PS Assessing the Relationship Between Aeolian Bedforms and Hydraulic Properties in the Jurassic Navajo Sandstone in Central Utah for the Evaluation of CO_2 Sequestration*

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Abstract

The anthropogenic origin of global climate change via increased CO_2 emissions into the atmosphere is the general consensus by the scientific community and CO_2 sequestration (long-term storage within the subsurface) has been proposed as an option for mitigating the effects of this greenhouse gas. Reliable and long-term CO_2 storage requires a porous, saline aquifer, such as the Navajo Sandstone in central Utah, for viable CO_2 sequestration. Geometric patterns of aeolian bedforms and petrophysical data (hydraulic properties) were mapped through the upper portion of the Navajo Sandstone in order to evaluate it for CO_2 sequestration. 3D reconstructions of aeolian depositional facies and bedform geometries demonstrate a wide variety of dune types in the Navajo Sandstones.

By mapping the angle and direction of bounding surfaces and internal erosional surfaces within the cosets, several dune types were recorded. Both simple large dunes and compound dunes, which preserve smaller superimposed dunes migrating along lee slopes of larger dunes, were recognized and mapped. Bounding surfaces range from subhorizontal 1^{st} order surfaces to steeply dipping reactivation surfaces generated from shifting wind direction, superimposed dunes or migration of scour-pits located at the base of the lee slope. Finer-grained wind ripple laminations line 1^{st} and 2^{nd} order bounding surfaces and are found up to 50 cm thick. Well-sorted, medium-grained sandstones composed of grain flow sediments occupy the majority of the sediments between bounding surfaces. Laboratory measurements suggest that porosity measurements can range up to 5 fold between wind ripple and grain flow facies. Measurements collected in the field demonstrate that permeability ranges significantly as well. Variations in hydraulic properties mimic shifts in facies along bounding surfaces. Bounding surface geometries range from subhorizontal to sinuous in 2D and 3D and act as baffles within the Navajo Sandstone reservoir.

Bedform reconstructions, geometries and hydraulic properties collected from the outcrop act as inputs for geostatistical and, in turn, fluid flow models of CO_2 migration. Preliminary modeling of 2D CO_2 migration through sinuous cross-bedding bounding surfaces suggests that these baffles influence the amount of CO_2 stored as well as its direction of migration and migration pathways. These models enable predictions of potential CO_2 sequestration sites and potential areas with inefficient storage capacity.

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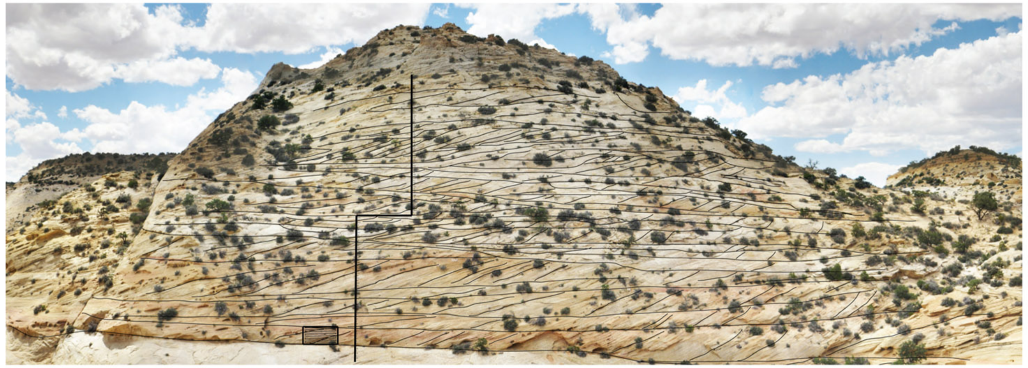
A Butte South B

B Alcove West C



C Alcove North D Alcove East E F

F G Butte East H

Photopans ofNavajo Sandstone outcrop near Devil's Canyon. Lines represent measured section locations. Lines with numbers indicate permeability measurements every 50 cm.
Each section is ~ 75 m long

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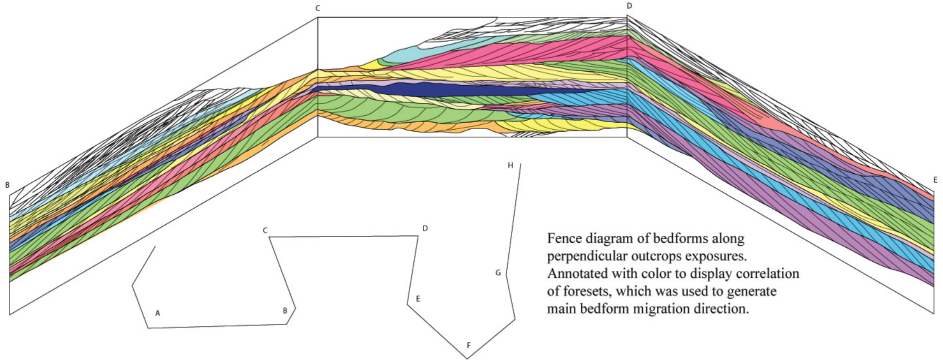
Outcrop Bedform Mapping



Fence diagram of bedforms along perpendicular outcrops exposures. Annotated with color to display correlation of foresets, which was used to generate main bedform migration direction.

Abstract

The anthropogenic origin of global climate change via increased CO2 emissions into the atmosphere is the general consensus by the scientific community and CO2 sequestration (long-term storage within the subsurface) has been proposed as an option for mitigating the effects of this greenhouse gas. Reliable and long-term CO2 storage requires a porous, saline aquifer, such as the Navajo Sandstone in central Utah, for viable CO2 sequestration. Geometric patterns of aeolian bedforms and petrophysical data (hydraulic properties) were mapped through the upper portion of the Navajo Sandstone in order to evaluate it for CO2 sequestration. 3D reconstructions of aeolian depositional facies and bedform geometries demonstrate a wide variety of dune types in the Navajo Sandstones. By mapping the angle and direction of bounding surfaces and internal erosional surfaces within the cosets, several dune types were recorded. Both simple large dunes and compound dunes, which preserve smaller superimposed dunes migrating along lee slopes of larger dunes, were recognized and mapped. Bounding surfaces range from subhorizontal 1st order surfaces to steeply dipping reactivation surfaces generated from shifting wind direction, superimposed dunes or migration of scour-pits located at the base of the lee slope. Finer-grained wind ripple laminations line 1st and 2nd order bounding surfaces and are found up to 50 cm thick. Well-sorted, medium-grained sandstones composed of grain flow sediments occupy the majority of the sediments between bounding surfaces. Laboratory measurements suggest that porosity measurements can range up to 5 fold between wind ripple and grain flow facies. Measurements collected in the field demonstrate that permeability ranges significantly as well. Variations in hydraulic properties mimic shifts in facies along bounding surfaces. Bounding surface geometries range from subhorizontal to sinuous in 2D and 3D and act as baffles within the Navajo Sandstone reservoir. Bedform reconstructions, geometries and hydraulic properties collected from the outcrop act as inputs for geostatistical and, in turn, fluid flow models of CO2 migration. Preliminary modeling of 2D CO2 migration through sinuous cross-bedding bounding surfaces suggests that these baffles influence the amount of CO2 stored as well as its direction of migration and migration pathways. These models enable predictions of potential CO2 sequestration sites and potential areas with inefficient storage capacity.

Research Questions

1) Is the Navajo Sandstone (a proxy for other aeolian systems) really homogeneous?

2) How do we characterize cross-bedding structures and bedforms?

3) Do the cross-bedding structures influence the prediction of CO2 migration and storage?

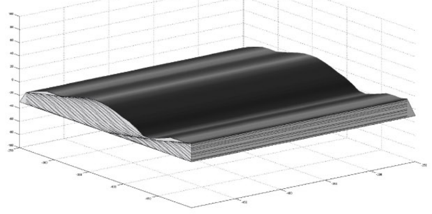
4) If so, what is the best method (e.g. upscaling) to include their effects efficiently in practice?

Facies

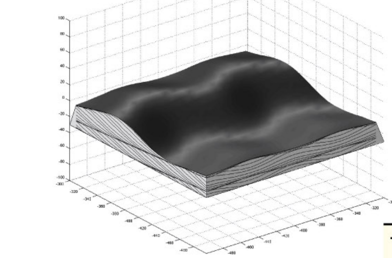
Facies	Lithology	Thickness	Context	k
Grain Flow (GF)	Fine to medium grained sandstone, well sorted, rounded	5-25 cm thick	Accounts for most of the sediments within aoelian cross beds	645
Wind Ripple Laminae (WRL)	Silt to very-fine grained sandstone	2 to 10 mm thick	Occurs along bedform surfaces, and thin up foreset boundary so that they are more common in the bottom half of the coset	418
Grain Flow with Coarse-grained lag (GF-CL)	Fine to medium grained sandstone with thin coarse grained lag at base	Coarse-grained lag - 2-7 mm thick	Found near base of coset along lower foreset	771
Grain Flow-Wind Ripple Lamina Mix (GF-WRL)	Alternations of thinly laminated GF and WRL	Each ~2-5 mm	Found near base of coset, along bounding surface	710
Wind Ripple Laminae with Coarse Lag (WRL-CL)	Silt and very fine sandstone with coarse-grained lags	Coarse-grained lag - 2-7 mm thick	Found at contact between foreset and basal coset bounding surface	788
Soft Sediment Deformation (SSD)	Fine to medium sandstone with some very fine and coarse grains	1-10 m	Found at base of section, not included in cross-bedding	1,113

Bedform Models

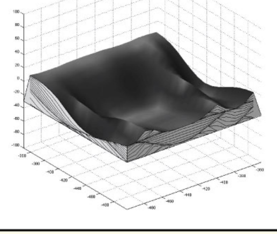
Type I



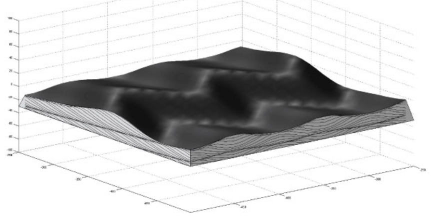
Type II



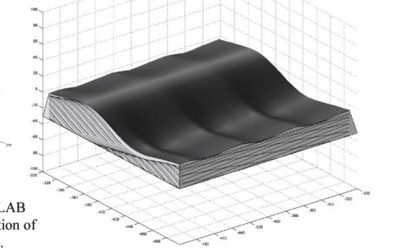
Type V

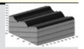
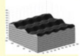
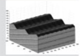
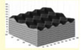
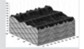


Type III



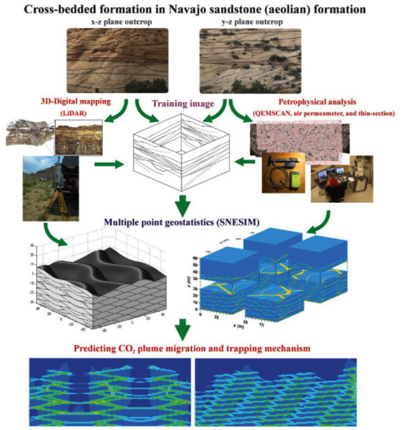
Type IV



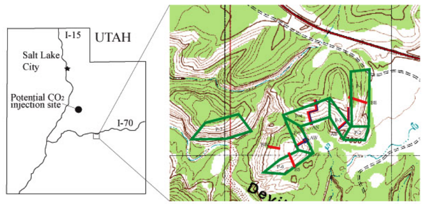
Type	Bedforms	Occurrence	
I	Compound. Large and small scale dunes migrating in same direction.	Very common through middle portion of the outcrop	
II	Concordant transverse bedforms gently dipping	Between type II and IV, gently dipping foresets are more common. Found throughout base of section.	
III	Compound. Small scale bedform migrating perpendicular to large scale migration direction.	Found in the middle of the section.	
IV	Concordant transverse bedforms gently dipping	Most common near the base of the section.	
V	Scours formed by large and small scale dunes migrating in the same direction.	Rare	

Basin of field observations, bedform models were generated in MATLAB (Rubin and Carter, 2005). Key parameters were direction and orientation of dipping foresets as well as size and shape (linear vs. sinuous) of dune.

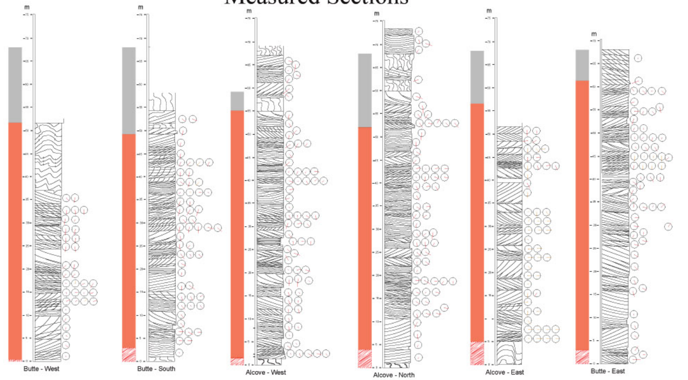
Methods



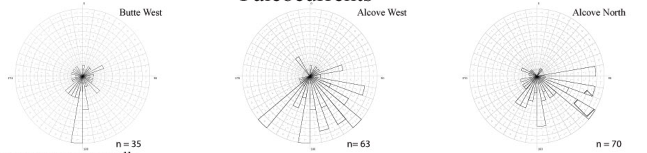
Location Map



Measured Sections

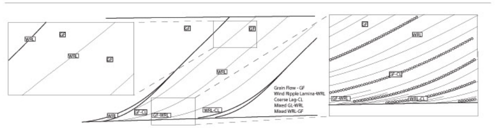


Paleocurrents



Paleocurrents are generally oriented to the south-southeast with minor southwest influences.

Detailed facies schematic displaying relationship between wind ripple laminae, grain flow and coarse-grained lags.



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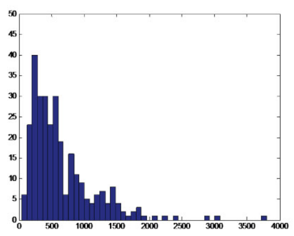
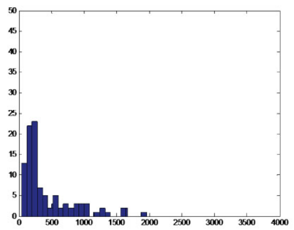
Permeability Histograms

Grain Flow



N : 296
Mean : 644.5
Min : 62.6
Max : 3,721.5
Stdev : 511.8

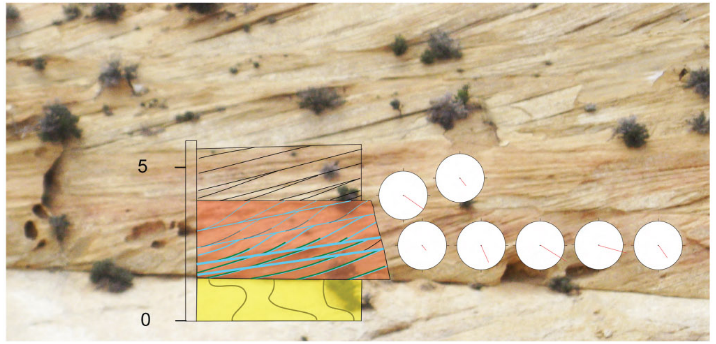
Wind Ripple Laminations



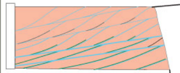
N : 100
Mean : 418.3
Min : 56.8
Max : 1,924.0
Stdev : 392.4

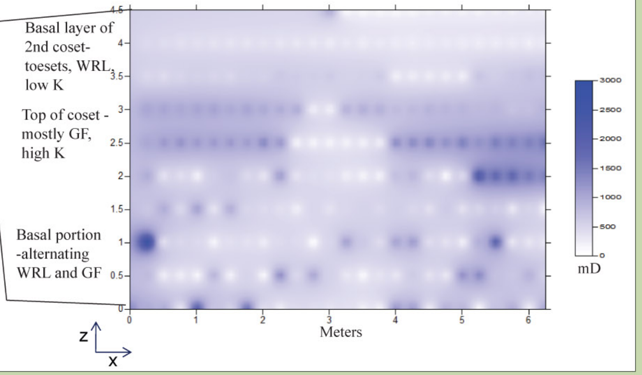
Histograms of permeability data (mD)

Permeability Grid



Grain Flow — Coarse grained lag — Wind ripple Laminations — Soft Sediment Deformation



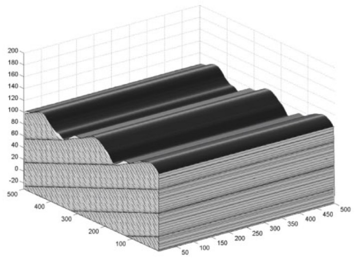


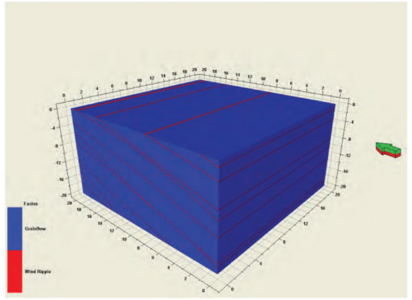
N : 240
dx : 0.25m
dz : 0.5m
Mean : 610.8 mD
Min : 33.8 mD
Max : 2,771.4 mD
Stdev : 463.7 mD

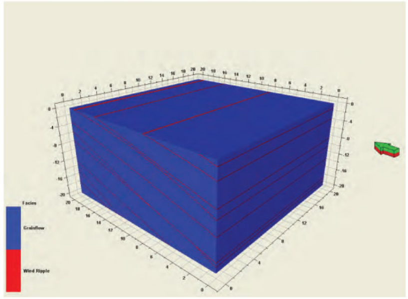
Spatial display of permeability data in grid above. Measurements were collected every 25 cm.

Geostatistics/Modeling Results

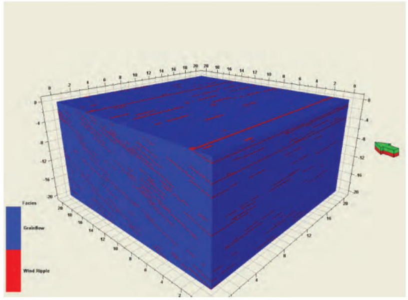
Type 1 Bedform





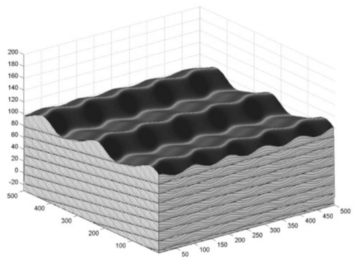


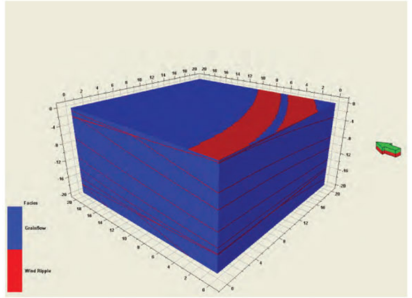
Training Image



Realization 1

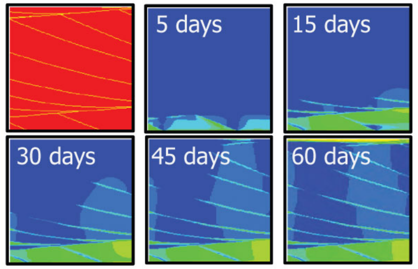
Type 2 Bedform

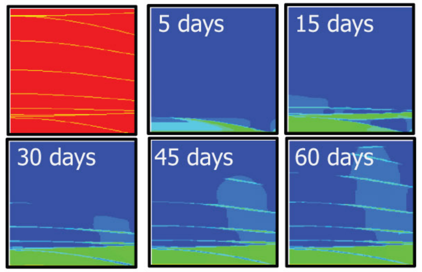


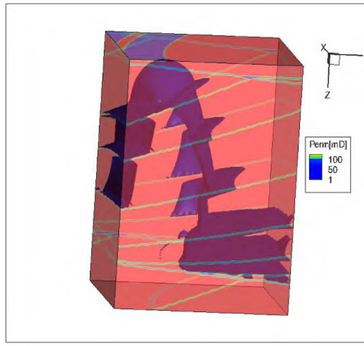


Geostatistical framework generated using MATLAB bedform model. Grid size influenced thin layers of wind ripple lamination. A delicate balance was formed between large grid sizes, which generated leakage points and the ability to shrink the grid size due to computational constraints.

Fluid Flow Modeling Results







Left: Snap-shots of supercritical CO_2 plume distribution at the two cross-section, indicating that the laminar structures in the aeolian cross-bedded formation significantly affect CO_2 plume distribution.

Above: 3D distribution aeolian laminar structures in cross-bedded formation and the isosurface of 0.1 CO_2 saturation fronts. Again, CO_2 plume distribution is not uniform instead the shows the directional flow pattern.

Conclusions

1) Is the Navajo Sandstone (a proxy for other aeolian systems) really homogeneous?
No! There are at least three distinct lithofacies that combine to form 6 different combinations. Wind ripple laminations are located along cosets and reactivation surfaces, especially near the toeset of the cross-bed, are finer grained and have lower permeabilities. Grain flow deposits account for a majority of the sediment within an aeolian bedform and are quite homogeneous. Coarse-grained lags are associated with both wind ripple laminations and grain flow deposits. While each facies deposited display different permeabilities, but the discrepancy is not as significant as predicted.

2) How do we characterize cross-bedding structures and bedforms?
The main parameters that influence cross-bedding structure are the directions of migration of both large-scale dunes and smaller dunes that migrate on top of dunes. Additionally, the wavelength of both dune sets and paleogeomorphology (linear vs. sinuous) of the dune affect the resulting cross-bedding.

3) Do the cross-bedding structures influence the prediction of CO2 migration and storage?
Yes, according to the models, CO2 plume migration is not uniform and follows wind ripple laminations and reactivation surfaces updip. The resulting plume moves laterally in accordance with the foresets and it migrates towards the surface.

4) If so, what is the best method (e.g. upscaling) to include their effects efficiently in practice?

Future Work

(1) Examine the dimensional effect on CO2 plume migration by comparing CO2 plume migration on 3D and 2D model domains.
(2) Conduct sensitivity studies understating CO2 plume behavior will be performed varying the parameters of cross-bedded formations.
(3) Evaluate upscaled permeability, relative permeability, and capillary pressure in cross-bedded formations.

Acknowledgements

We would like to thank the Utah Geologic Survey and the Southwest Regional Partnership for funding the project.

References

Rubin, D.M. and Carter, C.L., 2005, Bedforms 4.0: MATLAB Code for Simulating Bedforms and Cross-Bedding: USGS Open-File Report 2005-1272, v. 1., 13 p.