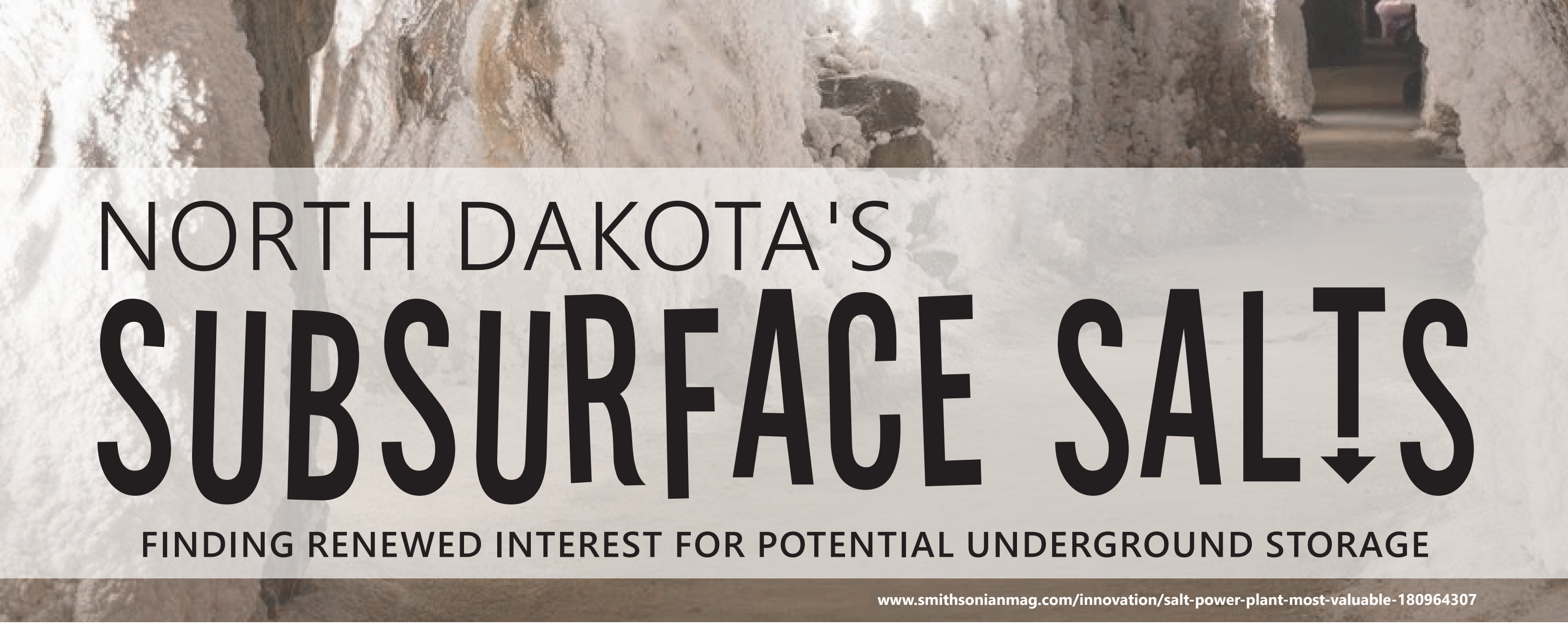

NORTH DAKOTA'S SUBSURFACE SALTS

FINDING RENEWED INTEREST FOR POTENTIAL UNDERGROUND STORAGE

www.smithsonianmag.com/innovation/salt-power-plant-most-valuable-180964307

BY TRAVIS D. STOLLDORF

In recent years, subsurface sequestration and storage of greenhouse gas, oil, natural gas, and compressed air has become a global topic of conversation. Sequestering CO_2 to cut greenhouse gas emissions substantially affects North Dakota's coal industry. Propane storage could benefit North Dakota farmers during harvest season when propane use is at its peak. Compressed Air Energy Storage (CAES) could provide emergency electricity during peak hours. All of these factors and others have combined to put a renewed focus on the Williston Basin and, specifically, North Dakota's subsurface salt deposits (fig. 1).

North Dakota has five major salt deposits in the subsurface (fig. 2). The oldest, stratigraphically lowest, thickest, and most laterally extensive salts in the Williston Basin are the Devonian Prairie Formation salts, (Murphy et al., 2009). Although too deep for sequestration or storage potential, the Prairie salt does contain potash (Kruger, 2021), a potassium-rich salt commonly used in fertilizer. The Madison Group's Charles Formation contains six distinct salt packages (Charles A-F salts). Deposited in the Mississippian (Murphy et al., 2009), all but one of the Charles salts are too deep for sequestration or storage potential. The uppermost Charles A (fig. 2) does have potential for underground sequestration and storage due to its shallower depths. The Permian-age Opeche Formation contains Opeche salts A&B (Murphy et al., 2009). The Opeche salts are not potential candidates for underground sequestration or storage due to their high sodium sulfate content which is not suitable for caverns. Later in the Permian, salts of the Pine Member of the Spearfish Formation were deposited in the Williston Basin (Murphy et al., 2009). The Pine salts are laterally extensive, moderately thick, and have potential for sequestration and storage. Lastly, the Dunham salts were deposited in the Jurassic within the Dunham Member of the Piper Formation (Murphy et al., 2009). The Dunham salts are the least laterally extensive of the major salt deposits (Stolldorf, 2021). However, the Dunham Salt holds many advantages over its competition. Dunham salts, when present, typically contain some of the thickest and purest halite in the basin at the shallowest depths below the surface. Thus, the Dunham salts have the highest potential for underground sequestration and storage in the basin.

In light of this renewed interest, the North Dakota Geological Survey (NDGS) has provided industry and the public with detailed summaries, extent, depth and thickness of the Dunham, Pine, and Charles A salts (fig. 3). These salts were chosen as they are all potential underground sequestration or storage prospects.

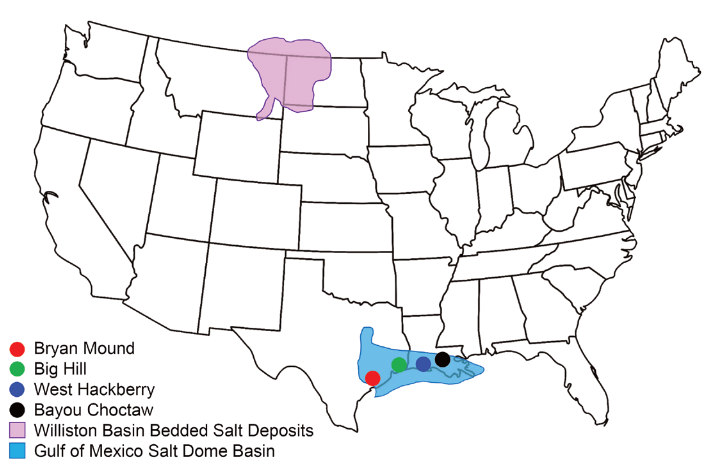

FIGURE 1.
The location of salt deposits in the Williston Basin and the Strategic Petroleum Reserve salt cavern storage complexes. Salt domes along the Gulf coast include the Bryan Mound (red dot), Big Hill (green dot), West Hackberry (blue dot) and Bayou Choctaw (black dot). Figure modified from What is a Salt Dome? (2022).

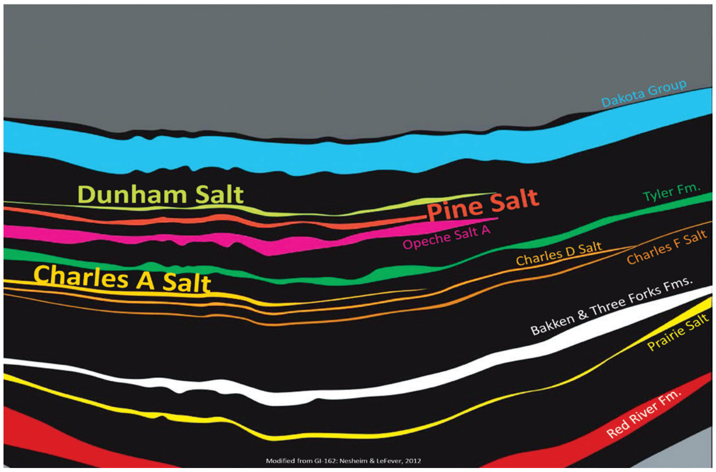

FIGURE 2.
Five major salt deposits lie within North Dakota's portion of the Williston Basin. In order from deepest to shallowest the salts are the Prairie, Charles, Opeche, Pine, and Dunham. The Red River Formation, Bakken-Three Forks Formations, Tyler Formation, and the Dakota Group are added for stratigraphic perspective. Specifically, the Dunham, Pine and Charles A salts are prospective for salt cavern storage. Figure modified from GI-162: Nesheim & LeFever (2012).

SALT CAVERN CREATION AND STORAGE

In order to create a salt cavern, several conditions must be present. The salt formation must be mostly pure with minimal insoluble material such as silt, sand, and clay. Additionally, it must be thick enough and laterally extensive enough to safely create a cavern. Finally, the salt must be within a depth range in which it is stable enough to construct a salt cavern. If all of these conditions are met, a well is drilled into the salt formation and fresh water is pumped into the salt through an independent tubing string. The water solubilizes the salt into a brine which is then removed through a separate tubing string as the cavern forms. A final tubing string provides a fluid blanket, often oil, which prevents erosion of the salt cavern's ceiling. Different circulation methods can alter the shape of the cavern (fig. 4). The direct circulation method, which circulates water through a lower inner tubing string and removes brine from an upper, outer tubing string, produces a consistent oval-shaped cavern. In contrast, the reverse circulation method creates a cavern that is substantially larger at the top than the bottom. This cavern structure is produced by circulating fresh water through the upper, outer tubing string and removing brine through the lower, inner tubing string.

Salt caverns are the preferred locations for storing fluids and gases across the globe due to several advantages. Salt caverns provide the highest flexibility of products that can be stored, from crude oil to compressed air (fig. 5). Due to its physical properties, salt holds pressure without sustaining losses and has no chemical reaction between the salts and the stored fluids or gases (Why Energy Storage, 2022). Salt caverns further provide unmatched deliverability of stored products and rapid cycling of products, going from injection to withdrawal very quickly (Warren, 2016).

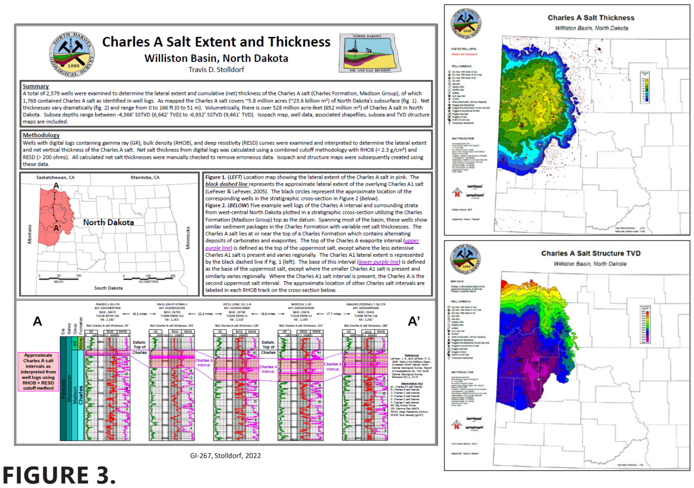

FIGURE 3.
An example of the products available from the North Dakota Geological Survey displaying a summary of the Charles A salt as well as salt thickness maps and structure maps. Similar products are available for the Dunham and Pine salts. Additionally, shapefiles are available for isopach and structure contours as well as well data. Figure from GI-267, Stolldorf (2022).

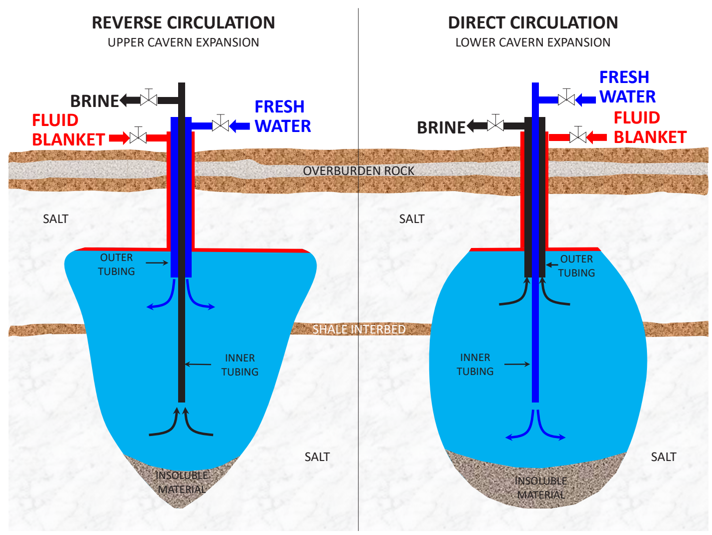

FIGURE 4.
Salt caverns are created by injecting water into salt, removing the resulting brine and replacing this void with other fluids or gases. The example on the right is direct circulation in which fresh water is injected into the lower portions of the cavern through the lower, inner tubing string and brine is removed through an upper, outer tubing string. The opposite is true for the reverse circulation method (left) where fresh water is injected through the upper, outer tubing string and brine is removed through the lower, inner tubing string. The reverse circulation method forms a cavern that is larger at the top than at its base. A fluid blanket (typically oil) is also necessary to prevent erosion of the cavern's ceiling.

STORAGE WITHIN SALT CAVERNS

Canada was the first North American country to use salt caverns for underground storage, using caverns to store oil during WWII. In 1949, the U.S. first stored liquified petroleum gas in Permian salts in Texas (Warren, 2016). In North Dakota, the Dakota Chemical Company constructed a plant in 1959 near Williston to mine the Charles salt and later planned to use the caverns for liquified petroleum gas (LPG) storage (UIC Permit, 1985). However, it could not be verified that any LPG was ever stored at the facility.

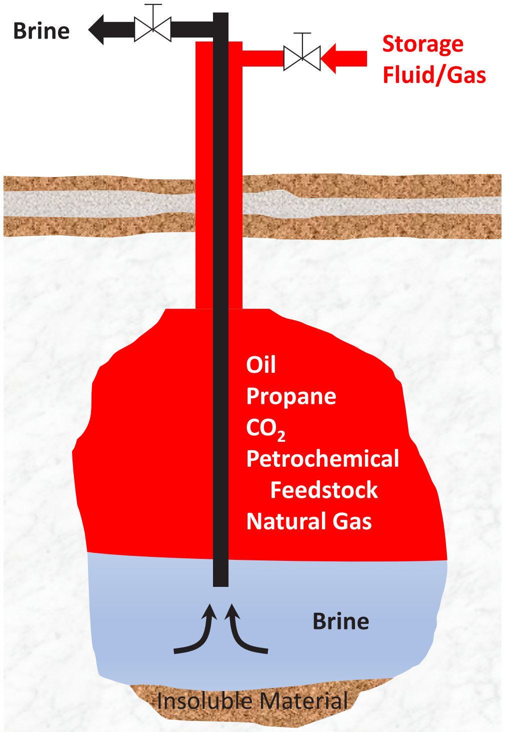

FIGURE 5.
Salt caverns offer higher deliverability and rapid cycling of a variety of fluids and gases. Oil, natural gases such as propane, and compressed air can be stored in salt caverns. Brine is removed as the storage fluid/gas is added. The reverse is true when removing the stored fluid/gas.

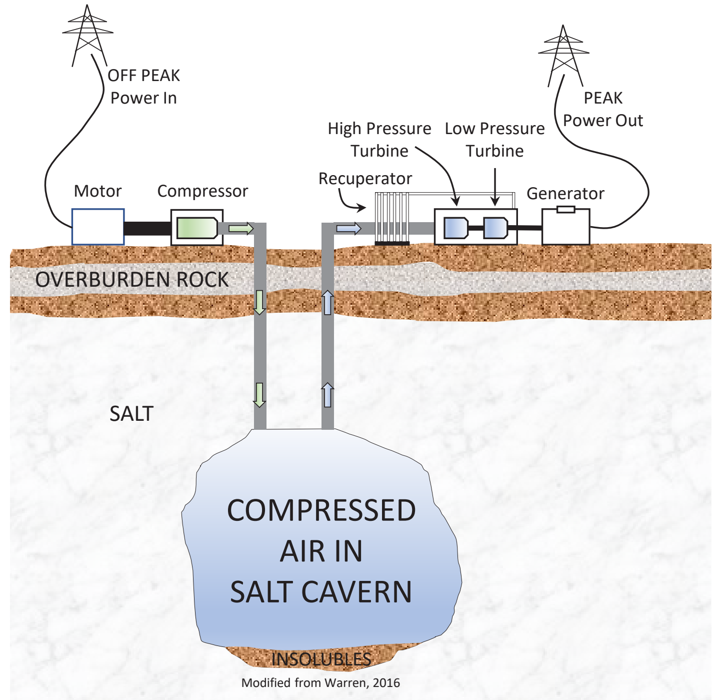

FIGURE 6.
Compress Air Energy Storage is a system in which air is compressed and injected into a salt cavern for temporary storage. The compressed air is released from the cavern and sent through conventional gas turbines which in turn power a generator that produces emergency electricity. Figure modified from Warren (2016).

Until the oil shocks of the 1970s, salt cavern storage had mainly been utilized by the petrochemical industry (Strategic Petroleum Reserve, 2022).

However, in 1975, Congress enacted the law that created the Strategic Petroleum Reserve (SPR) to diminish the impact of global supply disruptions and provide necessary reserves to the United States (Warren, 2016). The SPR is one of the most well-known salt cavern storage systems in the U.S. and today, the SPR is being talked about much more in light of recent world events. The SPR is the world's largest supply of emergency crude oil and, as of the end of 2021, the SPR held nearly 600 million barrels of oil, or the equivalent of over 3 years of petroleum imports (SPR, 2022). This crude oil is stored in four main salt cavern complexes located along the Gulf Coast (fig. 1) with two sites located in Texas (Bryan Mound and Big Hill) and two sites in Louisiana (Bayou Choctaw and West Hackberry). These locations were selected based on their proximity to large salt deposits along the Gulf Coast (fig. 1) and crude oil distribution pipelines. The four main complexes are made up of 60 individual salt caverns. Caverns vary in shape and size but are generally cylindrical and have an average diameter of 200 feet with a height of 2,550 feet (SPR, 2022).

Compress Air Energy Storage (CAES) is another way salt caverns are being utilized. CAES is a system where compressed air is injected into a salt cavern for storage (fig. 6). During peak electricity usage, the compressed air is released from the cavern and sent through conventional gas turbines which in turn power a generator that produces emergency electricity (Warren, 2016). In 1978, Germany was the first to use salt caverns for CAES. In 1991, the U.S. followed suit by creating the first CAES in North America near McIntosh, Alabama (Warren, 2016).

The various salt formations within North Dakota's subsurface have yet to be utilized for salt cavern development and storage. However, recent mapping completed by the NDGS adds valuable geologic information to future development as salt cavern storage may play an important role in North Dakota's economic future.

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