



WYOMING STATE GEOLOGICAL SURVEY

Gary B. Glass, State Geologist

Proceedings of the First International Soda Ash Conference Volume I

edited by

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Public Information Circular No. 39

1998

Laramie, Wyoming

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Foreword for Volume I

Soda ash is an important global commodity with a strong possibility of increasing demand. For this reason, utilization of world sodium carbonate resources into the twenty-first century will be extremely important. The First International Soda Ash Conference (ISAC) was held June 10-12, 1997, in Rock Springs, Wyoming, the largest city in Sweetwater County, the heart of the U.S. soda ash industry. The conference provided a forum for attendees to discuss, as a group, all facets of the industry and the resources.

This historic gathering was sponsored by the U.S. Geological Survey, the U.S. Bureau of Land Management, and the Wyoming State Geological Survey. More than 300 representatives from 15 countries and 30 states attended the meeting. The conference, stressing natural deposits of soda ash, featured 33 formal presentations and poster sessions by some of the world's leading experts in the geology, mining, processing, marketing, and environmental engineering of sodium carbonate resources. The date of the conference also coincided with the 50th anniversary of the beginning of the Wyoming soda ash industry, which will continue to be a major source of soda ash for the world.

The first group of papers included in Volume I of the conference proceedings are those concerned with marketing soda ash and forecasting future trends in the soda ash industry. Because these papers are relatively time-sensitive, it was deemed appropriate that these should be published first. The remaining papers shall be published in Volume II of the conference proceedings.

The conference organizers would like to express their gratitude to everyone who contributed to making this First ISAC a success.

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Editors' preface

The editors of the first ISAC proceedings volume would like to thank all the authors that contributed to this publication. Most of the papers published here were also presented at the meeting, and we would like to thank the authors for preparing not only a presentation for the meeting but also for preparing a preliminary manuscript that served as a basis for their article in this proceedings. We would also like to thank those unnamed people within the authors' organizations that reviewed the manuscripts before they were submitted for this volume. Their comments and suggestions certainly improved the overall quality of the papers and saved us much work.

The papers were reviewed first for technical and scientific content and then edited for style, language, and consistency. In some cases, word slides from the oral presentations were transcribed into text manuscript and headings.

We acknowledge the assistance of Fred H. Porter and Phyllis A. Ranz, cartographers with the Wyoming State Geological Survey (WSGS), for their work in redrafting, revising, or retouching some of the illustrations and photographs. We are especially grateful to Janet A. Van Nuys, Editorial Assistant with the WSGS, for word processing, design and layout of the publication, and proofreading of the manuscripts. Finally, we thank the organizers and committees of the First International Soda Ash Conference for the funding support necessary to produce the proceedings volumes.

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The origin of the U.S. natural and synthetic soda ash industries

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Abstract

The first International Soda Ash Conference (ISAC) which was held in June 1997, celebrated the 50th anniversary of the Wyoming trona industry. In 1947, or more than one-half century ago, the Westvaco Chemical Corporation (now known as FMC Corporation) sunk its first mine shaft into the Green River Basin in Wyoming, and reached the top of Bed 17 for the first time. Since then, more than 200 million short tons of soda ash has been produced from this mine and the four others that followed.

To appreciate the significance of Westvaco's endeavors, we need to recall the achievements and events that helped shape the history of the U.S. soda ash industry. The history begins in the early seventeenth century, when the Jamestown settlers needed a source of alkali to manufacture their glassware, continues through the late nineteenth century, when natural sodium carbonate deposits were being developed in the West and synthetic soda ash plants were being constructed in the East, and endures into the twentieth century. Although most of these older operations have shut down leaving very little physical evidence remaining to show they once existed, their successes and failures built the foundation of the present U.S. soda ash industry.

Because a comprehensive discussion of each company and facility is beyond the bounds of this presentation, four of the more important soda ash ventures in the United States will be discussed. Of the four operations, only FMC Corporation remains.

The U.S. Geological Survey and the U.S. soda ash industry

The relationship between the U.S. Geological Survey and the domestic soda ash industry dates back to the late nineteenth century. Many industry and government geologists, chemists, engineers, and hydrologists have used their technical expertise to develop the soda deposits of the West and to provide the knowledge that we take for granted today. Early geological expeditions prior to the formation of the U.S. Geological Survey evaluated the economic potential of the soda lakes in Nevada and Owens Lake in California. The first statistical data on soda ash production was collected by the U.S. Geological Survey. The responsibility of collecting this data was

transferred to the U.S. Bureau of Mines, and then transferred back to the U.S. Geological Survey in 1996.

Many natural and synthetic soda ash companies have existed in the United States, as shown in **Table 1**. Each company has provided soda ash at a time in U.S. history when the product was in strong demand, such as during the Industrial Revolution of the late nineteenth century, World Wars I and II, and the Korean Conflict. The domestic glass, chemical, and metals industries relied on a continuous and dependable source of soda ash for national needs.

Table 1. History of U.S. natural and synthetic soda ash plants in the United States, 1868 to 1997.

Company	Location	Deposit	Start up date	Closure date	Nameplate capacity (million short tons)				
					1950	1960	1970	1980	1990
Natural soda ash plants									
American Potash and Chemical Corp. ¹	Trona, CA	Searles Lake (south)	1926	1979	.150	.150	.150	—	—
California Alkali Co. ²	Cartago, CA	Owens Lake (south)	1917	1932	—	—	—	—	—
FMC Wyoming Corp.	Green River, WY	Green River trona	1948	—	.300	.500	1.250	2.550	2.850
General Chemical (Soda Ash) Partners ³	Green River, WY	Green River trona	1968	—	—	—	.550	2.200	2.400
Inyo Development Co. ⁴	Keeler, CA	Owens Lake (northeast)	1887	1920	—	—	—	—	—
Natron Soda Co. ⁵	Ragtown, NV	Big Soda Lake	1885	1907	—	—	—	—	—
Natural Soda Products Co. ⁶	Keeler, CA	Owens Lake (northeast)	1912	1952	.020	—	—	—	—
Nevada Soda Co. ⁷	Ragtown, NV	Little Soda Lake	1868	1907	—	—	—	—	—
North American Chemical Co. ⁸	Trona, CA	Searles Lake (northwest)	1978	—	—	—	—	1.300	1.300
Occidental Alkali Co.	Schurz, NV	Double Springs Marsh	1886	1917	—	—	—	—	—
OCI Chemical Co. ⁹	Green River, WY	Green River trona	1962	—	—	—	.750	1.520	2.200
Pacific Alkali Co. ¹⁰	Bartlett, CA	Owens Lake (northwest)	1926	1968	.009	.070	—	—	—
Permanente Metals Corp. ¹¹	Bartlett, CA	Owens Lake (west)	1947	1950	.022	—	—	—	—
Sodium Products Co. ¹²	Wilson Creek, WA	Mitchell Lake	1936	1941	—	—	—	—	—
Solvay Minerals, Inc. ¹³	Green River, WY	Green River trona	1982	—	—	—	—	—	1.850
Tg Soda Ash, Inc. ¹⁴	Granger, WY	Green River trona	1976	—	—	—	—	1.000	1.300
Union Pacific Alkali Works ¹⁵	Laramie, WY	Union Pacific Lakes	1895	NA	—	—	—	—	—
Washington Sodium Products Co.	Warden, WA	Carbonate Lake	1927	1941	—	—	—	—	—
West End Chemical Co. ¹⁶	Westend, CA	Searles Lake (southwest)	1926	1988	.150	.190	.160	.150	—
Western Alkali Corp.	Green River, WY	Green River brines	1907	1918	—	—	—	—	—
Total natural capacity					.651	.910	2.860	8.720	11.900
Synthetic soda ash plants									
Ammonia-soda process									
Diamond Alkali Co. ¹⁷	Painsville, OH	—	1912	1976	.727	.800	.800	—	—
Mathieson Alkali Works, Inc. ¹⁸	Lake Charles, LA	—	1935	1975	.365	.365	.375	—	—
Mathieson Alkali Works, Inc. ¹⁸	Saltville, VA	—	1893	1971	.200	.410	.400	—	—
Michigan Alkali Co.	Wyandotte, MI ¹⁹	—	1892	1978	.835	.700	.800	—	—
Pittsburgh Plate Glass Co.	Barberton, OH	—	1900	1973	.350	.600	.600	—	—
Solvay Process Co. ²⁰	Hutchinson, KS ²¹	—	1908	1918	—	—	—	—	—
Solvay Process Co. ²⁰	Baton Rouge, LA	—	1935	1975	.750	.750	.785	—	—
Solvay Process Co. ²⁰	Detroit, MI	—	1898	1969	.800	.800	—	—	—
Solvay Process Co. ²⁰	Syracuse, NY	—	1884	1986	.850	.900	1.000	.900	—
Southern Alkali Corp. ²²	Corpus Christi, TX	—	1934	1978	.200	.240	.270	—	—
Caustic carbonation process									
Dow Chemical Co.	Freeport, TX	—	1955	1970	—	.100	—	—	—
Total synthetic capacity					5.077	5.665	5.030	.900	—
Total industry capacity					5.728	6.575	7.890	9.620	11.900

NA = Not available. Note: This table does not include plants that used the electrolytic process or LeBlanc process.

¹Began as California Trona Co. in Feb. 17, 1908, which was acquired by American Trona Corp. on June 13, 1913. American Potash formed in 1926 and soda ash production began in 1931. Bought by Kerr-McGee Chemical Corp. in 1967; ceased production in 1979.

²Owned by Great Western Electro-Chemical Co., a subsidiary of Dow Chemical Co. Bought Inyo Development Co. in 1918 and was acquired in May 1924 by Inyo Chemical Co. Operated until January 1932.

³Formerly part of Allied Corp.; separated in 1985. Joint venture with ACI of Australia (1986-25%) and Tosoh of Japan (1992-24%).

⁴Sold to California Alkali Co. in 1918; property leased to Natural Soda Products Co. in 1922.

⁵Formed by Griswold and Epperson Sept. 22, 1885. Capacity about 1.5ktpy but only about 450 tons produced annually.

⁶Bankrupt in 1927; sold to receivership and kept operating until 1933. Natural Soda Products reorganized as subsidiary of Michigan Alkali Co. (part of Wyandotte Chemical Corp.). Resumed full production by 1942; sold to independent group in 1950; ended in June 1952.

⁷Sold by A. Kenyon in 1868 to Higgins & Duffy, who sold lake to San Francisco group Doe & Dowd. Nevada Soda Co. was probably their company until about 1879 when John Horstmann Co. acquired facility and operated until 1907. Produced about 300 tons annually.

⁸Plant began July 1978. Acquired Argus plant of Kerr-McGee Chemical Corp. Dec. 1, 1990. OCI of South Korea was 27% partner; now about 7%.

⁹Formerly Stauffer Chemical Co.; sold to Rhône-Poulenc of France in 1987, and to OCI in 1996. Joint venture with Union Pacific Resources (49%) and OCI of South Korea (51%).

¹⁰Operated until 1944 when acquired by Columbia Southern Chemical Corp. New plant built and onstream in late-1958. Became subsidiary of Pittsburgh Plate Glass Co. on Jan. 1, 1961. PPG closed plant in 1968.

¹¹Acquired as a division of Kaiser Aluminum and Chemical Corp.

¹²Reorganized into Sodac Chemical Co. in 1941.

¹³Formerly Tenneco Minerals. Joint venture with Asahi Glass of Japan (1990-20%) and Solvay of Belgium (1992-80%).

¹⁴Bought in 1987 by Société Nationale Elf Aquitaine of France (100%).

¹⁵Acquired by American Soda, Glass and Chemical Co. in 1899. The American Development Co. and American Native Soda, Glass and Chemical Co. incorporated in 1898 to develop the soda deposits in Wyoming.

¹⁶Formed as the Westend Chemical Co., subsidiary of Westend Consolidated Mining Co. in 1920. Bought by Stauffer Chemical Co. in 1956, which was sold to Kerr-McGee Chemical Corp. in 1974.

¹⁷Later became Diamond Shamrock Corp.

¹⁸Became Olin-Mathieson in 1954, and later Olin Corp.

¹⁹Facility had two plants; North plant built in 1892 and South plant built in 1895.

²⁰Became part of Allied Chemical and Dye Co. in 1920.

²¹During World War I, the plant was leased from Kansas Chemical Co. and sold to the Solvay Process Co.

²²Production began September 1934. Owned by Pittsburgh Plate Glass Co. and American Cyanamid Co.

Background

To appreciate the significance of the development of the U.S. soda ash industry, it is important to put it into historical perspective. The use of soda ash dates back to about 3500 B.C., when Egyptians used a natural material found along evaporite lakes known as “natron” to make glass ornaments. Natron also was used as a drying agent for preserving the remains of the Pharaohs and as an ingredient to make a silica-aluminate cement mortar. With the limited sources of natron, people discovered that certain vegetation (plants, trees, seaweed, kelp, bamboo, sagebrush, and straw) could be burned, leached with water, and dried in pots to recover a potassium-bearing alkali (called pot ash) that could be used as a substitute for natron in glass making (Bateman, 1919).

Early glassworks were located in the country where there was an abundance of timber. It was not long before there were complaints about the destruction of the forests. In 1641, a bill was introduced in the English Parliament to stop the felling of trees for fueling glass furnaces. After about 1675, glassworks were built nearer to towns where coal could be obtained (Moore, 1943, p. 11).

Various wood types yielded different ashes that had different properties and compositions. The composition of a typical ash was 50 to 80% potassium carbonate, 5 to 20% potassium sulfate, and smaller quantities of sodium carbonate, potassium chloride, and other salts (Martin and others, 1916). The trees also provided a source of energy to fuel the furnaces of the glassworks. Production of potash from the ashes of wood or plants flourished until about 1870, when mining of potassium mineral salts began in Germany (Gale, 1919).

Vegetation from salt-bearing soils (the Middle East), kelp (Scotland), and seaweed (Spanish barilla) was so different from that obtained from timber that it became known as “soda ash” because of the sodium content. This was the origin of the terms potash and soda ash. The use of potash or soda ash depended on the location and supply of natron or potassium-rich or sodium-rich vegetation. Because the demand for soda ash was greater than the supply, the price of soda ash was high. By the end of the eighteenth century, Spanish producers were raising their prices month by month. Lord MacDonald of Scotland, who owned some of the largest kelp beds in that country, made more than £10,000 annually selling soda ash in the 1780s (Froman, 1967).

Soda ash in colonial America

In May 1607, the first colonists arrived in Jamestown, Virginia, to establish what would become the first permanent English settlement. Later that year, they started what was perhaps the first commercial enterprise in the this country—a glassworks that was run by eight Dutch and Polish glass blowers. Silica sand from the James River was melted with wood ashes in furnaces to manufacture various glass articles that were exported to England; the wood ashes were probably the remains of the burned timber used to fuel the furnaces (Moore, 1943, p. 209). An analysis of the Jamestown glass showed the following composition: silica, 57%; lime, 25.8%; potassium, 4.5%; and soda, 1.3%. Reportedly, some soda ash was brought over from England and sparingly used (Harrington, 1972). By 1617, Captain Argall arrived in Jamestown and found that the glassworks had deteriorated. By about 1621, a second glassworks was built primarily for the manufacture of glass beads, which were made by Italian workmen sent by the London Company in England. The beads were traded with the local Native Americans who prized these ornamental decorations. The glassworks operated until about 1625 (McKearin and McKearin, 1989).

Potash alkali was used in glass making for the next 250 years. Sodium alkali made from Spanish barilla and other salt-bearing plants was known to have been imported, but records of quantities and origins are vague. At this time, England, France, and Scotland were known to have been producers of sodium alkali.

Soda ash during the Industrial Revolution

In the late eighteenth century, the Industrial Revolution in Western Europe put a strain on the availability of many raw materials. One of the scarce materials was soda ash. Because of the Seven Years War with England and the Napoleonic wars with other countries in Europe, France could not obtain sufficient quantities of Spanish barilla or other sources of soda ash. The demand for soda ash led the French Academy of Sciences in 1775 to offer a large prize of 2400 livres to anyone who could find an inexpensive method to make soda ash. In September 1791, French chemist Nicolas LeBlanc (1742-1806) developed such a technique at St. Denis that used salt, sulfuric acid, coal, and limestone. Basically, common

salt and sulfuric acid were reacted to produce hydrochloric acid and sodium sulfate, which was roasted with coal and limestone to produce soda ash and calcium sulfide. This finished product consisted of 39 to 45% sodium carbonate, 27 to 31% calcium sulfide, 9 to 11% calcium oxide, 5 to 6% unreacted coal, and minor quantities of sodium sulfate, sodium chloride, and silicates. The soda ash often was called “black ash” because of the dark color of the unreacted coal. During the French Revolution, his patent and factory were confiscated. He only received partial compensation for all his work. Napoleon returned his factory to him, but LeBlanc was unable to raise enough money to reopen it. A dejected and financially ruined man, LeBlanc committed suicide in 1806.

A small and unsuccessful LeBlanc plant was first built in England in 1814. With the repeal of the salt tax, Muspratt built a commercially successful operation in Liverpool. The process was introduced in Germany in 1843 and in Austria in 1851 (Harness and Coons, 1942) and was at its peak around 1880; the process began to decline as the Solvay process (which will be discussed later) became more popular. The LeBlanc process was used to a limited extent during World War I in Europe but had disappeared by World War II.

U.S. soda ash in the late nineteenth century

In the mid-nineteenth century, annual reports written by the U.S. Department of the Treasury and submitted to the Committee on Mines and Mining of the U.S. Congress described the status of mineral-resource activities in the states and territories west of the Rocky Mountains. Some of these reports provided general observations on occurrences of natural salts and alkali incrustations but included little detail.

Prior to the establishment of the U.S. Geological Survey in March 1879, several scientific expeditions mapped and collected information on mineral resources that provided some of the first detailed references to natural soda ash deposits (**Table 2**). The more important surveys included Clarence King’s Geological Exploration of the 40th Parallel, 1867-72; the Lt. George M. Wheeler Survey, 1875; and the U.S. Army’s U.S. Geographical Surveys West of the 100th Meridian, 1876. With the creation of the U.S. Geological Survey in 1879, annual reports were prepared for Congress on the status of the domestic mineral resources. This publication was known as Mineral Resources of the United States, the predecessor of the Minerals Yearbook that has been written each year since 1883 (**Table 2**).

Table 2. Chronology of U.S. Geological Survey and U.S. Bureau of Mines reports¹ on the U.S. soda ash industry.

Dates of chapters	Name of author(s)	Number of chapters written	Name of chapter
1882	(unknown)	—	Carbonate of Soda
1883-85	Joseph D. Weeks	3	Glass Materials
1886	(none)	(none written)	—
1887	William C. Day	1	Sodium Salts
1888-92	(none)	(none written)	—
1893	R. L. Packard	1	Natural Sodium Salts
1894-1911	(none)	(none written)	—
1912	(article on Searles Lake by Hoyt S. Gale)	—	Potash Salts
1913-16	(none)	(none written)	—
1917-20	Roger C. Wells	4	Sodium Salts (1917); Sodium and Sodium Compounds (1918); Sodium Compounds (1919-20)
1921-31	(none) ²	(none written)	—
1932-37	A. T. Coons	6	Natural Sodium Compounds and Boron Minerals
1938-39	Paul M. Tyler and A. T. Coons	2	Magnesium Compounds, Bromine, Calcium Chloride, Iodine, Sodium Sulfate, Borates, and Miscellaneous Salines
1940-41	Alvin Schallis and A. T. Coons (1940); with K. G. Warner (1941)	2	Magnesium Compounds and Miscellaneous Salines (1940-47)
1942-46	Charles L. Harness and Nan C. Jensen (1942-43); with F. M. Barsigian (1944-46)	5	Magnesium Compounds and Miscellaneous Salines
1947	G. W. Josephson and F. M. Barsigian	1	Magnesium Compounds and Miscellaneous Salines
1948-53	Joseph C. Arundale and F.M. Barsigian (Mentch) ³	6	Salines - Miscellaneous (1948-51); Sodium and Sodium Compounds (1952-80)
1954-63	Robert T. MacMillan and Annie L. Marks (Matilla) ³ , (1954-57); with James M. Foley (1958-59); and with Victoria M. Roman (Schreck) ³ , (1960-62)	10	Sodium and Sodium Compounds

Table 2 continued.

Dates of chapters	Name of author(s)	Number of chapters written	Name of chapter
1964-65	William H. Kerns	1	Sodium and Sodium Compounds
1966	(tables only)	(tables only)	Sodium and Sodium Compounds
1967-68	Benjamin Petkof	2	Sodium and Sodium Compounds
1969	Arnold M. Lansche	1	Sodium and Sodium Compounds
1970-75	Charles L. Klingman	6	Sodium and Sodium Compounds
1976-77	Russell J. Foster	2	Sodium and Sodium Compounds
1978-83	Dennis S. Kostick	6	Sodium and Sodium Compounds; Sodium Compounds (1981-87)
1984	James P. Searls	1	Sodium Compounds
1985-present	Dennis S. Kostick	12	Sodium Compounds; Soda Ash and Sodium Sulfate (1988); Soda Ash (1989-present)

¹U.S. Department of the Interior, U.S. Geological Survey 1882-1923; U.S. Department of Commerce, Bureau of Mines 1924-33; U.S. Department of the Interior, Bureau of Mines 1934-1995; U.S. Geological Survey 1996-.

²Beginning in 1923, sodium salts were discussed as by-products of potash production, but there was no data or information.

³Married names in parentheses.

Soda lakes, Nevada

The first natural soda ash deposit to be commercially developed in the United States was a small lake near the present town of Fallon, Churchill County, Nevada. As early as 1854, a small station was known to have existed on the Humboldt Overland Trail that served as a watering stop for westbound travelers who were crossing the desolate plains of the Forty Mile Desert on their way to California, where gold had been discovered in 1849 (Paher, 1970). Although many did not survive the rigors of this region, thousands did brave the long and treacherous journey in wagons, on foot, and on horseback hoping to find their fortunes. This station was the beginning of Ragtown, which got its name from the tattered clothing that the immigrant women washed in the Carson River and hung on the trees to dry. On August 1, 1854, a settler named Asa L. Kenyon (born April 20, 1830 in Rome, New York) and his wife Catherine arrived at Ragtown and set up a trading post to sell provisions and livestock to pioneers continuing their western journey. The settlement had a population of between 300 to 500 people, the majority of whom lived in crude willow houses and tents.

In 1855, Kenyon began acquiring land, including a little oval-shaped soda lake (now known as Little Soda Lake) about 4.02 kilometers (2.5 miles) northeast of Ragtown. At first, he thought the white surface was ice but soon realized the dry material was a soda alkali (Angel, 1958, p. 363). Surrounding the lake were extensive incrustations of white-colored salts that accumulated through the evaporation of the lake water. According to early land records, the name of this lake was Sal Soda Lake; when it was surveyed by the county surveyor, William A. Jackson, on April 29, 1865, it was called Saleratus Lake (Churchill County, 1865). This little lake, which had an area of about 6.5

hectares (16 acres) and occupied a depression that was approximately 23 meters (75 feet) below the local ground level, would be the site of the first natural soda ash deposit to be commercially developed in the United States.

In 1866, a larger lake about 0.8 kilometer (0.5 mile) to the northeast was surveyed. This lake, which was called Oil Lake (now called either Soda Lake or Big Soda Lake), covered an area of 108.7 hectares (268.5 acres), had a diameter of 1.2 kilometers (0.75 mile), and had a depth of 45 meters (147 feet). The lake may have gotten its name because of the soaplike feel of the water, which contained carbonate and bicarbonate; alkaline-water of subterranean origin filled part of the crater. Like Little Soda Lake, this lake occupied a depression in an extinct, nearly circular volcanic crater, which gently rose above the surface of the desert floor. The highest part of the wall that surrounded Big Soda Lake was 25.6 meters (84 feet) above the desert floor and was 50.3 meters (165 feet) higher than the surface of the lake. In the late nineteenth century, the geology and hydrology of the area was thoroughly examined by the U.S. Geological Survey (Russell, 1885). This report stated that the lake contained an estimated 1.8 million tonnes or metric tons (2 million short tons) of salts; 388,000 tonnes (428,000 short tons) of sodium carbonate, 310,000 tonnes (342,000 short tons) of sodium sulfate, and 1.16 million tonnes (1.284 million short tons) of sodium chloride. **Figure 1a** shows an early land survey of the two lakes done on July 17, 1865. **Figure 1b**, a 1951 U.S. Geological Survey topographic map of the area, and **Figure 1c**, a high-altitude photograph taken in 1980, are shown for comparison.

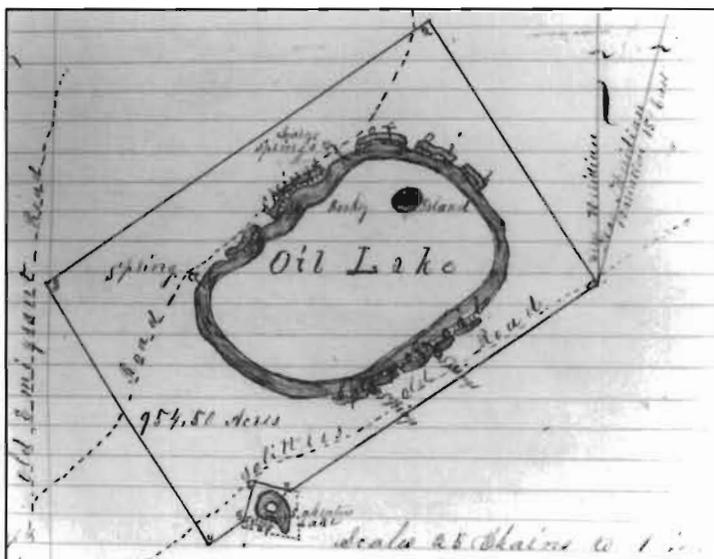


Figure 1a. Survey of the soda lakes near Ragtown, Nevada, July 17, 1865. (Photograph from Churchill County Museum and Archive, Fallon, Nevada.)

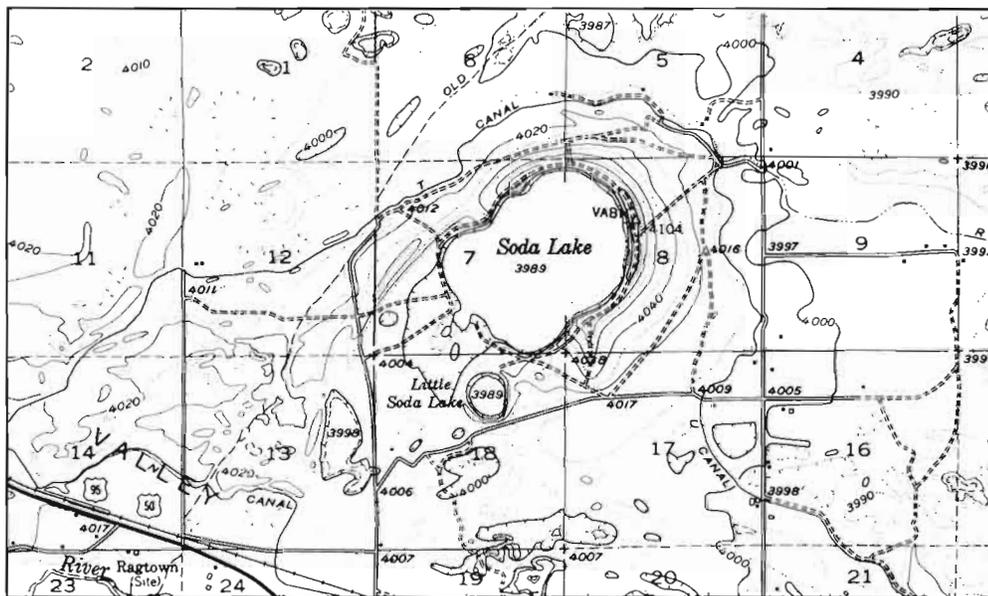


Figure 1b. Topographic map showing Ragtown (lower left) and the irrigation supply canals around both soda lakes, 1951. (From U.S. Geological Survey 1:62,500-scale topographic map.)

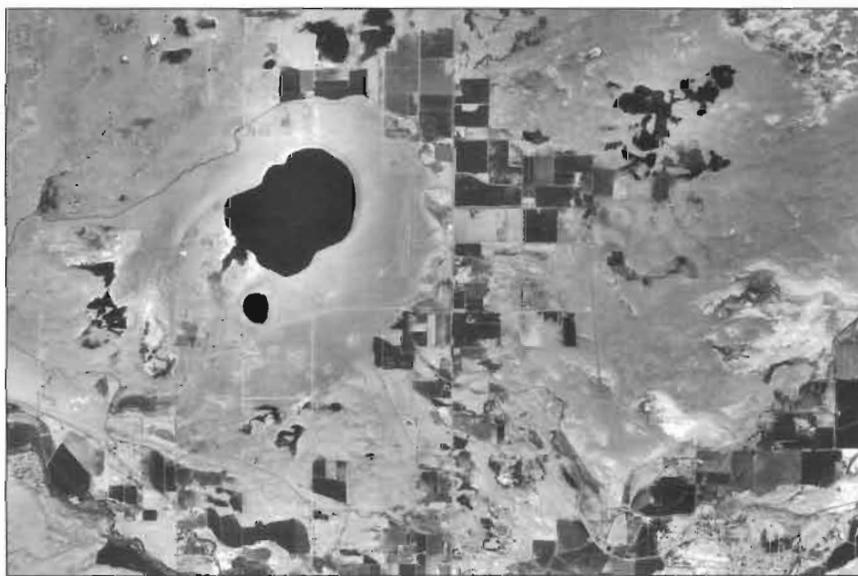


Figure 1c. High-altitude photograph of the soda lakes near Ragtown, Nevada, 1980. (From U.S. Geological Survey.)

In 1868, Kenyon sold the little soda lake to two businessmen, Higgins and Duffy, who in turn sold it to a business group from San Francisco, Doe and Dowd. The Nevada Soda Company (also later referred to as the Nevada and Pacific Soda Company) was formed, and a small plant that was erected along the lake margin annually produced about 272 tonnes (300 short tons) of crude soda dug from the surface of the lake bed during the summer.

Photographs taken sometime between 1867 and 1872 by Timothy O' Sullivan, a noted photographer during the Civil War and a member of the King expedition (Clarence King's Geological Exploration of the 40th Parallel, 1867-72), showed the presence of soda along the lake margins. **Figure 2** shows Little Soda Lake as it appeared during this time. A small wooden structure visible in the background of the photograph was probably a storage shed for the first crude soda collected. By 1872, the company claimed it could produce about 18,100 tonnes (20,000 short tons) of crude soda annually (State of Nevada, 1873). It is doubtful, however, that this level of production was ever achieved. Only five men were required to mine 54 tonnes (60 short tons) per month. At the height of its production, the operation produced between 360 and 450 tonnes (400 to 500 short tons) annually (Russell, 1885).

The mined material was loaded on horse-drawn wagons and taken 40 kilometers (25 miles) to Wadsworth, Nevada, for \$10 per ton and off loaded

for rail shipment for \$9 per ton to San Francisco, where it sold for about \$50 per ton. In San Francisco, the crude soda was refined and made into sal soda (also known as washing soda), sodium bicarbonate, and caustic soda (Virginia City Territorial Enterprise, 1878); many soap manufacturers and wool mills used these chemicals. Some of the Virginia City metal mines consumed from 27 to 36 tonnes (30 to 40 short tons) of soda monthly in metal refining from the Comstock Lode. An 1881 listing of people living in Churchill County showed that B.F. Gray from Illinois was the superintendent of the Nevada Soda Company operation and that A. Merry was the superintendent at the Big Soda Lake facility; G.W. Stone and Smith, both from Maine, were listed as employees at the Big Soda Lake operation (Angel, 1958). In the early 1880s, the Nevada Soda Company was sold to the John Horstmann Company, which operated it until its closure in about 1907.

During the next several years, the production of crude soda ash became more efficient. In the hot weather, or summer soda, process, a solution containing sodium carbonate and sodium bicarbonate was pumped into vats lined with clay bottoms and sides and allowed to evaporate by means of solar heat. The concentrated solution was sent to crystallizing vats where a deposit of sesquicarbonate accumulated by the end of the summer season. The thickness of the material varied from a few centimeters (inches) to as much as 30 centimeters (12 inches). As colder



Figure 2. Little Soda Lake. One of the members of the King Expedition is in the middle-left foreground. The arrow points to a small wooden structure that could have been used to store crude soda. Photograph taken by Timothy O' Sullivan sometime between 1867 and 1872. Compare with 1909 photograph on page 10. (Photograph from the National Archives.)

weather approached, the hard soda was broken up, collected, washed, and air-dried in a stockpile. After drying, the soda was heated in a reverberatory furnace and converted to a pure anhydrous product. In the cold weather, or winter soda, process, sodium carbonate in solution with sodium chloride precipitated out as sodium decahydrate. The salt in solution was drawn off and discarded. The soda was collected and placed on platforms to air dry to a sodium monocarbonate until spring, when the material was ready for shipment (Knapp, 1898). **Figure 3** is a panoramic view of Big Soda Lake in 1905 showing the evaporation ponds on the southern part of the lake.

On September 22, 1885, the Natron Soda Company was incorporated under California law with Eugene Griswold and W.D. Epperson as owners; Griswold had placer claims on Big Soda Lake since October 2, 1875 (*Natron Soda Company v. United States*, 1913). They built a soda ash facility on the shallow southeastern edge of Big Soda Lake. Although its capacity was about 1360 tonnes (1500 short tons) of soda ash per year, the operation only produced about 408 tonnes (450 short tons) per year which yielded an average annual profit of \$3,500. During this time period, natural soda ash was being produced by the Inyo Development Company at the soda deposit in Owens Lake, California and by the Union Pacific Alkali Works near Laramie, Wyoming, which had been formed by the Union Pacific Railroad to produce soda ash at some lakes it discovered in the early 1870s (Brown, 1995); the first synthetic soda ash facility in the United States went into operation near Syracuse, New York.

In 1903, the newly created U.S. Reclamation Service initiated the Newlands Project, which was an effort to take more than 80,940 hectares (200,000 acres) of barren desert land and convert it to useful farmland. The Derby Diversion Dam was constructed on the Truckee River that linked it with the Carson River via a 50.7-kilometer (31.5-mile) canal. Diversion canals were built to distribute the water through the area; two that passed close to the two lakes are shown in **Figure 1b**. During the summers of 1906 and 1907, the soda ash operators noticed that the evaporation of the waters from the lake surface was considerably below normal and that the level of the water was actually rising. They attributed this to seepage from the canals that migrated through the soil and into their lakes. Soon, however, the evaporation ponds began to flood and the levees broke, forcing both producers to terminate soda ash production. According to the correspondence between the Reclamation Service and Eugene Griswold which began in

1908 [letters from the files of the Truckee-Carson Irrigation District (TCID) (1908a, b; 1909)], beginning in 1908 the government determined that the excess water was from the higher-than-normal rainfall carried by the Carson River 4 kilometers (2.5 miles) away and not from their canals; therefore, the government denied any responsibility in the matter. In the 26 years before the canals were built, Griswold noticed there had been a net gain of between 20.3 and 25.4 centimeters (8 and 10 inches) of water in the lakes; however, the net increase had climbed to 61 centimeters (24 inches) since 1906 (TCID, 1908b).

Several years went by with both parties collecting data and exchanging letters. By January 1912, a new project engineer with the Reclamation Service, D.W. Cole, conceded that the canals did have a direct affect on the rise of the lake waters and suggested a settlement with the owners. He cautioned Griswold that he would have a hard time positively proving the extent to which the canal waters contributed to the damage because the farmers also had responsibility of irrigation control in the vicinity and that it would be impossible to determine the influence from either party. Although Griswold stated that his property was worth \$45,000 and generated an annual income of \$3,500, Cole recommended offering only a fraction of the value as settlement citing that Griswold would have a difficult and costly legal fight if the case went to court (TCID, 1909).

In July 1915, at the request of the U.S. Department of Justice, the U.S. Geological Survey began a comprehensive hydrologic investigation of the soda lakes to compare with the study done by Russell (1885). The report concluded that Big Soda Lake rose 4.76 meters (15.62 feet) between January 1, 1908, and December 22, 1915; the rise at Little Soda Lake was about the same. Since 1906, both of the lakes had risen about 5.18 meters (17 feet). Seepage loss was measured from the Carson River, canals, and irrigated lands; the direct source of water supply was from newly irrigated lands during the nonirrigating season and from irrigated lands adjacent to the soda lakes area (Lee and Clark, 1915). **Figure 4** shows Little Soda Lake in 1909.

The Natron Soda Company and the John Horstmann Company sued the U.S. government on June 25, 1917 for a total of \$205,000 in the U.S. Court of Claims in San Francisco. The case was decided on April 7, 1919, when the judge ruled in favor of the government (Court of Claims of the United States, 1919). The decision was appealed to the U.S. Supreme Court, which decided on November 21, 1921, that the government was not liable for dam-



Figure 3. Panorama of Big Soda Lake showing the evaporation ponds along the southern shore, 1905. (Photograph from Churchill County Museum and Archive, Fallon, Nevada.)



Figure 4. Little Soda Lake in 1909 from the same location as Figure 2. (Photograph from Churchill County Museum and Archive, Fallon, Nevada.)

ages. One major determining factor was the right-of-way agreement that Mr. Griswold and Mrs. Hattie Epperson had signed with the U.S. government on December 4, 1904. At the time, the U.S. government needed access onto their property to dig the diversion canals, and it seemed like a logical request. Nobody was aware of the potential water problems that would arise in the next couple of years with these canals. The agreement (TCID, 1908a) contained the following clause:

It is further agreed that in consideration of the premises the first party releases the second party from all claims for damages for entry, survey, or construction of said works.

Solicitor-General Beck issued a statement (Bulletin, 1921) that said the case set a precedent because:

The decision lays down the principle that the government is not liable for all actual damages resulting from public improvements, but only for such damages as inevitable to result and which, with due diligence and expert study, could have been anticipated.

Because the government had no prior knowledge that their canal project would adversely affect the soda lakes, both companies lost their bid to recover damages. It is an interesting note that the first commercial soda ash operation in the United States became involved in a landmark U.S. Supreme Court case.

It has been 90 years since the soda ash facilities were abandoned and flooded, and the level of Big Soda Lake is more than 15.2 meters (50 feet) higher today than it was in 1885 when detailed measurements were first taken. Through the years, the memories have faded about the events and the people associated with Little Soda and Big Soda Lakes and the part they played in the history of the U.S. soda ash industry. In 1978, however, people began telling stories about what was hidden in the murky depths of the lakes. At the request of the Churchill County museum, local divers Keith Chesnut, Ed Glass, and Mike Ansotegui volunteered to examine the bottom of Big Soda Lake to see if there was anything of historical significance (Taylor, 1987). Photographs were taken showing the remains of buildings, a stationary boiler (Figure 5a), kilns (Figure 5b), and

other equipment. In 1982, a detailed underwater archaeological survey mapped these locations. An effort was started in the 1980s to nominate the site to the

National Register of Historic Places; however, the momentum reportedly has waned. The operations may be gone, but they will never be forgotten.



Figure 5a. Diver examining the remains of a boiler at the bottom of Big Soda Lake. Underwater photograph taken at the request of the Churchill County Museum. (Photograph from Churchill County Museum and Archive, Fallon, Nevada.)



Figure 5b. Diver swimming past part of a furnace at the bottom of Big Soda Lake. Underwater photograph taken at the request of the Churchill County Museum. (Photograph from Churchill County Museum and Archive, Fallon, Nevada.)

Owens Lake, California

One of the earliest surveys of Owens Lake in Inyo County was done in 1856 and 1857 by A.W. von Schmidt, who established a meander line around the shore; this line has been used as a base in many subsequent surveys. Despite the dangers and difficulties encountered by the early pioneers in that part of the West, several important mineral locations were found for salt, soda, and borax as early as 1865 (Dub, 1947). Although John Wemple Searles first recognized the economic importance of borax in 1862, it was not until 1873 that he and his brother Dennis formed the San Bernardino Borax Mining Company. In 1908, the California Trona Company was formed to produce soda ash by using the old equipment from the Searles' borax plant. The operation was never successful. The first soda ash produced at Searles Lake in Trona, California was in 1931 by the American Potash and Chemical Corporation (Moulton, 1981).

Dr. Oscar Loew, who was a member of the Wheeler Survey in 1875, was perhaps the first to recognize the importance of finding sodium carbonate present in Owens Lake. He estimated that the deposit contained 20 million tonnes (22 million short tons) of dissolved sodium carbonate, enough to supply the United States for about 100 years (Chatard, 1890). At the time, the lake was 27.4 kilometers long by 14.5 kilometers wide (17 miles long by 9 miles wide) at its greatest width and had a total surface area of 285 square kilometers (110 square miles); its greatest depth was recorded at 15.5 meters (51 feet).

The fortunes made from the gold and silver mines of the Nevada Comstock Lode prompted investors to extend the rail lines to the south into the Owens Valley where prospectors were making discoveries of other minerals. In 1880, the Central Pacific Railroad in Reno connected with the Virginia and Truckee Railroad at Mound House, Nevada, which linked up with the narrow gage Carson and Colorado Railroad to reach Keeler on the eastern shore of Owens Lake in August 1883 (Ver Planck, 1959). The owners of the Carson and Colorado Railroad were D.O. Mills of New York and H.M. Yerington, who saw an opportunity to ship more than precious metals. After hearing about the abundance of sodium carbonate in Owens Lake and the growing demand for soda ash in the West, Mills and Yerington formed the first soda ash company in California—the Inyo Development Company—on April 2, 1885.

The Inyo Development Company constructed a plant north of Keeler that began producing crude soda during the winter of 1885-86 under the direction of L.F.J. Wrinkle, a mathematics professor at the University of Nevada (Dub, 1947). **Figure 6** shows a view of the plant that was taken about 1910. The first results were disappointing because of the lack of experience of the people involved. Dr. Thomas Marean Chatard, who was a noted chemist with the U.S. Geological Survey in Washington, D.C., visited Owens Lake during the summers of 1886 and 1887 and was permitted to collect and analyze samples of the lake water. In July 1886, Wrinkle obtained the services of a man named Browning, who had worked at the Ragtown soda lakes and was experienced in constructing evaporation vats (Wrinkle, 1886). Frank Gray, who also came from Ragtown, was hired to manage the operation when commercial production began in the summer of 1887. This is probably the same Mr. Gray who was referenced earlier as the operation supervisor of the Nevada Soda Company at Big Soda Lake in 1881.

At the beginning of warm weather, the evaporation ponds were filled with lake water. After evaporation, the brine reached a certain density, and trona began to crystallize on the bottom of the ponds. The mother liquor was often replaced with fresh lake water when other salts began to form. The ponds were drained around October 1, and the three-quarter inch layer of trona was harvested. Some of the trona was sold as crude soda, and the remainder was processed into a 95% pure soda ash product by heating it in a reverberatory furnace to drive off the water of crystallization and the excess carbon dioxide present in the sodium bicarbonate. The finished product was ground to produce a more dense material preferred by glass producers.

In November 1887, Chatard wrote to Yerington in response to a job offered to him the preceding summer. Apparently, Chatard had been asked to take charge of the operations because of his technical expertise (Chatard, 1887). He would be paid \$3,000 per year and 1000 shares of stock for his past services (Chatard, 1888b) and was told to keep the matter private. Chatard was prepared to resign from the U.S. Geological Survey in January 1888 and go to Keeler by March 1 but wanted confirmation from Yerington about the job (Chatard, 1888a). Wrinkle was furious that Chatard was being offered a job and implored



Figure 6. The Inyo Development Company plant north of Keeler, California, about 1910. (Photograph from Eastern California Museum, Independence, California.)

Yerington not hire him, stating that Chatard was “a mere laboratory chemist, inexperienced in the manufacture of soda,” that he was “dumb as an oyster” about how to crush the crude soda, and that “if he was any great shakes he would not be in a subordinate position in Government employ at \$120-per month” (Wrinkle, 1888). Wrinkle obviously regarded Chatard as a threat to his own position as superintendent and wanted to discredit him.

Without warning, Chatard was notified by a telegram from Yerington (Yerington, 1888) and told not to resign his job at the U.S. Geological Survey. Apparently an article had been written in a New York newspaper on January 21, 1888 that quoted Chatard as saying he was quitting his government job and going west, which Yerington wanted kept secret. Chatard also allegedly discussed the “drying out of the lake,” which Yerington interpreted as negative publicity about his operation. An appeal was made to D.O. Mills, Yerington’s partner. In a letter sent to Mills, Chatard adamantly denied talking with reporters but conceded that some newspapermen in Washington, D.C. could have found out about his plans to leave the U.S. Geological Survey because it was common knowledge within the organization (Chatard, 1888b). Chatard suspected that Wrinkle was somehow con-

nected to the news story, especially when he found out from Mills that the San Francisco Examiner carried a story about Owens Lake (with the information purportedly furnished by Wrinkle) that was used as the basis of the New York article (Chatard, 1888c). Although his opportunity to join the Inyo Development Company was gone, Chatard remained with the U.S. Geological Survey and published the results of his scientific investigations of Owens Lake in a comprehensive report (Chatard, 1890).

Soda ash on a 48 to 55% alkali basis sold in 1889 for \$15 per ton, f.o.b. Keeler, or \$25 per ton in carload lots in San Francisco. Imported soda ash from England was selling for \$29.75 per ton in San Francisco. Communication between Eugene Griswold, president of the Natron Soda Company at Big Soda Lake at Ragtown, Nevada, and H.W. Yerington suggested that both companies exchanged soda products and information to improve the quality of their respective products (Griswold, 1888). Both were now competing not only with imported soda ash on the West Coast, but synthetic soda ash, which had been first produced at Syracuse, New York in 1884. Because rail rates from Keeler to St. Louis and Chicago were \$10 per ton, no natural soda ash could economically be shipped to the Midwest (Wrinkle, 1890).

L.F.J. Wrinkle remained the superintendent of operations for the Inyo Development Company into 1893. Sometime before 1904, his son Noah Wrinkle assumed the position but resigned in July 1907 citing family responsibilities and a desire to leave the area (Wrinkle, 1907). In 1908, he was succeeded by F.E. Fritsche, who was succeeded by F.L. Young in 1909. Noah Wrinkle did not leave the area but instead formed the Natural Soda Products Company in 1912; it stayed in operation until 1927.

By 1900, the Inyo Development Company had an annual capacity of about 9072 tonnes (10,000 short tons) and employed about 150 workers during harvesting season. **Figure 7** shows some workers using picks and shovels to harvest the crude trona from the ponds and pushing wheelbarrows to haul it to the plant. By 1914, the demand for water in Los Angeles and other cities required the construction of the Los Angeles aqueduct, which diverted water from the eastern side of the Sierra Nevada in the Owens Valley. For the next several years, Owens Lake was drying up, which concentrated the level of sodium carbonate in the lake waters. In 1918, the company was sold to the California Alkali Company, which had constructed a soda ash plant in Cartago, California in 1917. The Inyo Development Company's facility operated until 1920, and the property was leased in 1922 to the Natural Soda Products Company, which never

did anything with the operation (Ver Planck, 1959). In the next few decades, several more soda ash companies built plants along the margins of Owens Lake.

Production of natural soda ash from Owens Lake could not keep up with the increased domestic demand caused by World War II and the Korean Conflict. Beginning about 1950, competition from the new natural soda ash venture in Green River, Wyoming also contributed to the decline in soda ash production in the West. The last plant to produce refined soda ash at Owens Lake was the PPG facility, which closed in 1968 (**Table 1**). Lake Minerals Corporation, which is a joint venture between Cominco American and Vulcan Chemical Company, continues to harvest crude sodium salts from the surface of Owens Lake.

Since Owens Lake became a dry lake bed about 75 years ago, the airborne particulate matter that has blown from the dry lake surface has caused respiratory and air pollution problems that exceed the requirements of the Clean Air Act. The air pollution control managers of Owens Valley and Inyo County have developed a mitigation plan that would force the Los Angeles Department of Water and Power to restore part of the water back to Owens Lake (Booth, 1997). This action would result in the flooding of this deposit, which could affect its economic potential



Figure 7. Workers using picks and shovels to harvest the crude trona from the evaporation ponds at Owens Lake, California. (Photograph from Eastern California Museum, Independence, California.)

because many companies continue to regard Owens Lake as a viable economic resource compared with other deposits in the world.

Water has played an important, if ironic, part in the history of the first natural soda ash operations in Nevada and California. Production from the Ragtown soda lakes ended because a water diversion project

flooded the lakes, and production from Owens Lake declined because a water diversion project dried up the lake. Water irrigation projects also caused the closure of two soda ash plants in Washington in 1941: the Sodium Products Company at Mitchell Lake and the Washington Sodium Products Company at Carbonate Lake.

Syracuse, New York

Origin of synthetic soda ash

Fresnel, the French optician, is credited with discovering the chemical reaction of the ammonia-soda process in 1811 but was unable to implement his idea fully. By this time, the LeBlanc process was in its infancy in Europe. In 1838, two Englishmen, Harrison Gray Dyar and John Hemming, obtained a patent for treating brine with carbonate of ammonia and a subsequent patent was issued to Delaunay in 1839. Dyar and Hemming built plants in Whitechapel, England, but after two years they were unable to commercialize the chemical process successfully and abandoned their project in frustration (Cominoli, 1990). The introduction of carbon dioxide in gaseous form was patented by Canning in 1840. In 1852, Crinus, a Frenchman, succeeded in recovering the gas liberated by the calcination of sodium bicarbonate. That same year, Chisholm patented the distillation of ammonium chloride with lime and the subsequent absorption of the gas in brine (Martin and others, 1916). By 1852, all of the chemical reactions necessary for synthesizing soda ash were known. Ernest and Alfred Solvay, sons of a Belgian salt manufacturer, became the first to incorporate successfully all the concepts and equipment necessary to develop the ammonia-soda process. On April 15, 1861, they received a patent for manufacturing soda ash by using salt, limestone, ammonia, and coal. The secret to their success was the addition of carbonating towers in the process. With the financial backing of Eudore Primez, Ernest formed Solvay and Company in 1863, constructed a plant at Couillet, Belgium in 1864, and began operations in January 1865. By 1866, the plant was producing 1.5 tonnes of synthetic soda ash daily. By 1872, production had increased to 10 tonnes per day. The success of the Couillet facility led to the construction of a second plant in Dombasle, France. This was the beginning of the ultimate displacement of the more expensive LeBlanc soda ash process.

In April 1872, Ernest Solvay was contacted by Ludwig Mond, who wanted to license the Solvay

technology and construct an ammonia-soda plant at Winnington, Cheshire, England. The agreement between the two was signed September 23, 1872. Mond and his friend and financial partner, John Tomlinson Brunner, formed Brunner Mond and Company in 1873, and the first English soda ash plant came onstream in 1874 (Dick, 1973). Synthetic soda ash production using the ammonia-soda process was now firmly established in Europe.

Synthetic soda ash in the United States

In February 1879, William B. Cogswell heard a presentation titled "The Manufacture of Soda by the Ammonia Process," by Oswald J. Heinrich in Baltimore, Maryland, at the American Institute of Mining Engineering. Heinrich cited the following advantages of the ammonia-soda process over the LeBlanc process: fuel economy, low production costs, and smaller investment (only one-tenth of the amount required in the LeBlanc method). The industrial growth after the Civil War in the United States caused the demand for soda ash to increase. Rather than relying on soda ash imports to supply the needs of the East Coast glass, detergent, and chemical manufacturers, Cogswell obtained letters of introduction from Heinrich, and sailed to Europe to meet with the Solvays about using their process in the United States. Unfortunately, the Solvays had an earlier bad experience with a boisterous American promoter who "planted his cowhide boots against Alfred Solvay's walnut desk, tilted back his chair, and proceeded to lay down the terms upon which he would make the Solvays a 'blooming, everlasting fortune'" (Haynes, 1940). Consequently, the brothers refused to see Cogswell. In time, however, Cogswell's knowledge, courtesy, and tact won the respect of the brothers who agreed to provide their technology in exchange for the right to subscribe to one-third of the stock (3000 shares at \$100 per share) and one half of the profits after 10% dividends had been declared to the stockholders (Cominoli, 1990).

In the fall of 1881, the Solvay Process Company was incorporated in New York for the purpose of constructing the first synthetic soda ash plant in the United States. With a capital of \$300,000 (one-third supplied by the Solvays and two-thirds supplied by Hazard, Cogswell, and a few of their friends in Syracuse), Rowland B. Hazard, William B. Cogswell, William A. Sweet, Earl B. Alvord, and George E. Dana began building the plant in September, 1881 on a 20.2-hectare (50-acre) tract in Geddes, which was about 4.8 kilometers (3 miles) west of Syracuse. The site was selected because of the availability of salt, limestone, and coal, which were the essential raw materials. Also, the location provided access to the New York Central Railroad and the Erie Canal to ship the finished product to customers. The first major problems were the lack of qualified workers and blueprints for construction. Because Cogswell and William L. Neill, who was the first employee hired by the new Solvay Process Company, could speak fluent French and German, they traveled to Dombasle, France in the winter of 1881-82 to work as apprentices to learn how to make synthetic soda ash at the Solvay plant. When Cogswell returned in the spring of 1882, he began recruiting chemists and engineers to operate the Syracuse facility; Edward N. Trump became the chief engineer. In April 1883, Neill was joined in France by Henry Cooper, John Bodot, and J. William Smith, who also learned the science of making soda ash from their European masters.

The first attempt to make soda ash at the first synthetic soda ash plant in the United States coincided with the night of the company's first official accident. At 11:00 p.m. on Tuesday, January 8, 1884, several men almost suffocated to death from the carbon dioxide gas contained in the carbonating towers. Cooper and Cogswell were hurt, and one man in the tower died (Cominoli, 1990). The operation officially began on January 10, 1884. Out of a possible 355 days that year, the facility actually ran for 332 days and produced about 11,160 tonnes (12,300 short tons) of 58% alkali. Later in the year, the first officers and staff of the Solvay Process Company posed for a group photograph with several officials from Europe, including Ernest Solvay and John Brunner (**Figure 8**). The first year of operation was not without its problems. At 4:10 a.m. on January 13, 1885, an improperly vented iron distilling vessel exploded and destroyed the roof of the main building. Of the 50 men who were subjected to falling debris, corrosive fumes, and scalding chemicals, only ten were injured and one died from ammonia inhalation. The accident forced the temporary closure of the plant for 30 days. In early 1885, plans were made to double the output

by expanding the facility. The expansion was completed in February 1886 and raised the annual soda ash capacity to nearly 40,800 tons (45,000 short tons). **Figure 9** shows the Syracuse plant and the Erie Canal about 1913.

In 1869, which was before the Syracuse plant was built, the United States imported 59,578 tonnes (65,674 short tons) of soda ash that sold at \$39.55 per tonne (\$35.88 per short ton). The selling price of Syracuse soda ash in 1885 was \$29.30 to \$30.63 per tonne (\$26.58 per short ton to \$27.79 per short ton), with 58% sodium oxide, whereas the price of imported soda ash that year declined to \$25.90 per tonne (\$23.50 per short ton) (Day, 1888). Soda ash production at Syracuse in 1885 was 15,240 tonnes (16,800 short tons) and total imports of soda ash, primarily from England, were 118,357 tonnes (130,466 short tons). In that same year, England produced 266,267 tonnes (293,509 short tons) of soda ash; 187,493 tonnes (206,675 short tons) of soda ash by the LeBlanc process and 78,775 tonnes (86,834 short tons) by the ammonia-soda process. If almost all the U.S. imports were from England, then the United States consumed 44% of England's total output. During the next decade, however, imports steadily declined as domestic soda ash production increased.

By the mid-1880s, natural soda ash production had begun at Owens Lake in California, and was at its peak at the soda lakes in Nevada; however, the output from these operations remained in the West because of the distance to eastern markets. In 1887, U.S. consumption of soda ash, by end use, was estimated at glass, 25%; sodium bicarbonate and sal soda, less than 25%; paper manufacture, 20%; soap and chemicals, nearly 20%; and other uses, 10% (Day, 1888). In 1898, only 39,936 tonnes (44,022 short tons) were imported from England. At its annual meeting on March 17, 1899, the United Alkali Company, Ltd., of Liverpool, England, met to discuss the problem of decreasing exports to the United States (Rothwell, 1899).

The Solvay Process Company constructed three more synthetic soda ash plants in United States during the next several years: Detroit, Michigan (1898), Hutchinson, Kansas (1908), and Baton Rouge, Louisiana (1935). Writing about his 50 years in the alkali industry, Edward Trump in 1933 believed the Solvay Process Company was perhaps the first American company to reduce shift work from 12 hours to 8 hours, and provide accident, health, and old-age pension plans (Trump, 1933).



Figure 8. The first officers and staff of the Solvay Process Company, Syracuse, New York, and European and other American officials, 1884. 1. William B. Cogswell, General Manager; 2. Edward Hannon, Solvay and Cie, Belgium; 3. Edward N. Trump, Chief Engineer; 4. Rowland G. Hazard, Vice President; 5. Ernest Solvay, Solvay and Cie, Belgium; 6. John Brunner, Brunner Mond and Company, Winnington, England; 7. Rowland Hazard, President; 8. John Wing, Wing and Evans, New York; 9. Frederick R. Hazard, Secretary; 10. J. William Smith, Engineer; 11. Henry R. Cooper, Engineer; 12. Baron Vanderstratten, Solvay and Cie, Belgium; 13. Nathaniel T. Bacon; and 14. Edmond Solvay, Solvay and Cie, Belgium. (From Allied Chemical Company, now known as General Chemical Corporation.)

The company expanded into other chemical enterprises and formed sister companies, such as the Semet-Solvay Company, and General Chemical Company, which were consolidated under the name of Allied Chemical and Dye Corporation on December 17, 1920. The General Chemical Company name was resurrected prior to the Syracuse shutdown in 1986 when Allied Chemical divested itself of its soda ash and other chemical businesses. General Chemical continues to operate soda ash plants in Amherstburg, Ontario, Canada (an ammonia-soda operation), Green River, Wyoming (a trona mine and soda ash refinery), and some other chemical plants.

With the demonstrated success of the Solvay process, other companies entered the synthetic soda ash

business, including Diamond Alkali Company (later renamed Diamond Shamrock Corporation), Mathieson Alkali Works, Inc. (renamed Olin-Mathieson; later Olin Corporation), Michigan Alkali Company (renamed BASF Wyandotte Corporation), Pittsburgh Plate Glass Company (later known as PPG), and Southern Alkali Corporation (owned by Pittsburgh Plate Glass Company and American Cyanamid Company). Dow Chemical Company also operated a caustic carbonation plant in Freeport, Texas. By 1939, ten Solvay plants were in operation in six states throughout the nation. Competition from the natural soda ash operations in California and Wyoming, the costs to implement pollution abatement equipment mandated by environmental legislation, and rising energy costs ultimately were responsible for closing



Figure 9. The Solvay Process Company, Syracuse, New York, seen from across the Erie Canal, 1913. (From Allied Chemical Company, now known as General Chemical Corporation.)

nine of the ten synthetic soda ash plants in the United States. On September 12, 1981, Allied Chemical celebrated the Syracuse plant's 100th anniversary. After 100 years of operation, the nation's first synthetic soda ash plant had the distinction of being the last one.

Glass production began decreasing after 1980 because of glass recycling and the growing use of aluminum cans and plastic bottles that displaced glass containers. By 1986, 30 glass plants had closed east of the Mississippi River, thus reducing soda ash con-

sumption. Competition from the natural soda ash plants in California and Wyoming also affected the economic position of the Syracuse facility. As a result, the Syracuse plant was officially closed on January 6, 1986; total shutdown was completed by February 1986. The closing of the 105-year-old plant eliminated 1500 jobs, or about one-third of the residents of the town of Solvay, and an annual payroll of \$46 million. Much of the complex has been demolished but parts still stand today as a tribute to this historic symbol of the U.S. soda ash industry.

Green River, Wyoming

The presence of alkali had been known in the territory that became Wyoming since at least 1835 when the Reverend Samuel Parker crossed the Rocky Mountains and noticed epsom salts on the ground near Independence Rock, Wyoming. Mormon pio-

neers traveled across the territory and found "sweetwater," a term for the taste of the waters and the name of the county that contains the majority of the trona resource. They reportedly used the natural sodium bicarbonate that occurs in the Sweetwater

River for laundry and medicinal purposes as early as 1849. One of the first famous geological expeditions in Wyoming was headed by Major John Wesley Powell, who later became the second director of the U.S. Geological Survey. Powell and nine other geologists, geographers, and scouts set out from Green River at 1:00 p.m., May 24, 1869 to follow the Green and Colorado Rivers and explore the last great un-mapped part of the continental United States (Powell, 1895).

Early soda ash production attempts

Attempts to produce soda ash in Wyoming from surface deposits or from underground brine sources were few and short-lived. The Union Pacific Railroad owned some soda deposits that it discovered in the early 1870s about 21 kilometers (13 miles) south of Laramie. They were known as the Union Pacific lakes, five lakes that had a total area of about 809 hectares (2000 acres). Jay Gould, who was a member of the Union Pacific board of directors, sent his chief engineer, T.E. Sickels, to Europe to find out how to make soda ash (Brown, 1995). Although homesteading pioneers around the lakes delayed the development of the deposits, some of the property was leased to Howard Hinckley, who constructed a plant that produced 2 tonnes of caustic soda daily by using the LeBlanc process (Weeks, 1886). Because problems in the design of the plant caused delays and losses of caustic soda, the plant operated only from July 1884 to January 1885. Other soda lakes in the region include the Donney lakes [three lakes with a combined area of 210 hectares (520 acres)] located 29 kilometers (18 miles) southwest of Laramie and the Dupont lakes [four lakes ranging from 2.4 to 809 hectares (6 to 2000 acres) in area and containing these five claims: the Omaha soda, the Wilkes Barre, the Wilmington, the New York, and the Philadelphia] located about 80 kilometers (50 miles) north of Rawlins. The absence of a railway prohibited the development of these deposits.

The Union Pacific Alkali Works built a plant to develop the soda deposits of the Union Pacific lakes in 1895. In 1898, the American Development Company, and the American Native Soda, Glass and Chemical Company were incorporated to also develop the soda deposits in the region. Another company, the American Soda, Glass and Chemical Company, acquired the Union Pacific Alkali Works and reportedly began production in 1899 (Rothwell, 1899).

Discovery of trona

In the late 1890s, the Green River Fuel and Oil Company drilled an exploration well near Green River, Wyoming, and found alkali water at 38 meters (125 feet) (Brown, 1995). In 1902, The Wyoming Chemical Company was formed but was sold four years later to the Western Alkali Company, which invested \$500,000 to improve the property. Soda brines were pumped from three wells and evaporated in large open-air concrete basins. Sal soda crystallized first. Slaked lime was added to the sal soda and heated to produce caustic soda, which was used locally by the Union Pacific Railroad in water softening and by soap manufacturers in nearby states. Because the company defaulted on its mortgage, the operation was sold to F.J. Siegel and Associates of Denver (FMC Corporation, 1961) in 1908. This was incorporated into the Wyoming Soda Products Company, which operated until about 1918.

On October 29, 1937, Mountain Fuel Supply Company began drilling the John Hay Jr. No. 1 exploratory well on Federal land to search for oil or gas. After drilling to a depth of 1622.5 meters (5323 feet), the well was abandoned on January 3, 1938 because no oil or gas was discovered. William T. Nightingale, who was the company's chief geologist, noticed a variety of minerals in the drill cores and sent sections of the cores taken from depths of 485.9 to 487.7 meters (1594 feet to 1600 feet) to Howard I. Smith, who was chief of the mining division of the U.S. Geological Survey in Washington, D.C. Although trona was identified in the cores by Roger C. Wells (who authored the 1917-20 sodium salts chapters in reports published by the U.S. Geological Survey; see table 2), it was the discovery of the new mineral, shortite, by Joseph J. Fahey that initially intrigued the U.S. Geological Survey (Fahey, 1939).

The following two sentences in an obscure paragraph in Fahey's 1939 article caught the attention of Robert D. Pike, a consulting chemical engineer from Pittsburgh (Anonymous, 1953). It stated:

Massive trona is present at depths of 1325 feet and 1587 1/2 feet, but is not found associated with the new mineral. At the lower depth shortite is present in the clay that overlies the massive trona.

Pike caught the significance of this statement and convinced the Union Pacific Railroad to do some more exploration. Joseph Fahey went to Wyoming to pack and ship the remainder of the core back to

Washington, D.C., where he finished logging and identifying the minerals in it. In January 1940, Walter C. Mendenhall, director of the U.S. Geological Survey, officially announced the occurrence of the Green River trona deposit (Mendenhall, 1940). Through the persistence of Pike, who was hired by the railroad at \$500 per month and no expenses, the Union Pacific Railroad cored two more holes, numbers 1 and 2, in 1940 that confirmed the existence of the trona bed discovered in the John Hay Jr. No. 1 well. Hole numbers 3 and 4 drilled in 1942 also confirmed the existence, analysis, thickness, and depth of the trona deposit. Senator Joseph C. O' Mahoney of Wyoming, who chaired the U.S. Senate subcommittee of the Public Lands Committee, heard about the trona find and invited Pike to testify on July 23, 1941 about its importance (Chemical and Metallurgical Engineering, 1941). Pike approached his friend, Dr. Max Y. Seaton, who was Executive Vice President of the Westvaco Chemical Corporation, to discuss the opportunity for developing this deposit despite the fact that Westvaco was not in the soda ash business.

Although Westvaco became interested in the idea, actual work on the operation was suspended until after the end of World War II. Between 1944 and 1946, Westvaco Chemical Corporation drilled three more wells in the region that showed that the main trona bed was at least 78 square kilometers (30 square miles) in area. In the spring of 1946, Westvaco notified the Union Pacific of its intention to sink a mine shaft and to construct a trona processing plant. A concrete-lined vertical shaft 3.7 meters (12 feet) in diameter was sunk during the early months of 1947.

After reaching the 457-meter (1500-foot) level, workers stood for the first time on top of the main trona bed, Bed 17; three companies currently mine this bed. Mining equipment was disassembled on the surface, lowered down the shaft, and reassembled below to begin the development of the honey-combed maze of rooms and pillars. After being deposited more than 52 million years ago, the first skipload of trona was brought to the surface in late 1947. In the fall of 1948, the Westvaco Chemical Corporation was acquired by the Food Machinery Corporation in the fall of 1948.

For the next two years, the company experimented with different mining techniques and equipment. **Figure 10** shows a Goodman 665 ore loader being delivered in 1949. In 1950, 38,896 tonnes (42,875 short tons) of trona was mined and processed into calcined trona, which was the first commercial product sold. In 1952, the Westvaco Chemicals Division of the Food Machinery and Chemical Corporation (later to be known as FMC Corporation) formed the Intermountain Chemical Company (**Figure 11**), which was Wyoming's first trona mining company. The company expanded its operation in April 1953 to begin producing refined soda ash by a sesquicarbonate process. The plant, which cost \$20 million and employed 325 persons, had a total annual nameplate capacity of 272,000 tonnes (300,000 tons).

Several people contributed to the success of the plant during its first year of operation including: C.A. Romano, resident manager; John Jacobucci, plant



Figure 10. Delivery of a Goodman 665 ore loader to Westvaco Chemical Corporation, 1949. (Photograph from Sweetwater County Historical Museum, Green River, Wyoming.)

superintendent; A.P. McCue, assistant plant superintendent; G.B. Gaylord, superintendent of underground operations; Robert F. Love, assistant mine superintendent; N.E. McDougal, superintendent of surface operations; William C. Bauer, superintendent of processing engineering; E.V. Birmingham, maintenance superintendent; and L.K. Marshall, mining engineer.



Figure 11. Construction of FMC's soda ash plant, 1952. (Photograph from Sweetwater County Historical Museum, Green River, Wyoming.)

For the next 50 years, FMC expanded to become the largest producer of natural soda ash in the world. It was followed by four more companies: OCI Chemical Company (formerly Stauffer Chemical Company and Rhône-Poulenc Basic Chemicals Company) in 1962;

General Chemical Corporation (formerly Allied Chemical Company) in 1968; Tg Soda Ash, Inc., in 1976; and Solvay Minerals, Inc. (formerly Tenneco Mineral Company) in 1982.

Summary

The Greek historian Thucydides (ca. 400 B.C.) once stated:

I shall be content if those shall pronounce my history useful who desire to have a clear view both of the events which have happened, and of those which will some day, in all human probability, happen again in a same or similar way.

In some ways, history is repeating itself. Some old company names that have come and gone have been resurrected: the formation of Brunner Mond and Company in 1881, its merger into ICI in January 1927, and the reappearance of the name Brunner

Mond in 1991; the formation of General Chemical Corporation in 1899, its merger into Allied Chemical and Dye Corporation in 1920, and the reappearance of the name "General Chemical" in 1985; and the reporting of soda ash information that began in the U.S. Geological Survey in 1882, its transfer to the U.S. Bureau of Mines in 1924, and its return to the U.S. Geological Survey in 1996. Perhaps Thucydides was right.

An industry is measured by the legacy it leaves to the next generation. The accomplishments and failures of this generation of soda ash producers will be measured by their successors in the twenty-first century.

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