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Department of Energy
National Waste Terminal
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Mr. Hubert S. Miller
S. Nuclear Regulatory Commission
Willste Building
7915 Eastern Avenue
Silver Springs, MD 20910

Dear Mr. Miller:

TRIP REPORT OF TOUR OF RETSOF MINE

Enclosed for your information is a trip report which may be of interest to you. Also enclosed are abstracts from the Sixth International Symposium of Salt.

J.O. Neff
Program Manager
NWTS Program Office

NPO:JON:LAC:kgh

Enclosures: 1) June 9, 1983 trip report by O. Swanson and R. Helgerson to distribution

2) Abstracts from the Sixth International Symposium on Salt in Toronto, Canada

ST# 405-83

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ONWI

BATTELLE Project Management Division

REPORT ON OFFICIAL TRAVEL

RECD JUN 16 1983

To Distribution Date June 9, 1983

By O. Swanson/R. Helgerson Project No.

Left Columbus May 22, 1983 Returned May 27, 1983

Trip to Toronto, Ontario, Canada

Distribution:

S Goldsmith	GE Heim	WE Newcomb	JO Neff/NPO (3)	SD Files
WA Carbiener	OE Swanson	MA Balderman	TA Baillieul/NPO	LB
SC Matthews	RN Helgerson	DL Ballmann	ONWI Files	

Purpose of trip: Attend the Sixth International Symposium on Salt and tour Retsof Mine

Attendees: See attached list.

Enclosure to 7/13/83 memo from Neff to Miller

Essential details of trip and summary of results obtained:

Retsof Mine Tour

The production shaft of the Retsof Bedded Salt Mine now in use was completed in 1922. This 9 x 28 foot shaft was apparently put down using conventional mining techniques. The present mine encompasses approximately 5,000 acres and has been in continuous operation since 1885. Some 95,000,000 tons of salt have been removed since operations began. The mine remains at a near constant 63°F year round with little reported condensate in the ventilated air flow.

The salt layer mined is at an average depth of 1,150 feet, averages about 12 feet in thickness (but varies up to 25 feet) and is extremely dry. The salt is coarsly crystalline gray halite with crystals averaging about one-quarter of an inch in size. The upper portion of the mined unit consists generally of a one-foot layer of coarser grained salt with individual crystals greater than one inch. Overlying and underlying the salt is black shale, with observable halite crystals in the matrix. Pronounced banding (anhydrite?) was observed, particularly in the upper portion of the salt unit.

The salt was observed to be extremely uniform in composition and texture during the 5 miles from the production shaft of the working face of the mine. The present day mining process recovers approximately 50 percent of the salt. Rooms 65 feet long and 65 wide are excavated around 65 x 65 foot pillars. Only about one-foot of salt is left (floor and roof). Rock bolting and cribbing were observed for roof support only in areas with room dimensions exceeding the normal 65 foot average. In general, observed roof support was absent over about 90 percent of the workings. Standard bolt length is 5 feet with some reported up to 15 feet. The main conveyor belt

the 5 miles is suspended from the mine roof as opposed to being supported by the floor. The conveyor system is on the order of 40 miles in length, including six feeder belts, and is suspended on chains spaced at about 30 feet intervals tied to 5 foot rock bolts. Mine personnel stated that occasionally these chains would part but seldom would rock bolts fail. This conveyor system was installed in the early 1970's and was operational in 1973. The conveyor belts replaced an extensive system of narrow-gauge rail cars originally used to transport bulk salt to the production shaft.

The conveyor system evidentally was installed to obviate the continued maintenance problem associated with releveling the track due to floor buckling. The present road had numerous bumps (floor heaves) of up to 5 feet, and undulated along its entire length. However, less pronounced undulations were present near the working face and were more pronounced in the older sections of the mine. In areas where these heaves have impaired vehicle clearance, the roof has been scaled mechanically to allow passage.

Although generally extremely dry, an older portion of the mine in the vicinity of a ventilation shaft has an influx of about 220 gpm. This water is apparently entering the mine due to an improperly sealed shaft. The water source is thought to be a major water-bearing unit (aquifer) at a depth of 200 feet. This area of the mine is generally abandoned, presumably due to the presence of the water and a combination of excessive floor heave and roof falls, rendering it almost impassable.

Currently, mining is accomplished by a combination of undercutting to 12 feet and drilling and blasting the face. In the past, a shearing machine (vertical undercutting) was used to control pillar configuration. Some spalling or scaling of the walls now occurs, whereas the use of the shearing machine produced smoother, more stable surfaces.

An old brining operation has resulted in an "underground lake" which has been avoided and which has not affected mining operations to date.

Small amounts of flamable gas have been encountered, however, it was difficult to determine an estimate of quantity (frequency and volume) from discussions with mine personnel. Prior to more stringent mining regulations, (20 to 25 years ago) this gas was simply flamed off when encountered.

Surface storage of bulk salt awaiting shipment over the past several years is accomplished, at least in part, by covering the pile with weighted plastic sheeting. There was little or no evidence of significant problems associated with this type of storage. Exposed portions of the pile were heavily crusted over and no evidence of wind erosion or scattering was observed. Only minor effort apparently is required to contain runoff and prevent entry to the large perennial stream flowing over the mined area.

The tour was extremely well organized and informative to a multi-national group of geologists, engineers, and mining personnel. The Retsof (Foster spelled backwards) Mine personnel were extremely helpful and cooperative. Discussions with mine personnel indicate the potential for additional tours of NWTS personnel if required.

REPORT ON OFFICIAL TRAVEL 3 June 9, 1983
To: Distribution
From: O. Swanson/R. Helgerson

Sixth International Symposium on Salt

The technical sessions, while interesting in themselves, did not offer a great deal towards solution of the problems encountered in the ONWI program. However, the personnel attending but not presenting were interested in discussing the program and their involvement, directly or peripherally, in salt exploration, research, or mining.

Of particular interest were discussions with Anthoney Iannacchione of the U.S. Bureau of Mines and H. John Head of Morton Salt. These discussions centered around the gas outburst potential in salt mines, the proposed MSHA rule changes and the potential for the NRC to adopt or accept some or all of the proposed MSHA rules.

Mr. Iannacchione has invited ONWI and our contractors to Pittsburgh to share the results of his research and testing of salt and gas in the Weeks Island Salt Mine and discuss the Bureau's involvement and future plans. Mr. Head has the interest of Morton Salt in Gulf Coast mines in Louisiana and Texas firmly in mind, and is intensely interested in any ONWI plans to address this issue. He also has requested a follow-up meeting in Chicago to share Morton's experience with gas problems and offer any assistance in future research, testing, or analysis in detecting or forecasting the presence of gas he can provide. Both meetings will be proposed to DOE for follow-up to address this anticipated SCR issue.

The environment one encounters at this type of seminar is of present and future benefit to the ONWI program. Such topics as rock mechanics, dissolution, exploration, mining experience in general, geologic/lithologic descriptions of evaporites and gas problems become more important in personal interactions than as prepared presentations. A wide range of attendees from a number of countires share various intersts with our salt program and are willing and eager to spend time discussing their experience. The range of attendees cover the owners, managers, technical research and development personnel, mine superintendents, rock mechanics researchers, exploration geologists and engineers, geochemists and hydrologists, to marketing and economic managers.

It is our recommendation that ONWI continue to maintain a presence at the salt symposium and become ever more involved in presentations as our experience broadens.

OES:RNH/jp

Attachments: Abstracts from the Sixth International
Symposium on Salt
List of attendees

A

ADKINS *New Safety Training Approaches in the Salt Industry*

Paul A. Krois and John Adkins, The Bendix Corporation, Englewood, Colorado, USA

When the United States government enacted the Federal Mine Safety and Health Act of 1977, the salt industry was directed toward providing its work force with training programs covering specific topics. Although mine trainers are aware of the types of courses they are required to deliver, there have been differences among mines in what has been included in each course and methods of instruction.

Joint efforts from government and industry are now moving toward more uniformity along three different tracks. First, course guides will soon be available through the Mine Safety and Health Administration consisting of plans and lessons for each of the required courses. These materials include training objectives for both instructor and employee, activities that demonstrate safety points, evaluation techniques, diverse films and slide programs, and extensively detailed outlines supporting an organized and thorough lecture, including visual illustrations and self-check guides. A second approach moves away from current classroom training practices that primarily seek to comply with mandated training hours and toward having employees demonstrate their skills and knowledge through exercises in the mine. Under sponsorship of the U.S. Bureau of Mines, Bendix is seeking to define satisfactory levels of performance on these criteria. The third approach seeks to support trainers in the use of new materials for safety talks and refresher training. One such resource is a series of motivational fictionalized stories based on accident reports of mine fatalities, supplemented with foremen-crew discussion questions and a safety engineer's critique.

Training requires an ongoing commitment on the part of management to assure the best prepared work force possible, and these three approaches represent several of the programs supporting these goals.

ALBRECHT *An In Situ Creep Experiment Using a Large Rock Salt Pillar*

Udo Hunsche, Ingo Plischke, Horst Albrecht and Manfred Wallner, Federal Institute for Geosciences and Natural Resources, Hannover, West Germany

The evaluation of constitutive laws for the creep behavior of rock salt on the basis of laboratory experiments is an important step for the design of a radioactive waste repository in a salt dome. In addition, the validity of these results has to be confirmed for large underground rock volumes. Therefore, an *in situ* creep experiment was carried out by the Federal Institute for Geosciences and Natural Resources in the Asse salt mine.

A salt pillar, 1.5 m on a side, was loaded up to 10 MPa with a steel flatjack, which was inserted in a horizontal slit in the middle of the pillar. The deformation was measured for several months in different directions by numerous deformation transducers. The total deformation of the two cube-shaped halves was calculated from these measurements. The influence of the experiment on the vertical convergence of the drift was measured with multiple extensometers by the Institut für Tieflagerung (IfT) of the Gesellschaft für

Strahlen- und Umweltforschung (GSF). The experiment was supplemented by laboratory creep experiments on the same material.

The comparison of the experiments with each other and with the previously derived creep law yields a consistent picture. For a refined evaluation, a finite-element model calculation was carried out using the ANSALT code.

ALDERMAN *Geology of the Owens Lake Evaporite Deposit*

Sidney S. Alderman, Jr., Mining Geologist, SEG, AIME, San Francisco, California, USA

The evaporite deposit covering 95 square kilometers of the dry bed of Owens Lake, California is a complex mixture of salts and brine. The chemical composition of the original brine lake, the evaporation parameters, the hydrologic history, and the present mineralogy, lithology and structure of the deposit are known in detail.

During the last six years, Lake Minerals Corporation has been producing crude trona salts from the deposit, and extensive studies have been carried out on the possibility of producing large tonnages of refined salts. In the course of this work, several thousand core and channel samples have been taken in the deposit and large amounts of analytical data are available.

The study of this deposit has led to several interesting observations. The compositions of the salts and brine change seasonally. Large amounts of bicarbonate, not present in the original lake brine, apparently formed during the crystallization of the salts, and very large amounts of sodium chloride, present in the original brine lake, have disappeared.

During the hot summer months sodium carbonate and sodium sulphate present in the solid phase as decahydrate salts release large amounts of water and enter the brine phase. During the cold season, the decahydrates crystallize, removing water from the brine phase. These phase changes cause serious changes in the physical and chemical characteristics of the deposit and affect mining and processing.

The total amount of bicarbonate in the present deposit is about three times the amount in the original lake, suggesting that a natural process of carbonation from carbon dioxide in the atmosphere may have been effective.

Only about 15 per cent of the sodium chloride in the original lake brine can be accounted for within the present evaporite deposit. It is suggested by the author that much of the concentrated brine phase has percolated downward into the lake bed sediments, taking the bulk of the sodium chloride with it. This process may be a mechanism for the enrichment of trona deposits.

B

BAUSCHLICHER *Production of Vacuum Salt Based on Seawater as Raw Material*

Hans Bauschlicher and W. Wöhlk, Standard Messo Duisberg, Gesellschaft für Chemietechnik MBH & Co., Duisberg, West Germany

This paper will give an idea about various processes and their selection based on different energy cost assumptions.
Processes to be discussed are

- Solar evaporation up to concentrated brine followed by thermal evaporation — crystallization
- Electrodialysis as preconcentration step followed by thermal evaporation — crystallization
- Multi-stage flash distillation (MSF) plant for preconcentration followed by thermal evaporation — crystallization
- Thermal evaporation — crystallization based on seawater.

For the process of thermal evaporation a comparison between multiple effect and mechanical vapour compression and the use of geothermal energy will be discussed.

BELLA *Energy Conservation Salt Evaporators*

Frank Bella, Jr., Swenson Division of Whiting Corporation, Harvey, Illinois, USA

This paper will compare the steam, electric power and cooling water requirements for various salt evaporator configurations, which include multiple effect with condensate flash systems, multiple effect with preheaters, mechanical vapor recompression and the combination of multiple effect and mechanical vapor recompression. For multiple-effect evaporators, the comparison will include quadruple, quintuple and sextuple effects.

In addition, the energy savings associated with turbine generator sets and with mechanical vacuum pumps in place of steam-jet air ejectors will be briefly discussed.

BHATT *Design and Layout of Solar Saltworks*

B.S. Joshi and R.B. Bhatt, Central Salt & Marine Chemicals Research Institute, Bhavnagar, India

The success of an ideal saltworks depends mainly on the optimum design and layout. Maximum yield and higher purity of salt can be achieved by proper layout. Based on gross yearly and seasonal evaporation rate, percolation losses, initial density of brine or sea

water, number of available days, evaporation rate of different density brines and expected production, evaporical relationships between their parameters is worked out. Evaporation rate of different density brines is correlated with fresh water evaporation rate using a standard evaporimeter to obtain area required for each pond holding a specific density range. Percolation losses are computed using 15 cm depth of saturated brine as the basis for calculations. Viscosity, density and the depth of brine are taken into consideration to obtain net losses of brine due to percolation in the earth pond. Effect of initial density of seawater on the ratio of crystallizer area to the remaining area is also shown in the calculations.

These computations form a basis and act as a guideline whenever a new saltworks is to be laid or improvement is sought in the existing saltworks.

BHATT *Utilization of Sub-Soil Brines, Potentialities and Problems*

G.D. Bhat, R.B. Bhatt and U.P. Saraiya, Central Salt & Marine Chemicals Research Institute, Bhavnagar, India

Sub-soil brines are concentrated compared to sea brine and are rich in magnesium and bromine. The largest single source of sub-soil brine in India is Rann of Kutch. Besides this, sub-soil brines are tapped on the seacoast, both on the East and West coast. Sub-soil brines vary in density from 8 to 21°Be' (1.059 to 1.170 spgr). Normally, multiple irrigation system is followed and Bharagara salt 2 cm to 2.5 cm size cubes are produced by solar evaporation. Open wells are constructed 5 to 10 m deep with bamboo reinforcements and brine is bailed out by manual labour.

Requirements of huge quantities of salt both for human consumption and for industries changed the pattern in the late seventies, and we now have bore wells 100 to 250 meters deep to obtain a copious supply of concentrated brine. The brine is pumped out by submersible pump sets, boosting salt production in the smallest area.

The paper deals with solar fractional crystallization of sub-soil brine and compares it with that of sea brine. Sub-soil brines have solved the problem of getting large tonnage in small areas, thereby cutting down the overhead charges per ton. However, it has some inherent problems; a few of these are discussed in the paper.

BODINE *Trioctahedral Clay Assemblages in Paleozoic Marine Evaporite Rocks*

Marc W. Bodine, Jr., U.S. Geological Survey, Denver, Colorado, USA

Clay-mineral assemblages from the Upper Silurian Retsof salt bed of the Salina Formation in western New York State, the Middle Pennsylvania Paradox Member of the Hermosa Formation in eastern Utah, and the Upper Permian Castile and Salado Formations in southeastern New Mexico consist chiefly of magnesium-rich trioctahedral clays. Except for variable quantities of illite, the dioctahedral clays are absent. Trioctahedral clay species include clinochlore (magnesium-rich chlorite); clinochlore-saponite mixed-layer clays, either regularly interstratified (corrensite) or randomly interstratified; saponite

(trioctahedral smectite); interstratified talc-saponite; talc and serpentine.

The distinctive mineralogy and magnesium-rich chemistry of the clay assemblages coupled with the absence of dioctahedral smectites and kaolinite strongly suggest an authigenic origin. Recrystallization and magnesium-metasomatism of conventional dioctahedral clay detritus to aluminum-bearing trioctahedral clays would be expected to occur in response to the increased Mg activities in marine evaporite brines. Variation in mineralogy of the aluminum-bearing trioctahedral clays, *e.g.*, corrensite *vs.* clinochlore, may be due to differences in extent of burial metamorphism. Talc and serpentine may have crystallized directly from brines with speciation a function of the $Mg^{2+}/(H^{+})^{2}$ activity ratio. The ratio appears to reach a maximum, thus serpentine stability, at the onset of halite crystallization during progressive evaporative concentration. Talc is stable in both more dilute and more concentrated segments of the progression. Interstratified talc-saponite in polyhalite beds of the Salado Formation may be a diagenetic replacement of earlier authigenic interstratified clinochlore-saponite and may have formed in the low pH environment accompanying polyhalite replacement of primary calcium sulfate.

BOEHNER ***Salt and Potash in Nova Scotia***

Robert Boehner, Nova Scotia Department of Mines and Energy, Halifax, Nova Scotia, Canada

The Windsor Group (Visean) is a regionally widespread unit up to 1000 m thick. It is dominated by subaqueous and diagenetic marine evaporites including halite, anhydrite, gypsum and potash with subordinate interstratified redbeds and marine carbonates. These rocks display a wide range of structural and stratigraphic complexities within the Carboniferous depositional and tectonic setting. Carboniferous basins in Nova Scotia are part of the complex Magdalen (Fundy) Basin system developed in the Acadian Orogen in Atlantic Canada. They contain up to 7000 m of pull-apart basin molassic sediments with minor, but economically important, marine evaporites of the Windsor Group. Deformation varies from negligible in the relatively stable platform blocks characterized by thin sediment accumulation to substantial in the fragmented basinal areas involving Hercynian strike slip, thrust and normal faulting, gravity sliding, evaporite diapirism and folding of the thick sedimentary fill.

Until recently, the distribution and geology of the evaporites, especially salt and potash, have been poorly understood because of limited data. Recent drilling has established that salt is present throughout the Windsor Group section. The principal salt unit including potash (sylvite and carnallite) is located in a major carbonate-sulphate-chloride cycle at the base of the Windsor Group. Thinner and younger salt beds with minor potash are locally present in association with anhydrite and marine carbonate in numerous saline "minicycles."

The large salt resources of Nova Scotia, together with geographic location and the presence of potash, are important factors in the future development of mining and chemical industries and underground storage facilities.

BREMER *Solar Salt Production at Exportadora de Sal*

Juan Bremer, Exportadora de Sal, S.A. de C.V., Guerrero Negro, B.C.S. México

ESSA, one of the largest solar salt plants in operation, is located on the Pacific side of the Peninsula of Baja California in the country of Mexico. It initiated operations in 1954 and at present its production capacity well exceeds six million metric tons per year and continues to expand. Not only has ESSA grown continously from 80,000 tons export in 1957 to over 5,000,000 tons at present, but it has also developed basic methods to maintain and increase its salt quality. These methods throughout the years have been used and improved to produce salt with low contents of impurities, such as calcium, magnesium, sulphates and insoluble matter, making the company one of the highest quality salt producers in the world.

BUSSON *Hydrological Patterns and Sedimentary Mechanisms Generating the Epeiric Evaporites and the Trough Evaporites*

Georges Busson, Muséum National d'Histoire Naturelle, Paris, France

The study of numerous deposits allows to distinguish objectively two main types of accumulation (BUSSON, 1968 to 1980): the epeiric evaporites ("évaporites de plate-forme") and the trough evaporites ("évaporites de cuvette"). We must examine now the hydrological and sedimentary mechanisms related to both these types. For the trough evaporites, two main phases are noticable:

- Preevaporitic and penesaline deposits accumulated as a result of progressive increase of salinity and of persistency of water column stratification (salinity, state of oxydoreduction). Among the deposits, limestones and gypsum occur mainly on the margins and on the higher zones, while the deeper zones receive only thin beds of laminites. The persistency of these vertical variations during geological times is little compatible with a very shallow water.
- The saline phase, during which this segregation disappears: halite and ultime salts fill up the residual central troughs.

For epeiric evaporites, the deposits of the successive zones ($CaCO_3$ and Mg, $CaSO_4$, NaCl, chlorides and potassium and magnesium sulphates) may have been more or less simultaneous. Then, at a given time, the water film covering the epeiric area should have shown lateral variations of salinity (3.5 to 4% on the edges of normal sea up to more than 35% in the distal part of the "evaporitic dead end"). The hydrologic segregation was synchronous and lateral. The water depth should have been shallow or very shallow. Thus, the two different geometric patterns originate from hydrologic mechanisms basically different.

C

CARSTENS *New Uses of Solar Energy*

Abraham Sadan, Consulting Engineer, Salt Lake City, Utah, USA

Production of saline minerals is made possible by utilizing new solar pond technology. Temperatures in excess of 200°F can be generated by absorbing the sun's energy in a salt solution. Low temperature chemical reactions are carried out in the solar pond to produce the following saline minerals in the crystalline form:

- Anhydrous sodium sulfate
- Magnesium sulfate monohydrate
- Sodium carbonate monohydrate
- Sodium borate pentahydrate.

Other uses of solar energy are also possible as follows:

- Waste management
- Brine deposit enrichment
- Hot solution mining
- Salting out processes.

These new uses of solar energy are of vital importance in light of the increasing cost of fossil fuel.

CAVANAUGH *Who Owns the Hole When the Salt is Gone? A Study in Comparative Law*

Michael Cavanaugh and LeRoy Lambert, Cavanaugh & Cavanaugh Attorneys. Baton Rouge, Louisiana, USA

Whether it is called a cavern, a jug or a cavity, there is a space left when salt is removed from the earth. Until recently, nobody thought to ask questions about the ownership of that space. But with the advent of profitable storage, especially in solution-mined domes, the question has become important. The paper begins with an overview of the problem, giving examples of how the problem might typically arise and the economics likely to be encountered.

After this overview, the paper discusses the competing interests and some of the practical considerations. Among these are:

- Those where the lessor is not involved in salt production or the storage of various substances, but the lessee is
- Those where one company produces salt and another uses the resulting storage space
- Those where characteristics of the particular dome prohibit dual use
- Controlling access
- The underlying theories of ownership
- Miscellaneous considerations, including negotiation tactics and the fact that many jurisdictions have not settled the question.

The third and final section of the paper reveals the legal solution to the problem in several selected jurisdictions, including Germany, Canada, France and the United States. In the United States special attention is given to Kentucky, Oklahoma, Louisiana, Texas, Virginia and Illinois.

COPELAND *Research in Molten Salts for Thermal Energy Transport and Storage in High Temperature Solar Thermal Systems*

Robert J. Copeland and Tom Coyle, Solar Energy Research Institute, Golden, Colorado, USA

Solar Thermal Collector systems are being developed for many different commercial applications. Low temperature systems are reaching the marketplace now; the high temperature systems require more research and development. For applications requiring heat up to 1100°C (2000°F), the Solar Energy Research Institute (SERI) is investigating molten salts. In this concept molten salts are employed for both thermal transport and storage. The molten salts are heated by concentrated solar thermal energy and then stored in a tank. During transients or for nighttime operation, the hot salt is withdrawn and used to meet the demand load. The cooled molten salt is stored in the liquid state. The tank is employed as a thermocline storing simultaneously both hot and cold salt.

Candidate salts include carbonates, chlorides and hydroxides of sodium, potassium, magnesium and lithium. These salts are low in cost and have good heat transport and storage properties at the temperatures of interest. Containment of the salts is one of the principal research issues: the current status of the research is described in this paper.

D

DAVIES *Structural Characteristics of a Deep-Seated Dissolution-Collapse Chimney in Bedded Salt*

Peter B. Davies, Department of Applied Earth Sciences, Stanford University, Stanford, California, USA

Collapse structures caused by natural salt dissolution occur in many salt-bearing sedimentary basins. Little is known about the structural characteristics of collapse within salt because access for direct observations is very rare. Because of its potential for broaching a thick salt unit, deep-seated dissolution-collapse activity is a hazard requiring thorough assessment for both mining operations and proposed nuclear waste repositories in bedded salt deposits.

On the northern rim of the Delaware Basin in New Mexico, a Pleistocene Age collapse chimney was recently exposed in a potash mine. This chimney has an 800-foot surface diameter and an estimated depth of 2850 feet. The mine workings reveal a transition, over a

distance of 165 feet, from undisturbed subhorizontal evaporite beds to breccia of the collapse chimney. Within the transition zone, bedding dips toward the collapse chimney, reaching a maximum dip of 30 degrees at the breccia contact. A fault, with 25 feet of dip-slip displacement, also occurs within this transition zone. The breccia comprises clasts of halite, anhydrite and polyhalite, with a matrix of clay and clear, recrystallized halite. The presence of faulting in the transition zone and of halite as clasts within the breccia show that collapse involved strain rates high enough to rupture halite.

Observations of the mine exposure suggest that water and trace amounts of oil have moved upward through the chimney from the carbonates that underlie the evaporite section. Oil occurs in seeps from the fault in the transition zone and in small (~ 1 mm) pockets within the recrystallized halite of the breccia matrix. Geochemical work by the U.S. Geological Survey shows that this oil is chemically similar to that found in the underlying carbonates. The breccia clasts provide evidence for water movement. The halite clasts are characterized by thin rinds of insoluble material and by the rounding of sharp corners, both of which suggest limited dissolution. In contrast, neither of these features is found associated with the less soluble anhydrite clasts.

DAVIS *Biotechnology for Solar Saltwork*

Joseph S. Davis, Department of Botany, University of Florida, Gainesville, Florida, USA

Quantitative biological data from studies at solar saltworks in tropical and subtropical locations is reported on 1) pond sealing properties of algae-bacteria bottom mats, clay and sand, 2) heat absorption of brines naturally colored red by halophilic bacteria and heat absorption of dyed and clear brines, 3) the value of brine animals (ciliates, nematode worms, molluscs, brine flies and brine shrimp) and bacteria in maintaining proper ratios of organic matter produced to organic matter consumed, 4) the relation of red halophilic bacteria nutrition to the intensity of the red color they produce in concentrated brines, and 5) the adverse effects of salina-produced organic matter and petroleum products in crystallizers on brine color, salt crystal shape, color and size, and on the ability of salt floors to support heavy machinery. The data emphasize the essentiality of the proper operation of the biological system in solar saltworks for continuous production of high quality product at design capacity. Technology to obtain, manage and modify biological systems in new and existing salinas of several types is discussed.

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de FLERS *Computerization of Solar Salt Production: Building of a Year-Round Software*

Pierre Marchand and Gerard Boudet, Compagnie des Salins du Midi et des Salines de l'Est, Paris, France

In solar saltworks, the annual production cycle is closely linked with weather conditions. In temperate climates, these conditions determine, in a more or less clear-cut way, two different periods, as follows:

- An active period, when salt is being produced and harvested on the crystallizers
- A passive period, during which optimum conservation conditions must be maintained for the bitterns of various concentrations that remain after the end of the active period.

Between these two periods, there are shorter, transient phases of activity when substantial movements of bitterns take place between the basins that make up the saltworks. All these elements of the annual operations cycle have been programmed for ELECTRONIC DATA PROCESSING. These programmes calculate, day by day and according to weather forecasts, the evolution of the various production parameters for each natural pond as well as for the whole complex.

The programmes include the following:

- A SATUR (production of saturated brines) programme with an auxiliary DATREC (harvesting dates) programme covering the so-called active period and permanently providing operational schedules and production forecasts
- A HIVER (winter) programme which determines parameters evolution during the passive period
- An ETALE (conservation of bitterns) programme to cover the intermediate phases that separate the active from the passive period.

Such programmes allow for permanent production management and also provide all types of forecasting possibilities based on advanced weather reports.

DIAMOND *The Solution Mining Research Institute — An Update*

H.W. Diamond, Morton Salt, Chicago, Illinois, USA

For the last 24 years, the Solution Mining Research Institute (SMRI) has sponsored a variety of research projects in the areas of:

- Dissolution Theory
- Drilling, Completion and Logging
- Subsidence and Cratering
- Cavern Utilization
- Rock Mechanics.

The projects completed since the last Salt Symposium in 1978 and those currently underway are reviewed. The SMRI also holds technical meetings twice a year; some of the recent papers are described.

DICKINSON *Present Situation in Salt Products in North America and Outlook for the Future*

William E. Dickinson, Salt Institute, Alexandria, Virginia, USA

The author proposes to trace the development of salt markets in the United States and Canada. Included will be an estimate of present salt use and projected salt use. The impact of the environmental movement as it affects the use of deicing salt will be traced. The question of the effect of sodium on health will be discussed as it affects the use of food grade salt, water conditioning salt and highway snow and ice control salt.

DJAHANGUIRI *Rock Mechanics Considerations for Design of a Nuclear Repository in Salt*

F. Djahanguiri, M.A. Mahtab, and S.C. Matthews, Battelle Office of Nuclear Waste Isolation, Columbus, Ohio, USA

This paper considers underground repository design concepts for emplacement of nuclear waste in domal salt, in particular long- and short-term stability of shaft and canister room pillars during development and post-emplacement phases of the repository. Domal salt-related anomalies such as shear zones, gas and brine pockets are discussed. Also, detection of these anomalies by various techniques are discussed, and new approaches are presented in detail. In addition, influence of backfilled rooms and techniques for retrievability of nuclear canisters after a specified period of time will be presented. Finally, research and development requirements for a better understanding of the utilization of domal salt stock for emplacement of nuclear waste will be briefly highlighted.

DOUGLAS *Computer Modeling of Underground Mine Production Systems*

William J. Douglas, Ketron, Inc., Wayne, Pennsylvania

This paper addresses three approaches for modeling underground mining production systems based on alternative requirements for different levels of planning. The first approach relates to time step simulation of face operations in which the system state is observed several times per minute, which is a very high level of detail appropriate to modeling one or two shifts.

The second approach uses analytical equations to estimate machine place time and a critical path model to describe machine place interactions over several cycles of a cut plan, or perhaps 50 to 100 shifts or more. This is appropriate for investigating stochastic behavior and machine failure-repair mechanisms.

The final model addresses full mine life planning over periods of perhaps 5 to 20 years. A mine strategy tree and equipment pool are processed in event step sequence to analyze equipment utilization, advance and production rates, and long term economics of mining. The models are compared over a range of problems.

DRUCE *The Contribution of Salt to the Diet and Consideration of Aspects of Its Role in Some Processed Foods*

Edward Druce, RHM Foods Limited, London, England

The sources of salt and its physiological role are briefly reviewed.

Estimates have been made of the contribution of natural foods, processed foods, cooking and table salt to the total salt (sodium chloride) content of the U.K. diet. Accurate assessment of the average total salt intake is not possible because of the large individual variation in diet selection. An approximate estimate arrived at by several methods of calculation is within the range 11.6 to 13.3 grammes per head per day. Salt added in cooking or at the table represents approximately 37 per cent of the total salt intake. Sodium derived from food additives represents some 5 to 6 per cent of the total sodium intake.

The use of salt in foods is partly a physiological necessity, a flavouring, a preservative and a processing aid. This forms the basis of the essential functions that salt serves in food technology. Some aspects of the multifunctional role of salt are reviewed in depth with examples selected from a wide spectrum of processed foods.

Some of the risks and benefits of sodium replacement and reduction in foods are considered.

DUTTA *The Separation of Potassium and Magnesium Salts from Crude Mineral Salts by Electrostatic Methods—A New Concept*

Ranen Dutta, The Bengal Salt Company Ltd., Calcutta, India

An average 30 million tons of Potash Crude Salts are being processed annually in the Federal Republic of Germany. Wet treatment methods as followed to date pose increasing environmental problems of disposal. Electrostatic separation methods initiated by H. Autenrieth at the Potash Research Institute, Hannover, West Germany, though earlier work by M.J.E. Lawver of International Minerals & Chemicals Corporation, Chicago showed the initial feasibility. Autenrieth's work, in practical terms, opened new possibilities such as 1) methods of separation applicable to minerals with high percentages of water of crystallization, 2) methods that tolerate high dust content in the feed-stock and 3) use of a wide range of conditioning agents.

Singewald's report on the present state of the art of electrostatic separation in the German Potash Industry and installation of so called electrostatic tube-separators offers itself as an alternative from the points of view of protection of the environment and of energy.

EPRON

A New Process for Reducing the Chlorine Effluent of a Vacuum Salt Plant

Alain Buffet and Bernard Millairs, Compagnie des Salins du Midi et des Salines de l'Est, Paris, France

The Compagnie des Salins du Midi et des Salines de l'Est operates a refinery at Varangeville, the nominal capacity of which is 600,000 metric tons of salt per annum. Until July 1978 all effluent from the mine was cycled back into the natural surroundings, which caused pollution of more than 4 kg of chlorine ions per second during periods of operation.

Since then this pollution has been reduced in two consecutive stages to about 0.5 kg of chlorine ions per second. This was achieved by:

- Causing the cleansing water from the evaporators functioning in crude brine (high suspension and rich in calcium chloride) to react with the cleansing water from evaporators supplied with purified brine containing sodium sulfate. After sedimentation and filtration this effluent is recycled in the production process
- Using the bulk of the other contaminated factory effluents to produce saturated brine for the drillings made in the Keuper salt deposits in Lorraine.

EPRON

Method of Optimizing Stock Control of Rock Salt for the Fluctuating Deicing Salt Market

André Caillaud and Gérard Boudet, Compagnie des Salins du Midi et des Salines de l'Est, Paris, France

Compagnie des Salins du Midi et des Salines de l'Est has a mine normally working at one shift per day which is enough to cover the needs of the deicing market in an "average" winter.

But deicing salt needs fluctuate in proportions of one to four, dependent on the winter. In order to serve this market without breakdown in supply, it is possible to double the production by working a second shift. Another solution consists of increasing salt stockpiles built up in the off season. Obviously the social difficulties and inconveniences involved in fluctuations of employment must be taken into account.

At a purely technical and financial level, our method nevertheless is aimed at finding the most economical solution. The model used simulates all possible developments in consumption, production and stocks, based on management rules and a history of the needs, and then calculates the corresponding costs.

Constraints taken into account are stockpiling capacity and the minimum salt stockpile required at the beginning of the winter.

Estimated deicing salt consumption levels are selected at random from the consumption records of the last few years. They are brought up to date to make allowance for past market growth and can be adjusted according to its estimated future growth. Studies are also being carried out to determine the correlation between deicing salt consumption and meteorological conditions (snowfalls, risk of black ice).

ERGUN

Origin of Primary and Secondary Gypsum in Miocene Evaporites of Cankiri-Corum Basin, Turkey

Osman Nuri Ergun, Geological Society of Turkey, Samsun, Turkey

The Miocene Evaporites of the Cankiri-Corum Basin, Turkey comprise cycle alternations of laminar gypsum rocks and gypsum-bearing mudstones which are the deposits of an intermontane playa lake complex. The gypsum of both the laminar gypsum rocks and the mudstones shows great diversity. In most cycles, it is wholly primary, while in others it is either wholly or in part secondary after anhydrite. The secondary gypsum rocks show evidence that suggests the original mineral was gypsum but that it was altered to anhydrite during early digenesis and this anhydrite was later hydrated to secondary gypsum in the course of exhumation.

The primary gypsum shows a variety of crystal habits and modes of growth. Some of the gypsum crystals grew interstitially in the sediment that now contains them, while others grew free at a sediment-water interface.

Where the gypsum is primary, the carbonate of the associated mudstones is dolomite, but where the gypsum is secondary after anhydrite the carbonate mineral is magnesite. Where the cycles comprise both primary and secondary gypsum the associated carbonate is a mixture of dolomite and magnesite. There is a relationship between the ratio of magnesite to dolomite and the extent of alteration of primary gypsum to anhydrite. The lines of evidence suggest that the magnesite was formed by the replacement or alteration of dolomite. The change from primary gypsum to anhydrite and from dolomite to magnesite is believed to have resulted from periodic drying out of playa.

The secondary gypsum rocks comprise porphyroblastic and alabastrine crystal fabrics and veins of satin-spar gypsum. The hydration is believed to have taken place later in the history of the rocks in response to exhumation and probably related to the present land surface.

EVANS

The Mississippian Salt Deposit at Malagash, Nova Scotia — An Epitaph

Robert Evans, Mobil Research and Development Corporation, Dallas, Texas, USA

The salt deposit at Malagash, Cumberland County, Nova Scotia was discovered serendipitously during drilling for water in 1912. A mine was opened in 1918 and remained in operation until 1959, when the operation was moved to the newly-discovered deposit at Pugwash, a few miles distant. The deposit is Mississippian in age, contained within an evaporite sequence in the Basal Windsor Group (Viséan). It occurs within an uplifted fault-block within the Malagash anticline, and the halite mass is extensively deformed. Bedding dips generally to the south, but two overturned folds complicate the structure, which is characterized by a regime of similar folding.

The salt is more than 100 meters thick, and most of the production came from two seams — the Lucas and the McKay — which varied between one meter and thirteen meters in thickness. Potash mineralization, mainly sylvinite, occurred in several discrete horizons

within the sequence. The Malagash deposit bears a notable resemblance to nearby deposits at Pugwash and Wallace, consisting as it does of halite, some anhydrite and abundant interbedded or finely-dispersed, fine-grained, grey and brown clastic material. The thickness of the deposit and the purity of much of the section exposed in the mine indicate that sedimentation occurred subaqueously from a body of brine of substantial depth.

FABRICIUS *Studies of Fluid Inclusions in Halite and Authigenic Quartz Crystal from Salt Domes in the Danish-Norwegian Basin*

Johannes Fabricius, Geological Survey of Denmark, Copenhagen, Denmark

Microthermometric investigations have been carried out on fluid inclusions in halite and authigenic quartz from salt domes in the dome area of N. Jutland, which is a part of the Danish-Norwegian Basin. The investigated salt is of Zechstein age.

Authigenic euhedral quartz crystals (length 800 to 1200 mm) have been extracted from selected core material from wells in different domes at various depths from 200m to 3500m. The homogenization temperature (T_h) and the melting temperature of the ice and the different hydrates have been measured on fluid inclusions in the quartz crystals. The trapping temperature (T_t), the salinity and the Ca:Mg ratio have been determined.

The maximum T_h has been measured to 105°C corresponding to an estimated T_t of approximately 140°C. Using the various phase diagrams of the system, $CaCl_2$-$MgCl_2$-NaCl-H_2O, the salinity has been determined to be approximately 35 wt% salt consisting of 1 to 2 wt% NaCl and about 33 wt% $CaCl_2$-$MgCl_2$ with a Ca:Mg ratio estimated to 1:1 to 1:3. Both T_t and the habit of the quartz crystals seem to have stratigraphic significance.

A parallel study of fluid inclusions in the corresponding halite has shown that the physical and chemical conditions of halite in connection with the brine give rise to measurements of unreliably high T_h and too high Ca:Mg ratios.

FERNANDEZ LOZANO *Preparation of Potassium Sulphate from Calcium Sulphate or Sodium Sulphate and Sylvite or Sylvanite in Nitrogen-Containing Solvents*

Jose A. Fernandez Lozano, Universidad de Oriente, Nucleo de Anzoategui, Puerto La Cruz, Venezuela, and Alan Wint, University of Nottingham, Nottingham, England

Potassium sulphate is usually produced by double decomposition of magnesium sulphate with potassium chloride. Of the two starting materials, potassium chloride is available in large quantities, while the amount of magnesium sulphate, as kieserite, $MgSO_4 \cdot H_2O$, in salt beds is constantly decreasing. New sources of raw materials therefore

must be found for the sulphate component, and these raw materials, calcium sulphate or sodium sulphate, can be produced in large quantities from solar salt plants as by-products.

The discovery reported here concerns a novel method for the preparation of potassium sulphate from calcium sulphate or sodium sulphate and sylvite or sylvinite in hydrazine-ammonia-water solvents. The lower vapor pressure of this new solvent compared with ammonia-water solvent allows the reaction to be carried out at room temperature and normal pressure. Laboratory tests demonstrated the process feasibility. This process could make the production of sodium chloride from seawater brines more profitable.

FISCHER *An Axisymmetric Method for Analyzing Salt Cavity Arrays*

F. Joseph Fischer, Shell Development Company, Houston, Texas, USA

Single, isolated cavities or small clusters of cavities far removed from the periphery of their host salt dome can usually be satisfactorily analyzed with two-dimensional methods. In some instances, three-dimensional effects of a cavity array and, perhaps, the sedimentary layers surrounding the host salt dome are important. In an attempt to capture essential three-dimensional effects within the constraints of a two-dimensional analysis capability, the concept of "axisymmetric rings" is introduced. This paper discusses the approach of axisymmetric rings and presents an example of its application, i.e., the analysis of the LOOP storage facility in the Clovelly salt dome.

FYNN *Salt Gradient Solar Ponds: Research Progress in Ohio and Future Prospects*

R. Peter Fynn, Research Associate, Ohio Agricultural Research & Development Center, Wooster, Ohio, USA

This paper presents the progress to date of those solar ponds designed, built and operated in Ohio by Ohio State University researchers in Columbus and Wooster, Ohio. The four solar ponds considered are the following:

- The solar pond at the Farm Science Review site, built by Dr. Carl Nielsen of the OSU Physics Department
- The solar pond at the Ohio Agricultural Research and Development Center in Wooster, Ohio, built by Dr. Ted Short of the Agricultural Engineering Department, OARDC
- The solar pond at Miamisburg, Ohio, built for the City of Miamisburg, designed by Dr. Nielsen of OSU and operated by Monsanto Chemicals
- The solar pond at the dairy center of OSU, built and operated by Dr. Nielsen of the OSU Physics Department.

The reason why the solar pond works is presented, as well as how the salt gradient of the solar pond is established and maintained. The use of sodium chloride as the stabilizing salt is explained and methods of recycling the diffused salt are discussed. Actual applications of

these four solar ponds are detailed, together with the mechanics of heat extraction from the solar pond storage zone.

The costs of building and operating a solar pond are presented together with a method of determining approximate solar pond sizing.

In the conclusion, some future applications, both in North America and abroad, are presented.

G

GARRETT ***An Improved Solar Heating Process***

Donald E. Garrett, Saline Processors, Inc., Ojai, California, USA

Considerable attention has been given recently to the potential production of power from "salt gradient" solar ponds. Their advantage is that they can be made quite large and thus gather considerable energy from the otherwise low-level source, sunlight. Similarly, test work and at least one commercial plant have used plastic bag solar heaters to gather the sun's energy to heat water or a process fluid.

Both methods have shown interesting results but also have many problems. They are comparatively expensive in first cost, and even more so in maintenance. The salt gradient ponds are quite unstable, and winds or improper design or operation can mix the stratified fluids and destroy their function. They are also quite thermally inefficient. The plastic bag ponds have a limited size and operating range.

A new solar collecting pond design has been developed that overcomes these problems. It is inexpensive in construction and simple and stable in its operation. Its thermal efficiency is high, thus making it smaller and much more cost effective for either water heating or power generation. Its design and construction are detailed in the report.

GARRETT ***Salting Out Process for Lithium Recovery***

Donald E. Garrett, Saline Processors, Inc., Ojai, California, USA and Martin Laborde, Codelco-Chili, Santiago, Chili

Lithium sulfate monohydrate may be recovered from certain brines by means of a "salting out" technique. For brines of the Na-K-Mg-Li-SO_4-Cl system, or others that may be concentrated by solar or plant evaporation beyond a certain concentration, lithium may be selectively partially removed by the addition of sulfate compounds such as sodium sulfate, magnesium sulfate and sulfuric acid. A process is described for simply obtaining this sulfate salt, concentrating the brine and recovering the lithium.

GARRETT — *The Chemistry and Origin of the Chilean Sodium Nitrate Deposits*

Donald E. Garrett, Saline Processors, Inc., Ojai, California, USA

The Chilean "caliche," or sodium nitrate, deposit is extensive, existing as surface or near-surface complex salt formations covering approximately 10,000 sq km. No similar deposit is known anywhere else in the world, and no satisfactory theory explains its existence. Literally dozens of mechanisms have been proposed to account for limited facets of the deposit, but none satisfactorily predicts all of its characteristics or explains why there are no similar deposits elsewhere.

New chemical and physical data, however, appear to satisfactorily detail the deposit's formation. First, the area has several unique features: 1) it is at a high elevation of generally 1,500 to 2,000m.; 2) it is covered by frequent coastal fogs and is extremely arid with no vegetation; and 3) there are numerous mineral springs (and a few evaporite salt bodies) above the nitrate fields, with extensive faults and porous strata to convey this water.

Recently, it has been shown that certain desert sands are excellent catalysts for the photochemical reaction of nitrogen with oxygen. Thus, with the fog to wash products from the catalyst, and no organic (reducing) material to destroy them, photochemical and oxidizing reactions can produce the deposit's nitrate, iodate and percholorate salts. It is believed these factors, along with frequent winds within the nitrate basin to spread the surface salts and capillary evaporation of the ground water, account for the composition and uniformity of the deposit and its exclusiveness to this location. Considerable data to support this theory are presented.

GEHLE — *Numerical Investigation of a Pressurized Borehole in Rock Salt*

Richard Gehle and Robert Thoms, Applied Geomechanics, Inc., Baton Rouge, Louisiana, USA

In situ tests with pressurized boreholes in rock salt were performed as one part of the compressed air energy storage (CAES) study at Louisiana State University. These included the hydraulic loading to fracture of a system of three closely spaced, parallel boreholes drilled beneath a salt mine pillar. A two-dimensional, finite-element analysis of the system is presented with a comparison of experimental data and numerical results. Material parameters employed in the analysis were derived from CAES laboratory testing of rock salt cores from a variety of sources.

GOODMAN *All Evaporite Salt Deposits Are the Same. Or Are They?*

Nordau R. Goodman, Consultant Geologist, New Glasgow, Nova Scotia, Canada

A brief outline of evaporite deposition is given as a basis to establish that the Canadian Salt Company mine at Pugwash, Nova Scotia and its Ojibway Mine at Windsor, Ontario have a similar origin. The general geology, mineralogy, petrology, structure and mining methods of both mines are summarized. Attention is drawn to their dissimilarity. A comparison is made of the geological differences and the mining problems that are produced and the advantages each mine enjoys. It is pointed out that the major difference is the salt thickness. The comparison is between a twenty-five-foot thickness at Ojibway and over one thousand feet at Pugwash. It is suggested there could be one twenty-five-foot horizon at Pugwash that would be comparable to Ojibway in quality, mineralogy and petrology. If we search deeply enough it can be shown that evaporite salt deposits, although varying markedly in physical appearance, are basically the same.

GUSTIN *Energy Storage in Salt*

James D. Gustin, Law Engineering Testing Company, Marietta, Georgia, USA

Compressed air energy storage (CAES) in geologic media such as salt is a viable concept using existing technology to conserve base-load power production and provide economical and environmentally sound peak power production. CAES utilizes off-peak electrical power to run a reversible compressor/turbine to compress air and store it in either a solution mined or conventionally mined salt cavern. When peak power is required, the stored air is drawn off, mixed with fuel oil or natural gas and burned to turn the compressor/turbine to generate electricity. Since the combustion turbine is not required to power its own compressor, one third to one half of the fuel of a traditional gas turbine is required.

The air storage cavern can consist of a traditional room and pillar mine, a series of interconnected parallel tunnels or a solution mined cavity. When air is released to generate power, water from a reservoir at the surface is allowed to flow down into the cavern to displace the volume of compressed air as it is withdrawn. Typical storage pressures are about 50 to 75 atmospheres. This paper presents a review of compressed air energy storage concepts in salt along with a discussion of siting criteria.

HARDIE — *The Problem of Distinguishing Between Primary and Secondary Features in Evaporites*

Lawrence A. Hardie, T.K. Lowenstein, Dept. of Earth and Planetary Sciences, The Johns Hopkins University, Baltimore, Maryland, USA, and R.J. Spencer, Dept. of Geology, University of Calgary, Calgary, Alberta, Canada

Because saline minerals are readily altered even on shallow burial, a full confrontation of the critical problem of distinguishing syndepositional (= primary) from post-burial (= secondary) features should be an absolute prerequisite to any study of an ancient evaporite. Toward resolution of this problem we offer the following criteria:

- *Syndepositional Features* — 1) sedimentary structures, e.g., lamination, ripple marks, etc., 2) detrital framework textures, both traction and settle-out, e.g., cumulates, 3) "open-space" crystal growth textures, e.g., vertical competitive growth of chevrons, etc., identified using the cement criteria of Bathurst (1975), 4) dissolution-reprecipitation features, such as rounding and epitaxial rebuilding of euhedra, etc., 5) fluid inclusions that show low homogenization temperatures, shrinkage bubbles as opposed to vapor under pressure, and banding that records systematic changes in salinity from core to rim, and 6) absence of high temperature salts
- *Post Burial Features* — 1) massive crystalline mosaics without bedding, 2) crystalline mosaic patches that cross cut bedding, 3) sutured mosaic textures, identified using the neomorphic spar criteria of Bathurst (1975), 4) polygonal mosaic textures with 120° triple junctions, e.g., "foam" structures due to annealling recrystallization, 5) solid inclusions, etc., purged to grain boundaries during recrystallization, 6) high temperature salts, either as mosaics, euhedra, nodules or pseudomorphous replacements, 7) fluid inclusions that show high homogenization temperatures, vapor bubbles under pressure, and no systematic salinity changes from core to rim, 8) deformation features such as folds, veins, foliation, stylolites, slip bands, etc.
- *Ambiguous Features* — minerals with wide temperature stability ranges that occur as 1) pseudomorphous replacements, 2) intrasediment growths as euhedra or nodules, 3) void-filled cements.

HARDY — *Laboratory and Theoretical Studies Relative to the Design of Salt Caverns for the Storage of Natural Gas*

H. Reginald Hardy, C.R. Chabannes, K. Bakhtar, M. Mrugala and E.J. Kimble, Jr., The Pennsylvania State University, University Park, Pennsylvania, USA

Although the mechanical behavior of salt has been investigated for many years, a review of the world literature indicates that criteria for the optimum design of engineering "structures" in salt are at present relatively limited. The present paper will deal mainly with basic problems associated with the design of salt caverns for the storage of natural gas.

although the results and conclusions, for the most part, will also apply to the more general use of such storage facilities.

In 1975 an industry-sponsored research project was initiated in the Penn State Rock Mechanics Laboratory involving the design and performance of salt caverns for natural gas storage. During the succeeding six-year study, research has been undertaken relative to the development of a better understanding of how salt behaves under conditions of stress and temperature equivalent to those found around a typical pressurized salt cavern and the application of established mechanics principles to the development of design criteria for such caverns. The project was completed in late 1981 and a detailed monograph on the study is presently in preparation.

This paper will consider the results of the various in-house studies, including a discussion of the basic laboratory studies undertaken to evaluate various mechanical properties of salt, and a discussion of the implications of a variety of analytical studies (closed-form and FEM). The paper will conclude with a brief discussion of the present "state-of-the-art" in respect to the design of salt caverns for the storage of natural gas.

HART *Current Design and Maintenance Practice in Salt Mine Shafts*

D. E. Hart, The Cementation Company of America, Inc., Brampton, Ontario, Canada

Deterioration of a salt mine shaft can result in the permanent loss of a mine for production purposes. Although this phenomenon has never occurred in North America there have been several near misses. In addition, many mine shafts have required, or will require, costly and prolonged production shutdowns for maintenance or major modifications. Other shafts require expensive maintenance programs on a regular basis.

The major maintenance problems common to all salt shafts result from the solubility of the ore, the corrosive action of brine and the visco-elastic properties of salt. Other problems originate from the overlying strata which may contain large volumes of water, corrosive water, gas and unstable horizons.

This paper describes several case histories of deterioration problems in salt mine shafts. The type and extent of the damage is illustrated and the steps taken to correct the damage are described.

The design of any new mine shaft requires the careful examination and analysis of the conditions in the overlying strata, climatic conditions, shaft utilization, etc. A shaft design for a salt mine must take into consideration the unique properties of salt. This paper includes a description of various shaft designs, their application to conditions found in the salt mining areas of North America, their major maintenance requirements and their relative costs.

HITE *The Sulfate Problem in Marine Evaporites*

Robert J. Hite, U.S. Geological Survey, Denver, Colorado, USA

One of the most puzzling characteristics of marine evaporite deposits is sulfate deficiency exclusive of calcium sulphate. Sulfate is the third most abundant ion in seawater, yet less than 40 per cent is removed by gypsum/anhyrite precipitation. Therefore, marine evaporite deposits should normally contain an abundance of other sulfate minerals.

An attractive explanation is reduction of SO_4^{2-} by sulfate-reducing bacteria and consequent escape of hydrogen sulfide to the atmosphere, a mechanism observed in modern evaporite environments. Measured rates of reduction suggest only a minor effect on brine modification. Further constraints include the large volume of organic matter required as an energy source by the bacteria, the suggestion (Neev and Emergy, 1967) that in evaporite basins such as the Dead Sea the SO_4^{2-} is merely recycled with H_2S reoxidized back to SO_4^{2-} in oxygenated surface layers, and the apparent lack of calcium or magnesium carbonates as a necessary by-product of the process (Carpenter, 1978). Sulfate depletion can also be brought about by the Haidinger reaction; however, it seems unlikely that sufficient Ca^{2+} would have been available to carry the reaction to completion.

It is proposed that the key to sulfate depletion is brine modification through Ca^{2+} enrichment, because the strong attraction of Ca^{2+} for SO_4^{2-} results in the reaction $Ca^{2+}_{(aq)} + SO_4^{2-}_{(aq)} + 2H_2O \rightarrow CaSO_4{\cdot}2H_2O_{(c)}$. Several mechanisms can be called upon for Ca^{2+} enrichment which include dolomitization and polyhalitization of *previously* deposited limestone and gypsum and substitution of Mg^{2+}, K^{1+}, and Na^{1+} for Ca^{2+} in reactions between detrital clay minerals and brine.

HÖFER *Investigations of the Yield Limit of Salt Rocks*

Karl-Heinz Höfer, Institute für Bergbausicherheit, Leipzig, East Germany

The yield limit of salt rocks is an important figure for the deformation behaviour of salt rocks *in situ*. It is a property "sensitive to structure" and, therefore, submitted to great variations.

The yield limit values determined in natural rock salt crystals presented variations within the limits of one decimal power according to the place where the salt has been found and to its preloading history.

Special influence upon the yield limit value is exercised by stress state, grain size, temperature, impurities, surrounding medium, radiation effects and loading history.

Results of investigations carried out in the laboratory and in situ are dealt with and are discussed with regard to their importance to underground excavations and other cavities in salt deposits.

Particular practical importance is taken by the determination of a "true yield limit" at which, indeed, creep begins but comes to a rest under constant loading conditions after a finite period of time.

HUNSCHE *Triaxial Rock Strength Determined on Cube-Shaped Samples*

Udo Hunsche and Claus Caninenberg, Federal Institute for Geosciences and Natural Resources, Hannover, West Germany

The evaluation of failure criteria for rock salt on the basis of laboratory experiments is an important step for the design of a radioactive waste repository in a salt dome. In addition to the common experiments on cylindrical samples, tests on cube-shaped samples using a true triaxial test rig are carried out in the Federal Institute for Geosciences and Natural Resources. This method has the advantage that all load geometries or stress paths are possible.

The reliability of the method has been demonstrated by the comparison with measurements on cylindrical samples and by extensive investigations of the influence of various technical aspects, e.g., lubrication, sample size and edge length of platens. A series of tests has been done on samples from different salt domes using load and deformation controlled experiments at temperatures up to 300°C.

The following results have been derived. The strength increases with hydrostatic pressure and also depends on the stress path. It decreases with increasing temperature. There are only small differences between the strengths of different types of rock salt, except when uniaxial tests are carried out. With additional studies a better understanding of the failure mechanisms could be obtained.

HUO *Characteristics of Salt Deposits in the Dry Salt Lake*

Yuan Jianqi, Huo Chengyu and Cai Keqin, The Beijing Graduate School of Wuhan College of Geology, Beijing, China

When the saline basin evolves into a stage of potash deposition, a vast expanse of salar coexists with some residual brine lakes. Such a special geologic and geographic setting is known as "dry salt lake." Salt deposits in that basin are quite different from "playa." The potash deposit in Chaidam Basin of China is cited as a typical example of a modern dry salt lake.

The difference between the water levels of the residual brine lake and the intercrystal brine within the salar, and their hydrogeological relationships, have decided the characteristics of salt deposits in the stage of dry salt lakes. The residual brine lake with the lowest water level is the main "potash basin." The potassium compounds are enriched in the brine lake by the processes of selective solution and vertical and horizontal differentiation of salts in the intercrystal brine within the salar. The bedded potash deposits are usually formed in the flat lake beach along the bordering regions of salar and lake. The mechanism of formation of the potash beds is similar to modern coastal sabkha, but the salts are supplied from the intercrystal brine in the salar.

The residual brine lakes in the stage of dry salt lake are not simply formed by structural depression; they are the comprehensive geological phenomena of structural depression, depositional compensation and, especially, the surface and underground drainage system of the lake basins.

IDE

Solar Pond Design for the Production of Potassium Salts from Salar de Atacama Brines

Fernando Ide, Luis Vergara-Edwards and Pedro Pavlovic, Comité de Sales Mixtas — CORFO, Santiago, Chile

The feasibility of producing potassium salts in the Salar de Atacama using solar evaporation rests on the construction of inexpensive clay ponds. To find a suitable area for pond construction the north side of the nucleus of the Salar was explored. Clays of good quality and of large extent were encountered under the salt cap. Permeability tests were performed in the laboratory and in the field. An area of good clays, with permeabilities less than 2.5×10^{-7} cm/sec^2, was found. An experimental *in situ* clay pond also was built to run leakage tests. To estimate the pond area required for the production of KCl and K_2SO_4, material balances were calculated for each crystallization stage using the evaporation rates and phase chemistry information. The basic design of solar ponds described here was proposed by Saline Processors Inc.

ISENOR

The Salt Institute Safety and Health Committee

M. Kendall Isenor, The Canadian Salt Company Limited, Windsor, Ontario, Canada

The purpose of this presentation is to illustrate, by narration and 35 mm slide characterizations, the history and function of the Salt Institute Safety and Health Committee from its inception to present.

Basically, the content will be composed of the following:

- A brief history of the Salt Institute
- A concise description of those member companies with representatives on the committee and/or having had representation in the past
- The Committee function, with particular emphasis on
  - purpose
  - objectives and achievements
  - safety awards (purpose, categories, criterion and recipients)
  - actual situations (seminars, visits at properties, meetings with educators and government personnel, etc.) that portray members in the pursuit of information to fulfill their mandate—"To establish and develop programs, teach, inform, influence and persuade management to adopt the necessary principles and programs that will 1) reduce injuries, 2) exceed the requirements of legislation and 3) produce a safe work environment for the preservation of life and property."

ISTVAN *Storage of Natural Gas In Salt Caverns*

J.A. Istvan and C.W. Querio, PB-KBB, Inc., Houston, Texas, USA

Millions of cubic feet of natural gas can be stored safely and economically in stable salt caverns. Spacing of the caverns, pillar to diameter ratios, maximum and minimum storage pressures, bottom hole temperature and the phenomenological method of evaluation should be considered and utilized.

Many existing caverns probably would not meet the criteria necessary to assume stable and tight high pressure subsurface storage vessels. Therefore, it is the intent of this paper to outline the studies necessary to design and construct new large scale facilities for surge capacity and peak-shaving purposes. Elements of these studies are dependent upon elastic, viscous and plastic material behavior.

JADHAV *Recovery of Crystalline Magnesium Chloride-Hexahydrate by Solar Evaporation of Sea Bitterns*

M.H. Jadhav, Chougule & Company Private Limited, Bombay, India

Bitterns available from the solar salt industry contain about 50 parts per thousand of magnesium ion which separates out in the form of bischofite ($MgCl_2.6H_2O$) and carnallite ($KCl_2.6H_2O$). Since bischofite is a highly hygroscopic salt, its recovery by solar evaporation of bitterns is restricted by conditions of atmospheric relative humidity. Its collection is further limited by the temperature of mother liquor.

Studies were carried out to find these limiting values of the relative humidity and the temperature of mother liquor. The work indicates that such value of relative humidity is limited to 55 per cent and that of temperature of mother liquor to 43.5°C. Such conditions are available in arid and semi-arid regions in the early part of the day. The method of collection of magnesium chloride-hexahydrate under such conditions is described.

JAVOR *Nutrients and Biology of Saltern Brines*

Barbara J. Javor, Scripps Institution of Oceanography, La Jolla, California, USA

In two case studies of the biology and nutrient chemistry of solar evaporation ponds, planktonic species composition and biomass were correlated with concentrations of dissolved phosphate, nitrate and ammonia. In comparison to the nutrient-rich pond system, the relatively nutrient-poor system maintained lower algal and brine shrimp populations in the lower density brines. In the NaCl-crystallizing ponds, the brine alga *Dunaliella* was absent. Strontium sulfate apparently precipitated around bacterial cells. In both systems, high purity NaCl precipitated.

JONES *Road Salt in the Environment*

P.H. Jones and A. Hutchon, Department of Civil Engineering and Institute for Environmental Studies, University of Toronto, Toronto, Ontario, Canada

The increasing use of salt for the control of snow and ice accumulation on the roads in winter has resulted in concern about its impact on the environment. The Institute for Environmental Studies therefore has established a coordinated approach to the study of the associated problems through the involvement of researchers, together with municipal engineers and politicians.

The impact of salt on the environment is examined in terms of water quality in streams and wells. It is found that some biota are not affected, but rising levels of sodium may be a threat to potable water supplies. Vegetation subjected to salt spray from roads may be substantially damaged through dieback of the foliage and absorption through the roots, although some species are more salt-resistant than others.

Close attention to policies governing the demands for chemical clearing of roads as well as management of the salt distribution system are shown to be effective ways of reducing the amount of salt entering the environment and a methodology for assuring successful coordination of these efforts is described. The legal liability of agencies responible for winter and road maintenance is examined through actual case histories describing vehicle accidents as well as environmental damage.

The relationship between safety, mobility and the presence of snow on the roads is explored through a study of vehicle accidents in Toronto during the winter months. This particular work is of a continuing nature and interim results are discussed.

JONGEMA *Optimization of the Fuel Consumption of an Evaporation Salt Plant with the Aid of the Exergy Concept*

P. Jongema, Akzo, Salt Chemicals Division, Hengelo, The Netherlands

In the last decade the prices of fuel oil and natural gas have risen much more than plant construction costs. So, it may be stated that the optimum energy consumption for the production of vacuum salt has been shifted to a value much lower than 10 years ago. To know this optimum is not only of interest in those cases where a new plant is envisaged but also for judging the performance of an existing one.

The main design variables of a multiple-effect evaporation plant are the number of effects and the steam pressure and, in the case that vapour compression is applied, the compression ratio is of major importance. The optimum value of these variables is highly dependent on the price at which steam and power are available. In their turn, these prices are related not only to the fuel price but also to the way these two forms of energy are raised from fuel.

To find the optimum, use can be made of the concept of exergy. Exergy is an expression for the work potential of a quantity of heat. By applying it, heat and the medium transferring it, steam, for example, is brought on an equal footing with mechanical or electrical power. Therefore, it is possible to get a much clearer insight into the way in which energy is consumed in actual processes.

It will be demonstrated that the exergy concept is a powerful tool to solve the problem of finding the optimum fuel consumption of a salt evaporation plant.

K

KARABLY *High-Integrity Isolation of Industrial Waste in Salt*

Louis S. Karably and R.R. Kelly, Law Engineering Testing Company, Marietta, Georgia, USA

Rock salt deposits underlie millions of acres in several areas of the United States. Salt deposits exist as dome salt, bedded salt or playa lakes.

Considerable evaluation and characterization of salt formations have been conducted for storage and waste isolation. On the basis of favorable salt characteristics, it is believed that solution mined cavities in salt can provide structurally stable isolation chambers for waste. Waste isolation in salt cavities may be a viable alternative to disposal by landfill and land treatment. Cavity utilization warrants careful thought and examination.

The favorable characteristics of salt, primarily compressive strength and impermeability, provide structurally stable chambers for waste isolation. Solution mining techniques are established for creating space for the storage of hydrocarbons in salt. The proposition of waste isolation in engineered salt cavities is similar to this practice relative to characterization, certification and safeguards. What materials are isolated and how

operations are conducted are the principle differences. Compatibility of wastes with other wastes must be considered, but hazards can be precluded by pre-testing and avoiding certain mixtures or by segregating waste streams in separate caverns. Waste material characteristics and cavity considerations are discussed.

KAWAHARA *Concentration of Seawater by New Electrodialysis Process*

Takuo Kawahara, Katsutoshi Asada and Kaichiro Suzuki, Asahi Glass Company, Ltd., Tokyo, Japan

Japan's electrodialysis technology, which has been developed with special emphasis on seawater concentration, is now at the world's top level. There is a growing recognition of the tendency reflecting the recent energy situation, and electrodialysis is now regarded as an excellent separation technique, both technically and commercially. As a matter of fact, there was a requirement to establish the energy-saving techniques for seawater concentration to reduce salt manufacturing cost in Japan.

Asahi Glass has succeeded in developing a new ion exchange membrane, "Selemion CMR and ASR," and new electrodialyzer, "CS-V," to meet the requirement of energy saving, and two commercial plants with a capacity of 170,000 tons NaCl per year are in operation for the production of table salt from seawater. The major characteristics of our new technology are low power consumption, high concentration, pure brine, and easy and stable operation, compared with the conventional type electrodialyzer Model CB-V.

According to the new technology, the operating cost for the recovery of salt from seawater has been remarkably reduced, and the electrodialytic concentration process has become far more competitive with other processes than earlier.

KAWATE *Energy Savings in Salt Manufacture by Ion Exchange Membrane Electrodialysis*

Hideo Kawate, Katsuhiko Miyaso and Mitsuhiko Takiguchi, Asahi Chemical Industry Company, Ltd., Tokyo, Japan

Although salt has been manufactured successfully for many years at plants in Japan, Taiwan and Korea by electrodialysis utilizing ion exchange membranes, rising oil prices since 1973 have increased the proportion of energy cost to over 50 per cent of the total salt manufacturing cost at these plants. It therefore has become increasingly important to find ways to reduce the consumption of electricity and thermal energy used in these plants, and important improvements have been developed and implemented.

This paper describes current and scheduled improvements for energy savings in the ion exchange membranes, electrodialyzer and evaporating crystallizer.

KELSALL

Geologic and Engineering Characteristics of Gulf Region Salt Domes Applied to Underground Storage and Mining

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Salt domes have been used extensively for salt mining and underground storage of hydrocarbons. In the future, salt domes may be used also as sites for radioactive waste disposal or for compressed air energy storage. This paper provides a comprehensive review of characteristics of Gulf Region salt domes and discusses how these characteristics influence the design of mined caverns or solution cavities.

Applications considered include shaft sinking, mine or storage cavity development and operations, and shaft sealing. Much of the information presented is obtained from recent investigations performed for the Strategic Petroleum Reserve and from feasibility studies for radioactive waste disposal, and it has not been openly published previously.

The general structure of the dome is discussed, especially the structure at the edge of the dome, in the salt and in the adjacent sediments. Caprock features are described, in particular the structure and hydrologic properties of the salt-caprock interface. Discussion of the geology of the salt stock emphasizes anomalous features such as impurities and gas and liquid inclusions with evidence obtained from mines, drill cores and solution mining records. Temperature gradients in Gulf Region salt domes are also discussed.

Finally, ranges and typical values of physical, thermal and mechanical properties of dome salt are reviewed, noting the wide range in results obtained and the sensitivity of properties such as strength and permeability to sample disturbance and testing method.

KOSTICK

The Future Supply/Demand Balance of Salt — A View by The U.S. Bureau of Mines

Dennis S. Kostick, Division of Industrial Minerals, U.S. Bureau of Mines, Washington, D.C., USA

The U.S. Bureau of Mines has been canvassing the U.S. salt industry since 1880 in order to obtain comprehensive data for the purpose of monitoring the supply/demand situation of the United States. The United States has sufficient salt resources to meet any increase in future demand. This demand, however, has been decreasing over the last few years because of the declining use of salt in road deicing, food flavoring and certain chemical industry products, such as polyvinyl chloride. Many economic, public awareness and environmental factors have contributed to shape the present demand situation for salt.

Through the use of various macroeconomic indicators, the Bureau of Mines is attempting to conduct short-term forecasting studies of the United States salt supply/demand pattern. The input of reliable and timely data, supplied by the aggregate U.S. salt industry, is essential in this project. Recent data will be used to show the present and future growth trends of salt in the United States.

KRATZ *Saltworks Engineering*

E.W. Kratz and E. Schmoll, Escher Wyss Ltd., Zurich, Switzerland

The paper deals with some specific aspects of saltworks engineering. A brief introduction on the status of conceptional design will be given, covering operational and manufacturing considerations. Evaporator/crystallizer design is reviewed, with emphasis on hydraulic flow and crystallization (crystal growth and abrasion) phenomena. Means for reducing energy consumption, advantages of mechanical vapor recompression and utilization of waste heat are discussed. Selection of materials of construction is compared to corrosion experience obtained from various plants.

KROIS *Improving Mine Operations by Recognizing Employee Attitudes*

Paul A. Krois and John Adkins, The Bendix Corporation, Englewood, Colorado, USA

Management has increasingly recognized that employee attitudes contribute to the peaks and valleys in production and safety. Data supportive of this position come from various industries, and several mines have undertaken efforts to assess and use information about employees' work attitudes to remove organization bottlenecks. These efforts reflect a family of methods known as organization development (OD) which are useful for addressing such issues as training, management controls and maintenance procedures.

The concept of OD represents both a goal and processes for reaching that goal. The goal is to improve mine productivity and the safety and morale of the work force. One particular process is employee attitude survey feedback, which uses a questionnaire having strong content validity because it is developed through input from local management and union leadership. The questionnaire is distributed to the work force and group interviews of randomly sampled employees are subsequently done to add perspective and round out the data collection process. Responses to the questions are tabulated, then this information is posted on the bathhouse bulletin board for review and is also discussed in a follow-up feedback meeting with employees.

Problem areas may be probed further by an analysis in which key questions are scaled together around central management and operations issues such as production pressure, safety attitudes and practices, and supervisor-crew relations, to mention a few. Management is frequently interested in how its operations compare to other mines, and this also provides for examining what courses of action to take to resolve identified problems. Recommendations recognize constraints existing at the mine and are prioritized for management goal setting.

L

LABORDE *Computer Model for the Area and Performance of Solar Ponds*

Martin Laborde, Codelco-Chile, Santiago, Chile

The increased price of fuel that has taken place since 1974 has enhanced the feasibility of other sources of energy. For the processing of saline minerals in zones of high solar radiation the utilization of solar energy to concentrate brines has proven to be a valuable economical alternative to plant processing, especially in desert or remote areas far from adequate port facilities and fuel supply.

Consequently, a study has been made on the calculation of the surface area of solar evaporation ponds employing the variables rate of evaporation, porosity of crystallized salts and the leakage rate through the pond bottom. It has been shown that with leakage rates in the order of 10^{-6} cm/sec, or more, permeability is the main variable. Evaporation rate is the most important variable when the leakage rates are better than 5×10^{-7} cm/sec.

LABORDE *Determination of Brine Evaporation Rates in Solar Ponds as a Function of Magnesium Chloride Concentration*

Martin Laborde, Codelco-Chile, Santiago, Chile

A parameter fundamental in the understanding of solar pond systems is the brine evaporation rate during the concentration process.

It is known that the evaporation rate diminishes as salinity in the brine increases, due to the influence of the dissolved solids on the water vapor pressure. The decline of water vapor pressure as aqueous solutions become more concentrated results in a lower quantity of energy leaving the solution as latent heat of vaporization, due to the lesser activity of mass transference in the interphase. The incident energy is transformed into latent heat, so that as salinity increases, a lower evaporation rate takes place.

Many empirical and theoretical correlations have been developed between the rate of evaporation and the main affecting parameters—wind, air and brine temperatures, and air relative humidity. It has been found that the brine evaporation rate diminishes as density increases, the latter being normally associated with increasing quantities of dissolved salts.

This paper proposes a fairly simple system to determine the evaporation rate in small metallic pans for alkali and alkaline earth brines of different compositions and densities. It does not attempt to extrapolate these results to industrial solar ponds, a subject to be discussed in another paper.

LANGILL *New Dimensions for Solar Evaporation Site Analysis*

Richard F. Langill, Richard F. Langill & Associates, Germantown, Massachusetts, USA

The availability of Landsat imagery adds a new dimension to preliminary evaluations of geohydrologic conditions at prospective solar evaporation sites. Landsat (ERTS) imagery is particularly useful during the initial screening stage when conventional maps and air photos may not be available. This paper presents the interpretation of factors affecting pond construction and operation at three sites in Venezuela. The use of the imagery to define usable areas and potential leakage conditions is described. Both false color and black and white imagery were used to assess problems from storm tides and excessive surface water runoff at the three sites.

After solving many unique problems, expansion of solar ponds and crystallizers has been completed at the Araya location. A Phase I expansion also has been completed at the Falcon Peninsula site. The use of Landsat imagery to interpret geohydrologic conditions at these two locations and a third site presently under investigation near Maracaibo will be explained.

An extensive study of technical reports on solar evaporation was made in connection with the site evaluations. This paper also presents a number of valuable graphs, charts, nomograms and formulae compiled during the study and discusses the application of these data to evaluate solar site design and construction in Venezuela.

LARSON *New Methods in Textural and Fabric Analyses of Rock Salt Related to Mechanical Test Data, Tostrup Salt Dome, Denmark*

Jorgen G. Larson, Denmark Geological Survey, Copenhagen, Denmark

Eight wells have been drilled to a depth of approximately 1700 m and a large number of oriented cores from the Zechstein salt deposits have been taken. The geological structure has been worked out at the Geological Survey of Denmark, as a consultant for Dansk Olie & Naturgas A/S, and the rock salt has been mechanically tested at different laboratories.

Preliminary petrographic studies, including fabric analyses and strain axis measurements, indicate that the strength of the salt is dependent on the shape of crystals and their orientation. The foliation and lineation of the rock salt are tentatively related to the stress conditions during the ascent of the salt dome.

LEONARD *Monitoring Procedures for Determining Components of Salt Dust and Evaluating Worker Exposure Potential*

Mary C. Leonard, Armak Company, Maple Shade, New Jersey, USA

Last year, MSHA issued a memo stating that the agency would enforce only those substances that are specifically listed in the Appendix E of the (ACGIH) TLV booklet. Since salt dust is not listed, it is no longer subject to the 10 mg/m^3 limit. However, MSHA has suggested that the composition of airborne salt dust may be somewhat different from the parent material and that certain hazardous substances warrant additional investigation.

Because of these statements, we decided to conduct a study to characterize airborne salt dust and determine whether the components of the dust present a health hazard. This paper discusses not only the results of the study but also the sampling and analytical methods used to monitor total and respirable dust, toxic contaminants such as free-crystalline silica and trace metals, plus total solubles and insolubles.

LIEDTKE *Evaluation of Salt Rock Stability Utilizing Numerical Calculations, Mine Survey and In-Situ Rock Measurements*

Lutz Liedtke, Klaus Dürr, Volkmar Graefe and Dieter Meister, Bundesanstalt für Geowissenschaften und Rohstoff, Hannover, West Germany

The stability of a rock salt pillar has been studied utilizing finite element calculations, measurements of deformation and acoustic emission, and mine surveying. The pillar is loaded by the pressure of the overburden and by stress redistribution from surrounding workings. As a result of this loading, the pillar exhibited steady state creep. The average creep rate in the pillar is about $3 \cdot 10^{-6}$ d^{-1} both in longitudinal compression and in transverse extension. Creep of the rock salt pillar is accompanied by emission of high frequency acoustic energy, which has been monitored together with the pillar deformation process over a long period of time.

The finite element calculations are based on the ADINA computer code for non-linear, time-dependent problems. The creep values that have been used for the calculations are derived from extensive laboratory experiments on rock salt.

The results of *in situ* measurements are compared with the results of the time-dependent finite element calculations and are found to be in agreement. The complete analysis of the measurements, calculations and safety assessment leads to the conclusion that, at present, the pillar is stable.

LIN

Technical Development of Solution Mining in Thinly Bedded Rock Salt Deposits of Ziliujing, Sichuan, China

Lin Yuanxiong and Nie Chengyun, China National Salt Corporation, Beijing, China

Ziliujing has a long history of salt exploitation and brine extraction and has been reputed as the "Salt City." Well drilling, brine extraction and salt production started at the end of the second century. Xinghai Well — a brine well — which is 1,001.4 m deep and the first deepest well in the world, was drilled in 1835 and has been protected as one of the major cultural relics. Extensive exploration has been conducted, great attention has been paid to the investigation and application of exploiting processes and techniques, and excellent achievements have been obtained since the founding of the People's Republic of China.

What strikes one most is the technical development of solution mining in thinly bedded mono-layer (10 – 15 m thick) in the depth of over 1,000 m. In the case of the unstable caprock of the rock salt, a new drilling technique is adopted, directional dual bores are drilled according to the natural declivity and cavities in the two wells are developed and connected by using oil pad. Drilling cost is reduced by 23 per cent, the speed of the well build-up is increased by 2.4 times, and one wellsite is saved. Reduction of pipe laying and simplification of facilities and management are realized during the oil pad operation and production. Saturated brine is produced with the connection of cavities in thin rock salt layers, and the recovery rate is raised.

Also described in this paper is some of the experience in exploiting extremely thinly-bedded rock salt with the thickness of 1 to 6 m.

LIU

A New Technique of Plastic Film Covering of the Solar Salt Production in the Rainy Region

Liu Dewan, Chai Minsheng, Wang Shihong, Wu Xihai, Salt Institute of China Light Industry Society, Beijing, China

This paper describes the key of the process reformation—the new technique of plastic film covering used to reduce rainfall effect, which has been found and solved according to the meteorological characteristics in the rainy region in China through scientific research and production practice.

The former short-period crystallization process with frequent salt harvesting has been converted into the year-round crystallization of salt production. Therefore, the purpose to utilize nature for high and stable salt production to improve salt quality and raise the mechanization level of salt production may be attained.

From the preliminary economic benefit obtained it can be seen that the production cost of solar salt is reduced by more than 20 per cent, meeting the demands of the development of salt production. In the paper, the method of spreading and collecting of plastic film and parameters concerned are also introduced. The new technique is considered to be applicable to solar salt production in rainy regions.

LUX *Creep Tests With Rock Salt Under Changing Stress as Basis for the Identification of Constitutive Laws*

K.H. Lux and S. Heusermann, University of Hannover, Hannover, West Germany

To describe the viscose material behaviour of rock salt international literature recommends constitutive laws which markedly differ not only in the parameters quoted but also in the basic theoretical statement. The alternative use of several constitutive laws in project design can lead to vast differences in the predicted long-term behaviour of a storage cavern in the rock salt mass and so to the question as to which constitutive law formation can produce a realistic estimation of viscose displacements even with extrapolations over longer periods.

To clarify this question, step loading tests have been carried out at the Institute for Underground Construction additional to the usual creep tests at constant stress. These step loading tests were run both with increasing as well as decreasing deviatoric stress. This paper shows that the creep behaviour measured under constant stress can be described by almost all constitutive laws with appropriate parameter selection. With extrapolations beyond the laboratory test time, large differences in the predicted viscose displacements occur, even with these simple boundary conditions. However, already within the laboratory period large differences occur if step loading tests with load increase or load decrease are recalculated using various constitutive laws. Only few laws prove suitable.

Additional to these comparison tests the results of creep tests under triaxial extension stress conditions using axially perforated samples are first compared to those obtained from theoretical constitutive laws. Due to the change in the geometric conditions of the sample more possibilities of constitutive law identification for rock salt on the basis of laboratory tests are produced.

LYONS *Hot Brine–Sediment Interaction in Modern Sabkhas*

William Berry Lyons and Henri E. Gaudette, Department of Earth Sciences and Ocean Process Analysis Laboratory, University of New Hampshire, Durham, New Hampshire, USA

Although there has been much recent interest in the chemical interaction of hot, saline solutions with oceanic crustal material, there has been little concern regarding the interaction of naturally occurring brines with sedimentary deposits. Our research on the diagenesis of marine hypersaline lake sediments coupled with a review of the literature suggest that chemical, mineralogical, and undoubtedly physical, changes do occur in modern sedimentary environments via hot brine-sediment interaction.

The available information indicates that detrital feldspar can be "weathered" by these interactions. Data from sabkha sediments in both the east coast of the Sinai and Bonaire, The Netherlands Antilles indicate that Na^+ rich minerals, possibly albite, are being altered to minerals that are Na^+ deficient. Published data suggest that the same phenomenon may be responsible for "weathering" K^+ feldspar. Thus the hot brine-

sediment reactions may greatly change the major action chemistry of naturally occurring brines. Previous work by our group (Lyons, Gaudette and Gustafson, Organic Geochemistry, 1982) demonstrated that sediment organic matter can also be solubilized by these hot brines. All these results will be discussed in light of their ramifications on the development of salt gradient salt ponds (SGSP) as an alternate energy resource.

M

MAHTAB ***A Numerical Analysis of the Mechanics of Gas Outbursts in Salt***

M. Ashraf Mahtab, Henry Krumb School of Mines, Columbia University, New York City, USA, and Bruce Trent, Science Applications, Inc., Steamboat Springs, Colorado, USA

Five of the six salt mines in Louisiana salt domes have experienced gas outbursts which carry potential risks to safety of personnel and the mine. The risks are especially acute if storage of hydrocarbons or toxic wastes is contemplated in domal salt. Typically, a gas outburst cavity in salt shows a conspicuous, thinly leaved bed separation on its surface, the scale-like fissures being convexly curved to the axis of the cavity. The outbursts in salt have been ascribed to "the change of stress in the burst-prone 'pocket' of rock from a triaxial to a biaxial or uniaxial state, resulting in sudden burst of rock and release of gas."

This paper describes the results of a numerical approach used to test the two-fold hypothesis for the mechanics of gas outbursts in Louisiana domal salt by the following means: 1) a gas outburst is initiated by disking and propagates by further disking and spalling of the cavity walls and 2) the outburst is terminated by a combination of dilatancy hardening, increase in stress along the cavity axis, and enlargement of the cavity to boundaries of the burst-prone (pressure) pocket of salt. The effectiveness of advance shock blasting (shot firing) in destressing and degassifying the pressure pocket, and thus controlling the gas outburst, is also examined.

MANNAR ***Design of Seawater Intake Facilities for Solar Sea Salt Plants***

M.G. Venkatesh Mannar, Marthi Crystal Salt Company Limited, Madras, India

For a solar sea salt plant, adequate quantities of undiluted seawater year-round can be ensured by proper survey and design of intake facilities. For this purpose, the topography of the coast and tidal and salinity variations are to be studied to determine the type of facility required. Various types of arrangements like tidal reservoirs and pumping stations, direct pumping from the sea with jetty-mounted rigid pipe lines or flexible suction lines laid on the sea bed are described. A procedure for selection of the facility to suit the site conditions is outlined.

MARTINEZ — *Energy Programs — A Contribution to Salt Dome Knowledge*

Joseph Didier Martinez, Consultant, Baton Rouge, Louisiana, USA

In recent years, several major federal energy programs involving salt domes have been initiated. An enormous amount of data has been accumulated concerning their occurrence, origin, character and utilization. This has resulted in an enhanced geological and technological understanding of salt domes. This should aid in the planning and development of their use both in an economic and environmental sense.

Studies of the utility of salt domes for the isolation of high-level nuclear waste were initiated in the early 1970s by the USGS and greatly expanded by the US Department of Energy. Another program, The Strategic Petroleum Reserve Project, was mandated by Congress in 1975. Its ultimate goal was to establish a reserve of one billion barrels of crude oil. Man-made cavities in Gulf Coast salt domes are being utilized for this purpose. A third effort has been the study of compressed air energy storage underground. An evaluation of the use of man-made cavities in salt domes for this purpose has been a major focus of this program.

Enhancement of scientific knowledge related to salt domes has included such fields as structural geology, petrology, hydrology, rock mechanics, mining methods, failure modes of underground structures and potential environmental impacts of salt domes utilization.

MAYRHOFER — *Systematic Underground Geology and Geophysics as a Prerequisite of Drilling Exploration*

Heimo Mayrhofer, Mining Geologist and Exploration Consultant, Kassel, West Germany

Stratigraphical, mineralogic-petrographical and chemical means are demonstrated by commented results on different types of deposits, also the possibilities and limits of underground geophysics. All those means are to be judged on the degree of reliability of the plotting and on the relation between costs and the practical advantage.

In this connection will be shown plan-views, cross-sections and three-dimensional examples of flat deposits like the Prairie-Evaporites in Saskatchewan, of little wavy ones like the Werra-Fulda area or the type of Congo-Brazzaville, of large slightly inclined anticlines like the Solling, West Germany, steeper anticlines (salt-pillows) in South Hannover, more or less laterally compressed synclines in New Brunswick, Canada or Sicily and Santa Rosa de Lima in Brazil, and also diapirs with different halofluidal style. It can be recognized how far the greater tectonical position and the different intrasalinar materials cause certain deformation degrees and types.

The main concern is to show what kind of drilling pattern should be used and what essential evaluations are to applicate on the explo-cores after the general recognition of the tectonical frame and by it the probable shape of the whole salt body. In all cases the safeguarding of hydrogeological facts inside of salt bodies and the framing clastics is explained.

MAYRHOFER — *World Reserves of Mineable Potash Based on Structural Analysis*

Heimo Mayrhofer, Mining Geologist and Exploration Consultant, Kassel, West Germany

After definition of terms about the categories and classes of mineral reserves and the mineability, the paper will demonstrate the criteria of evaluation, such as data about thickness, area, depth and grade, also degree of inhomogenity, primary or secondary changes of mineral facies, type of deformation and strength recognizable on mineralization and fabric. In addition, the stratigraphy and the configuration of the salt bodies dealt with and, finally, the physical properties of the framing overlying clastics, hydrogeology included.

Hence, result reductions of the reserves in place, besides those caused by stress-control, barrier-pillars, etc. From this standpoint, the paper deals with all relevant potash deposits from Williston Basin and New Mexico to New Brunswick, Carnopolis (Brazil), Point Noir (Congo), The Tertiary of Sicily, Spain and Elsass, to the Zechstein, the Donbass-Graben and Solikamsk-Beresniki with characteristic drawings.

Two world maps with graphs of actual K_2O demand and agronomic relevant areas, together with potash mining locations, show some ecogeographical connections and allow some conclusions.

Two other pictures show the world potash reserves by their geographical distribution according to Kruger, Ivanoff and Prokofljew with 129,000 million metric tons and my calculation of about 54,000 million tons.

McLAUGHLIN — *Geology of the Potash Deposits of Potash Corporation of Saskatchewan Mining Limited.*

T. Danyluk, Gary McLaughlin, G. Phillips and J. Warner, Potash Corporation of Saskatchewan Mining Limited, Saskatoon, Saskatchewan, Canada

Potash Corporation of Saskatchewan Mining Limited, the operating subsidiary of the Potash Corporation of Saskatchewan, operates three mines in the Saskatoon area of Saskatchewan — Cory Division, west of the city; Allan Division, east of the city; and Lanigan Division, located approximately 75 miles (120 kilometers) east of Saskatoon. A fourth mine, Rocanville Division, and the proposed mine at Bredenbury are located approximately 250 miles (400 kilometers) southeast of Saskatoon.

Cory, Allan and Lanigan Divisions mine the Patience Lake Member, the uppermost potash member, of the Prairie Evaporite Formation, while the Rocanville Division and the proposed Bredenbury mine are located in the Esterhazy Member, the lowermost mineable potash member.

Since 1977, expansions of the individual mining operations and increased geological and geophysical (principally seismic) studies have added to our knowledge of the potash deposits as well as raising new or additional questions concerning the formation and subsequent geological history of the deposits.

This paper presents a general review of the geology of each of the deposits, their similarities and differences in structure, stratigraphy, ore grade and geological anomalies encountered underground.

MELLEGARD *Constitutive Behavior of Saline Salt from the Cleveland Mine*

Kirby D. Mellegard, Tom W. Pfeifle and Paul E. Senseny, RE/SPEC, Inc., Rapid City, South Dakota, USA

Laboratory experiments were performed on 100-millimeter-diameter specimens of Salina Salt taken from the floor of the 540-meter level of the Cleveland mine. Quasi-static triaxial compression experiments were performed on 200-millimeter-long specimens at temperatures of 20°C, 100°C and 200°C to determine the elastic constants and failure envelope. The confining pressures in these tests were 0, 5, 10 and 15 MPa. Brazilian tests were performed on 50-millimeter-long specimens to determine the tensile strength. Twelve triaxial compression creep tests were also performed on 200-millimeter-long specimens. The test conditions covered the range of stress difference of 5 to 15 MPa and the range of temperature of 25 to 200°C. The confining pressure in all creep tests was 15 MPa.

The elastic constants, Young's modulus and Poisson's ratio, were found to be independent of confining pressure. Young's modulus decreased with temperature at the rate of 0.04 GPa/°C from the value of 30 GPa at 20°C. Poisson's ratio is nearly independent of temperature and has the value 0.35. Brittle failure could be produced only in the Brazilian tests and triaxial compression tests performed at 20°C and at confining pressures of 10 MPa and below. At other conditions, the test was terminated at an axial strain of 15 per cent because of the large changes in specimen geometry and because of the high strain rates accompanying small stress increases. The strength reported for these tests is the stress difference when the test is terminated. The strength envelope is nonlinear and is fitted to an exponential Mises-Schleicher criterion.

The creep data are used to determine parameter values in the exponential-time creep law. This law is based on first-order kinetics and models both transient and steady-state creep.

MENZEL *Results of Geomechanical Studies on the Installation of Storage Caverns in Salt Formations*

Wolfgang Menzel and Wolfgang Schreiner, Institut für Bergbausicherheit, Leipzig, East Germany

The Institute of Safety in Mines in Leipzig (GDR) has been working for more than ten years in the field of geomechanical research for the installation of cavern stores in leaching formations. Based on the example of the cavern store established in Bernburg, GDR, the paper presents the results of theoretical calculations, petrophysical laboratory tests and *in situ* measurements.

From the results of study, there are derived statements on cavern stability safe operating conditions under the aspect of rock mechanics, as well as on cavity convergence in the time and cover rock movements resulting from it.

MILLER *When is a Barrel Not a Barrel?*

Marvin M. Miller, Miller and Associates, Consulting Engineers, Inc.

As the solution mining and hydrocarbon underground storage industry grows into technical maturity, increasing awareness is developing about the necessity of accurate and reliable procedures to determine brined-salt quantities, resulting cavern volumes and the quantity and quality of stored hydrocarbons. Increasing operating costs, lowered overall company profit margins, and the recent ten-fold increase in stored product values now make it even more essential for operating companies to have dependable and current volumetric information about their facilities.

This paper reviews the limitation of some of industry's traditional measurement methods and discusses how they are now being modified to obtain improved results. The applications of "new" techniques and equipment that have been developed in related industries is discussed and evaluated.

MUNSON *Application of Mechanism Maps to Response of Storage Caverns in Salt*

Darrell E. Munson, Experimental Programs Division, Sandia National Laboratories, Albuquerque, New Mexico, USA

A growing number of solution mined caverns in salt formations are being developed for storage of gases and liquids. Concerns for safety, cavern tightness and site availability have caused the depth at which the caverns are located to increase. With the increased depth and, hence, the increased stresses, loss of cavern volume through time-dependent deformation of the salt has become much more pronounced. In some cases the volume loss is a significant problem because of decreased cavern operating life expectancy and diminished capacity.

It is essential in deep caverns that all factors controlling cavern behavior be understood so that optimal design and operating procedures can be developed. To aid in the optimization, detailed simulations of the thermomechanical response are possible through the use of finite element methods. The accuracy of these calculations are, however, dependent upon the adequacy of the constitutive model that describes the material response to stress and temperature. For salt, which is a relatively simple material but which creeps under low stresses, recent mechanistic analyses of the creep response have given considerable insight into its constitutive behavior.

In this paper, we examine the micromechanical deformation processes that govern deformation of salt and develop a deformation-mechanism map. The overburden stress, operating pressure and temperature conditions relevant to a particular storage cavern are placed on the mechanism map to show those deformation processes expected in caverns. On the basis of these expected processes, a constitutive model is developed for use in design and operation calculations. The implications of different deformation processes on observed response of existing caverns are discussed. These processes may be the key in selection of proper operating conditions for the intended life of a storage cavern.

MYERSON *The Formation of Solvent Inclusions During the Growth of Sodium Chloride from Aqueous Solutions*

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Solvent inclusions are pockets of solvent trapped as a second phase inside a growing crystal. The mechanism by which solvent occlusions are formed will be discussed along with results of a computer simulation of the process. Experimental results will be presented, illustrating the effects of crystal size, impurity content, agitation rate and crystal grown from aqueous solutions. Experimental studies will include studies of single crystal growth and studies of crystal growth in a mixed suspension, mixed product removal crystallizer.

NELSON *Ventilation Design for an Underground Salt Mine*

D.A. Nelson, V.B. Cook Company, Thunder Bay, Ontario, and R.E. Wedding, Thunder Bay, Ontario, Canada

A planned production increase of 1.25 million tonnes per year at Domtar's salt mine in Goderich, Ontario required an increase in the underground mine ventilation system from 320,000 scfm to 700,000 scfm. The design of the expanded facility included the addition of a 22-foot diameter shaft to augment the existing production and service shafts.

A preliminary review of the ventilation requirements indicated that in order to provide good economic design for the expanded system, a comprehensive ventilation survey of the existing system was required. The survey was completed in the latter part of 1980, and subsequent engineering design and equipment selection proceeded throughout 1981.

This paper presents the methods used to carry out the survey. Particular attention is given to the numerous challenges presented in determining air flows in the large 45-foot-wide by 43-foot-high airways. Emphasis is placed on practical field survey techniques.

A mathematical model of the ventilation system using a computer program is described, and the application of this program to provide design data and assist in equipment selection is discussed. Economic sizing of airways and fan selection are analysed considering horsepower and operating costs.

NEWMAN *Overcutting at Roof Level, Winsford Rock Salt Mine*

James H. Newman and Dennis H. Scotney, Mond Division, Salt/Lime Group, Imperial Chemical Industries PLC, Cheshire, England

The rock salt strata at the Winsford Mine of Imperial Chemical Industries (ICI) is of a typical bedded structure with a shallow dip between major geological folds. Mining takes place at about 180 meters below surface and is of a conventional room and pillar type. Rooms are up to 20 meters wide and 7.6 meters high with pillars 24 meters square. Rooms are undercut, drilled and blasted, pulling about 4.5 meters per round.

Roof scaling after blasting to achieve the required standard of safety is labour intensive, itself dangerous and has to be repeated several times. However, in an old section mined in the 1930s, a roof that had been precut still stands today, apparently as sound as the day it was formed.

R.L. Priestley in conjunction with ICI, Goodman & Fletcher Sutcliffe Wild have developed a mobile gantry to support a modified Goodman 2500 universal cutter equipped with a 4.88-meters long (16 ft.) jib which can precut at roof level from the floor, some 7.6 meters below. No subsequent roof scaling or treatment is required.

Operation of the prototype machine since June 1981 has been remarkably trouble free and the paper elaborates on the overcutting technique with details of the machine.

NIETTO *Mechanism of Sinkhole Formation Over Brine Workings, Windsor-Detroit Area*

A. Nietto, D. Russell and D. Stump, Geology Department, University of Illinois, Urbana, Illinois, USA

Solution mining in the Windsor-Detroit area since the turn of the century resulted in the unexpected development, unexpected because of the depth (at least 1200 ft) of the producing salt horizon of three large sinkholes between 1954 and 1971. A stoping mechanism, invoked as the probable cause, has been found inadequate because the bulking that develops in the failing overburden prevents the upward migration of the solution-induced voids over any significant vertical distances.

The present study indicates that unique mechanical properties of a relatively shallow (approximately 300 ft) Devonian sandstone (Sylvania) are responsible for the vertical propagation of the solution-induced voids. This sandstone is virtually without cement and derives its apparent cohesion from a pressure-solution-affected fabric. More importantly, upon failure, under unconfined conditions, a large volume of the sandstone is reduced to running sand.

The specific mechanism of vertical void migration involves 1) the failure of the Sylvania sandstone by high horizontal stresses which are a combination of *in situ* stresses and stresses induced by sag-type subsidence; 2) the downward movement of the running sand through fractured units underlying the Sylvania toward the deeper solution caverns; and

continued

3) the development of a shallow cavity in the Sylvania and its collapse to the surface.

Reported in this paper are the evaluation of brine field data, results of strength testing programs and petrographic studies of the Sylvania, evaluation of *in situ* stresses in the general region and results of stability analyses of Sylvania beds using Linear Arch Theory. It is suggested that this mechanism of sinkhole development may operate in other regions where sinkholes develop unexpectedly in response to deep solution mining.

OWENS *A New Theory for the Deposition of Potassium Salts*

L.J. Owens, Carlsbad, New Mexico, USA

This new theory describes a process in nature which explains potash deposition. The basis of the process is the roles of different energy factors such as heat of solution and heat of formation differences between sodium chloride and potassium chloride in the 20°C temperature range, ion migration, ion replacement, ion blinding and the law of least resistance, as systems change to attain equilibrium.

The consequences of the theory are that the previous discrepancies between what is observed in the laboratory and what is observed in ore deposits are no longer contradictory. In effect, the process described is nature's method of maintaining the chemical composition of seawater.

The correlation between reported characteristics of potassium ore bodies and what is expected from the theory explains several common characteristics such as clay beds, sulfates and chlorides, blue halite and alterations of several minerals, plus many more aspects.

This theory leads to the speculation that in non-equilibrium states, the path of least resistance may not always result in a state of increased entropy and, in fact, sodium and potassium at 20°C can produce a state of decreased entropy and in nature do so.

The value of the theory is that an insight to several aspects of nature can be gained. Also, the theory can offer a test of the mechanisms in nature which, if substantiated, will provide a much more intense knowledge of nature.

PASSARIS *Experimental Results from Triaxial Creep Tests in Rock Salt Related to the Storage Operations of Salt Caverns*

Evan Passaris, University of Newcastle upon Tyne, Newcastle upon Tyne, England

The results from triaxial compressive creep tests on Danish rock salt from Hvornum are presented as part of a larger experimental programme aimed at defining the mechanical characteristics of rock salt to storage salt caverns.

The scope of the laboratory experimental work was to define the rheological characteristics of rock salt when subjected to complex stress histories similar to those predicted for underground storage caverns.

All tests were conducted on salt specimens with 75mm diameter, a width-to-height ratio of 1:2 and a depth of origin ranging between 860m and 870m.

The ambient temperature during tests was 20°C, the relative humidity was 30% and the duration of tests was approximately 40 days for the time-variable stress tests and 120 days for the constant stress tests.

Two levels of confining pressure were employed during the experimental programme, namely 8.5 MPa and 17.5 MPa, while the axial stress varied according to the type of test.

Results have been interpreted employing a number of established creep constitutive models and these are critically appraised in the light of the experimental response of rock salt.

PATEL *Factors for Optimum Brine Treatment Process Design*

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Brine treatment generally consists of reduction of calcium, magnesium and sulfate impurities from brine. There are significant factors in brine treatment design. Lack of consideration of these factors during design can result in high capital cost, chemical treatment and maintenance costs and sometimes results in poor brine quality.

The equipment design discussed includes brine saturator, soda ash and caustic reaction tanks, sludge settler, brine filter and lime treatment tanks. Various examples are cited.

The factors to be considered in the brine saturator design are salt charging rate, undissolved solid removal, sand carryover, potential for magnesium spiking, salt caking and sparger design.

The calcium impurity in the brine is precipitated as calcium carbonate and magnesium as magnesium hydroxide in the reactors. Five major factors involved in reactor design are retention time, brine temperature, agitation, excess reaction chemicals and supersaturation of precipitates.

The sludge settler design is based upon the precipitates settling rate and quantity. The temperature inversion and slugging of the flow should be avoided. Improvement in settling rates can be obtained by using coagulants.

continued

The factors for the filter design should consider settler upsets and overloading of the filter. A test procedure is discussed. The operating cost due to body feed, precoat vs. increased settler capital costs for improved settling should be evaluated.

Sulfate in the recirculating brine system is controlled by either lime, phosphate, barium chloride or barium carbonate. A proper dosage and sizing of equipment is necessary to avoid scaling of lines and piping.

Lime is also used for raising calcium-to-magnesium ratio, which improves magnesium hydroxide precipitate settling. The optimum calcium magnesium ratio is discussed.

PATRICIU *Tazlau, the First Deposit of Potassium Salts from Romania*

Valeriu Patriciu, Geological Institute, Bucharest, Romania

Hundreds of millions of tons of potassium salts have been discovered as a result of geological prospecting during the last thirty years in the Transylvanian region of Romania. Evaluation of these deposits is not yet complete. Detailed stratigraphic work in the area from Transylvania to the East Carpathians has defined a Lower Miocene lagoonal but very complex evaporite sequence. In a thickness of 20 meters, 420 individual layers have been identified, and 244 of them contain potassium salts. The evaporite sequence is known to be continuous into the Pre-Carpathian depression in Moldavia, and exploration for potash should be extended into that region.

Important salt deposits have been worked in the Carpatho-Danubian region for thousands of years, and even the Paleolithic inhabitants of the region used them. When the Romanian people first inhabited Dacia, they too extracted salt, which is removed today at the rate of millions of tons per year. The potash deposits of Tazlau are, however, not yet worked but represent a significant resource.

PAVLOVIC *Recovery of Potassium Chloride, Potassium Sulfate and Boric Acid from the Salar de Atacama Brines*

Pedro Pavlovic, Luis Vergara-Edwards and Nancy Parada, Comité de Sales Mixtas—CORFO, Santiago, Chile

A great deal of technical data from the laboratory and test ponds have been gathered to allow fairly accurate plant designs to be made for the production of KCl, K_2SO_4 and H_3BO_3 from the brines of the Salar de Atacama, large dry lake located in the Atacama desert of Northern Chile.

The evaporation data collected indicate that very high rates are obtainable on the Salar, 10 $l/m^2/day$ as an annual average for water in metal pans, making possible the concentration of the brines by solar evaporation.

The brines from the Salar are pumped into a series of solar evaporation ponds, where a series of salts are precipitated. The crystallization sequence is halite, silvinite and sulfate salts (shoenite, kainite). The salts are harvested and then treated in chemical plants, except

halite, which is discarded to produce KCl and K_2SO_4. The final brine from the last solar evaporation stage is acidified in a crystallizer to precipitate the boric acid.

A detailed description of the processes involved and the economic estimates will be presented here.

PERINELLI *General Criteria for Quality Control of Food Grade Salt*

Maria Allesandra Perinelli, Monopoli di Stato-Italy, Rome, Italy

Due to the diffusion of national and international standardization for food grade salt, it is urgent that suitable plans be developed for quality control during manufacturing and before introducing salt into the market.

Difference in scope is pointed out if quality control is performed by public authorities on products sold on the market, or if monitoring is carried out by the producer at his own factory.

Having considered the difference both in the source and in the production process, the main critical points of manufacturing that can affect specific quality requirements are identified.

Feasibility of reliable plans for inspecting the compliance of produced salt with food grade standards is discussed on the basis of the results of a survey carried out in the last years. Plans concerning the control of both trade requirements and hazards of contamination are examined.

PERNETTE *In Situ Studies of the Mechanical Comportment of Solution Mined Cavities*

Eric Pernette, Bruno Hugout, Gaz de France, and Michel Dussaud, Sofregaz, Paris, France

A good management of huge gas pipe networks requires large gas storages. Nowadays, the two main techniques are solution mined cavities and underground storages in aquifers. The cavities, operated by gas expansion, have to withstand large variations of pressure. They must be studied in detail to be able to resist such mechanical strengths.

Computations, based on the principles of rock mechanics, allow the comportment of such underground works to be forecast, provided the characteristics of salt and other materials in salt layers are well known. Laboratory tests on core samples are of great use in defining the different kinds of rheological rock comportment and the input parameter range for computations. We know, however, that the transposition of laboratory tests to the computation of large underground structures is difficult, for the difference in scale induces an appreciable drift.

So, GDF has worked out its own method of *in situ* tests during the carrying out of solution mined cavities. Their purpose was to obtain a better understanding of the mechanical phenomena present in the operating conditions and a better forecasting for the

long-run comportment of the cavities. General knowledge of mechanical comportment has been obtained from the *in situ* tests for each GDF site (Tersanne, Drôme and Etrez, Ain. Charts have been worked out to enable the operating staff to forecast the effects of the different operating strategies.

PERNETTE — *Underground Storages at Tersanne and Etrez: Prediction and Simulation of Cavity Leaching in a Salt Layer Charged with Insoluable Materials*

Eric Pernette, Gaz de France, and Michel Dussard, Sofregaz, Paris, France

Since 1969, Gaz de France has been developing in Southeast France two underground storages of natural gas in solution mined cavities. The Tersanne site, which is 90 km south of Lyon, will have by 1984 fourteen cavities, 200,000 m^3 large and 1,450 m deep each: the whole volume will be 475 million m^3 (n) of gas. The Etrez site, which is 85 km north of Lyon, will allow between 1979 and 1998 the realization of twenty eight cavities, 200,000 m^3 large and 1,350 m or 850 m deep each: the whole volume will be about one million m^3(n) of gas.

For reasons of mechanical stability, the direct leaching method is used to create pear-shaped cavities. The composition of the salt layers led us to set up numerical programs able to simulate the leaching of salt layers charged with insoluble materials: the average content is 8 per cent in Tersanne and 15 per cent in Etrez. The deposit of insoluble materials freed by the leaching induces a rise of the bottom of the cavities which it is important to control, at the risk of losing a non-negligable height of the salt layer. This is especially true during the first step of the leaching where layers containing up to 50 per cent of insoluble materials risk creating superposed cavities. We have to take this into consideration in order to follow the leaching and the sedimentation at the bottom of the cavities.

PIERRE — *Polyhalite Replacement After Gypsum at Ojo de Liebre Lagoon (Baja California, Mexico): An Early Diagenesis by Mixing of Marine Brines and Continental Waters*

Catherine Pierre, Laboratoire d'Hydrologie et de Geochemie Isotopique, University of Paris-South, Orsay-Cedex, France

The presence of polyhalite in the supratidal evaporite flats around the Ojo de Liebre lagoon was first discovered by Holser (1966), who attributed its origin to the diagenesis of gypsum by interstitial marine brines. A large part of this area is now occupied by artifical salt ponds. However, some remnants of the ancient evaporite flats are still accessible, for example, on the southeast coast of the evaporitic complex, where sedimentological, chemical and isotopic investigations were performed on evaporitic sediments and interstitial solutions. In May 1979, the evaporitic succession was mainly composed of gypsum: a few centimeters below the surface, polyhalite was present in the

form of small nodules that were partially replacing former gypsum crystals. In May 1980, this evaporitic succession was drastically modified, since gypsum sediments lying below the water table were totally replaced by polyhalite. We have thus an exact timing for the mineral transformation, which clearly points to some chemical evolution of the solutions permeating the sediments.

During this one-year period, ionic concentrations of intersitial brines have increased from × 13 to × 18 with respect to sea water concentrations. Besides, chemical data indicate that SO_4^{2-} concentrations of interstitial solutions are higher than in normal marine brines and progressively increase in a landward direction, thus suggesting gypsum dissolution by groundwaters. That both water and aqueous sulphate of the solutions in this basin have a mixed marine and continental origin is also supported by isotopic analysis (^{18}O and ^{2}H of water, ^{18}O and ^{34}S of SO_4^{2-}). Thus, it appears that sulphate ions are provided for one part by marine brines, and for the other part by continental waters which have dissolved Pleistocene gypsum present at depth. The replacement of gypsum by polyhalite requires not only high Mg^{2+} and K^+, but also high SO_4^{2-} concentrations in the solutions (Braitsch, 1971).

These results illustrate a peculiar case where the gypsum diagenesis into polyhalite is promoted by the mixing of concentrated marine brines and sulfate ion-bearing continental waters.

PIPER — ***Subsidence Resulting from Solution Mining: Techniques for Detection of Subsidence and Research Into the Mechanics of Cratering***

Thomas B. Piper, Manager, BASF Wyandotte Corp., Wyandotte, Michigan, USA

Solution Mining and Subsidence. Removal of salt by dissolving alters the stress state in the remaining salt and in the overlying rocks. These materials respond by deflecting within narrow tensile limits or breaking and falling into the cavity, a mechanism referred to as stoping. Deflections translated to the earth's surface are expressed as downwarping subsidence, usually basin-shaped. Stoping results in formation of a crater when sequential breaking of rock layers encounters unconsolidated surface materials or daylight.

Detection Methods. Basins of downwarping subsidence can be detected by precise leveling of monuments to measure the vertical components of displacement and by measurement of elongation of slope distance and triangulation methods to measure horizontal displacement, particularly in periphery or hinge areas. Non-access methods are available but cost limiting. Precise leveling is most cost effective for general use.

Subsidence Research. The Solution Mining Research Institute (SMRI) is a not-for-profit technical association of companies interested in solution mining. The Institute has sponsored site review studies of areas where cratering has taken place and into theoretical concepts of subsidence based on rock mechanics technology. Currently underway are projects at Hutchinson, Kansas, in which SMRI and the U.S. Bureau of Mines are cooperating on test drilling and acoustic monitoring in the area of recent craters, and a project at the University of Illinois, which provides for investigation into granular layer. Also, a manual is being prepared on surveying methods for subsidence detection and data presentation. An appendix lists SMRI projects and reports.

POBORSKI *Geological Prediction of the Mining Feasibility Within the Salt Domes of Upper Permian Zechstein, Central Poland*

Józef Poborski and K. Ślizowski, Academy of Mining and Metallurgy, Krakow, Poland

The authors have presented the results of their geological investigations and mining experiences in Zechstein domes in central Poland. As it appears, the domes inner structure is extremely complex and entangled. However, the authors were able to establish certain regularities in that respect, taking into account the stratigraphic column petrophysical bipartition and their tectogenetic pattern. So, the mineable salt deposits mostly occur in the form of secondary diapiric anticlines forcing their way up to the gypsum cap. The larger area of the salt mirror occupied by the anticlines, the more favourable are the mining conditions. In consequence of the fact, comparative halotectonic and morphologic studies of the salt domes group were carried out. Certain functional interdependences have been discovered and graphically presented. On the basis of the diagram it is possible to predict more or less favourable conditions of mining exploitation as well as of localization and establishing of underground storage in the salt domes.

POULSEN *Production of Bischofite from Waste Effluent by Solar Evaporation*

Eldon R. Poulsen and D.C. Haag, Titanium Metals Corporation of America (TIMET), Henderson, Nevada, USA

Titanium Metals Corporation of America uses a leaching process in the production of titanium metal sponge. The spent leaching effluent contains magnesium chloride in solution. A process has been developed to use solar evaporation ponds to produce bischofite, $MgCl_2 \cdot 6H_2O$, from this effluent.

Uses for the products from the solar evaporation ponds are being developed. The first successful product marketed was the concentrated brine itself, for use as a dust control agent on dirt roads. Other possible applications include the use of the brine in solar ponds for thermal energy or electrical energy production, using the bischofite as a feed material in the manufacture of periclase and hydrochloric acid, or using the magnesium chloride to make oxychloride cements.

Information on pond construction, lining material, pond chemistry and temperature cycles will be included.

PREECE *Finite Element Analysis of Salt Caverns Employed in the Strategic Petroleum Reserve**

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A finite element computer program has been developed to accurately predict the creep response of rock salt. This program successfully predicted the creep response of several existing caverns using an approximation of the cavern geometry and material properties from the site.

The existing and future caverns at Bryan Mound, Texas have been analyzed by performing thermal calculations and using the resultng temperature field in a structural creep analysis. Element removal was used to simulate the leaching that occurs when oil is withdrawn and replaced with fresh water.

Each cavern was analyzed for thirty years and an indication of the long-term stability and volume change was obtained. This information was used to formulate operating procedures for the cavern.

* *This work was performed at Sandia National Laboratories and was supported by the U.S. Department of Energy under contract number DE-AC04-76DP00789.*

QIAN *Borate Minerals in Salt Lake Deposits at Chaidamu Basin, China*

Qian Ziqiang, Institute of Geology, Ministry of Chemical Industry, Zhuozian County, Heibei, China

There are many inland rich boron salt lakes in the north margin of Chaidamu Basin, such as Dachaidan, Xiaochaidan and Mahai Lakes, which formed in later Pleistocene. The main sources of boron materials are from the hot springs and mud volcanoes. Surface brines and intercrystalline brines in the salt lakes are $MgSO_4$-subtype. B_2O_3 content averages about 2000 mg/l, up to 5200 mg/l maximum. Borate ore bodies of the lake bottom and the lake shore occur in different deposited layers of salts. The main borate minerals are pinnoite and ulexite, the others are hydroboracite, Kurnakovite, inderite, carbobrite, macallisterite, hungchaoite and minor borax, which occur in the lake shore only. Borate minerals are associated with different salts such as calcite, aragonite, gypsum, halite, mirabilite, thenardite, glauberite, hydroglauberite, bloedite, epsomite, schoenite and uklonskovite.

According to the studies of morphology and occurrence of the borate ore bodies and paragenesis relationship of minerals, it was found that borate minerals of salt lake are not common evaporitic minerals. The results of observation and experiment show that rich boron brines during the desalination are often associated with the precipitation of borate

minerals. The precipitation of natural borate was under the influence of hydration to a greater degree, except it closely related to the concentration and ph of solutions. These studies have the significance to recognize the genesis of the borate minerals in the ancient salt deposits.

QUAST *Disposal of MAW and LAW in Leached Caverns*

Peter Quast and M.W. Schmidt, Kavernen Bau- und Betriebs-GMBH, Hannover, West Germany

Deposition in deep underground geological formations is regarded as a suitable and safe procedure for the disposal of radioactive waste. Of the numerous variants, disposal in suitable rock salt formations offers a number of special advantages.

As an alternative to previously successful repository technology variants for the disposal of medium- and low-level radioactive waste, investigations have been made of methods that permit the injection of waste into cavern type storage facilities without the use of canisters. Here the waste hardens into a quasi-monolithic block. The monolith that results by *in situ* hardening should have mechanical properties similar to those of the surrounding rock formation.

This paper provides a detailed description of a method for filling solution mined caverns with MAW and LAW in pellet form in a cement slurry mix. The establishment of such caverns from the viewpoints of size, configuration and location within the salt, together with their spacing, is discussed. Furthermore, the brine withdrawal, as well as the filling process via boreholes from the surface, is described, as well as the layout of the boreholes, their casing and cementation.

The possibility of filling such caverns was demonstrated on a reduced scale in a salt mine. Five solution mined and emptied caverns were filled with a mixture of cement slurry and simulated waste pellets after they were measured and instrumented. Details are given on the homogeneity of the mixture after setting as well as the non-steady state temperature field in and around the test caverns.

Finally, a general view of a bulk storage facility of this type, suitable for several hundred thousand cubic meters capacity, is given along with the necessary time requirement for its establishment and the associated costs.

RANDS *Solubility of Gypsum in Saturated Brines*

David G. Rands, Department of Chemistry, Southern Illinois University at Edwardsville, Edwardsville, Illinois, USA

It is well established that the presence of magnesium in brines enhances the solubility of gypsum through the phenomenon of ion-pairing. We will present calculations and experimental data that will show the effect of blending various amounts of bitterns with saturated brines being charged to crystallizers in solar evaporation plants. By enhancing gypsum solubility, increased magnesium levels in the brines would reduce gypsum levels in salt produced in the crystallizers.

RAPSON *Recovery of Salt from Pulp Mills*

Douglas W. Reeve, Department of Chemical Engineering, University of Toronto; Douglas C. Pryke, Douglas Reeve & Associates, Toronto; W.H. Rapson, Department of Chemical Engineering, University of Toronto, Toronto, Ontario, Canada; and Jerome A. Lukes, Lukes Process Development Corp., Ogden, Utah, USA

In the last fifteen years a radical concept called the effluent-free bleached kraft pulp mill has been under development. The process eliminates all contaminated aqueous discharge from bleached kraft pulp mills by internal recycling. Organic materials dissolved from the pulp are thereby retained in the mill for concentration and combustion. Spent bleaching chemical, sodium chloride, must be deliberately removed from the pulping chemical recovery cycle.

Early research work led to the discovery of a large number of feasible processes for recovering sodium chloride from the kraft sodium-sulphide-sodium-carbonate smelt green liquor and also from the kraft sodium-sulphide-sodium-hydroxide white liquor (regenerated pulping liquor).

The most technically and economically attractive process was found to be evaporation of white liquor to crystallize sodium chloride. This process was the subject of extensive laboratory and pilot plant research and was installed in a full-scale kraft pulp mill in Thunder Bay, Ontario in 1976.

White liquor is evaporated to twice its normal strong alkali concentration resulting in crystallization of sodium carbonate and sodium sulphate. Clarified liquor from this step is further concentrated and cooled to crystallize sodium chloride. This sodium chloride is purified by leaching and countercurrent washing.

The salt recovery plant has had process and equipment modifications to decrease unexpected heat transfer surface fouling, to accommodate wide variations in crystal size and to increase its efficiency. Plant availability is now over 90%. The plant processes 500 U.S. gallons per minute of white liquor associated with 800 air dry tons of bleached pulp per day and removes 25 tons of salt per day.

The salt is 99% pure and is used in the on-site chlorine dioxide plant for regeneration of bleaching chemicals.

ROCHA *New Aspects of Harvesting in Small Saltworks*

M. Rocha and F. Almeida, Direcção-Geral das Pescas, Lisbon, Portugal

In several regions, due to local ecological conditions, salt is traditionally obtained in very small scattered saltworks, with which it is often impossible to form bigger units. The methods utilized in past centuries are now obviously impractical and uncompetitive.

So, this type of salt pond either stops work or must undergo suitable transformations to be adapted to advanced mechanical systems of harvesting, based on the introduction of light machinery according to their sizes. The dragging methods have proved to be consistent with certain types of saltworks where they have been more and more employed.

In this paper, some details of the harvesting phases are individually analysed, according to the latest improvements and technical developments. Some characteristics and horary outputs of the equipment are given. Special attention is paid to the system involving:

- Dragging set activated by a winch coupled to an agricultural tractor
- Salt loading by means of a retroescavator
- Transportation by trailers pulled by agricultural tractors.

A small washing machine and simple piling devices are also mentioned: The dragging methods offer the further advantage of being easily adapted to use in excessively clayish ponds, where heavy machinery has difficulty operating without previous expensive compactions and other soil treatments.

All the processes are specially recommended for saltworks with a maximum annual output of about 10.000 tons. Actually, the expansion of these methods may add new possibilities and become more opportune, owing to the increasing costs of energy, particularly for developing countries.

ROKAHR *Creep Rupture Criteria for Rock Salt*

R.B. Rokahr, University of Hannover, Hannover, West Germany

Whereas extensive research work into the determination of rock salt deformation behaviour under long-term stress is undertaken and published, there are only a few laboratory and theoretical investigations that deal with the problem of creep rupture behaviour.

This paper presents the results of creep tests on rock salt under triaxial extension stress conditions, which reached tertiary creep and caused creep rupture within the test period. Hollow cylinders were also used as samples to enable stress relaxation in the sample itself.

The results clearly show that the failure strains obtained depend on the creep rate, which in turn is determined essentially by the deviatoric and isotropic stress state and the temperature. Here failure strains of over 25 per cent are achieved. The results are then finally evaluated with a view to the formulation of a creep rupture criterion, which is used to undertake the design of rock salt caverns, bearing in mind the long-term behaviour.

ROULSTON *Stratigraphic Comparison of the Mississippian Potash Deposits in New Brunswick, Canada*

Brian Roulston, Potash Company of America, and David C. E. Waugh, Denison Mines Ltd., Sussex, New Brunswick, Canada

Two structurally distinct but stratigraphically similar salt deposits in southeastern New Brunswick have undergone extensive surface exploration, followed by detailed underground study, since potash was first discovered in the Sussex area in 1971.

These Mississippian age (Windsor group) deposits are located 25 kilometers apart at the southwestern end of the Moncton sub-basin, part of the Fundy epieugeosyncline. A detailed comparison is made of the lithology, mineralogy (including bromine, borates, clays) and geophysical characteristics of the deposits. Also, utilizing type sections from each area, formations are described and informally subdivided.

Correlation of stratigraphic changes in the two evaporite sequences – the result of salinity fluctuations and influx of terrigenous material – indicates contemporaneous deposition. Differences may be explained as the result of paleogeographic location and variations in sub-basin topography.

RUDE *Environmentally Safe Salt — "Damp" Salt (Moisturized)*

Bruno J. Rude, Strassenverwaltung Rheinland-Pfalz, Koblenz, West Germany

Damp salt usage is a modern, environmentally safe and economic technology to fight ice—more complete, safer and longer lasting.

In Germany this method to moisturize NaCl with a $CaCl_2$ solution on the screen dish, and bringing it out during the insertion, has been tested since 1972 and is now being used in many areas. The writer is responsible for carrying out the winter service in Rheinland-Pfalz and has led a working group that has supervised the testing for the research society of the Road & Traffic Department. Following the research phase, during which the necessary spreading equipment was also developed, the State Traffic Department in Bonn has now recommended this procedure for general usage.

Even though the State Traffic Department had beforehand a saving of salt in mind, a noticeable saving of NaCl was not achieved, because now the salt is also weather conforming (prophylactic), that is, it can now be brought out before the forming of ice and because travellers more and more, even in outlying areas, ask for ice control with this new technology. Additionally, "damp salt" (moistured), can also be used when, during lower temperatures, regular NaCl is not as readily effective.

The following will be stated during the lecture:

- The reason for developing such a method
- The testing and the results explained
- The "damp salt" (moisturized) itself, its effectiveness and chemical analysis defined
- The manufacture of the solution explained

continued

- "Damp salt" spreading equipment and their mechanics introduced
- The usage area outlined
- The advantages for traffic, roads and environment explained.

The lecture itself will be illustrated by about 15 slides: it will include literature references and sketches and will be somewhat more detailed in writing.

RUSSO *Solution Mining Calculations for SPR Caverns**

A.J. Russo, Sandia National Laboratories, Albuquerque, New Mexico, USA

Several codes have been used in the development of solution mining schedules for the design of SPR caverns. One of these codes, SANSMIC, which predicts cavern shape and volume as a function of prescribed flow parameters, was developed to facilitate the calculation of shape changes while leaching is proceeding at the same time the cavern is being filled with oil (leach-fill) and when oil is being withdrawn by fresh water displacement.

The theory and overall numerical procedures used in SANSMIC are described. Implicit, finite difference methods are used to solve an axisymmetric mass conservation problem. Calculated results which exercise each of the code options are given, and comparisons with other calculations and data from SPR caverns currently being leached are provided.

This work performed at Sandia National Laboratories supported by the U.S. Department of Energy under contract DE-AC04-76DP00789.

SABERIAN *Utilization of Leaching Models in the Design of Large Crude Oil Storage Cavities*

Ahmad Saberian, A. Saberian & Associates, Austin, Texas, USA

LPG and other petroleum products have been stored in salt cavities in the U.S.A. since the 1950's. Underground storage of oil, however, was not widespread before the Strategic Petroleum Reserve Act of 1975. The first industrial underground storage of crude oil, Louisiana Offshore Oil Port storage facilities, did not proceed with the offshore and onshore construction before 1977.

A typical storage cavity has a volume of one million barrels. Considering the design capacities for the SPR Project (750 MMB) and LOOP Project (32 MMB), 1-MMB cavities were determined to be impractical. Each SPR cavity under development will have an initial 10-MMB storage capacity. LOOP's cavities are 4-MMB cavities. Development of the large cavities with the conventional circulation rates and leaching strings would have been a very lengthy process. LOOP has chosen large wells (30-inch final cemented casing) and high

circulation rates. SPR cavities are designed as single and multiple well cavities.

Some of these new designs have required a great deal of modification. With drilling and well completion costs at 50 per cent of cavity construction cost, the design modifications for cavities with completed wells had to be somewhat constrained. Numerical simulations were used to verify the designed leaching procedures and for providing appropriate modifications. Simulation is also being used during the course of cavity development, using the actual daily production data.

SAMMY *Biological Systems in Northwestern Australian Salt Fields*

Nathan Sammy, Dampier Salt Pty. Ltd., Perth, Western Australia

The principles of salt field biological management as developed by J.S. Davis have been modified and applied to some Northwestern Australian solar salt fields. A monitoring programme designed for planktonic organisms and physico-chemical parameters has been implemented for the Dampier Solar Salt Field at weekly intervals for nine years. This intensive monitoring together with laboratory investigations on selected halophilic and halotolerant organisms have revealed factors controlling biological proliferation in a continuous flow salt field.

Results from investigations on brine organisms in the Dampier salt field are widely applicable to Northwestern Australian salt fields. The practical aspects for effective biological management are noted and management measures duly described.

A computer model is being developed for the Dampier salt field biological systems as a tool in the management programme.

SCHNEIDER *New Method of Large Hole Drilling in West German Salt Mines*

Hans Schneider, Kali und Salz AG, Werk Niedersachsen-Riedel, Wathlingen, West Germany

In West Germany 40 million tons of crude salt is produced annually. Eleven million tons are hauled from 5 mines of the Kali und Salz Company operating in steep formation on salt diapirs. In mines operating in steep formation the mining process quickly advances into deep levels as a result of geological folding in salt diapirs. The deepest level, e.g. of the Niedersachsen-Riedel salt mine, is already at 1,320 m. High rock temperatures of more than 50°C cause, among other things, climatic problems. Necessary improvements can only be achieved by large quantities of ventilation. Necessary demand: quick and economic manufacture of shafts with large diameters, smooth wall and maximum lengths.

For many years, bore holes have been manufactured by the core drilling method. Maximum 200-meter bore length and diameters of 1 to 2.5 meters can be drilled. Efficiency is satisfactory; however, two different kinds of machines are necessary. Difficulties arise with variation of salt beds. Consequently, the "Raise-Boring Technique" has been adopted very successfully. With this technique, bore holes with up to 5 meters diameter and a maximum

length of 300 meters and with a drill rate of up to 25 m/day in all salt beds can be drilled. All technical demands are fulfilled and, as a consequence, a reduction of the high energy costs for ventilation can be achieved. Apart from the creation of ventilation shafts, an underground bunker system consisting of 10 separated storage bins— each 60 m in height and 5 m in diameter—for the storage of the different rock salt grades has been drilled. With this technique 19 holes with a total length of 2,600 m have so far been drilled.

The paper will illustrate, in conjunction with slides, drilling techniques, efficiency and costs.

SCHREIBER *Permian Evaporite Deposits of the Italian Alps (Dolomites): The Development of Unusual and Significant Factors*

B. Charlotte Schreiber and M.L. Helman, Lamont-Doherty Geological Observatory, Palisades, New York, USA

Evaporitic and evaporite related deposits in the Dolomite Mountains of Italy show a variety of deformational features superimposed upon depositional fabrics. Features typical of sabkha deposits (supratidal) and shallow-water, subaqueous gypsum deposits are found locally. In many areas original features have been diagenetically altered or destroyed by later tectonism. This has resulted in deformational fabrics that are gneissic, augen-like and mylonitic in appearance. These textures often are found in gently dipping, unfolded strata as well as in tightly folded beds.

Recognition of these deformational fabrics underscores one of the difficulties involved in interpretation of ancient evaporite sequences. However, it also adds to the compendium of known and recognizable evaporitic fabrics.

SCHWERDTNER *Evaporite Diapirism in the Sverdrup Basin: New Insights and Unsolved Problems*

W.M. Schwerdtner and K. Osadetz, Department of Geology, University of Toronto, Toronto, Ontario, Canada

Bipartite piercement domes and arcuate diapiric ridges in the central Sverdrup Basin are composed of a lower unit of rock salt and an upper unit of anhydrite with limestone interbeds. As revealed by analogue models of buoyancy-driven diapirs, a thick unit of heavy imporous anhydrite could not have risen actively together with the rock salt. Yet the anhydrite rocks have neither been attenuated nor pierced by the salt. Structural field evidence demonstrates unequivocally that the $CaSO_4$ material (gypsum and or anhydrite crystal mush) behaved as an active low-density medium in early stages of diapirism.

Because of many limestone interbeds, the crystal water liberated by dehydration of buried sedimentary gypsum may have remained in the $CaSO_4$ unit and preserved its low density for an unknown period of time. Gradually, the light $CaSO_4$ material turned into competent heavy anhydrite, which formed a thick hood on the rising plugs and ridges of

rock salt. After intensive shear along the flanks, this hood became a compact mass that was forced through the clastic overburden while breaking up internally.

The anhydrite mass of at least one bipartite dome seems to have been exposed intermittantly in the Upper Cretaceous. Some anhydrite cores of diapirs in the Eureka Sound fold belt behaved like those of the bipartite domes and may have been initiated geostatically. Other large diapirs seem to be related to major thrust faults and may have risen under horizontal tectonic stress.

SHARMA *Prediction of Coupled Flows, Heat and Mass Transfers Within Cavities Located in Salt Domes*

Devraj Sharma, Pierre-Jean Pralong and Robert J. Hopkirk, Dames & Moore, Golden, Colorado, USA

This paper presents the formulation and applications of mathematical models to the prediction of coupled hydrodynamics, heat and mass transfers. The formulation accounts for fluid turbulence, positive and negative buoyancy forces, as well as forced convection effects. The applications include salt-dissolution and fluid behavior in a large underground cavern created by solution mining. Of special importance is the mass transfer at the cavern wall surfaces and its influences upon negative buoyancy forces.

Both plain and axisymmetric geometries are considered in two dimensions and the subsequent uses of predicted results with lumped-parameter models are demonstrated.

The models themselves are based upon numerical solutions to a set of coupled partial differential equations. The solution procedure is of the finite-difference variety and possesses several novelties. The versatility of this modelling approach is emphasized.

SHEARMAN *Possible Textural and Structural Effects of Volume Changes Resulting from Mineral Replacements in Evaporites*

Douglas Shearman, Department of Geology, Royal School of Mines, Imperial College, London, England.

Mineral replacements are a common feature in evaporites and the paper inquires into the extent to which certain textural and structural features of evaporites may be expressions of the volume changes involved in replacements. Two examples are discussed.

1. Some beds of sylvanite are strongly contorted and the roof rocks are also caught up in the disturbance, but the beds above and below are virtually undisturbed. There is evidence which indicates that the sylvite is present as a late replacement of earlier carnallite. That replacement would have involved substantial reduction in the volume of the solid phase with concommitant release of magnesium chloride brine. It is suggested that disturbance of the potash beds and of the roof rocks resulted from the volume reduction and the fluidization of the beds by the brines released during the mineral replacement. *continued*

2. Many beds of anhydrite are nodular and were the products of growth of anhydrite penecontemporaneous with deposition of the host sediment. However, other beds of anhydrite lack any nodular structure and have markedly different crystal fabrics to the nodular varieties. They commonly comprise aggregates of fans and spherulites of anhydrite crystals, and there is some local mechanical breakage at the contact between adjacent fans and spherulites. It is suggested that the spherulitic fabrics were the products of late alteration of gypsum to anhydrite, probably in consequence of increase in rock temperature with depth of burial. A reduction in volume of the solid phase would have accompanied the change and that would have led to compaction of the fans and spherulites in response to overburden load as the water of crystalization of former gypsum escaped. It was that compaction that caused local breakage amongst some of the anhydrite fans and spherulites.

SHEFLIN *Road Salt: Friend or Foe?*

Michael J.E. Sheflin, Regional Municipality of Ottawa-Carleton, Ontario, Canada

The negative environmental aspects of road salt are well known and receive widespread publicity at the start of each winter season.

Municipalities and other road agencies conduct an annual search for a product that will provide the same benefit at about the same cost without negative side effects. Each year the result is the same and the annual supply of road salt is procured.

Beyond sweeping statements such as "our citizens need safe roads" or "chaos will result," there has been little effort to sell the positive monetary and safety returns of wintertime bare streets to the citizens.

What is needed is more research and surveys on the improvement in productivity and safety that arises from wintertime bare pavement along with the selling of existing information, basically the P. Claffey work.

SKROTZKI *Fibre Textures in Extruded Salt*

W. Skrotzki, Institut für Metallphysik, University of Göttingen, Göttingen, West Germany

Extrusion of salt leads to a [100] [111] double fibre texture. The formation of this texture can be qualitatively explained by slip on {110} <110> and {100} <110> generally observed as primary and secondary slip systems in NaCl-type ionic crystals. Connections to the diapirism of salt domes are discussed.

SKUDRZYK *A Method of Evaluating Subsurface Stress Conditions for Solution Mining*

Frank J. Skudrzyk. Mineral Engineering Department. University of Alaska. Fairbanks. Alaska. USA. and N.B. Aughenbaugh. University of Missouri-Rolla. Rolla. Missouri. USA

The magnitude and direction of the geostress field has two effects on the solution mining of salt. It will dictate the directions for fraction connecting wells in gallery development and it can give a preferential solution direction to a cavity.

This paper will present the theoretical analysis for a three-dimensional stress field on an ellipical cavity growth and its analogy to hydraulic fracturing and solution mining. Also. the paper will describe a perforated photoelastic coating method that was developed by the authors to evaluate the geostatic stress field from cores prior to hydraulic fracturing and solution mining. The method gives the direction and relative magnitude of the principal stresses. A project in which the method was applied is presented.

SOBRAL *Portuguese Market of Food Grade Salt*

Ana Maria Sobral and J. Sousa. Direcção-Geral da Adm. das Pescas. Lisbon. Portugal

Some statistical data are presented to show the food grade salt market evolution and to emphasize the purified salt consumption increase relative to crude salt. The sales of crude and purified salt are examined. Then. the raw material required by the purifying plants and their sales. between 1970 and 1980. are focused.

To verify the type of evolution along several years. the real values are compared with the forecasts gathered from a calculated regression straight line. The perspectives up to 1985 are also shown.

The distribution of purified salt food uses during the last years is more closely analysed. Some figures are quoted along those of some European countries. Attention is called upon the problems still existing in this type of evaluation.

Finally. the major limits of human salt intakes are estimated and a model test is proposed to investigate the real ones.

SONNENFELD *Clay Laminations in Halites: Their Cause and Effect*

Peter Sonnenfeld and P.P. Hudec, Geology Department, University of Windsor, Windsor, Ontario, Canada

Dust storms and mud flows generated by sudden cloudbursts are common events in semi-arid lands. Clay particles so mobilized settle in a hypersaline lagoon along the interface between concentrated brine and inflow.

The concentrated brine is a gravitationally stable system of near-horizontal microstratification mainly derived from slowly descending mixing fronts. Laser experiments show the refractive capacity of this microstratification and its ability to facilitate the absorption of solar radiation beneath the brine interface. The microstratification also sustains one or more bacterial plates of photosynthesizers and allows sundry shreds of organic matter to float. These shreds are in the main derived from organisms that have accidentally slipped through the interface between oxygenated surface waters and anaerobic brine.

Any influx of clay spreads out along the interface at the base of inflow as a submarine delta and then sinks slowly into the brine. The clay creates concentric Benard cells of convection that have been duplicated experimentally. They destroy the microstratification temporarily and drag any floating organic matter to the floor of the lagoon.

Once all the clay has reached the floor, the microstratification and a new set of bacterial plates reestablish themselves within the water mass. The clay on the bottom settles initially in card-house fashion, retaining an enormous amount of porosity and permeability. The weight of renewed precipitation of salts compacts these mixtures of clay and organic matter, but they retain a horizontal permeability for some considerable time. This permits later drainage of interstitial brine residues.

Laminations of organic matter with a minor clay base are common in salts. Just as common are anhydrite intercalations that are fractions of a millimeter thick and separate a few millimeters of halite. Every so often this alteration is interrupted by a dolomite break or a more substantial clay intercalation, the evident marks of a more substantial freshening.

Both the anhydrite intercalations and the dark lines of organic matter have been taken as marks of annual cycles of precipitation. However, their halite thicknesses are 1 to 2 orders of magnitude smaller than halite thicknesses estimated from rates of precipitation observed in modern salterns and lagoons. Either most of the salt slush in natural lagoons is annually redissolved, leaving each time a residue of nearly uniform thickness, or the laminations represent periodic events of meteorologic origin that are not necessarily of annual regularity.

SPENCER *The Role of Pore Fluids in Evaporitic Basins*

Ronald J. Spencer, Department of Geology and Geophysics, University of Calgary, Calgary, Alberta, Canada

Two closed basin systems in the western United States (Great Salt Lake, Utah, and Walker Lake, Nevada) are used to emphasize the importance of pore fluids in evaporitic basins. Pore fluids in these systems behave primarily as mass transport media. As a result of diffusive flux, pore fluids may act as major sources or sinks for dissolved constituents and form a bridge between surface brine bodies and subsurface diagenetic environments. In addition, pore fluid composition is much more sensitive to mineral reactions than is the sediment mineralogy; in this respect they provide an important tool in studying modern systems.

Differing hydrologic conditions in the two basins in the past are reflected in the pore fluid profiles at Great Salt Lake and Walker Lake. Deeper portions of each basin are underlain by salts, dissolved constituents (Na^+, SO_4^{2-} at Great Salt Lake; Na^+, K^+, Cl^-, SO_4^{2-}, CO_3^{2-} at Walker Lake) derived from these salts are transported toward the lakes through the pore fluids. In those portions of the lakes not underlain by salts and for dissolved species not present in the salts the pore fluids act as a major sink.

Pore fluids are also useful in pinpointing diagenetic reactions. At Walker Lake precipitation and dissolution of calcium carbonates and the uptake of Mg^{2+} in the sediment are evident from the pore fluids. At Great Salt Lake reactions involving gypsum, mirabilite, halite and magnesium silicates are interpreted using the pore fluids. These reactions are communicated to the lakes by diffusion through the pore fluids.

SUBRAMANIAN *Design and Operation of Solar Saltworks in India*

Pichumani Subramanian, Salt Department, Government of India, Madras, India

The design parameters adopted in India for construction of solar saltworks are described. Due to different climatic and soil conditions, various methods and techniques have been evolved through centuries in the selection, construction, operation and management of solar saltworks of varying capacities. By using ingenious techniques, various grades of solar salts have been produced for use both for alimentary and industrial purposes.

The problems of the operation of solar saltworks in India, efforts made by the salt producers and assistance given by the Government agencies are described. Specifications of various grades of salt adopted by Indian Standard Institution and the move for commercial production of iron-fortified salt for alimentary consumption are analysed.

SUBRAMANIAN *Production and Marketing of Solar Salt in India*

Pichumani Subramanian, Salt Department, Government of India, Madras, India

India produces about nine million tonnes of salt annually by solar evaporation of sea, sub-soil and inland lake brines. The recent technological improvements and innovations in the production techniques of various grades of solar salt are described. The latest developments of the chlor-alkali industry and Government regulations to preserve salt marshes and natural bird sanctuaries along the sea coast have emphasized the need for voluntary adoption of environmental and pollution controls in the salt industry. The case studies of the saltworks in Coromandel and in Saurashtra Coast in India have shown that judicious choice of their location, thoughtful alignment of brine intake points and construction of storage reservoirs have helped to preserve the flora and fauna of salt marshes and balance ecological systems.

The present and the future market demands of different varieties of salt in India and prospective plan for development are analysed. The distribution and marketing of salt in India have unique features, as the production centres are situated away from major consuming communities. The methods evolved for effective distribution and their working are described.

SUGITA *Scale Prevention on Salt Manufacturing Process by Ion-Exchange Membrane Method*

Shizuo Sugita, The Odawara Salt Experiment Station, Japan Tobacco and Salt Public Corporation, Kanagawa, Japan

Prevention of scale is one of the most troublesome problems in the salt manufacturing process by the ion-exchange membrane method in Japan. This study has been carried out on the prevention of such scales as calcium carbonate, calcium sulfate and di-sodium penta calcium sulfate ($Na_2SO_4 \cdot 5CaSO_4 \cdot 3H_2O$) in the process by the addition of sodium hexameta phosphate. The following problems are presented:

- Decomposition of sodium hexameta phosphate in heating the brine
- Effect of sodium hexameta phosphate on the prevention of calcium carbonate
- Effect of various additives on the preventing of calcium sulfate and di-sodium penta calcium sulfate.

A new method for preventing scaling was developed by use of sodium hexameta phosphate and hydrochloric acid. And the method has been successfully applied to the salt manufacturing process since 1975.

T

TAMMEMAGI *Thermomechanical Modeling and Salt Mining*

Hans Y. Tammemagi, Arlo F. Fossum and Paul E. Senseny, RE/SPEC Ltd., Calgary, Alberta, Canada

Significant advances have been made in the rock mechanics of salt over the last five to ten years, primarily through the support of nuclear waste disposal programs in the U.S.A. and other countries. Unfortunately, the practical application of this technology to the salt and potash mining industries has been slow in forthcoming.

This paper will provide a comprehensive review of the state of the art in numerical analysis of salt behavior, as well as a review of laboratory testing of salt and the attendant derivaton of equations describing its mechanical time-dependent behavior. A number of specific examples will be given which are applicable to salt and potash mining, either by underground mining or solution mining techniques. Examples will be given of the calculation of time-dependent room/cavern closure and pillar deformations. Factors that will be incorporated include the effects of various *in situ* stress levels, the effects of sequential mining, the effects of heat and other factors.

The purpose of this paper is to stimulate the broader use of recent advances in salt rock mechanics technology by the salt and potash mining industries.

TANI *The First Salt Plant in the Middle East Using Electrodialysis and Ion Exchange Membranes*

Yoshio Tani, Yasutoshi Kobuchi, Isao Hyuga, Tokuyama Soda Company, Ltd., Yamaguchi Prefecture, Japan

Tokuyama Soda has been undertaking a vital role in the modernized salt manufacturing industry in Japan, that is, supplying ion-exchange membranes called NEOSEPTA and establishing the seawater concentration technology which was granted to two other membrane producers in Japan. Now Tokuyama Soda, which initiated this process, continues to pioneer throughout the world.

Recently Tokuyama Soda signed a consultant contract with a Kuwaiti government company for installation of a salt manufacturing plant that will supply ion-exchange membranes and electrodialyzer based on the Tokuyama Soda salt manufacturing process following its successful export to that country of superior technology for an ion-exchange membrane process chlor-alkali plant. It has been a long-lasting dream to produce industrial salt from seawater and then electrolyze it to produce chlorine and caustic soda in commercial operation by means of ion-exchange membranes. This dream is going to be realized in Kuwait for the first time anywhere in the world.

In connection with this consistant membrane technology, Tokuyama Soda's ion-exchange membrane process is presented in this paper in the light of its experiences and background.

THIERBACH *Borehole Radar Probing in Salt Deposits*

E. Mundry, R. Thierbach, Niedersächsisches Landesamt für Bodenforschung, Hannover, West Germany, and F. Sender, H. Weichert, Prakla-Seismos GMBH, Hannover, West Germany

HF-electromagnetic radar probing has been used for about 10 years in salt mines to investigate exploitable salt structures. Boundaries of such deposits, like anhydrite, basalt, dolomite and clay, as well as brine cavities, can be located by direction and distance. Results are very important for the economy and security of mining.

Recently radar sondes have been developed to explore the interior of salt deposits from deep boreholes. Detailed knowledge of the geology of a salt deposit is very essential in planning of mines, the construction of caverns and for storage of fuel and gas or deposition of radioactive material.

Standard borehole logs can contribute information only of the close vicinity of the hole, whereas electromagnetic radar waves are able to penetrate into the salt up to several hundred meters. Discontinuities in the salt can be located by pulsed radiation of electromagnetic energy and reception of echoes measuring travel time and direction.

Construction of the radar sonde withstands temperature and pressure in boreholes down to more than 3,000 meters. The diameter is only 88 millimeters. The operating frequency can be selected between 20 and 100 MHz for the preference of either deep penetration or high resolution. Additional measurements between two boreholes are possible by separation of transmitter and receiver.

This paper explains the method and equipment, presents results of measurements in deep boreholes, and finally gives an overview of the interpretation as well as of further developments in this field.

THOMS *Borehole Tests to Predict Cavern Performance*

Robert L. Thoms and R.M. Gehle, Applied Geomechanics, Inc., Baton Rouge, Louisiana, USA

Exploratory boreholes generally are drilled in rock salt deposits prior to construction of storage caverns. Cores are taken over selected intervals of depth for first-hand inspection of salt geological characteristics, and also for possible laboratory tests to determine the mechanical properties ("strength") of the rock salt relative to the intended storage application. Applications can include storage of liquids, e.g., oil and other hydrocarbon products, and gases, e.g., natural gas or compressed air (for energy storage). Storage of gases generally includes cavern stability considerations, which may be vital for deep caverns (depths greater than around 800 m) subject to cyclic internal pressure. Additional complications can occur if the rock salt formation contains "impurities", e.g., shale and/or clay, or if the *in situ* stress state is other than lithostatic, i.e., due to overburden alone.

Borehole testing can be used to predict cavern performance on the basis of dimensional analysis and physical model theory. Such tests have the advantages of incorporating site

specific features. Effects of relatively undisturbed salt and *in situ* stresses are taken into account over the depths of planned cavern development. Test programs can be designed in stages of complexity (and costs) to fit the level of concern for the intended storage project.

A first stage of tests includes performing initial and subsequent borehole caliper surveys, along with monitoring outflow of drilling fluid from open boreholes. On the basis of dimensional analysis, predicted volume changes of a cylindrical cavern over a selected depth interval at the borehole site can be derived as $\Delta V_C = (D^2_C/D^2_B)\,\Delta V_B$, where ΔV, D are volume change and diameter respectively, and the subscripts C, B refer to cavern and borehole respectively. More precise data can be obtained by sealing off portions of boreholes with packers or plugs.

Other borehole tests are outlined and discussed, with potential benefits, for the geostorage industry working in rock salt.

THOMS

Monitoring Ground Movements Over Undisturbed Salt Domes With Precise Leveling

Robert L. Thoms and R.M. Gehle, Applied Geomechanics, Inc., Baton Rouge, Louisiana, USA

Precise leveling was performed over two salt domes in North Louisiana for a four-year period. The objective of the leveling was to collect data for naturally occurring ground surface movements over salt domes undisturbed by man-made activities, e.g., salt and sulphur mining or hydrocarbon production. The collected data furnish examples of levels of "background" surface movements due to rainfall and possible seasonal effects.

Networks of leveling monuments were established over the Vacherie and Rayburn's domes by the National Geodetic Survey (NGS) in 1977. Subsequently, re-leveling surveys were performed in 1978, 1979 and 1982 over the Vacherie dome, whereas re-leveling over the Rayburn's dome was performed only in early and late 1979.

Computer graphics techniques were used to produce contour and surface maps of elevation changes over the domes. Possible reasons for apparent surface movements are discussed relative to site specific characteristics at locations of the leveling monuments. Amounts of rainfall and levels of water tables apparently caused seasonally related small changes in surface elevations. The ground surface elevation changes were relatively small over the four-year monitoring period, and no general patterns of change developed that could be attributed to possible movements of the underlying salt stock of the domes.

Possible monitoring systems which incorporate leveling are summarized for mining activities in evaporite formations.

van EEKELEN — *Analytical Solution of Some Bischofite Creep Problems*

H.A.M. van Eekelen, Koninklijke/Shell Exploration and Production Laboratory, Rijswijk, The Netherlands

Near Veendam, The Netherlands, solution mining cavities are being created in a layered deposit of halite, carnallite and bischofite. Of these three salts, bischofite has by far the lowest resistance to creep. As a consequence, boreholes or cavities in which the fluid pressure is less than overburden will be slowly filled by an influx of bischofite.

In laboratory tests, the steady state creep rate of bischofite as a function of differential stress has been found to obey a double power law, the behaviour at strain rates of less than 5×10^{-8} per second being significantly different from the behaviour at higher strain rates. These test results have been used to estimate the rate of bischofite influx into an underpressured borehole or cavity by means of an analytical solution of the governing differential equations. For a borehole the procedure is fairly straightforward. Calculation of the influx of a layer of bischofite into a large cavity involves an analysis of the interaction between deformation of the overburden and underburden (presumed elastic), and viscous flow of the central layer of bischofite. The analysis also yields some useful scaling laws.

VAN FOSSAN — *A Characterization for the Soundness of Cased Boreholes and Solution Caverns*

Neal E. Van Fossan, Texas Brine Corporation, Houston, Texas, USA

The U.S. Enviromental Protection Agency's (EPA) Safe Drinking Water Act (Public Law 93-523) contains an Underground Injection Control (UIC) program covering systems used for injection of hazardous materials down cased boreholes penetrating useable water aquifers. The sodium chloride brine producing industry and the underground storage industry are subject to these regulations. UIC regulations contain a requirement that the "mechanical integrity" (soundness) of the underground injection system be proven prior to issuance of a use permit, and periodically thereafter. This could lead to controversy between the regulator and industry, since the conditions that must prevail for "mechanical integrity" to be attained are not specified in most UIC regulations.

The object of this paper is to establish a reference framework (with respect to concepts, design criteria, test acceptance criteria, etc.), within which the regulatory agency(ies) and industry can agree that "mechanical integrity" is inherent in an underground injection system design, is proven to exist by a given test result and will continue to exist provided appropriate operational procedures are used and retesting is performed as prescribed in the UIC regulation.

The author's comments are based on some thirty years of experience in the underground storage field, a long-term interchange of ideas with other specialists, and participation in various industry association committees whose function was to develop an industry consensus on matters relating to this field.

VERGARA-EDWARDS

Study of the Phase Chemistry of the Salar de Atacama Brines

Luis Vergara-Edwards and Nancy Parada. Comité de Sales Mixtas – CORFO. Santiago, Chile

In order to study the phase chemistry of the Salar de Atacama brine as it evaporates and to determine the crystallization characteristics of potassium and lithium salts, a complete solar evaporation sequence was made. The data came primarily from small (1.5 - 2 m diameter) metal pans sitting on the surface of the Salar. Also, some laboratory evaporation tests were done. The data collected represent nearly four years of solar evaporation experiments.

The Salar de Atacama brine represents a complex multicomponent system saturated in NaCl. The ions present in this brine are Na, K, Li, Mg, Ca, B, Cl, SO_4. An attempt was made to correlate the brine data into a generalized phase diagram of the Autenreith type and to determine where the various potash fields occur in the crystallizing brine.

It was observed that weather conditions (summer and winter) largely influence the crystallization path of the potash salts due to the presence of lithium.

VOUILLE

Application of the Theory of Viscoplasticity to the Calculations of a Rock Salt Mine Optimal Extraction Ratio

Gérard Vouille, Sidi Mohamed Tijani, Centre Mines-Infrastructures de l'Ecole Nationale Superieure des Mines de Paris, and Philippe Tassel, Compagnie des Salins du Midi et des Salines de l'Est, Paris, France

A great number of mechanical tests have been carried out on Varangeville rock salt in order to define its rheological behavior. From the results of the uniaxial compressive tests, uniaxial and triaxial creep tests and biaxial relaxation tests, it was possible to deduce that an elastoviscoplastic rheological model describes correctly the behavior of the Varangeville rock salt. The main characteristics of this model are a Young modulus of 26,000 MPa, a Poisson ratio of 0.19, a cohesion close to 3 MPa, a null internal friction angle and a creep law being a power law of stresses and time.

Using these data, numerical simulations were carried out by means of the finite element method, and it was proved that the long-term stability of the mine could be obtained, even when plastic zones exist in the pillars, provided that the middle part of the pillar still behaves elastically.

When, for safety purposes, 50 per cent is assumed to be the upper bound of the ratio of the volume of the plastic zone with respect to the volume of the pillar, an extraction ratio may be derived that ensures an evolution of stresses and strains toward a stable equilibrium state with initially low and continuously decreasing stress and strain rates.

VOUILLE

Application of the Theory of Viscoplasticity to the Calculations of a Rock Salt Mine Optimal Extraction Ratio

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WALCOTT

Energy Efficient Multiple Effect, Thermo and Vapor Compression Evaporator

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The paper will cover two separate subjects. First, a sodium chloride evaporator crystallizer system involving a thermocompressor that was designed, installed and is now operating; and second, four alternative ways to increase capacity of an existing set of evaporators, including features for energy conservation to minimize operation cost.

The sodium chloride evaporator-crystallizer system consisted of a conispherical vapor body, a thermocompressor, a vertical long tube forced-circulation heat exchanger and an axial flow recirculation pump. The thermocompressor is 26 inches × 26 inches and 22 inches long and is designed to compress 85,000 lbs/hr of vapors at 28.9 psia to a discharge pressure of 50.7 psia using 79,000 lbs/hr motive steam at 450 psig. The discharge of the thermocompressor supplied steam to the new salt evaporator plus steam to a present set of quads.

In the study done on the capacity increase, the following alternatives will be discussed:

- High pressure steam turbine drive mechanical vapor compression with discharge supplying a set of quads
- New thermocompressor salt evaporator with some of the vapors supplying two forced circulation evaporators
- A quadruple effect crystallization system replacing calandria bodies
- Two three-body mechanical vapor compressor systems, one with a motor driven compressor and one with a gas turbine driven compressor.

In all four cases, brine preheating and condensate flash was included to reduce energy consumption.

WARREN *On the Significance of Evaporite Lamination*

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Primary lamination in an evaporite is caused by periodic changes in the brine chemistry. Some geologists interpret laterally extensive, horizontal mm laminae in ancient evaporites as subaqueous "deep water" phenomena; others have said evaporite laminae can form under subaerial conditions. This dilemma of interpretation is in part due to the lack of a documented Holocene analog. However, laminated and non-laminated evaporites are forming today in some Holocene salinas along the southern coastline of Australia.

The overall facies pattern in the South Australian salinas is a bull's-eye. Laminated and/or fenestral carbonates containing stromatolites and tepee structures surround a more basinward, relatively pure, gypsum unit. In some salinas the bulk of the gypsum unit is a mm laminated gypsarenite; in others the unit is composed of bedded to finely laminated coarser grained gypsum (selenite). The laterally extensive, mm laminated gypsum forms in a subaqueous environment where the brine pond is subject to periodic (but not necessarily seasonal) freshening. However, not all the subaqueous salina gypsum is laminated. In the deeper portions ($\approx$ 10 m depth) of these density stratified brine ponds there are large, poorly layered domes of gypsum forming under a regime of continuously subaqueous, stable brines. A laminated gypsum unit always passes up into a non-laminated, relatively pure gypsarenite unit which formed in a seasonally vadose to subaerial environment.

A laterally extensive, mm laminated gypsum unit forms subaqueously but a non-laminated gypsum unit need not have formed subaerially. If a reliable palaeoenvironmental determination is made in ancient evaporites then morphology and textural relationships must be considered as primary indicators of palaeohydrology and secondary indicators of palaeoenvironment.

WASSMAN *Cavity Utilization in The Netherlands*

T. H. Wassman, Akzo Zout Chemie, Hengelo, The Netherlands

The industrial centres of The Netherlands, situated around the cities of Rotterdam and Amsterdam, are connected with the natural gas fields of Slochteren and the North Sea by a complete system of high pressure, large diameter pipelines and compressor stations. At the same time, the Dutch, and even part of the Belgian and German strategic oil reserves, are stored in huge surface tank areas around Rotterdam.

The Dutch salt domes in the northeastern part of the country are considered of no importance to the storage of these products because of their isolated position. Akzo's salt chemicals division had already started investigations for other uses of their cavities in the sixties. As a result of these studies AZC started the disposal of slurries from its brine purification plants in Hengelo, followed a few years later by small amounts of salty drilling muds.

In the seventies, plans were worked out for the disposal of chemical wastes in small caverns specially made for this purpose, one above the other as a string of pearls, from one drilling. It resulted only in a successful solution mining test because of the negative attitude of the Dutch environmental authorities. At this moment a huge cavity is used for the storage of concentrated $MgCl_2$ brines. Together with the international oil industry working in The Netherlands, plans have been developed and permits applied for in view of the disposal of the complete range of drilling muds and cuttings produced in our country.

WAUGH *The Geology of Denison — Potacan's New Brunswick Potash Deposit*

David C. E. Waugh, Potash Division, Denison Mines Ltd., Sussex, New Brunswick, Canada

The Mississippian age Cassidy Lake potash deposit is located in the Moncton Subbasin of southeastern New Brunswick. Following an extensive surface exploration program, Denison Mines Limited began sinking a shaft in September 1979, reaching the Windsor Group evaporites at 744 metres in early 1982.

Underground exploration began in May 1982, continuing until August 1982. Over 3000 metres of openings were cut, covering an area of approximately 100 hectares. An extensive drilling program was undertaken, producing 8000 metres of core utilizing both conventional wire line as well as counter-flush coring methods.

An underground radar program was utilized to define the upper and lower salt/anhydrite contacts and identify potentially hazardous areas.

The geologic mapping of drifts and core logging in conjunction with the radar surveys, as well as surface exploration data, has enabled a very detailed understanding of the stratigraphic and structural setting of this deposit.

WEGENER — *Sinking of a New Shaft and Watertight Lining of an Old Shaft at the Heilbronn Rock Salt Mine*

Wilhelm Wegener, Südwestdeutsche Salzwerke AG, Heilbronn, West Germany

The Heilbronn rock salt mine, which operated for nearly 90 years with only one shaft, was provided with a second shaft of 238 m depth and an internal diameter of 5.0 m in 1971/72. Cement was injected into the water-bearing open seams of the overthrust mountain in four sections, one time from the surface and three times from the shaft bottom.

Shaft sinking was done conventionally by blasting work, loading by grabs and bucket extraction. During this work a circular wall made out of preformed concrete blocks was carried along to secure the wall face of the rock. Remarkable is the lining in the water-bearing overthrust mountain. The watertight lining, consisting of a reinforced concrete cylinder (50 cm) and a steel plate cylinder (9 mm) was mounted onto a wedge-shaped foundation ring at a depth of 139 m. A ring joint between this composite cylinder and the masonry connected to the rock was at last poured with asphalt to reach a total watertightness in the horizontal and vertical direction and to protect the steel plate cylinder against corrosion.

This lining method, first used in coal mines with unstable strata, was also used when repairing the shaft in Heilbronn. The masonry of this shaft, which was finished in 1885, was penetrated right from the beginning by approximately 120 liters of water per minute coming out of the surrounding rock. This water was controlled, collected and pumped to the surface via a pipe duct. In the course of the general reconstruction of the shaft the water inflow could be prevented successfully.

Shaft No. 2 was equipped with a skip conveyor of 1000 t/h capacity, Shaft No. 1 with a skip conveyor of 300 t/h capacity.

WHITE — *Characterization of Salt Domes for Storage and Waste Disposal*

Robert M. White and Charles Spiers, Law Engineering Testing Company, Marietta, Georgia, USA

Gulf Coast Salt Domes are currently being studied for waste disposal and storage purposes. Specific applications are radioactive waste disposal, oil and gas storage, and compressed air energy storage. This paper describes the geophysical techniques currently being used to characterize the geologic and hydrologic aspects of the salt domes for suitability for such storage purposes.

Geological and hydrological characterization of the salt domes is done with detailed gravity work, shallow high resolution reflection seismic surveys, surface electrical resistivity, and down-hole geophysical logging to add a third dimension to all of the surface techniques. Bore-hole geophysical logs are also used to determine the stratigraphy around the dome with respect to confining beds which affect groundwater flow. Salinity profiles are also determined by use of electrical logs.

The logic of the combined geophysical surveys will be discussed as well as their relative economics and their relationship to the overall characterization effort.

WIERCZEYKO *Determination of the Change in Shape and Volume of Salt Caverns During Storage Operation*

Erich Wierczeyko, Geophysical Engineering Department, Prakla-Seismos GMBH, Hannover, West Germany

Storage caverns produced by solution mining can be filled with various liquid or gaseous mediums. Echometric surveys for determining changes in shape and volume of storage caverns in operation are only useful if specific rock mechanic effects, i.e., caving and sheeting, and especially actual convergence processes, can be detected. A direct determination of convergence process is only possible by an areal comparison of correspondingly closely spaced and accurately measured horizontal cross sections, i.e., by direct comparing of the mean value of radii for depth regions in an extensively homogeneous salt.

In order to attain the necessary survey accuracy, the following technical improvements have been achieved:

- Development of new ultrasonic transducer and electric systems, of which ratio of range to power concentration can be adjusted to various mediums, for example, crude oil or natural gas
- Introduction of true computer-controlled measurements with computer-assisted interpretation and results display, so that with any survey point density can be efficiently surveyed.

For the echometric survey of storage caverns which are filled with gaseous mediums, an echo-sonde was developed additionally to work on the basis of travel times measurements of laser pulses that are reflected from the cavern wall. From 1982 it consequently has become possible to make complete laser surveys in compressed air storage caverns with survey distances of up to about 50 m. In storage caverns with natural gas under high pressure, larger survey distances could still not be attained. It will therefore probably be possible in the future to jointly apply the two different physical survey methods, i.e., pulsed laser and ultrasonic, only to caverns up to a certain diameter.

In irregularly shaped gas or compressed air caverns there is the possibility of applying, in addition to echo surveying, the photographic technique of panoramic pictures, especially in the roof area and the uncased cavern neck.

WOUCH *Salt Dome Plumes and Dissolution Features. Are They Related?*

Martin L. Wouch and Joseph D. Martinez, Institute for Environmental Studies, Louisiana State University, Baton Rouge, Louisiana, USA

Salt domes, historically of interest in hydrocarbon production and salt mining, later were recognized for their value as reservoirs to store petroleum products, energy as compressed air and possibly hazardous wastes. One of the problems encountered when drilling into the salt stock prior to the leaching of a cavity is a loss of drilling fluids in the cavernous zones that overlie many salt domes. Of particular interest are cavernous zones at

the salt-caprock interface, where active dissolution of the salt by circulating groundwater is most likely to be occurring.

The salt-caprock interface zone may be characterized by a tight, cavernous or sandy (granular anhydrite) contact. The condition of the salt-caprock interface not only affects solution mining of cavities where lost circulation hinders drilling operations prior to penetrating the salt, but it also may have implications to the long-term hydrologic stability or degree of ongoing dissolution of the dome for consideration in planning waste storage projects.

Dissolution cavities or residual anhydrite sand (previously embedded in the salt) at the salt-caprock interface and the presence of saline plumes in aquifers in contact with the salt have been used as evidence of dissolution. A positive correlation between dissolution features at the interface and the presence of saline plumes in surrounding aquifers could be useful in the prediction of drilling problems at the interface when planning salt dome utilization projects. Studies, based on limited data, have proven inconclusive thus far; additional field evidence may resolve this question. A better understanding of the relationships between dissolution features and saline plumes would also be helpful in hydrologic stability studies of waste storage projects.

X Y Z

YAMANAKA *Salt Industry in Japan*

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Since long ago, in Japan there have been no available resources such as rock salt or natural brine to produce salt except seawater. Climate is also unfavourable for solar salt fields because of frequent precipitation all through the year. Thus, a modified solar salt field system,"IRIHAMA," which can only concentrate seawater by solar energy using sand, was developed in the 17th century.

After World War II, a new concentrating system which consisted of a sloping down salt field system, "RYUKASHIKI ENDEN," with gradient concentrator, "SHIJOKA," was developed, and the productivity was raised to about 300 ton/Ha/Year. However, the cost of the produced salt was still far more expensive than imported salt.

In 1971, those salt field systems were switched to the electrodialysis method by using ion-exchange membranes. Since then about 1.2 million tons of salt is produced yearly by seven factories. The amount is almost equivalent to the edible salt consumption in Japan.

This report presents the Japanese existing state of the electrodialysis method, in relation to the history of the salt production method, and also introduces the outline of the Japanese present situation of demand and supply of salt.