ST. CROIX OPERATING, INC.

GEOLOGIC FORMATION SUMMARY

WASHINGTON COUNTY, COLORADO

LYONS SANDSTONE – DENVER BASIN

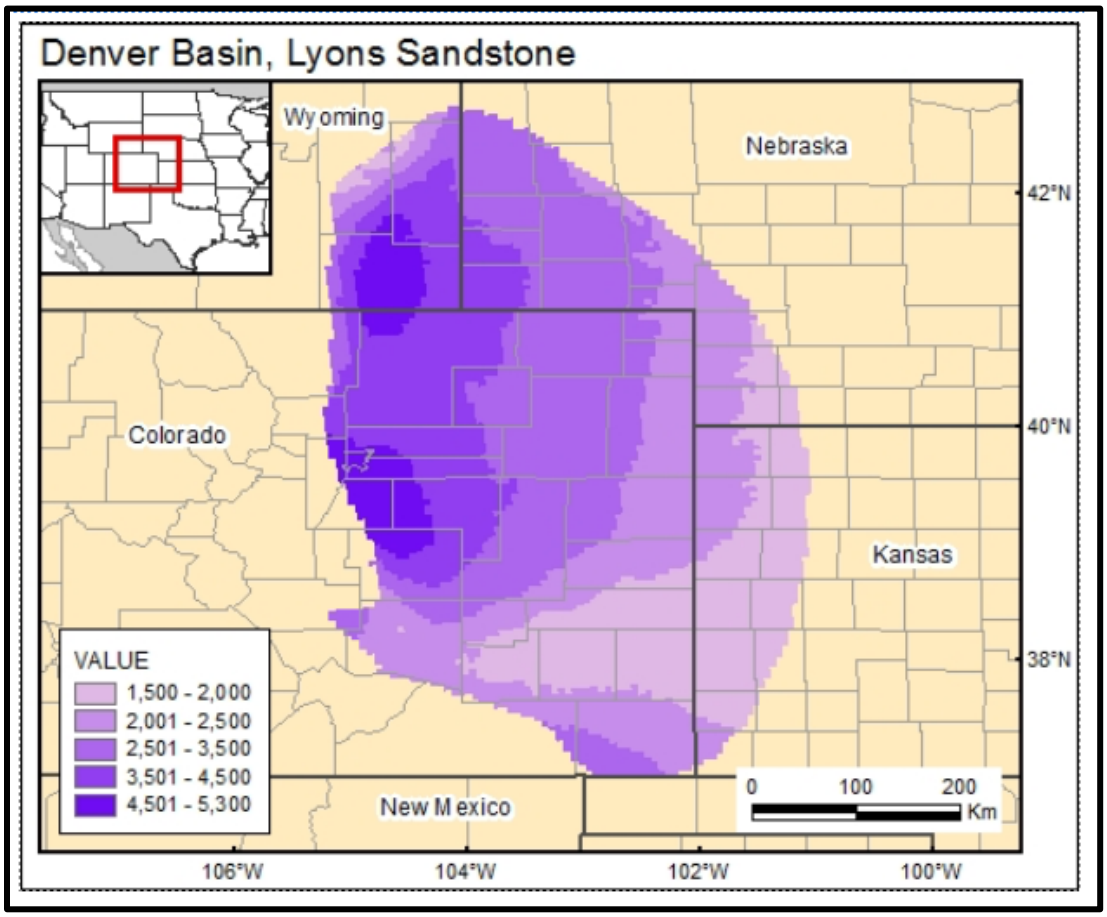
The Lyons Sandstone, as found in Washington County, Colorado, is an expansive and contiguous sand body that stretches across the county. The Lyons Formation does not contain commercial amounts of hydrocarbons in the area, but is known to be productive in some of the western parts of the Denver Julesburg (DJ) Basin. The most common documented use for the Lyons in Washington County is for the disposal of produced water. The Lyons conforms to an overall East to West dipping structure across the DJ Basin, ranging from about 4500' on the west side of the county to about 3500' on the east side of the county. The gross thickness of the Lyons formation in this region ranges from 301'-400', Sonnenberg (1981).

The Lyons formation is bounded above by the Lykins formation which ranges from a thickness of 51 to 75 feet. The Lykins is composed of red shale, siltstone, evaporite and carbonate, with increasing percentage of Clastic Rocks from 50-100% West to the East in Washington County, Geological Atlas of the Rocky Mountain Region (1972). The diagenetic cementation in the Lyons Sandstone also limits the potential of vertical flow, providing additional fluid migration limiting properties.

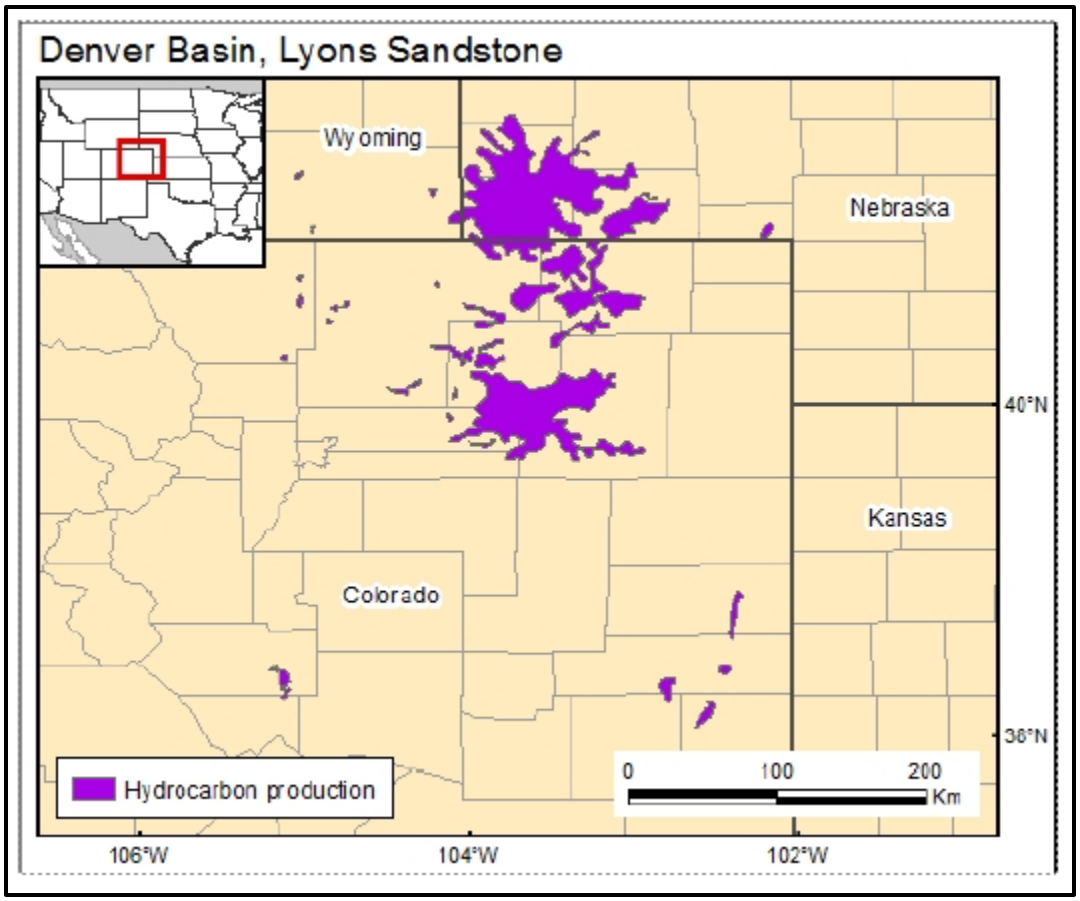
Confining Zones are below. Hydrocarbon Zones are in Red.

Upper	Lithology	Top Depth (ft)	Bottom Depth (ft)
Carlile Shale	marine shale	3950'	4075'
Greenhorn Lime	Marine marlstone, limestone, shale	4075'	4125'
Graneros Shale	marine shale	4125'	4325'
D Sand	fine grained fluvial sand shale sequence	4325'	4375'
Huntsman Shale	black marine shale	4375'	4425'
J Sand	fine grained fluvial sand shale sequence	4425'	4650'
Skull Creek Shale	Marine silty shale	4650'	4750'
Lakota Sandstone	fine grained fluvial sand	4750'	5050'
"O" Sand	fine grained fluvial sand	5050'	5100'
Morrison Formation	fine grained fluvial sand	5100'	5300'
Lykins	fine grained fluvial sand	5300'	5620'
Fountain Formation	fluvial silty shale	5740'	5820'

The depth map shown below uses the Dakota as an estimation of the Lyons Depths across the DJ Basin.



The Lyons Formation has produced economic quantities of hydrocarbons in some areas of the Denver Basin and was first discovered in 1953 at Keaton field. Most Lyons production was in the Black Hollow and Pierce fields in Weld County, Colorado, each producing over 10MMbbl. Other notable fields include the Berthoud field and New Windsor field in western Weld County.



Formation Properties for the Lyons Sandstone include porosity ranging from 9-12% and permeability ranging from 21-88 md in the active or producing fields.

Average Water Chemistry - Lee, M. L., and Bethke, C., 1994, Groundwater flow, late cementation and petroleum accumulation in the Permian Lyons Sandstone,

Na (mg/L)	110
Ca (mg/L)	19
K (mg/L)	5
Mg (mg/L)	1
SiO_2 (mg/L)	49
HCO_3 (mg/L)	310
Cl (mg/L)	55
SO_4 (mg/L)	36

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Underground Source(s) of Drinking Water

There are zero domestic water wells within a 1-mile radius of the Longknife #3 SWD facility. The two closest domestic use water wells to the Longknife #3 SWD facility are producing from the Ogallala formation, at depths of 98 feet and 245 feet. The USGS Groundwater report attached outlines the water resources in Washington County. Most wells are going to be less than 300 ft and utilize the formations shown in the table below. The table also includes the names and geologic characterizations of each formation. The Ogallala is the main aquifer used in this region. The below excerpts from the USGS report better explain the potable resources in the area.

"*Most of the potable ground water in Washington County occurs in two distinct ground-water provinces. These provinces correspond to the two principal surface drainage systems. The province in the South Platte River basin consists chiefly of alluvial deposits of the South Platte River and its tributaries. The province in the Kansas River basin consists chiefly of the Ogallala Formation, which forms the surface of the High Plains, as well as alluvial deposits of the stream valleys that cut across the Ogallala. The boundary between the two provinces in Washington County is shown on most of the figures. For ease of discussion, the westernmost one will be referred to as the South Platte ground-water province and the easternmost as the High Plains ground-water province.*" GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1777, 1964.

"*The Chadron Formation contains potable water and in places is capable of yielding appreciable amounts to wells. However, by comparison to the other ground-water reservoirs, this aquifer seems to have less potential for development. The aquifer in the Chadron occurs in both ground-water provinces, in places underlies the major aquifers, and is hydraulically connected to them. Present knowledge of the aquifer indicates that the water occurs chiefly in fractures in the clay, but also in lenses or channel-like stringers of sand. It is not known whether the water-bearing zones are continuous, or in which direction the water is moving. Answers to these and other questions about the hydraulic nature of this ground-water reservoir will require additional field studies that will include major exploration of the subsurface.*" GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1777, 1964.

"*The depth to water is a major factor affecting the cost of drilling wells and operating pumps. In parts of Washington County, where the depth to water is greater than 100 feet, pumping for irrigation may not be economically feasible owing to the high cost of operation and low yields. Small quantities of water for stock and domestic uses are pumped from considerably greater depths in some areas. The depth to water in the Ogallala Formation ranges from about 10 feet in the center of the county to about 250 feet along the east edge. In the South Platte valley, the Beaver valley, and the Arikaree valley, the depth to water ranges from a few feet to about 50 feet depending on the proximity of the well to the flood plain of the stream. The depth to water in the Pierre Shale and the Chadron Formation is unpredictable because the water-bearing zones may be almost anywhere in the formation or may be completely absent.*" GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1777, 1964.

TABLE 1.—*Generalized section of the geologic units exposed in Washington County, Colo.*

System	Series	Geologic unit	Thickness	Physical character	Water supply
Quaternary	Recent and Pleistocene	Dune sand	0–100±	Reddish-orange windblown sand	Serves as catchment area for recharge but does not yield water to wells. Generally above water table.
		Alluvium	0–250+	Pink, brown, and gray sand, gravel, clay, and silt.	Yields small to large quantities of water to wells.
	Pleistocene	Peorian Loess	0–120+	Massive yellowish-brown eolian silt. Well sorted and slightly cemented.	Yields no water to wells. Generally above water table.
Tertiary	Pliocene	Ogallala Formation	0–350	Gray to red sand, gravel, silt, and clay containing abundant caliche. Has caprock of algal limestone.	Yields small to large quantities of water to wells.
	Oligocene	Chadron Formation	0–300±	Massive olive to tan siltstone containing lenses and channels of sandstone.	Yields small to moderate quantities of water from channel deposits and fractures.
Cretaceous	Upper Cretaceous	Pierre Shale	2,000–4,500±	Thin-bedded, gray to dark-gray shale and sandy shale containing limestone and limonite concretions.	Yields small quantities of water to wells from the upper weathered zone. Forms the lower confining layer for water in overlying unconsolidated deposits.

REFERENCES

Clayton, J., and Swetland, P., 1988, Petroleum generation and migration in Denver Basin: American Association of Petroleum Geologists Bulletin, v. 64, no. 10, p. 1613-1633.

Geological Atlas of the Rocky Mountain Region, 1972, Rocky Mountain Association of Geologists.

Adams, J., and Patton, J., 1979, Sebkha-Dune Deposition in the Lyons Formation (Permian) Northern Front Range, Colorado: The Mountain Geologist, v.16, no. 2, p.47-57.

Belitz, K., and Bredehoeft, J., 1988, Hydrodynamics of Denver Basin: explanation of subnormal fluid pressures: American Association of Petroleum Geologists Bulletin, v. 72, no. 11, p. 1334–1359.

Clayton, J., and Swetland, P., 1988, Petroleum generation and migration in Denver Basin: American Association of Petroleum Geologists Bulletin, v. 64, no. 10, p. 1613–1633.

Garbarini, G., and Veal, H. K., 1968, Potential of Denver Basin for disposal of liquid wastes, subsurface disposal in geologic basins—a study of reservoir strata: American Association of Petroleum Geologists Memoir, p. 165–185.

Geological Atlas of the Rocky Mountain Region, 1972, Rocky Mountain Association of Geologists.

Hubert, J. F., 1960, Petrology of the Fountain and Lyons formations, Front Range, Colorado: Colorado School of Mines Quarterly, v. 55, no. 1, p. 1–242.

Lee, M. L., and Bethke, C., 1994, Groundwater flow, late cementation and petroleum accumulation in the Permian Lyons Sandstone, Denver Basin: American Association of Petroleum Geologists Bulletin, v. 78, no. 2, p. 227–237.

Levandowski, D., Kaley, M., and Smalley, R., 1973, Cementation in the Lyons Sandstone and its role in oil accumulation, Denver Basin, Colorado: American Association of Petroleum Geologists Bulletin, v. 57, no. 11, p. 2217–2244.

Martin, C., 1965, Denver Basin: American Association of Petroleum Geologists Bulletin, v. 49, no. 11, p. 1908–1925.

McGOVERN, Harold E. Geology and Groundwater Resources of Washington County Colorado. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1777.

McGovern, Harold Edward, 1924- Geology and ground-water resources of Washington County, Colorado. Washington, U.S. Govt. Print. Off., 1964. iv, 46 p. maps (4 fold. col. in pocket) diagrs., tables. 24 cm. (U.S. Geological Survey. Water-Supply Paper 1777) Prepared in cooperation with the Colorado Water Conservation Board. Bibliography: p. 46. 1. Geology Colorado Washington1 Co. 2. Water,

Underground Colorado Washington Co. 3. Water-supply Colorado Washington Co. I. Colorado. Water Conservation Board. (Series)

Sonnenberg, S., 1981, Tectonics, sedimentation and petroleum potential, northern Denver Basin, Wyoming, and Nebraska: Colorado School of Mines Quarterly, v. 72, no. 2, p. 215. Prepared by Martha Romero.

Romero, M. (n.d.). Lyons Sandstone, Denver Basin. Bureau of Economic Geology. Retrieved November 23, 2022, from https://www.beg.utexas.edu/gccc/co2-data/lyons-00