March 14, 2019

Final Report for two-year OSMP-BCPOS-JCOS proposal: "*Identifying a mass extinction in Front Range open space: Age & environments of the Lykins Formation*"

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Project Summary:

For this project, we analyzed the paleontology, sedimentology, diagenesis, geochemistry and geochronology of the Lykins Formation in JCOS, OSMP, and BCPOS, integrating results from this work with data from other regional exposures of the Lykins Formation and equivalent units. Key outcomes include: A) identification of the overall age of the Lykins Formation and the interval in which the Permian-Triassic boundary occurs; B) assessment of the environments that produced the Lykins and associated strata; and C) characterization of locations in Open Space parcels that may be suitable for connecting the public to the science and history of these rocks. These accomplishments and opportunities are synthesized below.

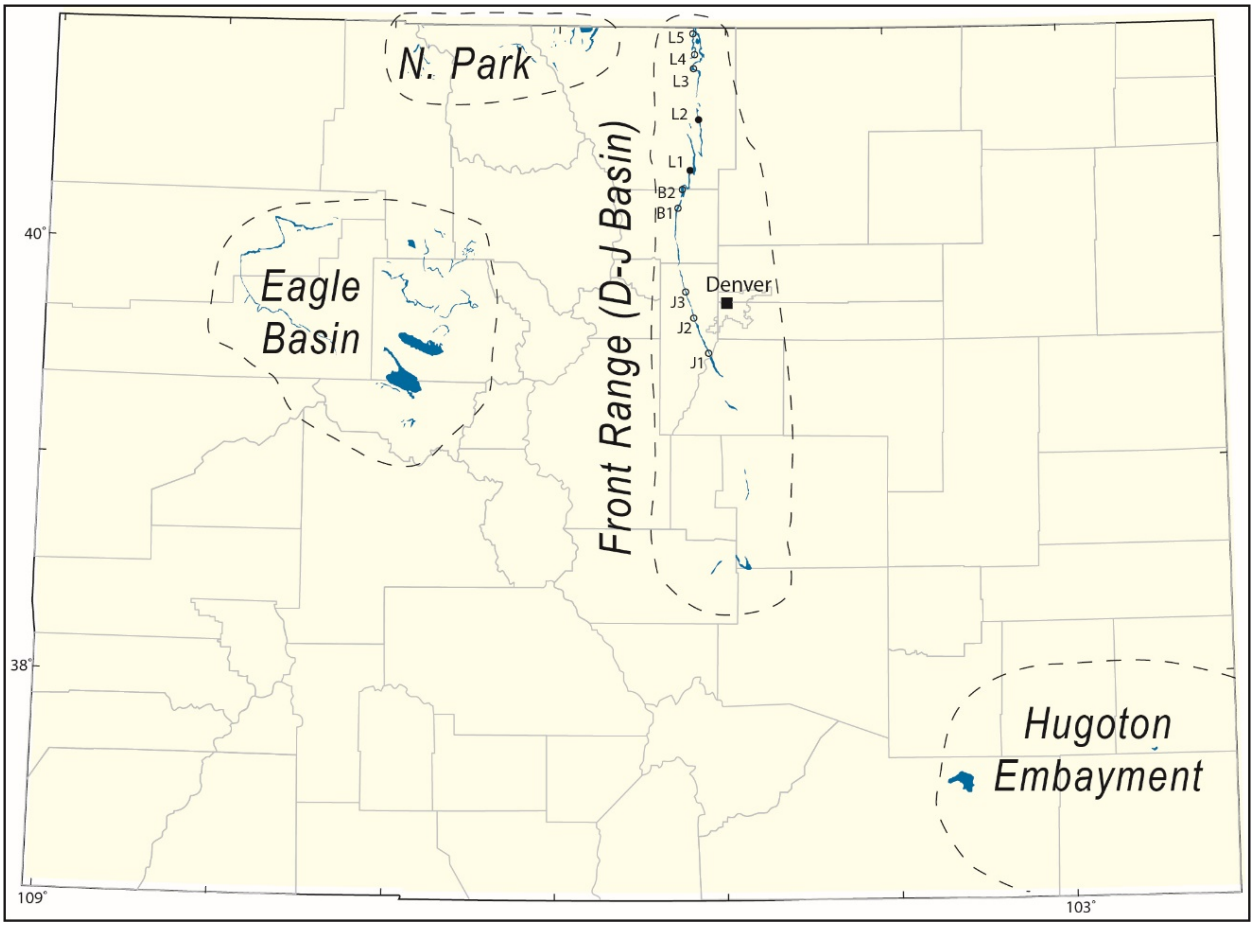


Figure 1: *Major basins (dashed outlines) in which Permian-Triassic sedimentary rocks (blue) are exposed.*

A) Age of the Lykins Formation and position of the Permian-Triassic transition

The studied outcrops represent surface exposures of strata that also occur below the surface in the Denver-Julesberg Basin, and they have correlatives in three other Colorado basins, known as the Eagle Basin, Hugoton Embayment, and North Park Basin (Fig. 1). Although the focus of this scholarship is on the surface exposures in OSMP-BCPOS-JCOS, (J1-J3, B1-B2 in Figs. 1, 3) we augment them with data from core (DH01-640; L1-L2 in Fig 1) and outcrop in Larimer County Open Space (L3-L5 in Figs. 1, 3) and elsewhere in Colorado.

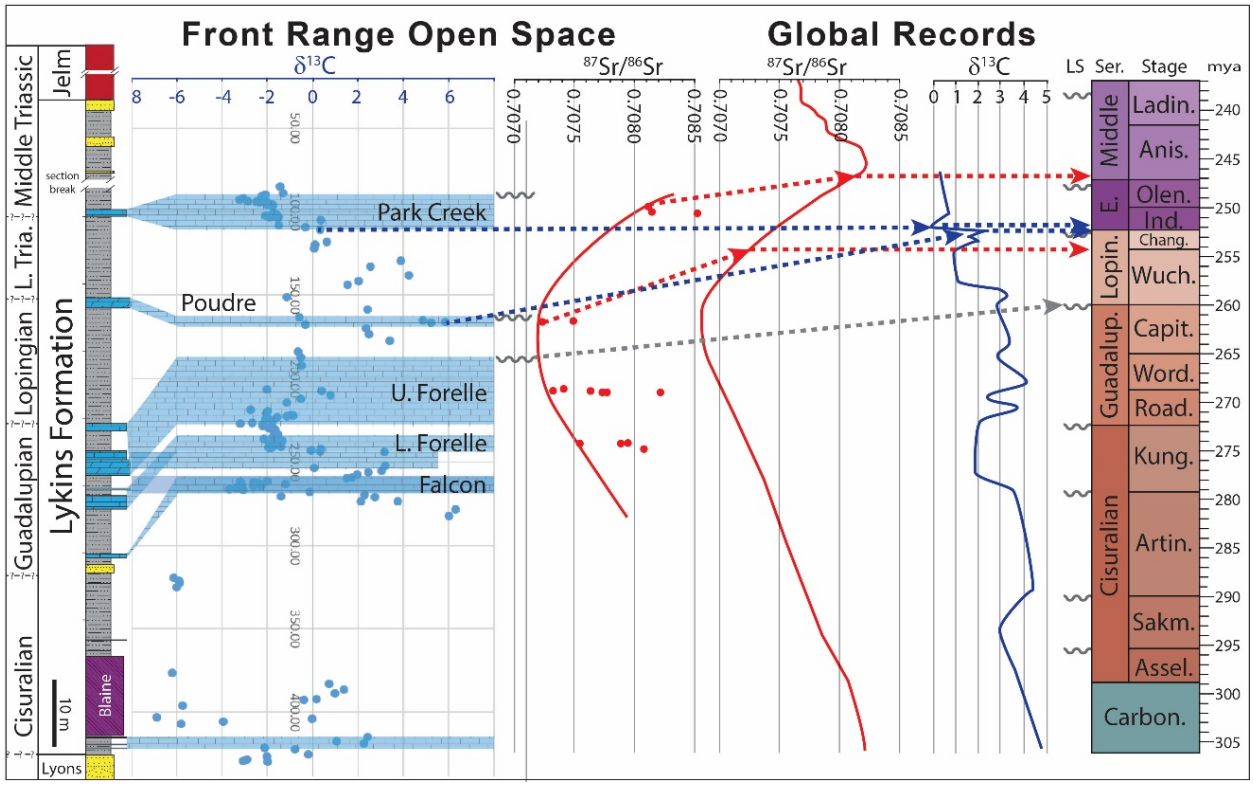


Figure 2: *Geochronologic framework for the Lykins Formation in Colorado's Front Range Open Spaces, grounded in chemostratigraphic data from core DH01-640 at left. Global chemostratigraphy and geochronology, together with Permian (brown) and Triassic (purple) time periods and stages at right. The data illustrate that the Permian-Triassic transition is probably at or very close to the Poudre Limestone Member of the Lykins Formation.*

Based on analysis of these exposures and core, the Lykins Formation spans the latest Permian and earliest to middle Triassic periods, with the transition between the two epochs falling close to the Poudre Limestone Member of the Lykins Formation (Fig. 2). In part this age span is based on Roadian age conodont microfossils found in the Falcon Member of the Lykins Formation elsewhere in Colorado, and Middle Triassic detrital zircons found in the overlying Jelm Formation (Fig. 5). Throughout Colorado and in the studied Front Range Open Spaces, the Forelle contains a regionally extensive karsted surface that is dominated by solution collapse features. This suite of features signals the presence of a substantial unconformity (=gap in time and associated erosional event), which we interpret to represent the global low in sea-level that is known from the end of the Guadalupian stage of the Permian period (grey dashed line in Fig. 2). The overlying Poudre Limestone contains a nearly +5‰ $\delta^{13}C$ excursion that mirrors a similar globally synchronous excursion known from the boundary between the latest Permian stage (Lopingian) and the Early Triassic period (lower blue dashed line in Fig. 2). Similarly, the least-

radiogenic $^{87}Sr/^{86}Sr$ signature in the entire Lykins Formation occurs in the Poudre Limestone, and matches the values known for the Permian-Triassic transition elsewhere (lower red dashed line in Fig. 2). $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ values for the overlying Park Creek Limestone are also internally consistent with global patterns, and suggest deposition during earliest Triassic time.

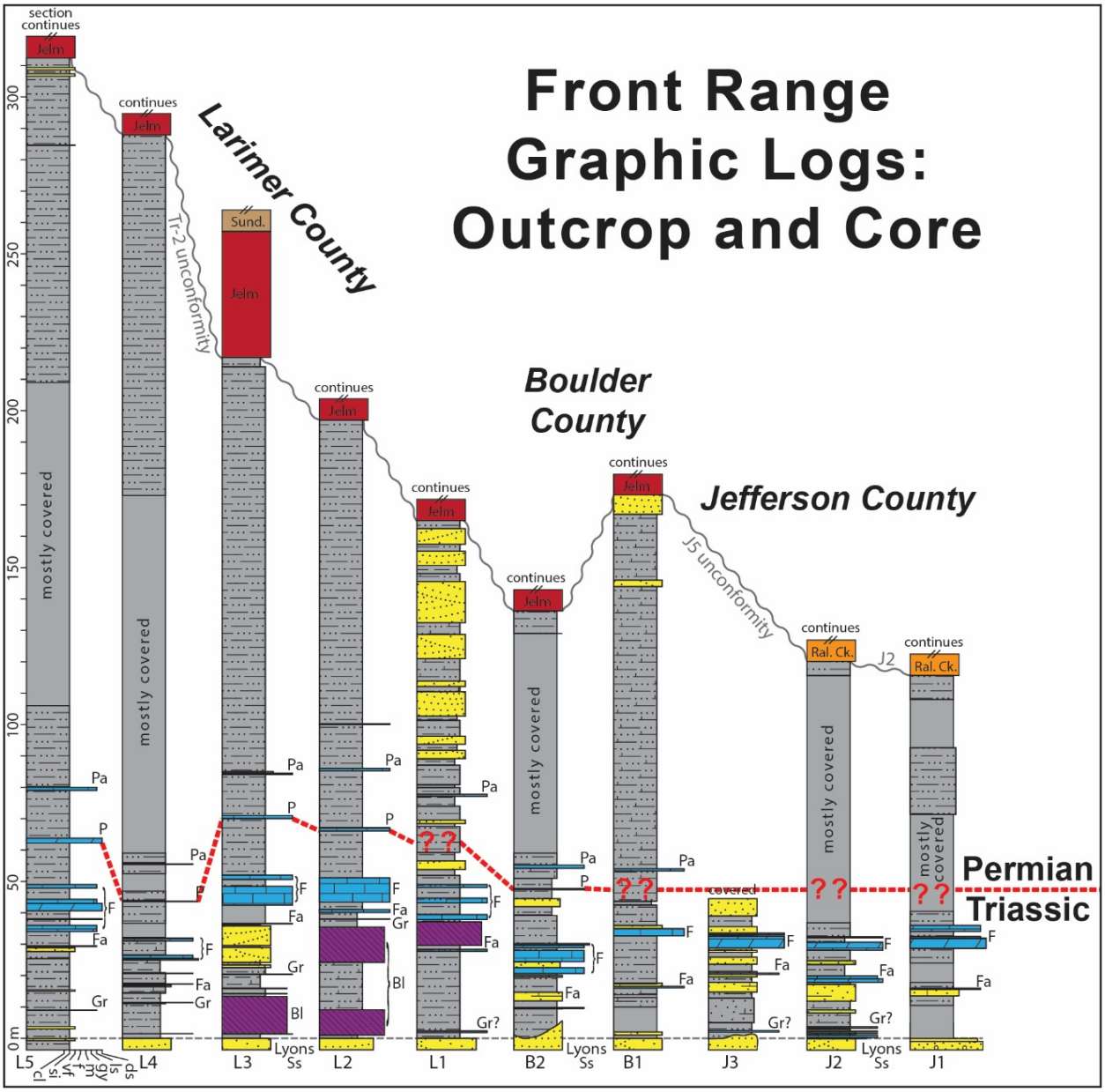


Figure 3: *Representative measured sections of strata exposed in Front Range Open Spaces, illustrating the hypothesized position of the Permian-Triassic transition (red dashed line) and progressively more erosive removal of the tops of these successions from north to south (grey wiggly lines). Key: Yellow (sandstone), grey (siltstone), blue (limestone-dolostone), purple (gypsum-anhydrite), red/brown/orange (overlying units of rock).*

Although the Permian-Triassic transition ought to fall in or very near the Poudre Limestone Member of the Lykins Formation, unfortunately this unit is thin, often covered, and difficult to identify where outcrops are overgrown or have extensive soil development (red question marks in Fig. 3). Moreover, in some areas, the upper portions of the Lykins Formation have been eroded by geologically younger

events associated with subsequent mountain-building or flooding by inland seas (Fig. 3). Thus, although the Lykins Formation is present at all studied Open Spaces, we were not always able to identify the Poudre because it may not be everywhere present or preserved.

B) Environments

Everywhere the Lykins Formation interfingers with the cross-bedded fine to very fine well-sorted tan-to-pink sandstones of the Lyons Formation, a unit that represents deposition in and between giant eolian (wind-dominated) dunes (Fig. 4). The unit contains classic wind-blown bedforms and sand grain populations, like those of the dune deposits represented by coeval formations elsewhere in Colorado (e.g., the Weber, Fryingpan, and Whitehorse Sandstones, Fig. 5).

Figure 4: *Oblique view of an ephemeral stream dissecting dunes like those that are thought to have produced the Lyons Sandstone. Image courtesy of IGP & DMNS.*

Thinly bedded red siltstone is the signature rock type of the Lykins Formation and although rare low-amplitude oscillation and ladder-shaped ripples and halite crystal impressions occur, the majority of siltstone and interbedded very fine sandstone is structureless. Windblown zircon crystal grains in these red siltstones are small, abraded, and are similar in age as those found in nearly every other Permian and Triassic rock in Colorado (Fig. 5). The Lykins has a remarkable absence of coarse sands, gravels, conglomerates, channels, or other structures typical of high velocity flow regimes common to rivers, streams, and landslides, and their absence also signals a near-absence of nearby topographic relief. Together these features suggest that the majority of the Lykins Formation accumulated as windblown dust became trapped on a broad, flat, wet landscape – an interpretation that is consistent with what we know of the regional paleogeography of this time period, where Colorado was situated near the middle of a vast supercontinent called Pangea, during a time when Pangea straddled the equator.

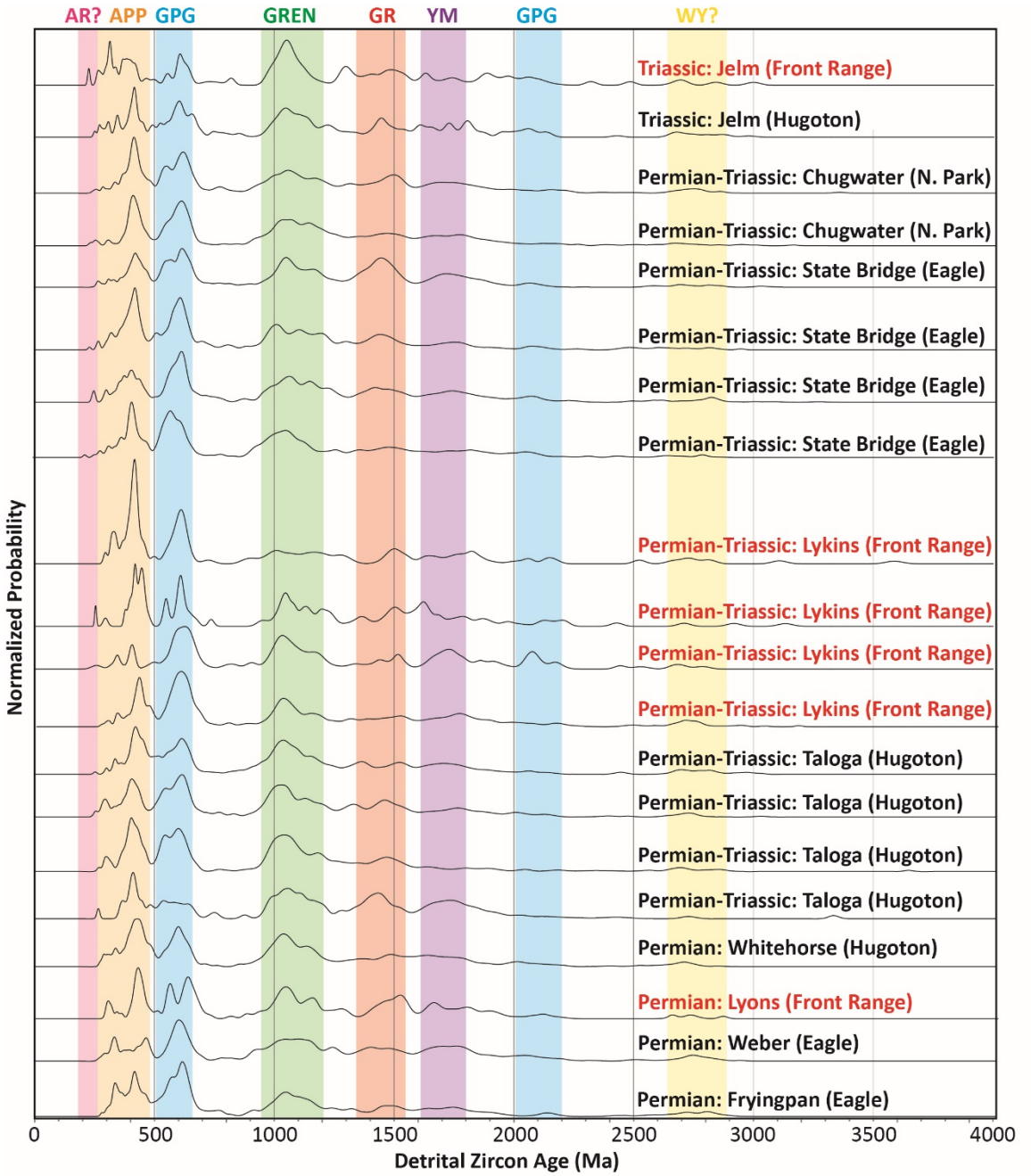


Figure 5: *Relative composition (normalized to 100%) of detrital zircon crystal ages of Front Range Open Space strata (red), compared to similar strata from Colorado's other sedimentary basins. The vertical color-shaded columns represent the different ancient mountain ranges from which these zircon crystals came, and gives a sense of the diversity of grains deposited locally.*

Intercalated in between the redbeds of the Lykins are a series of thin limestone and dolostone beds that reflect the flooding of this supercontinent by shallow seas, and the growth of beachball- to bus-sized microbial 'reefs' called stromatolites. These limestones record chemical changes through the Lykins that mirror global-scale perturbations in ocean chemistry that have been documented elsewhere in the world, and that are associated with mass extinction and oceanic overturn events. These limstones also bear microfossils characteristic of marine settings, such as ostracods, forams, sponge spicules, and calcispheres, as well as rare gastropods and bivalves. These strata, particularly the Forelle Limestone,

are often eroded at their tops, and have features like terra rosa, karst, solution collapse breccias, and related geochemical signatures consistent with exposure of these limestones to rainwater after the interior sea retreated. Such features form today in stranded reefs and limestones in Florida, Belize and the Bahamas. The basal Lykins Formation also has a thick but easily eroded gypsum bed present, called the Blaine Gypsum, that is rarely exposed at the surface. It signals the evaporation of a distal tongue of an interior seaway, and deposition of this salt may have occurred in settings analogous to those of the Dead Sea or Persian Gulf.

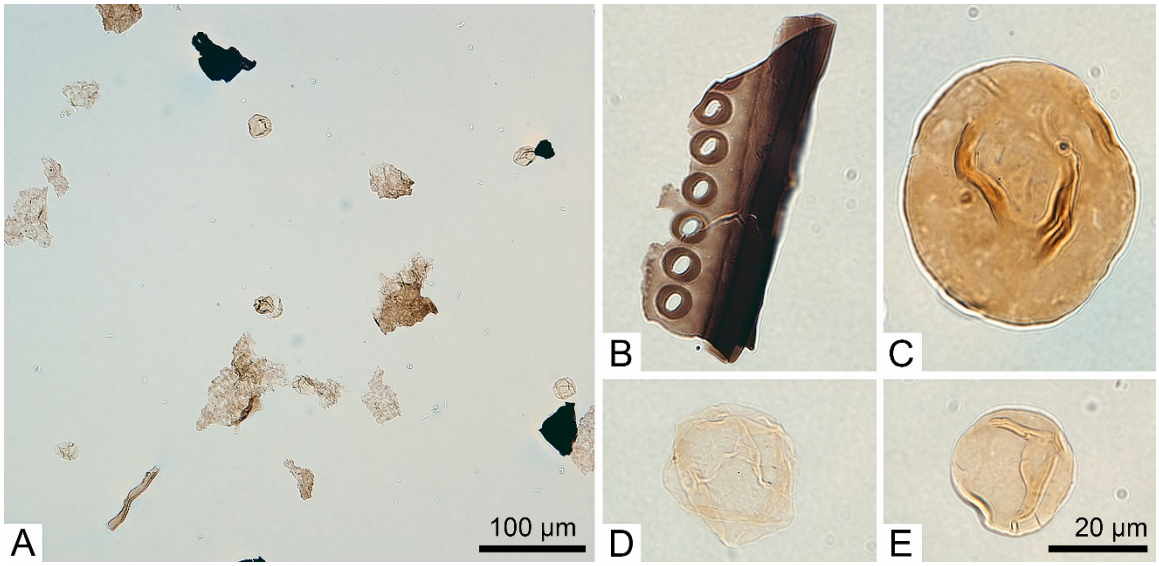


Figure 6: *Transmitted light micrographs of organic fossils from the basal black shale in the Lykins Formation, including A) miscellaneous debris; B) woody cuticle; C-E) marine acritarchs.*

Palynomaceral	3:CO-RMOS-6b	1:CO-MU-1AB	2:CO-MU-1C	4:DH01-640-L	5:DH01-640-R	7:DH01-640-FFF	6:DH01-640-QQ
I: Palynomorphs							
All	**135** (27.0%)	**0** (0.0%)	**0** (0.0%)	**0** (0.0%)	**0** (0.0%)	**1** (0.2%)	**0** (0.0%)
II: SOM							
Black wood	**72** (14.4%)	**0** (0.0%)	**119** (23.8%)	**16** (3.2%)	**0** (0.0%)	**8** (1.6%)	**18** (3.6%)
Brown wood	**37** (7.4%)	**4** (0.8%)	**21** (4.2%)	**2** (0.4%)	**1** (0.2%)	**0** (0.0%)	**0** (0.0%)
Charcoal	**0** (0.0%)	**3** (0.6%)	**0** (0.0%)	**0** (0.0%)	**0** (0.0%)	**0** (0.0%)	**0** (0.0%)
Cuticles	**227** (45.4%)	**0** (0.0%)	**0** (0.0%)	**0** (0.0%)	**3** (0.6%)	**0** (0.0%)	**0** (0.0%)
Phytoclasts	**23** (4.6%)	**0** (0.0%)	**82** (16.4%)	**104** (20.8%)	**122** (24.4%)	**221** (44.2%)	**295** (59.0%)
III: USTOM							
Amorphous	**6** (1.2%)	**493** (98.6%)	**278** (55.6%)	**378** (75.6%)	**374** (74.8%)	**270** (54.0%)	**187** (37.4%)
Total:	500	500	500	500	500	500	500

Figure 7: *Absolute and relative abundance of palynomorphs from Front Range Open Spaces.*

Additionally, plant-related microfossils known as palynomorphs occur in a rare black shale that immediately underlies the Blaine Gypsum, and includes pieces of woody debris and single-celled marine organisms called acritarchs (Fig. 6). Pairing data from this black shale with palynomorphs from core DH01-640 and the Blaine Gypsum allows an additional, independent assessment of depositional environments of the Gypsum-shale portion of the succession (Fig. 7).

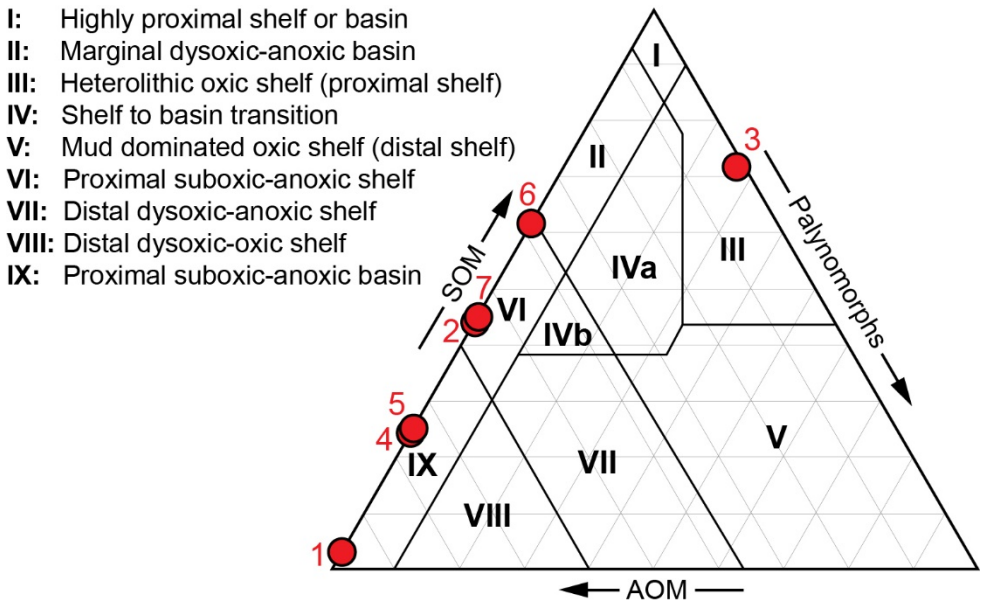


Figure 8: *Depositional environmental interpretation of palynomorphs from Front Range Open Spaces (red dots keyed to Fig. 6).*

Collectively, the data suggests deposition of these strata in a shallow near-shore basin that had low oxygen concentrations in its bottom waters, but that was periodically flushed by well oxygenated waters (Fig. 8). Such conditions are common in shallow epi-continental seas throughout earth history, such as Colorado's many Cretaceous interior seaways. Such a setting might have looked like the paleoenvironmental reconstruction in Figure 9.

Figure 9: *Oblique view of an emergent stromatolite-covered seascape like that thought to have produced the Forelle Limestone. Image courtesy of IGP & DMNS.*

C) Opportunities & next steps

We see two major opportunities stemming from our collaboration with BCPOS, OSMP, and JCOS to study the Lykins Formation in Front Range Open Spaces.

First, there are fantastic opportunities to connect the public with the story of these rocks, to reveal the colorful geology and paleontology underfoot, and to partner with land stewards to integrate 'reading of these rocks' with outdoor experiences. Many of these opportunities are on or adjacent to existing trailheads and vistas and can be accomplished in an accessible manner. With this in mind we re-mapped exposures of key members of the Lykins Formation as part of our work, and have detailed these opportunities in the attached Appendix. This appendix keys open space resources with potential Lykins Formation interpretive opportunities, overlain on paired geologic, topographic, and trail maps. In the same vein, our DMNS team has begun partnering with Paul Weimer's Interactive Geology Project (IGP), as well as other scientific illustrators and animators to develop visually compelling content that can foster such experiences (e.g., Figs. 4, 9) and are excited to extend such work in new directions to benefit communities that visit our open spaces.

Second, based on this first two-year study, we have learned where the "target zone" in which the Permian-Triassic transition occurs, and emerging analytical techniques offer an opportunity to precisely identify the boundary with further work. For example, we now know to focus efforts on the Poudre Limestone and adjacent redbeds, and in this interval we can employ two techniques that were recently successfully used to identify the Permian-Triassic boundary in redbed successions in South Africa and North Texas. By using high-resolution magnetostratigraphy in tandem with two-phase-leaching and isotopic analysis of dolomite siltstone cements, geologists in Texas and South Africa were able to drive a proverbial "golden spike" into the boundary in these areas, and have inspired us to try to do the same here in Colorado.

We are grateful for your support over the last two years, and are eager to partner with you again to realize these further outreach and scientific opportunities, or to support others on your team to leverage these strata and their stories to public benefit.

Appendix I: OSMP, BCPOS, JCOS Outreach Opportunities

In the ensuing pages are maps and descriptions of accessible locations to examine the Lykins Formation in Front Range Open Spaces. These are not the only places where the Lykins is exposed, but represent ideal targets where the unit is crossed by existing trails or where there exist panoramic views that could be augmented by slopers, interpretive signage, or smartphone-based map apps.

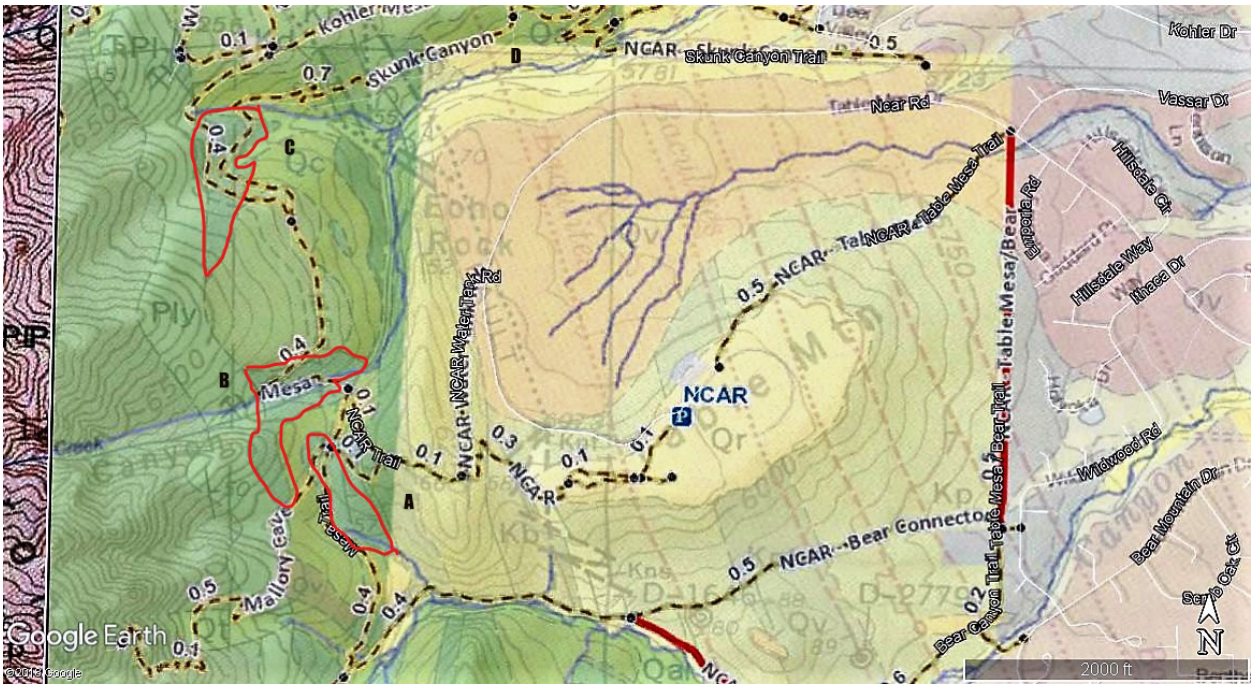
City of Boulder Parks and Open Spaces

<u>Foothill trails immediately accessible from NCAR trailhead</u>

**NCAR Trail:

A: The NCAR trail starts at the NCAR trailhead off the main parking lot. As the trail descends into the valley, it crosses from east to west, the Cretaceous Benton shale, the Cretaceous Dakota sandstone, and the Jurassic Morrison and Ralston Creek formations before entering the Permo-Triassic Lykins formation. Wells (1967), who mapped the Boulder quadrangle, left the Lykins undifferentiated, i.e. did not delineate any of its members such as the Harriman sh, Falcon ls or Forelle ls.

The Lykins formation is primarily thinly bedded reddish-brown to reddish-maroon siltstones and very fine grained sandstones intercalated with minor beds of limestone/dolostone. Because it weathers very easily, it is often poorly exposed. At this locality, the presence of the Lykins formation is inferred by the bright red soil color and the scattered boulders of yellowish-white limestone/dolostone exhibiting pin-stripe lamination, wavy lamination, small stromatolite domes and brecciation. Those boulders are quite apparent when looking across the small valley as one enters the meadow at the base of the NCAR trail. Looking west beyond the Lykins formation and its string of white boulders, the Lyons sandstone (white), Fountain formation (red, traditional "flatirons") and Pre-Cambrian granites can be seen.



The NCAR trail branches into two trails when it reaches the base of the hill: Mallory Cave Trail continuing straight ahead and to the southwest and Mesa Trail branching off to the right (heading northwest). Three targets for interpretation exist, outlined by red lines above.

**Mallory Cave Trail:

B: The Mallory Cave trail only crosses the Lykins formation at the beginning of the Mallory Cave Trail. At this location, it is poorly exposed except for the line of white limestone boulders scattered across the west side of the valley and along the trail. These most likely represent the Forelle limestone (aka Glennon limestone) member of the Lykins formation. A close examination of these boulders show biosedimentary structures such as pin-stripe laminations, small stromatolite domes, wavy laminations, fenestrae.

**Mesa Trail:

C: Mesa Trail leads northwest following the curve of the foothills. The trails crosses the Permo-Triassic Lykins formation in three different locations. A detour up Skunk Creek brings one to the Lyons-Lykins contact – Harriman shale (thinly bedded red siltstones and very fine grained sandstones) overlying Lyons sandstone (grayish-white sandstone). We were not able to specifically identify the Falcon limestone member along this stretch of creek bed.

D: However, continuing northwest along this trail passed the junction with Skunk Canyon trail, one encounters an outcrop of Forelle limestone on the southwest side of the trail. Forelle strata are perpendicular to the trail so one can see individual beds and some biosedimentary structures particularly pin-striping and wavy laminations (at right).

**Skunk Canyon Trail:

E: The Skunk Canyon Trail branches off Mesa Trail traversing downhill to the east. The trail sits on top of Quaternary alluvium and colluvium and Jurassic/Cretaceous strata.

Geology: TrPl = Lykins fm; red and light-green calcareous siltstone and fine-grained sandstone; 8 ft (2.5 m) thick crinkly limestone 100 ft (30.5 m) above the base

Geology of the Eldorado Springs quadrangle, Boulder and Jefferson Counties, Colorado, 1967, Wells, J.D., US Geological Survey B-1221-D, scale 1:24000.

Joder Ranch Open Space

**Interim Joder Ranch Trail

A: At this locality, outlined by a red line in the geologic-trail map above, the Interim Joder Ranch Trail crosses the Lykins formation (at right). The Lykins formation is primarily thinly bedded reddish-brown siltstones and very fine grained sandstones with minor beds of limestone/dolostone. Because the formation weathers easily, it is difficult to identify due to vegetation and cover along the trail. As a result, the Permian-Triassic transition which may be represented by this strata will be hard to define. The lower contact with the Lyons sandstone and upper contact with Jurassic Sundance formation maybe identifiable. The Forelle limestone member of the Lykins formation is exposed in the trail bed for approximately 2 ft (60 cm) but disappears into the ground cover along the trail. At this locality as well, the strata is offset by a fault running north-south.

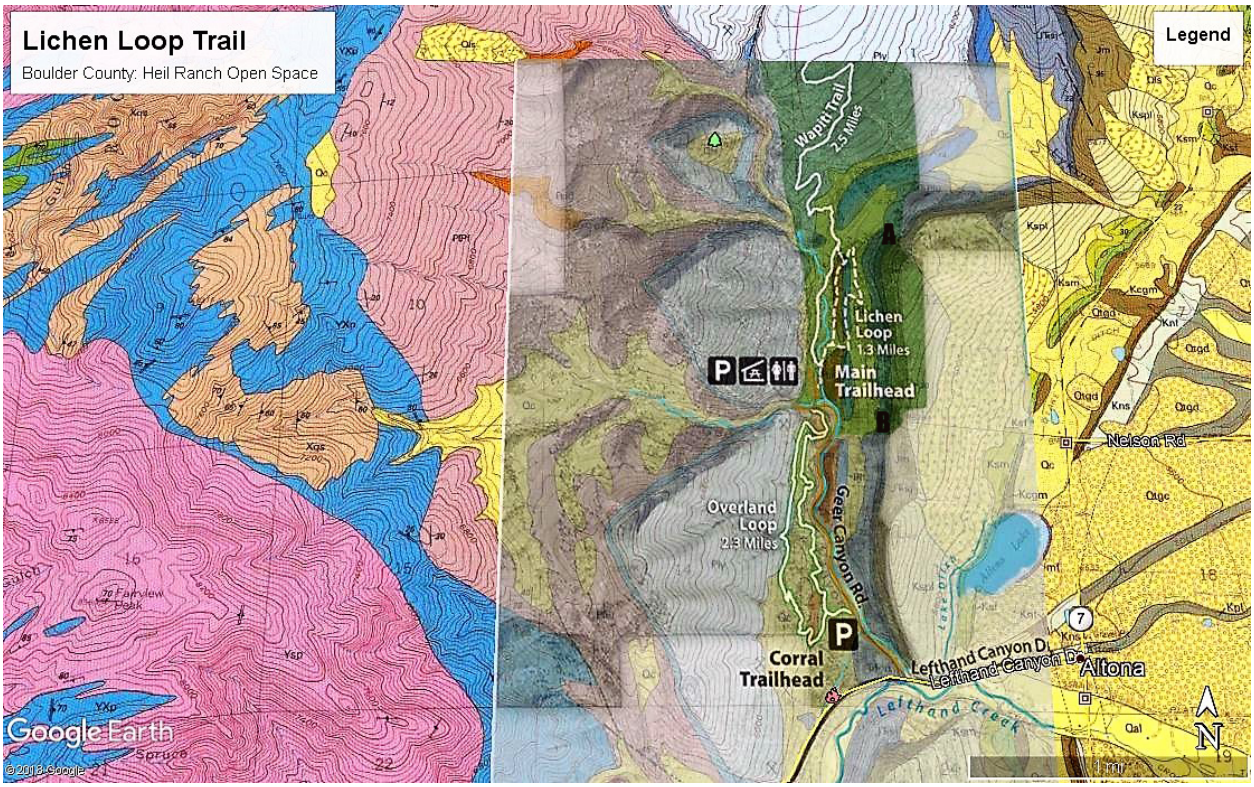
Geology: Trll—upper Lykins ledge-forming unit; light brown to pale reddish-brown, silty fine grained sandstone and siltstone; TRPlu—upper Lykins slope-forming unit; pale reddish-brown sandstone and sandy siltstone; Plg—Glennon ls (aka Forelle ls); pale red dolomitic siltstone and silty dolomite; Pll—lower Lykins ledge-forming unit; pale reddish-brown to moderate-reddish brown siltstone and sandstone; gypsum nodules locally; Js—Sundance fm

Geologic Map of the Boulder Quadrangle, Boulder County, Colorado, 1967, Wrucke, C.T. and Wilson, R.F., US Geological Survey OF-67-218, 1:24:000

Boulder County Parks and Open Spaces

Heil Valley Ranch Open Space (North)

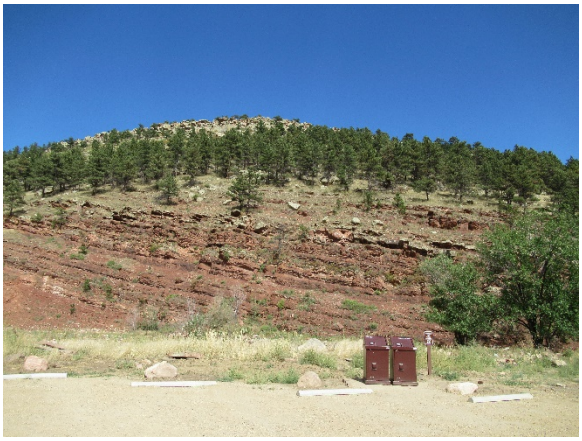
Here east of the Heil Valley Ranch Open Space Main Parking lot and Day Use Area, there are two “islands” of the Lower Lykins formation with its Forelle limestone member. The “islands” are surrounded by Quaternary colluvium/alluvium.



**Lichen Loop Trail:

A: The Lichen Loop Trail traverses the outer edge of the northern “island”. The Lykins formation is primarily thinly bedded reddish-brown to reddish-maroon siltstones and very fine grained sandstones with minor beds of limestone. The Forelle limestone member of the Lykins was significant enough to be mapped at this locality. Along the trail, there are occasional small outcrops of the Forelle limestone. However, the Forelle mostly shows up as scattered white limestone/dolomite boulders along the trail and in the adjacent meadows. Brecciation (at right), pin-striped laminations, wavy laminations, small stromatolite domes (planar view) and fenestrae are common biosedimentary structures. Pre-Cambrian dacite forms the lower contact of the Lykins at this locality.

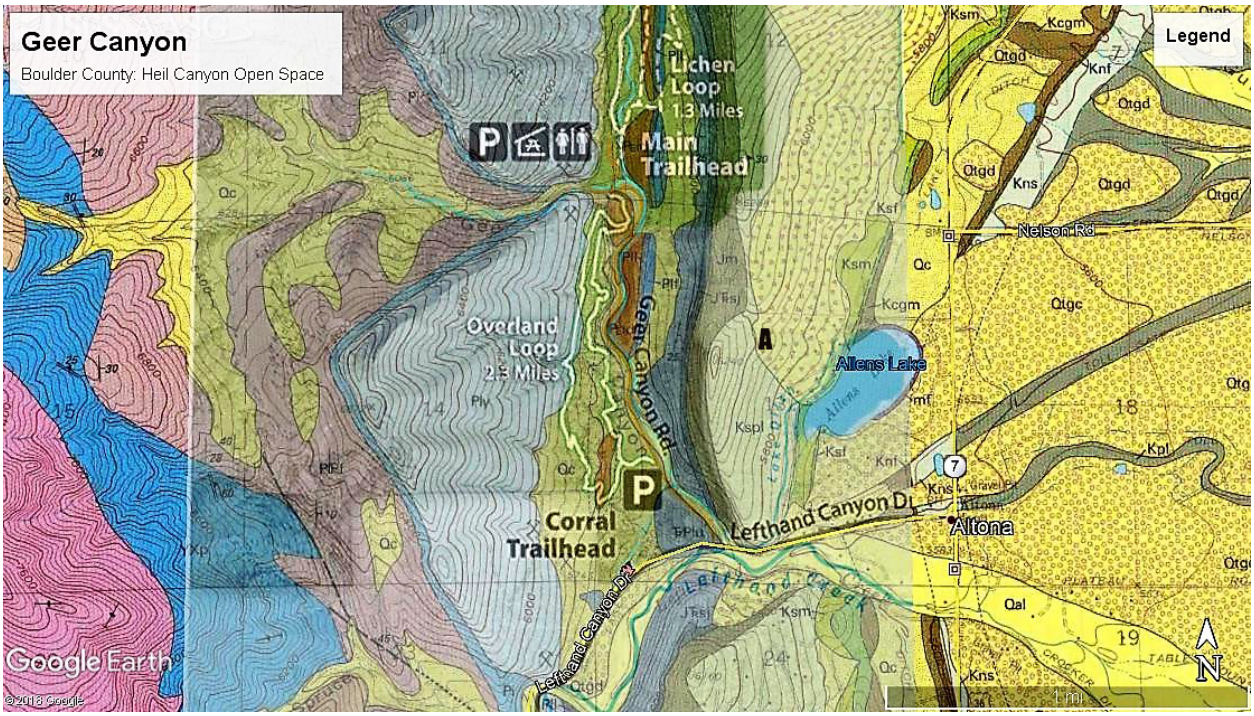
B: The southern “island” of Lower Lykins and the Forelle limestone member of the Lykins lies directly east of the Main Parking lot and Day Use area (at right). There are no trails crossing it.



Geology: Lykins fm: thickness at this location 640 ft (195 m); Pll = Lower Lykins (Bergen sh aka Glendo sh, Falcon ls, Harriman sh) moderate reddish-brown, silty shale with minor ls; Plf = Forelle ls member, yellowish-brown, finely laminated; thickness 20 ft (6 m); TrPlu = Upper Lykins = Strain sh with 2 ft (60 cm) thick Park Creek ls member 60 ft (18 m) above top of Forelle ls; maroon to reddish-brown siltstone and sandstone. No Poudre ls found

Geologic Map of the Lyons Quadrangle, Boulder County, Colorado, 1988*,* William A. Braddock, Rodney G. Houston, Roger B. Colton, and James C. Cole, US Geological Survey GQ-1629, scale 1:24000.

<u>Heil Valley Ranch Open Space (Central)</u>



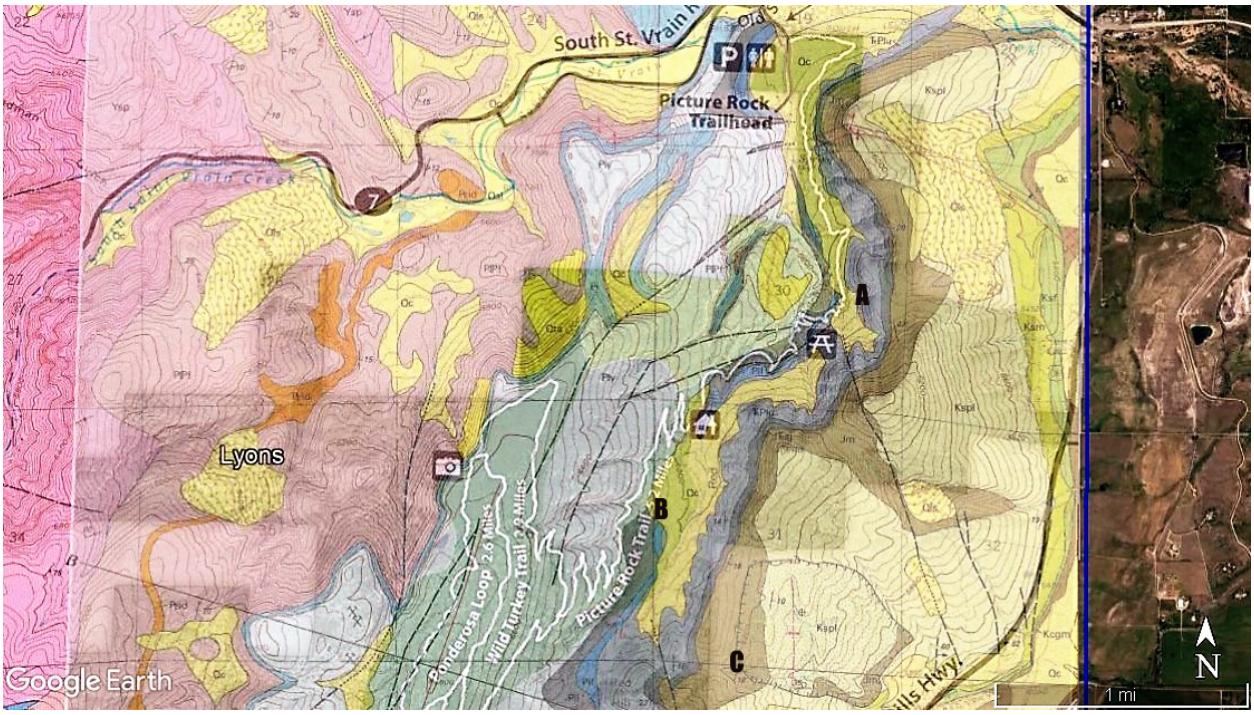
**Geer Canyon – south entrance into Heil Valley Ranch from Left Hand Canyon Rd, Forelle limestone member and the Upper Lykins formation are exposed in the creek bed and on the east side of canyon. Possibly a good location for an Overview as the entrance road to Heil Valley Open Space borders the locality.

A: Forelle limestone member and Upper Lykins formation(Strain shale member of the Lykins) and overlying formations – Triassic Jelm, Jurassic Sundance and Morrison formations followed by Cretaceous South Platte formation (ridge forming sandstone). The Permian-Triassic transition may be represented by this strata. The Upper Lykins continues northward to the east of the Lichen Loop Trail – Colluvium/Alluvium separates the Upper Lykins from the “islands” of Lower Lykins formation and Forelle limestone member. The less resistant red beds of the Lykins formation having formed “valleys” that the colluvium/alluvium filled.

Geology: Lykins fm: thickness at this location 640 ft (185 m); Pll = Lower Lykins (Bergen sh aka Glendo sh, Falcon ls, Harriman sh) moderate reddish-brown, silty shale with minor ls; Plf = Forelle ls member, yellowish-brown, finely laminated; thickness 20 ft (6 m); TrPlu = Upper Lykins = Strain sh with 2 ft (60 cm) thick Park Creek ls member 60 ft (18 m) above top of Forelle ls; maroon to reddish-brown siltstone and sandstone. No Poudre occurs.

Geologic Map of the Lyons Quadrangle, Boulder County, Colorado, 1988, William A. Braddock, Rodney G. Houston, Roger B. Colton, and James C. Cole, US Geological Survey GQ-1629, scale 1:24000.

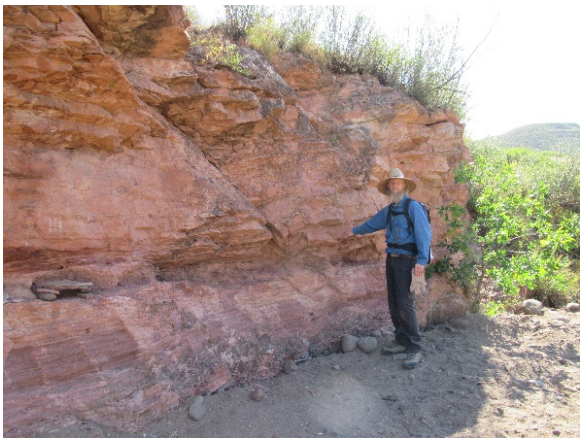
<u>Heil Valley Ranch Open Space (South)</u>



**Picture Rock Trail:

A: trail encounters Lower Lykins formation. The Forelle limestone member of the Lykins is mapped but is more difficult to identify due to vegetation and cover along the trail. The Lykins formation is primarily thinly bedded reddish-brown to reddish-maroon siltstones and very fine grained sandstones with minor beds of limestone. The siltstone/sandstone beds weather easily forming valleys between the more resistant Lyons sandstone and Jelm/Sundance formations which, respectively, form the lower and upper contact with the Lykins formation. The thickest and most prominent limestone bed is the Forelle limestone (at right). Locally, it can vary in thickness anywhere from .5 m to 20 m. Where the carbonate beds outcrop, one can see pin-striping, wavy laminations, small stromatolite domes, brecciation and fenestrae. In the area, the Forelle member has been quarried for its limestone. There is a nice outcrop of Forelle ls in the stream bed forming the north end of Red Hill Gulch (private property).

B: trail encounters Lower Lykins formation and Forelle limestone. Possibly good spot to see the contact between the Lyons sandstone and the Lower Lykins as well as exposures of Forelle limestone member. Again possible biosedimentary structures include fine laminae, stromatolite domes, brecciation and fenestrae (at right).



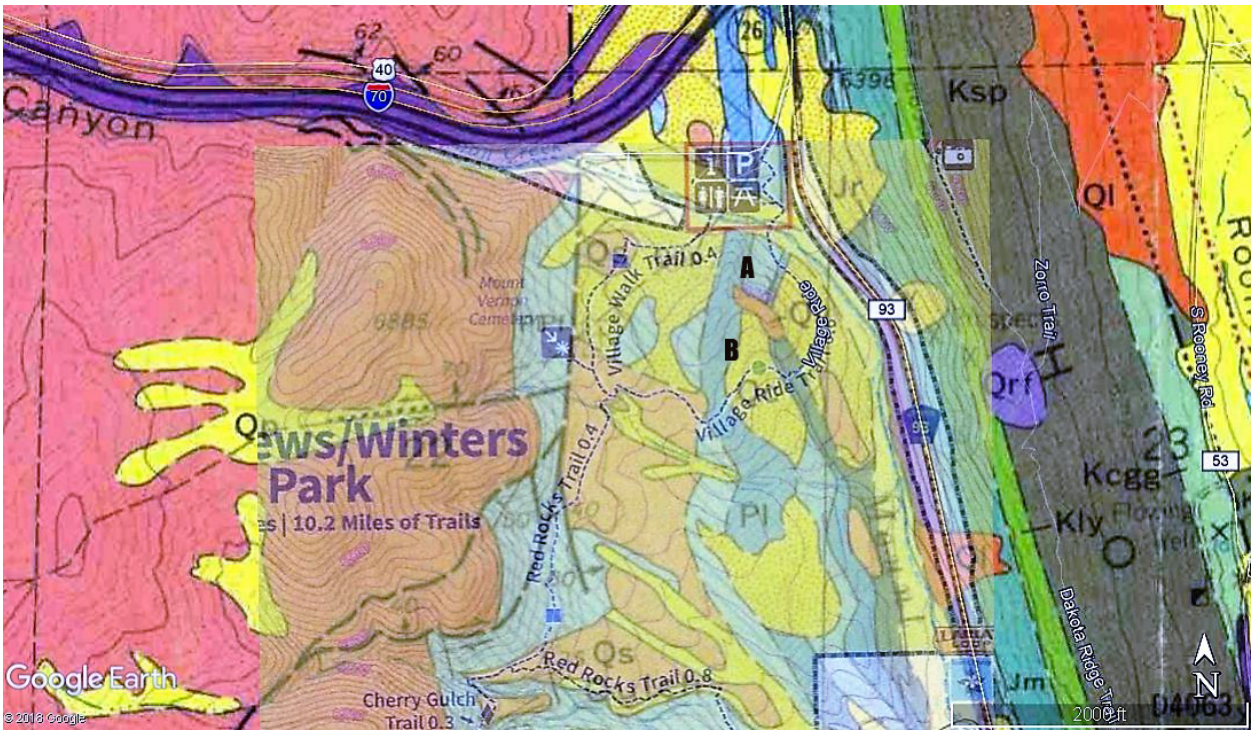
C: Overview -- an almost complete section of Lykins formation is present here at Red Hill. It includes the Lower Lykins, the Forelle member and the Upper Lykins with the Park Creek limestone member; only the Poudre limestone is missing. This is also the farthest south that the Park Creek limestone member is exposed. Lower contact with Lyons sandstone and upper contact with Jelm/Sundance formation. This strata may also represent the Permian-Triassic transition.

Geology: Lykins fm: thickness at this location 640 ft (195 m); Pll = Lower Lykins (Bergen sh aka Glendo sh, Falcon ls, Harriman sh) moderate reddish-brown, silty shale with minor ls; Plf = Forelle ls member, yellowish-brown, finely laminated; thickness 20 ft (6 m); TrPlu = Upper Lykins = Strain sh with 2 ft (60 cm) thick Park Creek ls member 60 ft (18 m) above top of Forelle ls; maroon to reddish-brown siltstone and sandstone. No Poudre occurs.

Geologic Map of the Lyons Quadrangle, Boulder County, Colorado, 1988, William A. Braddock, Rodney G. Houston, Roger B. Colton, and James C. Cole, US Geological Survey GQ-1629, scale 1:24,000.

Jefferson County Parks and Open Spaces

Matthews/Winters Open Space



**Village Ride Trail:

A: This trail is designated for bikes and accessed from the Matthews/Winters parking lot off of the Hwy 93 and I-70 interchange. The Lykins formation is comprised of reddish-brown thinly bedded siltstones and sandstones with minor limestone/dolostone beds (at right). The siltstones and sandstones are easily weathered. One can see the effects of this as you cross the bridge over Mount Vernon Creek. Looking to the right one sees the white outcrops of the Lyons sandstone forming the low ridge. The softer Lykins siltstone and sandstone has eroded way leaving the top on the Lyons sandstone exposed as an east facing dip-slope. The soil is here a reddish-brown color and one can see the remnants of an old quarry where the limestone beds of the Lower Lykins have been mined for lime. The Upper Lykins (Strain shale) is poorly exposed and the presence of Permo-Triassic boundary would be difficult to establish at this locality. NOTE: There are possible WPA-era structures present where the Forelle might have been quarried in the past, and where there are bunker-like excavations and trenches with small walls and berms present. These might present an opportunity to illustrate historic use of these rocks as building or agricultural materials and/or to provide a window into early settlement of the region.

B: The trail crosses perpendicular to the strike of the Lower Lykins formation and the Forelle limestone member. Looking southeast from this vantage point, one can trace the ridge of resistant Lyons sandstone and the smaller ridge of Forelle limestone south towards Morrison. Locally, the Forelle limestone can be divided into a lower Forelle (limestone), middle Forelle (red siltstone beds) and upper Forelle (limestone). Where present, a small swale can be seen in the landscape between the two more resistant limestone beds. Pin-stripe laminae, wavy laminae, small stromatolite domes (visible above) and fenestrae characterize the Forelle limestone.

C: None of the Winters-Matthews Open Space trails cross this section. However, C outlines a continuous section of strata starting with the Fountain formation, overlain by the Lyons sandstone, followed by the Lykins formation. At this locality, the Lower Lykins, Forelle limestone member and Upper Lykins, i.e., the Strain shale are present (at right). The upper contact with the Lykins formation is covered by Quaternary alluvium.

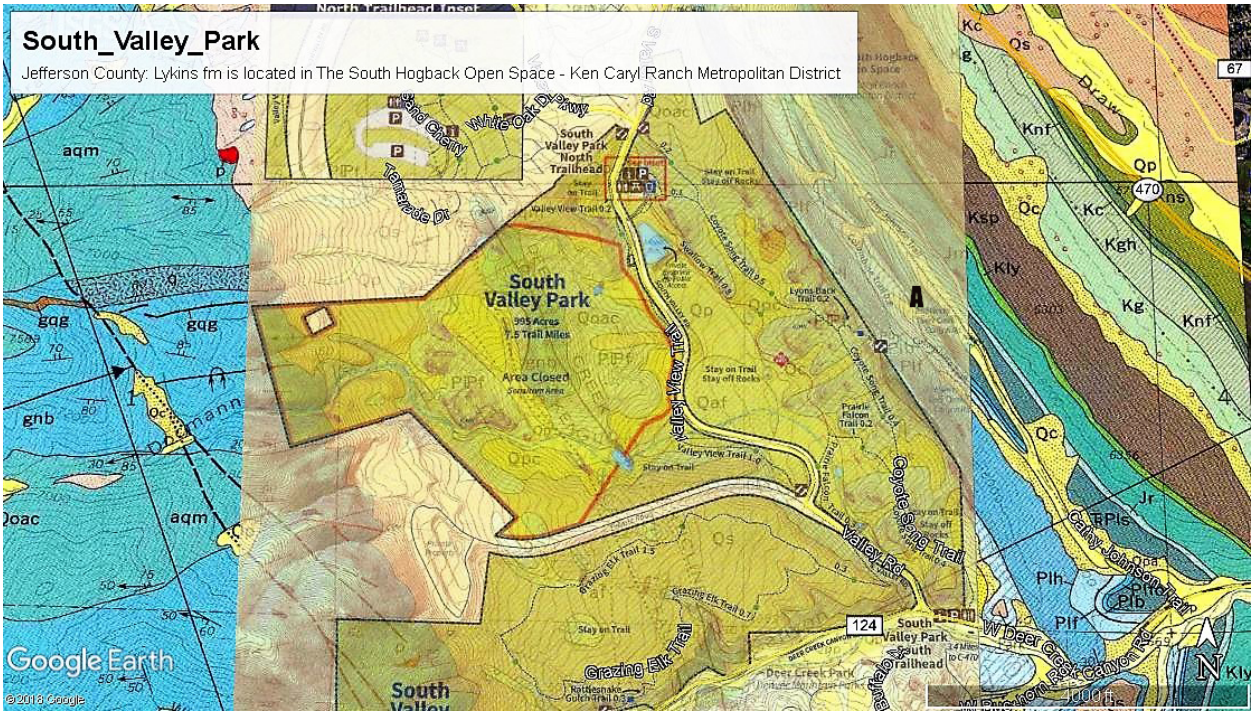
Geology: Plb – Bergen sh, Falcon ls, Harriman sh (Bergen aka Glendo sh); moderate reddish-brown, thin bedded siltstone with minor limestone bed; Plf – Forelle ls; 15 to 20 ft (4.5 to 6 m) thick, gray to orange-pink, thin bedded, chert bearing, finely laminated,

wavy, sandy limestone; TrPls – Strain sh (Upper Lykins fm); moderate yellowish-reddish-brown siltstone, interbeds of light gray-green siltstone and light brown sandstone

Geologic Map of the Morrison quadrangle, Jefferson County, Colorado, 1972, Scott, G.R., US Geological Survey I-791-A, scale 1:24000.

South Valley Park:

The South Valley Park sits on the Fountain formation and Lyons sandstone. The Lykins formation outcrops in The Ken Caryl Ranch Metropolitan District's South Hogback Open Space, which abuts the eastern edge of Jefferson County's South Valley Park.



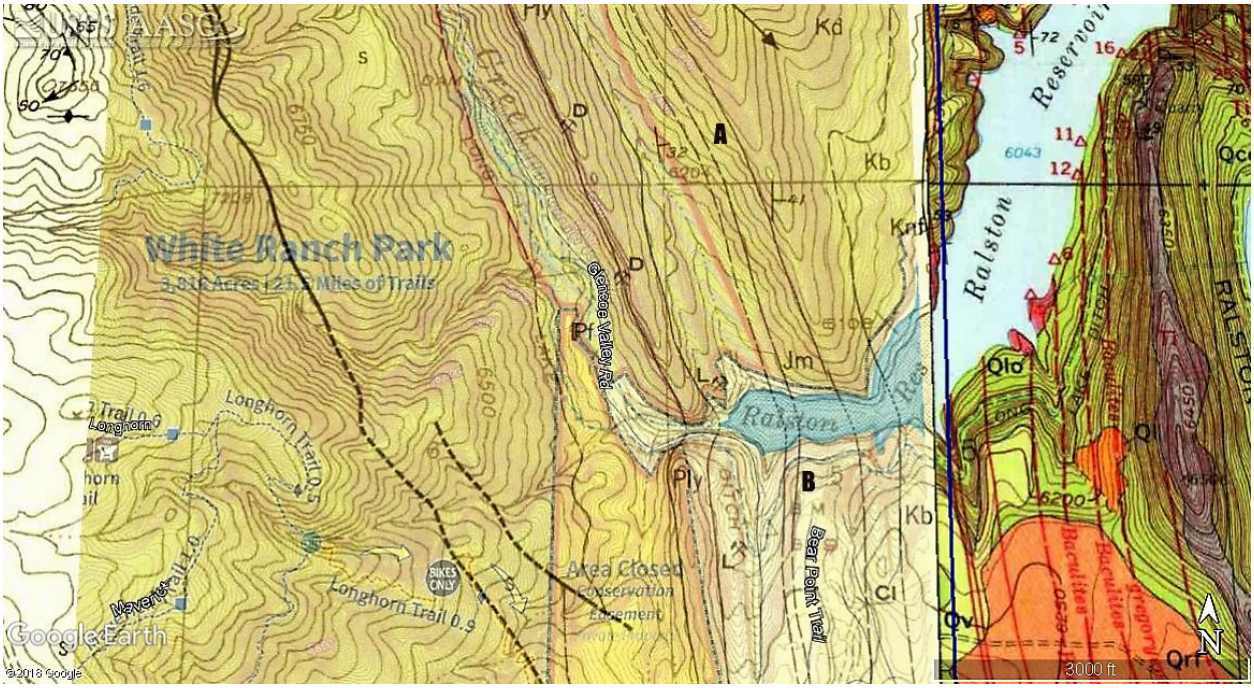
**Coyote Song Trail:

A: An "overlook" from the Coyote Song Trail is a possibility. The trail is very close to the Lyons-Lykins contact exposed here. An "overlook" would take in the Lyons sandstone and the Lykins, Ralston Creek, Morrison, Lytle and South Platte formations. The Lykins formation is primarily yellowish-reddish-brown siltstones and very fine grained sandstones with minor beds of limestone and dolostone. As one looks east, the valley is formed by the less resistant Lykins formation which sits between the more resistant Lyons sandstone (west edge of valley) and the eastern hogback comprised of the Ralston Creek, Morrison, Lytle and South Platte formations. The Lykins formation outcrops close to Hwy 124 (Deer Creek Rd.) where individual members of the Lykins have been mapped. However, this exposure is part of the Ken Caryl Ranch Open Space.

Geology: Plb – Bergen sh, Falcon ls, Harriman sh (Bergen aka Glendo sh); moderate reddish-brown, thin bedded siltstone with minor limestone bed; Plf – Forelle ls; 15 – 20 ft (4.5 – 6 m) thick, gray to orange-pink, thin bedded, chert bearing, finely laminated, wavy, sandy limestone; TrPls – Strain sh (Upper Lykins fm); moderate yellowish-reddish-brown siltstone, interbeds of light gray-green siltstone and light brown sandstone.

Geologic map of Indian Hills quadrangle, Jefferson County, Colorado, 1973, Bryant, Bruce, Miller, R.D., and Scott, G.R., US Geological Survey GQ-1073, Scale 1:24,000.

White Ranch Open Space



**Reconnaissance of limited access area of open space along Glencoe Valley Rd and western end of Ralston Reservoir.

A: Throughout the Ralston Butte quadrangle, the Lykins formation forms a linear band which runs parallel to the Front Range, overlying the Lyons sandstone and underlying the Ralston Creek formation. "A" outlines a portion of the hogback. The Lyons sandstone forms the western edge of the hogback and the Lykins formation overlies it to the east. The Lykins formation is principally grayish-red siltstone with minor crinkly limestone. The hogback is cut by the Ralston Creek and the western tip of Ralston Reservoir. The resulting outcrop is perpendicular to the strata so one can see the Lyons/Lykins contact and the strata associated with Lower Lykins. The Forelle limestone, being more resistant, is well exposed along the beach on the north side of the reservoir (at right). When we were there, we were able to walk from the road along the Ralston Creek bed to the beach to see this exposure. When the reservoir is fuller, this outcrop would be inaccessible. Remnants of quarry suggest that the Forelle limestone may have been quarried for its lime. An intermittent stream runs parallel to the hogback through the less resistant siltstones and sandstones of the Upper Lykins. The Ralston Creek formation caps the Lykins formation on the east. The Forelle limestone at this locality is 10 to 15 ft (3 to

4.5 m) thick, thinly bedded, yellowish-white-gray limestone. Biosedimentary structures observed included pin-stripe laminations, stromatolite domes, brecciation and fenestrae. Van Horn (1957) reported finding the calcareous dasycladacean alga, *Mizzia minuta*, in the upper portion of Forelle limestone in this area.

B: On the south side of the reservoir, the white limestone/dolostone of the Forelle limestone member is quite distinctive in the red soil of the Lykins siltstones and sandstones. One can easily trace the white band on the west side of Glencoe Valley Rd. between the reservoir and the road's juncture with Bear Point Trail. Boulders of Forelle are scattered on the landscape. Remnants of an older quarry suggest that the Forelle limestone was quarried for its lime.

Geology: TrPlk – principally grayish-red, siltstone with thin beds of light-gray, very fine grained sandstone and minor crinkly limestone beds in lower part

Preliminary map of the bedrock geology of the Ralston Buttes quadrangle, Jefferson County, Colorado, 1958, D.M. Sheridan, C.H. Maxwell, A.L. Albee, and Richard Van Horn, US Geological Survey MF-179, 1:24,000.

Maps accessed via USGS National Geologic Map Database, Map View, and Google Earth (kmz)