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Observation and Research on Re-exploitation of the Rock Salt Brine in the Changshan Laimu Mining Area, Weixi Rock Salt Deposit

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ABSTRACT

A common problem in water solution mining of rock-salt by drilling wells is that, after being mined for several years, the rock-salt beds are dissolved and the caprock collapses severely causing wells to be damaged and production to be stopped. However, using high-resolution seismic survey technology to observe the dissolution and permeating state of the underground rock-salt beds, we can obtain better economic results by drilling the wells again, with well-controlled gush-preventing technology, at the place where rock-salt has been dissolved away and saturated brine has permeated through the fractured zone.

GENERAL SITUATION

Water solution mining technology has developed very rapidly in recent decades in China. The use of oil blanket and hydrofracturing methods, has greatly increased both efficiency and the total production of salt. China is one of the first countries to mined rock-salt by drilling wells and water solution mining. As early as 1892, rock-salt ore was found at Dafenbao, a small town in Zigong, Sichuan. Since 1895, the method of connecting wells by water solution has been utilised, which injects water into one well and extracts salt water from the other(s). The use of present-day mining technology, i.e. mainly single-well circulation, hydrofracturing and the oil or air blanket method, started at the end of the 1950s. Because water solution mining has been used for a long time, it is often found that where well groups have been connected in a large area, caprocks have collapsed severely and production well groups have been damaged so that a large part of the mining area has had to be discarded, with subsequent ill-effects for industrial production. Re-exploiting these old mining areas is a very important task in present-day rock-salt mining. It is proposed in this paper that high-resolution seismic surveys can be used to survey the dissolution of underground rock-salt bed sand and to analyse the permeation state of the brine in order to re-exploit the artificial rock-salt brine. Furthermore, we should turn our attention from mining the rock-salt beds to mining the saturated fracture saltwater in the vicinity of the rock-salt beds, in order to obtain potential beneficial results by using well-controlled gush-preventing technology in drilling wells.

GEOLOGICAL SYNOPSIS OF LAIMU MINING AREA, WEIXI ROCK SALT DEPOSIT IN SICHUAN

Weixi rock-salt deposit is a large-scale mesozoic marine facies ore deposit which is large in area, shallow in depth, high in grade, simple in structure, and convenient for transport. The Changshan Laimu mining area lies south-east of the Weixi salt deposit. The outcropped strata are the Lower Shaxi Formation of Chongqing Group, Da'anzhai Member and Ma'anshan Member of Ziliujing Formation and some Quaternary eluvium, the slopes of which are gentle, dipping northwest with dip angles from 3 to 6°. There is no fault. The rock-salt ore bed exists in the bottom part of the Third Member of Leikoupo Formation of the Triassic System, with depths from 1000–1030 m. The ore bed, which is quite stable, is an average of 16.55 m anhydrite-bearing salt whose content of NaCl is as high as 85–90%.

Based on rock-salt bed, the strata can be divided into two sections from top to bottom:

First section (approx. 769 m thick)

Chongqing Group: Belonging to the Jurassic, comprised of purple-red mudstone, sandy mudstone with intercalated beds of purplish-red siltstone and fine sandstone.

Ziliujing Formation: Belonging to the Jurassic, comprised of purple-red mudstone, green-grey sandstone with grey limestone intercalated.

Xujiahe Formation: Belonging to the Triassic, comprised of light grey massive feldspar-quartz sandstone, which is interbedded with dark grey shale and sandy shale and intercalated by coal seams, with marl and conglomerate at the bottom.

Second section (180 m thick)

Leikoupo Formation: Belonging to the Triassic, comprised of dark grey limestone with intercalations brownish grey dolostone and locally thin layers of anhydrock in the upper part, and dark grey limestone with intercalated beds of dolostone and dolomitic anhydrock in the lower part in which fractures have developed and cores are broken, with porosities from 0.35–0.95%, whose inflow of water is 0.298 m^3/day and permeability is 0.0022–0.00035 m/day by water-pressing test, belonging to a weak aquifer.

Rock-salt ore bed (average thickness 16.55 m)

Simple pure salt, comprised of alternate colourless and black-grey rock-salt, transparent or semi-transparent, and is mainly of a medium-grained texture, containing anhydrite stains and muddy material, with localized coarse salt crystals (Fig. 1).

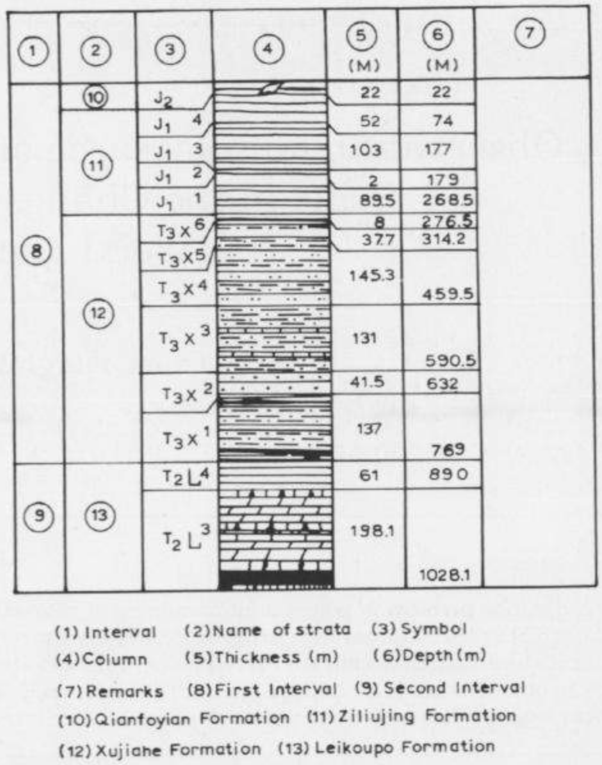

Fig. 1. The sequence of strata. Tx: Triassic period, Xujiahe stratum. Jz: Jurassic period, Zijiujing stratum. Jc: Jurassic period, Chong ging stratum.

WATER SOLUTION MINING BY DRILLING

Water solution mining has been used in the Changshan Laimu mining area since 1970. Eleven wells divided into three well-groups have been drilled along a highway running in a south-east/north-west direction, of which the northern group consists of five wells and the others of three wells (Fig. 2).

The distances between wells are unequal, ranging from 75–242 m. They yield their brine by single well circulation and are connected by hydrofracturing. By 1989, some of the wells had been discarded, although some are still in production but yield little brine, and salinities are not high. Some are therefore only used as water-injecting wells which no longer yield brine. From 1971 to 1988, the cumulative production of brine converted into only 549,000 t of salt. The extraction ratio is only up to 12.48% of the mining reserves of the well-groups. In the area controlled by the well-groups, which is about several ten thousand square metres, the top part of the rock-salt bed has been dissolved and the caprock has already collapsed, severely damaging production casings. The injected production freshwater has seeped into the caprock strata in large quantities and the wells have been connected to each other and interfere with other, but there is no ground sink on the surface. Since the production casings have been damaged, the circulation production cannot be maintained. The flow pressure is quite high and it is difficult to prevent a well from erupting while being re-appraised. How to further exploit the discarded mining area (or that to be discarded) is a problem we need to study and solve.

PROBING AND EXAMINING THE DISSOLUTION OF THE UNDERGROUND ROCK-SALT BEDS IN THE MINING AREA

Probe the dissolution of rock-salt beds with high-resolution seismic technology.

The high-resolution seismic survey is a conventional seismic method which is characterized by a closer time and space sampling rate. It works within quite a wide shot with fine correction, and the dis-

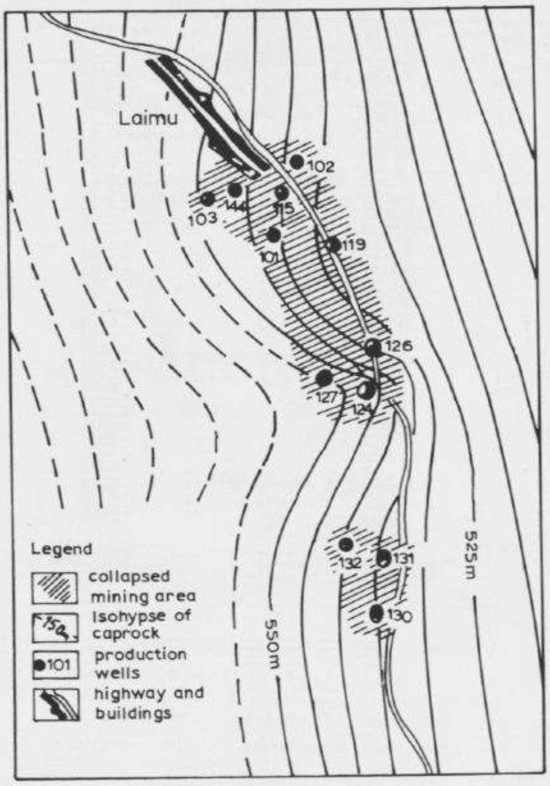

Fig. 2. Location map of Laimu mining area.

tance of detection and the interval of sampling are shortened. This is the first time that we have applied seismic methods in salt mining research to explore the change of dissolved rock-salt beds. This method was hitherto only applied to oil prospecting. It is based on the principle that the high seismic wave propagation velocity (>6000 m/s) of the anhydrite and rock-salt beds will decrease after a large quantity of injected freshwater permeates through the caprock strata when rock-salt is dissolved, thus marking the physical property of the rock-salt beds. A seismic survey was carried out in the vicinity of the mining area with an SN338HR digital seismograph. After processing the reflection wave groups, we classified them into five wave groups, in which T_3 is the top surface of the Leikoupo Formation, and T_5 the rock-salt member whose rock-salt has been dissolved away (Fig. 3). The reflection wave group of the stratum under the salt beds shows a downward curve and that of the overlying stratum exhibits an unsmoothed, discontinuous upward line. The frequency of the reflection wave has also decreased because the propagation velocity of the stratum has decreased, affected by water filling in the stratum when the rock-salt beds are dissolved. The height influenced by this process is as much as 200 m or more. This is the feature of seismic reflection wave

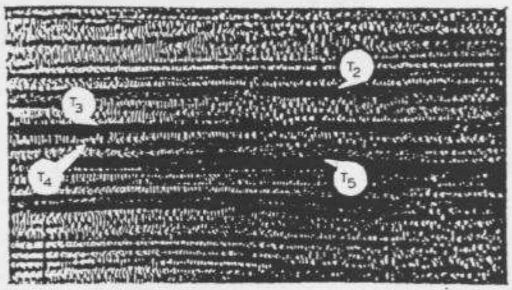

Fig. 3. Stacking map of high resolution seismic survey.

groups of the water-soaked caprock strata when the rock-salt has been dissolved.

The formation of underground artificial rock-salt brine reservoir beds

Since the Changshan Laimu mining area has undergone drilling, water injection, dissolving, permeating and mining for 20 years, an artificial fracture aquifer, about 180 m thick, has formed over the rock-salt beds. The inflow of water in the strata has increased from the original 0.298 m^3/day to above 1000 m^3/day. The existence of the fracture aquifer of the caprock strata has been verified by high-resolution seismic survey and the drilling of Well 144, whose reserves are fairly abundant. If we calculate the brine according to a recovery to injection ratio of 69.7%, which is the actual ratio obtained in the past twenty years' production in this mining area, the total groundwater stored in the caprock strata and the cavities dissolved is about 925.5 thousand m^3, and will increase more and more with time and with the increase of salt recovered. There is no fault in the mining area. The water has, therefore, all seeped into the fractures of limestone or dolostone over the rock-salt beds and is stored in the cavities formed by the dissolution of rock-salt. There is a bed of broken limestone and muddy limestone, 10–15 m thick, separated from the rock-salt bed by a layer of anhydrite which is about 3–5 m thick. Affected by such factors as electrochemical osmosis, diffusion by temperature difference, and permeating by pressure, the saturated salt-dissolved fracture brine has formed in the vicinity of the strata over the rock-salt bed. The chlorine content of the mud fluid in the interval of the Leikoupo Formation drilled in Well 144 has been measured, and has been found to increase from 1,427.10 ppm to 44,596.88 ppm, reaching the content of that obtained from drilling into rock-salt beds. This indicates that a saturated fracture brine reservoir has formed in the caprock strata of the rock-salt bed, which has provided the material prerequisite for the re-exploitation of the rock-salt brine (Figs. 4 and 5).

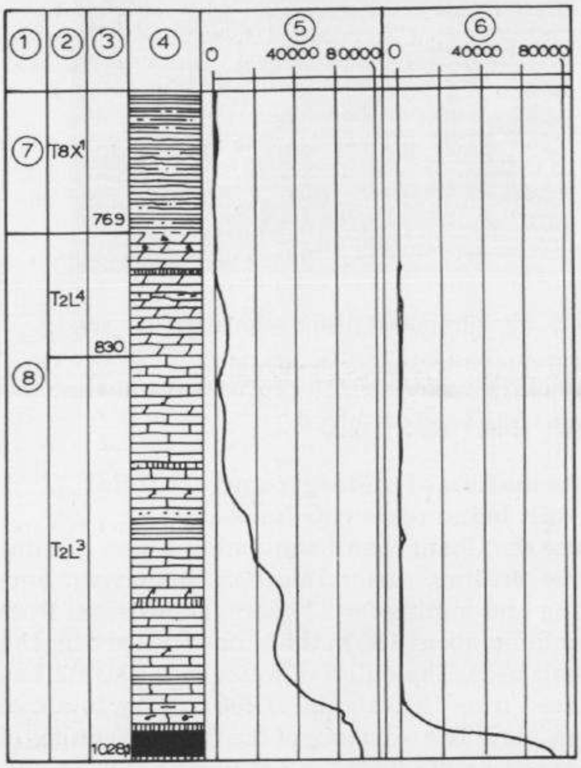

Fig. 4. Correlation map of Cl^- content between Well 144 and Well 103.

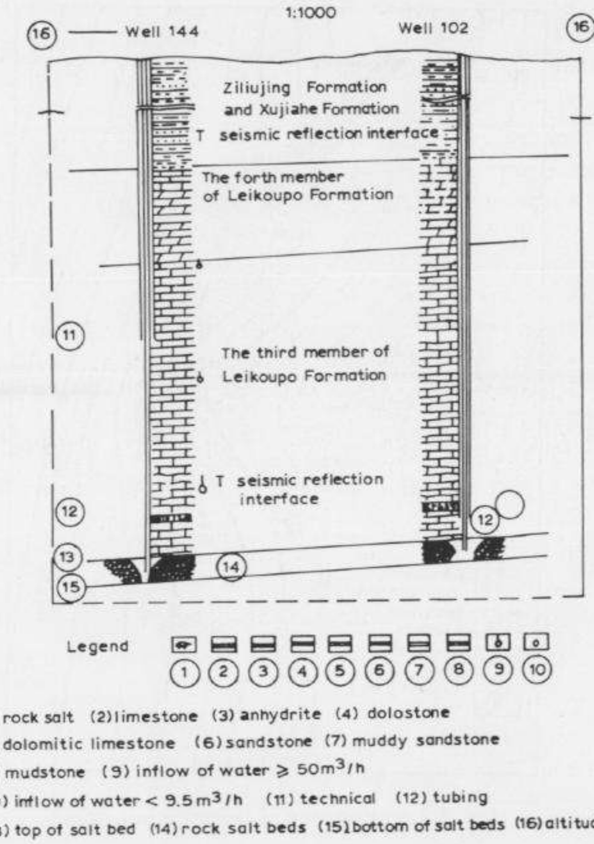

Fig. 5. Geological section from Well 144 to Well 102.

THE RE-EXPLOITATION OF THE ROCK-SALT DEPOSIT: EXTRACTING THE UNDERGROUND ARTIFICIAL ROCK-SALT BRINE

In salt mining, emphasis has long been laid on research into rock-salt beds. Whether we use the hydrofracturing or oil blanket method, we can obtain the most economic and rational mining of the rock-salt deposit by researching the mechanical strength of rock-salt beds or the controls of dissolution of rock-salt. However, as the amount of salt mined has increased and with the passing of time, great changes have taken place in the vicinity of the underground rock-salt beds. Since a large quantity of saturated brine has been stored in the vicinity of rock-salt beds, it is timely to redirect our starting point of exploitation of mining rock-salt ore beds to extracting the artificial rock-salt brine, namely extracting underground high salinity brine, which is a change in mining horizon and in ore faces. Based upon the dynamics of groundwater and hydrochemistry, and by researching the percolation rule of the fracture brine after solution of the underground rock-salt beds, we can obtain better economic results by utilizing well-controlled drilling. It is necessary to prevent blowing while drilling at places where the rock-salt beds have collapsed by dissolving, fractures have developed, the pressure of the fracture brine in the formation is high and the inflow of water is large.

According to the above-mentioned analysis we drilled Well 144 in the centre of the old mining area at Changshan Laimu in July 1990, with great success. The data on drill completion are as follows:

Depth of completion	1028.10 m
Depth of caprock	1011.88 m
Depth of bottom plate	1027.07 m
Thickness of salt bed	15.19 m
Casing depth of 7″ technical pipe	830.05 m
Depth of 5″ central tubing	1027.06 m

From October 1990 to September 1991, the water-injecting pressures were 3.8–4.0 MPa, the out-going water pressures 0.6–0.8 MPa, the average outflow 34.5 m^3/h, the salinity 302.94 g/l, and the cumulative production of brine 78.7 thousand tonnes of salt converted. This represented the best productive efficiency in brine mining by the connection method in the mine.

CONCLUSIONS

1. Seismic survey technology can be utilized not only in oil prospecting but also in the survey of rock-salt mining, which has great significance in ascertaining the dissolution of rock-salt beds and the collapse or seepage of caprock strata, especially in an old mining area where rock salt had been exhausted.

2. Through seismic survey and mining analysis, we can turn the exploitation from mining rock salt beds to extracting the artificial rock-salt brine reservoir above the salt beds in an old mining area. Based upon dynamics of groundwater and hydrochemistry we can achieve economic results by drilling the desired wells.

3. By seismically surveying the old mining area which has been mined for twenty years, the seismic reflection shows that the strata in both first and second intervals possess quite a good continuity except for some local minor faults. It is still safe to mine there.

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