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Preliminary investigation on the geological potential for underground hydrogen storage (UHS) in saline formations in Italy

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In the last years, energy transition from fossil fuels to renewable resources has been largely acknowledged as a necessity to reduce emissions of greenhouse gases in the atmosphere. Hydrogen, the simplest element on Earth, can play an important role in this transition. It is not as an energy source but rather as an energy carrier: in layman's terms, electricity is converted in chemical energy, which can then be converted again in electricity or in green methane, if combined with carbon dioxide. Because hydrogen can be obtained from the excess of electricity produced from power plants or from renewable energy sources, such as solar panels or wind mills, it is a clean and sustainable form of energy, to be stored and used when needed. As a consequence, a key issue is hydrogen storage. Large metallic containers are typically used to this end but their capacity is limited. Given the increasing hydrogen production and perspective large use, the only viable alternative is underground storage in geological formations, which can be depleted hydrocarbon reservoirs, deep saline aquifers, or cavities in salt domes. Underground hydrogen storage (UHS) is already in use in various countries and mostly in salt caverns artificially made by circulation of fresh water. In the Italian territory there are several areas where saline deposits are both observable as outcrops or detected deep in the subsoil. Their thickness and their geological, petrophysical and mechanical characteristics vary from one area to another depending on the depositional conditions, which favored the formation of different sedimentary facies. These characteristics have a strong impact on the decision to convert a saline dome into a hydrogen storage and, therefore, they should be thoroughly investigated. The aim of this work is to map the salt formations mapped on the Italian territory and to preliminarily assess their potential on the basis of the geological characteristics for a possible future use as underground hydrogen storages.

Keywords: *energy transition, underground storage, hydrogen, saline formations, Italy.*

Indagine preliminare sul potenziale geologico per lo stoccaggio sotterraneo di idrogeno (UHS) in formazioni saline in Italia. *Negli ultimi anni la transizione energetica dai combustibili fossili alle risorse rinnovabili è stata ampiamente riconosciuta come una necessità per ridurre le emissioni di gas serra nell'atmosfera. L'idrogeno, l'elemento più semplice sulla Terra, può svolgere un ruolo importante in questa transizione. Non è una fonte di energia, ma piuttosto un vettore energetico: in estrema sintesi, l'elettricità viene convertita in energia chimica, che può essere poi convertita nuovamente in elettricità o, se combinato con anidride carbonica, in metano verde. Poiché l'idrogeno può essere ottenuto dall'eccesso di elettricità prodotta da centrali elettriche o da fonti di energia rinnovabile, come quella solari o eolica, è una forma di energia pulita e sostenibile, da immagazzinare e utilizzare quando necessario. Di conseguenza, un problema particolarmente rilevante è lo stoccaggio. A tal fine vengono generalmente utilizzati grandi contenitori metallici, ma la loro capacità è limitata. Data la crescente produzione di idrogeno e la prospettiva di un suo utilizzo ampio, l'unica alternativa praticabile è lo stoccaggio sotterraneo in formazioni geologiche, che possono essere giacimenti di idrocarburi esauriti, acquiferi salini profondi o cavità in duomi saline. Lo stoccaggio sotterraneo dell'idrogeno (UHS) è già in uso in diversi paesi e per lo più in caverne saline prodotte artificialmente mediante la circolazione di acqua dolce. In diverse aree del territorio italiano sono presenti depositi salini, sia in affioramento sia in profondità nel sottosuolo. Il loro spessore e le loro caratteristiche geologiche, petrofisiche e meccaniche variano da un'area all'altra in base all'ambiente deposizionale che ha favorito la formazione di diverse facies sedimentarie*

1. Introduction

The main reason why hydrogen is becoming increasingly important in different energy sectors is energy storage. Energy storage involves converting energy from forms that are difficult to store to more conveniently or economically storable forms. Hydrogen does not exist in nature by itself, but it can be produced using different conversion processes: some of these methods involve fossil fuels, such as steam reforming of natural gas, partial oxidation of hydrocarbons and coal gasification (HPFS, 2016); others, such as electrolysis, use an electric current to split water into hydrogen and oxygen. Then, it needs to be stored for subsequent use as a fuel (pure or mixed with natural gas), to generate power through chemical reactions (Albrecth *et al.*, 2015) or to generate green methane if combined with carbon dioxide, as envisioned in the Final report of the High-Level Panel of the European Decarbonisation Pathways Initiative, European Commission (2018).

Traditionally, hydrogen is stored at very low temperatures inside metal containers positioned above ground, but only underground geological formations can provide large storage capacity. The technology and techniques are similar to those used for underground natural gas storage, which can be stored in a variety of rock types and geological conditions: depleted gas fields, aquifers or salt caverns. Storage in salt caverns, that

Tali caratteristiche hanno un forte impatto sulla decisione di convertire un duomo salino in uno stoccaggio di idrogeno e, pertanto, dovrebbero essere analizzate accuratamente. Lo scopo del presente lavoro è quello di identificare le formazioni saline presenti sul territorio italiano e di valutarne preliminarmente il potenziale per un eventuale utilizzo futuro come stoccaggi sotterranei di idrogeno sulla base delle loro caratteristiche geologiche di base.
Parole chiave: *transizione energetica, stoccaggio sotterraneo, idrogeno, formazioni saline, Italia.*

are artificially made cavities inside rock salt formations, is a valid option for hydrogen storage due to the exploitation of the mechanical behavior of the rock, the possibility to achieve high storage pressures, the low cost of construction and the low footprint for surface installations (Kruck *et al.*, 2013).

2. Underground hydrogen storage (UHS)

Foh *et al.* (1979) confirmed the feasibility of underground hydrogen storage with the conclusion that "... current underground gas storage practice can be used to economically and safely store hydrogen in widely available reservoirs". However, in the same report the authors stated that, although the research results were positive, many technical and economic issues were still to be addressed and also the economic part was the most challenging issue. Safe and economic storage of natural gas in underground geological formations started at the beginning of the 20th century, and most of the nearly 700 facilities currently operated worldwide are depleted gas reservoirs and natural aquifer formations (Verga, 2018). Storage in artificial caverns in salt formations is also a possibility (Crotogino *et al.*, 2010). The physical characteristics of salt offer protection against appearance and spreading of fractures and, according to Kireeva and Berestovskaya, (2012), also against bacteria.

The construction of a cavern involves drilling of a well inside the rock salt to inject water and produce brine. During water circulation, the salt is dissolved and the cavity is progressively enlarged until the cavern takes its final form. Examples of salt caverns for hydrogen and gas storage around the world are presented in fig. 1.

Currently, hydrogen storage in salt caverns is used in various countries around the world (United States, UK, and Germany). In the United States hydrogen is stored in the Clemmons salt dome since the 1980's. The cavern has a diameter of 49 m and a height of 300 m with a usable hydrogen capacity of 30 million m^3. In Kiel, Germany, hydrogen is stored in a salt cavern having a capacity of 32000 m^3 since 1971. In England hydrogen is stored in three salt caverns almost 400 m deep,

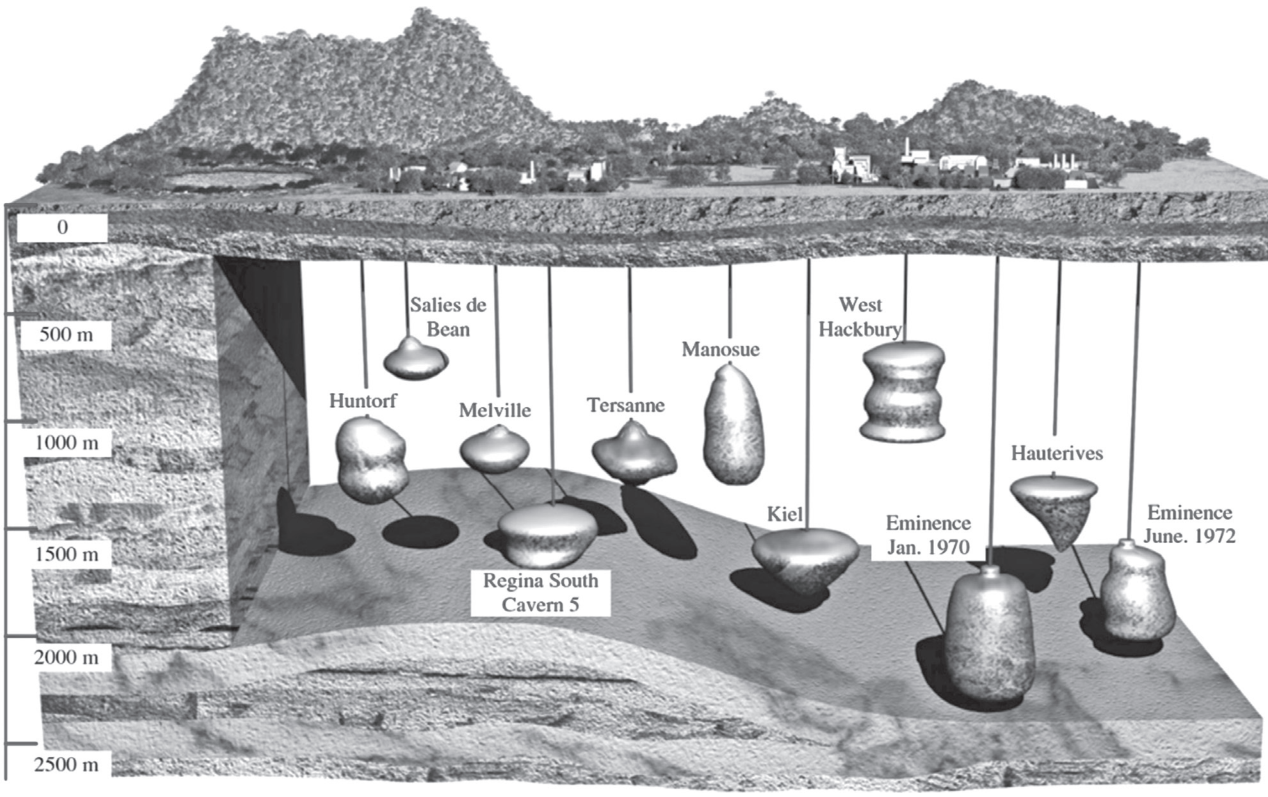

Fig. 1. Shape and depth of salt caverns around the world used for hydrogen or gas storage (from Wang *et al.*, 2014).
Forma e profondità delle caverne di sale in tutto il mondo utilizzate per lo stoccaggio dell'idrogeno o del gas.

for a total volume of 210000 m^3 (Landigher and Crotogino, 2007). Various studies were made in Europe to investigate the potential for hydrogen storage in underground formations. In Poland, for example, such work was done by Tarkowski (2017) and Tarkowski and Czapowski (2018) who analyzed both depleted reservoirs and salt formations. In the HyUnder European project (2014), a study which took 5 European countries into consideration, it is envisioned that the storage facilities needed by 2050 could be distributed as follows: 74 in Germany, 43 in the Netherlands, 24 in Spain, 21 in the UK and 1 in Romania. Very recently, Caglayan *et al.* (2020) identified salt structures suitable for hydrogen underground storage in various countries of Europe.

3. Rock salt deposits in Italy

3.1. Introduction

In the Italian territory salt deposits are linked to the Messinian Salinity Crisis (hereafter MSC) that started almost 5.97 Ma ago and ended abruptly at 5.33 Ma (Manzi *et al.*, 2013; Roveri *et al.*, 2019). During this period accumulations of huge volumes of evaporites (sulfates, halite and K-Mg salts) occurred in both shallow and deep sub-basins of the Mediterranean area. Evaporitic deposits are found in various parts of the peninsula (Fig. 2). Speranza *et al.* (2013) presented an investigation on the paleoenvironmental conditions during Messinian halite deposition from various Italian sites, including salt cores (Volterra Basin, northern Italy), a salt diapir (Crotone Basin, southern Italy) and salt mines (Caltanissetta Basin, Sicily). Their work identifies the main halite deposition areas in Italy.

3.2. Sicily – Caltanissetta basin

Halite deposits are located in the Caltanissetta basin which is a NE-SW elongated depression located in south-western Sicily (Fig. 3). The area consists of a complex system of synclines/sub-basins which provided accommodation space for evaporite sedimentation during the MSC.

The sedimentary fill of the whole basin includes Tortonian subaerial clastic rocks, shallow marine sands and evaporite deposits related to the MSC (Gessoso Solfifera Fm.), which mainly consist of Gypsum and salt deposits which differ in terms of facies and depositional setting (Roveri *et al.*, 2008; Roveri *et al.*, 2014).

Halite deposits occur as several independent bodies aligned NE-SW, some of which contain K-Mg salt deposits. These bodies have been affected by intense compressive tectonic with diapiric folds, reaching an average thickness of 500 m (Reghizzi, 2017).

Salt deposits shows small-scale lithological cyclicity expressing the

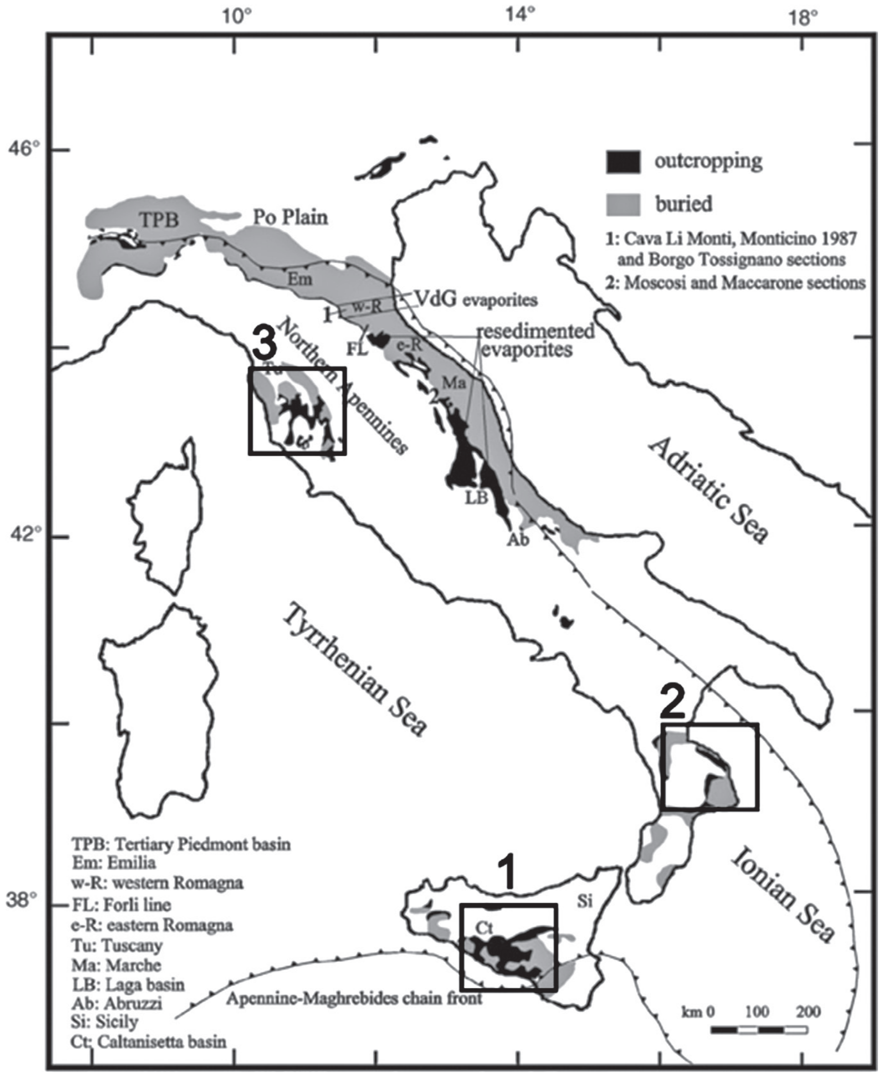

Fig. 2. Distribution of Messinian deposits within the Apennine-Maghrebian foredeep and surrounding areas with indication of the 1) Caltanissetta basin in Sicily, 2) Crotone basin in Calabria and 3) Volterra basin in Tuscany (Modified from Bertini, 2006).
Distribuzione dei depositi messiniani nell'avamfossa Appennino-Magrebina e nelle zone limitrofe con indicazioni del 1) bacino di Caltanissetta in Sicilia, 2) bacino di Crotone in Calabria e 3) bacino di Volterra in Toscana.

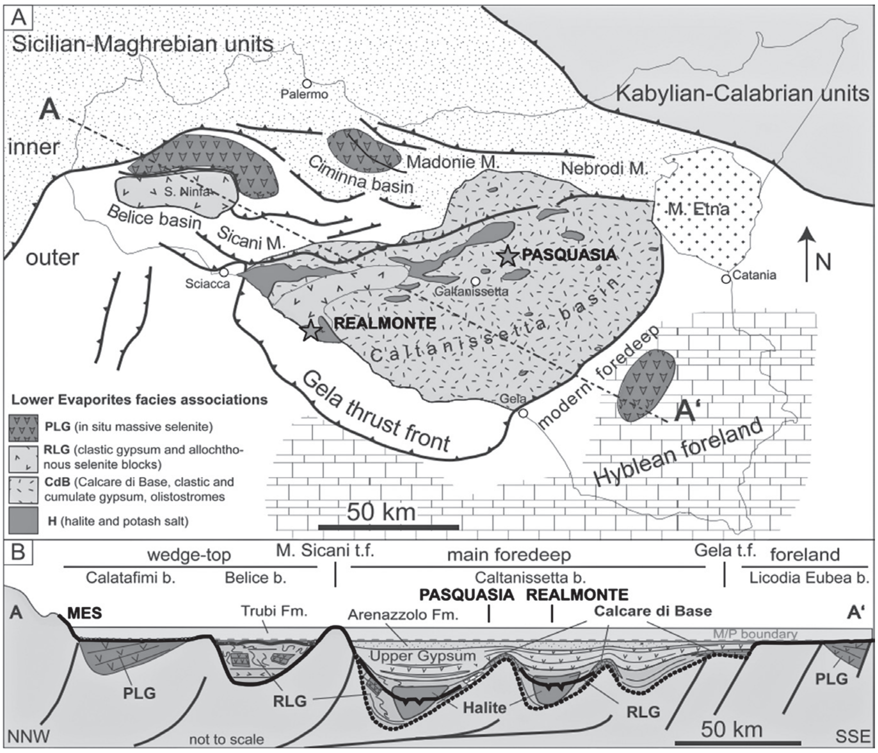

Fig. 3. (A) Schematic geological map of Sicily with the distribution of the Lower Evaporites within the Caltanissetta basin; (B) schematic geological cross-section of Sicily (from Manzi *et al.*, 2012).
(A) Carta geologica schematica della Sicilia con la distribuzione delle Evaporiti inferiori all'interno del bacino di Caltanissetta; (B) Sezione geologica schematica della Sicilia (da Manzi et al., 2012).

multi-scale temporal manifestation of depositional mechanisms influenced by climatic variations. These deposits are represented by laminae consisting of thin (centimeter) to very thin (millimeter) clay-bearing veins and pure halite alternations. Analysis on halite samples from salt mine (e.g. Realmonte mine) demonstrate that the halite deposits have low porosity (2.5-8.5%) and negligible permeability, due to the weak presence of pores and the total lack of interconnection among them, and densities ranging from 2.14 to 2.23 g/cm^3 (Samperi *et al.*, 2020).

3.3. Calabria – Crotone basin

The Crotone Basin, where halite deposits can be found, is a forearc basin in central Calabria. Three sedimentary cycles characterize the sedimentary succession of the basin. They mostly include conglomerates, sandstones and claystone deposits, as well as an interval belonging to a Messinian evaporitic deposition that includes gypsum and halite. Zecchin *et al.* (2020) describe the Evaporite Formation being up to approximately 100 m thick along the western and northern margins of the Crotone area. The halite deposit has variable thickness and can be identified through surface outcrops in the northern part of the basin, where diapiric structures cut through the uppermost Messinian and Lower Pliocene claystone deposits (Speranza *et al.*, 2013). Seismic and well data from salt mining areas show that halite is interposed between organic-rich material at the base and arenites, gypsarenaties and pelites on the top (Lugli *et al.*, 2007). According to well log analysis and well correlation halite deposits are found at the top of the Messinian succession at various wells in the area. The well Timpa del Salto 2 and well Vitrano 1 where the halite deposits are found at almost 500 m and 700 m of depth, respectively, are shown in fig. 4.

Lugli *et al.* (2007) performed a

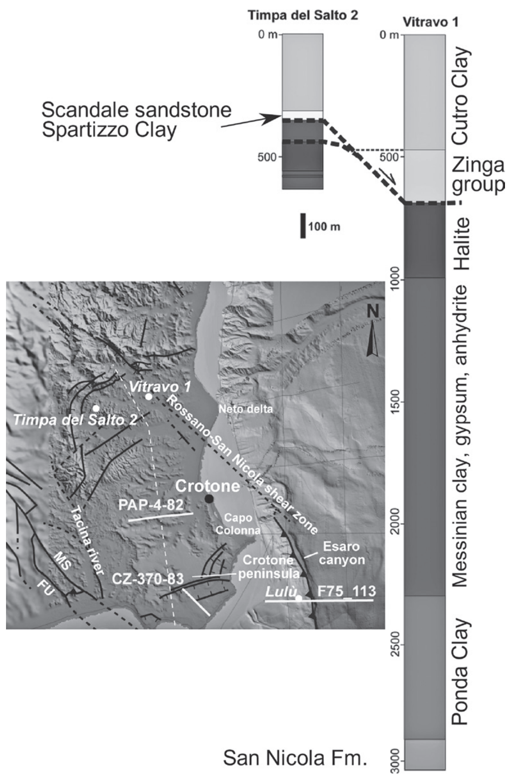

Fig. 4. Simplified stratigraphy of the Timpa del Salto 2 and Vitravo 1 wells (modified from Mangano *et al.*, 2020).
Stratigrafia semplificata dei pozzi Timpa del Salto 2 e Vitravo 1 (modificato da Mangano et al., 2020).

detailed analysis on halite deposits in the Crotone area. They observed that halite is strongly modified by folding and recrystallization and were able to identify four basic facies: banded halite, massive halite, clear facies and breccia facies.

3.4. Tuscany – Volterra basin

The Messinian evaporites of central Tuscany were deposited in NW–SE elongated extensional basins, opened along with the Tyrrhenian Basin, beginning in the late Tortonian on the back of the eastward migrating Apennine thrust-belt (Testa and Lugli, 2000). The Volterra basin is filled with a thick sedimentary succession that includes a Messinian evaporites consisting of gypsum, clastic deposits and halite. The salt deposits present intercalations with clay, silt and anhydrite for a total thickness of almost 200 m. Halite represents roughly 40% of total volume of the series and can be described by bending and small diapiric movements. Drilling performed in the area brought to light cores of halite as the one shown in fig. 5.

Speranza *et al*. (2016) performed a series of laboratory analyses on salt samples from various locations of Italy, among which the Volterra basin, to study their crystals characteristics, petrophysical parameters and elastic properties. They were able to identify different behaviors of the halite facies depending on their physical characteristics: this information can be very useful for a preliminary feasibility study to convert an underground formation into a hydrogen storage facility.

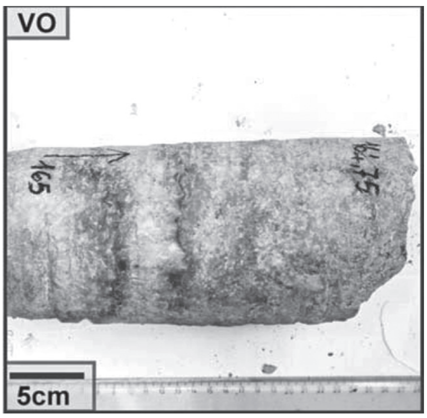

Fig. 5. Halite sample from Volterra basin (from Speranza *et al*., 2013).
Campione di alite dal bacino di Volterra (da Speranza et al., 2013).

4. Conclusions

Energy transition is a topic that attracts an increasing scientific attention and discussions (e.g. Benetatos *et al.*, 2019) since countries worldwide are gradually moving from fossil fuels to sustainable and cleaner energy sources. In the years to come, hydrogen has the potential to play a significant role in energy transition. Its storage is thus of fundamental importance for a large-scale use. So far the only possibility for storing hydrogen in large quantities is to use subsurface geological formations and in particular salt rocks. Salt rocks have physical and mechanical properties suited for reaching high pressures during storage, do not allow chemical reactions between hydrogen and the rock and at the same time offer the possibility of expanding a storage facilities by creating clusters of underground caverns. In the Italian territory saline deposits exist in the Volterra basin, Tuscany, in the Caltanissetta basin, Sicily, and in the Crotone basin, Calabria; they were identified both from well logs and from outcrops. These deposits are related to the Messinian sedimentary successions and include halite intercalated usually with gypsum, sandstone, conglomerates and claystone. The thickness of the halite deposits as well as the petrophysical and mechanical characteristics of the rocks vary from place to place depending on the geological conditions occurring during their deposition. On the one hand the presence of these type of deposits can support the prospect of creating artificial caverns for underground hydrogen storage, on the other hand the suitability of each deposit should be thoroughly verified through a detailed analysis of its properties against the technical requirements for the cavern construction and management.

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