

# **PS Quantitative Outcrop Characterization of Incised Valley Fill Combining UAV-Based Photogrammetry and Traditional Geologic Field Methods, Kaiparowits Plateau, Southern Utah, USA\***

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## **Abstract**

A scalable, readily repeatable methodology for quantitative outcrop characterization has been developed combining Unmanned Aerial Vehicle (UAV) based photogrammetry with more typical field-based outcrop characterization techniques. The utility of this methodology is demonstrated in extracting high-resolution dimensional data from estuarine incised valley fill deposits exposed in the Cretaceous John Henry Member of the Straight Cliffs Formation in southern Utah, USA. While the use of photogrammetry to produce 3D outcrop models is not new to the geosciences, the increased availability of UAVs has improved our ability to efficiently collect high-resolution outcrop imagery necessary to develop these models. Spatially oriented outcrop models facilitate quantitative outcrop characterization from the bedding- to petroleum system-scale. Transgressive estuarine incised valley fills possess significant potential as hydrocarbon reservoirs in the subsurface, though the dynamic nature of tidal systems make them especially heterogeneous. The complex architectures expressed from the geobody- to reservoir-scale introduce substantial uncertainty to reservoir volume and performance prediction. Quantitative outcrop analog characterization provides dimensional data for geobodies and key surfaces required to improve subsurface reservoir predictions. A 3D outcrop model was produced using Structure from Motion (SfM) to combine overlapping aerial imagery and GPS data collected in the field. Decimeter-scale stratigraphic sections were then draped over the outcrop model, serving as the primary control points for an iterative process of 3D geologic interpretation (definition of geobodies and identification of key bounding surfaces). Dimensional data was extracted to quantify the thickness, aerial extent, stacking, and internal architecture of a laterally accreting mid-estuarine bar and multiple tidal channels. The thickness and lateral extent of key bounding surfaces were also measured. This data has been added to a dimensional database for paralic systems created as part of an ongoing research effort and will be used to inform future performance prediction simulations. Based on the internal architecture and stacking of geobodies within the incised valley fill we expect significant connectivity between channels and bars, where they overlap, and with the underlying sand-rich shoreface deposits. Internal shale drapes form the greatest potential for reservoir compartmentalization.

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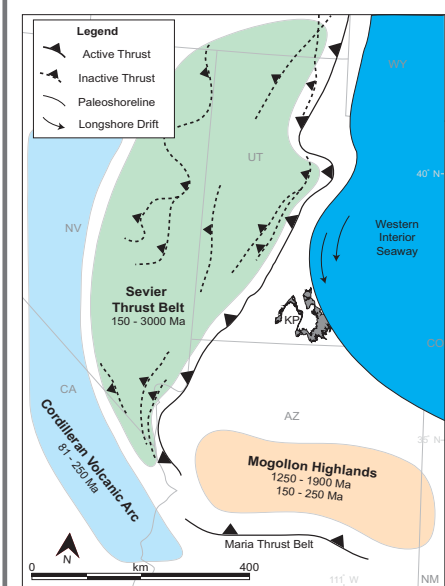
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## Objectives

- 1) Develop a 3D outcrop model of a preserved mid-estuarine bar combining Unmanned Aerial Vehicle (UAV) -based photogrammetry and traditional field-based outcrop characterization techniques.
- 2) Identify and describe the nature/extent of bounding surfaces which could influence the static and dynamic connectivity of a mid-estuarine bar and surrounding reservoir units.
- 3) Create a quantitative dataset which describes the facies architecture, transitions, and internal stacking from bed- to geobody-scale.

## Geologic Background



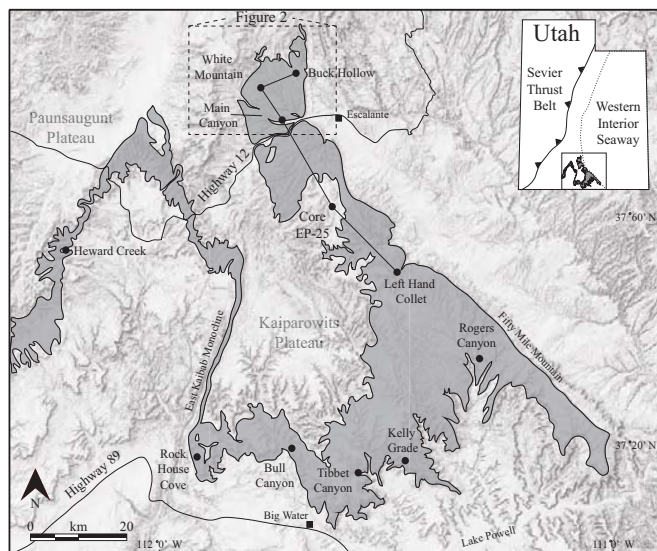
### Late Cretaceous Tectonics and Sedimentation

Turonian to early Campanian Straight Cliffs Formation was deposited in the retroarc foreland basin which developed in response to crustal loading of the Sevier Thrust Belt

In the Kaiparowits Plateau, the Straight Cliffs Formation records deposition of siliciclastic detritus derived from the Sevier fold and thrust belt, Mogollon Highlands, and Cordilleran Volcanic Arc carried by a northeast flowing distributary fluvial system (Lawton et al., 2003; Szwarc et al., 2014)

Complex interactions of this fluvial system with transgressive-regressive cyclicity of the Western Interior Seaway are captured in outcrops uplifted during the Cretaceous Laramide Orogeny

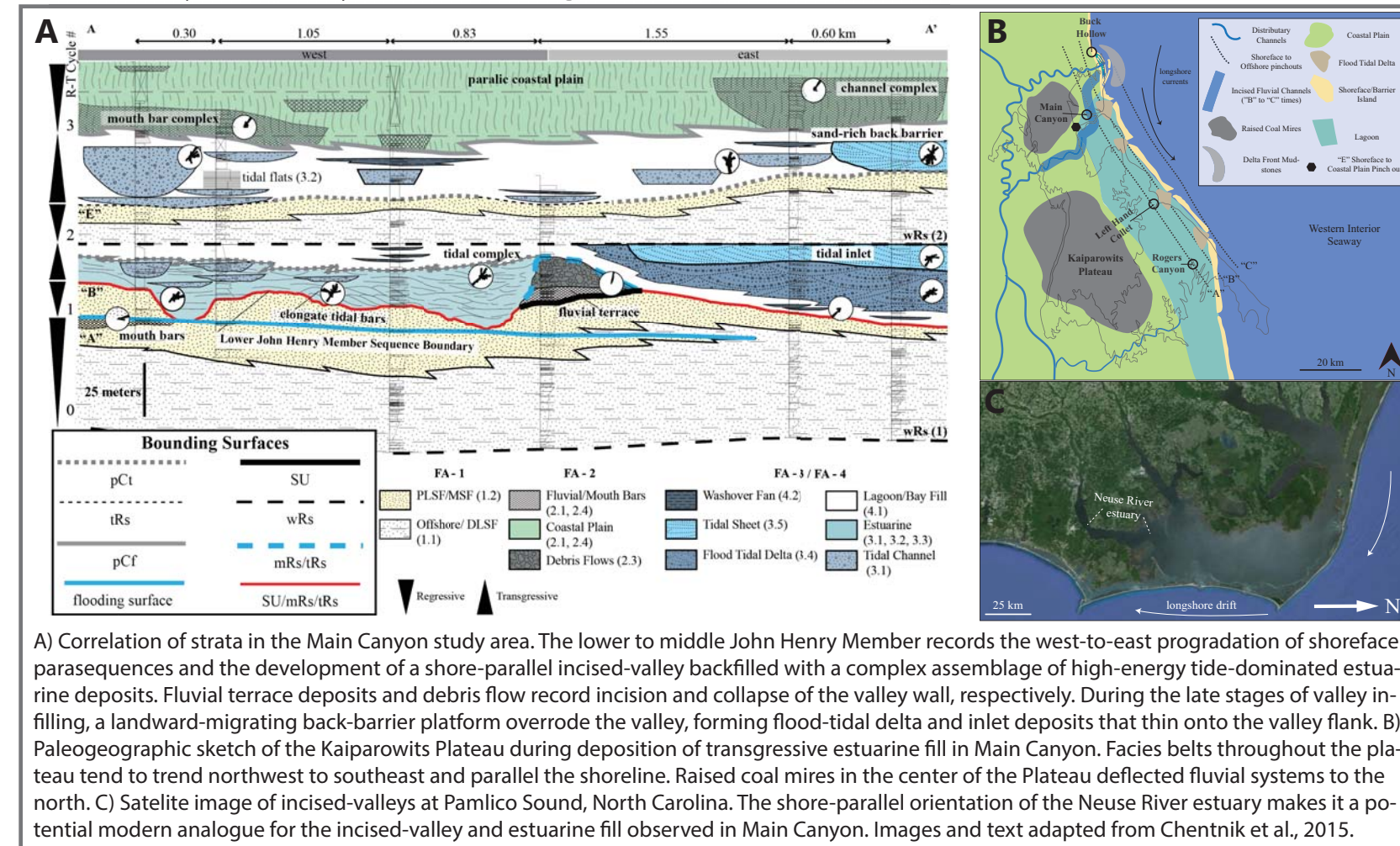
Left: Regional tectonic setting during the Late Cretaceous time. Szwarc et al (2014) used detrital zircon ages, sandstone composition data, and paleocurrent analysis to identify a pervasive SW to NE flowing axial fluvial system present throught deposition of the Straight Cliffs Formation.



Above Left: Map of the Kaiparowits Plateau with exposure of the Straight Cliffs Formation in dark grey, highlighting locations of past research by the Rocks2Models industry consortium. Fluvial strata transition to the NE-E across the Plateau into paralic coal bearing strata with zones of tidal influence documented in Tibbet Canyon and Kelly Grade. The eastern Plateau preserves shoreface and paralic strata with incised esturine valleys and fill exposed near Main Canyon in the north.

Above Right: The John Henry Member of the Straight Cliffs Formation consists of siliciclastic sandstone, mudstone, and coal divided into 7 shoreface successions (A-G) identified by Peterson (1969). These shoreface successions provide inportant stratigraphic context for interpretation of the complex depostis of the eastern Plateau. Evidence of transgressive estuarine fill of fluvially incised valleys above the A shoreface are most pronounced along Highway 12 and in Main Canyon, the primary study area for this research.

## Main Canyon Study Area: Stratigraphic Context



## Utility of Unmanned Aerial Vehicles (UAVs) for Outcrop-Based Research

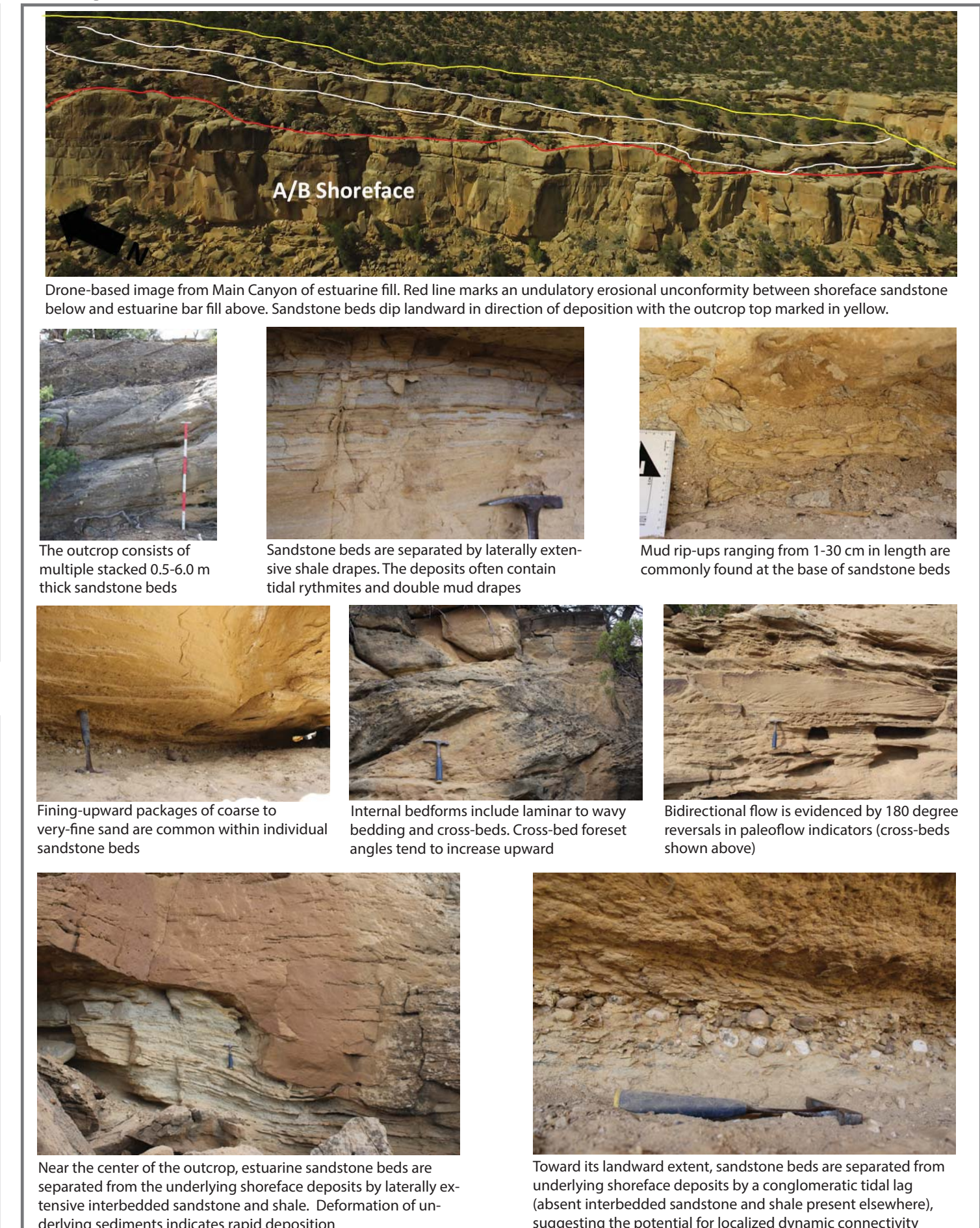


UAV-based photogrammetric models enhance outcrop characterization and interpretation by providing:

- 1) Increased ability to visualize otherwise inaccessible portions of the exposure
- 2) Added perspective at different scales of observation facilitated by the ability to rapidly zoom in and out
- 3) Myriad vantage points and false coloration to highlight geologic features
- 4) A framework for geospatial analysis and the quantitative interpretation of structural geometries and sedimentological architectures
- 5) A geological/geostatistical framework for development of dynamic flow models used to elucidate flow behavior

Text adapted from Jones et al. (2008). *Calibration and validation of reservoir models: the importance of high resolution, quantitative outcrop analogues*. Geological Society of London, Special Publications.

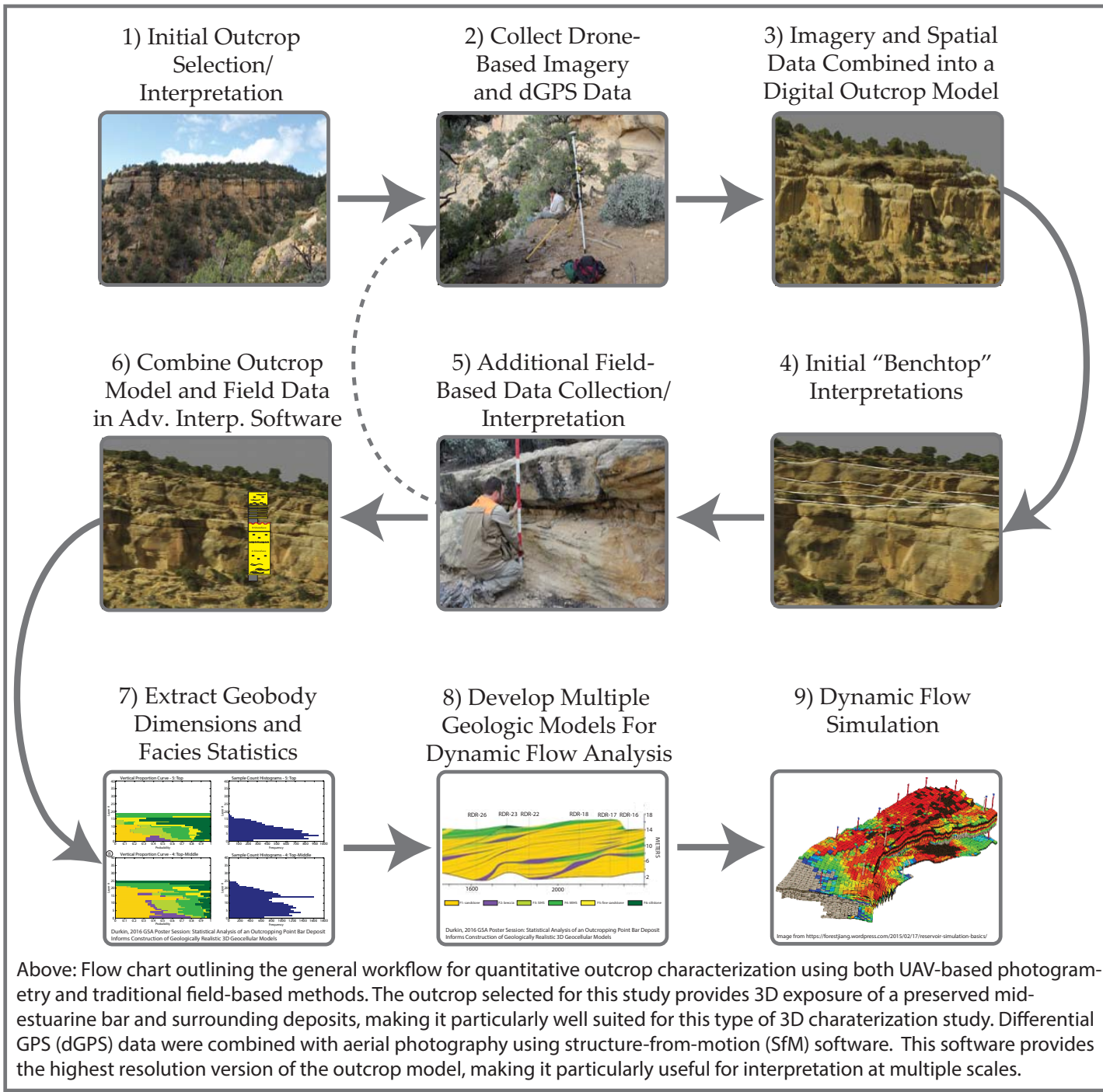
## Recognition of a Mid-Estuarine Bar in Outcrop



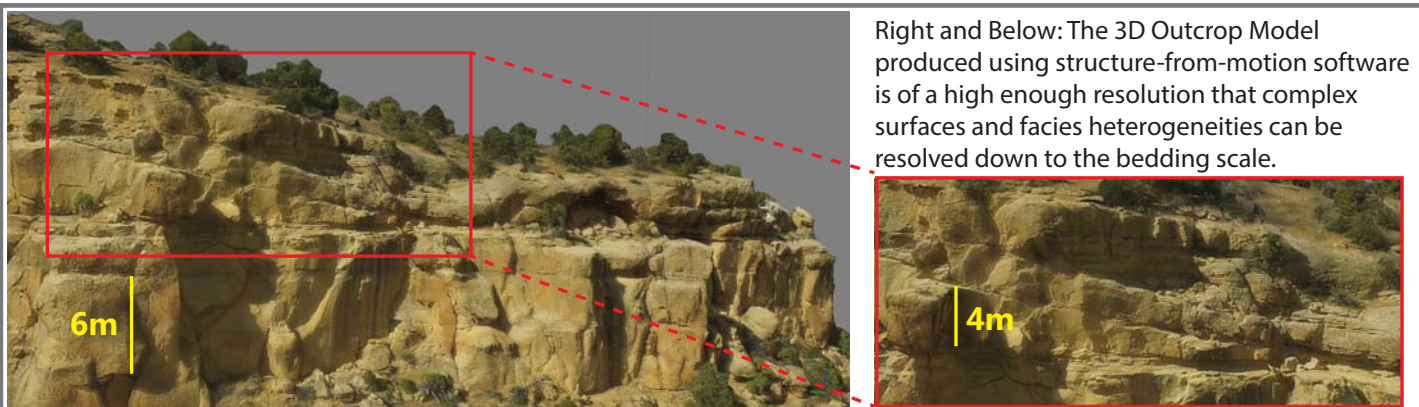
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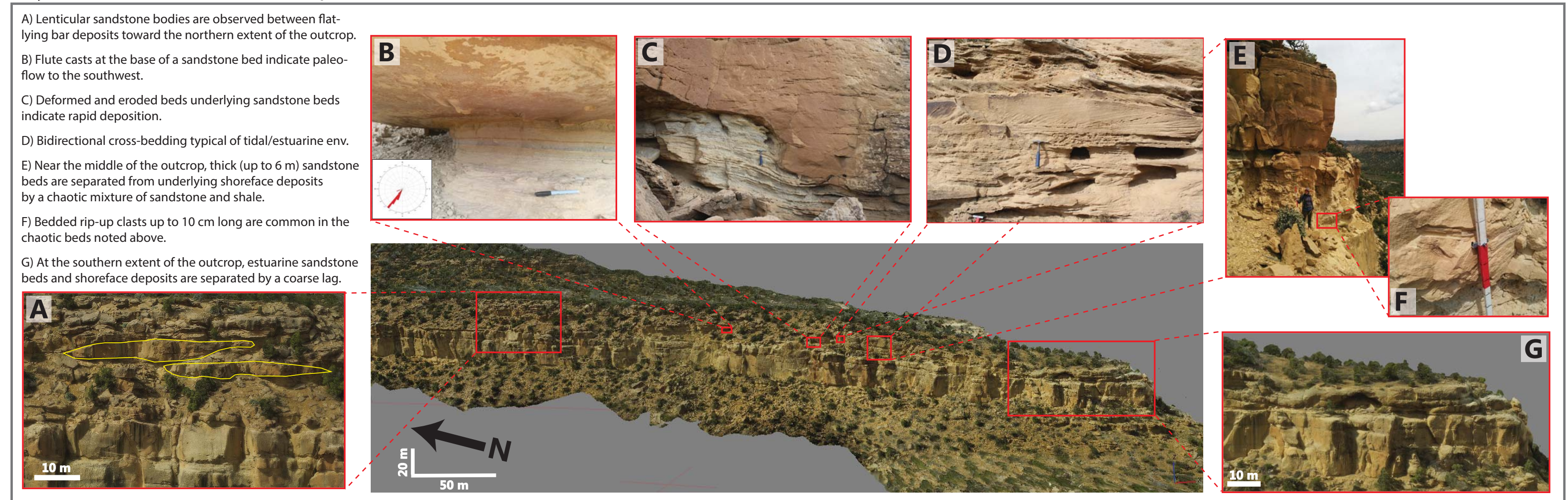
## Workflow



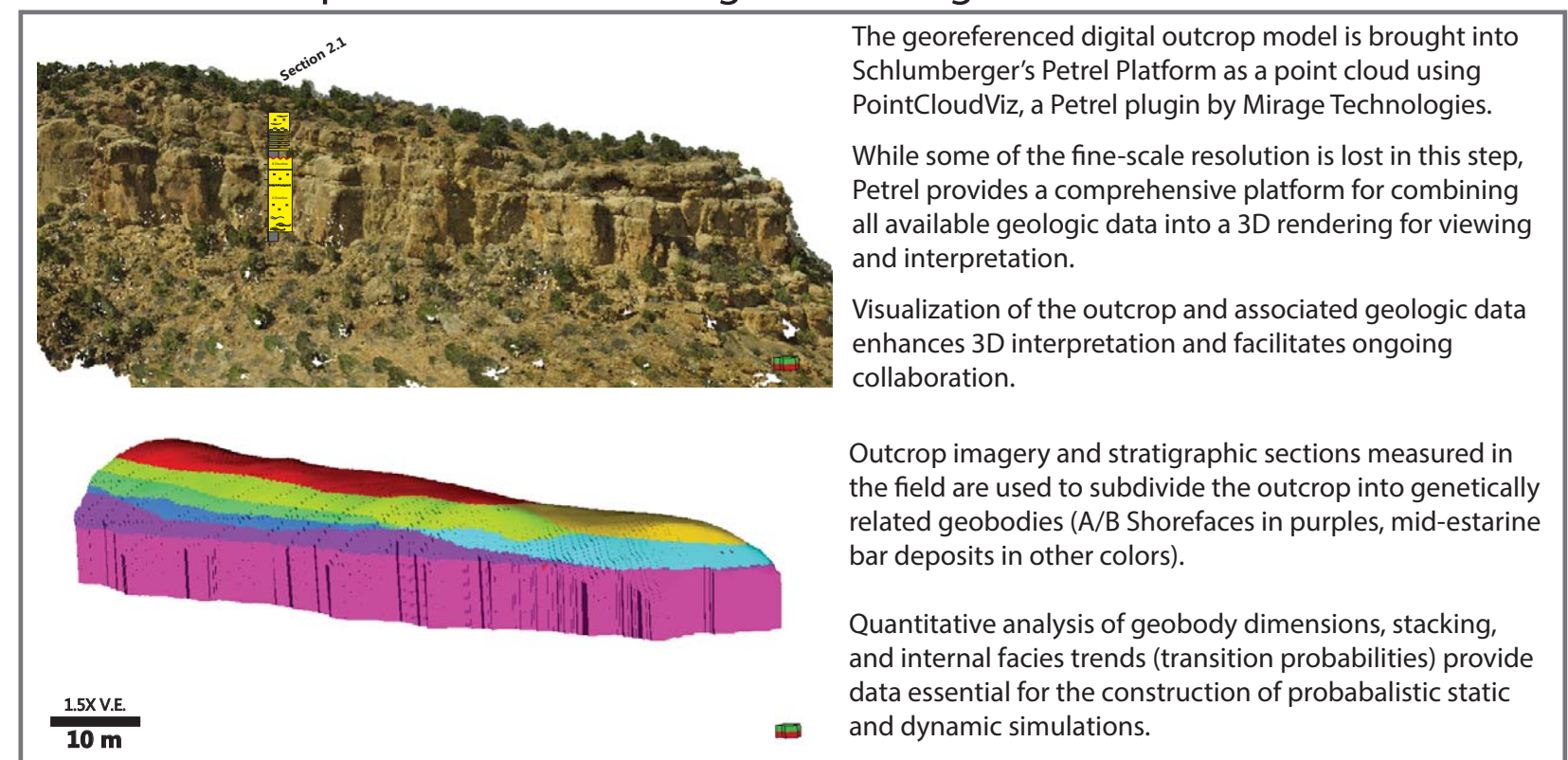
## Outcrop Model Resolution



## Key Features From The Outcrop



## Advanced Interpretation and Geologic Modeling



## Conclusions/Next Steps

- 1) A 3D outcrop model of a preserved mid-estuarine bar has been created, combining UAV-based photogrammetry and field-based geologic characterization.
- 2) Key characteristics of a preserved mid-estuarine bar include: stacked sandstone beds (approx. 130 m long and 3.5 m thick) separated by laterally extensive mudstones and shales (0.1 to 0.5 m thick), net-landward deposition, rip-up clasts at the base of sandstone geobodies, bidirectional tidal indicators, steepening upward trough-cross stratification, and fining upward sandstone packages.
- 3) Though generally shale draped, tidal lags within the lower bounding surface suggest the potential for localized connectivity with underlying shoreface deposits.
- 4) Future efforts include ongoing field characterization, quantification of geobody dimensions/facies architecture, and development of a probabalistic static model.

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