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Technical Conference Paper

Non-Seismic Geophysics for Salt Dome and Cavern Imaging

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SMRI Fall 2024 Technical Conference
22-25 September 2024
Edmonton, Alberta, Canada

Solution Mining Research Institute Fall 2024 Technical Conference
Edmonton, Alberta, Canada 22-25 September 2024

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Abstract

In the past decade 3D seismic depth imaging has become the industry standard for imaging of salt domes. Vertical and horizontal resolution as fine as 50 to 100 feet (15 to 30m) has been reported using modern high resolution seismic data and advanced depth migration algorithms. However, other geophysical techniques, such as potential fields and electrical fields, have a place in the evaluation of salt domes and salt caverns. Newer techniques, such as muon exploration, may also be appropriate for cavern imaging under certain circumstances.

Gravity surveys were one of the earliest ways to explore for salt domes. Gravity surveys in Rumania and Germany in 1917 and 1918 used an Eotvos torsion balance to outline both bedded salt and diapiric deposits. The technique detects the density contrast between halite (ρ=2.20) and the surrounding host rock. The gravity anomaly can be either positive or negative, depending on the density of the host rock and caprock that may be present. Modern gravity meters are the most sensitive field instruments in the world, capable of measuring to within 1 nanogal, or one trillionth of the gravity measured at the earth's surface. A high-density gravity survey can be recorded over an exploration prospect swiftly and for modest expense.

Forward modeling of the expected gravity response over the target is important to determine the sensitivity of gravity to the specific local salt geometry. Although gravity is good for delineating the gross features of a salt dome, in most cases gravity cannot discriminate finer details of salt domes. Nevertheless, because it is easy and inexpensive to acquire it is often useful as a first-order indicator of salt geometry and is especially useful for initial exploration of salt domes where there is limited existing seismic data or few well penetrations of salt.

Saturated brine and solid halite salt have enormous contrasts in electrical resistivity. This presents the possibility of using electrical methods for the delineation of conductive brine-filled caverns in a highly resistive solid salt matrix. In theory, magnetotelluric techniques can be used to determine the extent of brine-filled caverns in bedded or diapiric salt, however, interference from metal cultural reflectors, such as powerlines and fences make it impractical in most cases. Modern electrical resistivity tomography (ERT) is an excellent near-surface geophysical tool for delineating resistivity contrasts, but unfortunately its practical depth limit is usually about 200m (660ft), too shallow for delineating most caverns. However, the high resistivity of salt does lend itself to radar investigation. Borehole radar surveys can image as far as 1000m (3280ft) away from the borehole in clean salt, and can be used to image the edges of caverns and intra-salt heterogeneities.

A recently developed geophysical technique suitable for cavern or salt delineation is muon exploration. Muons are subatomic particles that bombard the earth's surface with uniform distribution and can be detected as much as 3000 feet (900m) into the earth. Sensitive muon detectors are placed downhole and count muon arrivals in the borehole for several weeks. The measured direction of arrival and relative muon count is used to create a tomographic solution of density distribution for depths above the sensors.

Key words: Gravity Exploration, Ground Penetrating Radar Exploration, Muon Exploration, Seismic Exploration, Salt Dome, Cavern Storage, Salt Diapir, Cavern Imaging