[PS]Sedimentology and Diagenesis of Mississippian (Kinderhookian and Osagean: Tournaisian and Visean) Buildups in Southwest Missouri, Northwest Arkansas, and Northeast Oklahoma*

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Abstract

Carbonate buildups are present in the Kinderhookian Compton and basal Osagean Pierson formations in SW Missouri and adjoining Arkansas and Oklahoma. Their depositional origin, biota, and diagenesis are key to evaluating their potential as subsurface petroleum reservoirs. They formed on aggradational to progradational distally-steepened ramps. Those in the Pierson are mainly layered bafflestones; they contain abundant fenestrate bryozoans and crinoids, and are capped by crinoid grainstones. They are interpreted to have been deposited in a relatively shallow, high-energy environment, and locally they are oil-saturated. The older Compton buildups instead are hybrid mud-dominated lithoherms/fenestrate bryozoan-crinoid muddy bafflestones that are associated with nodular-bedded, shaly mudstones. They are interpreted to have been deposited in low-energy, deeper-water environments than the Pierson buildups. One of the Compton buildups is a stromatactis-type "reef" with abundant marine cement-filled vugs. The lithoherm/bafflestone buildups were uplifted and subaerially exposed in mid-Compton time within an EW-trending belt in the study area. Meteoric-dissolution vugs formed and were occluded by detrital dolomite and coarse calcite cement, and then the buildups were dislodged and redeposited to the north within thick sections of upper Compton that downlap an intraformational exposure surface. Such allochthonous buildups might be mappable in the subsurface by thickness trends.

SEDIMENTOLOGY AND DIAGENESIS OF MISSISSIPPIAN (KINDERHOOKIAN AND OSAGEAN: TOURNAISIAN AND VISEAN) BUILDUPS IN SOUTHWEST MISSOURI, NORTHWEST ARKANSAS, AND NORTHEAST OKLAHOMA

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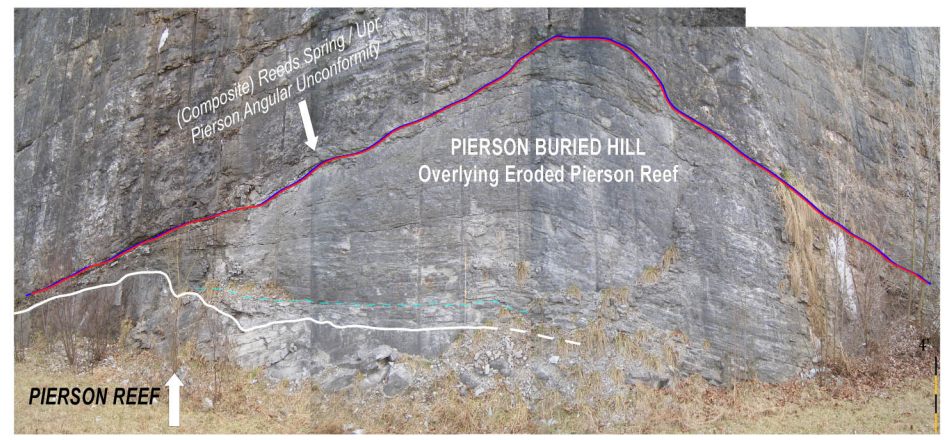
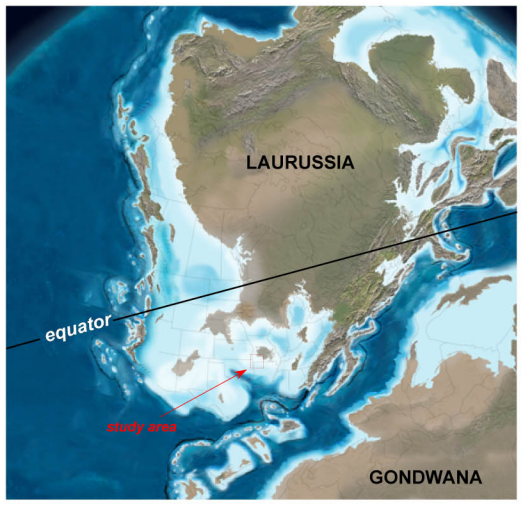


LAYERED FENESTRATE BRYOZOAN-CRINOID BAFFLESTONES COMPRISING A CORE FACIES AND CAPPED BY CRINOIDAL GRAINSTONE CRESTAL DEPOSITS...NOT WAULSORTIAN REEFS

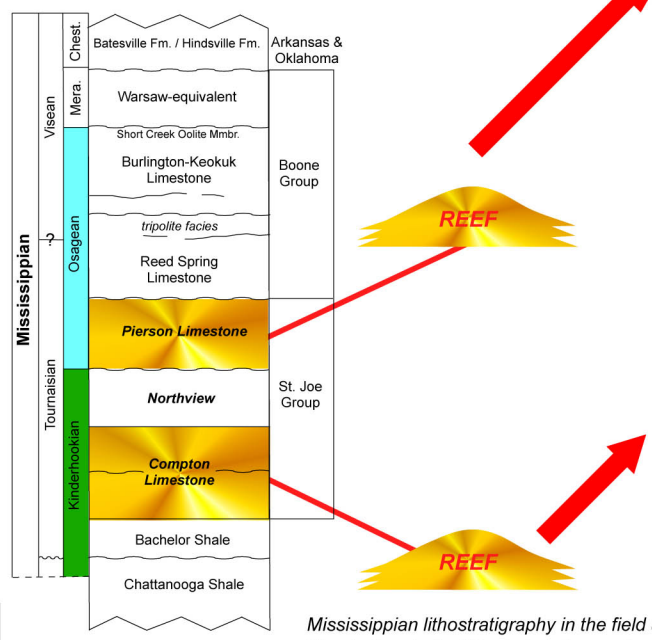
STUDY AREA

Southwest Missouri, Northwest Arkansas, and Northeast Oklahoma

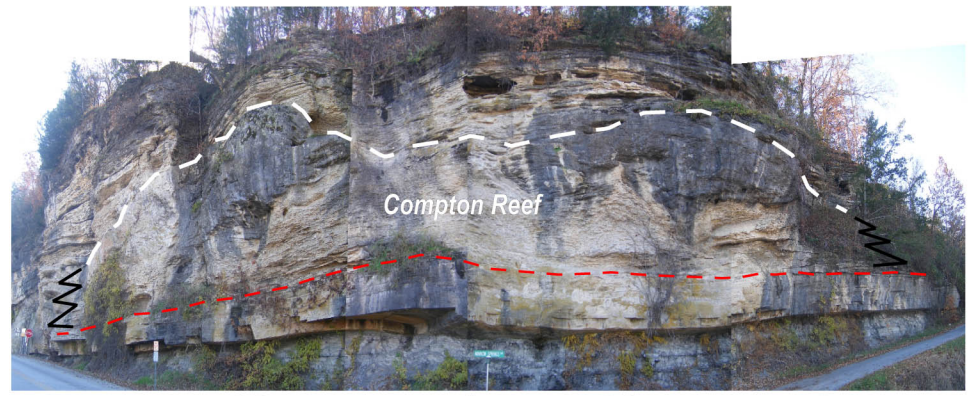


Paleogeographic representation of the study area during middle Mississippian (Kinderhookian and Osagean) time after Blakely (2005). The study area highlighted in red would have been South of the paleo-equator (Gutschick and Sandberg, 1983) within the Paleozoic Ozark Uplift, and to the North of the Laurussia and Gondwana plate-convergence zone.

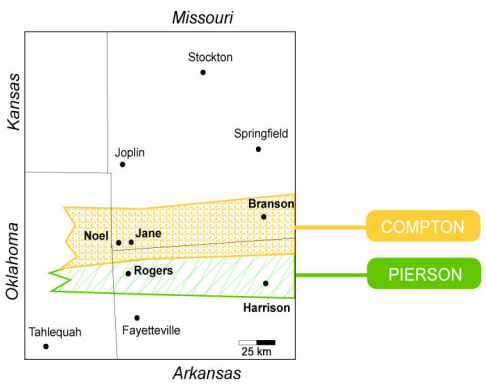
MISSISSIPPIAN OUTCROP STRATIGRAPHY



Mississippian lithostratigraphy in the field area includes Kinderhookian through Chesterian strata, this study is focused on Kinderhookian age, Compton and Osagean age, Pierson formations, which are the two reef bearing formations within the section. Correlatives of these units are present within the subsurface of southern Kansas and northern Oklahoma, and locally are prolific oil and gas reservoirs. They are commonly referred to as the St. Joe, Chouteau, or Gilmore City Lst in Kansas and/or the St. Joe Group in Oklahoma



WAULSORTIAN AND NON-WAULSORTIAN REEFS



E-W Trending Belt of Anomalous Stratigraphy

Compton and Pierson reefs occur only within a E-W belt of anomalous stratigraphy in the field area

- *normal Compton thickness is roughly 8'-15' of shallow water limestones*
  anomalous Compton sections are up to 40' (+) thick and locally include reefs
- *normal Pierson thickness is between 10'-20' thick of shallow water limestones*
  anomalous Pierson sections are up to 70' (+) thick and locally include reefs

METHODS OF STUDY

- ***17 of 18 total reefs on outcrop analyzed and described in detail***
- **measured reef thickness, sampling beds** ● underlying ● overlying ● & adjoining
- ***further outcrop descriptions included*** ● lithologies ● biotas ● & vertical or lateral changes evident on the outcrop
- ***THIN-SECTION PETROGRAPHIC STUDY***
- **detailed interpretation of** ● biotas ● microbiotas ● rock textures ● *& PRESENCE OF MARINE OR METEORIC CEMENTS*

JANE (BEAU'S REEF)		
	N 360 32' 47.00" W 940 19' 34.96"	18-21N-31W (NW NW SE)
JANE REEFS (3)		
	N 360 32' 47.00" W 940 19' 34.96"	18-21N-31W (NW NW SE)
JANE SOUTH (2)		
	N 360 32' 43.47" W 940 19' 24.03"	18-21N-31W (NE NW SE)
JANE NORTH (4)		
	N 360 33' 26.74" W 940 20' 11.18"	12-21N-32W (NW NE SE)
NOEL DD REEF		
	N 360 34' 4.38" W 940 30' 10.98"	9-21N-33W (SE SW NE)
NOEL DD N REEF		
	N 360 34' 9.59" W 940 30' 11.54"	9-21N-33W (E2 SW NE)
59&90 REEF *(inaccessible)*		
	N 360 32' 54.37" W 940 29' 41.12"	15-21N-33W (SE NW SW)
HWY. 86 REEF		
	N 360 31' 50.44" W 930 27' 50.32"	18-21N-23W (NE NW NE)
Highway 412 Reefs (4)		
	N 360 10' 17.12" W 940 23' 22.51"	9-17N-32W (NE NE NE)

Previous studies of reefs within the field area

Harbaugh J. W., 1957, Mississippian bioherms in northeast Oklahoma: AAPG Bulletin, v. 41, p. 2,530 - 2,544
Massively bedded, crinoid dominated bioherms within the St. Joe Member of the Boone Formation, northeast Oklahoma: formed by the growth and accumulation of crinoids.

King, D. T., 1986, Waulsortian-type buildups and resedimented (carbonate-turbidite) facies, early Mississippian Burlington shelf, central Missouri: Journal of Sedimentary Petrology, v. 56, p. 471-479.
Waulsortian-type buildups and associated carbonate turbidite facies in central Missouri. Comprised by a dolomitized bryozoan-crinoid, lime mudstone core flanked by crinoidal packstones and grainstones, and having formed along the Burlington Shelf margin in the foreslope to near toe-of-slope depositional settings.

Troell, A. R., 1962, Lower Mississippian bioherms of southwestern Missouri and northwestern Arkansas: Journal of Sedimentary Petrology, v. 32, p. 629-644.
Mudstone cored bioherms within thin bedded crinoidal limestones in southwest Missouri and northwest Arkansas: formed by the interaction of physical environmental factors and bathymetry; sediment trapping and stabilizing activities of fenestrate bryozoans; and sediment trapping and stabilizing activities of plants not preserved.

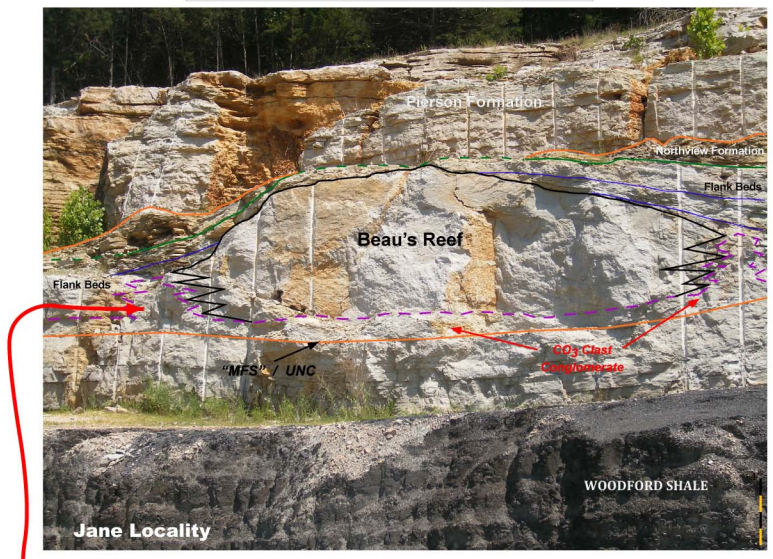
AUTHORS INTERPRETATIONS

Waulsortian and non-Waulsortian reefs developed in the medial ramp settings on aggradational to progradational distally-steepened ramps, some of which have been dislodged due to fore-bulge syndepositional tectonism. They have indicative evidence of subaerial meteoric exposure and syndepostional marine cements. Both Compton and Pierson reefs have oil staining, and Pierson reefs are locally oil saturated on the outcrop.

COMPTON REEFS

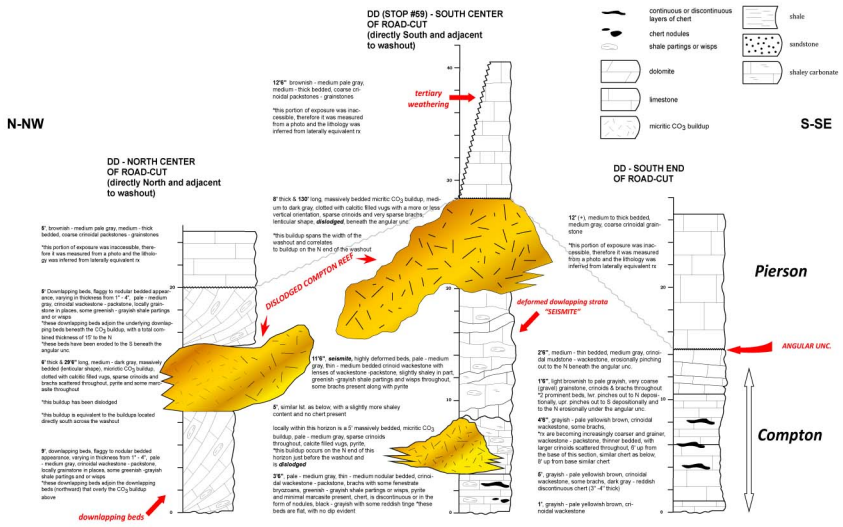
WAULSORTIAN & NON-WAULSORTIAN REEFS

Tabular - Flat Bottom Convex Top Shapes between 5' - 30' thick on outcrop



thick ***CO_3 Clast Conglomerate*** *bulldozed up along sides of reef during slide*

Beau's Reef along Highway 71 just north of Jane, Missouri. The Compton Formation at this locality overlies the Devonian Woodford Shale, and the Kinderhookian Bachelor Formation. The Bachelor and the lower Compton comprise a T-R cycle of crinoidal sands (packstones & grainstones) that are overlain by a pronounced carbonate clast conglomerate that represents a regional disconformity within the Compton throughout most of the field area and is even traceable into the subsurface of Kansas. Sandwiched between T-R cycles of the lower and upper Compton are tabular blocks of dislodged reefs and associated shaly - muddy downlapping beds. The reefs and their associated facies are all dislodged or downlapping in a northward direction (opposite of the supposed basin to the south). We have interpreted this northward progadation to represent syndepositional tectonism in relation to a fore —bulge.



Composite measured section northwest of Noel, Missouri on Highway DD. Large, tabular, dislodged reef blocks and associated downlapping strata (NORTHWARD opposite of the suggested basin) directly overlying seismite beds, indicative of active tectonism. Reef blocks are tapered as suggested in columnar section, as they were semi-lithified when displaced.

COMPOSITE SECTION representing out-of-place reefs

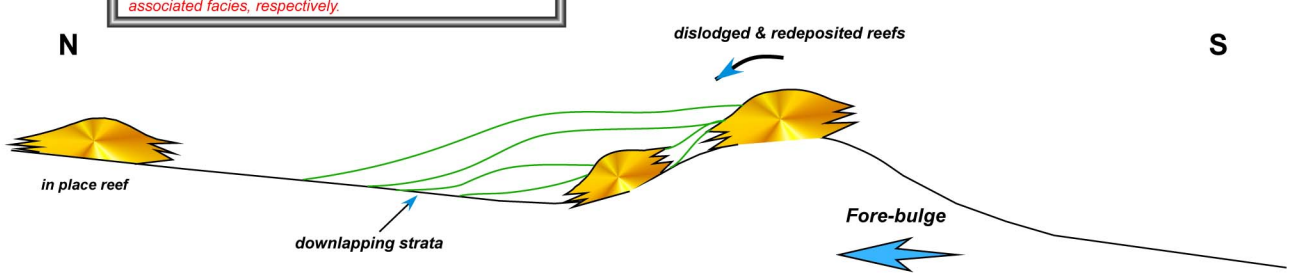
DEPOSITIONAL ARCHITECTURE OF COMPTON REEFS

Based upon lithology and regional stratigraphy and sedimentology, the Compton Formation is interpreted as having been deposited on a very low-relief aggradational to slightly progradational distally-steepened ramp. Compton facies consist of muddy carbonates in the proximal and distal ramp settings, with reefs and their associated facies in the medial portion.

Mazzullo et. al., 2011

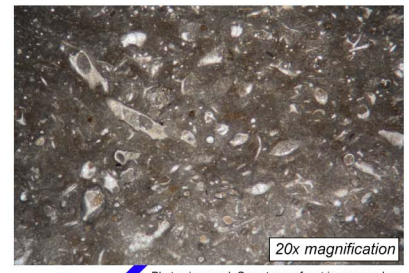
★ **REEFS DEVELOP IN MEDIAL RAMP SETTINGS**

Syndepositional fore-bulge tectonism *during Compton time resulted in the* ***uplifting*** *and* ***subaerial exposure*** *of Compton reefs in an East - West trending belt within the study area. Likewise, fore-bulge tectonics are the basis for northward dislodgement and progradation of reefs and their associated facies, respectively.*



★ *All Compton reefs within the field area are inferred to be OUT-OF-PLACE (DISLODGED) except for the Hwy. 86 locality South of Branson, Missouri showing no apparent evidence of being out-of-place.*

DIAGENETIC FABRICS

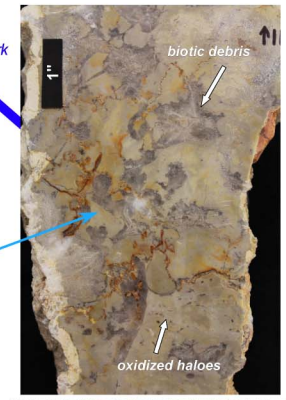


Photomicrograph Compton reef matrix. cross polars

- *Bryozoan and Crinoid rich matrix (acting as bafflers of sediment)*
  - *associated biotic constituents include: brachiopods, bivalves, spicules, and minor rugose coral*
- *textures vary from primarily wackestones to micritic-rich or muddy lithologies*
  - *cement fabrics include: locally recrystallized micrite to micro and pseudospar (partially attributing to the semi-lithified nature of these reefs during deposition and dislodgement)*
  - *former High Magnesium Calcite Bladed Marine cements within shells and some vugs; considerable HMC intraparticle cementation during depostion "syndepositional marine cements*
  - ***METEORIC DISSOLUTION VUGS*** *(related to syndepostional tectonism)*
  - *vugs locally filled with biotic debris, internal vadose crystal silt, and occluded by coarse pore filling calcite*
  - *dolomitization of crystal silt filling vugs, locally hematite rimmed*
- ***Stromatactis type marine cements, characteristic of Waulsortian Reefs ARE ONLY RECOGNIZED IN ONE Compton reef locality South of Branson, Missouri.***

Bryozoan Rich Internal Framework

Large Calcite Occluded Vugs

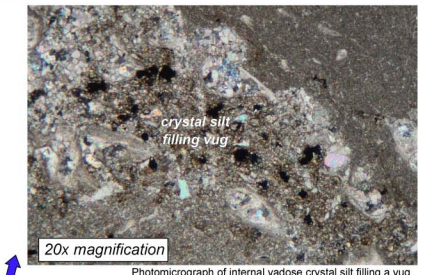


Hand sample photo with abundant meteoric dissolution vugs

Meteoric Dissolution Vugs of

tubular fenestrae
laminoid fenestrae
irregular fenestrae
→ *shape*

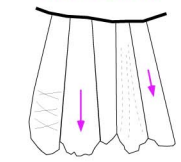
Grover and Read, 1978



Photomicrograph of internal vadose crystal silt filling a vug, later occluded by coarse pore filling calcite. cross polars

internal vadose crystal silt:
eroded marine cements & biotic particles forming "crystal silt" Dunham, 1969

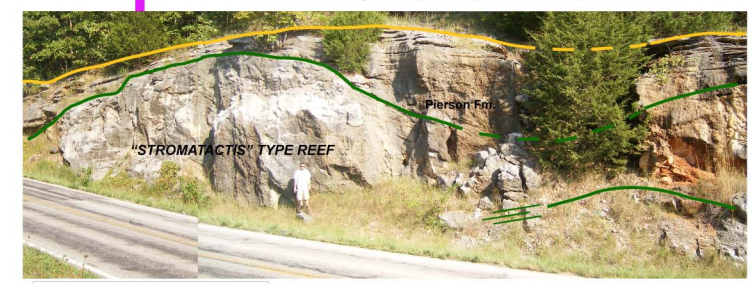
RADIAXIAL FIBROUS CALCITE "MARINE CEMENTS"



after Kendall (1985)

Photomicrograph of RFC marine cements "stromatactis". 20x magnification, cross polars

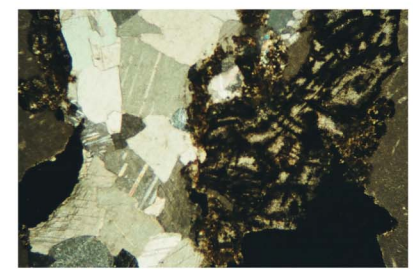
Along Highway 86 South of Branson, Missouri exposed along the North side of the road is a 20' (+) Compton reef, unconformably overlain by shallow water crinoidal sands of the Pierson Formation. This reef bears similar lithologic characteristics to other Compton reefs (i.e. bryozoan-crinoid rich bafflestone type frameworks; meteoric dissolution vugs with crystal silt) however, abundant ***"STROMATACTIS"*** occluded by mosaics of ***radiaxial fibrous calcite marine cements*** are present throughout. Perhaps genetic difference along with no evidence of being out-of-place represents an in-place reef.



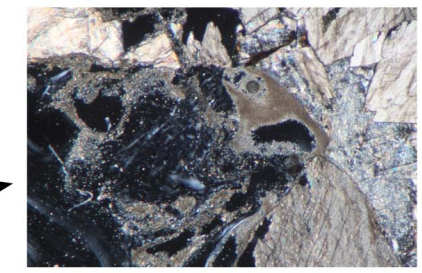
Hwy. 86 Locality Robert Turner for scale

Evidence Of Unconformity & FORMATION OF POROSITY

- ***oxidized haloes and reddish discoloration along fractures and some vugs***
- ***clasts of reef matrix within vugs***
- ***dissolutional vugs and associated fractures***
- ***internal vadose crystal silt within vugs and fractures***
- ***abundant crinoid overgrowths***



porosity within vugs



★ *place the same reef in the subsurface and strip away all the calcite occluded porosity* ★

result

REEF WITH 20%-25% POROSITY

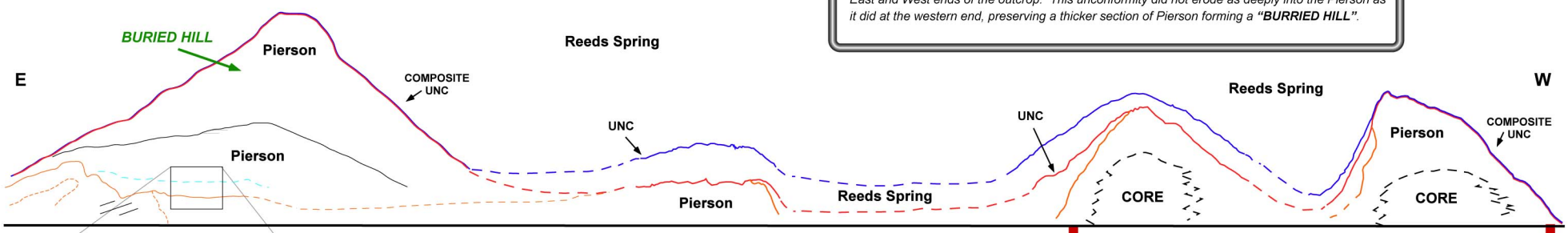
locally porosity has been occluded on the outcrop

RESERVOIR OBJECTIVE

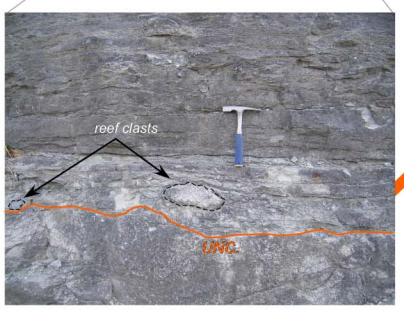
PIERSON REEFS — NOT WAULSORTIAN REEFS

*Composite sketch of Pierson Reefs cropping out along the South side of Highway 412, East of Siloam Springs, Arkansas. The Pierson at this locality is upwards of 20' (+) thick comprised of shallow water limestones and reefs, overlain by roughly 30' of Reeds Spring Formation. A total of four reefs are present from East to West along the outcrop with the eastern two representing primarily crestal/capping facies (crinoidal sands), and the western two exposing both the reef core and crestal deposits. There are multiple unconformities throughout the Pierson section, most notably the upper most Pierson unconformity that locally becomes a composite unconformity at the East and West ends of the outcrop. This unconformity did not erode as deeply into the Pierson as it did at the western end, preserving a thicker section of Pierson forming a **"BURRIED HILL"**.*

"Hwy. 412 Locality" Panoramic View

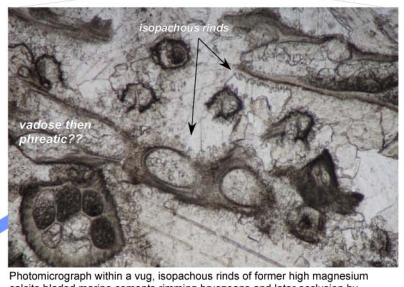


flat-bottom convex top shapes
up to 16' thick on outcrop



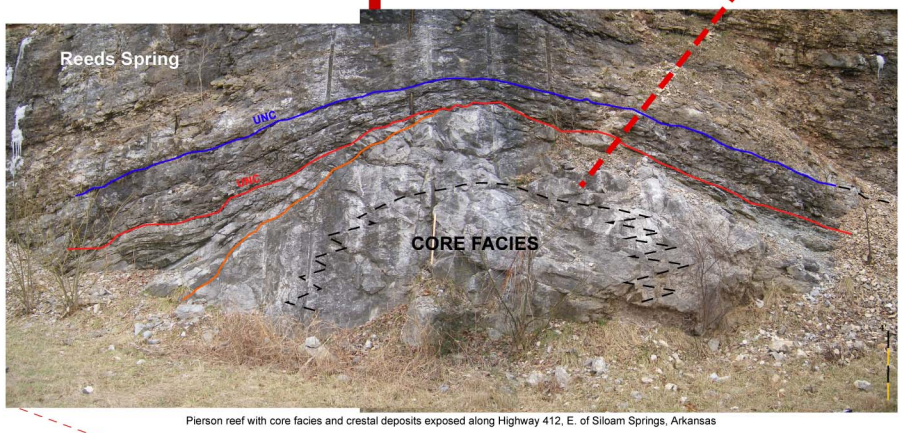
ERODED PIERSON REEF
burried hill overlying eroded Pierson reef (primarily crinoid crestal deposits exposed), with large clasts of reef and debris scattered throughout post unconformity beds

dissolutional vug



Photomicrograph within a vug, isopachous rinds of former high magnesium calcite bladed marine cements rimming bryozoans and later occlusion by coarse pore filling calcite. 20x magnification, plain light

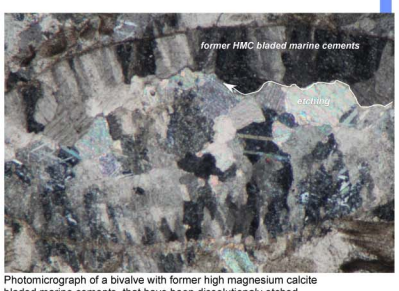
POROUS OIL SATURATED CRESTAL DEPOSITS/CRINOIDAL SANDS



Pierson reef with core facies and crestal deposits exposed along Highway 412, E. of Siloam Springs, Arkansas

RESERVOIR OBJECTIVES

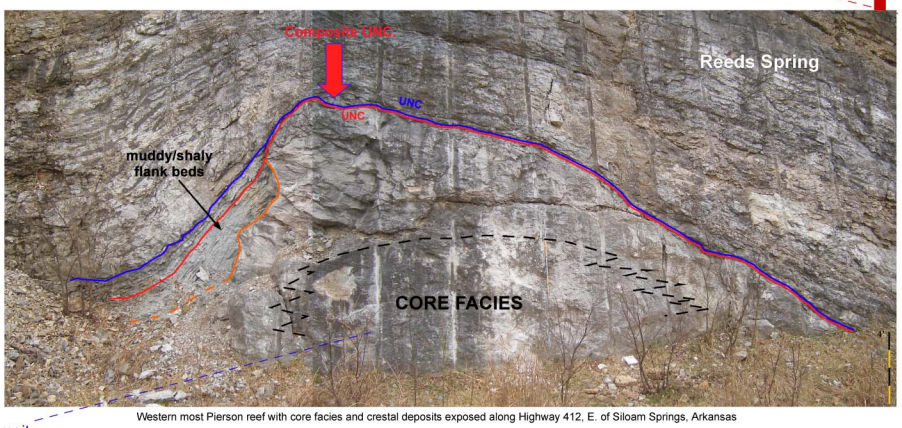
Hand sample photograph of reef core facies (layered bryozoan-crinoid bafflestone), with meteoric dissolution vugs, & marine cements



Photomicrograph of a bivalve with former high magnesium calcite bladed marine cements, that have been dissolutionaly etched. 20x magnification, cross polars

COMPOSITIONAL CHANGE IN MISSISSIPPIAN REEFS THROUGHOUT TIME

- **CORE FACIES** — *Bryozoan-crinoid rich layered bafflestone locally grading from wackestone - packstone textures*
- **CRESTAL DEPOSITS/ CORE CAPPING FACIES** — *crinoid grainstones* ***LOCALLY OIL SATURATED!!!***
- **CEMENT FABRICS** — *within these layered bafflestones are meteoric dissolution vugs "**subaerial exposure" (FORMATION OF POROSITY**) and fenestral cavities not of meteoric origin, locally occluded with coarse pore filling calcite. Vugs also contain **abundant former high magnesium calcite bladed marine cements of isopachous, interparticle, and intraparticle nature**. Distinctive thick **radiaxial fibrous crusts of pendant shape** within meteoric vugs and skeletal fragments along with some **internal vadose crystal silt** are present, however not as notably as in Compton reefs. Likewise, throughout much of the reefs **silicified fabrics** such as, chalcedony are common. Crinoid overgrowths are prominent throughout much of the crestal deposits as well as in local areas of the core facies, and are generally associated with coarse pseudospar patches when in reef matrix.*



Western most Pierson reef with core facies and crestal deposits exposed along Highway 412, E. of Siloam Springs, Arkansas

core facies porosity mostly occluded on outcrop

FORMATION OF POROSITY WITHIN CORE FACIES & CRINOIDAL SAND CRESTAL DEPOSITS

reefs such as these within the subsurface, *WITHOUT* POROSITY OCCLUSION might range between 18%-20% porosity

★ *NO EVIDENCE SUGGEST PIERSON REEFS ARE DISLODGED "OUT-OF-PLACE"* ★

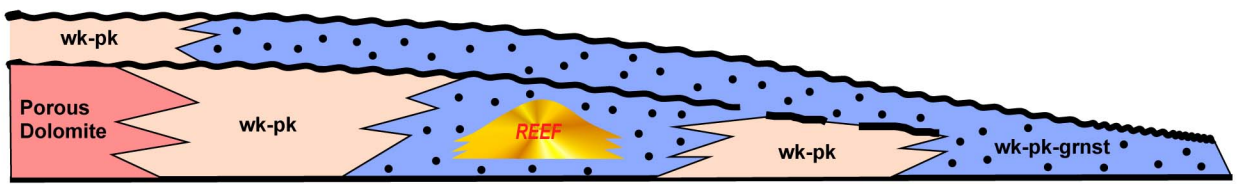
DEPOSITIONAL ARCHITECTURE OF PIERSON REEFS

The Pierson like the Compton Formation was deposited on a distally-steepened ramp, however a major change in ramp settings took place during Pierson time shifting from a primarily aggradational to progradational ramp. At its top the Pierson is marked by a prominent unconformity in areas of anomalous stratigraphy, with nearshore and shallow-marine carbonates in the proximal and distal portions and reefs associated with shallow-water limestones (crinoid sands) in medial ramp settings.

Mazzullo et. al., 2011

DISTALLY-STEEPENED "PROGRADATIONAL" RAMP

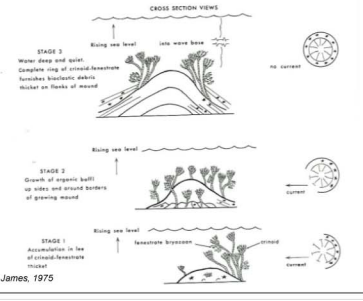
shallower-water, higher-energy environments that Compton reefs



Mazzullo et. al., 2011

Mississippian reefs of similar stratigraphic and sedimentologic architecture are interpreted to have formed in a three part process, James (1975):

1) *sediment accumulation would occur on the sea floor in the lee of a bryozoan and crinoid thicket, producing a small topographic rise to the surrounding sea floor*
2) *growth would have occurred throughout the structure by the processes of continued sediment baffling, colonization of organisms, and death and disarticulation of organisms*
3) *as the reef developed and grew, colonization of crinoid thickets would have covered the surface reaching into active wave base*



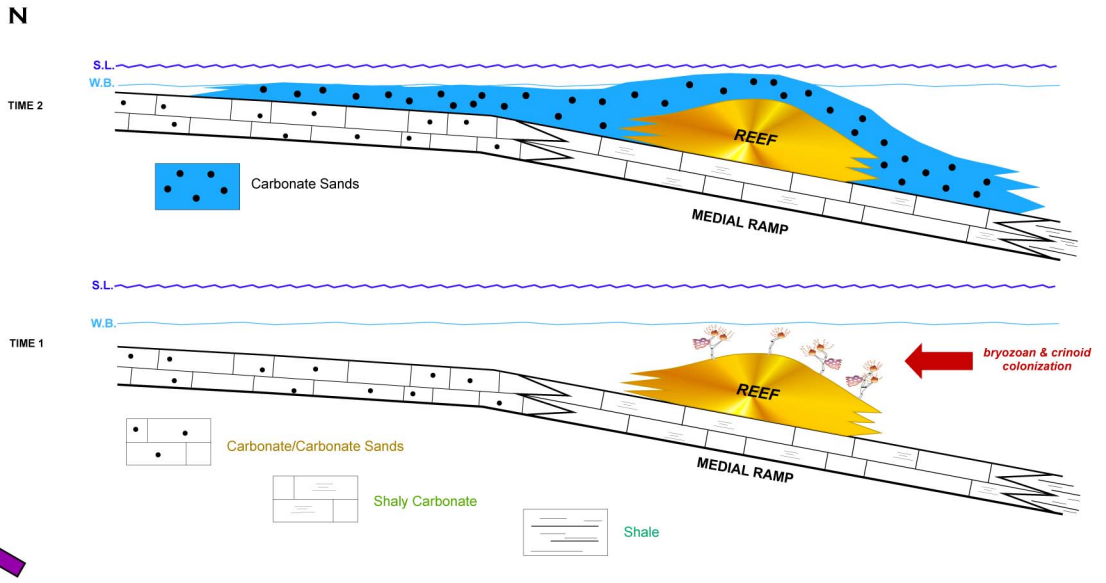
James, 1975

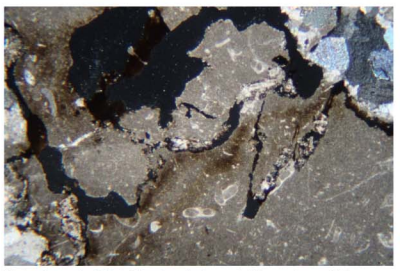
MODELS FOR RECOGNIZING REEFS AND POTENTIAL REEF BELTS

A FRONTIER EXPLORATION PLAY

The sedimentary architecture, depositional and diagenetic history of Kinderhookian and lower Osagean age reefs encompassed within this study provides a template for subsurface exploration in Kansas and northern Oklahoma. As these reefs have shows of oil on the outcrop, they may likely prove to be reservoirs in the adjoining subsurface. Little known evidence exists other than rumor as to whether or not there currently is production from lower Mississippian reefs in Kansas. This may be due to a clouded subsurface Mississippian stratigraphic nomenclature and/or a lack of understanding of Mississippian reefs.

temporal model of reefs on outcrop as subsurface analogs





Photomicrograph of oil staining along fractures, stylolites and vugs within a Compton reef. 20x magnification, cross polars

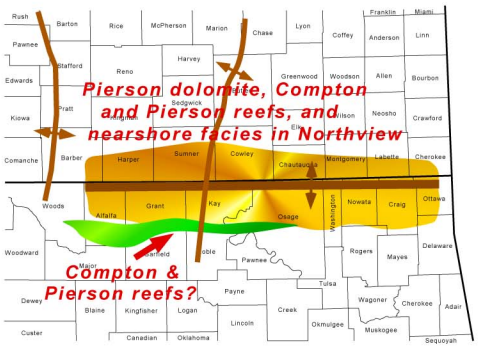
Core photographs of live oil stained Mississippian section from eastern Kansas, where the St. Joe is locally thick.

oil shows on outcrop, core, and hand sample (see reference sample #38 crinoid grainstone crestal deposits overlying a Pierson reef)

detailed lithologic recognition and interpretation, through sample and core evaluation

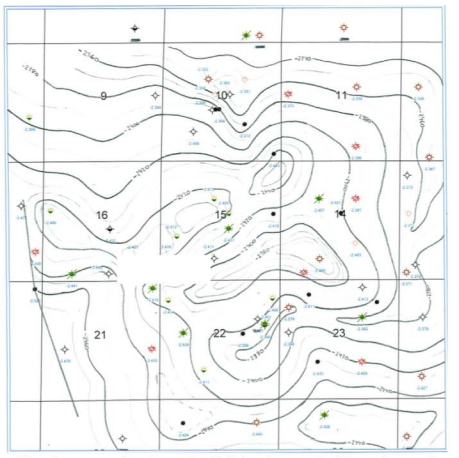
Within the subsurface of Kansas and northern Oklahoma our analog model suggests that Compton and Pierson reefs are developed within medial ramp settings. As such, these reefs need not be dislodged or out-of-place to develop reservoir characteristics, as this is merely a facet of Compton reefs seen on outcrop. They will however, likely be associated with thick anomalous stratigraphy. Hence, these reefs or reef bearing units are mappable within thickness trends and possibly corresponding structure. As Kansas and Oklahoma are mature areas of exploration the use of existing and newly taken core and samples are invaluable tools when such a detailed lithologic recognition and interpretation are needed.

Candidates for high-resolution 3D SEISMIC surveys



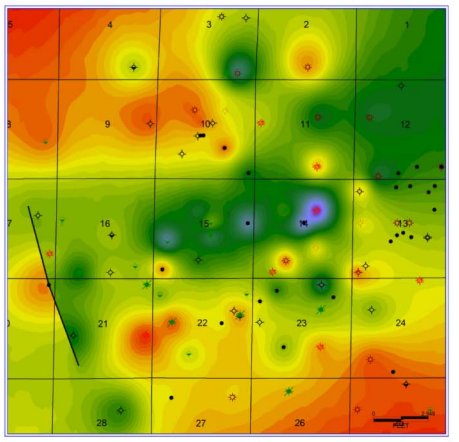
Kansas and Oklahoma county map, representing the major tectonic-physiographic features.

Reefs within the field are not of reservoir scale, however as we chase these reefs into the subsurface increased accommadation space may permit extensive growth of reefs. Likewise, beds flanking and overlying these reefs imaged, would have an onlapping characteristic easily identifiable on seismic.



Structure map showing potential development of Compton reefs

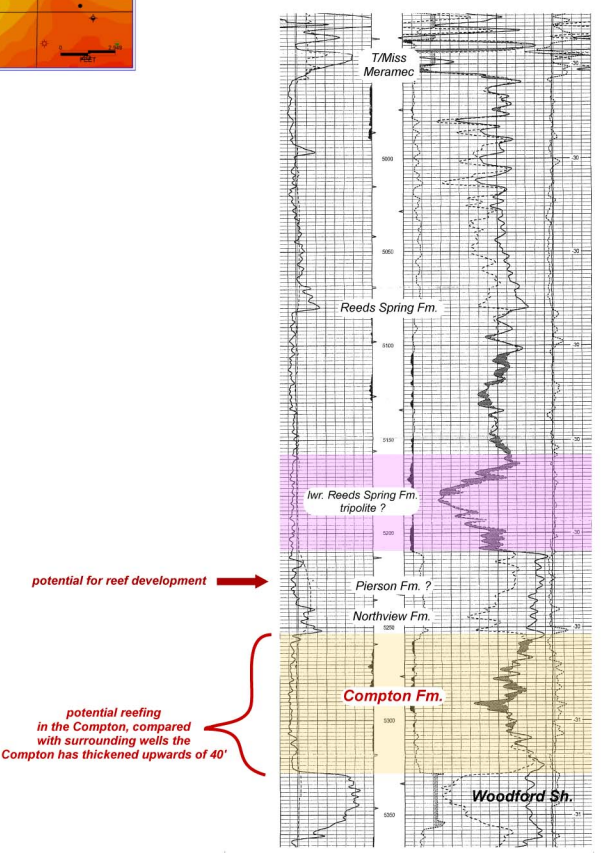
reef belts can be mapped in the subsurface with thickness trends



CONCLUSIONS

- ***Reefs of tabular to convex top shape of Kinderhookian and lower Osagean age are exposed in an E - W trending belt within the study area, associated with thick "anomalous stratigraphy" in their respective stratigraphic sections***
- ***COMPTON REEFS***
- ***classified as WAULSORTIAN AND NON-WAULSORTIAN REEFS, and are associated with muddy-shaly limestones***
- ***they were subaerially exposed during middle Compton time in relation to fore-bulge syndepositional tectonics and developed meteoric dissolution vugs and internal vadose crystal silt***
- ***all reefs except one (Hwy. 86 Locality) are inferred to be dislodged or redeposited***
- ***likewise, the Hwy. 86 reef locality is the only "stromatactis type" reef present is within the field area, and with abundant radiaxial fibrous calcite marine cements***
- ***PIERSON REEFS***
- ***different from Compton reefs, are layered bryozoan-crinoid rich bafflestones comprised of a bryozoan rich core facies and crinoid grainstone crestal deposits, that are locally oil saturated, NOT WAULSORTIAN REEFS***
- ***they were subaerially exposed forming some meteoric dissolution vugs and associated vadose crystal silt and pendant shape RFC cements***
- ***former HMC bladed cements of isopachous, interparticle, and intraparticle nature are common throughout***
- ***they show no evidence of being dislodged or redeposited***
- ***Pierson reefs occur in a belt further South of Compton reefs indicating overall basinward progradation***

- ***This study provides a temporal analysis of reefs in outcrop along with their sedimentary and depositional architectures serving as a model for recognizing reefs and/or reef belts within the subsurface of Kansas and northern Oklahoma.***



Compensated neutron density well log from south-central Kansas with thick (70' +) section of Compton Formation overlying the Woodford shale. Average porosity across the Compton is 6% with a peak at 13%, most of which has a gas cross-over effect.