Subsurface and seismic interpretations of Carbondale and the surrounding Roaring Fork valley



Modified from https://ngmdb.usgs.gov/Prodesc/proddesc 94638.htm Quad Link

6/17/2020 sinkhole on Hwy 133: "Crews filled, tamped down, capped, and paved the sinkhole, which measured 15 feet in diameter by 12 feet deep. Filling the sinkhole required 125 tons of road base material, delivered with 10 truckloads. Once the sinkhole was repaired and repaved, northbound CO 133 was restored to the roadway at approximately 3:30pm and CDOT ended the short detour nearby."

https://www.bing.com/search?pglt=43&q=sopris+sun+carbondale+colorado+6%2F17%2F2020&cvid=fce623c3b3f145d880a1ba072da3afbc&gs_brp=EgZjaHJvbWUyBggAEEUYOTIGCAEQABhAMgYIAhAAGEAyBggDEAA YQDIGCAQQABhAMgYIBRAAGEDSAQgzNzAzajBqMagCALACAA&FORM=ANNTA1&PC=U531

Don Marlin prior background:

Certified Geophysicist #41 (AAPG)

Certified Professional Geologist #7696 (AIPG)

Professional Geoscientist #91 (LBOPG) B.S. & M.S. Geology, LSU

(Publications on seismic, salt, and subsurface available on request)

COLORADO GROLOGICAL SURVEY DEPARTMENT OF NATURAL RESOURCES DENVER, COLORADO

Colorado Map of Potential Evaporite Dissolution and Evaporite Karst Subsidence Hazards

By Jonathan L. White

Reference: https://colorado geologicalsurvey.org/publica tions/evaporite-dissolution-

karst-subsidence-hazard-

map-colorado/





			meters	
0	Pliocene or Miocene	Sedimentary units	0-250	
zoi	Q - Miocene	Volcanic units	0-400	
Cenozoio	Eocene and Paleocene	Uinta, Green River, and Wasatch Formations	0-3,300	222
sno	Honor	Mesaverde Grp.	1,450	2ª
Cretaceous	Upper Cretaceous	Mancos Shale	1,400	
	L. Cret.	Dakota Ss.	50-70	
	per Jurassic	Morrison Fm.	75-150	
_	Jurassic	Entrada Ss.	20-30	S. N.
Up	per Triassic	Chinle Fm.	20-90	1
L. Tri	as., L. Perm.	State Bridge Fm.		
L. P	ermian	Maroon Formation	1,150- 4,900	AL S
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	ambrian	Sawatch Quartzite	65-165	

Modified from https://coloradogeologicalsurvey.org/wpcontent/uploads/RT-0061890-i0-8137-2366-3-366-0-1.pdf

Conglomerate, sandstone, and siltstone

Mostly basaltic flows and minor silicic flows and ash-flow tuffs

Uinta Fm.: ss., slst., and calcareous mdst. Green River Fm.: oil sh., calcareous mdst., ss., and slst. Wasatch Fm.: clyst., mdst., slst., ss., and cgl.

Williams Fork Fm. : ss., slst., mdst., sh.,coal, and clinker

Iles Fm.: ss., sh., and slst.; Rollins Ss. Mbr. at top; Cozzette Ss. Mbr. in lower part; Corcoran Sandstone Mbr. at base

Upper mbr.: dark-gray, locally bentonitic, carbonaceous sh.; ss. beds near top, calcareous sh. at base; Niobrara Mbr.: shaly ls.; ls. beds in lower part; lower mbr: gray, very pale gray-weathering, calcareous sh., and dark gray sh., silty sh., calcareous ss., slts., and ls.

Very pale gray ss., minor carbonaceous shale Greenish-gray to grayish-red slts., clyst., white _ss., and gray ls. near base

Gray to pale orangish-gray cross-bedded ss.

Pale to reddish-brown calcareous slts., silty ss., and ls. pebble conglomerate

Pale red, grayish-red, and reddish-brown slts. and minor ss.

Schoolhouse Mbr.; gray sandstone Main body: grayish-red and reddish-brown arkosic, ss., conglomeratic ss., and mudstone Lower mbr.; grayish-red and reddish-brown ss.,slts., mdst., white ss., and a few beds of Is., silty Is., gypsum, and anhydrite

Ss., slts., Is., and silty Is. in various shades of gray; some red, brown, and orange beds; a few beds of gypsum and anhydrite

Pale gray to white gypsum, anhydrite, halite, and gray, partly gypsiferous slts., sh., ss., and fossliferous ls.

Medium-gray to black and dark brown carbonaceous sh. and gray fossliferous Is.

Bluish gray, coarse- to fine-grained Is. and dol.

Dolomitic ss., dol., ls., gray fossiliferous ls., ss., and dol. sh.

Dol., Is. cgl., calcareous sh., ss., and Is.

Thinly bedded dol., dolomitic ss., dolomitic sh., dolomitic cgl., and algal ls.

White to yellowish-gray, quartzite; beds of brown sandy dol. in upper part; local arkosic quartz pebble cgl. near base

Gneissic granitic rocks, sillimanite mica gneiss, amphibolite, and felsic gneiss

Figure 3. Generalized stratigraphic relations in west-central Colorado. Adapted from Tweto and Lovering (1977), Johnson et al. (1990), Kirkham et al. (1997a), Scott and Shroba (1997), Bryant et al. (1998), Lidke (1998, 2002), Scott

Don Marlin notes: Stratigraphy between highlighted intervals eroded away in study area. et al. (1999), Shroba and Scott (1997, 2001), Scott et al. (2001), and Scott et al. (2002).



Don Marlin notes: Stratigraphy between highlighted intervals eroded away in study area. et al. (1999), Shroba and Scott (1997, 2001), Scott et al. (2001), and Scott et al. (2002).

Colorado Map of Potential Evaporite Dissolution and Evaporite Karst Subsidence Hazards



EXPLANATION

Evaporite Bedrock: These exposed and near-surface rock units are composed of high percentages of the evaporite minerals anhydrite (CaSO₄) and halite (rock salt - NaCI) at depth, and gypsum (CaSO₄*H₂O) near the surface. Evaporite rocks are soluble in water and near-surface voids and loose rubble zones can form through dissolution. Settlement and collapse of the ground surface into these subsurface voids can create ground depressions and sinkholes, known collectively as karst landforms. Rock deformation has typically contorted the rock strata so surface exposure can have high lateral variability in rock properties for engineering purposes. Active dissolution of evaporite rocks also cause environmental problems with salt and other total dissolved solids in groundwater and surface waters. See map report for additional information.

Regional Collapse Centers: Regional zones of ground deformation and subsidence where strong evidence suggests the cause is related to salt tectonics, dissolution, and subsidence. Named locations are further discussed in map report.

Modified from Jonathan White 2012: https://coloradogeologicalsurvey.org/publications/evaporite-dissolutionkarst-subsidence-hazard-map-colorado/



Figure 4. Illustration of typical karst and stages of sinkhole development. Sinkholes form by the upward progression of cavern roof collapse that reaches the surface. Small sinkholes can also occur by piping of fine grained sediments into solution slots.

Colorado Map of Potential Evaporite Dissolution and Evaporite Karst Subsidence Hazards

> bv Jonathan L. White

Colorado Geological Survey Department of Natural Resources Denver, Colorado 2012



Figure 3. Several sinkholes pockmark a mid-Pleistocene glacio-fluvial terrace in the Roaring Fork ar Carbondale in Garfield County



Modified from https://coloradogeologicalsurvey.org/publications/evaporite-dissolution-karstsubsidence-hazard-map-colorado/ Photos from OF-12-02 Report



Figure 10. Large sinkhole opened in 2005 at golf course club grounds at Ironbridge Development. Two golf carts inside the structure were lost down the throat of the sinkhole. View is to the northwest, down the Roaring Fork River valley towards Glenwood Springs. Red cliffs are the Maroon Formation. For scale, note person in white hardhat standing in the snow. Viocene unconsolidated sediments lie directly on Late Pennsylvanian evaporative bedrock in the valley.

Don Marlin notes: Visual summary and schematic of hazards in the study area since Holocene-

The Roaring Fork has a subsurface salt structure that has pushed up the Eagle Valley evaporites. River downcutting and freshwater dissolution creates complex recumbent folds near CRMS along Edgerton Creek And Hwy 108 (Thompson Creek Road).



View North from Mt Sopris Well found salt at 2125'



View South from Grandstaff Mt Biking trail"stacks"

"In the subsurface near Cattle Creek Station (the Rose well), the evaporite is gray to brown anhydrite interbedded with light-colored siltstone and sandstone and a few dark shale beds to a depth of 2,125 feet. Below this level halite is the principal rock. No halite is present at the surface anywhere in the area." Mallory, W.W., 1971, The Eagle Valley Evaporite, northwest Colorado: A regional synthesis: U.S. Geological Survey Bulletin 1311-E, 37 p. https://pubs.usgs.gov/bul/1311e/report.pdf report.pdf (usgs.gov)

Don Marlin notes: Pictures taken in 2024 illustrate the instability of evaporite outcrops and how they intrude into surrounding topography from mobilized salt rising to the surface and confirmed by 1960 well control.



CATTLE CREEK QUADRANGLE GEOLOGIC MAP, GARFIELD COUNTY, COLORADO

FUNDAMENTAL TOOLS OF SUBSURFACE MAPPING



OUTCROPs

SURFACE PROJECTION

WELL TIES

<u>Modified from</u> <u>https://ngmdb.usgs.gov/Prodesc/proddesc 101352</u> <u>.htm</u>



4) Integrate two-dimensional reflection seismic to revise steps 1-3 and fill in missing information for more accuracy.

SEISMIC

<u>Modified from</u> <u>https://www.usgs.gov/publications/implicationsevaporite-tectonism-carbondale-and-eaglecollapse-centers-west-central</u>



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GEOLOGIC MAP OF THE CARBONDALE QUADRANGLE, GARFIELD COUNTY, COLORADO

By Robert M: Kirkham and Beth L. Widmann 2008 not solely used

not solely used for future exploratory drilling.



Don Marlin notes: The 2008 guad should be modified...



2500

SEISMIC AND SUBSURFACE WELL **CONTROL MODIFY THIS CROSS** SECTION TO SHOW NEAR SURFACE FAULTING AND SALT NOT ONLY **EVAPORITES**

Link: https://ngmdb.usgs.gov/Prodesc/proddesc 94638.htm



SEISMIC AND SUBSURFACE WELL CONTROL MODIFY THIS **CROSS SECTION** TO SHOW **NEAR SURFACE FAULTING** AND SALT NOT ONLY **EVAPORITES** Link:

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Seismic modified https://www.usgs.gov/publications/implicationsevaporite-tectonism-carbondale-and-eagle-collapsecenters-west-central 2

Seismic base location https://www.seitel.com/index.php/seitel-map/

Prodesc/proddesc 94638.ht m Lower quad modified from

https://ngmdb.usgs.gov/Prod esc/proddesc 41291.htm

Don Marlin notes: Quad map approximate position of depth processed Line 103 from Perry (2002) approximating the location of reflectors that are interpreted to be a salt structure under Crystal River Ranch with surface features, a salt synclinal axis under the Crystal River, questionable subsurface faulting near the town center, and a rise of possible salt which may tie to lost circulation below 1700' and inferred to be salt below 2320' TD in 1962 Champlin well 1 mile East off this line position.



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fromhttps://ngmdb.usgs.gov/ Prodesc/proddesc 94638.ht m Lower quad modified from https://ngmdb.usgs.gov/Prod esc/proddesc 41291.htm

Upper quad modified

2500



activity in peripheral areas and surface mounds on ranch.



Seismic Line 104 North from Crystal River Ranch to Prince Creek Road

illustrates the salt axis is West of Carbondale and a listric fault bounds South side of town

Sopris Park

Crystal River Baptist Church

111

Crystal Ri

Tertiary gravels

PPMAPev

^{šea} level

Arince Ck Rd

Cleer (2024)

a level Don Marlin notes: Oriented line approximate position of depth processed Line 104 from Perry (2002) approximating the location of reflectors that are interpreted to be a salt structure under Crystal River Ranch with Sumace reasons and suggest the salt axis follows the Solid strain of the 2008 quad map, a large listric and

possible contemporaneous fault that reache the surface as a fault scarp at outcrop level and extends 7000' into the subsurface and may b the basis of the Sopris Bowl of Kirkham 2002, and a projection ~4 miles North of this line to the 1960 Shannon Rose #1 that encountered 4 lenses of salt at 2125' to 3070' below the surface at the South end of the current Iron Bridge subdivision. The current 2008 guad map and section is suggested to be modified.



Elevation in feet

5,000

Line 103

Seismic modified

https://www.usgs.gov/publications/implicationsevaporite-tectonism-carbondale-and-eagle-collapsecenters-west-central 2

Seismic base location https://www.seitel.com/index.php/seitel-map/ Pale gray to white gypsum, anhydrite, halite, and gray, partly gypsiferous slts., sh., ss., and fossliferous Is.

sits., is., and sitty is. in various shades of gray; some red, own, and orange beds; a few beds of gypsum and anhydrite

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LINE 104

top of bedrock?

133

Crystal River

Medium-gray to black and dark brown carbonaceous sh. and grav fossliferous Is

Bluish gray, coarse- to fine-grained Is. and dol.

Strat section modified from https://www.usgs.gov/publications/implicationsevaporite-tectonism-carbondale-and-eaglecollapse-centers-west-central

Seismic from Perry etal January 2002 Geological Society of America Special Papers 366:55-72

2024 Basemap (Seitel)

2024 reinterpretation (red)

Don Marlin notes: Seismic basemap position of four depth processed lines from Perry (2002) used for approximating the location of reflectors that are interpreted to be a top and base of salt structure under the Roaring Fork and Crystal River valleys. Approximate positions of key subsurface well control is also shown by circles.



В

Seismic modified 5.000 https://www.usgs.gov/publications/implicationsevaporite-tectonism-carbondale-and-eagle-collapsecenters-west-central 2 Sealowei

Seismic base location https://www.seitel.com/index.php/seitel-map/

Shannon Rose #1 Sample Log (not published, located in archive file June 2024)

Grey-white salt from 2125' to 3060' in 4 lenses (935' gross interval)





Salt at ~2200' under Carbondale

created by manually projecting depths of interpreted top of salt to approximate SP positions and well control and contouring the same in depth above sea level. The map suggests a split of the salt diapir going West of the town of Carbondale and ENE of the town bifurcated by the listric fault-bounded Sopris bowl. The Westerly salt trend underlies the 2008 quadrangle map subsidence trough and trends south merging with the Elk Creek anticline and Grand Hogback bounding the Piceance basin on the East.

Seismic modified https://www.usgs.gov/publicati ons/implications-evaporitetectonism-carbondale-andeagle-collapse-centers-westcentral 2

Seismic base location https://www.seitel.com/index.p hp/seitel-map/

Subsurface Top Salt Structure Map



Don Marlin notes: An aerial view of the salt structure and possible interpreted subsurface and surface fault trends and well control as if the overlying layers were stripped away down to the top of salt. This map was created by manually projecting depths of interpreted top of salt to approximate SP positions and well control and contouring the same in depth above sea level. The map suggests a split of the salt diapir going West of the town of Carbondale and ENE of the town bifurcated by the listric fault-bounded Sopris bowl. The Westerly salt trend underlies the 2008 quadrangle map subsidence trough and trends south merging with the Elk Creek anticline and Grand Hogback bounding the Piceance basin on the East.

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<u>Seismic base location</u> https://www.seitel.com/index.p hp/seitel-map/



Karst base modified fromhttps://www.americangeosciences.org/sites/ default/files/Environment-colorado4.pdf

Valley Sinkholes....Carbondale may be related to contemporaneous / listric faulting and underlying salt

Seismic modified https://www.usgs.gov/publications/im plications-evaporite-tectonismcarbond ale-and-eagle-collap se

Seismic base location https://www.seitel.com/index.php/seit el-map/

centers-west-central 2

Modified from: Collapsible Soils and Evaporite Karst Hazards Map of the Roaring Fork River Corridor, Garfield, Eagle, and Pitkin Counties, Colorado Jonathan White, 2002

Sinkholes and subsidence features— Ground depression areas created either by (1) piping or collapse of surficial deposits into dissolution fissures, voids, or caverns within underlying Eagle Valley Evaporite, (2) downward movement of gravel chimneys into deep bedrock voids, (3) dissolution caverns in outcrops of Eagle Valley Evaporite, or (4) large-scale collapse or settlement of low-density surficial deposits. A black dot denotes small sinkholes or clusters of small sinkholes, and closed, hatured lines denote the larger subsidence areas. Many small sinkholes in addition to those shown are probably present where the Eagle Valley Evaporite is shown, but have not been detected or mapped. ucroites sinal sinkholes of clusters of sinal sinkholes, and closed, hatured lines denote the larger subsidence areas. Many small sinkholes in addition to those shown are probably present where the Eagle Valley Evaporite is shown, but have not been detected or mapped.

Soil-collapse locations—Historical occurrences of soil settlement, damage to structures, and/or collapsible soils verified by soil testing. These data were compiled by CCS as part of the Statewide Collapsible Soil Study (White and Greenman, in prep.). Red triangles show approximate locations of historical occurrences of collapsible soils or damage to a structure as a result of soil collapse and settlement. A Red triangle with black edging denotes approximate locations of historical occurrences of both collapsible soils and sinkholes.



Don Marlin notes: Summary of salt and fault trends versus the new top of salt subsurface map.



- Contact-Dashed where approximately located;
- Diapiric contact-Contact between evaporitic formations and overlying formations where the evaporitic rocks are intrusive or piercing into the overlying formations. Teeth are on the intrusive
- Fault-Dashed where approximately located; dotted where concealed; bar and ball on downthrown side; includes faults related to dissolution and
- Anticline—Showing axial trace; dashed where approximately located; dotted where concealed; arrow on end of axis indicates direction of plunge
- Syncline—Showing axial trace; dashed where approximately located; dotted where concealed; these structures may be synclinal sags, but they lack supportive evidence for this origin
- Synclinal sag or subsidence trough-Showing axial trace of synclinal sag or subsidence trough related to evaporite tectonism; synclinal sags occur in bedrock, subsidence troughs are in river terraces and overlying deposits; dashed where approximately located; dotted where concealed; limbs of synclinal sags and subsidence troughs may be faulted; closed and nearly closed depressions in collapse debris (QTcd), which likely are at least in

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Quadrangle map modifications From seismic

Seismic modified https://www.usgs.gov/publications/im plications-evaporite-tectonismcarbondale-and-eagle-collapsecenters-west-central 2

Seismic base location https://www.seitel.com/index.php/seit el-map/





FORMATION TOPS.	ISITY TYPE	POROSITY GRADE	гтногост	CRYSTALLINE. Grain or Fragment Size	NG-DIAG, TYPE	IG DIAG, DEGREE	D OF IEWORK TC FILLER	DESCRIPTION SHANNON ROSE #1	JGGESTED 4V-ROMMENT	NEERING DATA		Don Marlin notes: Astratigraphic correl November 2023 geothermal wellbore h surface in the Roaring Fork Valley.			ndlatera	l hete	rogeneity	
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Figure 4. Illustration of typical karst and stages of sinkhole development. Sinkholes form by the upward progression of cavern roof collapse that reaches the surface. Small sinkholes can also occur by piping of fine grained sediments into solution slots.

Don Marlin notes: Vertical and lateral heterogeneity could lead to encountering new hazards in the shallow subsurface with dense geothermal drilling. Caution is advised.

Colorado Map of Potential Evaporite Dissolution and Evaporite Karst Subsidence Hazards

by Jonathan L. White

Colorado Geological Survey Department of Natural Resources Denver, Colorado 2012



Figure 3. Several sinkholes pockmark a mid-Pleistocene glacio-fluvial terrace in the Roaring Fork Valley near Carbondale in Garfield County.



Modified from https://coloradogeologicalsurvey.org/publications/evaporitedissolution-karst-subsidence-hazard-map-colorado/ Photos from OF-12-02 Report



Figure 10. Large sinkhole opened in 2005 at golf course club grounds at Ironbridge Development. Two golf carts inside the structure were lost down the throat of the sinkhole. View is to the northwest, down the Roaring Fork River valley towards Glenwood Springs. Red cliffs are the Maroon Formation. For scale, note person in white hardhat standing in the snow.

COMMENTS:	(16NOV) Gravel in the upper 40' of hole caused concern to driller, casing installed after drilling 120' (POOH). Casing consisted of 2x20' 6" dia Cresline HDPE, top ~4.5' were cut after insertion (~35' casing). <u>Casing would not stay</u>
	seated so drillers packed more hole plug (total 2 bags) and SDFN to allow to set overnight.
	(17NOV) Casing reseated with more hole plug (5 addtl bags) and drilling continued without issue to 500'. Drillers experienced difficulty pulling string at 400' and bit was stuck at ~360' for remainder of day - the mud pump had reduced circulation and driller believed <u>cuttings accumulated atop the bit</u> on the way down.
	(18NOV) Mud pump repaired and hole redrilled extending an additional 20' (520' total). <u>Initial attempt to install loop failed ~350' due to debris / narrowing in hole</u> . Redrilled hole to 520'. Second attempt got loop to 450', trimmed ~4 feet above ground, ends melted shut, tied to metal stake, and grouted with 20 bags of TG Lite and 10 bags of PowerTEC.
	(20NOV) Grout settled to 18' below surface (within casing), drillers backfilled with mudchips, cleaned up, and vacated site.
	Summary notes:
	40 to 60' in adjacent areas may require casing due to unstable ground and large hard rock gravels (granite, basalt). This driller widened the hole to 8" down to 40' and installed 2x20' sections of locally sourced 6" dia Cresline HDPE and sealed with 3/8" bentonite hole plug. Production drillers may consider bringing preferred casing/hole plug to site as local supply/variety could be limited.
	300' to TD may contain <u>unstable carbonaceous shale lenses in adjacent areas</u> , loop depths may vary within this range although head driller said he is confident 450' loop depth is achievable at scale.
	Drilling crew were helpful, hard working, and a pleasure to work with. They spoke highly of their company and were happy with the equipment they were using.
	Head driller notes: Clarity on mud/cutting disposal prior to arriving at site would have been helpful and allowed them to coordinate
	disposal option prior to arrival. This could cause delays for future exploratory holes depending on local disposal
	Options. Drilling Comments Link: https://gdr.openei.org/submissions/1598

Drilling 0 - 520'

7:54

Drilling

Hrs:Min



Summary

- To present an interpretation based on additional subsurface / seismic since quads do not accurately depict this area as accurately as possible without these tools.
- Faulting that reaches the surface is a better basis for sinkholes than solely salt in town proper area....but nearby evaporite outcrops and faulting creates further instability risk.
- Instability risk may be diminished by obtaining additional 2D seismic very close to the 3rd street Center area by providing additional subsurface control for drilling.
- Wellbore instability is likely to continue in the project area.