*How it's made: Subsurface structure of the Quarry Mountain foothills from seismic reflection imaging, Steamboat Springs, Colorado*

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**ABSRACT**

Seismic reflection is a subsurface imaging technique that generates acoustic waves, tracks their reflections from geological interfaces, and analyzes travel time to reveal the Earth's internal structure. In 2025, students of the Colorado School of Mines Geophysics Field Session conducted seismic reflection surveys along Routt County Roads (CR) 43 and 45 in Steamboat Springs, Colorado. In conjunction with seismic reflection surveys from the 2023 and 2024 field sessions, in which students imaged CR-33A, 42, and 44, we were able to make interpretations of the subsurface structure of the Quarry Mountain foothills region. Our analysis of the region reveals shear zones can be reactivated from younger tectonic events.

***Index Terms*** **–** Seismic reflection imaging.

## 1. INTRODUCTION

Detailed insights into the structure of the Precambrian shear zone in Steamboat Springs, Colorado remain limited. To address this gap, the 2025 Colorado School of Mines Geophysics Field Session conducted two seismic reflection imaging lines – one along CR-45 and a second along CR-43. The Precambrian shear zone plays a critical role in moderating fluid migration and seismic activity within the Yampa Valley. It acts as a high-permeability pathway, allowing hydrothermal fluid to cycle through warming at depth, migrating to the surface as a hot spring, and cooling to sink again. The presence of this shear zone contributes to local seismicity as strain accumulates along reactivated fault planes and generates small-magnitude earthquakes. Understanding the structure and extent of this shear zone is essential for characterizing its influence on regional hydrothermal systems, prompting our use of seismic reflection imaging to map the subsurface structure.

The stratigraphic column below (figure 1) represents the geologic history of the Yampa Valley. The known geology of the region helps in providing a framework for analysis, guiding our exploration to focus on the Precambrian basement as the feature of interest, an area characterized as a shear zone.

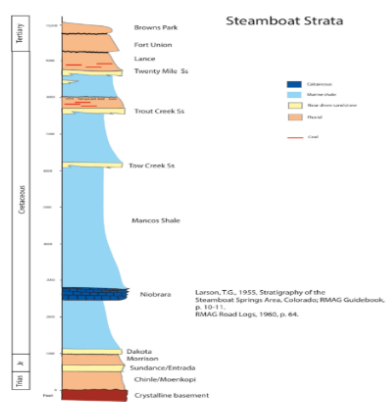


*Figure 1: Strata Column of Steamboat Springs, Colorado [1].*

## 2. METHODS

In 2025, seismic reflection was used to image the subsurface along two survey lines: CR-43 (west-east orientation) and CR-45 (southeast-northwest orientation). These lines were selected due to a known fault that bisects CR-45 and runs adjacent to CR-43.

For processing, seismic lines from the 2023 and 2024 Field Session were incorporated: CR-33A, 42, 44. The following figure shows the seismic lines overlain on a geologic map of the region, indicating surface geologic formations and known major faults.

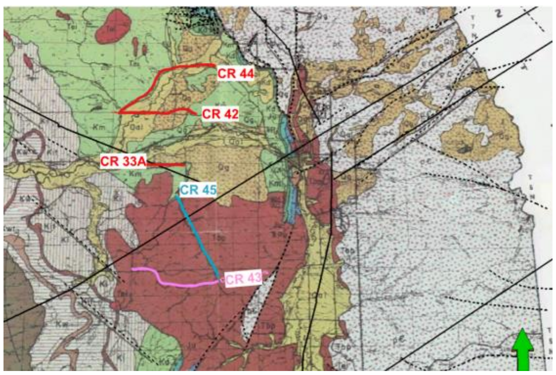


*Figure 2: Map of seismic lines overlain on geologic map of Steamboat Springs, Colorado [2].*

The acquisition setup included 430 nodes along CR-45 and 421 nodes along CR-43, with a 15-meter spacing between each node. A 60,000 lbs. Vibroeis truck was used as the seismic source, generating a 16-second linear sweep with a frequency range of 4 - 50 Hz up-sweep.

The donated 60,000 lbs. Vibroseis truck enabled high-energy input, enhancing signal penetration, which is essential for resolving deeper structures, including the shear zone. The 16-second linear sweep improved signal coherence and the 4-50 frequency range balanced depth and resolution, as low frequencies penetrate deeply while high frequencies prioritize resolution.

Processing began with collecting raw shot gathers, sweeps, and log files from Dawson Geophysics. The first step involved trimming and correlating the shot gathers to ensure signal clarity and remove noise. Next, we performed initial processing to define the survey geometry and eliminate background interference.

To refine the seismic imaging, a velocity analysis was conducted, producing both brute stacks for preliminary analysis and velocity stacks for improved structural resolution. After obtaining said stacks, we applied several transformations and filters in Python, such as the Hilbert transform, a band pass filter, and a Sobel filter, to enhance signal quality and suppress unwanted artifacts.

Following these enhancements, we used Petrel to generate a 3D analysis of the reflecting interface, integrating velocity models to characterize subsurface material properties. In conjunction with a depth migration, we were able to accurately position the geological features in space, enabling detailed interpretation of fault structures and a dipping layer.

## 3. RESULTS

Our processing yielded a depth-migrated profile of CR-43 and CR-45.

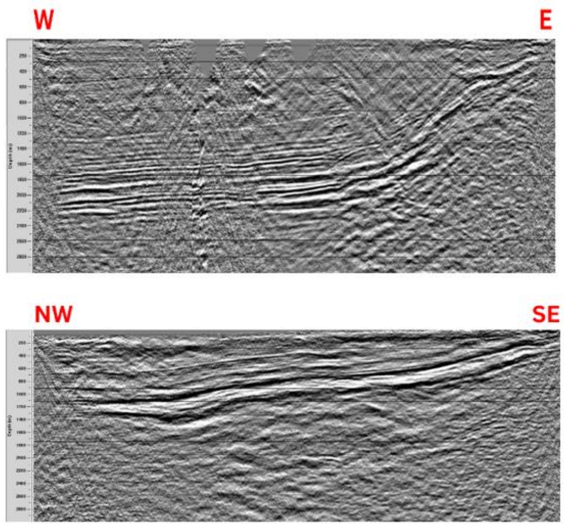


*Figure 3: Depth-migrated profile of CR-43 (top) and CR-45 (bottom).*

From our depth migration profiles (figure 3), we found several subsurface features. On CR-43, there is a large, high-amplitude feature that dips toward the west. Likewise, on CR-45, we can see a high amplitude feature that dips less significantly toward the northwest.

## 4. DISCUSSION

### *Interpretation*

Our interpretation of the two seismic profiles in conjunction with previous seismic reflection data taken in the region leads us to believe that the Precambrian shear zone that underlies Steamboat Springs was reactivated in the form of faulting. Based on the local geology (figures 1 and 2), sediment was deposited on top of the Precambrian basement around 160 to 100 million years ago. The strata were then tilted and uplifted from the Laramide orogeny around 60 million years ago [3] and then further deformed from extensional tectonics in the area around 20-10 million years ago [4]. The crustal extension then reactivated the shear zone in the form of normal faulting, which we can see in Figure 4.

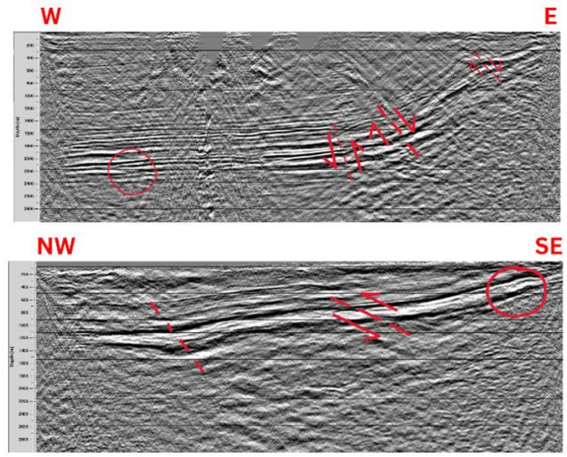


*Figure 4: Annotated depth migration profiles of seismic reflection lines CR-43 (top) and CR-45 (bottom). Dashed lines indicate potential faults, and circles represent folds.*

In these figures, we can see high amplitude structures that have reflections that are bent or broken, which are indicative of faulting or folding.

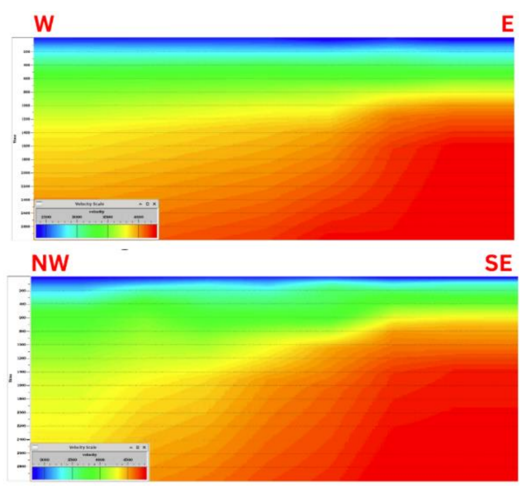


*Figure 4: Velocity model of seismic profile for CR-43 (top) and CR-45 (bottom).*

On top of this, when combined with the generated velocity models (figure 5), we can see that aligning structure has a velocity range of 4000-5000 m/s. This velocity is consistent with what we would expect of Precambrian basement rock [5], leading us to interpret the dipping features in these profiles are the Precambrian shear zone that has been highly faulted from regional tectonic activity.

The reactivation of the Precambrian shear zone in Steamboat Springs has significant implications for the geothermal system in the region, potentially impacting fluid migration dynamics. Understanding these fault structures is crucial as they may affect the system's characteristics. Additionally, identifying zones of high faulting activity contributes to seismic risk assessment which can help aid in informed risk management for the region.

***Uncertainties and Limitations***

During the data collection process, we had to change some of our surveying parameters. Namely, we had to shift from collecting four stacks to two and skip over nodes on CR-43 due to a resident's concerns. Having fewer stacks resulted in having less coherent data meaning some of our interpreted faults could be due to noise or that we could not see faulting in areas of higher noise.

Additionally, the nodes that were skipped resulted in lower spatial resolution in the area. There were also features that were uninterpretable because of the curving of the road. This could have resulted in features that were not found due to incoherence.

## 5. SUMMARY AND FUTURE WORK

We found that ancient crustal structures are able to reactivate from younger tectonic events. Such events create faults in the region that influence fluid migration, seismic activity, and risk mitigation.

We suggest that future groups continue to explore the Precambrian shear zone to the east to gain a better understanding of how it influences the geologic water system in Steamboat Springs, Colorado. This structure is likely a catalyst for groundwater flow and the expression of hot springs in the area. As this shear zone is expected to become shallower east of past surveys, the area becomes well-suited for a refraction seismic survey. This type of survey may be able to identify variations characteristic of fluid pathways, such as fractures, while seismic reflection is useful for investigating larger and deeper features. The combination of these two methods could provide a more complete understanding of how the shear zone has impacted the subsurface water systems in the area.

## 6. ACKNOWLEDGMENTS

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## 7. AUTHOR CONTRIBUTIONS

Data was collected during the 2025 Geophysics Field Session in a collaborative effort by students and instructors. Todd Fockler and Jim Simmons serve as instructors, with Maile Corso, Mia Jungman, Maddie Pels, Jackson Krieger, and Lexi Herr as teaching assistants.

Julia Berglind focused on SeiSpace analysis and interpretation. Renee Fischer focused on coordination with experts, abstract, introduction, results, and methods. Peyton Chandler focused on Petrel analysis, uncertainties and limitations, and summary and future work. Kadidia Mariko focused on coordination and results.

## 8. REFERENCES

[1] Larson, T.G., "Stratigraphy of the Steamboat Springs Area, Colorado," *RMAG Guidebook*, pp. 10-11, RMAG Road Logs, 1960, p. 64.

[2] "MS-01 Geologic, Energy and Mineral Resources Map of Routt County - Colorado – Colorado Geological Survey – Colorado Geological Survey," Colorado Geological Survey – Colorado Geological Survey, Jul. 29, 2924. [Online]. Available: https://coloradogeologicalsurvey.org/publications/geologic-energy-mineral-resource-routt-colorado/.

[3] "Colorado Geology | Colorado Encyclopedia," coloradoencyclopedia.org. Available: https://coloradoencyclopedia.org/article/colorado-geology

[4] K. Howard, B. John, G. Davis, J. Andersen, and P. Cans, "A Guide to Miocene Extension and Magmatism in the Lower Colorado River Region, Nevada, Arizona, and California," 1994. Available: https://pubs.usgs.gov/of/1994/0246/report.pdf

[5] S. Earle, "9.1 Understanding Earth Through Seismology," *Opentextbc.ca*, Sep. 23, 2019. Available: https://opentextbc.ca/physicalgeology2ed/chapter/9-1-understanding-earth-through-seismology/