Revisions to Mid-Carboniferous Heath and Tyler Formations Stratigraphy and Nomenclature, Big Snowy Trough, Central Montana, USA

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Abstract

Mid-Carboniferous black shales in central Montana were included in the Heath Formation of the Big Snowy Group by Scott in 1935. Poor surface exposures have led to debate as to: 1) the existence of an unconformity between the Heath and the overlying Tyler formations, 2) the age of similar Tyler facies, and 3) whether strata assigned to the Tyler are mappable. New subsurface cores provide data that facilitate an internal subdivision of the Heath and enhance understanding of the relationship between Heath and Tyler strata.

Historically, the definition of the base of the Heath has been based on a color change from bright green shales in the Otter to black shales in the Heath. This is problematic in that the contact is not exposed at the surface and is not mappable with precision. This study proposes that the base of the Heath / top of the Otter be re-defined as the top of a laterally persistent limestone bed that is regionally correlative in the subsurface and is mappable at the surface (Scott, 1935). All of the bright green mudrocks of the type Otter are below this limestone, and all of the black mudrocks of the type Heath are above this limestone.

The top of the Heath Formation should be defined as the sequence boundary above which sandstones and large wood fragments are present. The clastic-bearing unit above the Heath, deposited in incised valleys, is assigned to the Stonehouse Canyon Member of the Tyler. The Bear Gulch Limestone is within the Stonehouse Canyon and it should be included in the Tyler. The overlying Cameron Creek is distinguished by the predominance of red and green mudrocks and overlies a regional unconformity.

New data allow for an informal subdivision of the Heath. These units, in ascending order, are the lower Heath, Van Dusen zone, Cox Ranch Oil Shale Interval (expanded from the original definition), Red Hill Carbonate (includes the Loco Ridge Gypsum bed), Winnett Shale (lowstand basin fill), and upper Heath. These cyclic, mudrock-dominated strata record an overall rising relative sea level during Heath deposition and a changing climate from moderately humid during deposition of the Van Dusen to very arid during deposition of the Red Hill Carbonate. Large eustatic sea level falls resulted in sequence boundaries at the Heath-Stonehouse Canyon and Stonehouse Canyon-Cameron Creek contacts.

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#302 Revisions to Mid-Carboniferous Heath & Tyler Stratigraphy and Nomenclature, Big Snowy Trough, Central Montana, USA

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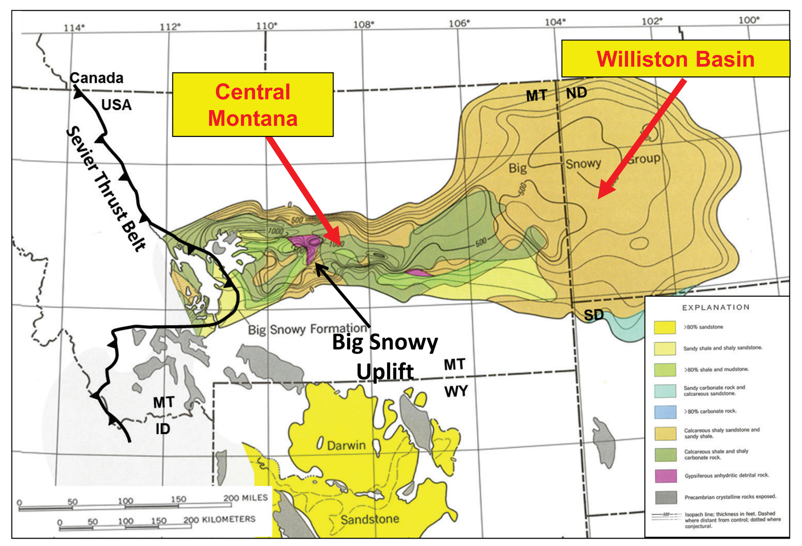
SETTING

- Central Montana, USA
- Latest Mississippian & earliest Pennsylvanian (~ 335 Ma – 320 Ma)
- Study interval spans contact between Sloss (1963) Kaskaskia & Absaroka sequences (major regional hiatus)
- Strata show high degree of cyclicity and document the onset of Carboniferous glaciations & glacio-eustatic sea level fluctuations
- Integration of "outcrops" in Big Snowy Uplift and subsurface cores and geophysical logs

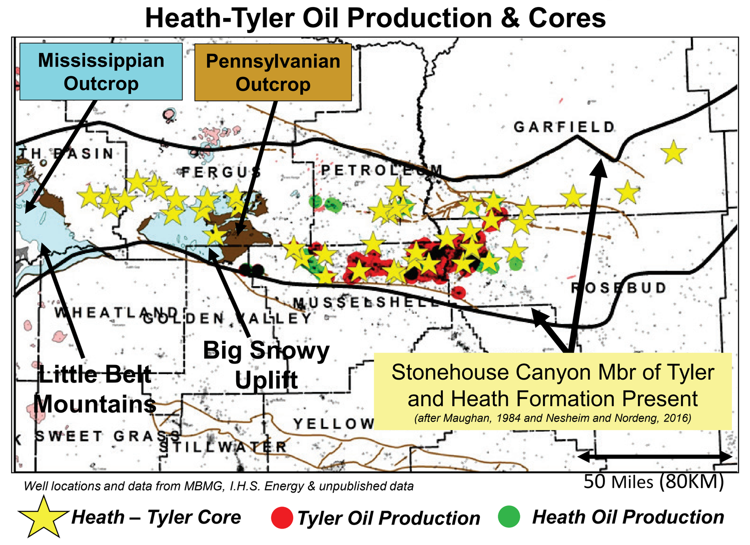
LATE MISSISSIPPIAN ISOPACH

Craig et al RMAG Atlas(1972)



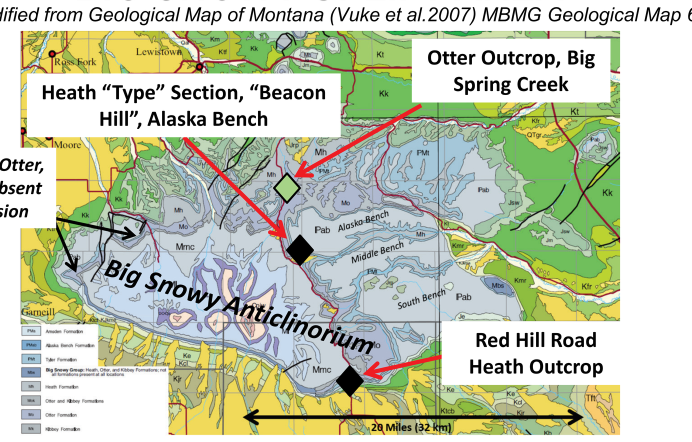
Central Montana Index Map

Heath-Tyler Oil Production & Cores

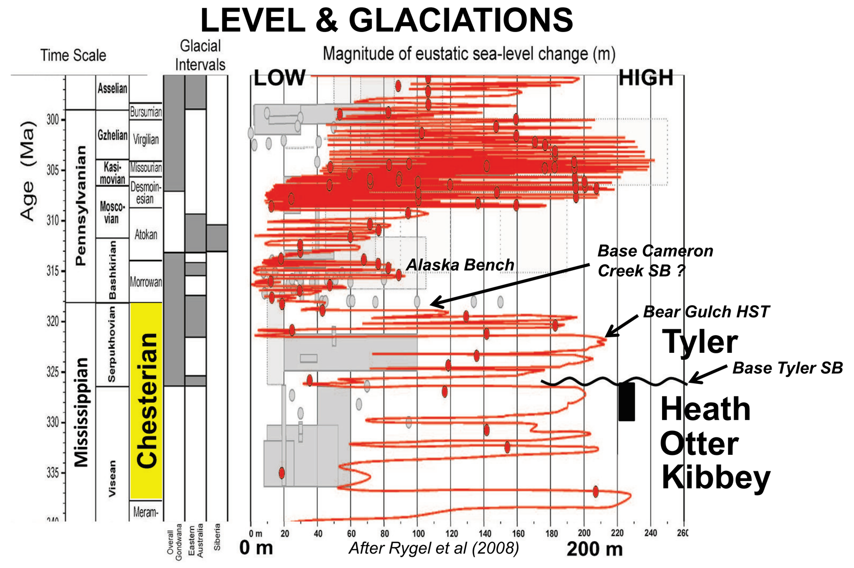


SURFACE GEOLOGICAL MAP, BIG SNOWY UPLIFT AREA

Modified from Geological Map of Montana (Vuke et al.2007) MBMG Geological Map 62



LATE MISSISSIPPIAN – PENNSYLVANIAN SEA LEVEL & GLACIATIONS



PROBLEM

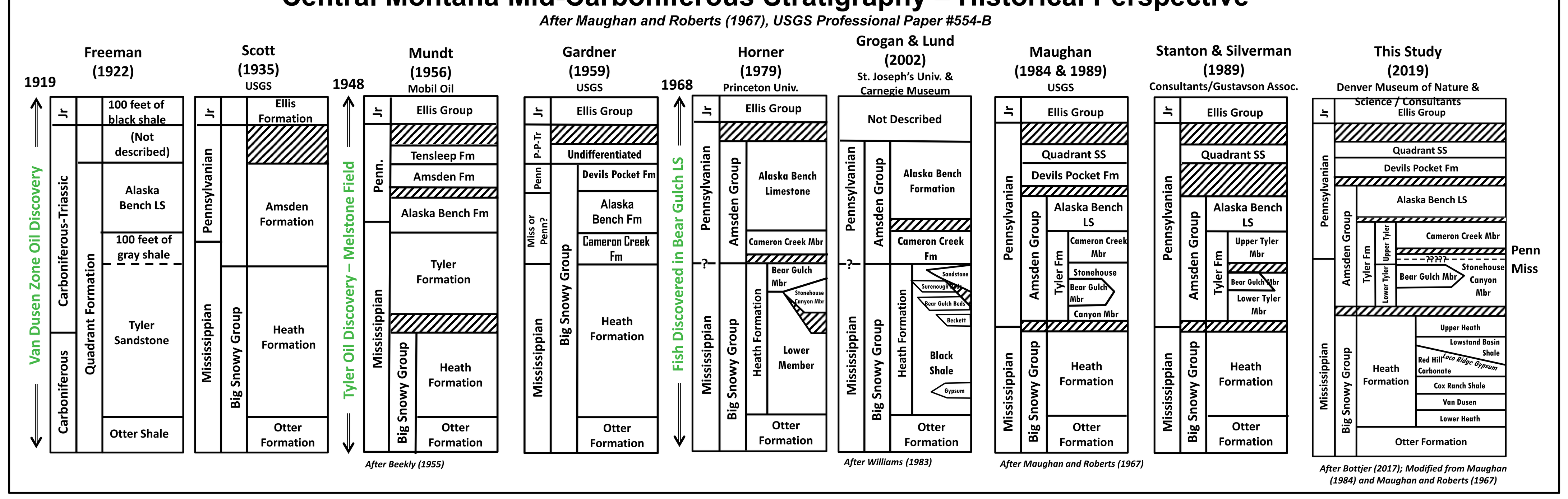
- Historical definition of the Heath-Otter contact is not mappable with precision.
- The debate about the nature of the top of the Heath (unconformable vs. conformable) and whether or not the Tyler should be broken out as a separate unit continues. This is resolved by integration of new data and multiple data sources.
- Detailed internal stratigraphic subdivisions of the Heath are now possible due to extensive new core data.

HISTORY

- Oil was discovered in Heath strata in 1919
- Heath formally recognized in outcrop and named in 1935 as uppermost formation in Big Snowy Group by Scott (Alaska Bench "Beacon Hill")
- Definition of top of Heath debated in 1940s-1960s
- Integration of surface & subsurface data by Maughan & Roberts (1967) led to acceptance of unconformity between Heath & Tyler
- 1968 Extensive well-preserved fish & other fossils discovered in Bear Gulch Limestone – definitive late Mississippian (Chesterian) age
- 1980s – MBMG & USGS drill 7 coreholes to evaluate oil shale mining potential of Heath (cores needed due to poor outcrops)
- 1984 Tyler assigned Pennsylvanian age (Maughan, 1984) in spite of recent work on Bear Gulch
- 1980s-2000s Some workers follow original 1935 terminology (no Tyler) (e.g. Dumoulin, et al., 2017); others use terminology that recognizes unconformity between Heath & Tyler
- 2010-2014 oil & gas industry recovers > 2400 ft (~800m) of new Heath-Tyler cores in Montana to evaluate Heath oil potential
- 2015-Present new cores become publicly available (e.g. donations to U.S.G.S. CRC)

Central Montana Mid-Carboniferous Stratigraphy – Historical Perspective

After Maughan and Roberts (1967), USGS Professional Paper #554-B



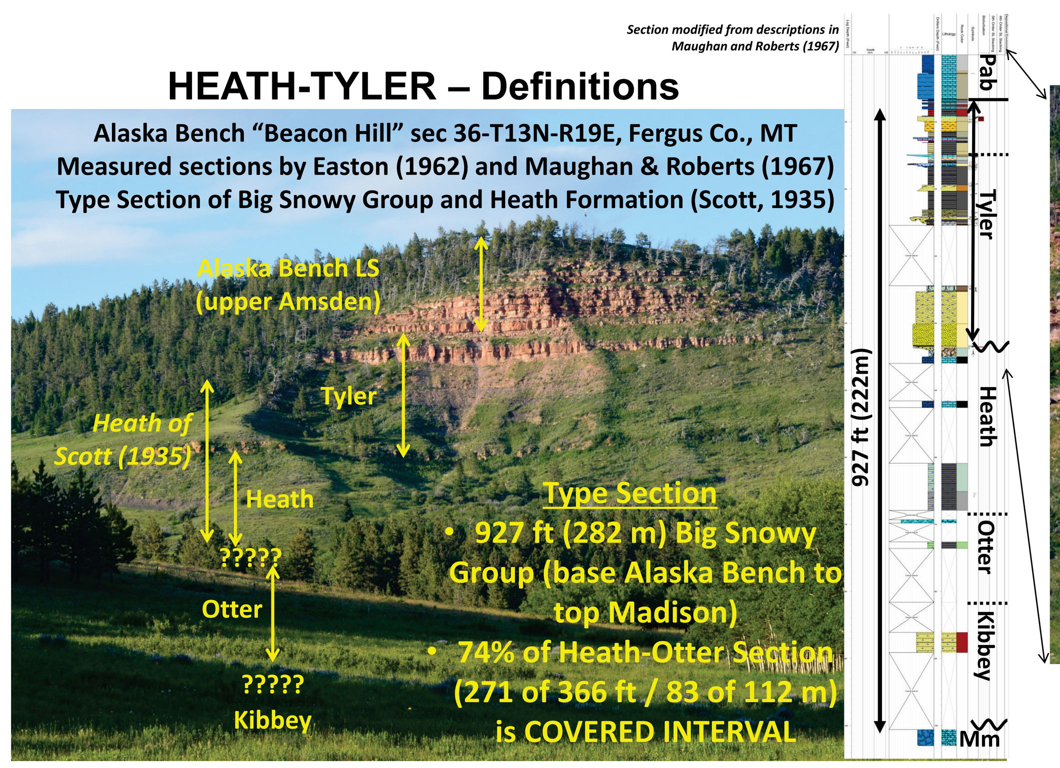
DEFINITIONS

- Cameron Creek is characterized by red and grayish-green mudstones, limestones, and sandstones. Most commonly considered a member of the Tyler Formation.
- Stonehouse Canyon characterized by lenticular sandstones and dark gray to black shales with abundant wood fragments. Bear Gulch Limestone is locally present within the Stonehouse Canyon and is most commonly considered a member of the Tyler Formation.
- Tyler was assigned a Pennsylvanian age based on recovery of the spore *Monoletes* from the upper part of the Tyler at Alaska Bench "Beacon Hill" outcrop (Maughan & Roberts, 1967; Maughan, 1984) – today *Monoletes* is known as *Schopfipollenites* and ranges from late Visean-Serpukhovian-early Pennsylvanian – it is NOT useful for defining the age of the Tyler in detail.
- Heath is characterized by dark brownish gray to black, petroliferous shales and limestones of marine origin. It locally contains gypsum and coal.
- Otter contains grayish-green to bright green shales and gray, green, and tan limestones.

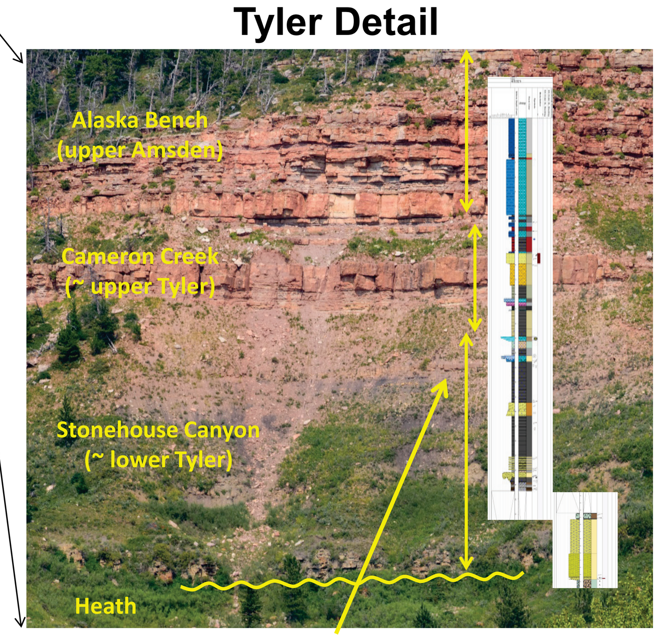
HEATH-TYLER – Definitions

Alaska Bench "Beacon Hill" sec 36-T13N-R19E, Fergus Co., MT
Measured sections by Easton (1962) and Maughan & Roberts (1967)
Type Section of Big Snowy Group and Heath Formation (Scott, 1935)

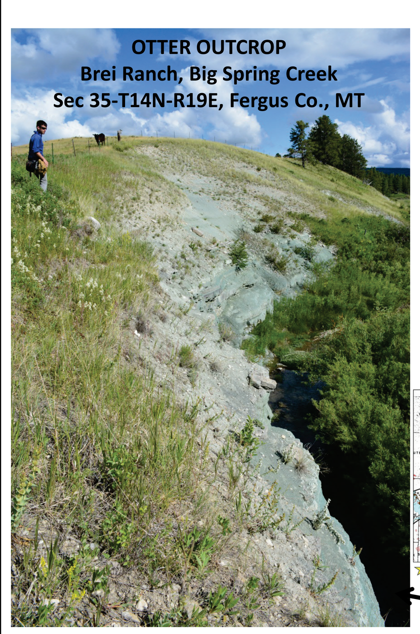
Section modified from descriptions in Maughan and Roberts (1967)



Tyler Detail



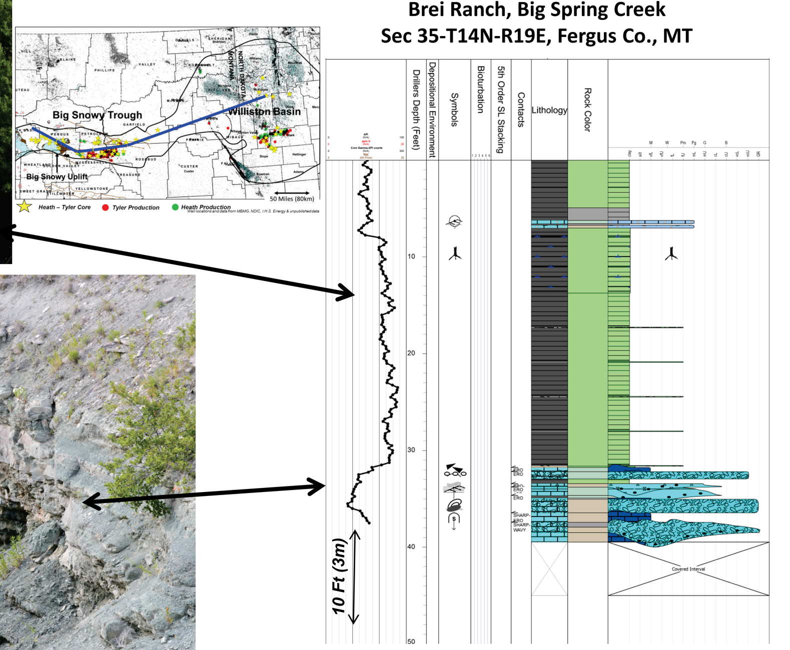
Spore Monoletes recovered from Bed 21; tentative interpretation as Pennsylvanian spore (Tschudy, in Maughan & Roberts 1967)

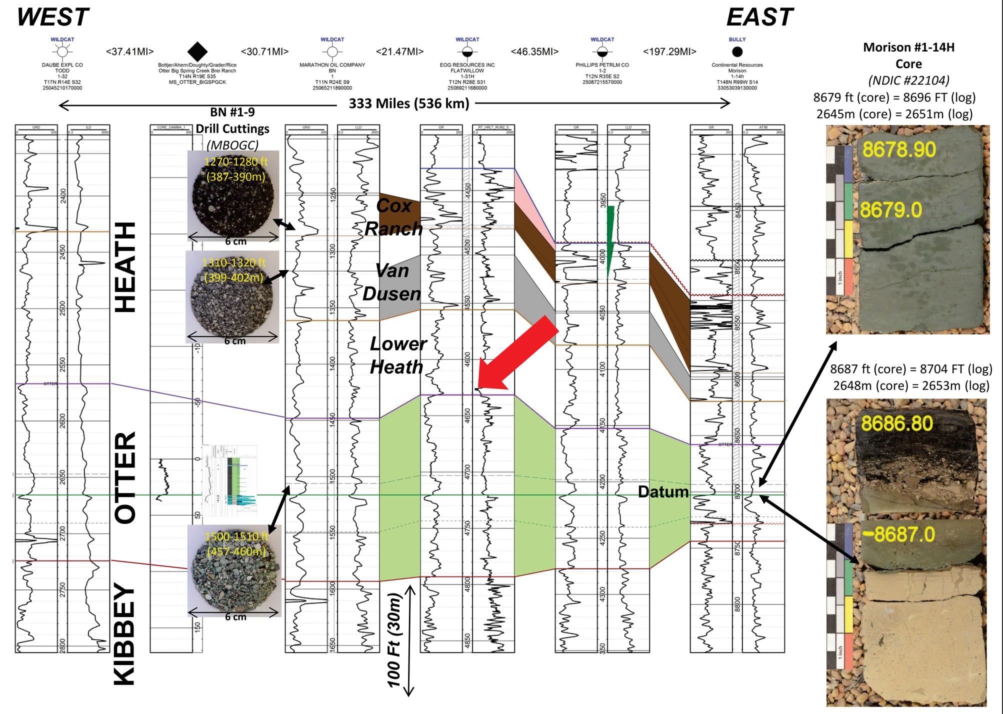


OTTER-HEATH CONTACT

- Otter defined by presence of bright green shales; Heath typified by dark gray to black shales
- Contact is NOT exposed at the surface
- Heath-Otter contact previously defined as base of a *productid*-bearing limestone bed (Easton, 1962, modification of Scott, 1935) separating overlying black shales from underlying green shales (high percentage of covered interval) (this definition does not lead to a precisely mappable contact).
- Base Heath/Top Otter contact recently re-defined as top of cream-tan limestone bed at 4632 ft depth (1412m) in EOG Flatwillow #1-31H wellbore. This is a mappable horizon in the subsurface and on seismic and separates the overlying gray & black mudrocks from underlying green mudrocks (Bottjer, 2017).

OTTER OUTCROP
Brei Ranch, Big Spring Creek
Sec 35-T14N-R19E, Fergus Co., MT





Heath vs. Heath + Tyler

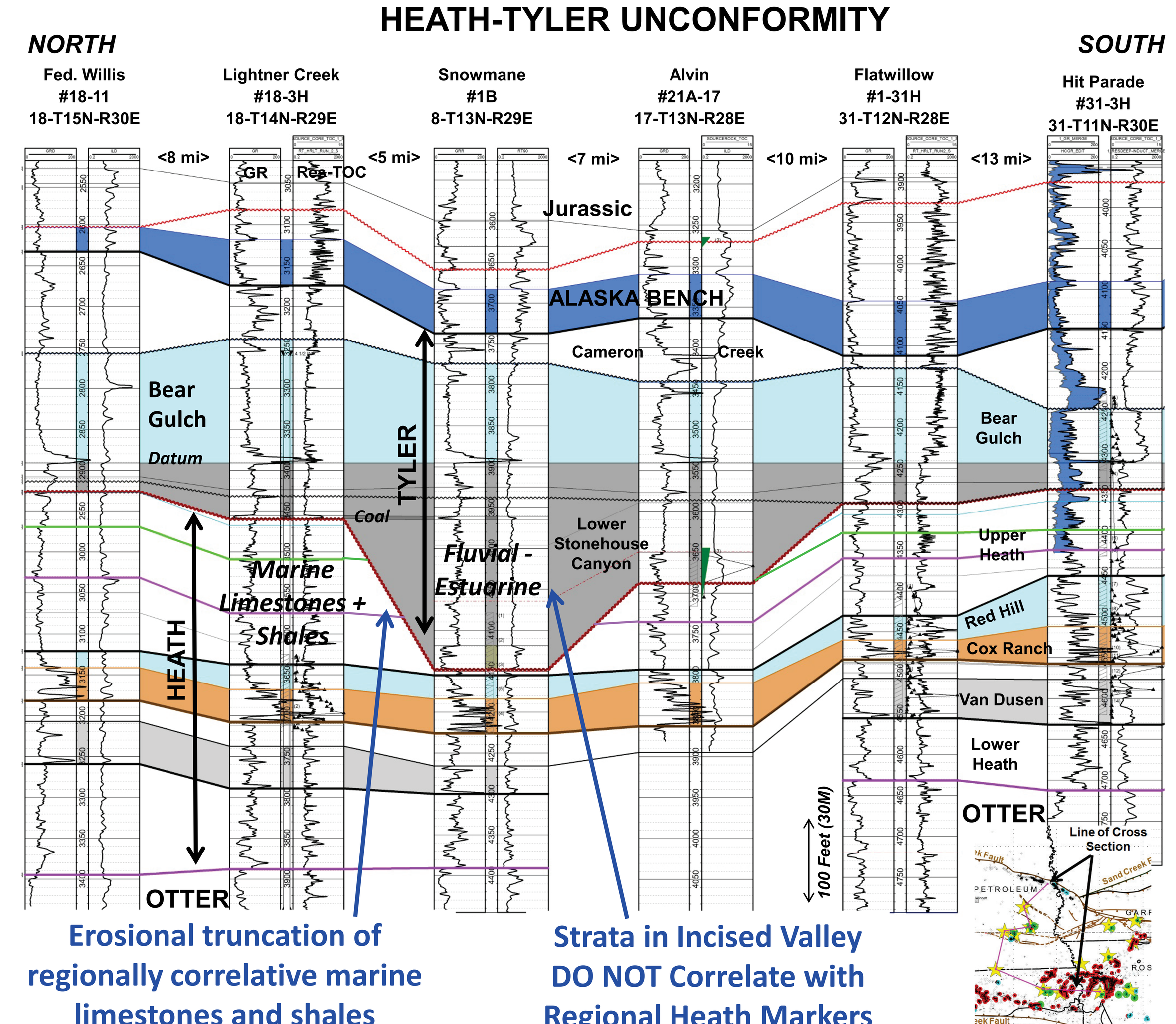
ARGUMENTS FOR INCLUDING TYLER STRATA IN HEATH

1. Tyler strata included in Heath in original definition by Scott (1935).
2. Insufficient surface or field evidence for unconformity.
3. Tyler not a mappable unit.
4. Dark gray and black shales look the same.
5. Sandstones in "Tyler" are "lateral facies equivalents of Heath limestones and mudrocks.

ARGUMENTS FOR SEPARATION OF TYLER AND HEATH STRATA

1. New cores and core-calibrated interpretations support presence of unconformity with > 400 ft (129m) of relief, in the Judith Basin to the west and in central Montana to the east of the Big Snowy Mtns. "outcrops".
2. Poor outcrops hide erosional contact, especially between incised valleys where paleosols are covered with vegetation. Paleosols are identified in cores.
3. Tyler mapped separately from Heath by MBMG (Derkey, et al 1985; Porter, et al., 1996; Porter and Wilde, 1999).
4. Black mudrocks in Heath are laterally continuous and have abundant algal organic matter; black mudrocks above unconformity (i.e. in Tyler) are laterally discontinuous and contain abundant large wood and plant fragments.
5. Lateral discontinuity of sandstones is due to their deposition in laterally discontinuous incised valleys in fluvial and estuarine environments.

HEATH-TYLER UNCONFORMITY

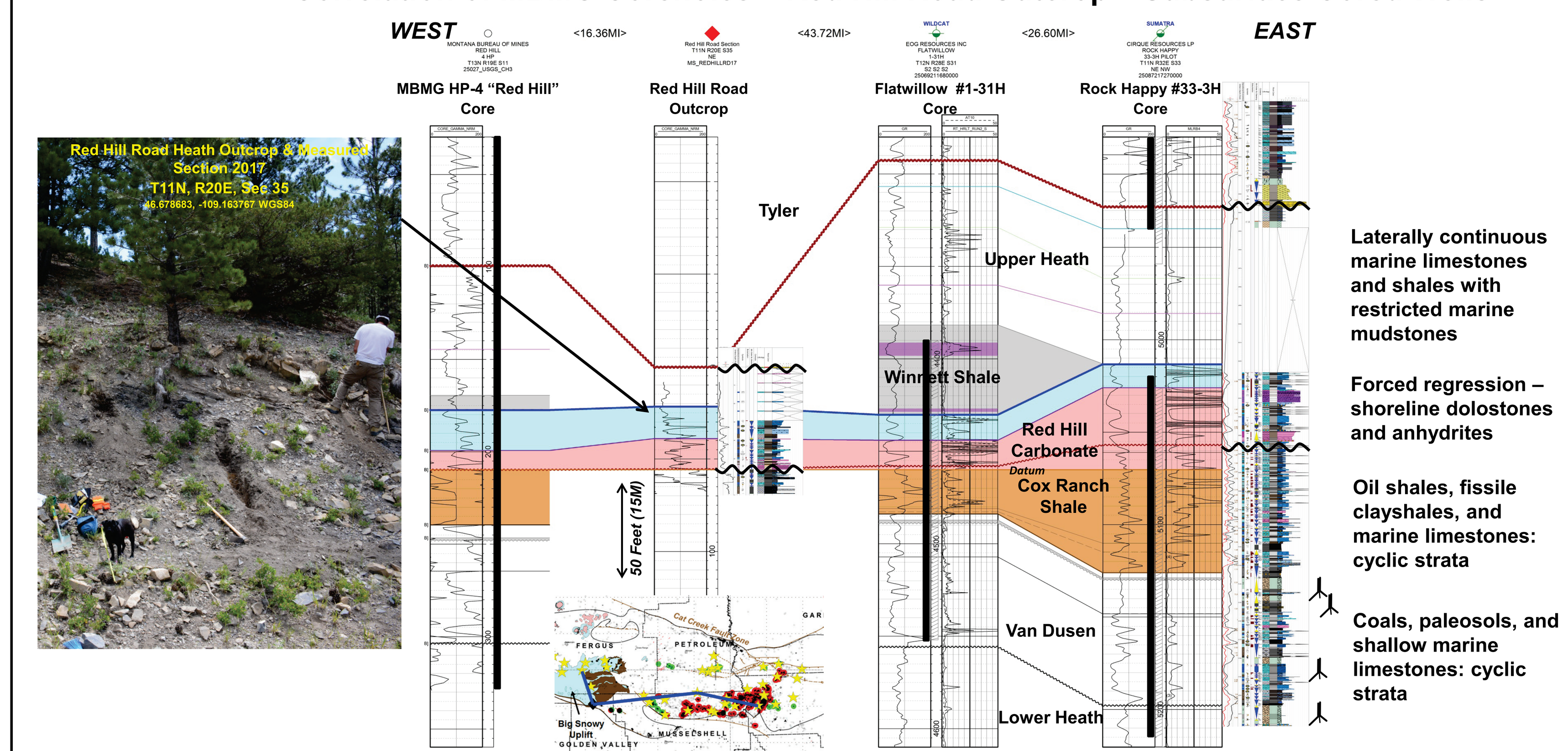


NEW DATA & HEATH INTERNAL STRATIGRAPHIC ARCHITECTURE

- Multiple new continuous cores facilitate a detailed subdivision of Heath strata (build on early work of Derkey, et al., 1985)
- Heath can be subdivided into informal units, in ascending order, lower Heath, Van Dusen, Cox Ranch, Red Hill Carbonate, Winnett Shale, and upper Heath.
- Lower Heath strata (i.e. Van Dusen & Cox Ranch) are laterally continuous
- Middle Heath strata (i.e. Red Hill Carbonate & Loco Ridge Gypsum) are affected by lateral facies changes & forced regression
- Oil and source rock geochemistry indicates Heath mudrock deposition in marine environments populated with algal phytoplankton and green sulfur bacteria. Low sulfur, high TOC (up to 27%), low wax. The abundance of gammacerane, aryl isoprenoids, and C34 extended hopanes indicate deposition in a marine, stratified water column with photic zone euxinia and suggests hypersaline, evaporitic, restricted conditions.
- Up-section trend towards dryer & hotter conditions culminating in evaporation of Big Snowy Trough at end of Red Hill Carbonate deposition
- Cyclic sedimentation in the Heath is indicative of the onset of the Late Paleozoic Ice Age (Ahern and Fielding, 2019)

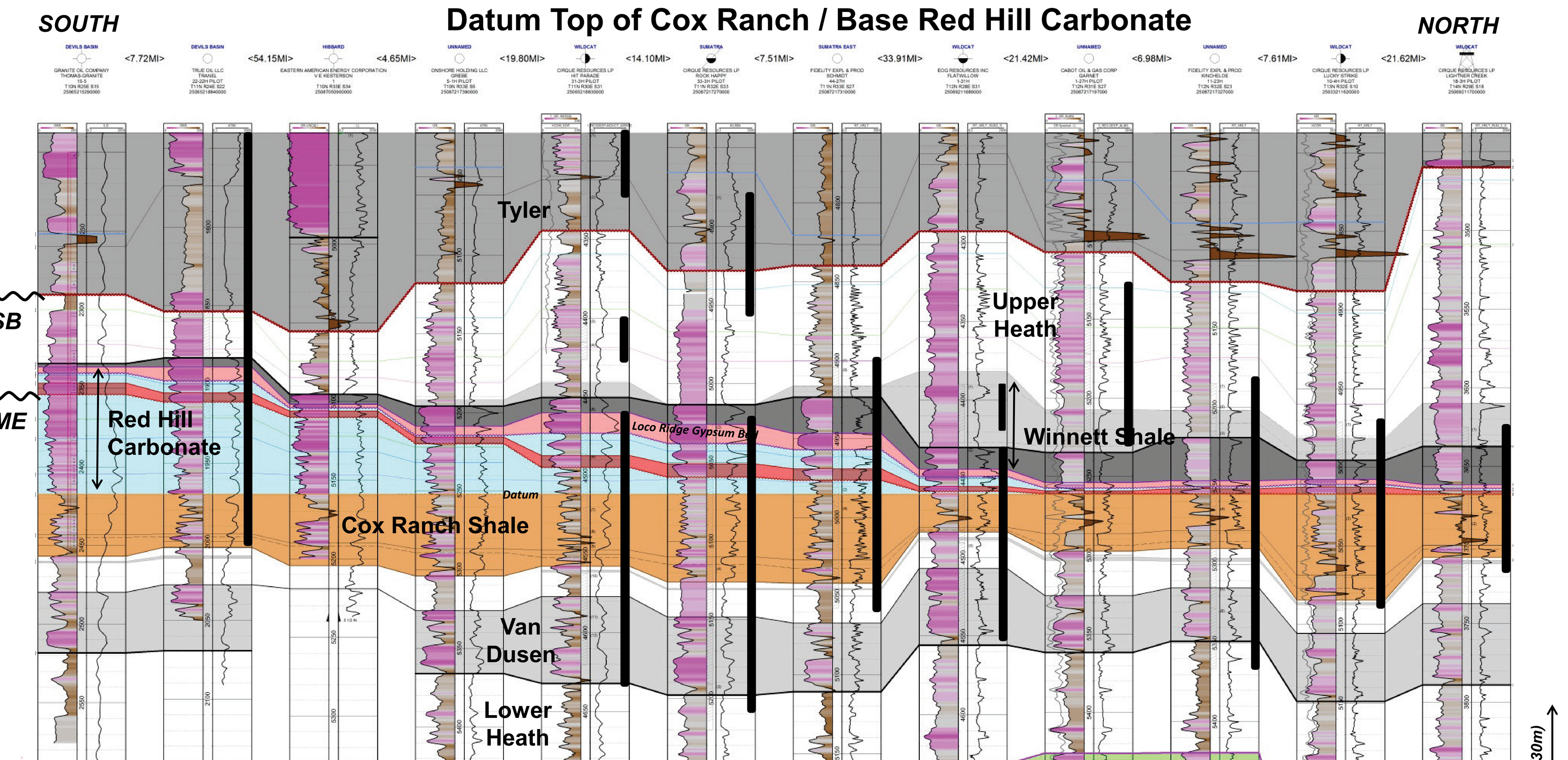
MIDDLE HEATH INTERNAL STRATIGRAPHY

Correlation of MBMG Coreholes – Red Hill Road Outcrop – Subsurface Cored Wells



MIDDLE HEATH INTERNAL STRATIGRAPHY

Datum Top of Cox Ranch / Base Red Hill Carbonate



- Upper Heath, Cox Ranch, & Van Dusen are correlative over large area
- "Red Hill Carbonate" – 2 forced regressions w/ arid shoreline dolostones & anhydrites (Loco Ridge Gypsum Bed of Derkey, et al (1985))
- Lowstand basin–filling "Winnett Shale "in North

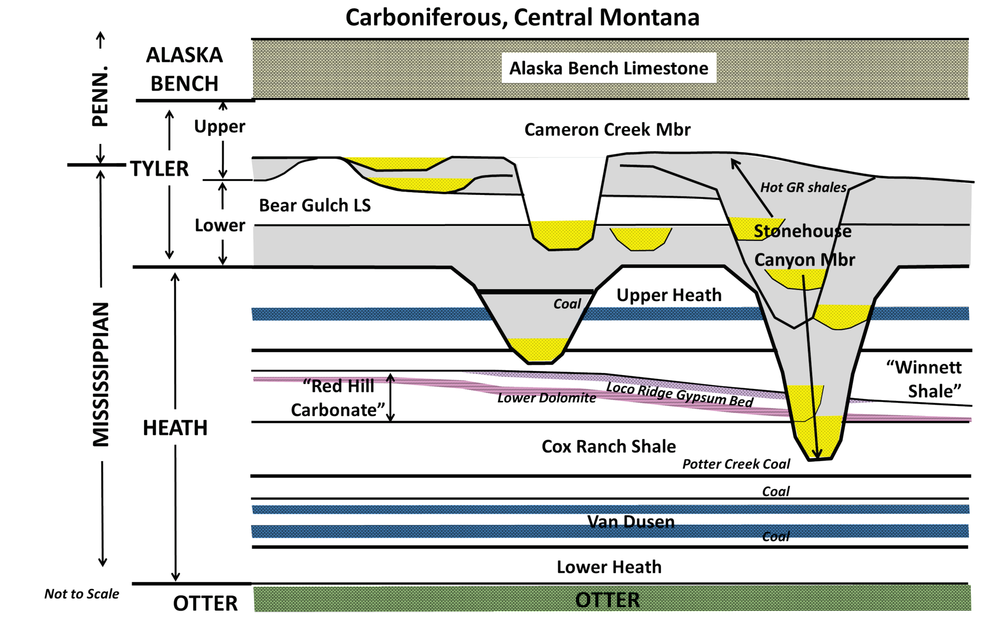
After Bottjer and Doughty (2017)

ONGOING & FUTURE WORK

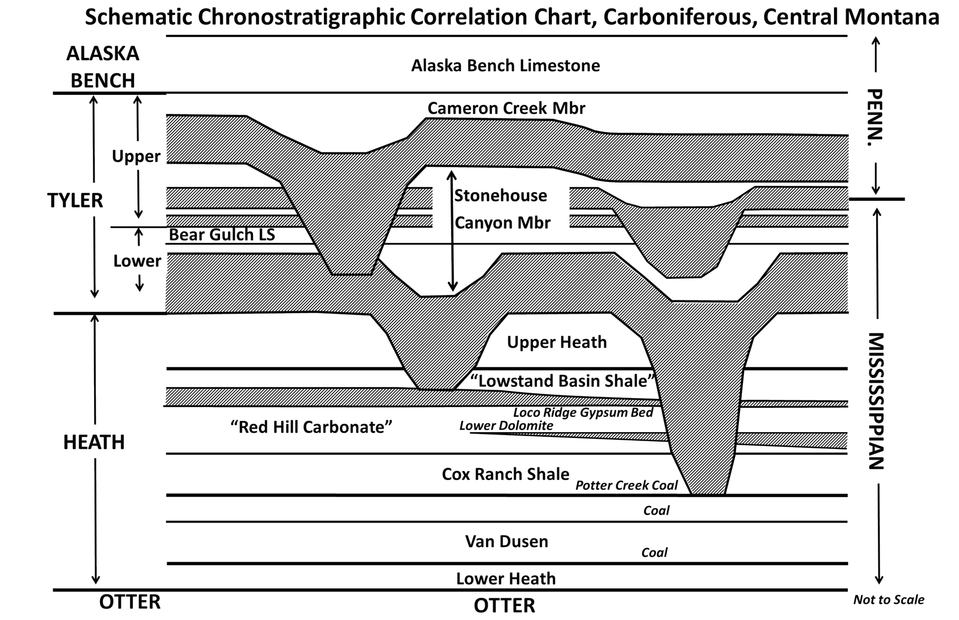
- Secure additional core donations to public repositories
- Palynology sampling and interpretation (high-resolution paleontology is especially helpful in marginal to non-marine strata) (in progress)
- Detrital zircon sampling and evaluation of sandstones to determine a) differences in provenance, b) evolution of mid-Carboniferous drainage systems, and c) potential utility of detrital zircon analyses to help with correlations. (collaboration with D. Orme & students at Montana State Univ.) (in progress)
- Correlation of Heath & Tyler strata from type area in Montana to North Dakota, maximizing use of numerous new Williston Basin cores now at NDGS.
- Integrate new central Montana data with outcrop work from southwestern Montana & southeastern Idaho – Locate the lowstand basin associated with Tyler incised valleys!

Schematic Lithostratigraphic Correlation Chart
Carboniferous, Central Montana

After Bottjer (2017)



Schematic Chronostratigraphic Correlation Chart, Carboniferous, Central Montana



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NO RECORDING

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Tyler on Heath Unconformity

1. Tyler erosionally overlies different beds in the Heath depending on the depth of valley incision & paleostructural position.
2. Erosion at the base of the Tyler is difficult to see in outcrop due to vegetative cover and a lack of laterally continuous outcrops.
3. Basal Tyler lithology is most commonly sandstone or pebble conglomerate
4. Where basal Tyler lithology is mudrock, the underlying Heath is a greenish-gray, rooted claystone (paleosol).
5. Wood and plant fragments are common above the unconformable surface, but are rare to absent in Heath strata below the unconformity.

Smith #6-1
T137N-R100W-6
USGS CRC S615
Sequence Boundary @ 8269.9 ft (2520.7m)
Basal Tyler sandstone erosionally overlying grayish-green clayshale
Tyler / Otter

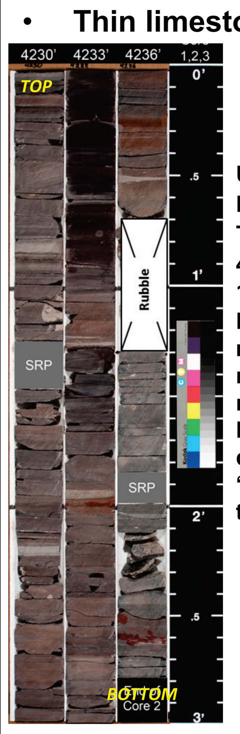
Alaska Bench "Beacon Hill"
T13N-R19E-36
Beds 27-28
Basal Tyler sandstone, base is covered with vegetation. Light gray soil below sandstone is mottled silty claystone (paleosol) – top of Heath

Rock Happy #33-3H
T11N-R32E-33
USGS CRC #T449
Sequence Boundary @ 4936.0 ft (1504.5m)
Basal Tyler sandstone and pebble conglomerate erosionally overlying fissile mudstone
Tyler / Upper Heath

Alvin C #21A-17
T13N-R28E-17
USGS CRC #T310
Sequence Boundary @ 3684.55 ft (1123.1m)
Basal Tyler sandstone erosionally overlying dolomite grainstone, with pyritized roots
Tyler / Upper Heath

Tyler – Cameron Creek Lithofacies

- Maroon to brick red, light gray, grayish-green mudrocks
- Sandstones, fine- to crs-grained, local pebble conglomerate, red - lt. gray - tan, abdnt limestone clasts
- Sandstones are cross-bedded, ripple cross-laminated, commonly fossiliferous
- Abundant oxidized wood fragments
- Thin limestones and dolostones, ranging from mudstone to fossiliferous grainstone, commonly sandy



USGS CRC #T490
Hit Parade #31-3H
T11N-R30E-31
4230-4239 ft (1289-1292m)
Fissile clayshale to silty mudstone, medium reddish gray to maroon red, hematitic, occ. red hematite beds, diagenetic calcite "beef" beds up to 4mm thick

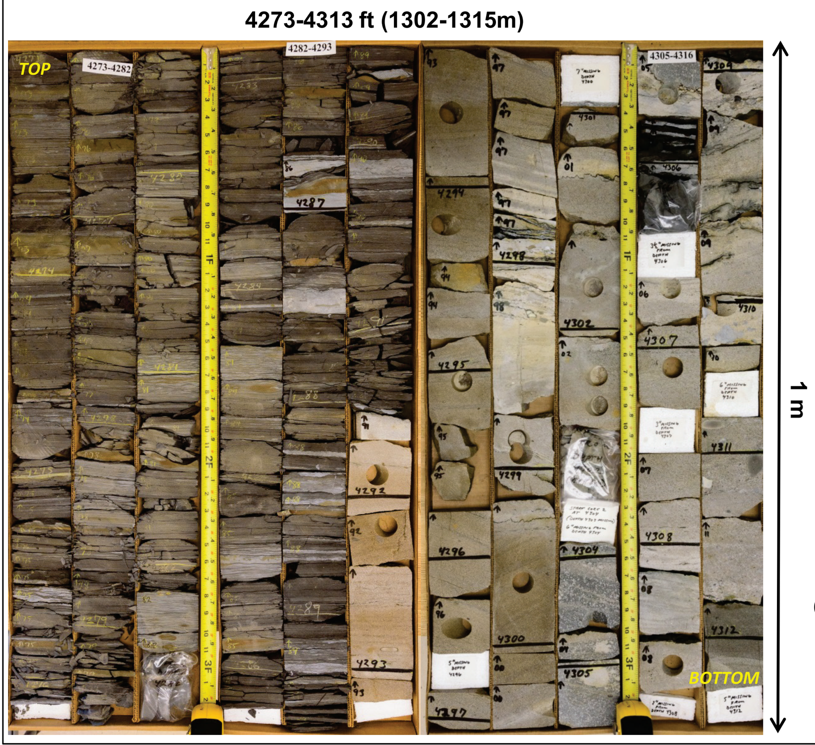
Alaska Bench "Beacon Hill"
T13N-R19E-33
Bed 13
Lepidodendron Strobilus, oxidized

USGS CRC #R505
Jerrell #11-34-16-4
T16N-R42E-34
6381-6405 ft (1945-1952m)
Maroon to brick red to light gray to light tan, cross-bedded sandstone, 175-400u (fL–mU)

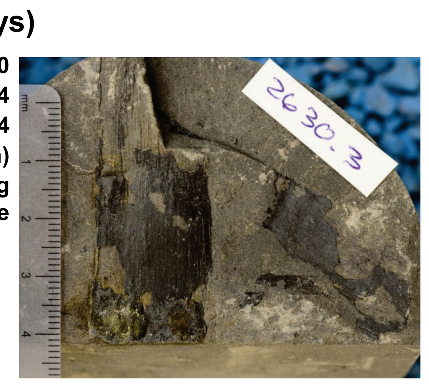
Tyler – Stonehouse Canyon Lithofacies

- Dark gray to black mudrocks, fissile clayshale, calcareous mudstone, locally sideritic
- Sandstones, fine- to coarse-grained, local pebble conglomerate, light gray to tan
- High energy cross-bedded facies and soft-sediment deformed inclined heterolithic strata
- Abundant wood fragments and leaf impressions
- Thin limestones and dolostones, ranging from mudstone to fossiliferous grainstone
- Beds are laterally discontinuous – highly channelized (multiple incised valleys)

Hougen #32-17 USGS CRC #E319
T10N-R29E-17
4273-4313 ft (1302-1315m)



USGS CRC #T260
Stoiberg #14C-14
T10N-R25E-14
2630.3 ft (801.7m)
Wood fragments on bedding plane, silty claystone

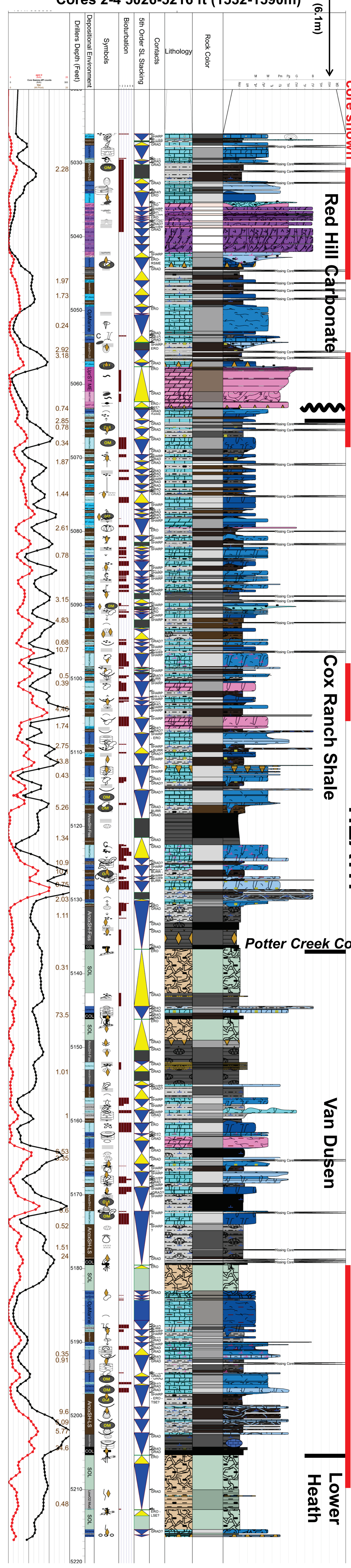


USGS CRC #R505
Jerrell #11-34-16-4
T16N-R42E-34
6479.8-6480.5 ft (1975-1975.3m)
Soft-sediment deformation & microfaulting
Fine-grained SS (150u), ripple cross-laminated

Stoiberg #14C-14 USGS CRC #T260
T10N-R25E-14
2627.7 ft (800.9m)
Palm Leaves on bedding plane, silty claystone

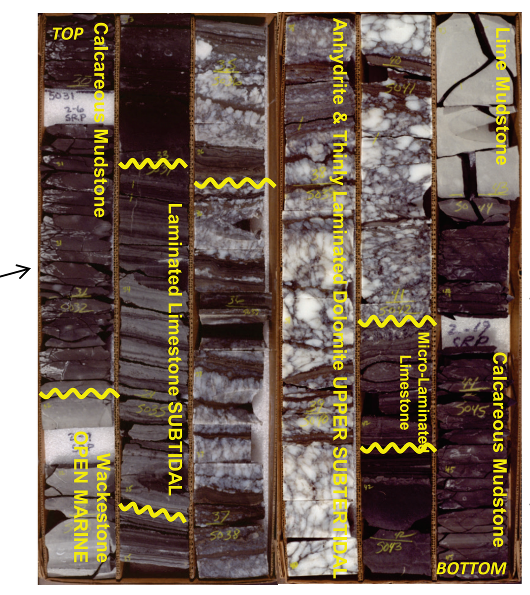
HEATH CORE

Rock Happy #33-3H
T11N-R32E-33
USGS CRC #T449
Cores 2-4 5026-5216 ft (1532-1590m)

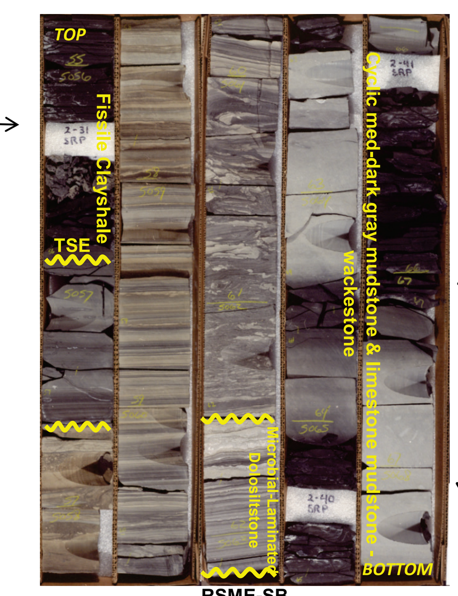


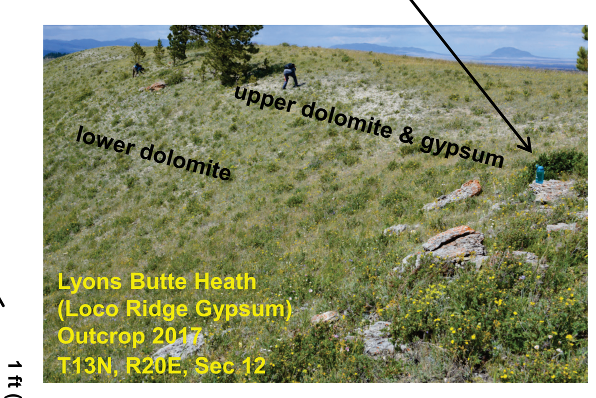
Heath – Red Hill Carbonate Lithofacies

- Progradational arid-shoreline dolograinstones with sharp bases – forced regression
- Anhydrite
- Cox Ranch – type cycles in lower parts of Red Hill Carbonate
- Some units correlate for long distances, regional low-angle erosion surfaces truncate underlying limestones mudstones



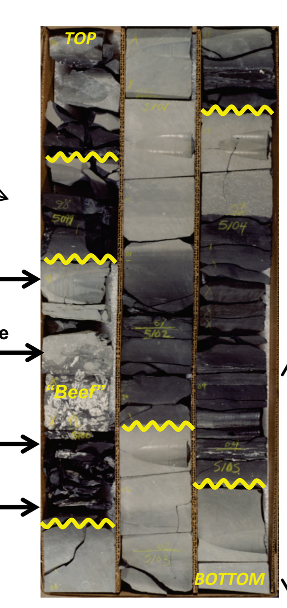
- *Includes "Loco Ridge Gypsum Bed" of Derkey et al (1985)*
- *Big Snowy Trough dried & evaporated*
- *Lowstand basin near Winnett, MT*





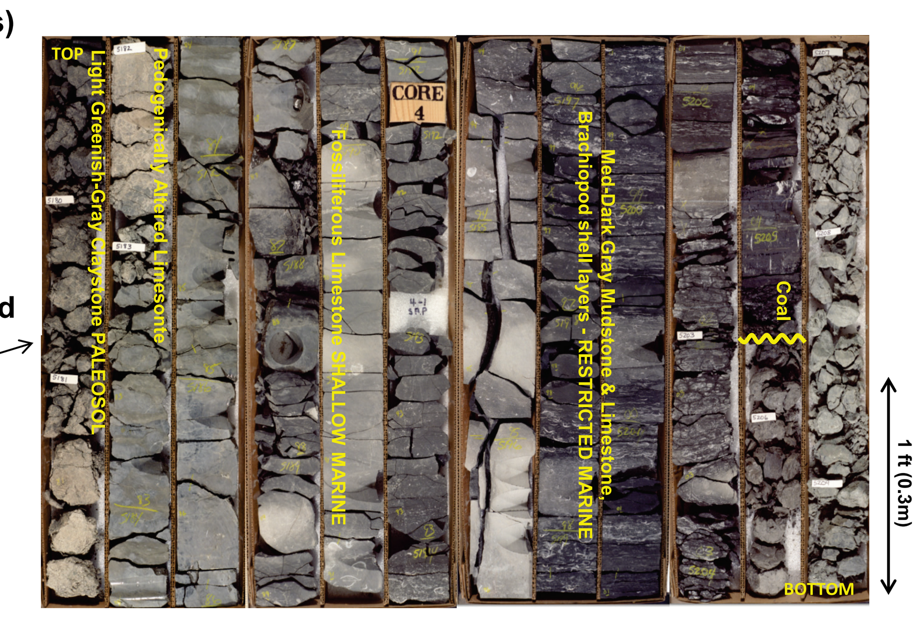
Heath – Cox Ranch Shale Lithofacies

- Fossiliferous marine limestone
- Burrowed limestone
- Calcareous dark brownish-gray to black mudstones
- Fissile black clayshale
- Common erosion at cycle base
- Good correlations for long distances



Heath – Van Dusen Lithofacies

- Light Greenish-Gray Claystones (Paleosols)
- Open Marine Limestones
- Restricted Marine Shales/ Mudstones
- Coal
- Subaerial exposure at cycle base
- Good correlations for long distances
- No outcrops – easily weathered & vegetated



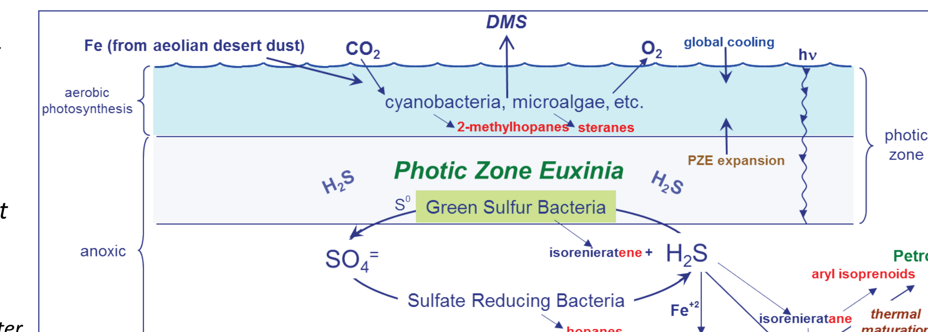
Heath – Oils and Source Rocks Organic Geochemistry

Analysis of > 50 produced oils and source rock extracts from Heath and Tyler cores and reservoirs by Geomark

- Marine environments, algal phytoplankton & green sulfur bacteria
- Family 3 = Red Hill Carbonate (high C27, low C29) – more shelfal environ. than Cox Ranch
- Family 4 = Cox Ranch Oil Shale (low C27, high C29, prominent C34 extended hopanes)
- Both contain aryl isoprenoids – PZE (photic zone euxinia)
- Both contain Gammacerane (a C30 Triterpane) – stratified water column
- Gammacerane, aryl isoprenoids, and C34 extended Hopanes associated with hypersaline, evaporitic, restricted environments
- Van Dusen extracts = biomarkers indicate a more terrestrial/coaly source

CONCLUSION: Restricted marine environment with stratified water column and photic zone anoxia and/or euxinia

Selected References: Damste, et al (1995); Koopmans, et al (1996a & 1996b); Moldowan et al (1985); Obermajor, et al (2000); Clark & Philp (1989); Schwark & Frimmel (2004); Li, et al (2017); Hill, et al (2007)



Bottjer et al (2016) after GeoMark (2011)

CONCLUSIONS

- The Heath – Otter contact is redefined as top of cream-tan oolitic limestone bed that is correlated from the Judith Basin to the Williston Basin, effectively separates overlying dark gray mudrocks (Heath) from underlying bright green mudrocks (Otter), and is a mappable surface.
- The Heath and Tyler are separated by a regional unconformity and are distinct mappable units. Heath strata are marine limestones and mudrocks that are laterally continuous over long distances. Tyler strata are predominantly fluvial and estuarine sandstones and mudrocks deposited in incised valleys that have limited areal distribution.
- Multiple new continuous cores facilitate a detailed subdivision of Heath strata (building on previous work of Derkey, et al., 1985)
- Heath is subdivided into informal units, in ascending order, lower Heath, Van Dusen, Cox Ranch, Red Hill Carbonate, Winnett Shale, and upper Heath.
- Lower Heath strata (i.e. Van Dusen & Cox Ranch) are laterally continuous
- Middle Heath strata (i.e. Red Hill Carbonate & Loco Ridge Gypsum) are affected by lateral facies changes & forced regression
- Up-section trend towards dryer & hotter conditions culminating in evaporation of Big Snowy Trough at end of Red Hill Carbonate deposition
- Cyclic sedimentation in the Heath is indicative of the onset of the Late Paleozoic Ice Age (Ahern and Fielding, 2019)