[PS]Controls on Regional Distribution Patterns in Prolific Western Interior Shelf Sand Reservoirs: Tocito, El Vado and Gallup Sands of the San Juan Basin*

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Abstract

The Tocito Sandstone (TS) has been long proven to be a highly prolific reservoir system in the largest domestic onshore conventional gas basin in the U.S., the San Juan Basin (SJB). Similar shelf sand types associated with the pre-Tocito Gallup Sands and the more transgressive post-Tocito El Vado Sandstones have proven equally productive in recent wells resulting in a mini-boom of sorts in the SJB. Studies of the nature of all these shelf sand systems from outcrop, core, logs and seismic reveal thick (1-2 m) cycles of heterolithic wave-rippled, moderately to intensely bioturbated marine sands stacked in 8-12 m thick shelf sequences that are spatially extensive throughout the eastern as well as western SJB. Tocito sands in the western SJB outcrop are much more proximal in nature with tidal channel and bar facies associations predominate. Tocito intervals in the southeastern SJB outcrop show at least six sanding and thickening upward cycles composed of thinly-laminated, wave-rippled sands (Facies 3) interbedded with marine shales (Facies 1) progressing upward to moderately bioturbated, sand-rich parasequences (Facies 4). Shelf parasequences compensationally stack in near paleo-shoreline regions around Cabazon Peak northward to subsurface localities at least 140 km north of the paleoshoreline. Near-shore cycles near Cabazon Peak transition just 8 kilometers northward to contain extensive mega-hummocks (Facies 2). Analysis of hummocks in the Tocito sands suggest mega-swell waves up to 9 m high may have affected the paleo-shelf distributing sands widely across the region, and possibly contributed to the submarine erosion of up to 60 meters of material from the paleo-shelf. This regional study of SJB shelf reservoir sands is the first to quantify the regional nature of sand distribution, link super-greenhouse processes to potential shelfal submarine erosion and redistribution of sediments, and to examine prograding versus transgressive shelf reservoir systems.

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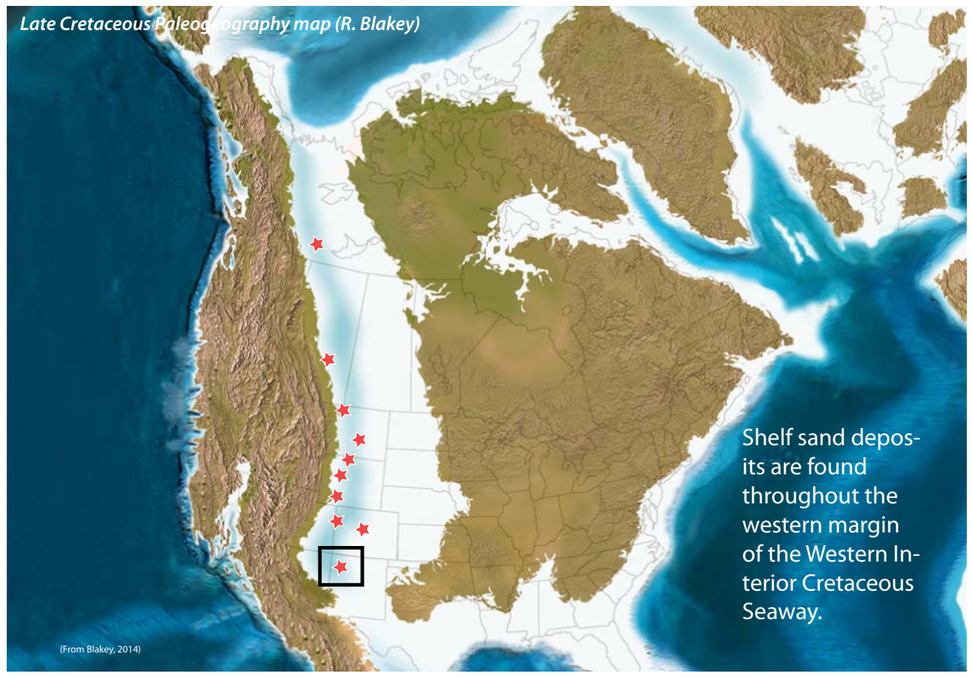
Problem

· The Tocito Sandstones and the El Vado Sandstones of the San Juan Basin, New Mexico are two of the most prolific units in one of the most prolific onshore hydrocarbon basins in the U.S., however their nature west to east across the basin is very poorly understood.
· Huge amounts of submarine erosion post-date deposition of the Gallup. The origin and implications of this erosion are poorly understood.
· Some of the largest hummocks in the world outcrop in the Tocito and El Vado intervals and can be used to discern the scale of wave processes that have affected the super-Greenhouse shelf of the Cenomanian-Turonian boundary time in the basin.
· How does the Tocito and El Vado vary lithologically across the basin and what are the implications for fracturability and production in these units?

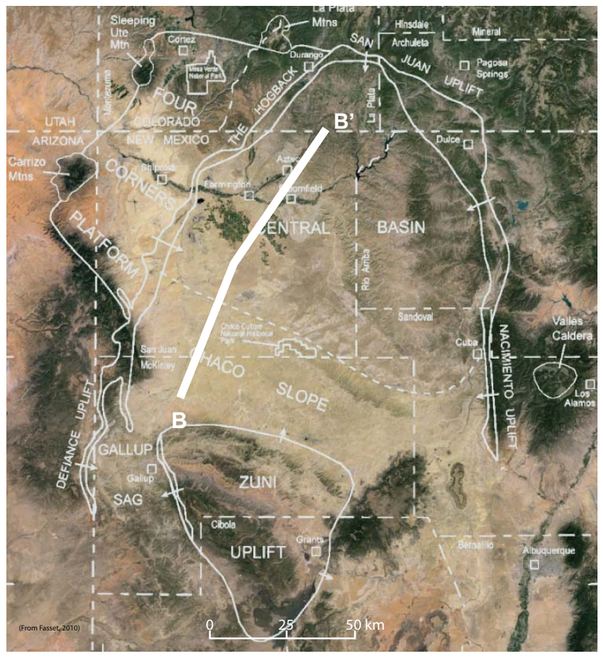
Key Questions

1. How are the Tocito and El Vado intervals distributed basin-wide, especially on the extreme margin? Where are the sands in these intervals coming from on the eastern basin margin and could the submarine forebulge influence deposition?
2. What are the temporal relationships between proximal and distal outcrops of the Tocito/Lower and Upper El Vado and Gallup sandstones?
3. Are large scale hummocks, documented in eastern Tocito outcrops, also present to the northwest and could the mega-storm processes responsible for their deposition have contributed to the nearly 120 m of submarine erosion found in the paleo-submarine shelf?
4. Can greenhouse climate storm systems help explain far-field deposition of Tocito sands?
5. Why do far northwestern Tocito outcrops look distal (heavily interbedded with shales) when Tocito outcrops at Hogback and Rattlesnake exhibit more proximal facies?
6. What are the controls on reservoir quality and distribution of porosity and permeability, and fracture properties in the Tocito/El Vado interval?

Western Interior Seaway Paleogeography

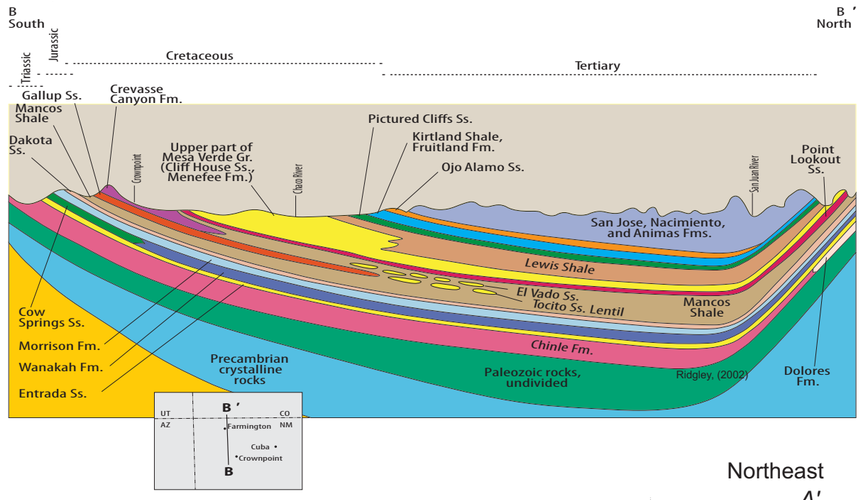


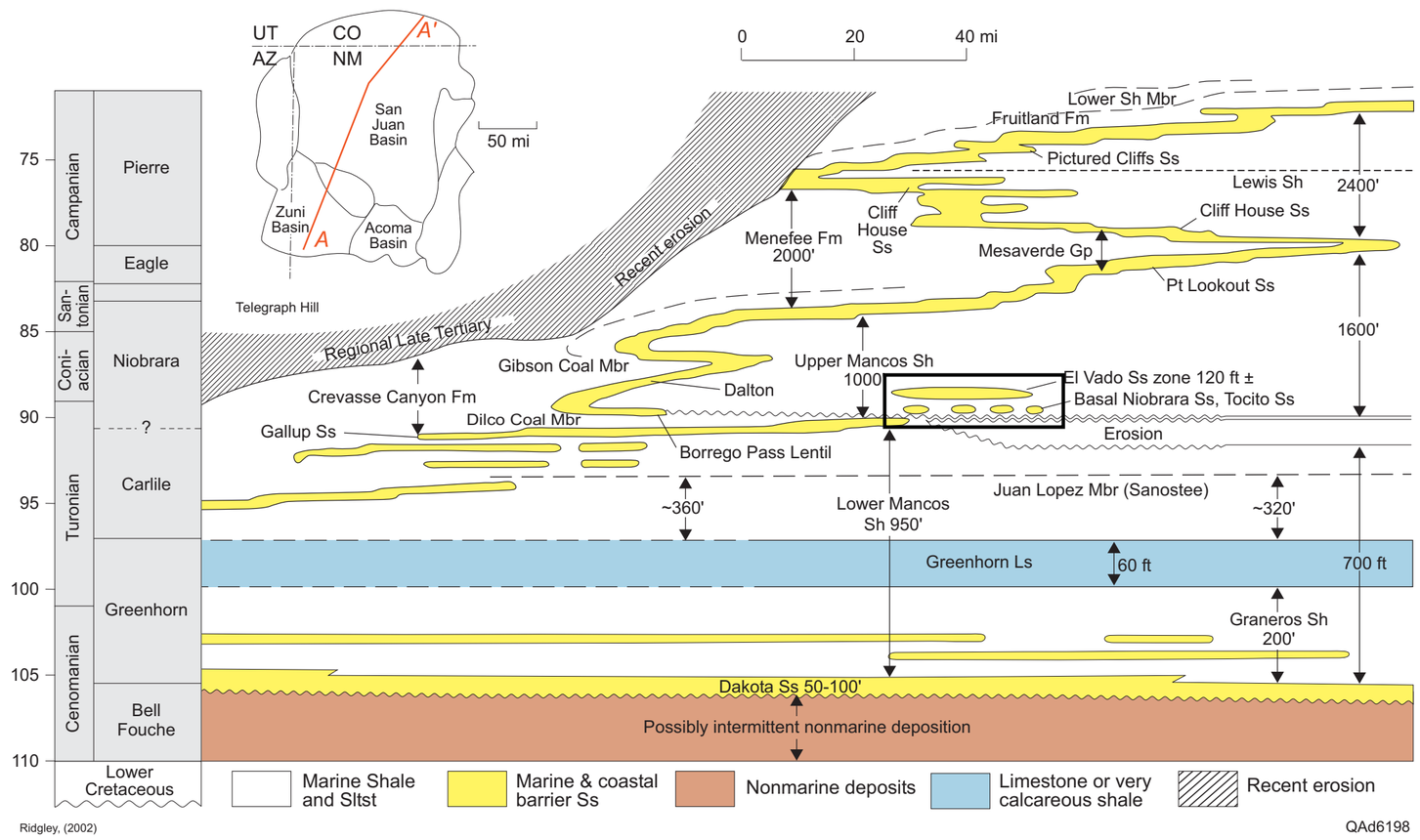
Stratigraphic and Structural Context



The San Juan Basin (SJB) is a predominantly Laramide basin extending over 20,000 sq miles in the northwest corner of New Mexico. It is a roughly circular, asymmetrical basin, the deepest portion towards the northern extent. It is bounded on the east by Nacimiento and Archuleta arch, on the north by the Hogback Monocline and the Four Corners platform and on the south by the Chaco slope/Zuni uplift. The SJB formation mechanism is a combination of active and passive processes (subsidence + surrounding uplift), typical of Western Interior basins such as the Piceance, Uinta, DJ and Powder River.

Stratigraphy of the basin is an exemplary case of transgressive and regressive sedimentation and large scale intertonguing of the Late Cretatceous sequence of sandstones in the Western Interior Seaway (WIS).





Outcrop Image of Isolated Sands

Many of these distal sand bodies have a highly heterolithic nature. They are often composed of multiple cycles of sanding up stratigraphy and are all deposited in dominantly subaqueous positions, sometime very long distances from the shoreline. The El Vado Sandstone, New Mexico is located some 120 km from its shoreline.

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Subsurface and Outcrop Examples

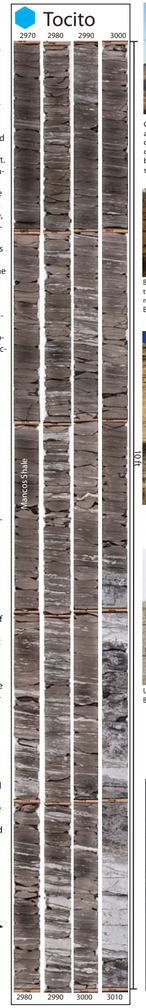
"Gallup" (U. El Vado)

The "Gallup" is the industry name for the recent conventional and unconventional target found above the Tocito in the subsurface. It is part of a regressive wedge of sandstones deposited in an overall transgressive environment. It consists of compensationally stacked parasequences made of interbedded black shale, silty mudstone, and fine-grained, carbonaceous, very bioturbated, fossiliferous sandstone. It has been correlated to the subsurface Upper El Vado unit. Typically observed core facies include wavy to hummocky cross-bedded sandstone, heavy bioturbation, natural fractures and oil coated fossils.

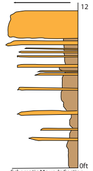
The Tocito Sandstones are the primary oil reservoir in the SJB, lie unconformably on multiple units and are encased above and below by marine mud.

The Tocito consists of shoreline-parallel elongate bodies that trend northwest-southeast. The facies differ from the surface to subsurface and basin-wide. Erosional boundaries at the base of Tocito packages (which merge from east to west) are related to changes in relative sea level. The Tocito has been interpreted as lowstand incised valleys, transgressive infill on the shelf ridge and a detached shoreface, and is the subject of much debate.

Tocito

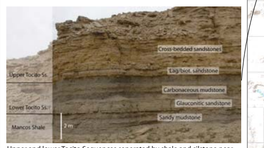


Outcrop of Tocito near Towuac, CO, known as Mounds. Sandstone at this locality is coarse grained, glauconitic, and contains caliche nodules. It is bounded above and below by Mancos marine shales and siltstones



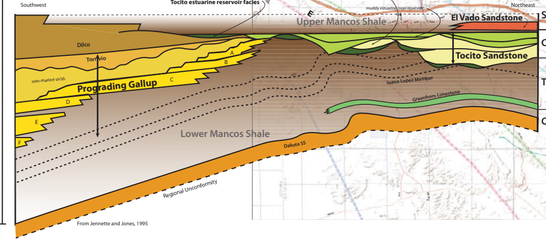
Below the Tocito in the Northwest is the poorly exposed Juana Lopez, a regional calcarenite that outcrops at El Vado dam and is important for correlation.

Tocito near the Hogback is medium grained, glauconitic, bioturbated with extensive cross-bedding, interbedded shales and siltstones and pinch out features.



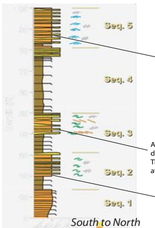
Upper and lower Tocito Sequences seperated by shale and silstone near Beautiful Mountain

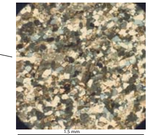
Schematic cross-section showing the stratigraphic relationship of the Gallup, Tocito and El Vado from southwest to northeast.



Regional Outcrop and Subsurface Map

Subsurface and Outcrop Examples

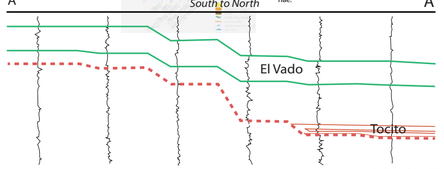




Abundant oyster hash occurs on bedding surfaces throughout the El Vado. The hash is likely the source of carbonate cements in the outcrop and subsurface.

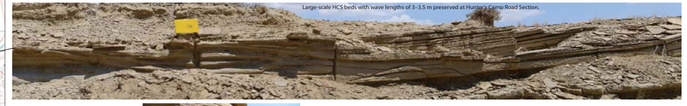
Beds are finely laminated sands (~1 cm) and shales (>1 cm) with bioturbation in the shale laminae.

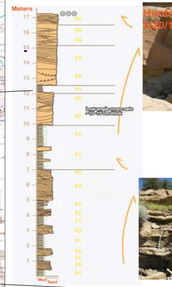
Thin, multiple stacked parasequences consisting of interbedded black shale and laminated gray sandstone. Burrowing and bioturbation in shale and silt layers. Soft sediment deformation, local cut and fill.

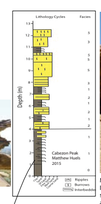


(Modified after Ridgley, 2000)

Ridgley (2000) shows that overall the entire stratigraphic interval of the Mulatto Tongue of the Mancos Shale is thickening northward. The El Vado is mapped by Ridgley to be a consistent thickness from south to north with the Tocito, stratigraphically older but present in the eastern parts of the basin, lapping out to the south on the unconformity.







Meters thick cycles of cm to sub-cm, wavy-laminated, ripped fine to very fine sands. Surprisingly little mud. Sands show internal migrating ripples and drapes of mud over ripple surfaces. Rare, thin swaley to hummocky-like beds do occur. Appear to represent very small scale process events. Only a trace of bioturbation.

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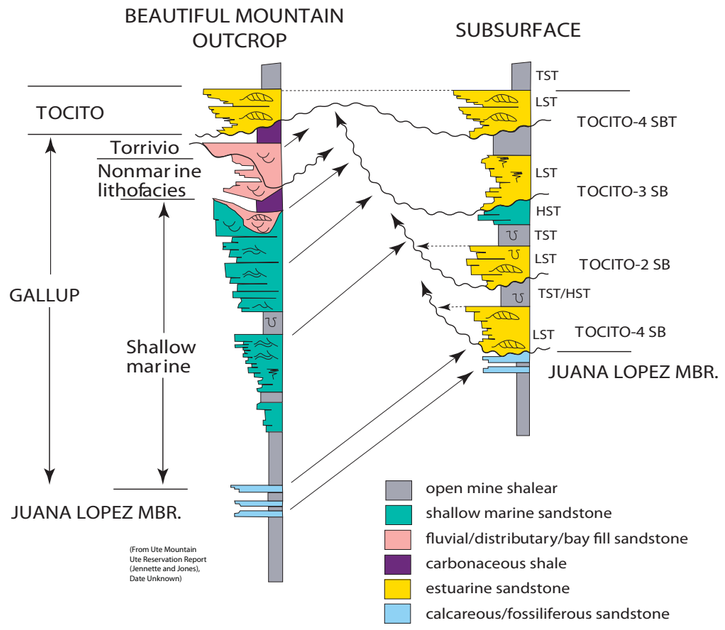
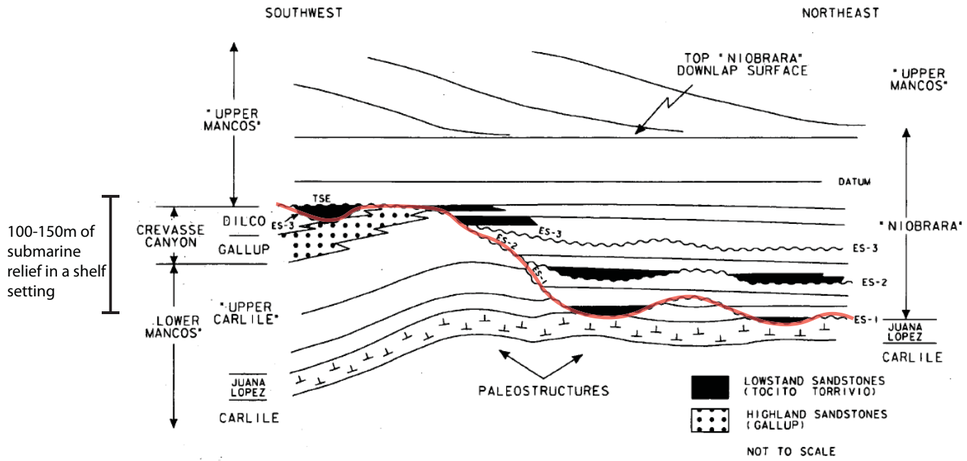
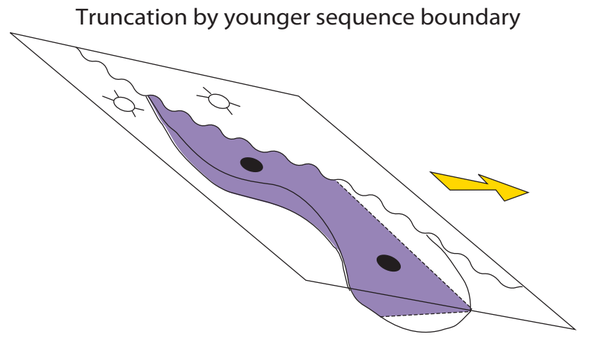
Erosion Problem



Erosion and truncation play a significant role in the stratigraphic relationships of the Tocito. It rests unconformably on the Torrivio, Gallup, Juana Lopez and Mancos and younger Tocito sequences incise older, producing stratagraphic pinch outs and stacked reservoirs. Several hypotheses try to account for the nearly 120m of missing section.

Transgressive erosion would not have the erosive power to remove that much section. Regressive erosion related to subaerial exposure is a possibility, although evidence for exposure includes only carbonate nodules. Jennette and Jones (1995) and Nummedal and Riley (1999) suggested it was primarily regressive erosion and later transgressive erosion that erased evidence of subaerial exposure. This hypothesis involves local uplift that would not have persisted through all four Tocito sequences and would not have been basin-wide.

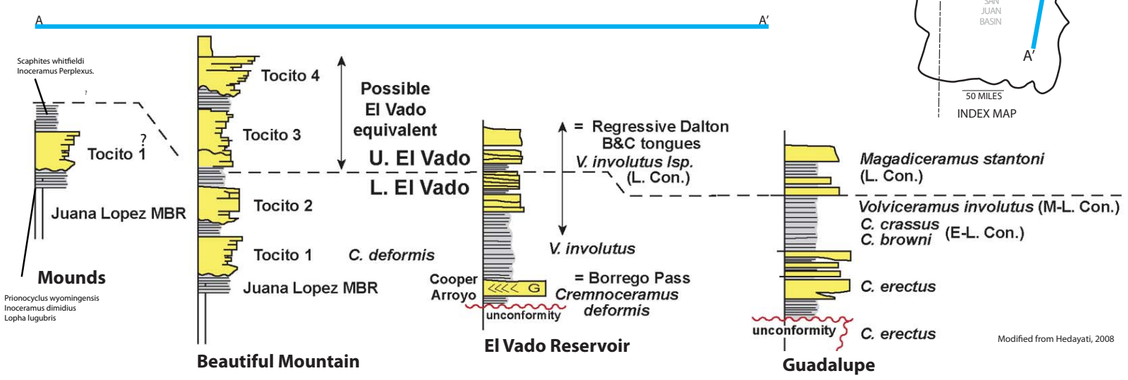


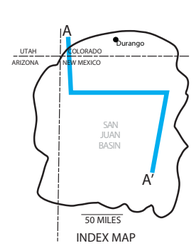


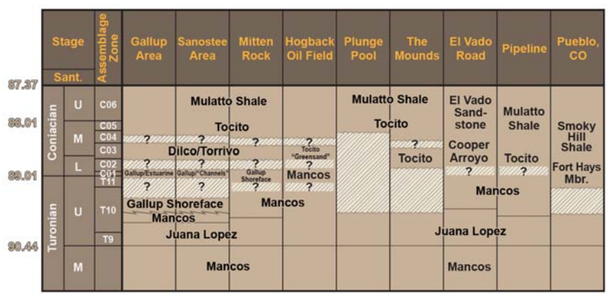
(Modified from Bottjer and Stein, 1995)

The Correlation Problem

Jenette and Jones (1991) divided the Tocito into four distinct sequences that can likely be subdivided into upper and lower units based on lithologic and paleontologic distinctions (lower being regressive deposits and upper more transgressive). Cremnoceramus Deformis found in the lower Tocito near Beautiful Mountain is equivalent to the lowermost shale of the Mancos named the Mulatto tongue. This suggests a regional shale divides the upper and lower Tocito and El Vado units.







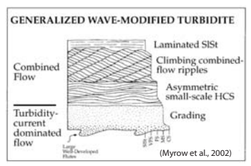
Nummedal and Molenaar (1994) published an attempt to integrate various outcrop locations into a west to east correlation using ammonite zonations. Notice the large amounts of apparent submarine erosion from Plunge Pool and The Mounds eastward to El Vado Road, Pipeline and north to Pueblo Colorado.


Ammonite fragments collected from Tocito at Cabezon Peak

Mega Hummocks

Hummocks in the Tocito formed by low long-period swell waves generated by distant severe storms

Abundant and large-scale hummocks occur in shelf deposited sands throughout the Cenomanian-Turonian super-Greenhouse deposits of the Western Interior Seaway. The preservation of such abundance of hummocks may be due to increased storm wave base and deeper development of hummocks than are other times in the rock record (Arora et al, in prep).



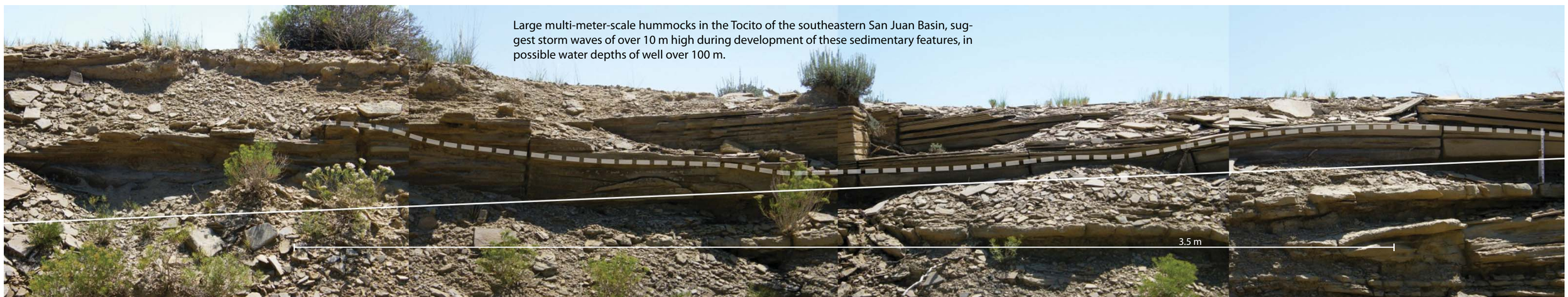
Gentle slopes on ramp shelves make it difficult to sustain shelf turbidites. However, storm-generated waves such as those indicated by the mega-hummocks of the Tocito and El Vado intervals suggest the possibility of combined flow with hyperpycnal plunging plumes formed by storm-associated floods interacting with decayed swell waves that are extremely large in size. These combined processes may explain why sands can move far distances in ramp settings. Physical modeling studies (Arora, et al, in prep) prove the impact of such combined processes.

Preliminary Conclusions

- El Vado to the northwest looks very different from El Vado to the northeast
- Tocito may be shelf bound inboard of major submarine erosion surface
- Significant submarine erosion has occurred in the SJB - up to 160m
- Significant waves impacted cross-shelf sand movement

Future Work

- Integration of new core and drilling data from the northwest
- Additional ammonite collection & integration
- Additional subsurface to outcrop correlation of Tocito & El Vado isolated sand intervals



Large multi-meter-scale hummocks in the Tocito of the southeastern San Juan Basin, suggest storm waves of over 10 m high during development of these sedimentary features, in possible water depths of well over 100 m.