GLACIAL DEPOSIT IDENTIFICATION WITHIN THE YAMPA RIVER VALLEY, COLORADO

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ABSTRACT

As modern glacial retreat accelerates due to climate change, understanding past glacial extents becomes increasingly important. Glacial deposits can function as a proxy for maximum glacial extent in the past, while also serving as a source of industrial aggregate. In the Yampa River Valley of Northwestern Colorado, topographic indicators of deposits are evident, yet subsurface data from the region remains sparse. Here we use multichannel analysis of seismic surface waves (MASW) to build a 2D velocity model to map subsurface evidence of glacial deposits extending across Routt County Road (CR) 22. Our results suggest a low shear-wave velocity (Vs) between 550 and 750 m/s with large spatial variability. This indicates a high-energy depositional environment characteristic of an outwash plain with glacial and fluvial influence. This work provides both geologic insight and information for attractive economic pursuits within the Yampa River Valley.

Index Terms—Glacial Deposit, Outwash Plain, Fluvial Fan, Aggregate, Multichannel Analysis of Surface Waves (MASW), High-Energy Depositional Environment, Digital Elevation Model (DEM)

1. INTRODUCTION

Glacial landforms and deposits serve as important indicators of past climates as well as a natural resource for industrial materials. Particularly, glacial features, such as valleys, moraines, and outwash plains, can indicate the maximum extent and direction of past glaciers, as well as serve as a valuable location for aggregate extraction. However, glacial features are not always expressed at the surface and can be concealed by superimposed layers of sediment. Therefore, geophysical methods can be a valuable tool to map the subsurface extent of, and characterize, glacial features.

In the Yampa River Valley of Northwest Colorado, multiple tributaries join the Yampa River, including Walton Creek, which flows into the Yampa River to the East of CR 22. In the surrounding region, two well documented glaciers have been identified, the Fish Creek glacier approximately 6.5 km to the North, and the Rabbit Ears glacier approximately 10 km to the Northeast [1] [2]. A map of known glacial extent from the last glacial maximum is included in Appendix 10.2.

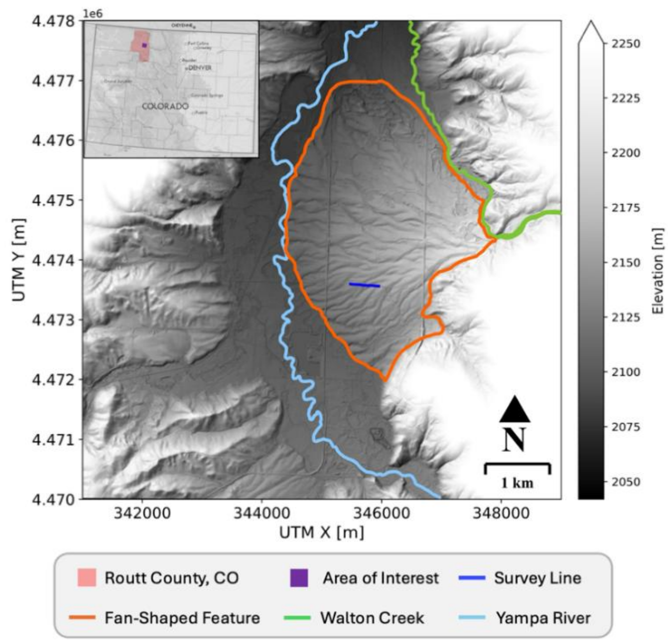

Figure 1: Study area within the Yampa River Valley of Northwestern Colorado. Airborne LiDAR derived, 1 m resolution basemap [3].

Additionally, a sizeable fan-shaped feature is present where Walton Creek flows out of the narrower valley into the larger Yampa River Basin, near CR 22 as shown in Figure 1. This fan is a noteworthy feature, as topographic fans in other regions of the world have been directly linked to glacial activity [4] [5]. The fan-shaped feature at Walton Creek may correspond to a transition from glacial to fluvial processes because of high-load runoff from glacial melt in the upper Walton Creek valley [5].

Unlike other valleys in the region that maintain a U-shape throughout, Walton Creek opens from a V- to a U-shaped valley. This transition from V- to U-shaped suggests glacial activity as well as fluvial erosion and is well-displayed in Figure 2 [6].

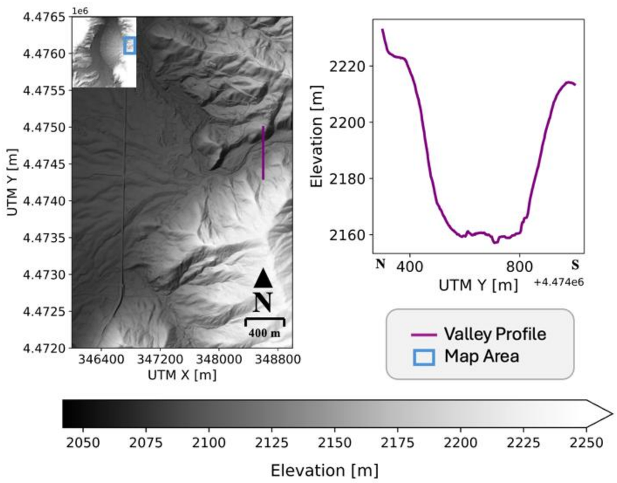

Figure 2: Walton Creek valley investigation. U-shaped valley profile indicates glacial erosion [3].

Previous surveys conducted along CR 22 during the 2022 Colorado School of Mines (CSM) Geophysics Field Camp focused on the geology of the Yampa River Valley, implementing gravity and deep seismic survey methods [7] [8]. While useful, this investigation did not confirm the presence of glacial activity in the area [9] [10]. To build on these efforts and address this knowledge gap, we conducted a near surface seismic survey along CR 22 to further characterize shallow subsurface structure during the 2025 CSM Geophysics Field Camp. We then performed MASW on the collected data. Based on the region's glacial history, and geological indications of glacial activity near CR 22, we can conclude that that the valley housing Walton Creek had glacial influences.

2. METHODS

2.1. Survey Design

During the 2025 Colorado School of Mines Geophysics Field Camp, we collected seismic refraction data along a 475 m line on CR 22 in Routt County, Colorado, oriented West-East [11]. Our survey utilized 96 14 Hz vertical component geophones, with 5 m of spacing between each to ensure adequate spatial resolution [12].

We used an accelerated weight drop mounted on the bed of a pickup truck for our seismic source. This typically produces frequencies between 10 and 250 Hz . We took shots every 15 m until 300 m offset was reached, with variable stacks at each location. One additional shot stack was taken at 350 m due to a large accumulation of surface water on the roadway. In total, we took 22 shot positions along the survey line. Due to time constraints during the survey, we did not take shots in the last 75 m of the survey line.

We chose a sampling interval of 0.25 ms, or a sampling frequency of 4000 Hz, with a 0 s delay and a 1.5 s listening time. We used an Emlid Reach RS3 to take the coordinates of each geophone location along the line.

2.2. Processing

In initial data investigations, we identified strong amplitude direct and surface wave arrivals but had little to no confidence in identifying refraction arrivals. See Appendix 10.3 for an example of this uncertainty. For this reason, we chose to generate subsurface images using MASW.

To process the data, we used the software package ParkSEIS V.3 AUTO; an MASW tool that generates 2-D cross sections of Vs . We imported 22 raw seismic shot gathers (record 1001-1022) into ParkSEIS, where we applied a dynamic high-cut filter to remove high-frequency noise from the records. This generally removed frequencies greater than 100 Hz but varied between each record.

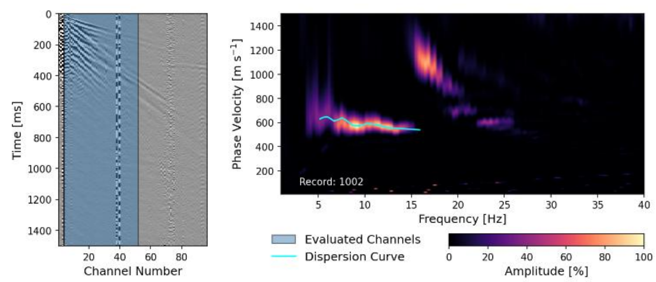

Figure 3: Left: Shot record 1002 with a synthetic roll along highlighted in blue. All channels outside of this highlighted region are removed for following processing steps. Right: Generated dispersion image with extracted dispersion curve for record 1002. The lower-left hotspot shows the dispersion of surface waves, while the other hotspot is a harmonic and should not be considered for the dispersion curve.

We synthesized a 48-channel roll along survey to capture the dispersive nature of the surface waves and avoid the noise introduced by far offsets. See Appendix 10.3. In Figure 3, we show the dispersion image for channels 4-52 for record 1002. We generated this image for frequencies between 1-60 Hz and velocities from 10-3000 m/s. The right panel of Figure 3 shows the picked dispersion curve from record 1002.

To pick the dispersion curve, we used the ParkSEIS automatic picking tool for guidance and adjusted the curves to create a smoother line that follows the dominant trend. We repeated this process for all records with 48 channels past the source. Given our line length, we could only achieve synthetic roll-along for records 1002–1016. Once picked, we inverted the dispersion curves using a 5-layer model with 5 iterations to create a 2D Vs cross section of the survey line.

3. RESULTS

The Vs model generated from an inversion of the dispersion curves resulted in a range of subsurface Vs between approximately 550 m/s to 750 m/s. Velocities were resolved up to 100 m in depth while excluding results with model confidence less than 30%, as shown in Figure 4. Vs values generally increased with depth; however lower Vs ranges were situated directly adjacent to high Vs values throughout the cross-section.

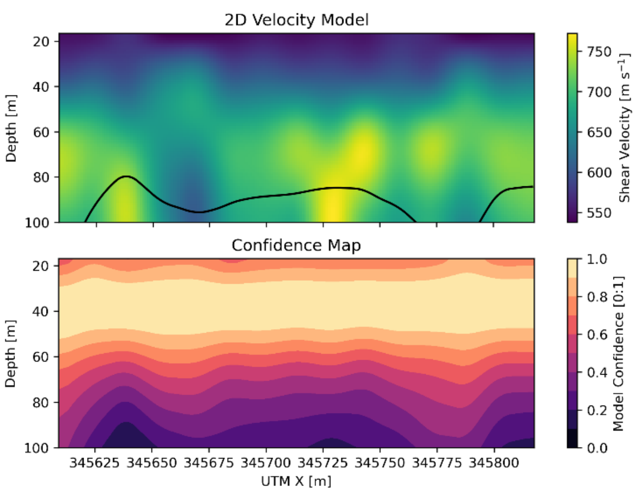

Figure 4: The top panel shows the 2D Shear Velocity Cross-Section of CR 22. Black line in model indicates threshold of 30% confidence. The bottom panel shows the inversion confidence map, which generally decreases with depth.

4. DISCUSSION

These pockets of high and low shear velocity material indicate a heterogeneous deposition of sediment up to depths of 100 m. The velocity range of the model aligns with known Vs values of gravels, sands, and other loose materials, leading us to conclude that this subsurface section is composed of poorly sorted sediment .

Pockets of contrasting material of a poorly sorted nature indicate a high energy depositional environment, where large volumes of water are required to erode and carry larger grain sizes. Present-day Walton Creek has an average flow rate of 15.94 m^3/s which is too low to deposit the variety of sediments seen in Figure 4 . Additionally, the headwaters of Walton Creek are located approximately 15 km East of CR 22 at the Continental Divide, which limits the source and volume of water available during historical flow regimes. It is unlikely that Walton Creek would have ever had the flow rate required to deposit a fluvial fan of the size that is observed in the Yampa River Valley.

Because the fan-shaped feature was not deposited by Walton Creek and considering the U-shaped valley profile shown in Figure 2, we conclude that the feature is not a fluvial fan but rather a glacial outwash plain. See Appendix 10.4 for a present-day example.

Glacial outwash plains form as large fluxes of water and sediment are discharged from a receding glacier [4]. The volume of material and energy of deposition carves features that have a strong resemblance to fluvial fans. This glacial outwash plain over CR 22 has not been previously identified or referenced in studies of Yampa River Valley glacial features. This finding therefore expands our understanding of Park Range glaciation during the Last Glacial Maximum, suggesting that the extent of glaciation in the Yampa River Valley extended further South than previously mapped.

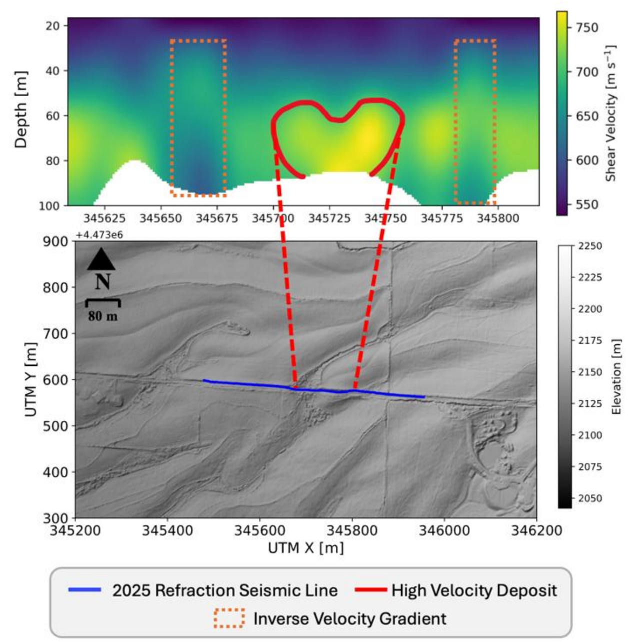

Figure 5: Interpretation of Figure 4 extended to topographic features. Profile section with confidence below 30% threshold was removed [3].

Orange boxes in Figure 5 show two areas with layers of high Vs material sitting over low Vs material, which indicates that these sediments were transported and deposited in recent geologic history and have not yet compacted into solid sedimentary rock. These features suggest that the glacial outwash plain was deposited and shaped during the most recent glacial recession, with smaller-scale fluvial erosion and deposits from Walton Creek occurring post-formation. The layers of loose glacial till present in the 2D cross-section, and likely in other regions of the glacial outwash plain, serve as potential areas of investigation for aggregate mining.

The high Vs deposition, outlined in red in Figure 5, aligns with the lobe-shaped structure within the glacial outwash plain. While this feature is identifiable in the Digital Elevation Model (DEM), the inverse velocity gradients, outlined in orange in Figure 5, are not immediately linked to features on the surface. Because topography analysis would not provide enough evidence to classify this feature as a glacial outwash plain, subsurface investigations are a necessary step, and MASW is a viable method for discovering evidence of glacial deposits.

5. SUMMARY

We collected a 475 m array of near-surface seismic data on CR 22 to investigate a hypothesized glacial deposit in the area. We applied a high-cut filter to improve data clarity, used MASW to pick dispersion curves, and created a 2D inversion model to image structures within the subsurface. We interpret the pockets of high and low velocity material in the resultant 2D Vs cross section as poorly sorted sediment, indicating a high energy depositional environment that could not be achieved by Walton Creek. This evidence, in addition to the U-shaped profile of the valley and previous glaciation in the region, leads us to conclude that the fan-shaped feature is a glacial outwash plain. This extends our previous understanding of glacial extent in the Yampa River Valley during the Last Glacial Maximum and provides a new area of investigation for aggregate mining opportunities.

6. FUTURE WORK

To confirm the results of this survey, we recommend that sediment cores are taken over our identified region of glacial outwash to confirm the proposed high energy depositional environment. Radiometric dating of these sediment cores should also be performed, to determine the date of the last surface exposure of this material and help constrain the timeframe of glacial activity in the area. Additionally, to compare our results with a larger region, we would like to continue MASW with the datasets collected by the 2022 CSM Geophysics Field Camp. Furthermore, we believe it would be useful to investigate the transition from the Yampa River's flood plain to the identified glacial outwash plain using a near surface seismic survey. This will strengthen the evidence supporting our conclusions and contribute to a more comprehensive understanding of glacial dynamics in the Yampa River Valley.

7. ACKNOWLEDGEMENTS

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8. AUTHOR CONTRIBUTIONS

The 2025 CSM Geophysics Field Camp collected the seismic refraction data along CR 22 with assistance from the visiting faculty of Collier Geophysics, LLC. K. Dougherty, J. Logan, E. Ross, and O. Wills all contributed to the processing of the seismic refraction data using ParkSEIS Software, under guidance from Roy Bowling of Collier Geophysics, LLC. J. Logan created the final Vs model. E. Ross created a map for the area of investigation, including survey locations.

K. Dougherty, E. Ross, and O. Wills wrote the Abstract. O. Wills wrote the Introduction. O. Wills and K. Dougherty wrote the Methods section. O. Wills and J. Logan wrote the Data Processing section. E. Ross wrote the Discussion section. K. Dougherty, E. Ross, and O. Wills wrote the Summary section. K. Dougherty and O. Wills wrote the Future Work and Acknowledgments sections. K. Dougherty wrote the Appendix.

E. Ross produced Figures 1 and 2. J. Logan produced Figures 3, and 4. E. Ross and J. Logan produced Figures 5 and A3. O. Wills produced Figures A1 and A2. K. Dougherty and J. Logan produced Figure A3.

9. REFERENCES

[1] V. Matthews and J. P. McCaplin, "Jaunt #1: From Walmart to Waterfall," in *Land of Ice: Jaunts Into Colorado's Glacial Landscape*, Golden, Colorado Geological Survey, 2024, pp. 75-78.

[2] W. W. Atwood Jr., "Records of Pleistocene Glaciers in the Medicine Bow and Park Ranges," *The Journal of Geology,* vol. 45, no. 2, pp. 113-140, 1937.

[3] Colorado Water Conservation Board, "Colorado Hazard Mapping & Risk MAP Portal," 1 10 2016. [Online]. Available: https://coloradohazardmapping.com/lidarDownload. [Accessed 05 06 2025].

[4] F. An, Q. Bading, S. Li, D. Gao and T. Chen, "Glacier-Induced Alluvial Fan Development on the Northeast Tibetan Plateau Since the Late Pleistocene," *Frontiers in Earth Science,* vol. 9, pp. 1-14, 2021.

[5] D. F. Ritter and N. W. Ten Brink, "Alluvial Fan Development and the Glacial-Glaciofluvial Cycle, Nenana Valley, Alaska," *The Joural of Geology,* vol. 94, no. 4, pp. 613-624, 1986.

[6] National Park Service, "U-Shaped Valleys, Fjords, and Hanging Valleys," National Park Service, [Online]. Available: https://www.nps.gov/articles/ushapedvalleysfjordshangingvalleys.htm. [Accessed 03 06 2025].

[7] CSM Geophysics Field Camp, "CR 22 Gravity Survey Data," CSM Department of Geophysics, Yampa River Valley, 2022.

[8] CSM Geophysics Field Camp, "CR 22 Reflection Seismic Data," CSM Department of Geophysics, Yampa River Valley, 2022.

[9] 2022 Mines Geophysics Field Camp Participants, "Defining the Geometry of Yampa Valley Moraine Field South of Steamboat Springs by Multi-physics Integration," Colorado School of Mines , Golden, 2022.

[10] 2022 Mines Geophysics Field Camp Participants, "Defining the geometry of Yampa Valley moraine field south of Steamboat by multi-physics integration," Colorado School of Mines, Golden, 2022.

[11] CSM Geophysics Field Camp, "CR 22 Refraction Seismic Data," CSM Department of Geophysics, Yampa River Valley, 2025.

[12] R. Bowling, *Lecture on Seismic Refraction for Ivestigation of a Potential Subsurface Moraine,* Steamboat Springs, 2025.

[13] Exploration Instruments LLC, "PEG-40 Accelerated Weight Drop Seismic Source," 2024. [Online]. Available: https://www.exiusa.com/item/uncategorized/peg-40-awd. [Accessed 02 06 2025].

[14] Park Seismic, "ParkSEIS," Park Seismic LLC, [Online]. Available: https://www.parkseismic.com/parkseis/. [Accessed 03 06 2025].

[15] D. L. B. Kip K. Allander, "Seismic Velocities and Thicknesses of Alluvial Deposits along Baker Creek in the Great Basin National Park, East-Central Nevada," USGS, 2009.

[16] USGS, "Walton Creek Near Steamboat Springs, Co," 30 September 1987. [Online]. Available: https://waterdata.usgs.gov/monitoring-location/09238500/#dataTypeId=continuous-00060-0&period=P7D&showMedian=true.

[17] C. K. Atwood and W. W. Atwood, "Land Utilization in a Glaciated Mountain Range," *Economic Geography,* vol. 13, no. 4, pp. 365-378, 1937.

10. APPENDIX

10.1. Workflow Diagram

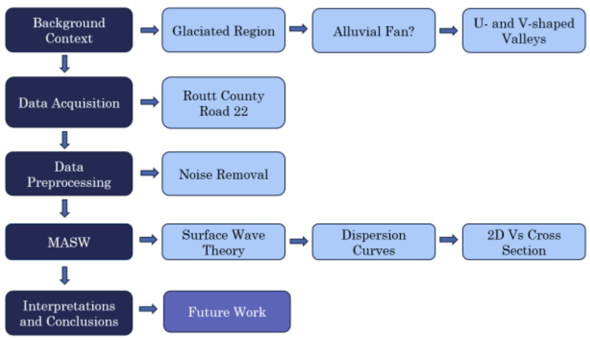

Figure A1: Project workflow diagram.

10.2. GLACIAL EXTENT OF REGION

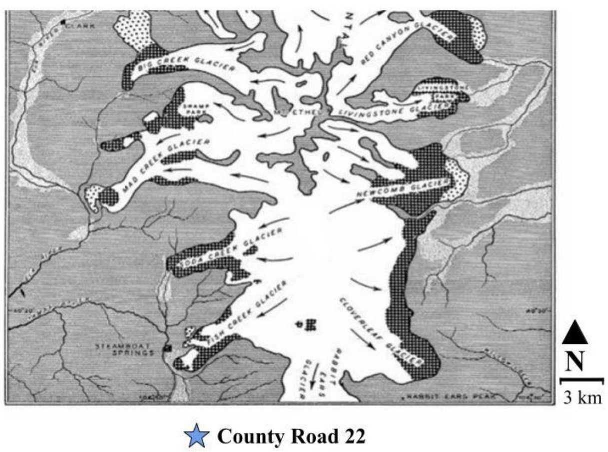

Figure A2: Map of previous glacial extent within the Park Range of Colorado, adapted from .

10.3. Annotated Shot Record from 2025 CR 22 Dataset

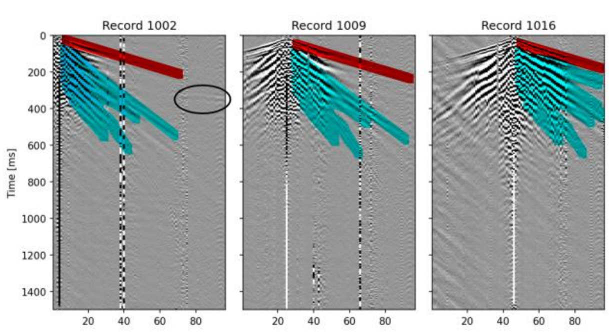

Figure A3: Annotated shot record example with high-cut filtering applied. Red highlight identifies the direct wave, blue highlight identifies surface waves, and the black circle denotes a potential refraction that was inconsistent among shot records.

10.4. Synthetic Roll-Along

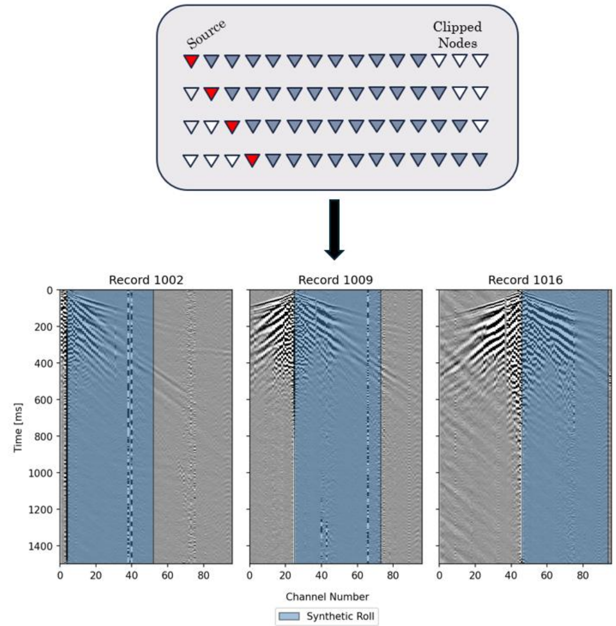

Figure A3: Diagram depicting the application process of synthetic roll-along to band-pass filtered data for MASW.

10.5. Nenana Valley Outwash Plain, Alaska [5]

Figure A4: Identified glacial outwash plain located in Nenana Valley, Alaska [5].

10.6. Data Availability Statement

Contact CSM Department of Geophysics for access to the 2022 CSM Geophysics Field Camp CR 22 gravity [7] and deep reflection seismic array [8] surveys, 2025 CSM Geophysics Field Camp CR 22 refraction seismic array survey [11], and 2022 CSM Geophysics Field Camp abstracts [9] [17].