



# **FOUR CORNERS GEOLOGICAL SOCIETY**

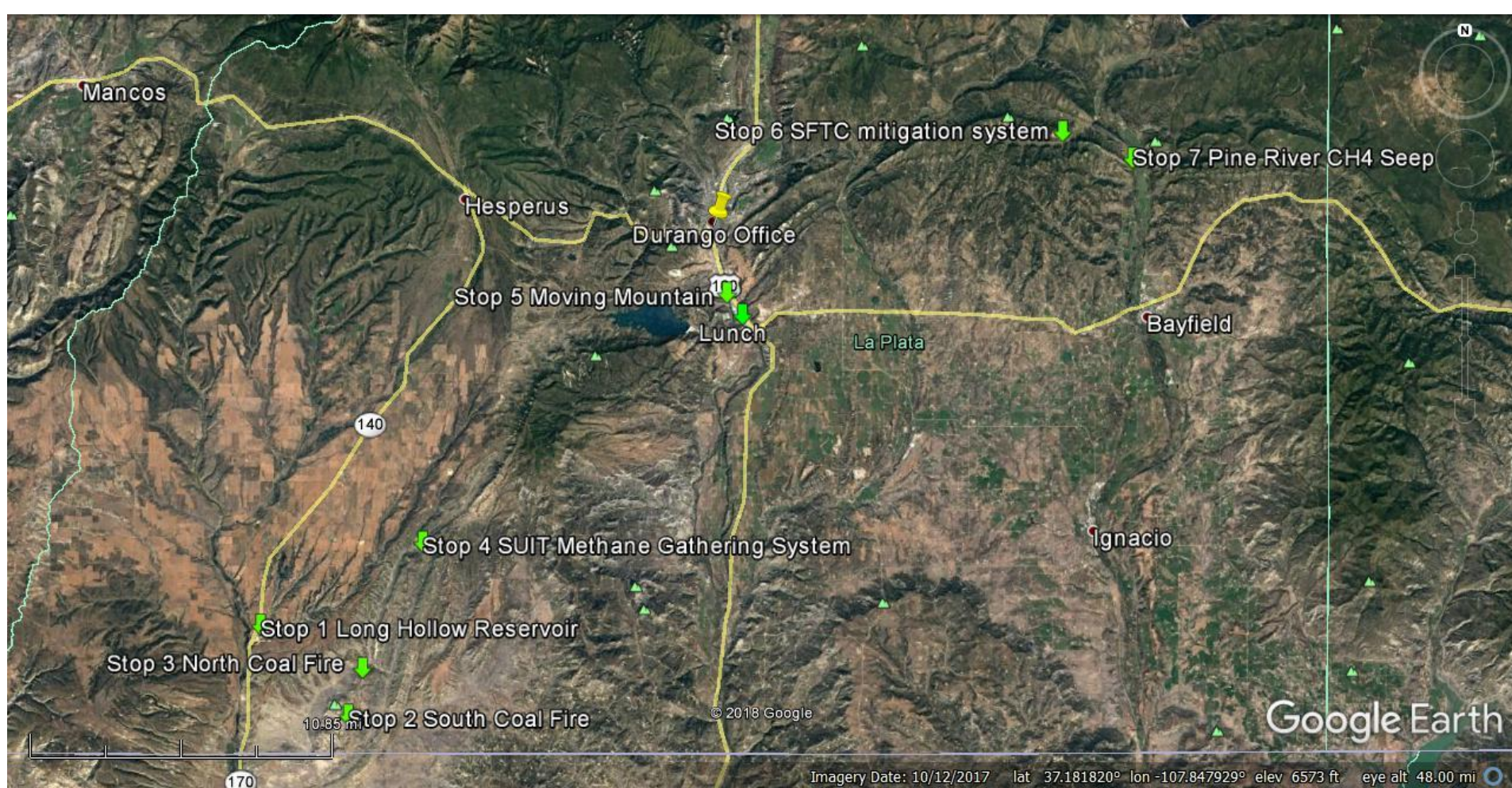
Methane Seeps and Hydrology of the Durango Area  
Fieldtrip Guide

May 11<sup>th</sup> 2019



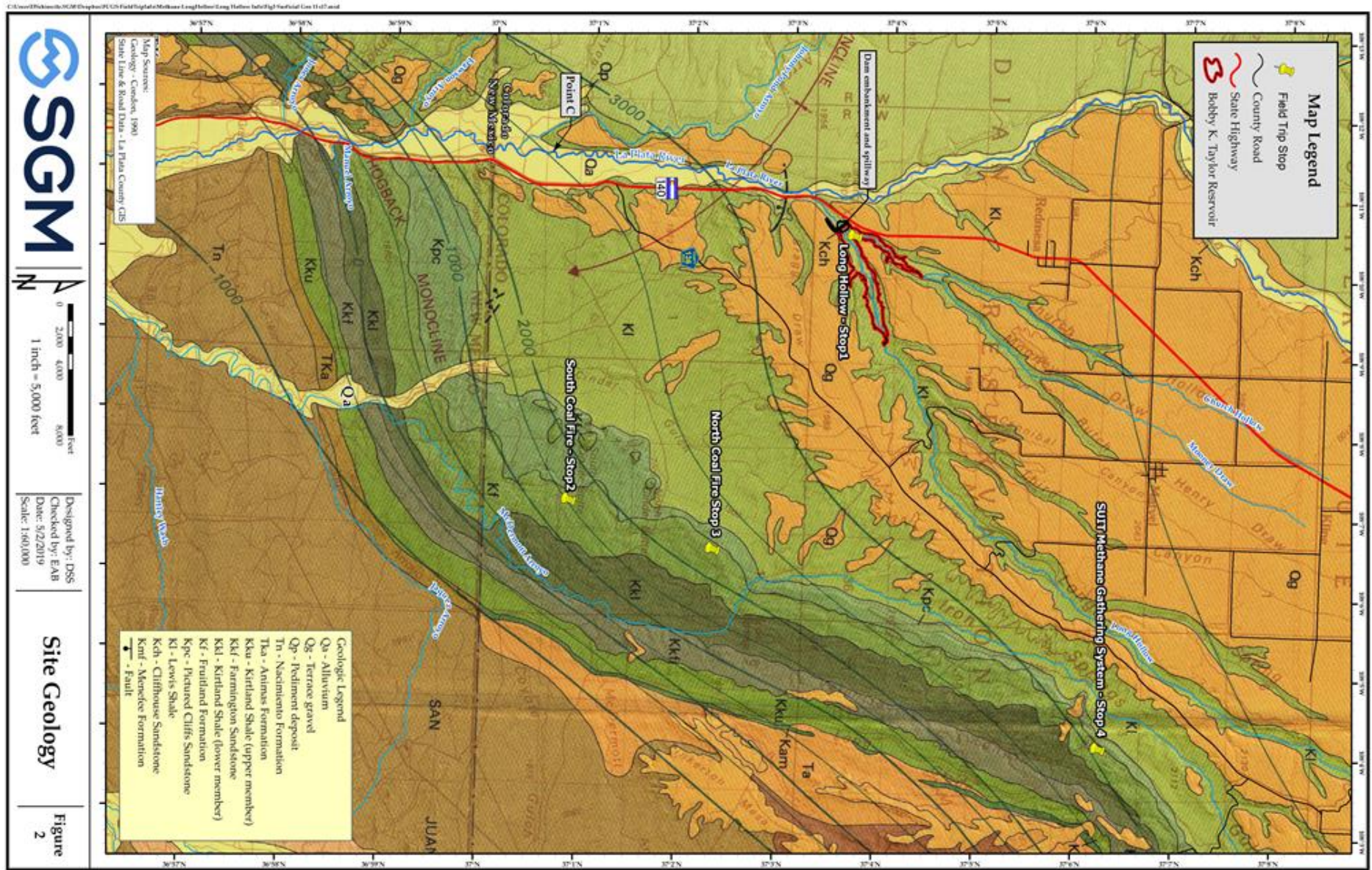


# Overview

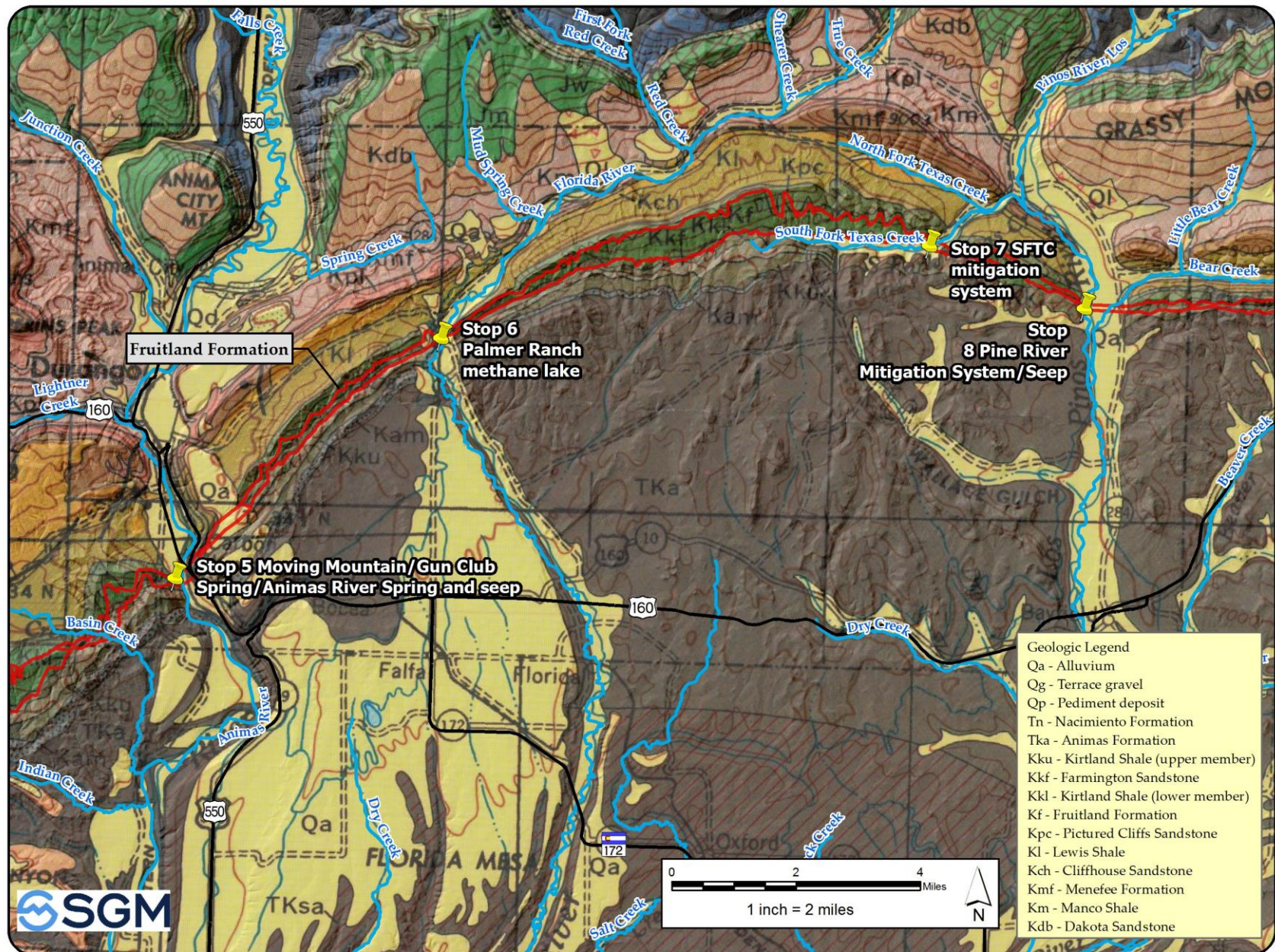




# Overview

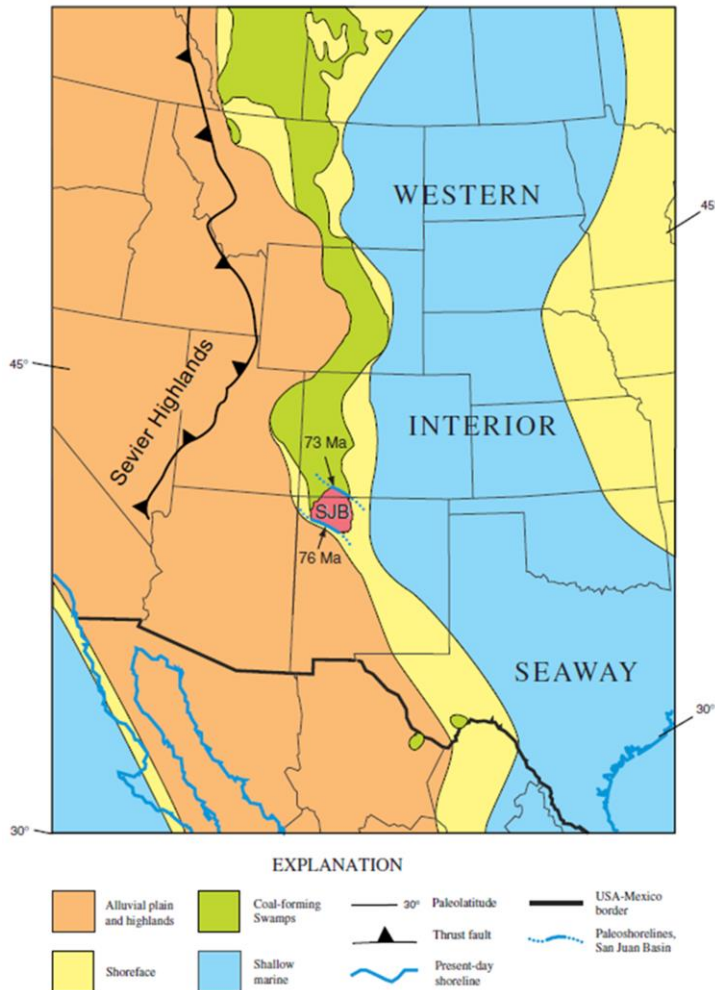




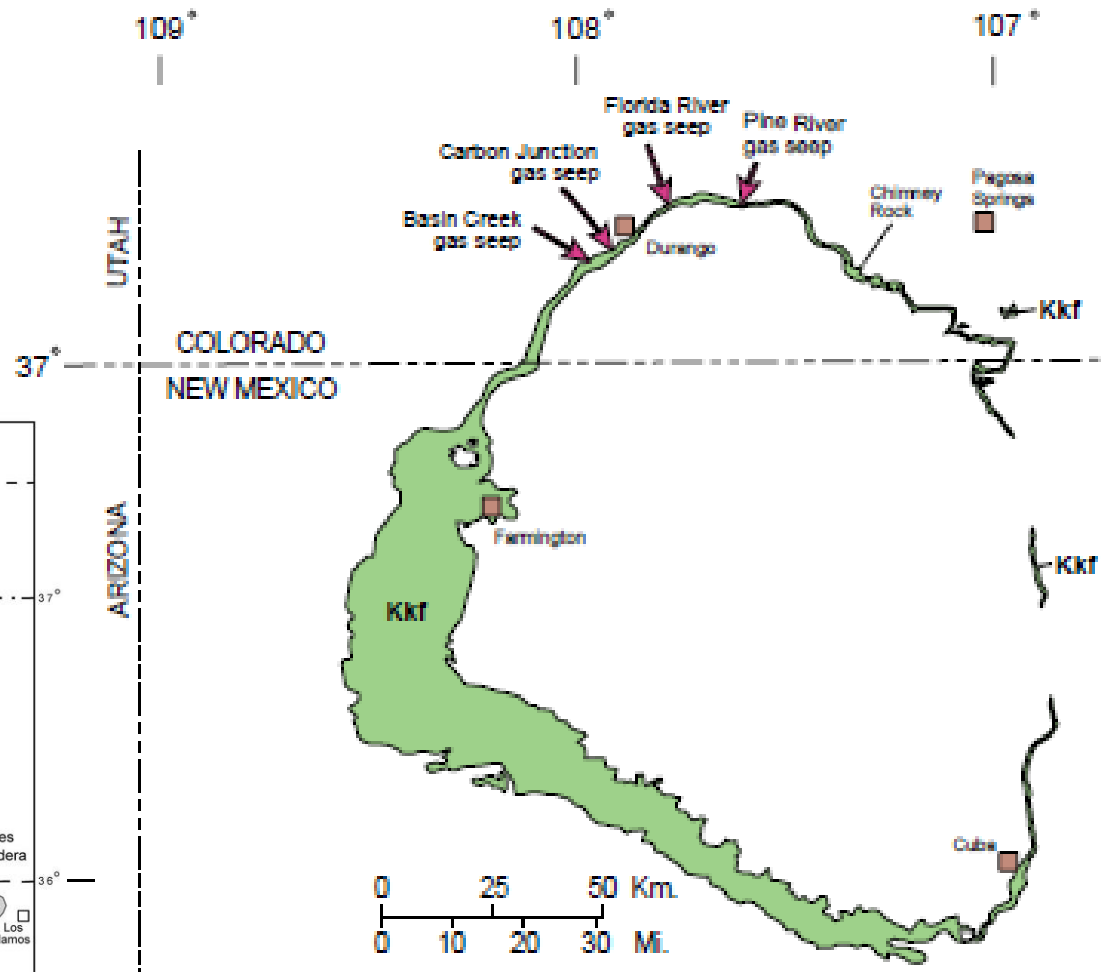
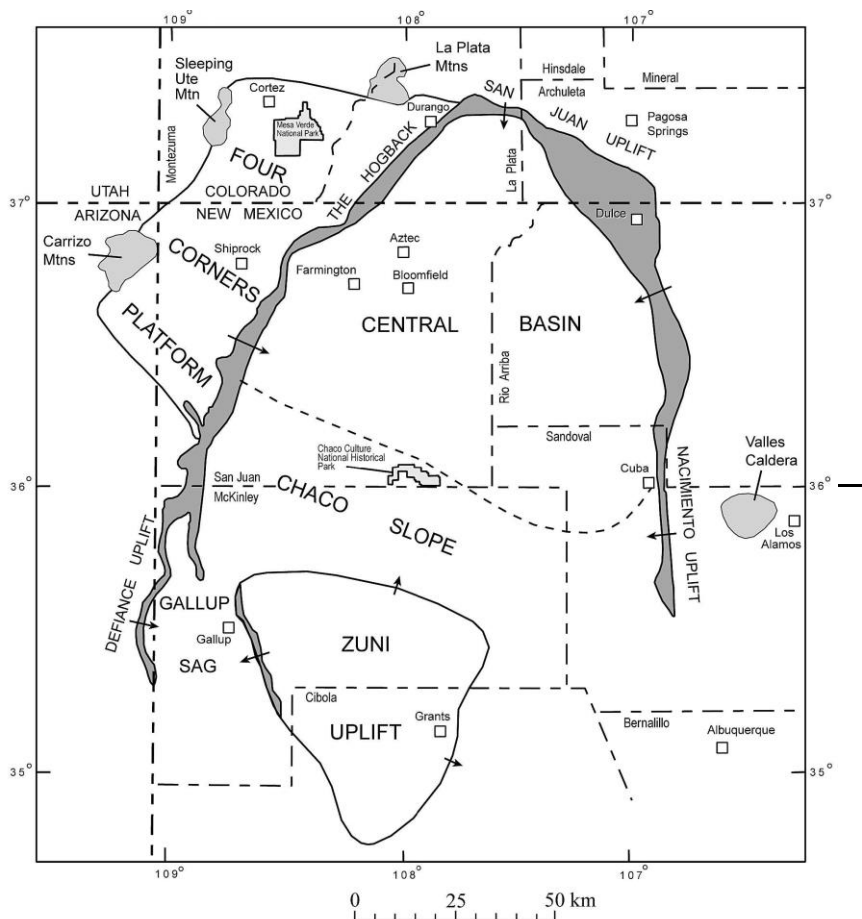




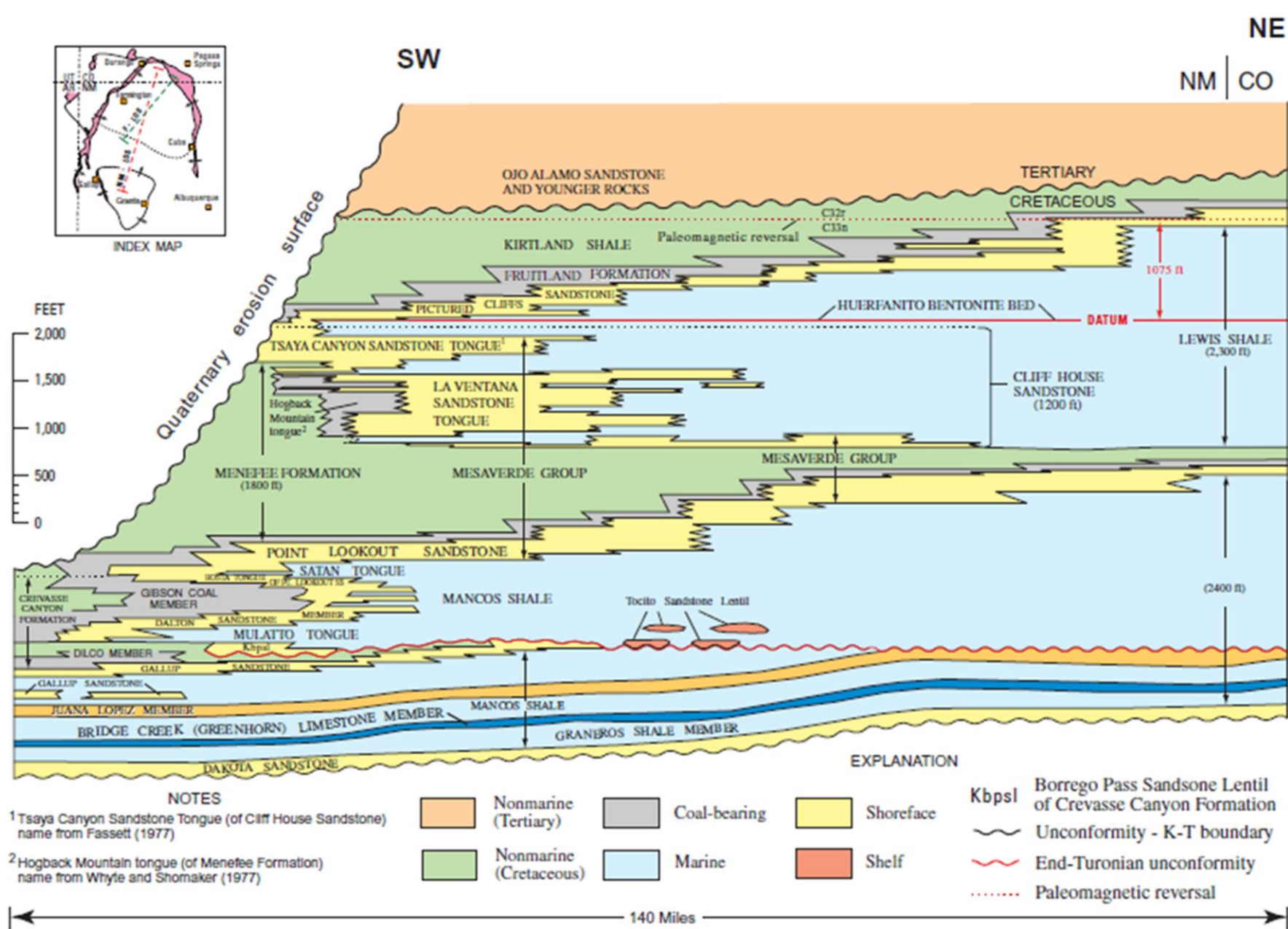
The Fruitland Formation is the major coal-bearing rock unit in the San Juan Basin of New Mexico and Colorado. The Fruitland contains in excess of 200 billion tons of coal throughout the basin (Fassett and Hinds, 1971) and crops out around most of the margin of the basin. Fruitland coals are present throughout the subsurface of the basin to a maximum depth of slightly more than 4,000 feet and the deposition of the coals was closely related to the regression of the Western Interior Seaway as it retreated from the San Juan Basin area in Late Cretaceous time. Fruitland coals formed in a time-transgressive manner; radiometric age dates (Fassett and Steiner) indicate that Fruitland coals in the southwest part of the basin are 3 million years older than coals in the north-east part of the basin. Fruitland coals occur in a complicated, stratigraphically rising, en-echelon geometry across the basin (Fassett et. al. 1997).



Index map showing the geographic and structural setting of the San Juan Basin. Structural elements were generalized from a structure map of the basin area by Thaden and Zech (1984). Areas of steeper dip (monoclines) are patterned; arrows indicate the direction of dip. The dashed line separating the central basin from the Chaco slope is drawn approximately along the outcrop of the Pictured Cliffs Sandstone (Fassett, J.E., 2000).



Index map showing the locations of the Pine River, Florida River, Carbon Junction, and Basin Creek gas seeps. Kkf is the outcrop of the Fruitland Formation and Kirtland Shale, undivided (from Fassett and Hinds, 1971) (Fassett et. al. 1997).



Stratigraphic section showing Upper Cretaceous rocks in the San Juan Basin, New Mexico and Colorado. Tocito Sandstone Lentil and coal-bearing zones are shown diagrammatically. Stratigraphy of rock units from the Point Lookout Sandstone upward is modified from Fassett (1977), stratigraphy for lower part of section is modified from Nummedal and Molenaar (1995). F - LOS on index map is Fassett (1977) line of cross section; NM - LOS is Nummedal and Molenaar (1995) line of cross section. Position of paleomagnetic reversal from chron C33n to C32r is from Fassett and Steiner (1997). Vertical exaggeration x 55.

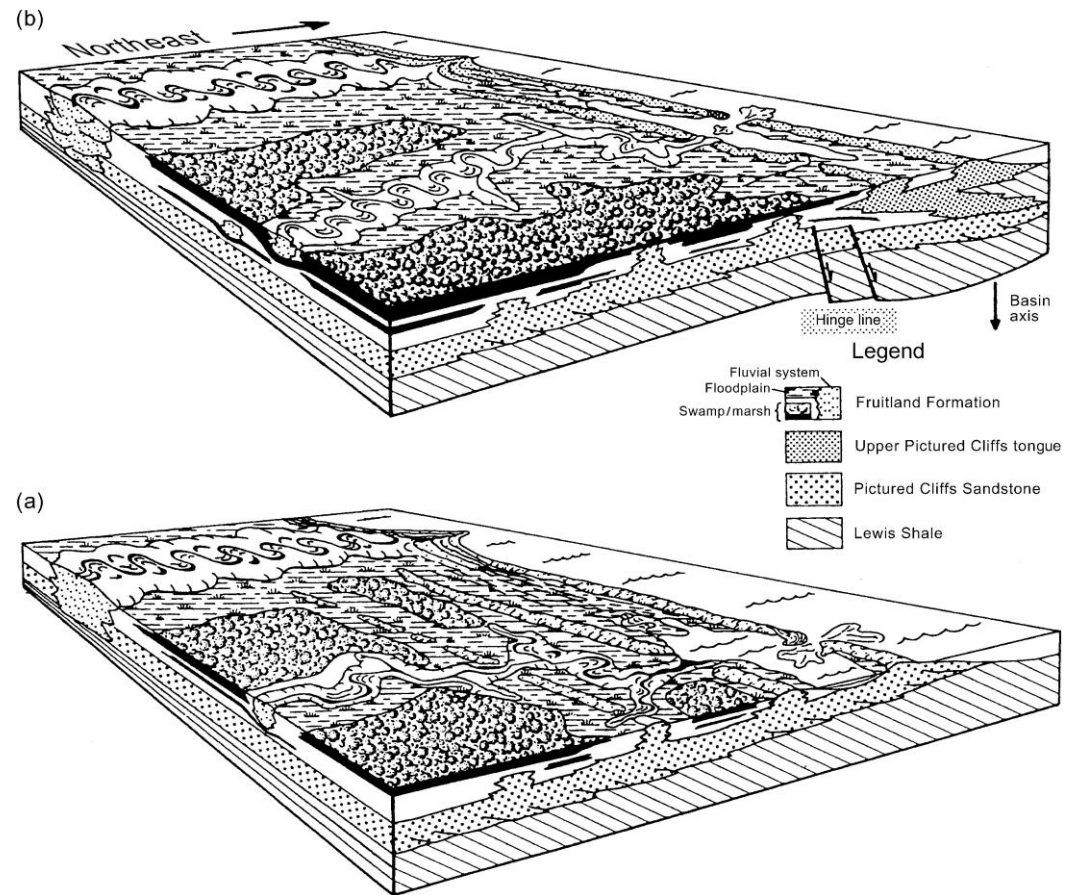
Fassett, J.E., 2000



The Fruitland Formation represents swamp, river, lake, and flood plain deposits laid down landward from and on top of the Pictured Cliffs Sandstone. The Fruitland has been defined as the lower or coal-bearing portion of the continental sequence above the Pictured Cliffs.



Lithologically, the Fruitland is composed of shale, siltstone, coal, carbonaceous shale, and rarely sandstone. The sandstone beds are invariably in the form of discrete channels. Silicified logs and wood fragments are abundant in the Fruitland and are useful criteria in separating the Fruitland from the underlying Lewis Shale in areas of poor exposure along the east side of the basin. The Fruitland is the most commercially important coal-bearing unit in the basin; however, it contains almost no coal along the eastern rim (Fassett and Hinds, 1971). Again, this suggests uplift along the Nacimientos front at the time of Fruitland deposition because the creation of coal requires stable swamps in which vegetal matter can accumulate. Coal does occur in the Fruitland in the subsurface only a few miles west of the outcrop (Fassett and Hinds, 1971) indicating that the uplift taking place in the Nacimientos was not of large magnitude and probably only produced a shoal in the Pictured Cliffs sea and probably had relatively little relief at the time the Fruitland was being deposited.



Depositional model for Fruitland coal in the northern San Juan Basin. (a) Peat is deposited behind abandoned and foundered Pictured Cliffs shoreline sandstones, as well as in flood basins between Fruitland rivers. (b) Intermittently high subsidence rates north of the structural hinge line result in shore-line stillstands, allowing aggradation of the coastal plain. Peat swamps overspread abandoned shoreline and fluvial channel-fill sandstone complexes south of the active shoreline to form extensive deposits. Ayers et al.(1994) (after Ayers et al., 1991b) (Ayers Jr., W. B., 2003).



The following literature review was taken from a paper by Baldwin and Oldaker (1997) presented to the Colorado School of Mines, 1997 Rocky Mountain Symposium on Environmental Issues in Oil and Gas Operations, 14-15 July 1997. It has been expanded using information from a presentation by Oldaker to the Geological Society of America (2017). It has been edited for emphasis on the Fruitland Formation Outcrop for the Four Corners Geological Society Field Trip (2019 May 11).

1200 circa- Coal mining practiced on Black Mesa, AZ by Native Americans. It is assumed that Native Americans practiced coal mining in the San Juan Basin.

1859- Professor John Newberry comments on the "bituminous" nature of rocks in what are later Archuleta, La Plata, and Montezuma counties (Macomb 1876). He was the first geologist to visit the San Juan Basin.

1888- Explosive gas was noted in the Carbonero coal mine at the Animas River/Fruitland Formation subcrop (Lakes 1889).

1902- Professor Arthur Lakes of the Colorado School of Mines visited the San Juan River/Fruitland Formation subcrop near Westwater, New Mexico and described burning coal beds emitting gas which had killed pinon trees (Lakes 1902).

1902- Work on an oil well in Durango, La Plata County was begun (Denver Times 1902). This was the first oil and gas well drilled in the Colorado portion of the San Juan Basin.

1910- The Ritter Ranch water well near Ignacio was drilled to 125 feet and made methane, so a venting pipe was added to the well (Dugan 1994). This was the first drilled water well in the Pine River valley.

1924- The Tendrick Coal Mine exploded and blew an estimated 1,000,000 CFD of gas like an out of control gas well for a week (Bayfield Blade 1924).

1932- In June a mystery explosion shook Durango, Colorado. Six months later the Fruitland Formation on the west side of the Animas River began sliding towards the river. Explosions and landslides continued as late as March, 1933 (Durango Herald Democrat 1932-1933). It was named Moving Mountain and advertised as a tourist attraction.

1940's- Gas seep on Halverson Ranch, Archuleta county could be set on fire (Dugan 1994).

1950's- The gas seep at the Animas River/Fruitland Formation subcrop was noted by Mr. Lauth (1994) and Mr. Porter (Dugan 1994).

1948- Construction on a 48 inch natural gas pipeline to California was begun, based on 1 TCF of conventional natural gas reserves.

1960's- Methane gas seeps were noted on South Fork of Texas Creek to the northwest of the Pine River Ranches study area on the McCoy property (SE/4. Section 8, T35N, R7W, Dugan 1994).

1960's- The Pine River was accidentally ignited just north of the Pine River Ranches study area by Mr. Hocker (Sections 3, 10, 11, T35N, R7W, Dugan 1994). "...The burning stick started a fire on the river that covered several hundred feet in length....".

1966- A water well with methane was drilled near the Pine River Ranches study area to the east on the Wommer property (SE/4, NE/4, Section 14, T35N, R7W, Dugan 1994).



1970's- The gas seep at the Animas River/Fruitland Formations subcrop was noted by Mr. Wasinger (Dugan 1994).

1971- The U.S. Geological Survey released a paper on the geology of the Kirtland/Fruitland Formations (Fassett and Hinds 1971).

1976- Modern coal bed methane (CBM) production in the San Juan basin begins with the drilling and production of the Cahn #1 well by Amoco (RMAG 1989). Major expansion of CBM drilling started in 1980 after an investment tax credit was enacted (Oldaker 2017).

1978- Monitoring wells were installed in the Fruitland Formation coal seams on the Gallo Wash Coal Project (GWWCC 1978) near Chaco Canyon National Monument. Both water and gas were identified in the coal seams.

Before this time the Fruitland Formation was considered to be dry since the large open pit Navajo and San Juan mines did not have water inflow. The low permeability limits the pit inflow to negligible amounts.

1981- Monitoring wells were installed in the Fruitland Formation coal seams and the Pictured Cliffs Formation on the La Plata Coal Project (Oldaker 1982, Utah Int. 1982). Both water and gas were identified in the coal seams of the Fruitland Formation and the Pictured Cliffs Formation.

1981- The Animas River gas seep located in the transition zone subcrop of the Kirtland and Fruitland Formations was noted (Oldaker 1982).

1982- During drilling of the Oxford well project, gas production was identified in the transition zone between the Kirtland and Fruitland Formations (Kelso 1982).

1989- Gas was encountered in the Kirtland/Fruitland Formations transition zone during drilling of Emerald Operating Co. (now Enervest Operating Co.) wells on the northern part of Florida Mesa (Casey 1995).

1993/1994- Pine River Ranches gas seeps were identified in the Los Pinos River (Amoco et. al. 1994, COGCC 1994).

1996- A cooperative regulatory/industry study of the entire Fruitland Formation outcrop was completed showing gas seepage mainly in the subcrop areas (Stonebrooke 1996). The seepage matched different places in the Kirtland/Fruitland Formations section.

1997- A cooperative regulatory/industry study of the Fruitland Formation geology was completed by the U.S. Geological Survey (Fassett et. al. 1997). This study concluded poor to no continuity of the coal seams in most of the northern San Juan Basin subcrop areas. The study also included portions of the Kirtland and Pictured Cliffs Formations. The Texas Creek Seeps were associated with the Pictured Cliffs Formation.

2007- San Juan Basin conventional and CBM production was 1.32 TCFG from over 39,000 wells. This was the highest from a basin in the USA that year (Fassett 2010 and Oldaker 2017).

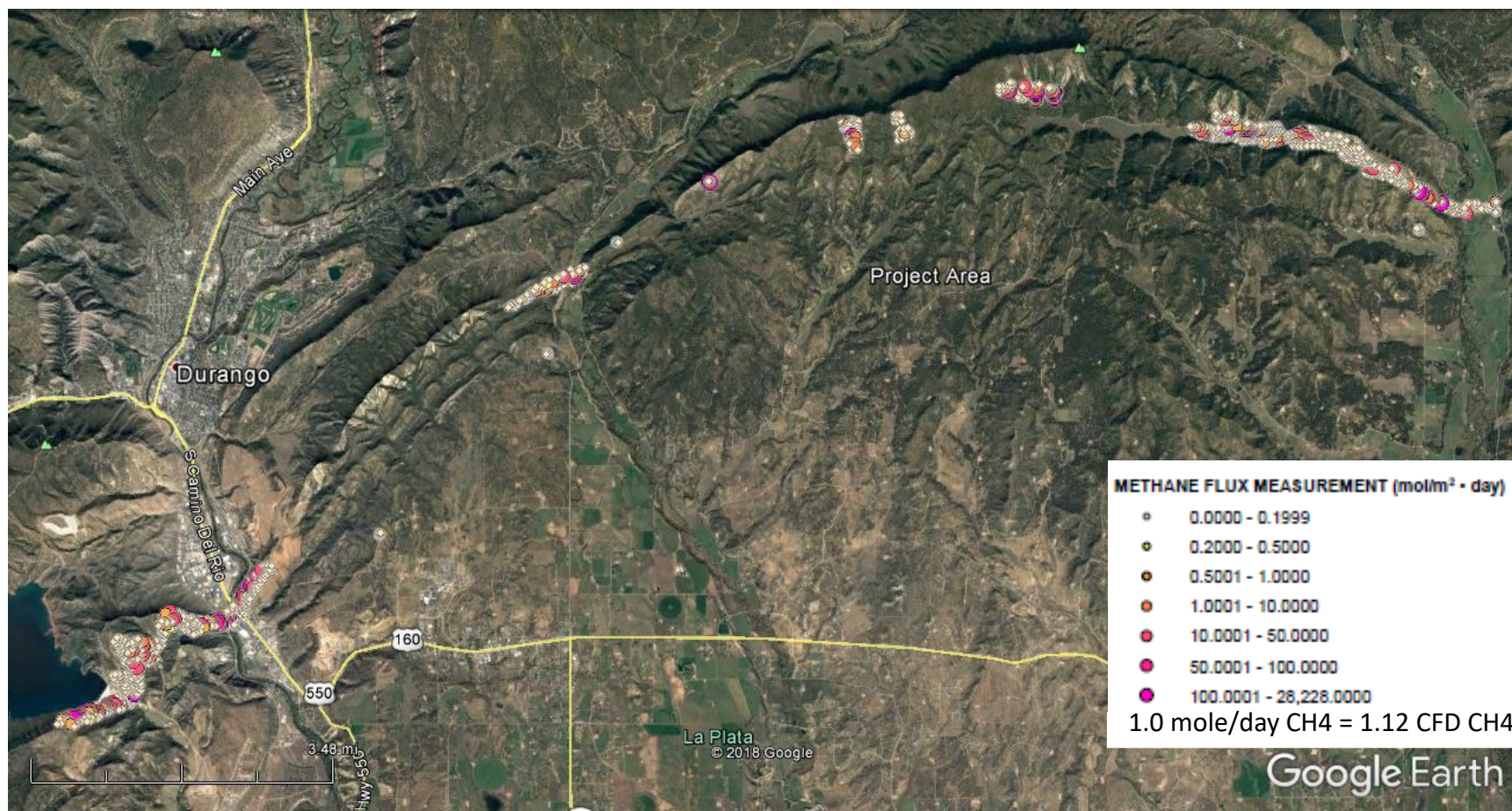
2009- Fruitland CBM cumulative production was 15.7 TCFG from over 7,700 wells (Fassett 2010 and Oldaker 2017). An estimated 30 TCFG of proven reserves were remaining. Enhanced Coal Bed Methane (ECBM) or horizontal recovery laterals were not included.



## Fruitland Formation Methane Seep Monitoring (LTE 2007-2018)

Since 1997, LT Environmental, Inc. (LTE) has conducted methane seep monitoring along the Fruitland Formation (Kf) outcrop in La Plata County, Colorado. The project area is located along the north rim of the San Juan Basin, north of the Southern Ute Indian Tribe Reservation boundary. The Kf outcrop monitoring is conducted in order to comply with the Colorado Oil and Gas Conservation Commission (COGCC) Orders 112-156 and 112-157.

The objective of the methane seep monitoring program is to observe and document the relative change in methane seepage from the Kf outcrop over time and space. In total, the scope of work provides an efficient and repeatable means to characterize gas seepage in the project area by inspecting those areas with the greatest potential for seeps based on geological characteristics and historical field observations.

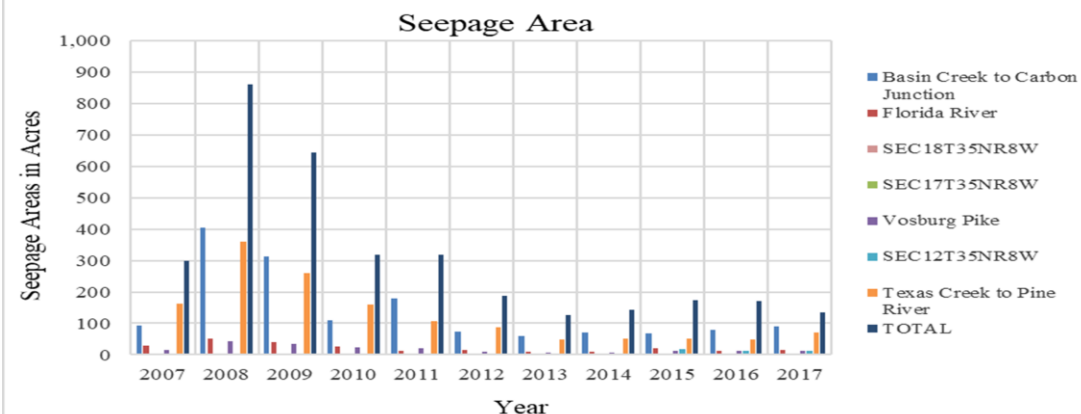
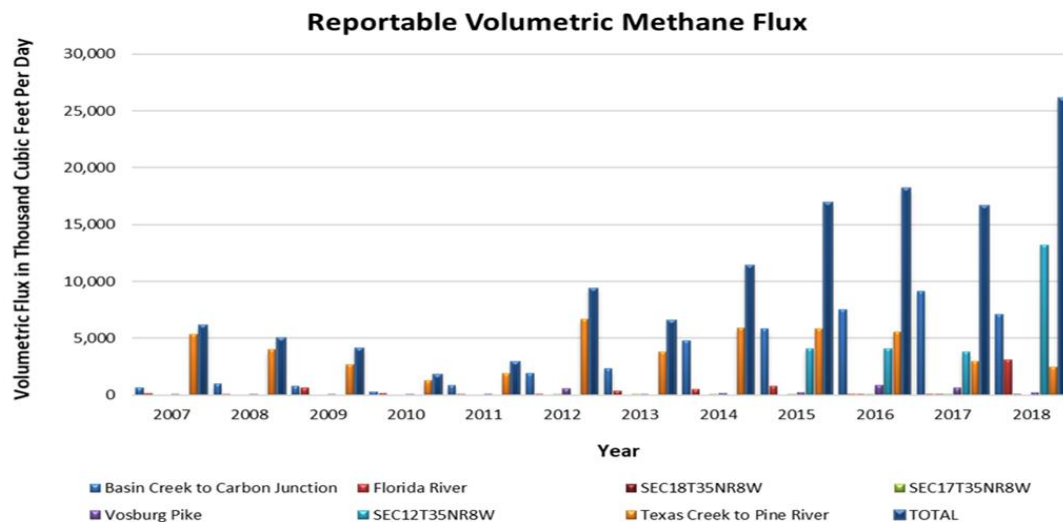


(Above) Intensity bubbles showing prominent methane seep locations along the Fruitland Outcrop (2018 survey)



# Fruitland Formation Methane Seep Monitoring (LTE 2007-2018)

Increase in seepage observed from 2007 to 2018 in La Plata County (6,099 MCFD to 26,101 MCFD);  
 Maximum observed 26,101 MCFD in 2018;  
 Minimum observed 1,748 MCFD in 2010;  
 Seepage areal extent decreased from 2008 to 2018;  
 Elevated concentration of dissolved methane have been detected in natural springs that are sourced from the Fruitland Formation;  
 Additional seep areas have been discovered during regional reconnaissance surveys.



## Owned and Operated by La Plata Water Conservancy District



**Key Information** - Mobilization began in July of 2012 and the project was completed in the Fall of 2014. The Reservoir helps Colorado meet its obligation to New Mexico as outlined in the 1922 La Plata River Compact (Compact), while providing supplemental water to the irrigators in Colorado by release and exchange to upstream water users.

The Reservoir is located at the confluence of Government Draw and Long Hollow, just upstream of their confluence with the La Plata River and about four miles north of the New Mexico State line (see Figure 1 and 2). The drainage basin above the dam is approximately 43 square miles.

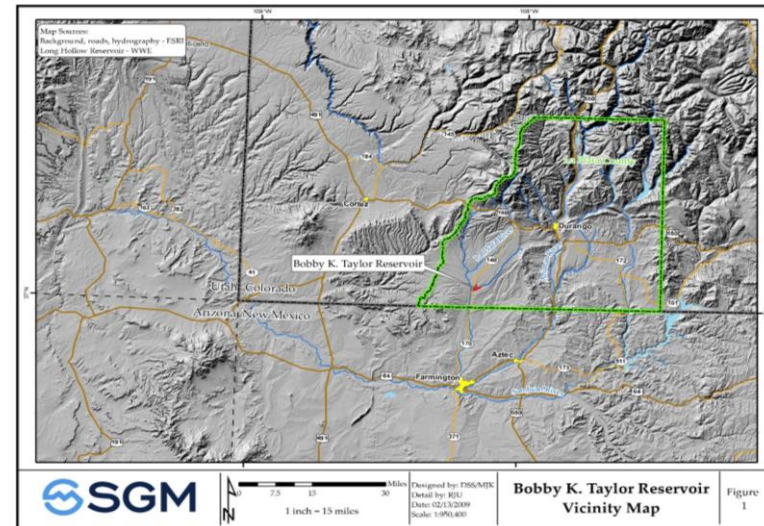
The reservoir has a maximum pool capacity of about 5,309 acre-feet (AF), maximum surface area of 160 acres and at full-pool the reservoir extends approximately 1.5 miles upstream. The project includes approximately 3.75 acres of wetland mitigation, cultural preservation, creek restoration, fish protection, a 152-foot high embankment consisting of over 900,000 cy of zoned material, fish screen, a 120-cfs controlled outlet works facility, and a 1,400-foot-long by 100-foot-wide spillway (see Figure 2 and 3). The peak outflow through the spillway during the inflow design flood is 20,000 cfs.

Bikis Water Consultants was responsible for the overall project management. Weeminuche Construction Authority (WCA), owned by the Ute Mountain Ute Tribe, conducted the dam construction, GEI Consultants, Inc. (GEI) was responsible for the design, and Ehat Consulting LLC, performed the construction management (CM).

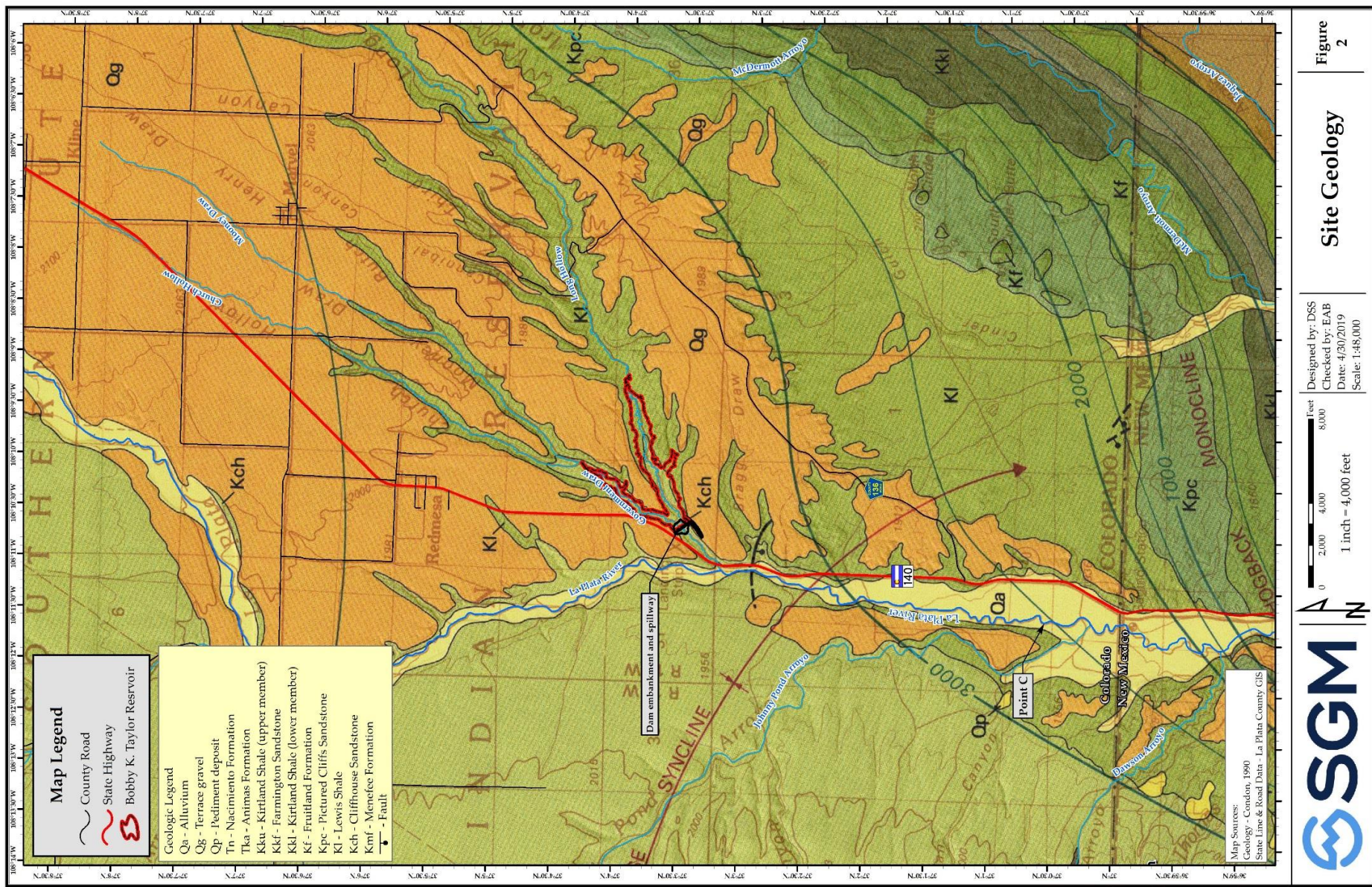
## Site Geology

The spillway and dam embankment were constructed in the Upper Cretaceous Cliff House Sandstone (Kch) and Lewis Shale (KI) (see Figure 2). The Cliff House Sandstone is the upper unit of the Mesaverde Group and consists of an interbedded sequence of thin beds of moderately hard, yellowish-orange to white, very fine- to fine-grained calcareous sandstone and easily eroded light-gray mudstone, siltstone, and silty shale (, Kirkham et al, 2000). The sandstone beds contain locally abundant Ophiomorpha burrows. The Cliff House Sandstone is a transgressive, shallow marine unit rapidly deposited on the upper shoreface zone of a barrier-island beach front (Siemers and King, 1974, Kirkham et al, 2000). Thickness averages about 400 ft and thins east and thickens west of the area. Shale beds in the unit may have moderate to high swell potential and the formation is an important natural gas reservoir and producer in the San Juan Basin (Kirkham et al, 2000).

At the site the Cliff House Sandstone consists of thinly interbedded sandstone and clay/mudstone and a few relatively thick massive sandstone beds. The rock has several sets of joints. These joints are partly due to stress relief and are generally steeply dipping, strike upstream/downstream in the abutments and canyon bottom with some horizontal in the canyon bottom.



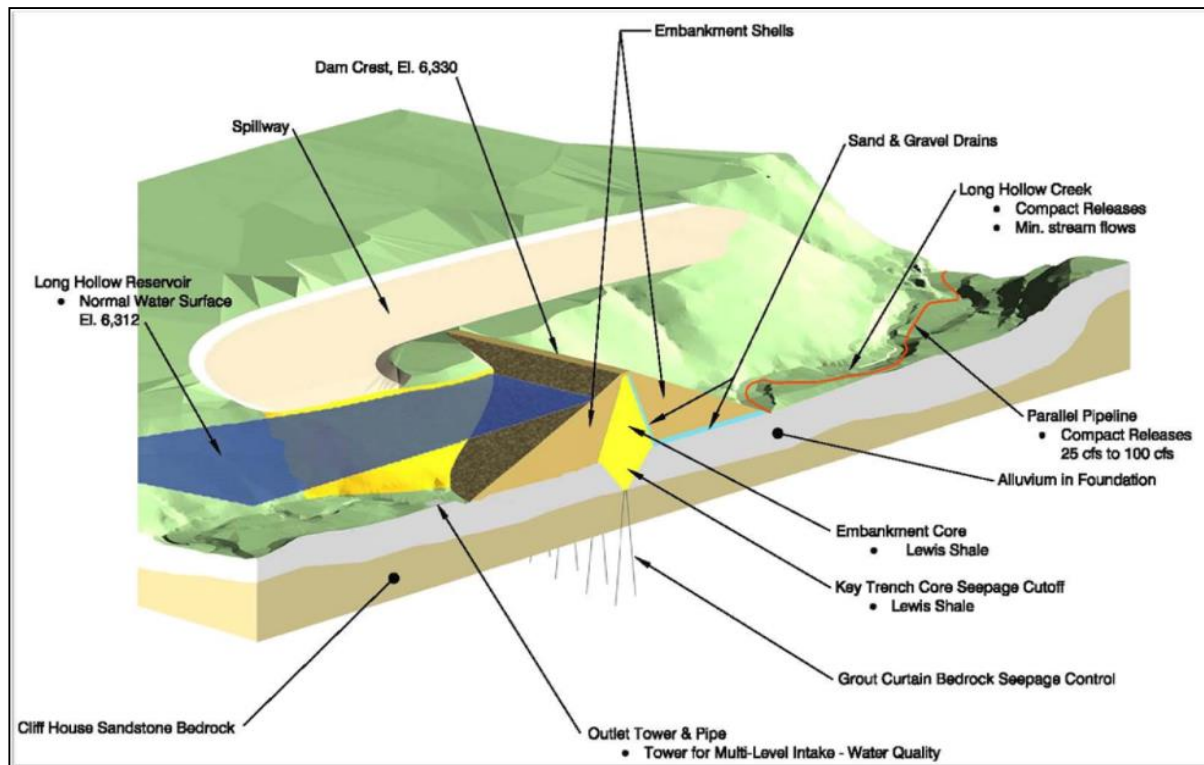






Geology continued... The Lewis Shale is a dark gray, fissile shale containing thin sandstone beds at top and gray, rusty-weathering cretaceous limestone in the lower part (Kirkham et al, 2000). Altered volcanic ash beds (Huerfano Bentonite Bed) within the Lewis Shale, have been used as time-stratigraphic markers throughout the San Juan Basin (dated at 75.76 Ma by Fassett and Steiner, 1997). The unit weathers easily and is generally covered by surficial deposits (Kirkham et al, 2000). The contact with the underlying Cliff House Sandstone is conformable and usually gradational (Kirkham et al, 2000). The Lewis Shale was deposited in a low-energy, off-shore, marine environment (Fassett and Hinds, 1971, and Kirkham et al, 2000). Formation thickness averages about 1,800 ft and it is a reservoir for natural gas in the San Juan Basin (Kirkham et al, 2000). The shale is prone to landsliding, and is highly susceptible to shrink swell problems where it contains expansive clays (Kirkham et al, 2000).

**Figure 3. Conceptual diagram of the Long Hollow Dam. (Source GEI)**



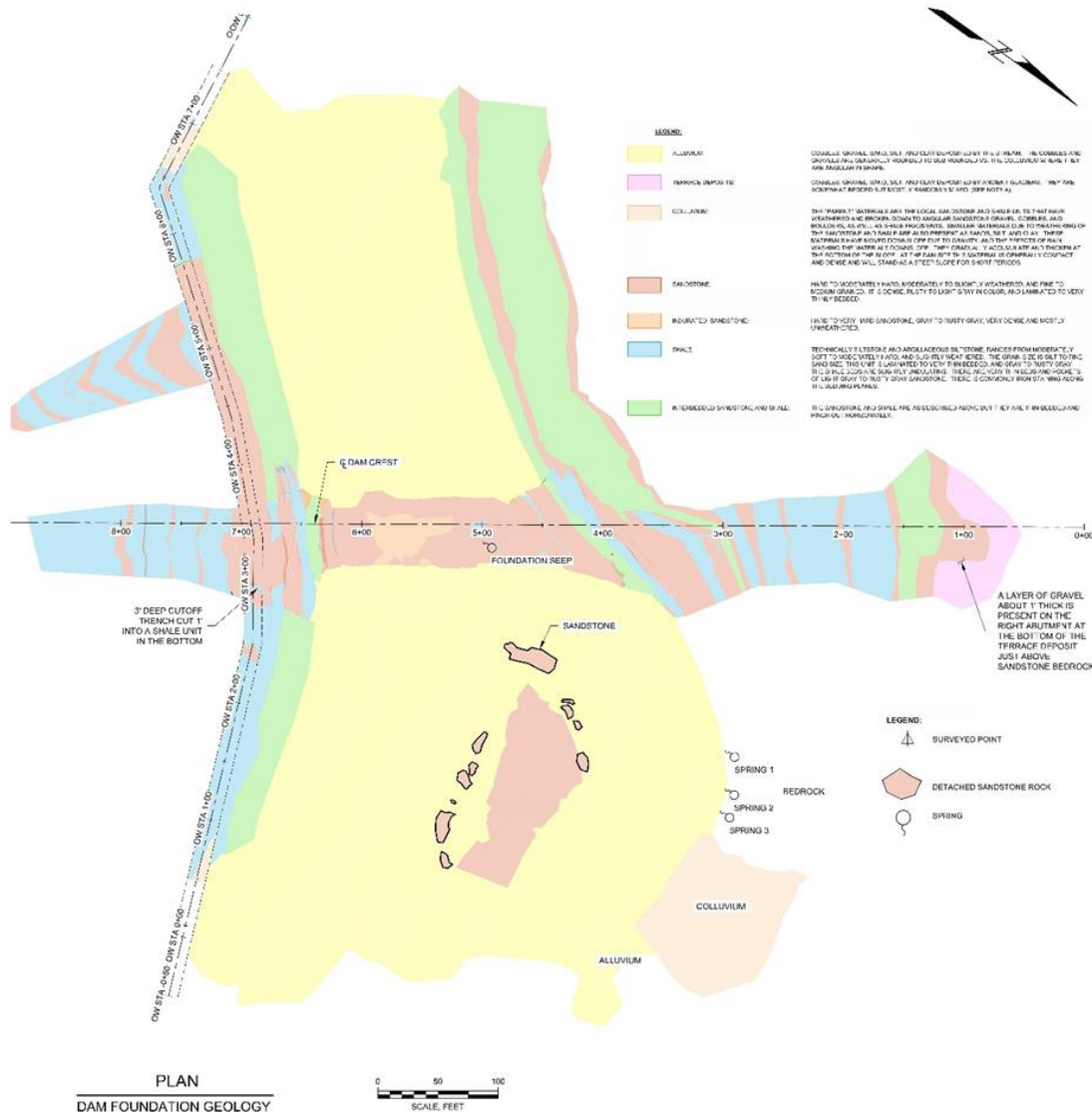
### Embankment

The configuration of the embankment is shown in Figure 3. The dam consists of a zoned earthfill embankment with a height above streambed of approximately 152 feet. It is approximately 800 feet long and has a crest width of 25 feet. The upstream slopes of the main section of the embankment are 3H:1V, and the downstream slopes vary from 2.5H to 2.25H:1V (Ehat, 2013).

The embankment is divided into different material zones including a central clay core (Zone 1) constructed of low-permeability clay material, and upstream and downstream shells. As the reservoir levels are anticipated to fluctuate significantly throughout the year, the upstream shell was designed to be relatively free draining and was constructed with pit run alluvium granular fill. The downstream shell used random fill consisting of clay, sand, gravel, cobble, and sand- and claystone with oversized material removed. Fine and coarse granular filter/drain materials (Zone 4 and 4A respectively) were used in a horizontal blanket collection drain, which is connected to an abutment blanket filter and drain system. A chimney filter is located immediately downstream of the Zone 1 clay core. The chimney filter has adequate drainage capacity and is not combined with a coarser drain. The vertical chimney ties into the horizontal blanket collection drain (Ehat, 2013).



Figure 4. Geologic Map of the Dam Embankment (source GEI).



## Construction Conditions

Excavation of the spillway channel was easier than anticipated and less blasting was required. However, very little suitable slope lining material for the dam was produced (see Figure 4) (Ehat, 2013).

Excavation at the core trench revealed highly fractured, thinly inter-bedded sandstone, and shale layers with significant stress relief cracks in several of the sandstone units. Due to the highly fractured nature of the foundation, foundation preparation in the core trench presented significant challenges. This was compounded by the fact that a considerable amount of shale was encountered, which quickly deteriorated when exposed to air. In addition, many of the thicker sandstone units broke nearly vertical along joints and did not provide an adequate shape for placing contact clay. Large dental concrete placements were required at these vertical features, adding cost to the budget. The foundation for the outlet works rock notch also required special treatment of slush grouting, dental concrete, cleaning, and special shallow grouting configurations (Ehat, 2013).

The geology of the site resulted in an extensive grouting program and challenging foundation preparation including significant dental concrete over the sandstone beds in the abutments and in the outlet works foundation. In the valley portion of the foundation some methane gas and hydrogen sulfide were encountered along joints and in some grout holes. The gas was interpreted to be from the underlying Menefee Formation coal beds. WCA elected to pursue a substantial foundation grouting specification adjustment in order to utilize similar means and methods to those used in Reclamation's Ridges Basin Dam for A-LP. After considerable discussion, the SEO approved a design change order and the grouting program was implemented. These foundation defects resulted in significant grout takes to meet acceptable closure criteria (Ehat, 2013).

## Red Mesa Aquifer and Long Hollow

The major source of water supply for the Reservoir is derived from surface and groundwater return flows from precipitation and irrigation practices on Red Mesa. Red Mesa consists of approximately 28 square miles of land that slopes uniformly at approximately 2 percent from Breen to the town of Red Mesa (see Figure 5). The Red Mesa is situated between the La Plata River and Long Hollow, a tributary to the mainstem of the La Plata River. These two rivers define the east and west extents of the mesa. The southern extent of the Red Mesa is the confluence of the Long Hollow and the La Plata River. The northern terminus lies approximately 1 mile north of Highway 141, east of the Old Fort Lewis. Red Mesa and its adjacent drainages trend from the northeast to the southwest, descending approximately 1,300 feet in about 12 miles. The Red Mesa is located in the eastern portion of the Colorado Plateau near the northern edge of the San Juan Basin. Cretaceous sandstones and shales form the bedrock in the region and in the vicinity of Red Mesa (see Figure 6), the Cliff House Sandstone and Lewis Shale dip gently to the south.

Glacial outwash gravel deposits from the La Plata Mountains overlay most of the bedrock on the mesa. These deposits mantle the bedrock and form a gently sloping mesa. This terrace gravel is generally thinnest to the south near the confluence of the La Plata River and Long Hollow where it is approximately 30 feet thick. The gravel wedge thickens to the north and northeast, with thicknesses typically measured from 50-100 feet between the towns of Marvel and Kline. The relatively permeable glacial material on top of semi-impervious bedrock layer makes up the Red Mesa Aquifer. Groundwater recharge of the terrace gravel aquifer is derived from deep infiltration of irrigation water and precipitation on Red Mesa. There is no regional groundwater system that supplies this area. The Red Mesa Aquifer is a closed system, affected only by surface water infiltration from irrigation and precipitation patterns.

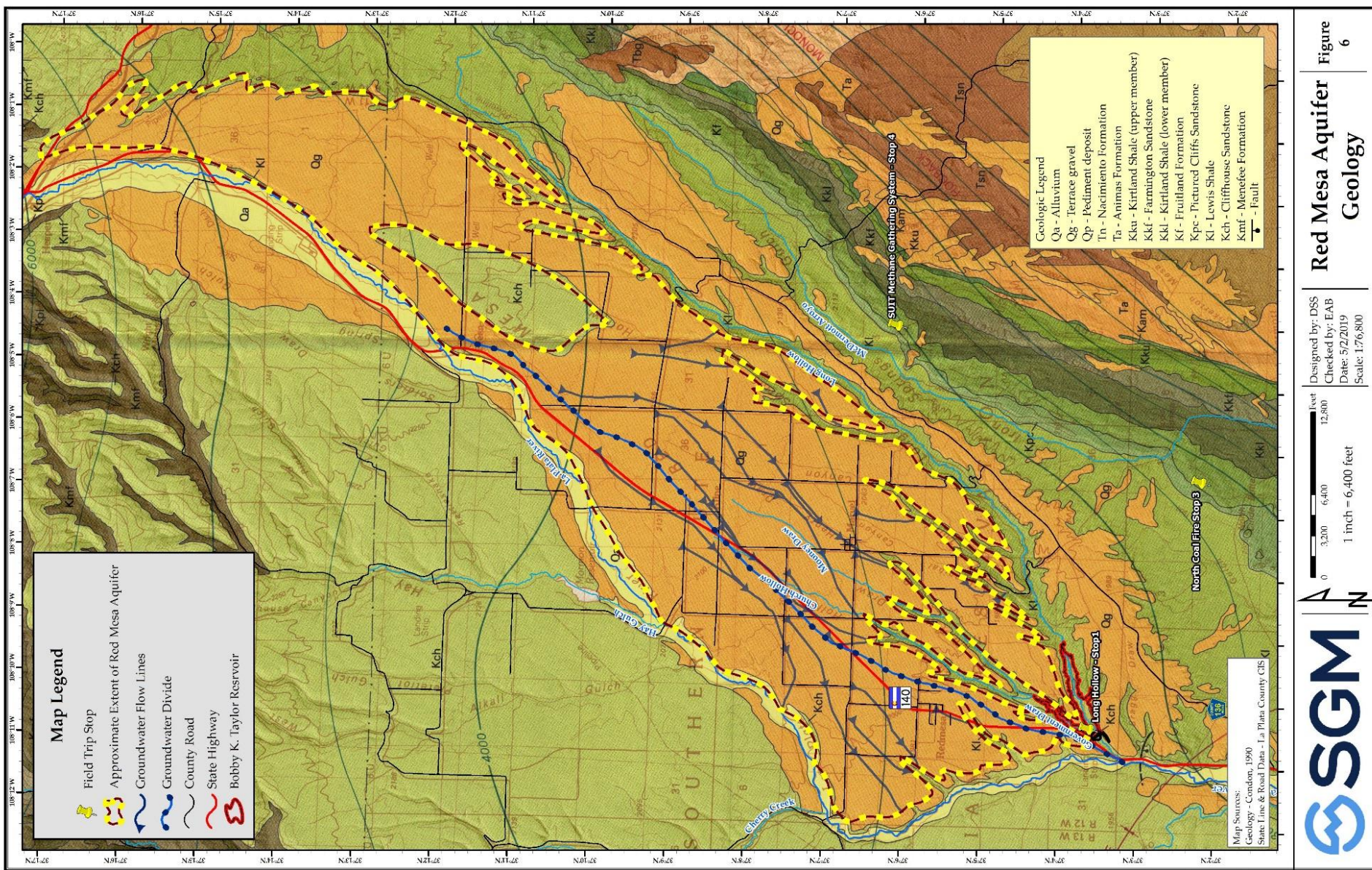
Based on a groundwater study conducted for the LPCWD, the general direction of groundwater flow is from northeast to southwest (see Figure 5). Groundwater discharges either directly to the La Plata River or to Long Hollow and its associated draws, and then to the La Plata River. At the northern end of the mesa an outcrop of Cliff House Sandstone protrudes to the surface and no terrace gravels exist in this area east of Breen. The water table is effectively bifurcated in this area by the less permeable sandstone bedrock. A groundwater divide occurs roughly coincident to Highway 140. Substantially more area of the aquifer flows to Long Hollow and its tributaries than to the La Plata River. Flows and springs have been observed year-round in Mooney Draw, Church Hollow, Spring Hollow and Third Canyon. Consistent flows in Long Hollow and its tributaries are evidence that groundwater inflows influence flow in Long Hollow throughout the year and provide the major filling source for Bobby K. Taylor Reservoir.

LPWCD and SGM are in the process of study sites to construct recharge pits, where during free-river conditions, water would be diverted into the pits, allowed to infiltrate and slowly return to Long Hollow.





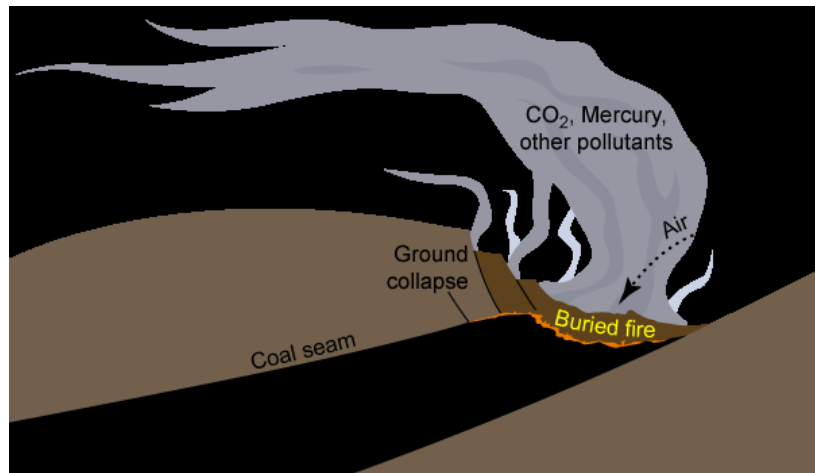
Figure 5 -Geologic Map of Long Hollow and Red Mesa Area from Condon, Steven. 1990. Showing the extent of the Red Mesa Aquifer and groundwater flow lines.



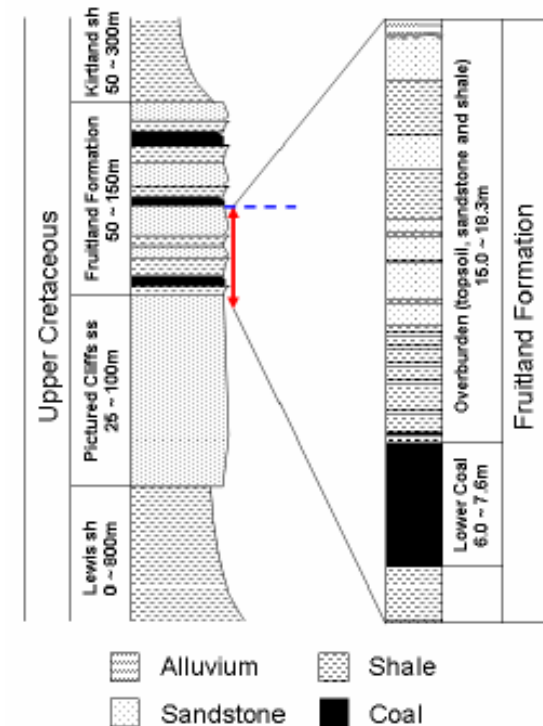
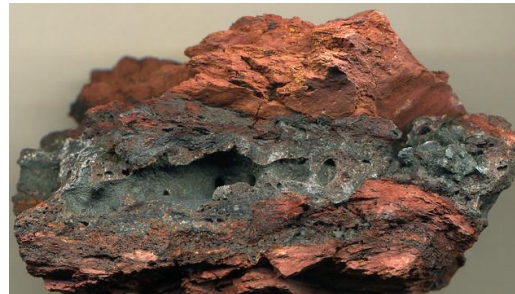


# Cinder Butte/Coal Seam Fires

## Stops 2 and 3



Clinker is derived from shale, siltstone, and sandstone beds surrounding the burned coal seams. The term “clinker” comes from the “clink” sound made when the baked rocks are walked on or struck by a rock hammer. Some of the clinker looks like vesicular basalt in hues of red, orange, and brown, or even pistachio green. Some is nearly glassy like obsidian but with colors akin to Neapolitan ice cream. Much of the coloration comes from iron impurities. The red hues form under oxidizing conditions (iron oxides), while the greens form under reducing (oxygen-depleted) conditions. Fused breccias can form when overlying rock collapses into the void left by the burned coal seams.



Stratigraphic column representative of the top 25 meters of the lithology over the North Coalbed Fire (above). Over the coalbed fire, formations above the blue dotted line have been removed due to weathering. Stratigraphic column (Ide et. al. 2009).

A coal-seam fire is a natural burning of an outcrop or underground coal seam. Most coal-seam fires exhibit smoldering combustion, particularly underground coal-seam fires, because of limited atmospheric oxygen availability. (Rein, G 2013). Due to fine thermal insulation and the avoidance of rain/snow extinguishment by the crust, underground coal-seam fires are the most persistent fires on Earth and can burn for thousands of years. Coal-seam fires can be ignited by self-heating of low-temperature oxidation, lightning, wildfires and even arson (Song, Z, Kuenzer, C). Once ignited, the coal is reduced to ash, and its volume can decrease by more than 90 percent. Overlying rocks can then collapse into the resultant void space. Cracks formed by collapse can propagate to the surface, which allows more oxygen to reach additional coal below the surface and keeps the fires going (Ide et. al. 2009).



A total of 28 wells are used to intercept and collect methane gas that would have otherwise entered the atmosphere at the Fruitland outcrop. The methane collected at these interceptor wells is piped to a compressor station, which ties into an existing gas pipeline used for regional methane production. The gathering system effectively reduces greenhouse gas pollution. The high price of gas in 2007 (~ 8-10 mmcf) helped in justifying the expense of the installation of the interceptor wells and collection piping near the outcrop. After the price of gas dropped around 2010 the gathering system was entered into a carbon credit program which helped offset the lost revenue from the low price of gas.



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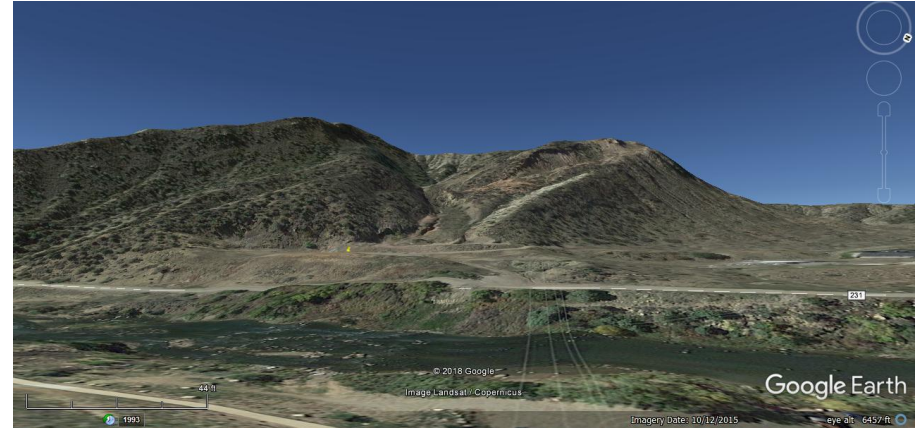
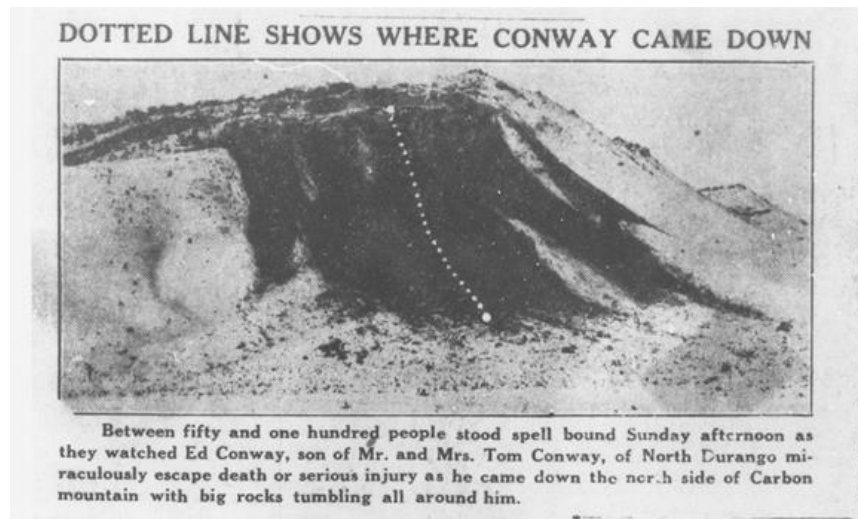
1888- Gas observed in the Carbonero Mine on the east side of the Animas River. Several attempts were made to raise money for drilling an oil & gas well nearby.

1918- First landslides on Carbon Mountain. These were remembered during later events.

1932 June- Mystery night explosion shakes Durango. All big boilers in city checked (Usual suspects were rounded up). No explosion evidence found in city or nearby.

1932 December 23- Explosions and north landslides on Carbon Mountain. Headline says mountain is moving south of Durango. Many theories are put forward. The explosions continue as late as March 1933. Rocks from explosions were found among the rail yards on the east side of the Animas River. The north "landslides" ejected coal into Tortilla Flats (now Bodo Park). At least one person is taken for a ride down these landslides (see following picture). The east landslide develops along strike toward the east and the Animas River. There are fears of it damming the Animas River. Only one coal mine is identified in proximity to Moving Mountain. This was the McCloskey West mine. It was said to have had a lot of methane.

### Durango Herald January 9, 1933



1934- A USGS geologist visits the site and writes a paper about the east landslide. The north landslides are not mentioned. The coal mine (assumed to be the McCloskey West) is visited and no damage is noted. A stream of water is flowing out of the adit that smells of hydrogen sulfide. The geologist concludes the "noise" of the landslide sounded like explosions.

1935- Moving Mountain is visited by Will Rogers who jokes that a few sticks of dynamite would make it move better.

1939 or 1940- Landslide on Moving Mountain remembered by Joe and Miriam Salmon. The author has not found mention in local papers.

1950's- Large landslide on Moving Mountain. The dust cloud was seen from town. KSUT radio watched it all day. The author has not found mention in local papers. There were lots of new geologists in town for the oil and gas boom. I find almost no mention in the literature. Some remember gas seeps in the river near the base of the east landslide.

1980's- Professor Robb Blair noticed new landslide scarps high on Moving Mountain. Paul Oldaker observes the river gas seeps near the base of the east landslide.

2006 June- Mr. Walt Walker of La Plata County finds old coal mine at the southwest end of the gun range. This is assumed to be the only identified mine which was the McCloskey West. The mine is not under Carbon Mountain, but the first ridge to the south which has been known as Parson's Mountain. No apparent explosion or landslide damage to this coal mine.

Authors Conclusion- The outcrop was ignited due to unknown cause and started a coal fire in the lower Fruitland Formation coals. Methane gas seepage from the Fruitland Formation coals was ignited causing explosive ejectate to the north into Bodo Park. The east landslide develops along strike due to structural failure.

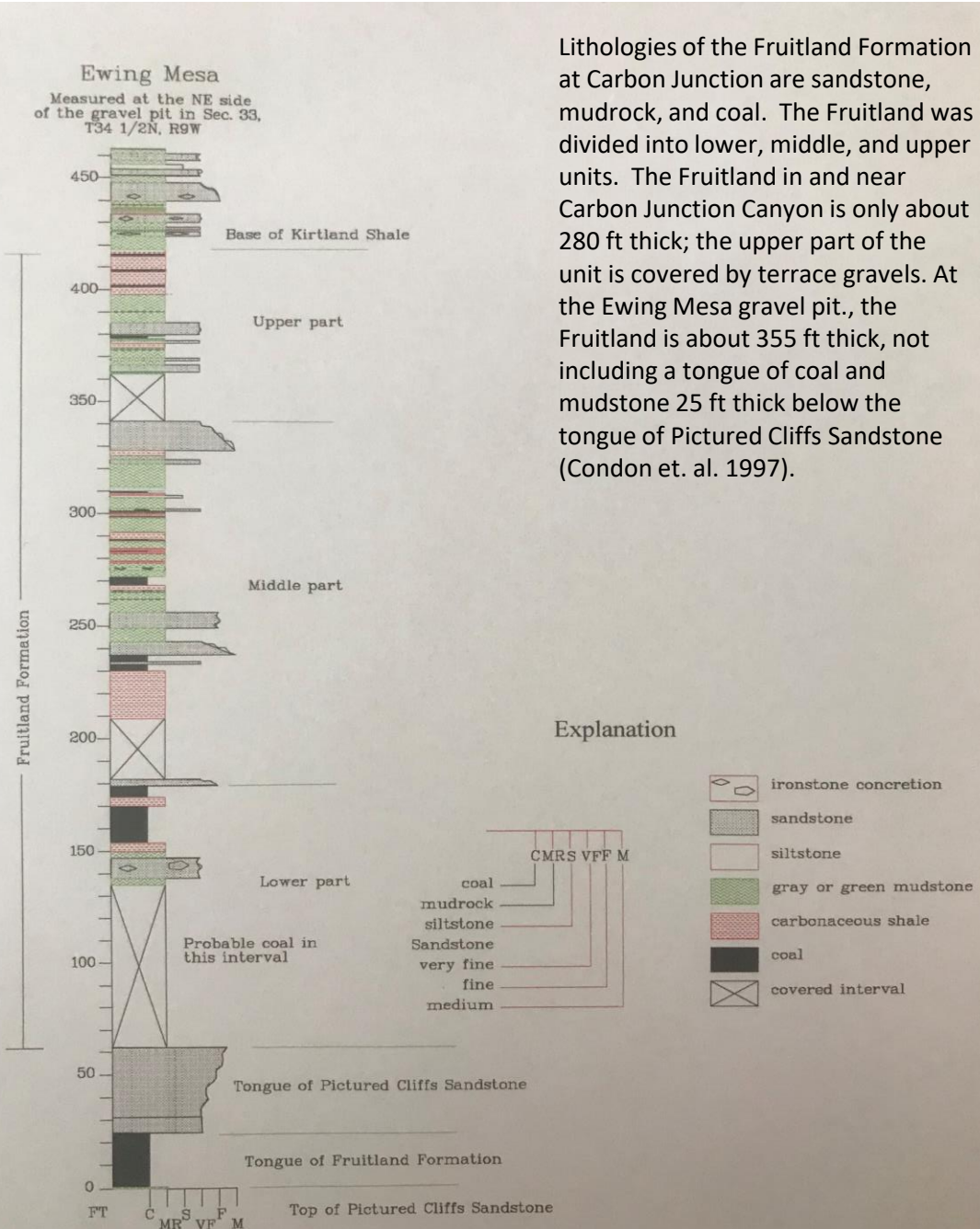




Methane seep measurements, along the Fruitland Outcrop









# SFTC (methane mitigation system)

## Stop 6

The objective methane mitigation system is to demonstrate the technical viability to recover and use methane seepage at specific locations where methane seeps to the surface along the Fruitland Formation Outcrop. An additional goal of the mitigation system is to protect the environment, which includes reducing carbon emissions and improving plant growth. To accomplish these objectives, LTE designed and installed vapor collection and barrier systems for methane collection at the South Fork Texas Creek (SFTC) site. Recovered methane is used to fuel a turbine, which generates electricity to operate the collection system. The turbine returns the excess generated power to the local electrical grid for credit as a renewable energy resource. The initial design, installation, and startup of the 4M methane mitigation systems were completed in 2008 and 2009.

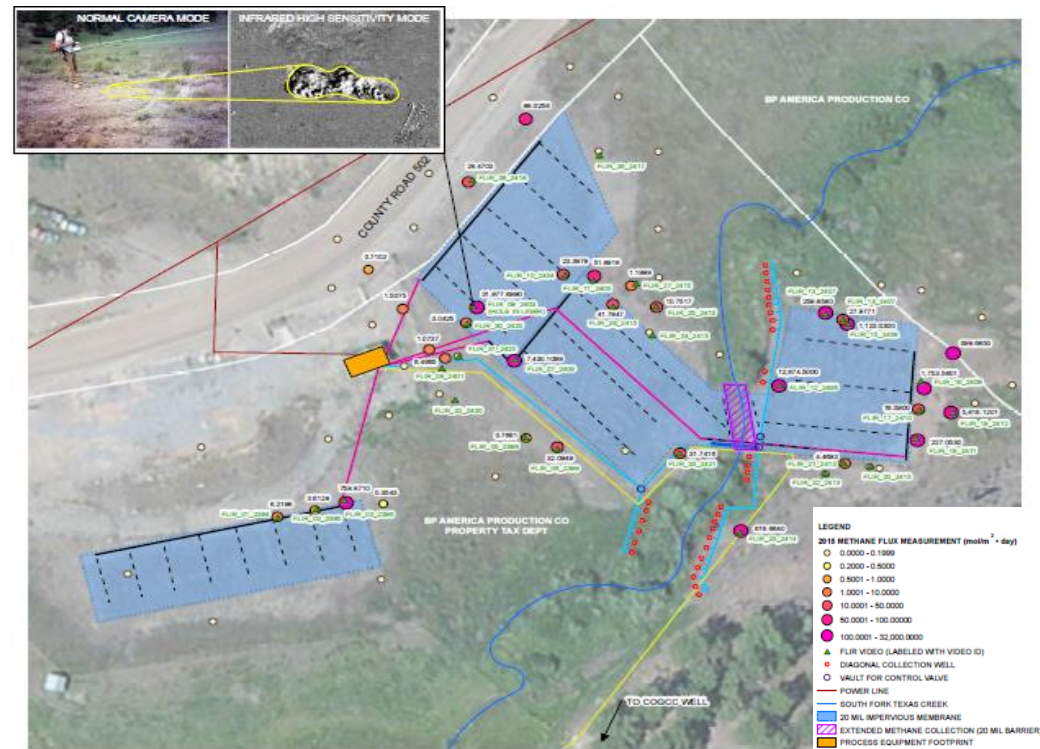


FIGURE 5  
SOUTH FORK TEXAS CREEK METHANE GAS FLOW  
4M OUTCROP MITIGATION PROJECT  
BP AMERICA PRODUCTION COMPANY & COLORADO OIL AND GAS CONSERVATION COMMISSION

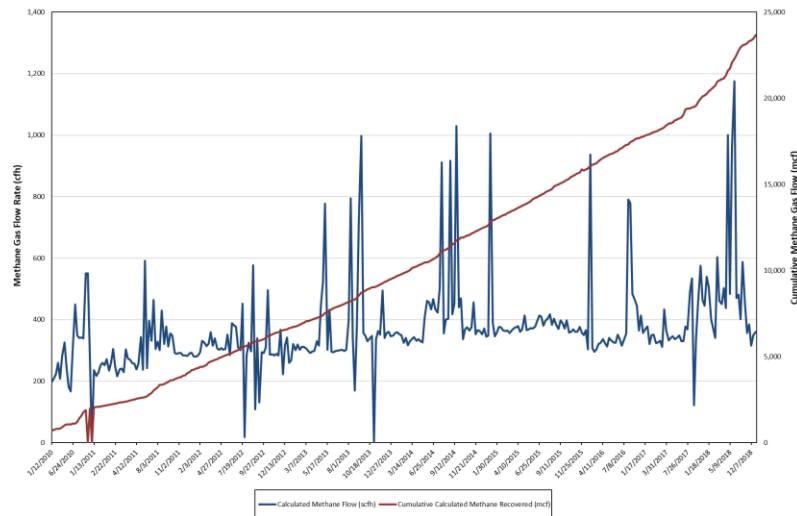
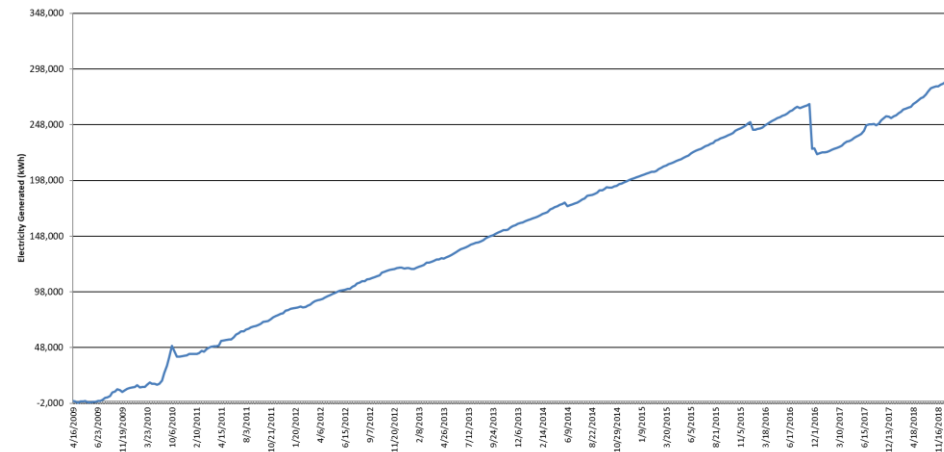
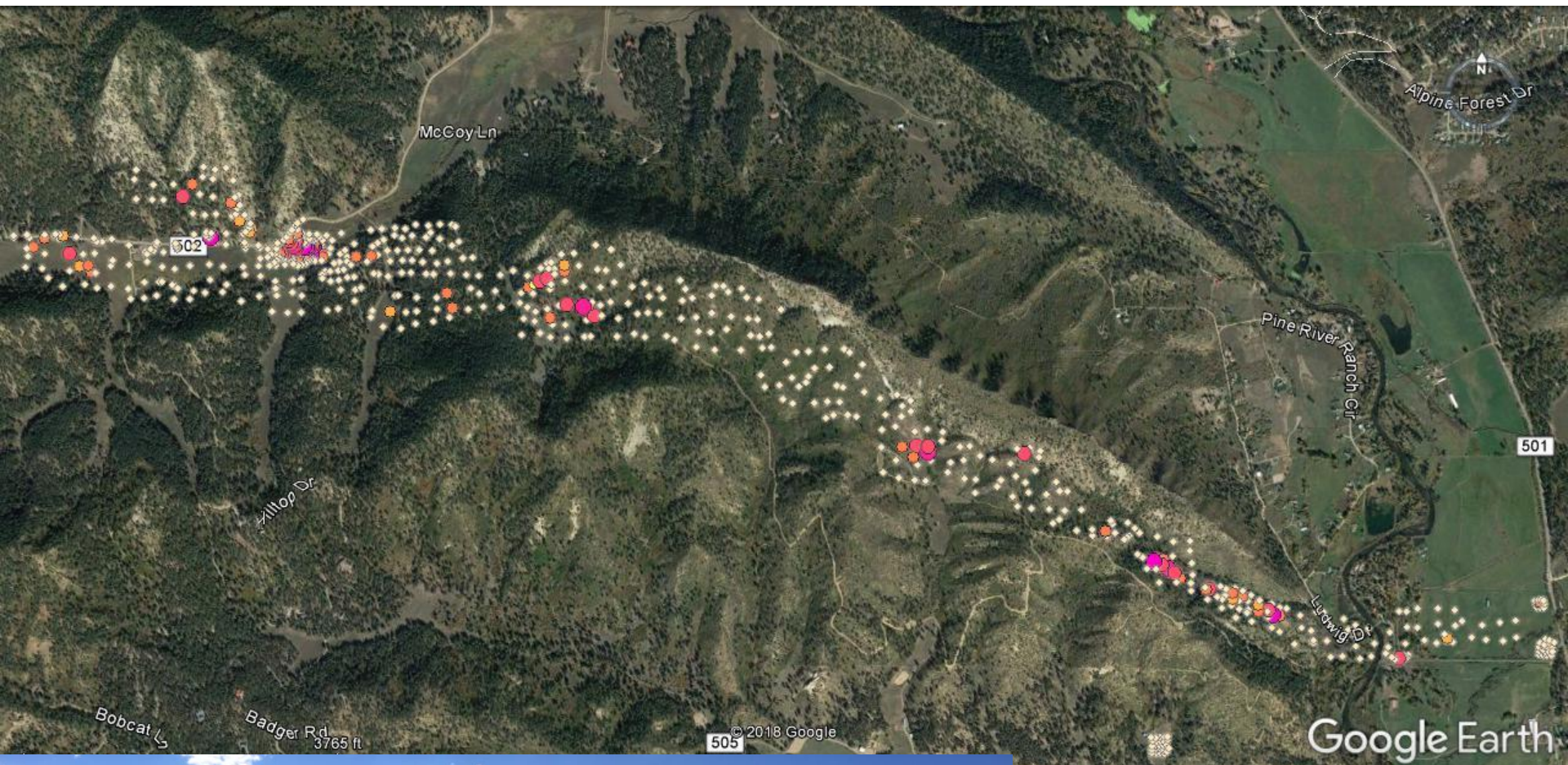


FIGURE 6  
SOUTH FORK TEXAS CREEK  
SURPLUS ELECTRICITY GENERATED  
4M OUTCROP MITIGATION PROJECT  
BP AMERICA PRODUCTION COMPANY & COLORADO OIL AND GAS CONSERVATION COMMISSION







5 lat 37.3

**METHANE FLUX MEASUREMENT (mol/m<sup>2</sup> · day)**

⬤	0.0000 - 0.1999
⬤	0.2000 - 0.5000
⬤	0.5001 - 1.0000
⬤	1.0001 - 10.0000
⬤	10.0001 - 50.0000
⬤	50.0001 - 100.0000
⬤	100.0001 - 28,228.0000

1.0 mole/day CH<sub>4</sub> = 1.12 CFD CH<sub>4</sub>



Stop 7

Pine River Methane Mitigation System



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