PS Facies Reconstruction of the Ingleside and Casper Formations: a Mixed Carbonate-Siliciclastic System*

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Abstract

The mixed carbonate-siliciclastic succession of the Pennsylvanian-Permian Ingleside and Casper Formations were deposited along the flanks of the Ancestral Front Range because of Late Paleozoic tectonism and eustatic sea level changes. Extending from central Colorado to southeastern Wyoming, the Ingleside and Casper Formations are composed of carbonate intervals representing relative sea level rises and siliciclastic intervals representing relative sea level falls. Outcrop and drill core data from the Ingleside and Casper Formations were combined to measure fourteen stratigraphic sections. A north-south transect of the measured sections extends from Albany, Wyoming south to Boulder, Colorado. East-west transects extend within Albany, Wyoming and from Larimer, Colorado east to Welds, Colorado. General thickness of the formations increases towards the north and east. Stratigraphic intervals vary laterally from intervening carbonates and siliciclastics in the north to pure sandstones in the south. Deepening upwards carbonate facies transitioning from grainstones to mudstones represent a marine environment. Siliciclastic facies transitioning from shallow-marine massive sandstones to eolian cross-bedded sandstones represent an increasingly arid environment. Laterally continuous shale stringers lie adjacent to shelf carbonates and shoreface cross-bedded sandstones. Pure carbonate or siliciclastic units are rare, with siliciclastic grains observed in carbonate beds and carbonate components observed in siliciclastic beds. Mixing of the two sediment components indicates a constantly active carbonate factory. The model explaining carbonate-siliciclastic mixing in this system therefore differs from the common reciprocal sedimentation model, which suggests the complete cutoff of carbonate production during lowstand periods. The results of this study can be used to produce an idealized depositional model to facilitate field recognition of an environment that consists of an eolian dune field extending into a siliciclastic foreshore, a transitional shoreface, and an offshore carbonate ramp. This model will contain regressive siliciclastic facies and transgressive carbonate facies, with eolian sandstones representing maximum regressions and basinal shales representing maximum transgressions. Proximal eolian sandstones have been productive in the Casper Formation and would hold the maximum reservoir potential in such a system because of high intergranular porosities and permeability.

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Abstract

The mixed carbonate-siliciclastic succession of the Pennsylvanian-Permian Ingleside and Casper Formations were deposited along the flanks of the Ancestral Front Range as a result of Late Paleozoic tectonism and eustatic sea level changes. Extending from central Colorado to southeastern Wyoming, the Ingleside and Casper Formations are composed of carbonate intervals representing relative sea level rises and siliciclastic intervals representing relative sea level falls.
Outcrop and drill core data from the Ingleside and Casper Formations were combined to measure thirteen stratigraphic sections. A northeast-southwest transect of the measured sections extends from Albany, Wyoming south to Boulder, Colorado. East-west transects extend within Albany, Wyoming and from Larimer, Colorado east to Welds, Colorado. Thickness of the formations increases towards the north and east. Stratigraphic intervals vary laterally from intervening carbonates and siliciclastics in the north to pure sandstones in the south. Deepening upwards carbonate facies transitioning from grainstones to mudstones represent a marine environment. Siliciclastic facies transitioning from shallow-marine massive sandstones to eolian cross-bedded sandstones represent an increasingly arid environment. Laterally continuous shale stringers lie adjacent to shelf carbonates and shoreface to foreshore sandstones. Pure carbonate or siliciclastic units are rare, with siliciclastic grains observed in carbonate beds and carbonate components observed in siliciclastic beds.
The results of this study can be used to produce an idealized depositional model to facilitate field recognition of an environment that consists of an eolian dune field extending into a siliciclastic foreshore, a transitional shoreface, and an offshore carbonate ramp. This model will contain regressive siliciclastic facies and transgressive carbonate facies, with eolian sandstones representing maximum regressions and carbonate mudstones representing maximum transgressions. Proximal eolian sandstones have been productive in the Casper Formation and would hold the maximum reservoir potential in such a system. The sandstones in such systems would likely be cemented and result in tight reservoirs.

GEOLOGICAL BACKGROUND

The Ancestral Rocky Mountain deformation along western Laurentia occurred as a result of intercontinental stresses associated with the subduction of the western mnargin of Laurentia beneath Gondwana.

The Ancestral Front Range Highland extended from the present-day Sangre de Cristo Mountains in southern Colorado to the present-day Sierra Madre in south-central Wyoming.

Synchronous with the tectonism, the Late Paleozoic was a time of southern hemisphere Gondwanaland glaciation.Global icehouse conditions and eustatic sea level changes led to deposition of cyclic stratal sequences throughout the western United States.

Adjacent to the Ancestral Front Range Highland lay a shallow-marine basin wherein the Pennsylvanian seas transgressed from the north and east.

The advancing sea during the Late Pennsylvanian resulted in deposition of the sandstone and interfingering carbonate units of the Casper and Ingleside Formations.

In Late Pennsylvanian and Early Permian times, the Ancestral Rocky Mountain uplift stabilized and slowly declined. This was accompanied by a fall in relative sea level and a gradual change in climate from humid with alternating semi-arid intervals to more arid conditions. Climate at this time resulted in deposition of cross-bedded, eolian sandstones that make up the upper parts of the Ingleside and Casper Formations.

Study Area extended from Colorado to south-east Wyoming, along the eastern flanks of the Front Range.

Locations of studied outcrop and drill core sections
OUTCROP SECTIONS
DRILL CORE SECTIONS

OBJECTIVES

Develop a detailed depositional model for the Pennsylvanian-Permian Ingleside and Casper Formations in order to predict carbonate production and sandstone distribution patterns in this sedimentary system

Determine how sea level changes influences this system and could influence reservoir geometries in similar mixed systems

Identify sources of the sandstones that make up the Ingleside Formation using detrital zircon geochronology

FACIES ASSOCIATIONS

Eolian Sandstones

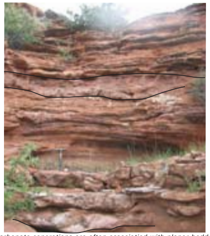
Cross beds displaying translatent cross stratification

Flat bed wind ripples

Trough Cross Beds in core sections

- Trough cross-bedded sandstones showing high angle dips and climbing translatent stratification
- Ripple laminated sandstones

Foreshore Deposits



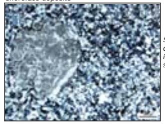
Carbonate concretions are often associatied with planar bedded sandstones

Climbing ripples occur in association with planar bedded sandstones

- Planar bedded sandstones showing horizontal laminations in some places
- Ripple laminated sandstones
- Massive sandstone
- Discontinuous oolitic carbonate beds

Shoreface Deposits

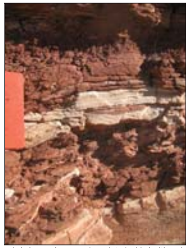
Lenticular wedges of tabular corssbedded sandstones define the shoreface deposits



Significant carbonate componentsare observed in a cross bedded sandstone deposit

- Tabular cross-bedded sandstones displaying horizontal laminations in some places and admixtures of carbonate grains
- Discontinuous conglomeratic sandstone beds, quartz and feldspar rich
- Massive, bioturbated sandstones
- Discontinuous oolitic carbonate beds with siliciclastic components

Shallow Marine Shales

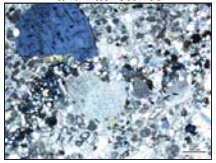


Dark red shales are in some places interbedded with carbonate mud or massive sandstone beds

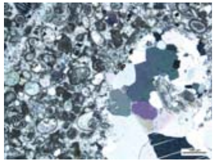
Carbonate concretions are often observed in association with shale beds

- Dark red, horizontally bedded siliciclastic mudstones
- Massive bioturbated sandstones
- Ripple laminated sandstones displaying climbing ripples

Offshore Carbonate Grainstones and Packstones



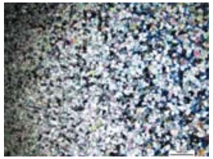
High siliciclastic components are commonly observed in fossiliferous carbonates



Oolitic packstone with some siliciclastic and fossil content, and an infilled vug.

- Fossiliferous carbonate packstones and grainstones include whole fossils and broken fragments of crinoids, brachiopods, bryozoans, gastropods, and foraminifera
- Siliciclastic carbonates are commonly observed and can contain up to 40% clastic components

Offshore Carbonate Mudstones

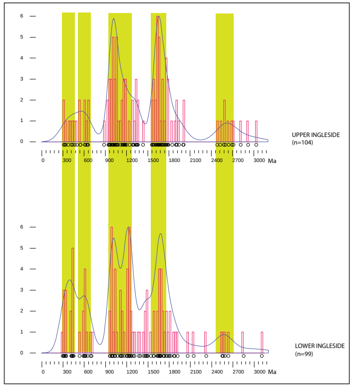


Carbonate mudstones are in some places heavily dolomitized. Here gradual compactionand decrease in pore spaces is observed in the carbonates

Infilled carbonate vugs, identified as birdseye fenestrae can range from a few mms toseveral cms in width

- Carbonate mudstones to wackestones, typically displaying isolated cavities that are partically or completely filled with cement or evaporite minerals

DETRITAL ZIRCON GEOCHRONOLOGY

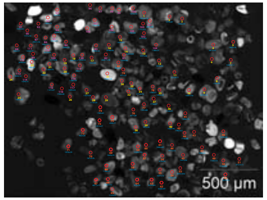


Sandstone samples were collected from the base and top of the Ingleside Formation at the Owl Canyon sections for zircon geochronology. U-Pb analyses of detrital zircons demonstrate that the provenance of sandstones varied significantly.

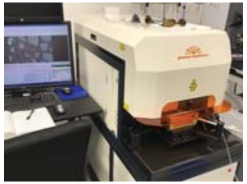
2400-2700 Ma and 1600-1800 Ma are dominant ages derived from the sandstones suggesting that the older grains were likely shed Precambrian basement of southwestern or midcontinent United States. In addition, the significant population of 1300-900 Ma grains suggests derivation from Grenville basement terrane.

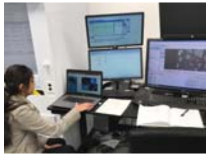
A small population of ages (7%) range between 380 and 480. The most likely source of grains for these ages is the Appalachian orogeny, which contains widespread Ordovician-Devonian igneous rocks

Detrial zircon geochronology data collected from various Paleozoic sandstone strata extending from the Grand Canyon to Utah by previous workers demonstrate that a small percentage of detritus that makes up the sandstones was derived from the Appalchian Orogen. Major river or wind systems were carrying sediments westward across the North American continent from the Appalachians have been suggested for the small population of 380-480 Ma zircons found in Pennsylvanian-Permian sandstones across the midcontinent United States.



Cathodoluminescence images of zircons from the uppermost sandstone sample show spots picked for zircon dating and ages obtained.





Cathodoluminescence images of zircons were used to pick spots that were dates using the Mass Spectrometer at the USGS in Denver

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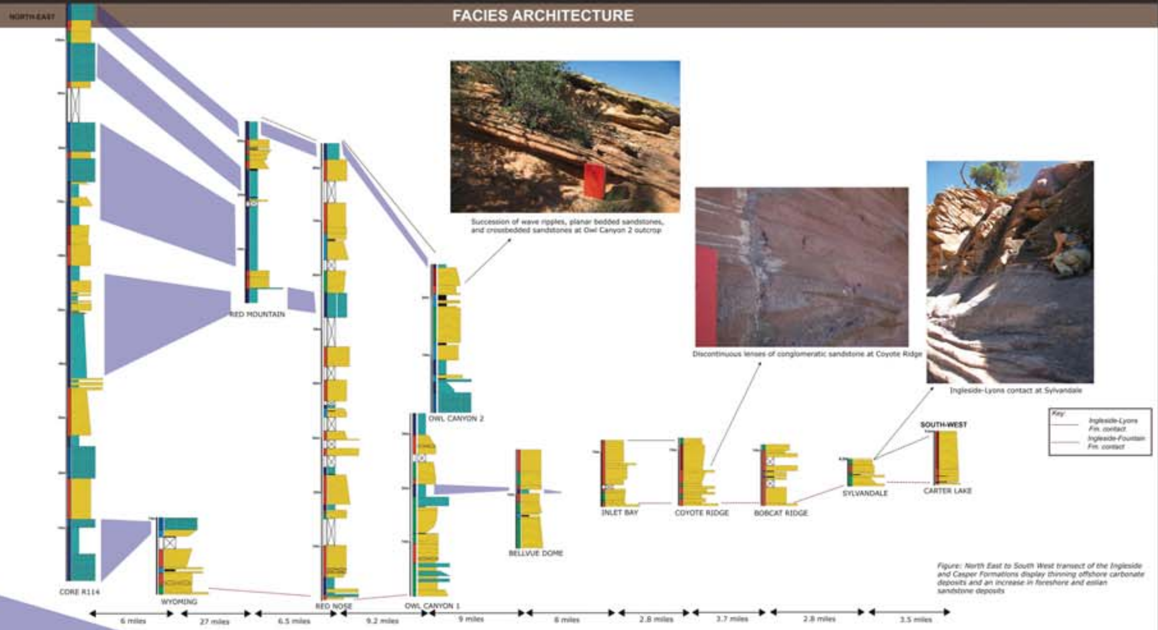
FACIES ARCHITECTURE



Succession of wave ripples, planar bedded sandstones, and crossbedded sandstones at Owl Canyon 2 outcrop

Discontinuous lenses of conglomeratic sandstone at Coyote Ridge

Ingleside-Lyons contact at Sylvandale

Figure: North East to South West transect of the Ingleside and Casper Formations display thinning offshore carbonate deposits and an increase in foreshore and eolian sandstone deposits

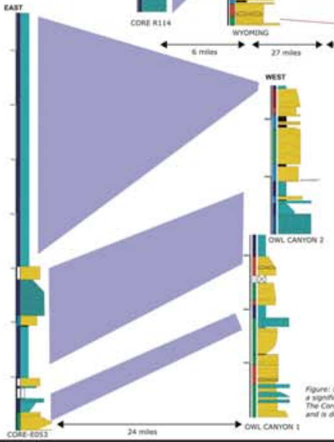


Figure: East to West transect of the Ingleside Formation show a significant thinning of offshore carbonate deposits. The Core-E053 section is the easternmost section investigated and is dominated by carbonate packstones and mudstones

Type section of the Ingleside Formation at Owl Canyon

Stratigraphy

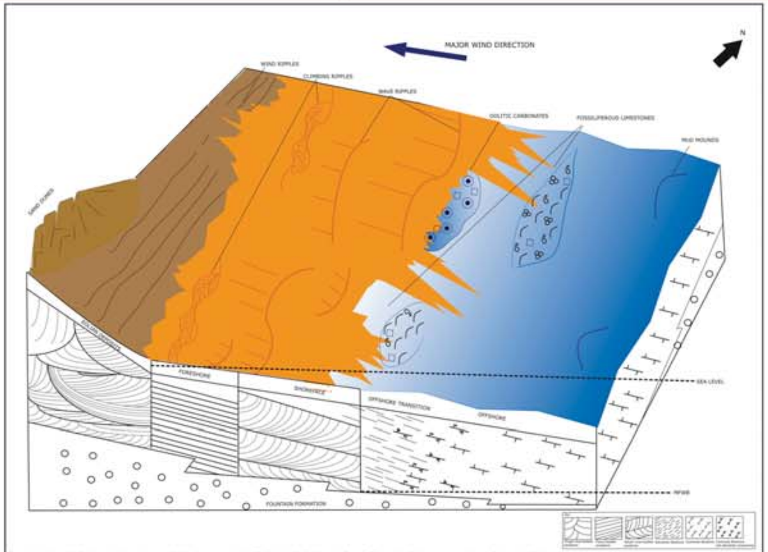
The base of the successions are generally identified by a decrease in grain size as the coarse grained sandstone deposits of the Fountain Formation grades into the fine grained, tabular cross-bedded sandstone deposits of the Ingleside and Casper Formations.

Offshore carbonate deposits range from fossiliferous grainstones and packstones to pure mudstones. Fossil content in the carbonate units increase towards the northeast. In general, carbonate units thin southwards and the last carbonate unit is observed at the Bellvue Dome section. South of Bellvue Dome, the sections are made up of shoreface and foreshore sandstones with some local, discontinuous eolian deposits.

Continuous shale stringers appear as distinctive markers within the succession, often extending for several miles and correlating across two or threesections.

The top of the successions are marked by a carbonate mudstone deposit that suggested to extend until the Owl Canyon section. South of Owl Canyon, the top of the successions are marked by either planar bedded or cross bedded sandstones.

Depositional Model



Depositional model for the mixed carbonate-siliciclastic system indentified in the Ingleside and Casper Formation. Paleocurrent analyses of cross-bedded sandstones led to the conclusion that major wind direction is towards the South-West. Oolitic and Fossiliferous carbonate occur as discontinuous units within the sections and are therefore charecterized as local deposits within the system. Ripples were studied wherever possible to disytinguish between wave or wind deposits. This system is charecterized by heavy mixing of carbonates and sandstones, with intermixing of sediments gradually decreasing from proximal to distal units.

The Ingleside and Casper Formations are likely a result of Pennsylvanian-Permian cyclothems that have been recorded throughout midcontinent North America.

Sea level rise and falls are likely the most important control on this mixed system. Generally, carbonate deposits are indicators of rising sea level and sandstone deposits are indicators of a more arid environment. Smaller scale sea level fluctuations are also identified within a continuous package of sandstone or carbonate units. Further studies will be done to distinguish influences of absolute sea level changes from relative sea level changes in the system.

Bioclastic grainstones and packstones commonly contain a high siliciclastic component and are overlain by sandstones, indicating that the two were deposited together until sand was dominant. In some places, sandstone units contain carbonate grains, likely as a result of secondary erosive processes. Howeverer, in a large part of the system carbonate production and siliciclastic seidmentation were found to be mutually exclusive.

Maximum regressions are in some places identified by conglomeratic sandstone deposits that occur as a result of erosion from adjacent highlands and local eolian dune systems. A wind system towards the north is suggested for the deposition of eolian dunes.

Maximum transgressions are in some places identified by deepening upward carbonate units that are rarely capped by thin shale deposits.

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Acknowledgements

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