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Details of ancient fluvial systems: capturing 3-D architecture and testing depositional models with UAVs, photogrammetry, and fieldwork

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Fluvial sandstones serve as critical reservoirs in petroleum basins throughout the world. Although highly productive, these units can be challenging owing to their complex and variable nature. Outcrops of fluvial strata have long served as critical sources of information on sandstone variability, allowing scientists to better predict reservoir properties in the subsurface. However, outcrop studies are typically constrained to two-dimensional, vertical exposures, which do not expose changes in sandstone body morphology in the third dimension (into- and out-of- the outcrop plane). In those rare locations where all three dimensions of sandstone outcrops are present, current sedimentary measuring techniques struggle to incorporate the additional data and present the information in a comprehensive manner. Here, we have focused on utilizing emerging technologies to create improved stratigraphic models of fluvial outcrops and provide quantitative reconstructions of sandstone body dimensions. These insights can help inform petroleum models and provide improved depositional reconstructions of distributive fluvial systems. The funding provided by the PRF New Directions grant was instrumental in allowing us (PI and students) to undertake this exciting new research.

We examined the Salt Wash Member of the Morrison Formation (Jurassic), which is exposed in central Utah, near the town of Green River (Fig. 1). The Salt Wash Member is arguably one of the best ancient examples of a distributive fluvial system (DFS) – an ancient river system that emanated from the Cordillera to the west and ‘fanned-out’ into the adjacent basin. DFS depositional models are new and currently focus on changes over large scales (~100 km); features at the 1-10 km scale have yet to be characterized. We focused on a relatively unique area of the Salt Wash Member that is exposed in three dimensions, in both vertical and plan-view outcrops.

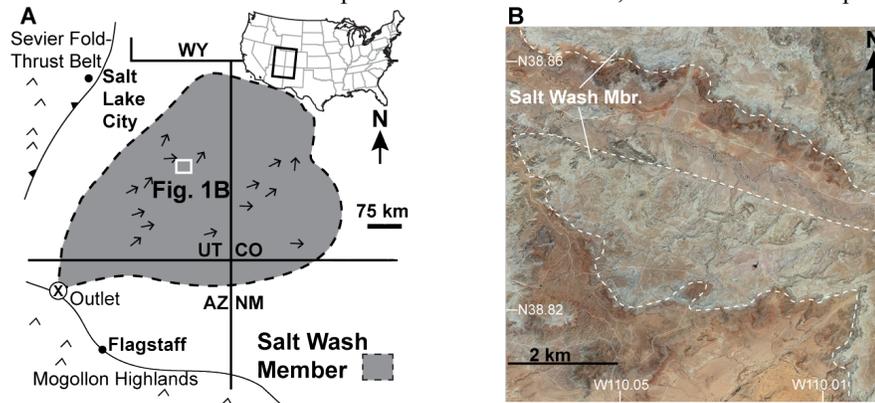


Figure 1. Salt Wash Member of the Morrison Formation. A) The Salt Wash Member was deposited by the Jurassic Salt Wash DFS (shaded area); figure modified from Owen et al. (2015c). Arrows depict generalized paleocurrent directions. Location of Part B is shown. B) Plan view of Salt Wash Member outcrop exposures. The study area is located approximately 20 km southeast of the town of Green River, Utah. Exposures of the Salt Wash Member are highlighted with the dotted lines. Image from GoogleEarth.

To capture the three-dimensional nature of the sandstone exposures we used a camera-mounted unmanned aerial vehicle (UAV, or drone) to collect thousands of low-altitude images that were then processed using Structure-from-Motion (SfM) photogrammetry to create geolocated three dimensional point clouds, digital surface models and orthomosaics. SfM uses multiple overlapping images of a feature to reconstruct numerous key points of the feature in three dimensional space. We spent much of our first year testing this technique, developing optimal workflows, and assessing the resolution and accuracy of this technique (2017). Our current research has been focused on examining a larger portion of the outcrop exposure in an effort to quantify the different sandstone bodies (Fig. 2).

The UAV collected images at an altitude of 105 m (above local surface) and collected images with 80% lateral and longitudinal overlap, at a resolution of 3.4 cm/pixel. A total of 26 flights were flown to cover an ~ 10 km² area with > 5,000 digital images (Fig. 2).

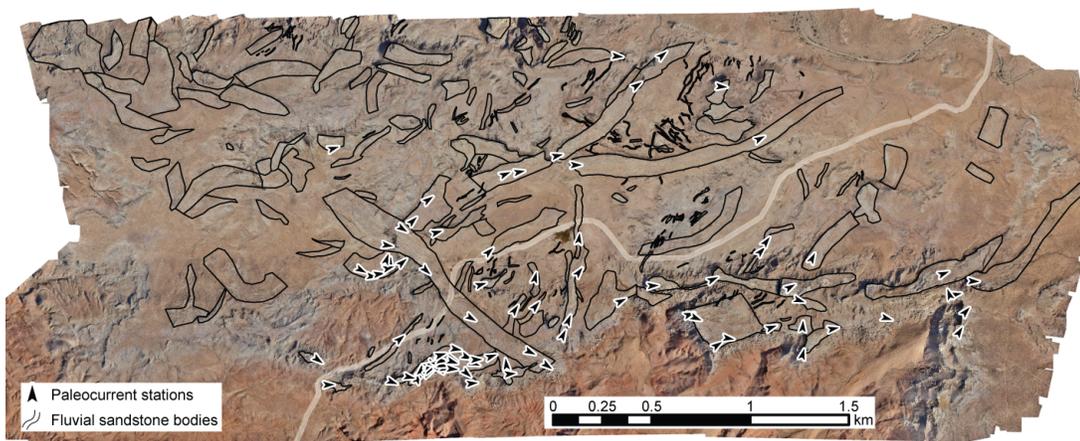


Figure 2. Plan-view orthomosaic of the Salt Wash Member in the study area. The orthomosaic was created using SfM and derived from over 5000 digital images collected by a UAV. Resolution of the image is roughly 3 cm/pixel. Fluvial sandstone bodies are outlined and paleocurrent stations shown. Each paleocurrent station (arrowhead) is the mean of 7-10 measurements in that location. White line is a road that crosses the area.

The sandstone bodies are tentatively classified into four groups based on their width and sinuosity. The different sandstones include: 1) very narrow sandstone bodies; 2) narrow sandstone bodies; 3) medium-width sandstone bodies; and 4) “other” sandstone bodies, which include eroded sandstone bodies and those with margins that are not exposed at the surface (Fig. 3).

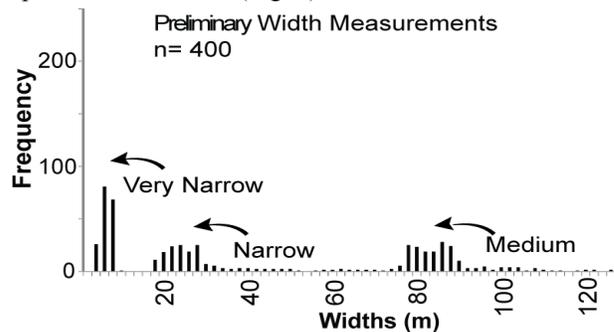


Figure 3. Preliminary width measurements of sandstone bodies in the study area. There appear to be at least 3 distinct classes based on sandstone-body width. These different sizes correspond to differing dimensions and styles of the original river systems.

The preliminary data from our study area suggests this portion of the DFS was occupied by several different fluvial system, each with its own width and sinuosity. However, additional measurements are needed to confirm these initial results and to correlate gross measurements with outcrop observations.

Thus far, two masters students and 3 undergraduate students have been supported as part of this project. Portions of this work have been published in a peer-reviewed journal and presented at several international geoscientific conferences. An additional manuscript is in review.