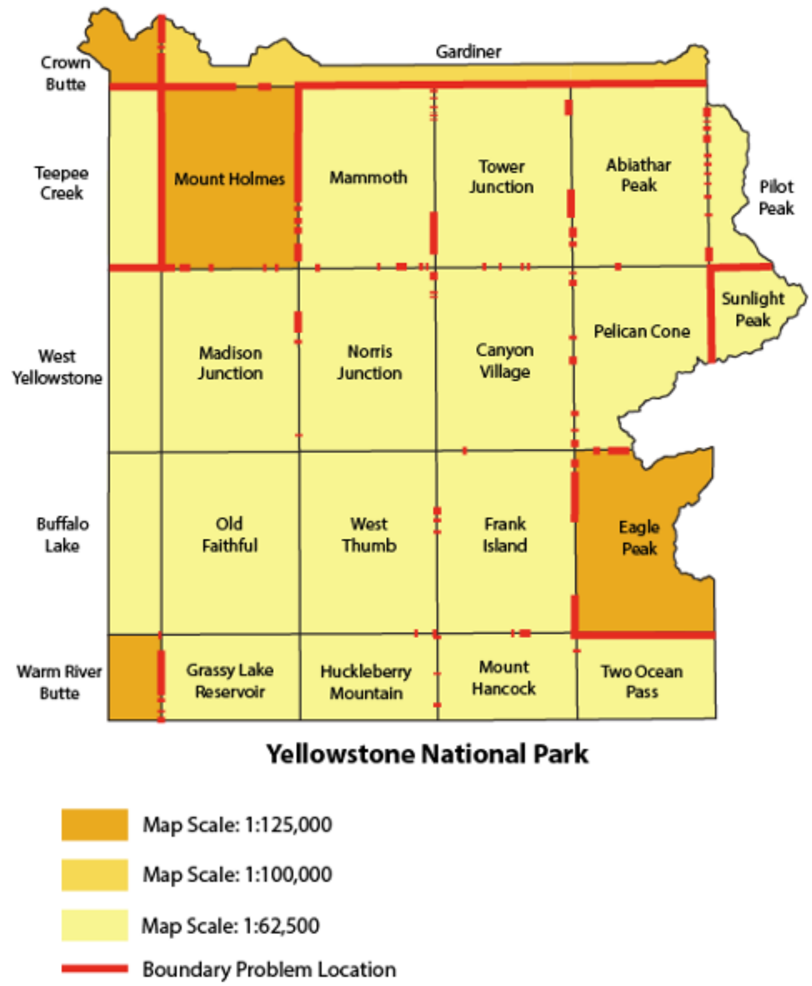

FIGURE 2: Reference map of the current, most detailed geologic maps in Yellowstone National Park. The red lines between maps represent known boundary disagreements throughout the park.

THE PROJECT

Yellowstone National Park is located a short 1.5 hours from Bozeman, MT, home of Montana State University. We began work on this project in June of 2020 with the ambitious (and in retrospect, naïve) hope of addressing the majority of the 485 boundary problems discovered in the park, to be covered over the course of two field seasons. We soon discovered that the task we set out to complete would be incredibly difficult, if not impossible. The reason for this is largely due to the landscape. For those that haven't travelled off trail in Yellowstone, we describe it as a uniquely difficult area to work. First off, this area is very heavily forested. And I don't mean a walk in the woods. It's filled with lodgepole pines, which tend to produce two landscapes: a stack of pickup sticks where your best bet is to walk the downed tree highway (like playing the game "the ground is lava"), or a tightly clustered network of young trees with clinging branches (referred to as Dog Hair Timber) that can quickly lead to claustrophobia **(Fig. 3)**. Many times, our field excursions resulted in miles of walking to find that any 'outcrop' only occurs within the roots of overturned trees; hardly the place to make strong geologic decisions and resolve boundary issues. Another factor adding to the difficulty is that the greater Yellowstone ecosystem was heavily glaciated for the majority of the last 150,000 years, so much of the rock outcrop has been buried by glacial sediment or is heavily eroded.

That said, all was not lost. Thus far we have visited over 60 boundary issues and resolved 30. The unresolved areas require more time to solve than we can offer in this project and are noted in detail with suggestions on how to address them in the future. Through these field visits, we have learned vast amounts about the issues of our current geologic maps. In essence, not all boundary problems are created equal, either in their complexity or in their reason for existence. To help assess and evaluate this complexity, we divided boundary problems into four types **(Fig. 4)**:

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1) "detail difference" problems (n = 264),
2) "contact offset" problems (n = 105),
3) "full stop" problems (n = 110), and
4) "double take" problems (n = 6).

Detail difference problems are the most frequent boundary problems and are defined as two maps disagreeing in their naming scheme, often due to differences in scale (which, if we are being honest, appears to be the reason for most boundary problems). For example, where a larger-scale, greater detailed map might divide out Quaternary units into "glacial outwash," "landslides," and "alluvium", a smaller-scale, more general map would group those units into a more broad "Quaternary sediments." These maps do not necessarily disagree with each other, but ultimately it is an issue that needs to be resolved for combining the two maps. The next most common boundary problem is referred to as a "contact offset" problem and is likely what most geologists would expect to come across when compiling geologic maps. This error occurs when the contact between rock units does not line up across the boundary, appearing offset. This offset is only an issue if it is beyond the National Map Accuracy Standard (NMAS) snapping tolerance. For all contact offsets outside of snapping tolerance, the boundary in question needs to be visited in person to determine the true contact location.

The third most common type of boundary problem is the "full stop" problem. This is the most blatant of errors, where one map has a rock unit crossing a boundary that then completely disappears in the neighboring map, where a different unit then appears. These errors are the most puzzling of the three types and tend to be (surprise!) between maps of different scales. These boundary problems also must be addressed in person and, we have found, often take more than one trip to resolve.

Finally, the least common type of error is the "double-take" error. This error occurs when one map shows a rock unit that stops short of the map boundary, then reappears on the adjacent map. This would suggest that it should cross over the boundary. Since both maps agree on the rock unit type, it then becomes a 'simple' matter of whether or not the contacts are within snapping error, according to NMAS guidelines. If so, we can simply proceed with the contact that makes most sense with the topography. If not… well, back to boots on the ground.

FIGURE 3: MSU team making their way through "dog hair timber" in Yellowstone's backcountry.

While MSU's field team will cover a great deal of the park in the duration of our research, it is unlikely that all problems will be addressed in time to produce a new geologic map for 2022. We deeply apologize. However, the fact is that our work has

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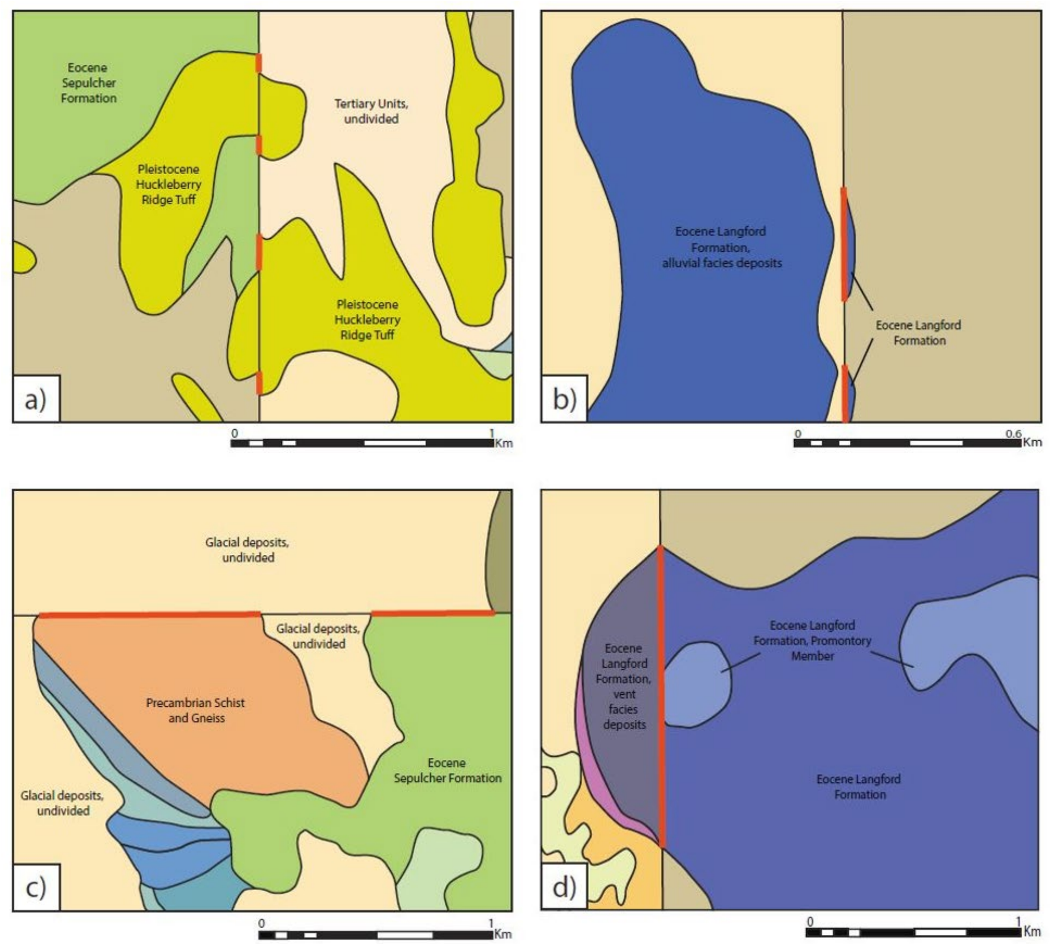

FIGURE 4: The four panels are examples of a) a "contact offset" boundary problem, b) a "double take" boundary problem, c) a "full stop" boundary problem and d) a "detail difference" boundary problem.

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highlighted that there is ample room for mapping projects to occur in Yellowstone. This leaves the field of opportunity wide open for graduate students, USGS geologic mappers, state survey geoscientists, and many others to begin efforts of mapping the park at a higher resolution. At the very minimum, the nine quadrangles in the park that have not been mapped at a 1:62,500 scale should be brought up to the speed of their counterparts published in 1972. From there, a new comprehensive geologic map of the whole park could be published at varying scales (1:62,500, 1:100,000).

UNDERGRADUATE RESEARCH AND FIELD EXPERIENCE OPPORTUNITIES

One unexpected but wonderful outcome of this work is that it has provided a unique opportunity to bring undergraduate Earth Science majors into a large Earth Science project. Helping to update the geologic map of Yellowstone not only allowed them to increase their field experience and knowledge of Montana and Wyoming geology but allowed them to add a remarkable experience to their resume. In the summer of 2020, we worked with five undergraduate students who then spent their summer in Yellowstone mapping outcrops, backpacking, and describing a range of rocks (over 300 units make up the park!). In 2021, we brought on three more. The experience was so influential it led to one of these undergraduates deciding to pursue his master's degree in our lab group and two others ended up in field-based, exploration geology internships the following summer.

Because of the broad appeal of working on such a massive and important project, we felt we had the

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FIGURE 5: MSU field hands, volunteers, and master's students checking out a glacial erratic on Mount Everts.

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potential to involve a larger number of students in smaller field experiences. Field experiences have been found to be a huge part of Earth Science identity, but also can be non-inclusive in terms of both the financial burden and lack of exposure to outdoor safety. So, in 2021, we initiated a volunteer program where undergraduates from MSU's Earth Science Department could participate in a short, and somewhat tailored, field experiences in Yellowstone **(Fig. 5)**. Volunteers would come out for one week at a time and join in either a backpacking trip (field supplies and food provided) or a front country experience for newer participants in the outdoors. All volunteers gained experience in sample collecting, writing rock descriptions, and orienting themselves with the GPS.

One might wonder how the student volunteers fared, especially considering some of them volunteered with little geology background and outdoors experience. We were also curious. Here's what we learned from an anonymous survey of our volunteers:

One student commented that "the week I volunteered was seriously the best week of my entire summer. It really showed me that I chose the right major and that I truly wanted to learn more about geology and the Earth Sciences as a whole." Another student said, "Fantastic – I grew a lot as an individual over the course of this summer and I also got a deeper connection to the Earth Sciences department and I gained a sense of belonging within it."

The same survey asked volunteers to give advice or recommendations for future volunteers and one response read, "If you're considering it, but aren't sure if it's for you, do it! I promise. I was on the edge and decided to go and it has easily been the best decision I've probably made in the last five years, including when I decided to go to college."

CONCLUSION

Ultimately, Yellowstone is a place that will continue to enthrall, mystify and educate for centuries to come. We have been lucky to take part in what we like to think is the rejuvenation of interest of geologic mapping in Yellowstone. We will leave this project with a new stratigraphic column, >50 resolved boundary problems, a new generation of inspired students, and a laundry list of future work to be accomplished.