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The Lithium Production Curve: A Measure of Many Things

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Curves that trace the production history of mineral commodities in an industrialized nation, like the ink blots of the psychoanalyst, may be seen differently by different persons, their viewpoints being affected by prior conditioning. The curve shown here (Figure 1), although recording a single, pounds-per-year statistic, might be viewed as reflecting variously the labor and skill involved in winning the raw material; the state of health of a given concern or group of concerns; the availability of raw materials at given times: variations in the demand for the materials as controlled by changing use patterns and population growth; or the degree to which an industry can adjust to national emergencies. The viewpoint(s) held would depend upon the primary interest of the viewer, who might be a mine or mill superintendent, company executive, exploration geologist, mineral economist, historian-demographer, or any other interested person. To at least some Pennsylvanians, the lithium production curve holds special interest, because considerably more than half of the world's output of lithium is produced by a company based in the state, namely, the Foote Mineral Company of Exton, Pa., and also because this company is sponsoring a research project in the College of Earth & Mineral Sciences at Penn State that may well provide an indication of the future shape of the curve.

The curve shows several periods of rapid growth in the production of lithium chemicals, each of which was succeeded by a period of over-capacity and lower prices.[1] These factors have tended to stimulate the development of additional uses resulting in yet another round of expansion. They have also stimulated the search for new sources from which lithium could be extracted more economically.

Lithium from Zoned Pegmatites

The prime sources of lithium prior to the late 1930's were pegmatite bodies containing high-grade but relatively small

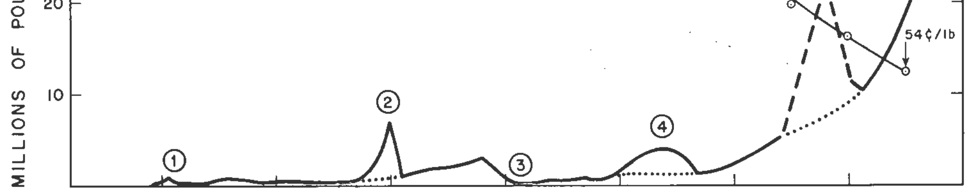

Fig. 1. *Curves showing lithium production in United States, as pounds of LiOH equivalents, and the price of lithium hydroxide in recent years. Index map shows locations of principal sources; each indicates point on curve that represents time of initial production from that source. Numbers refer to irregularities on production curve caused, in order, by (1) opening of lepidolite bodies at the Stewart mine, San Diego County, Calif. (Fig. 2); (2) renewed activity at the Stewart mine and the first use (during World War I) of lithium in alkaline storage batteries; (3) the economic depression; (4) use (during World War II) of large quantities of lithium hydroxide to inflate rescue apparatus, and in the development of multipurpose lithium greases; (5) lithium purchase program of the U. S. Atomic Energy Commission.*

concentrations of lithium minerals. Although approximately 145 minerals contain lithium as a major constituent, only spodumene, lepidolite, amblygonite, petalite, and eucryptite have been commercial sources of lithium. Each occurs in pegmatite bodies. These minerals have been mined from irregular, shallow workings, and generally hand sorted. Early investigators of lithium-bearing pegmatites believed that the concentrations of lithium minerals were unsystematically distributed within a given body. During and after World War II, however, detailed studies of pegmatites by geologists of the U. S. Geological Survey showed that most lithium - bearing pegmatite bodies display an orderly internal structure featured by zones of contrasting mineralogy and/or texture (Figure 2). Although an understanding of the nature and distribution of these zones facilitated the exploration for lithium, mining of the lithium minerals continued to be difficult and costly.

The best known and most productive of the zoned pegmatite operations was the Etta Mine, in the Black Hills of South Dakota, where spodumene was produced almost continuously for fifty years. Several other zoned pegmatites in the Black Hills and in southern California (Figure 2), northern New Mexico, and Colorado, had noteworthy records of production in those early years.

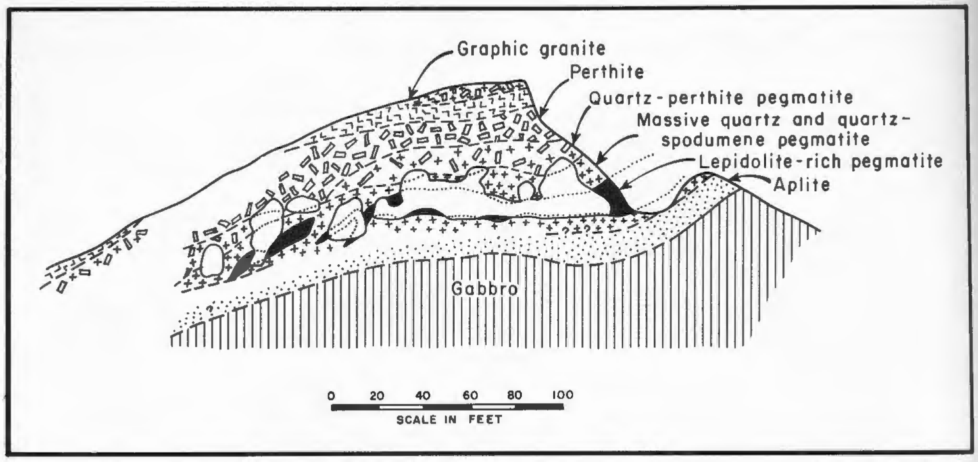

Fig. 2. *Generalized geologic cross section through zoned, lepidolite-bearing pegmatite dike at the Stewart mine, San Diego County, Calif., modified from Jahns and Wright.*[4]

Searles Lake, California

For as long as the zoned pegmatite bodies constituted the only obvious reserves of lithium-bearing raw material, it was generally assumed that lithium compounds would continue to be available only in limited amounts compared with most other industrial mineral substances. Then, in 1938, a hitherto unnoticed lithium reserve became suddenly productive when the American Potash and Chemical Corporation began to produce dilithium sodium phosphate in its chemical plant at Trona in the desert of eastern California. This plant, which had been constructed during World War I to recover potassium chloride and sodium carbonate from brine pumped from beneath the dry surface of Searles Lake, had since become a major source of these and other chemicals, including borax and sodium sulphate.

Although the brine of Searles Lake contains the equivalent of only about 0.015 percent Li_2O by weight, at one step in the main cycle of brine treatment the extraction of this lithium proved economically feasible. As the lithium of Searles Lake was recovered as a byproduct, expansion of the domestic lithium industry continued to seem restricted. The immediate effect of the lithium development at Searles Lake, although unevidenced on the curve, was curtailment of the pegmatite operations. It also called attention to the possibility that systematic exploration would reveal occurrences of brines that could be treated largely or solely for the recovery of lithium.

Foote Mineral Company entered the field of industrial chemicals in 1933, and just before the outbreak of World War II opened a plant at Exton, Pa., which was quickly expanded to handle government contracts for the purchase of lithium chemicals for various wartime applications. The plant utilized dilithium-sodium-phosphate for these purposes from the operation at Trona.

Kings Mountain, North Carolina

During World War II, the lithium industry was brought under the authority of the War Production Board, which ordered an immediate expansion of production facilities. The search for sources of lithium was intensified and resulted in exploration of a group of unzoned bodies of spodumene - bearing pegmatite distributed along a narrow sinuous belt averaging less than a mile wide, and extending from Gaffney, S. C., northward for about thirty miles to Lincolnton, N. C. These bodies proved to contain the world's largest known reserve of spodumene. They occur in weakly metamorphosed rocks, the largest of the pegmatite bodies filling northeasterly trending fractures in gneiss and schist. The largest known concentration of spodumene-bearing pegmatite in this belt was discovered at a locality southeast of Kings Mountain, N. C. There several large and closely spaced bodies crop out within an area two miles long and half a mile wide. The largest of these is about 1,500 feet long and 350 feet wide.

Before 1940, mining operations in the area were small scale and intermittent. Then the Solvay Process Company acquired the property, built a flotation plant, and began production of both spodumene and feldspar. This operation, which lasted from 1942 to 1945, yielded less than 15,000 tons of spodumene concentrate, most of which was sold to the Foote Mineral Company. By 1948, the market for lithium chemicals had become large enough to encourage the Foote Mineral Company to acquire a long-term reserve of raw material, and the company bought the Solvay property in October, 1950.

Extensive exploration by drilling at Kings Mountain has proved an ore reserve of more than 20 million tons, averaging about 1.53 percent Li_2O.[2] In addition, indicated and inferred ore bring the total reserves to more than 35 million tons. The pegmatite bodies at Kings Mountain are currently being mined by open-pit methods (Figure 3). The present pit has eleven benches, each 20 feet high. In general practice, three benches are mined simultaneously with a new, deeper bench being opened as the upper one becomes exhausted of ore.

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The method by which a given pegmatite body is mined is determined largely by its width. In the quarrying of large bodies, the surrounding waste is removed first, thus exposing the ore on three sides to prevent contamination. Medium-sized orebodies are quarried after country rock has been first removed from the hanging wall side. This method permits the ore to be shot down-dip, thereby reducing both dilution of the ore and loss of ore in the waste.

Quarried ore from the open pit is transported by truck to a primary gyratory crusher which reduces it to 6 inches. From the primary, the ore is crushed further, then screened and separated by conventional flotation methods into a spodumene concentrate and various by-products. The spodumene concentrate is moved by rail to Foote's lithium processing plants at Sunbright, Va., and Exton. Spodumene ore from Kings Mountain is also purchased by Lithium Corporation of America, Inc. for conversion to lithium compounds at their plant at Bessemer City, N. C.

Purchasing Program of the Atomic Energy Commission

Lithium production was given a major impetus in 1953 with the announcement that the U. S. Atomic Energy Commission needed relatively large quantities of lithium hydroxide as a source of natural lithium for use in the production of thermonuclear bombs. Following fulfillment of the AEC contracts in 1960, the industry was left with three large plants and a disproportionately small market.

These developments forced producers to decrease prices and accelerate research expenditures in an effort to develop new uses and a wider acceptance by consumers. The "depression" also resulted in increased exploration for a less expensive source of lithium. Those engaged in the exploration were encouraged by the knowledge that lithium was known to exist in small proportions but large amounts in some brine, like that at Searles Lake; in hot springs; and in some clays, especially the mineral hectorite. The latter is higher in magnesia and lower in silica than most clay minerals and contains about one percent lithium. It is mined at a single locality in the Mojave Desert of eastern California. Although it is yet to be treated commercially for its lithium content, hectorite is used as a constituent of oil well drilling mud, as a constituent of pharmaceuticals, and as a beverage decolorizer.

A major objective of the search for lithium was discovery of a brine from which lithium could be recovered as a primary product, and if possible by a process that involved solar evaporation, thus assuring significant economies in energy costs and in the steps required to produce a saleable product from a lithium-bearing raw material. In such a brine a low magnesium content also is desirable because in the treatment of magnesium-bearing brines, magnesium hydroxide forms early and tends to absorb lithium which has remained in solution. Separation of the two is difficult and expensive.

Silver Peak, Nevada

An especially promising brine was discovered in a dry lake near Silver Peak in Clayton Valley, Nev., by Leprechaun Mining and Chemical Company of Las Vegas. In 1964, the Foote Mineral Company acquired Leprechaun's leases, continued exploration and development, and converted a mill, formerly used to treat silver ore by the cyanide processes, into a plant designed to recover lithium carbonate.

Foote is presently operating about thirty gravel-packed wells ranging from 300 to 800 feet deep. Brine with an average lithium content of about 0.03 percent is pumped through transit pipe lines into a series of evaporation ponds, where solar power is used to concentrate it many fold. Present total pond area exceeds 1,500 acres (Figure 4).

The strong, evaporated brine is pumped from the pond area to the processing plant in the village of Silver Peak, where it is treated for the final removal of calcium and magnesium. This purified solution is reacted with soda ash, and the resulting lithium carbonate is washed and dried.

The dry lake containing the brine covers an area of about 32 square miles in the center of a natural basin of interior drainage. Clayton Valley, being in the eastern rain shadow of the Sierra Nevada, is very arid. The evaporation rate averages about 54 inches per year; annual rainfall rarely exceeds 5 inches. The valley lies within the Basin and Range province and, like most valleys of the province, represents a structural as well as a topographic depression downdropped, with respect to the bordering ranges, along faults. The lake beds thus consist mostly of detritus derived largely or wholly from the ranges. Lithium in the brine may have been derived from the weathering of rocks in these ranges; it also may be of volcanic origin, as evidenced by the presence at the margins of the lake of lithium-bearing hot springs that appear to be genetically related to nearby volcanic rocks.

The research now underway in the College of Earth & Mineral Sciences is aimed at an improved understanding of the origin of the brine through (1) reconstruction of the history of Pleistocene sedimentation in Clayton Valley; (2) detailed studies of the mineralogy of lake bed cores; and (3) a search for possible lithium-rich source rocks in the bordering areas of bedrock.

Fig. 3. *View of quarry at Kings Mountain, N. C. Light-colored, spodumene-bearing pegmatite is selectively removed from darker waste rock along 20-foot benches.*

Fig. 4. *Evaporation ponds of the Foote Mineral Company in Clayton Valley, Nev. These cover about 1,500 acres. Lithium-bearing brine is pumped from wells located between the ponds and the far ridge. Part of the historic mining settlement of Silver Peak is in foreground.*

Studies of the cores have shown that the lake bed particles range in size from coarse-grained around the margin of the lake to fine-grained in the center. In the area from which the brine is now being pumped the beds consist chiefly of clay and silt and contain layers of salt in the upper part of the cored section. A lithium-rich clay mineral, probably hectorite, is abundant in the cores studied, and the brine from this area is also richer in lithium than in some other areas of the lake.

The possibility that most of the lithium has been brought to the basin from nearby hot springs is supported by the observation that, if water now issuing from the springs were to be concentrated to one tenth of its present volume, its composition would approximate that of the brine. Moreover, the presence of halite and gypsum in the lake beds suggests a high rate of evaporation during sedimentation. Thermal waters of volcanic affinities, however, have been shown to consist mainly of meteoric water and a relatively small proportion of juvenile water.[3] The lithium content of the springs in Clayton Valley, therefore, may be attributable to contamination by the brine. On the other hand, the lithium may have been introduced to the clay by thermal waters.

If the lithium in the brine was indeed derived primarily from the weathering of rocks that compose the nearby ranges, one could expect to find there units of relatively high lithium content. The ranges consist of rocks of an exceptionally wide variety of ages and types, including a terrane of crystalline rocks that contains at least one lithium-bearing pegmatite dike of Mesozoic or Tertiary age. Perhaps of greatest significance, with respect to the source of the lithium, is the extensive exposure along the margin of Clayton of faulted and tilted lake beds and extrusive volcanic rocks, both of late Tertiary age. Chemical analyses of the lake beds, of the soluble chloride salts contained in them, and of the extrusive volcanic rocks show relatively high lithium contents and suggest that these materials have contributed much of the lithium now contained in the beds and brine of the present lake.

Thus, a peculiar combination of chemical, structural, and climatic conditions apparently has controlled formation of the unusual lithium deposit. A genetic relationship between the lithium and the late Tertiary volcanism is strongly suggested, but whether the lithium in the brine is a direct product of the volcanism or of a secondary origin, derived by leaching of the Tertiary rocks, or whether it has still another origin, remains speculative.

Changing Use Patterns and Changing Prices

Changes in use patterns and prices have affected the configuration of the lithium production curve, just as much as have increases in the availability of raw materials. Indeed, the three controls are closely related, as the increase in recoverable reserves of lithium raw materials and the resulting economies of volume production have permitted lower market prices and have led to the development of new uses and markets. These have, in turn, increased the demand for the raw materials.

Today, lithium is marketed in three forms—as an ore and concentrate, as a metal, and as chemical compounds. About 57 percent of the tonnage of lithium-bearing raw materials produced annually in the United States is consumed in the form of lithium compounds, which are used principally in glass and other ceramic products, lubricating greases, absorption-type air conditioners, alkaline storage batteries, welding fluxes and brazing alloys, sanitizers, bleaches, fuels, and pharmaceuticals.

Ores and concentrates are consumed by the glass, ceramic, and porcelain enamel industries. About 34 percent of the total annual lithium output is in this form.

Metallic lithium is used in self-fluxing brazing alloys, polymer catalysts, high energy fuels, and many other materials, and accounts for less than 10 percent of the lithium market.

In the years ahead, these uses possibly will be overshadowed by the use of lithium in batteries designed to replace gasoline engines in automobiles and in other machines, thus serving to reduce air pollution. Lithium batteries developed for such purposes would contain lithium anodes and, perhaps, lithium-bearing electrolytes, and would be theoretically much longer-lived and lighter in weight than batteries that contain lead. At the present time they remain unperfected. If the large-scale use of lithium batteries should become feasible, the demand for lithium would increase far beyond anything envisioned by the early producers. The available reserves of lithium, however, seem adequate to serve this purpose and even to sustain a continuing rise in the curve.

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Zinc Plating of Carbonitrided Steel Parts

HAROLD J. READ, *Professor of Metallurgy*

During recent years there has been a marked growth in the use of industrial surface hardening techniques to increase the wear resistance of small parts such as screws, bolts, and components of calculators, typewriters, and other business machines. Because of its adaptability to mass-production methods, carbonitriding is one technique being used extensively to surface harden small parts made of soft, easily machinable, and inexpensive steels.

Unfortunately, hardened steel is even more susceptible to corrosion than ordinary steel; it is necessary, therefore, to provide corrosion protection for the hardened parts. A zinc coating, applied by electroplating the parts while they are being tumbled in a perforated barrel in a plating tank, has proven to be the best means of achieving this resistance, both in storage and in service.

Although the barrel zinc plating operation is a comparatively simple process and has been in extensive use for many years, problems began to appear when parts treated by gas carbonitriding were processed. Some batches would plate satisfactorily, whereas in some only a portion of the parts would plate. In still others none of the parts would take a deposit. The two latter situations occurred with sufficient frequency to constitute a major industrial problem. Accordingly, the American Electroplaters' Society sponsored a research project in the metallurgy section of the department of materials science of the College of Earth & Mineral Sciences to determine the basic cause of the plating failures. Under my direction, John Strasser undertook the project as a subject for his master's thesis.

Metallurgical examination by a number of metallographic and electro-chemical techniques—including electron and optical microscopy, electron-beam microprobe examination, hardness surveys, and polarization studies by potentiostatic methods—revealed that the common denominator in nonplatable parts was an abnormally high concentration of nitrogen in the surface of the hardened steel.

This discovery proved that when nonplating troubles occurred it was the operators in the heat treating department rather than those in the plating department who were at fault. More importantly, it pointed the way to simple remedial measures in the heat-treating operation, for it has been established that the nitrogen content of the coating can be controlled by proper regulation of the temperature and the ratio of natural gas to ammonia in the carbonitriding atmosphere. Industrial tests carried out in a plant in Chicago confirmed these findings.

Because it is likely that, owing to furnace and atmosphere control problems, some batches of nonplatable parts will always be produced, a remedial technique would be helpful. As a result of the research carried out by Mr. Strasser and me, it was found that a simple, inexpensive, low temperature heat treatment that did not significantly lower the hardness of the parts would diffuse enough nitrogen from the surface into the main body of the parts to make them platable.

Alumnus Arrested as Spy

Paul T. Bail, a graduate of the College of Earth & Mineral Sciences, was recently released after having been under arrest in Baghdad, Iraq, for more than a month. An oil engineer on loan to the internationally-owned Iraq Petroleum Company, the main exporter of Iraqi oil, Mr. Bail was held in connection with what Iraqi authorities described as "matters related to espionage." He went to Iraq a year ago for a two-year tour on loan from Standard Oil of New Jersey's Humble Oil Company. The Iraqi Information Minister said that Mr. Bail had been caught in possession of a radio transmitter and that he had been in contact with Iraqis now held on charges of spying.

Mr. Bail, who received the B.S. degree in 1943 and the M.S. degrees in 1956 in petroleum and natural gas engineering, denied the charges and said he only had an old short-wave receiver; that the outsize antenna it required aroused the suspicions of the Iraqis at the time of the trial and execution of 14 persons as spies, and that, in fact, he did not own a radio transmitter. The short-wave receiver was used by the Bails to pick up broadcasts from Britain.

Mr. Bail's wife, Elizabeth, who had also been placed under house arrest, was freed a few days before her husband's release.

AIME Annual Meeting

During the 98th annual meeting of the American Institute of Mining, Metallurgical, and Petroleum Engineers held in Washington, D. C., February 16-20, the following members of the faculty of the College of Earth & Mineral Sciences were among those who actively participated:

F. F. Aplan, head of the department of mineral preparation, served as co-chairman of the Minerals Processing Fundamentals Sessions I and III. He also presented a paper entitled "The Influence of Structure and Properties on the Grinding Ferrosilicon," co-authored with G. M. Kirby.

S. C. Sun, professor of mineral preparation, co-authored with J. A. L. Campbell and presented a paper entitled "The Electrokinetic Behavior of Anthracite." Dr. Sun was also the co-author of a second paper with J. A. L. Campbell, "Bituminous Coal Electrokinetics."

T. S. Spicer, professor of mineral preparation engineering, served as a panelist at the discussion on "The Pelletizing of Coal."

J. D. Ridge, professor of economic geology and mineral economics and head, department of mineral economics, presented a paper on "Distinguishing the Epigenetic from the Syngenetic Ore Deposits."

Richard Gordon, associate professor of mineral economics, presented a paper entitled "Beauty and the GNP—The Problem of Choice."

George Schenck, assistant professor of mineral economics, presented a paper entitled "Transportation Innovations and the Demand for Fuels." He also served as co-chairman of the session on "Turning Rocks and Minerals into Gold."

Richard T. Newcomb, assistant professor of mineral economics, presented a paper on "Cross-Price Variation and Substitution in the Metal Market: Aluminum, Copper and Steel."

Robert Stefanko, professor of mining and head of the department of mining, and D. S. Choi, graduate assistant, department of mining, presented a paper entitled "Anchorage Performance in Rock Bolting." Dr. Stefanko also presented a second paper, "Subsurface Disposal of Mine Water." In addition, he presided as chairman of two committees—Scholarship Selection and Student Prize Paper awards. Finally, Dr. Stefanko attended sessions of the Rock Mechanics Committee, of which he is also a member.

B. J. Kochanowsky, professor of mining, presented a paper on "Dynamic Cost Analysis."

E. F. Osborn, Vice President for Research and professor of geochemistry, attended the meeting as chairman of the National Academy Committee on Mineral Science and Technology. At a panel discussion he presented the report of this committee on the "Purpose of Minerals Science and Technology Study," the result of two years of work. Dr. Rustum Roy, professor of geochemistry and director of the Materials Research Laboratory, served as one of the chairmen of the "Nonmetallic Materials" panel that discussed the Committee's study.

Other faculty members of the College who attended the AIME meeting were: Dr. E. Willard Miller, assistant dean for resident instruction and continuing education; Lauren A. Wright, professor of geology and head of the department of geology and geophysics; H. M. Lovell, director, Mine Drainage Research; Arnulf Muan, head of the department of geochemistry and mineralogy; and Deverle P. Harris, assistant professor of mineral economics.

National Colloquy on the Field of Minerals

A national colloquy on the field of materials will be held April 14-16 at University Park. This meeting is planned as a convocation of the nation's scientists and engineers managing research and/or teaching in the field of materials, with a principal objective being the assessment of the development of research and training in materials science and engineering since its emergence. Other aims of the meeting include a study of the complex relationships and a delineation of the goals of materials science and engineering within contemporary science and technology. It is expected that the colloquy will lead to improved university curriculum planning, as well as new development of the field.

More than fifty national and international leaders will appear on the program as speakers or discussants. Among these will be Harvey Brooks, dean of applied science at Harvard University, who will present a paper on "Possible Impact of U. S. National Policies and Goals on Materials Science and Engineering." Others, who will discuss materials research in the U. S., Britain, and France, respectively, will be W. O. Baker, vice president for research, Bell Telephone Company; L. Rotherham, Central Electricity Generating Board, London, England; and C. Crussard, Societe Pechiney, Paris, France.

Dr. Rustum Roy, director of the materials research laboratory at Penn State, will be chairman of the program committee for the colloquy. The committee includes representatives of Pennsylvania industry and academic institutions serving on the materials advisory panel of the Governor's Science Advisory Committee, as well as others from all over the country in keeping with the national scope of the meeting. Financial support for the program has been provided through the Pennsylvania Science and Engineering Foundation.

Summer Jobs in the Mineral Industry

A listing of summer job opportunities for students in mineral engineering (geology, metallurgy, mineral preparation, mineral economics, mining engineering, etc.) is posted outside Room 123, Mineral Industries Building. Compiled by the Western Field Office of the American Institute of Mining, Metallurgical, and Petroleum Engineers, the listing is supplemented from time to time as new jobs become available. Bulletin 1 is currently posted.

A Burgeoning New Fuel — LNG

GEORGE H. K. SCHENCK, *Assistant Professor of Mineral Economics*

Charles G. Simpson of Philadelphia Gas Works recently spent considerable time in Venezuela negotiating for reserves of natural gas that may be burned in Eastern Pennsylvania homes as early as the mid-1970's. Last winter, Boston Gas Company fed gas from Algeria to homes in the Massachusetts Bay Area. These actions are the vanguard of consumption of a burgeoning new fuel, liquefied natural gas —better known as LNG.

It has long been known that liquefaction of natural gas, which is mostly methane, can reduce volume by a factor of over 600. This is done at atmospheric pressure and a temperature of minus 260°F. A mineral economics master's thesis, *Ocean Transport of LNG* by Karl Andren, indicates that the average total cost of liquefaction of natural gas at large plants is about 20¢ per thousand cubic feet (Mcf). This means that LNG delivered by tanker from overseas has the potential to supply Eastern U. S. markets if procurement and destination costs can be kept low enough—even though the anticipated total delivered cost of 50¢ is relatively high compared to an average of 37¢ per Mcf for pipeline gas delivered to East Coast gas utilities such as Philadelphia Gas Works.

The first commercial ocean shipments of LNG began in 1965 with gas from the Sahara (Algeria) delivered at a rate of 100,000 Mcf per day to England. A second project to deliver over three times as much to Southern Europe from Libya started in early 1969.

Officials of the American Gas Institute (AGI) anticipate that in about a decade it will be necessary to augment supplies of natural gas delivered to the Eastern U. S. by trunkline with some substitute such as imported LNG, or producer gas. This expectation is based on AGI forecasts that show demand growing at about five per cent annually, outstripping supply as measured by discovery of new reserves in the U. S. The present rate of discovery about equals consumption.

LNG is a new fuel because of its distinct characteristics, although it may be used identically to pipeline natural gas. When LNG is regasified for combustion, it is the cleanest of all fuels, thoroughly purified and free from inert components. It mixes freely with air and combines readily with atmospheric oxygen in the simple combustion reaction $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. LNG contains 20 per cent more BTU's than an equal volume of jet aircraft fuel, is easily transferred and transported, is extremely cold, and has a lower flame temperature than other liquid hydrocarbon fuels.

The potential demand for LNG can be classified into three primary uses and one by-product use. As a transport fuel, LNG will compete primarily against other liquid hydrocarbons such as gasoline, diesel oil, kerosene, and LPG. As a substitute for trunkline delivered gas, LNG will compete with pipeline gas and producer gas from coal, oil, or LPG. As a primary energy source, LNG will compete with coal, crude oil, natural gas, and electricity from hydroelectric sources, coal, oil, or nuclear fuels. Cryogenic temperatures are reached as a by-product of the regasification of LNG and this cold could provide a significant credit against operating costs if it is feasible for it to be utilized, such as in flash-freezing of foods, for example.

In this country the main application of LNG to date has been by gas distribution companies that liquefy pipeline-delivered gas at off-peak seasons and store it to be regasified during peak demand periods. Additional liquefaction capacity at these plants can be provided at a low marginal cost to supply liquid fuel for customers, such as operators of fleets of commercial vehicles. There are now about a dozen peak-shaving LNG projects in the U. S. ranging in capacity from about 1000 up to 20,000 Mcf per day.

In contrast, a regasification plant built as part of a gas utility's facilities used to meet base-load demand would be one or more orders of magnitude larger than peak-shaving plants. Any ocean transport LNG project supplying a portion of the base-load requirements of a U. S. city would represent a major market breakthrough. LNG would be easily available from such a project for sale to vehicular users, such as common carriers.

LNG burns with a smokeless exhaust that makes it very attractive for use in metropolitan areas where there is a growing concern regarding air pollution caused by crowding of gasoline-driven vehicles. Tests have shown that cars powered by LNG can easily cruise at 70 miles per hour, while their emissions of unburned hydrocarbons are cut by 50 per cent and carbon monoxide by 90 per cent compared with regular gasoline. Operating costs are reported to be slightly higher, but it has been claimed that efficiency could be improved with a specially designed engine.

Growing use of LNG for utility peak-shaving is assured, and such availability will result in this liquid fuel being used to power a public or private fleet of vehicles in a city with a natural gas liquefaction facility and also plagued with an air pollution problem. Utility base load use, while less predictable, should exist at an East Coast port city within a decade.

College News Notes

Four members of the department of meteorology recently participated in panel discussions at various meetings of the American Meteorological Society in Washington, D. C. On February 10, Dr. Hans Neuberger, professor of meteorology, participated in a panel which was charged with answering the questions "Why Do We Take Meteorological Observations?" and "What Is Wrong With Our Meteorological Observations?" The latter panel was composed of, among others, the directors of the Weather Services in Germany, Canada, and the United States. On February 14, with Dr. Alfred K. Blackadar acting as moderator, Dr. Hans Panofsky, professor of meteorology, and Dr. Charles L. Hosler, dean of the College of Earth & Mineral Sciences, participated with four other atmospheric scientists on a panel which discussed "The Major Problems Facing The Atmospheric Sciences And The Instrumentation Needed To Solve Them."

Peter H. Given, chairman of the fuel science section of the materials science department, returned at the beginning of the Winter Term from a sabbatical leave which he spent in the Organic Geochemistry Unit of the Geology Department of the University of Newcastle-upon-Tyne, England. During this time, Dr. Given carried out research on the geochemistry of jet. This black substance, which became popular in the 19th century for making jewelry, is, in fact, an unusual kind of coal which underwent biogenesis and metamorphism in a marine environment. The type locality is found in the cliffs on the seashore at Whitby, near Newcastle-upon-Tyne. While in

Europe, Dr. Given also attended the 7th International Conference on Coal Science in Prague, Czechoslovakia, in June, and the 4th Symposium on Organic Geochemistry held in Amsterdam, The Netherlands, in September.

R. H. Essenhigh, professor of fuel science, attended the College-Industry Committee meeting of the Industrial Heating Equipment Association held at Cleveland, Ohio, January 30. This is a newly-formed committee whose objective is to develop educational contacts with educational institutions in order to meet the needs of implementing and improving heat process education.

Wilbur Zelinsky, professor of geography, is the organizer and chairman of a session on Population Geography to be held during the April 10-12 meeting of the Population Association of America at Atlantic City, N. J. Dr. Zelinsky was also recently elected chairman of the Honors Committee of the Association of American Geographers for a one-year term.

Jon J. Weber, and R. F. Schmalz, associate professors of geology, are the authors of a paper entitled "Factors Affecting the Carbon and Oxygen Isotopic Composition of Marine Carbonate Sediments, III: Eniwetok" in the January issue of the *Journal of Sedimentary Petrology*. Dr. Schmalz is also the co-author with F. J. Swanson, graduate student of the department of geology and geophysics, of a paper entitled "Dirunal Changes in Carbonate Saturation of Natural Seawaters" which appeared in the March issue of the same journal. A further paper by Dr. Schmalz entitled "Deep Water Evaporite Deposition—A Genetic Model" appears in the April issue of the *American Association of Petroleum Geologists' Bulletin*.

Richard H. Merkel, NDEA Fellow in geophysics, gave two lectures in December at St. Lawrence University, N. Y., entitled "Recent Developments in Geophysical Techniques to Study the Earth's Interior."

Alfred Traverse, associate professor of geology and biology, gave three lectures as the American Geologic Institute Visiting Scientist at East Carolina University on February 3. The lectures were entitled "Palynology as a Geologic Tool," "Fossil Spores as Sedimentary Particles," and "Fossil Spores as Indications of Plant Evolution."

C. W. Burnham, professor of geochemistry, and Arthur W. Rose, associate professor of geochemistry and staff geologist, Mineral Conservation Section, attended the 1st Penrose Conference of the Geological Society of America on Depositional Environment of the Porphyry Copper Deposits held in Tucson, Ariz., January 20-25. Dr. Burnham presented two papers at the conference, "A Model for the Derivation of Hydrothermal Solutions from Magmas," and "K/H and Na/H and the Beginnings of Alteration." During the conference, Dr. Rose also gave a talk entitled "Zonal Relations of Alteration, Sulfide Abundances, and Intrusives at Porphyry Copper Deposits."

H. L. Barnes, professor of geochemistry, was recently invited to lecture at three European universities. On February 13 he spoke on "Aqueous Complexes of Metallic Sulfides" at the Laboratory for Inorganic Chemistry, Technische Hochschule of Zurich, Switzerland. On March 4 he spoke on "Mineral Stabilities—Hydrothermal versus Anhydrous Results and Geologic Consequences" at the Mineralogy-Petrology Institute, University of Heidelberg, Germany. He also attended a research conference at the Geochemistry Institute, University of Goettingen, Germany.

John D. Ridge, professor of economic geology and mineral economics and head of the department of mineral economics, attended the annual meeting of the National Research Council in Washington, D. C., March 9-11. He is the representative of the Society of Economic Geologists on the Division of Earth Sciences.

Dr. Ridge will attend the Society's symposium on "A Paleoaquifer and its Relation to Economic Mineral Deposits" to be held in Knoxville, Tenn., March 27-29. His views on the problems to be discussed were published in 1968 in "Applied Earth Science," Section B of the *Transactions of the Society of Mining and Metallurgy*, Vol. 77, pp. B6-B17. He is not in agreement with the currently largely accepted hypothesis in the district that the ores were deposited at the end of Mascot time in solution cavities developed immediately prior to ore deposition.

Hans A. Panofsky, professor of meteorology, will continue his lecture tour on Air Pollution Meteorology sponsored by Sigma Xi, national honorary science society, March 15-29. During this time he will visit State University College, Fredonia; Alfred University, Alfred; Cornell University, Geneva; Hamilton College, Clinton; Union College, Schenectady; SUNY at Plattsburgh; Polytechnic Institute of Brooklyn, Brooklyn; Adelphia University, Garden City; IBM Poughkeepsie Research Branch, Hopewell Jct.; and Fordham University, Bronx, all in New York. In addition, he will present a lecture at SUNY at Albany on "Structure of Atmosphere Turbulence on the Ground."

(*Cont'd on page 52*)

Jack H. Wernick To Receive McFarland Award

Jack H. Wernick, head of the Physical Metallurgical Research Department, Bell Telephone Laboratories, Murray Hill, N. J., has been named twenty-first recipient of the David Ford McFarland Award for Achievement in Metallurgy. This award, given annually by the Penn State chapter of the American Society for Metals to an alumnus of the University's department of metallurgy, recognizes outstanding achievement in some aspect of the metallurgical profession.

The award will be made at a banquet to be held on May 4 at 6:30 p.m. at the Centre Hills Country Club, State College, Pa. Following the banquet, Dr. Wernick will address chapter members and guests on "Some Recent Metallurgical Developments in Communications." There will be a separate program for the ladies.

Dr. Wernick received the B.S. and the M.S. degrees in metallurgical engineering from the University of Minnesota in 1947 and 1948, respectively. In 1954 he was awarded the Ph.D. degree in metallurgy by Penn State, and immediately joined the Bell Telephone Laboratories technical staff at Murray Hill. He was appointed to his current position in 1964.

All of Dr. Wernick's research activities have been concerned with various aspects of the solid state, with his studies on materials including insulators, metals (both magnetic and nonmagnetic), semiconductors (magnetic and nonmagnetic), and superconductors. Author or co-author of 114 papers relating to the solid state, Dr. Wernick holds fifteen patents and has two applications on file. His memberships in professional and honorary societies include AIME, ASM, American

Physical Society, New York Academy of Sciences, AAAS, Sigma Xi, and Phi Lambda Upsilon.

Individual tickets for the banquet, which is informal, are $6.50, with tax and gratuity included. They may be secured by sending a postal money order or check for the number of tickets desired to Dr. R. W. Lindsay, 221 Mineral Industries Building, University Park, Pa. 16802. Tickets will be mailed for orders received by April 25, but will be held at the door for monies received after that date.

Alumnus to Head Oil Slick Commission

John C. Calhoun, Jr., who received the M.S. degree in 1941 and the Ph.D. degree in 1946 in petroleum and natural gas engineering at Penn State, has been named chairman of the commission set up to investigate the causes of and remedies for the oil slick that was recently released from a leaking drill off the coast at Santa Barbara, California.

Dr. Calhoun was head of the department of petroleum and natural gas engineering in the College of Earth & Mineral Sciences from 1950-54, when he left to become Chancellor for Development at Texas A. & M. University. He took a leave of absence from this post to serve two years as science adviser to the Secretary of the Interior in Washington, D. C., and has since rejoined the faculty at Texas. Dr. Calhoun is also an ex-president of the Society of Petroleum Engineers.

Gould Article In "Harper's"

Dr. Peter R. Gould, professor of geography, is the author of an article entitled "The New Geography" which appears in the March issue of *Harper's Magazine*. In his article, Dr. Gould elaborates on how, more than any other social and behavioral science, geography has exploded during the last decade, pointing out that the revolution extends from the graduate level down to the high schools where the NSF-supported High School Project is now revising out-dated notions.

The article goes on to explain how the development of geographic theory has accelerated with the availability of large, and very fast computers, although many spatial problems still exceed available computer capacities, particularly when it comes to real-world applications. Mathematical intractability is less of a constraint now that large-scale simulation is possible.

Dr. Gould further points out that new approaches and new tools are producing drastic revisions in worn-out curriculums, and communication to other social and behavioral sciences with similar contemporary aspects is gaining rapidly. As a result, geography graduates from Penn State are now joining environmental research and development teams in private industry and government, as well as staffing some of the more advanced university departments in the United States and Europe.

College News Notes

(*Cont'd*)

At the meetings of the National Research Council held in Washington, D. C. March 9-11, the College of Earth & Mineral Sciences was represented by three faculty members—Dr. Alfred K. Blackadar, professor and head of the department of meteorology, Dr. Peter Gould, professor of geography, and Dr. John D. Ridge, professor and head of the department of mineral economics. Dr. Blackadar and Dr. Ridge are members of the Earth Sciences Division, and Dr. Blackadar is a member of that division's executive committee. Dr. Gould is a member of the Behavioral Sciences Division.

Alfred K. Blackadar, head of the department of meteorology, presented an invited paper entitled "Implications of Similarity Principles of the Atmospheric Boundary Layer" at a symposium on the occasion of the dedication of the Geophysical Fluid Dynamics Laboratory at Princeton University on January 25. Dr. Blackadar also attended a two-day meeting of the U. S. National Committee for Global Atmospheric Research Program that met in Princeton following the symposium.

Directory of Graduates

Readers are reminded that the revised edition of the *Directory of Graduates* is now available, and this new edition may be obtained by sending $1.00 (to defray handling and postage and help to build up a new fund for a future edition) to the Office of the Dean, College of Earth & Mineral Sciences, The Pennsylvania State University, University Park, Pa. 16802.

Once again, all alumni are urged to keep the College informed of any changes in their personal data or of address changes so that records may be kept as up-to-date as possible.

Reprints Available

Recent publications of the College of Earth & Mineral Sciences are listed below. Those desiring reprints should address their requests to the authors whose name appears in italics (if there is more than one), 5 Mineral Industries Building, University Park, Pa. 16802.

Title, Author, and Source

Equilibrium Distribution of Elements between Coexisting Solid-Solution Phases. Arnulf Muan. Origin and Distribution of the Elements, 619-627, 1968.

Effect of Pressure and Temperature on the Reversal Transitions of Stishovite. P. D. Gigl and *Frank Dachille*. Meteoritics, 4, 2, Oct. 1968.

Synthesis and Crystal Structure of Mg_2PtO_4 and Zn_2PtO_4. *Olaf Muller* and Rustum Roy. Mat. Res. Bull. 4, 39-44, 1969.

Phase Equilibria in the Systems NiO-Cr_2O_3-O_2, MgO-Cr_2O_3-O_2, and CdO-Cr_2O_3-O_2 at High Oxygen Pressures. *Olaf Muller*, Rustum Roy, and W. B. White. J. Amer. Ceram. Soc., 51, 693-699, 1968.

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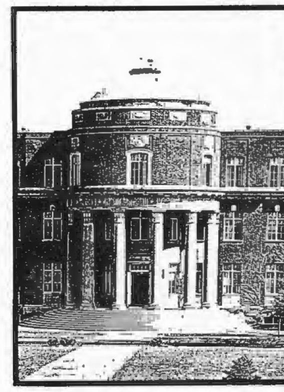

VOLUME 38 NO. 7 APRIL 1969

The Role of Weather Modification in the Alleviation of Drought

C. L. HOSLER, *Dean, College of Earth & Mineral Sciences*

Introduction

The primary causes of drought are, of course, related to the long wave positions in the westerlies. At present (as well as in the foreseeable future) we do not have at our disposal weather modification techniques which would enable us to alter long wave positions or intensity. Thus, we must resign ourselves at the present time to deal with types of modification within the large scale patterns of circulation which nature presents to us.

Before elaborating on the types of modification of natural precipitation which now appear operationally feasible, I should make clear that in my opinion the principal weapon man has and will continue to have to fight the effects of drought is good planning of water storage and distribution facilities. In this respect, many parts of the United States still lag behind civilizations that preceded us by thousands of years. In proportion to our concentration of population and the degree of dependence of our industry and daily lives upon an abundant supply of fresh water, the engineering works of today are dwarfed by the works of the ancients.

Even though weather records, for the most part, date back to less than two hundred years ago in the northeastern United States, one would have to be oblivious indeed upon looking at them not to realize that circulation patterns have assumed in the past and will assume in the future such proportions as to cause extended periods of drought. Just as when one designs a flood-control system one must consider the probability of high flows in the design of water distribution systems, one must also design for extended periods of inadequate precipitation.

With man's demands constantly pushing against his ability to supply adequate water even in the short periods of drought that have been experienced recently in the Northeast, we run a great risk of disaster in this country. Before land and rights of way become unobtainable, it seems mandatory that we should be thinking of major engineering works in the Northeast to provide the type of fresh water storage we have traditionally thought of as only being necessary in the Western part of our country. I have yet to see a contemplated design of a desalting plant and accompanying trans-

Typical tropical cumuli in which colloidal instability in the cloud on the right resulted in rain, but at a time when it evaporated before reaching the ground. Modification techniques are aimed at inducing the precipitation sooner.

portation system which will be of significant help to the majority of the population in the northeastern United States.

While I take this opportunity to emphasize that the alleviation of drought, in my opinion, will principally come through engineering works, I hasten to add that in the selection of sites for augmented storage of fresh water, the potential of weather modification for increasing water yield in these watersheds should be considered. Significant increases in snow and rainfall are possible over restricted areas utilizing cloud modification techniques presently under test.

While some of these same techniques may be utilized to augment precipitation during periods when the drought temporarily relaxes and minor atmospheric disturbances move through the region, the amount of precipitation which can be extracted artificially from such weak and transient systems, while certainly not negligible appears to be very limited in most cases.

The great hope lies in the increased efficiency of precipitation utilization which can be realized during periods of normal storm frequency and intensity by concentrating natural precipitation in catchment basins. "People problems" are less apt to become aggravated also when artificial focusing of precipitation is limited to periods of fairly widespread precipitation when the disturbance covers a large area and precipitation amounts generally are likely to be adequate for most agricultural and other needs. During a drought, some types of modification to increase shower development may have side effects in depriving people locally of precipitation on either side of the area where it was augmented. The basis for techniques which might be employed to concentrate precipitation in a given watershed are described in this article.

EARTH & MINERAL SCIENCES

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Colloidal Instability

The physical basis for most operations in the past has been the hope that seeding would produce colloidal instability in clouds, either prematurely, to a greater degree, or with greater efficiency than nature. It is assumed that so doing would result in a net increase in rainfall. Most cloud seeding presumes that at least a portion of the treated cloud is supercooled, that nature is not producing any or enough ice at the temperature of the cloud, and that treatment with chemical agents or refrigerants will change a proportion of the cloud to ice. The resultant mixture of water and ice is not stable because of the vapor pressure difference between water and ice at all temperatures below 0°C. Thus, there will be rapid deposition of water vapor upon the ice and simultaneous evaporation of water from supercooled droplets.[4] The ice crystals so formed become large enough to fall relative to remaining droplets or smaller crystals. Growth by collection of droplets or crystals in the path of the falling large crystal enhances the probability that particles of ice or water will grow large enough to fall from the cloud and through the unsaturated air below the cloud, thus reaching the ground as precipitation.

In a natural, continuously produced stratiform, or layer cloud, which is supercooled and whose base is reasonably close to the ground and where nature is deficient in providing the ice phase, this process is not only theoretically capable of producing precipitation artificially, but it has been statistically demonstrated to be effective in field tests. From the very early days of weather modification, the orographically produced supercooled cloud has been the most consistent target of cloud seeders and the bright hope of the proponents of weather modification. Continued renewal of the orographic cloud makes it more likely to produce important amounts of precipitation than a transient cloud layer formed naturally and then artificially expended by seeding. A cloud 10,000 feet thick must reproduce itself at least ten to twenty times for a moderate rainfall to result. For many years, operational cloud seeding in the Sierras of California has employed this philosophy.

The cumulus cloud has also been a target of the cloud seeder bent on inducing colloidal instability in supercooled clouds. Again, the hope has been to induce precipitation earlier than would nature in a cloud which might have naturally achieved colloidal instability at a later time, or in a cloud whose size or lifetime would not have been sufficient to produce precipitation naturally. In addition to the initiation of the ice phase, cloud seeders have also used water drops and hygroscopic particles to produce or initiate large drops which might begin the chain reaction of coalescence and breaking of large drops to produce more coalescence. In all of these cases, broadening of the drop size distribution and hence a broader range of fall velocities of cloud particles is the desired outcome. Introducing water or large hygroscopic particles can increase the number of large droplets. Therefore, there have been attempts to induce colloidal instability in warm clouds as well as in supercooled clouds. Choosing which convective cloud precipitates and regulation of the time required could provide an important contribution to the management of small watersheds.

The results of warm cloud modification attempts have thus far not been as encouraging as those of the cold cloud experiments. Evidently, the margin of difference between natural and seeded warm clouds is small and even less easy to detect than for cold clouds. However, in view of the volume of warm clouds present in the atmosphere—whether production of rain, or dissipation of cloud or fog is desired—one of the greatest possible breakthroughs in cloud and weather modification would be development of a technique to radically alter the colloidal stability of clouds warmer than 0°C.

Dynamic Effects through Cloud Seeding

Many early experimenters with cloud seeding reported growth or dynamic effects on stratiform or cumulus clouds. These results were treated merely as interesting side effects until fairly recently. Actually, in terms of the long-range impact of cloud seeding in weather modification, the dynamic effects will be, in my opinion, the important ones. The amount of water available for release from naturally formed clouds that do not precipitate naturally is rather limited. Lack of rainfall in a given place is primarily due to lack of uplift, which will consistently produce clouds of appreciable thickness and horizontal extent. If, through controlled cloud seeding, additional uplift can be promoted in selected local areas, the productivity in terms of water will be higher whether the actual precipitation mechanism is natural or artificial. During drought conditions, the encouragement of additional cloud growth under marginally stable conditions could be very important.

When high rainfall and intensities occur, they are almost always produced by convective clouds either isolated, or embedded within larger cloud systems. Most cyclonic storms produce only very slow upward motions of the order of centimeters per second. These large-scale upward motions destabilize the atmosphere and render it susceptible to being disturbed by all manner of smaller scale perturbations, which may produce convective systems with vertical velocities of meters per second. A variety of triggering mechanisms are frequently available in the atmosphere. In some places orographic lifting may be important. Along coastlines, near large cities, and in areas of varied land use, temperature and roughness differences produce pressure gradients which promote local lifting. Gravity waves induced by a variety of causes may generate bands of locally intense uplift within the larger cloud system. Most of the aforementioned are not easily susceptible to alteration. However, there are equally important microphysical parameters which can cause patterns within general cloud and precipitation areas.

Douglas, *et al.*[2] showed the importance of cirrus trails in naturally seeding supercooled layer clouds, thereby inducing colloidal instability and releasing the heat of fusion in layers where this heat can induce significant vertical motions. Kraus and Squires[3] noted this dynamic effect of seeding on individual cumulus, and Weickmann[4] noted formation of a squall line in seeded stratocumulus. Hosler, Davis, and Booker[5] pointed out that not only the heat of fusion from freezing the liquid water but also the heat released by condensation of excess vapor is available to promote convection. Once completely glaciated, vapor pressure in the cloud is reduced to the equilibrium vapor pressure over ice instead of water. The temperature excess produced by conversion of the cloud to ice is from 1 to 2 centigrade degrees in a typical cloud. This is sufficient to cause cumulus or convective growth. MacCready[6] has also recently calculated the temperature excesses that are potentially possible by conversion of supercooled clouds to ice, and he concluded that as much as a 2.5°C excess is possible if all water were converted to ice. Davis and Hosler have pointed out that experiments clearly demonstrate the ability to promote growth of cumulus clouds in a predictable manner by freezing the supercooled portions.[7] Mathematical models, even though relatively crude, predict natural cloud behavior, and in addition enable one to anticipate the effect of cloud seeding on cloud growth. Bethwaite, Smith, *et al.*[8] have conducted field tests demonstrating that the effect of seeding on cumulus growth is significant. Simpson[9] has also demonstrated the potency of this tool for weather modification. As minor disturbances move through a region under drought conditions, stimulation of cloud growth could make great differences in precipitation in restricted areas. If the atmosphere were monitored so as to reveal the times and places of susceptibility, shower stimulation could be pinpointed over watersheds.

Cumulus clouds grow by virtue of a slight excess in temperature over the environmental temperature. In the case of the isolated cumulus cloud, the crucial process in determining whether a cloud grows to great height, aside from the confining limits placed by stable layers or inversions and over-all stability, is the amount of entrainment of dry air from the environment. Austin and Fleisher[10] and others have shown this to be very important. The dry air brought in from the environment must be saturated by evaporating cloud water, which results in cooling and loss of buoyancy. In addition, the air is cooler than the warm buoyant cloud, and thus cloud temperature is reduced by mixing. The greater the amount of heat which can be released by ice production and removal of vapor by reducing the vapor pressure to that over ice, the longer the cloud can continue to grow.

Perhaps most exciting is what happens when nature produces a deep cloud layer which is supercooled, or mostly so, with a vertical temperature distribution which is at least moist adiabatic. In this case, production of a warm region by producing ice and ice saturation will promote convection. The air entrained into the updraft will be saturated with respect to water and will bring liquid water with it. The result is that instead of cloud droplets losing moisture to the entrained air as in the case of the isolated cumulus, moisture is added to the cloud with an attendant release of heat to feed the convection and compensate for the fact that the entrained environmental cloud air is cooler than the cloud air. This results in vigorous showers or shower bands within a large cloud or precipitation system such as occurs naturally, presumably due to inhomogeneity in freezing nucleus populations, seeding from cirrus bands, or cumulonimbus anvils.

Investigations in Pennsylvania indicate that more than 90 per cent of the summer rainfall comes from organized lines or bands. Even when individual cumulus clouds in clear air are the source of the rain, the significant precipitation is most likely to occur when groups of clouds occur together or in lines. It is assumed that the mutual protection afforded by their togetherness promotes growth by minimizing entrainment. In a field of randomly dispersed cumulus with the potential of developing into showers, selective glaciation of groups or lines may well be more advantageous than the treatment of isolated clouds because of the ability to minimize entrainment and organize the convective energy into a few vigorous systems. Treating all clouds would only contribute to dissipating cloud energy into many small cells. Organization will stabilize the surroundings through descending motion, suppress competing cumulus, and preserve the warm, moist, low-level air to provide inflow into the organized lines where ascent is further steepening the lapse rate. It must be reiterated that, in general, this organization may occur naturally through a number of avenues; however, there is no reason to believe that precipitation-producing efficiency could not be improved by deliberate planning of when and where some of these mesocale systems should be started. For example, Myers[11] has shown that an increase in the area and velocity of saturated downdrafts will enhance the available energy and areal extent of showers. Herein may lie one of the untested benefits of an organized seeding program.

A tower reaches from the top of a cumulus cloud in response to release of the heat fusion by glaciation in a restricted area as a result of cloud seeding.

Cloud Dissipation Thermal Effects

Above I have concentrated on the production of precipitaton by cloud modification that causes cloud growth or colloidal instability. The term weather modification, of course, also embraces the demonstrated ability to dissipate clouds. Where processes of formation are slow, or when a supercooled cloud has been formed and is in a state of equilibrium or slow dissipation, seeding with ice-producing materials will cause the water to become concentrated on a relatively few large crystals which will then fall to a lower level. They may reach the ground in the case of fog or low stratus, but more likely will evaporate into the drier air below the cloud base. This procedure has been worked out quantitatively and is used commercially and for military operations. Large scale cloud dissipation is also feasible by this technique; however, this has not been used commercially. Presumably, where economic gains are apparent from increased radiation, this could be useful now. For example, in the fall increased solar radiation that would be achieved by dissipating stratocumulus could increase sugar production in grapes to the lee of Lake Erie, thus enhancing crop value. The secondary meteorological effects of local heating by day and cooling at night at the surface under a cleared area in the midst of a large cloud-covered area are also of interest, but have not yet been explored on a large scale. Federov[13] reports temperature anomalies up to 8°C possible over thousands of square kilometers, and Weickmann[4] has noted these possibilities. Such temperature anomalies could possibly be used to induce mesoscale circulations which would concentrate precipitation in local areas.

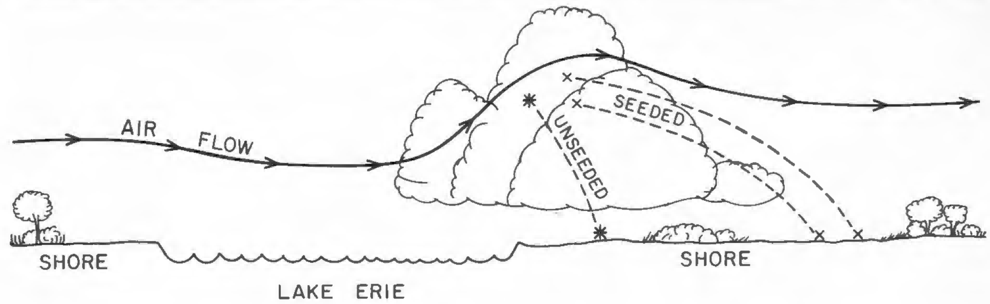
Cloud Formation Thermal Effects

Casual observation of jet aircraft operation reveals a technique whereby cloud cover can be produced artificially over large areas. At the very low temperatures of the lower stratosphere and upper troposphere, very small additions of water vapor result in high supersaturations and condensation. Not infrequently, layers exist in these regions which are saturated or slightly supersaturated with respect to ice, yet the supersaturations are not great enough to produce condensation in the presence of the nuclei available. Injection of additional vapor and nuclei by the aircraft causes high supersaturation and formation of a cloud. The often-seen condensation trail is of no great consequence unless it is formed in one of the supersaturated layers.

In this case, the lateral and vertical mixing will propagate the cloud over the sky to form a layer of cirrus cloud. Again, the meteorological effects of deliberately seeking supersaturated layers and filling them with cloud have not been thoroughly examined. In such a case, there may be important effects upon the radiation balance over the region, as well as a possible effect downwind as a result of the precipitation of abundant ice into middle or low clouds. Natural seeding of supercooled clouds by ice falling from cirrus clouds is under certain circumstances the most effective type of cloud seeding possible.

Controlling Precipitation Size and Trajectory

Examination of Great Lakes storms has indicated that there may be hope of improving on nature even where nature



Schematic representation of the movement of snow as much as twenty miles downwind by reducing the size of snow flakes and flattening their trajectories.

produces an extremely intense perturbation, such as when the cold air in the early winter flows across the Great Lakes and is warmed and moistened from below. In this case, bands of convective clouds form along the lee lake shore with vigorous updrafts, a very high rate of condensation, and large liquid water content.

Precipitation elements in these clouds grow and are transported downwind until they achieve a sufficient size to fall through the updrafts producing the clouds. Because the intense updrafts are concentrated along the immediate lake shore, and velocities decrease rapidly downwind, most of the precipitation is dumped in a very narrow band immediately downwind of these updrafts. The trajectories of snowflakes are, of course, determined by the air motion in which they are embedded and their terminal velocity, the latter depending on flake size and shape.

Calculations show that there is a reasonable expectation that high rates of seeding upwind of the cloud band might significantly reduce the amount of precipitation falling as large flakes and graupel on the immediate lake shore, while increasing the number of smaller, lighter flakes and crystals which would travel several miles farther downwind. The effect of seeding would then be to redistribute the same amount of precipitation over an area two or three times greater than would have been the case naturally. The advantage of such an operation would be twofold: a decrease of the "snow burst" hazard on the immediate lake shore, and the availability of water farther from the lake, which would also contribute to surface and underground storage facilities. Additional cloud growth is not likely to result from seeding the typical lee shore snow squall because of the strong inversion that caps the clouds. Under many precipitation-producing regimes alteration of trajectories could be important in concentrating precipitation in a watershed.

Another weather modification technique which has been tried in several countries, with varying success, is the prevention of hail by cloud seeding. In this case the objective is to provide additional centers for ice growth, resulting in either smaller hail or a reduction in the amount of supercooled water upon which hail growth depends. The formation of smaller stones results in their inability to reach the surface before melting.

Altering Surface Characteristics

On a typical unstable day, convective clouds are widespread, but only a few of these develop into showers, and it is apparent that very subtle selective processes operate. As mentioned before, many types of contrast in the underlying surface can cause added lift or convergence at low levels to enhance cloud growth. Small thermal contrasts provide one of the most obvious modulators of convective cloud patterns. Photographs from manned orbiting vehicles have been especially useful in demonstrating that small lakes, islands, peninsulas, and shorelines of no significant relief profoundly affect convective patterns. Black *et al.*[12] have suggested that increased absorption of solar energy by an asphalt-coated area might in some limited regions, where only a small amount of lift is required to set off convection, orient and localize convection, and thereby create a cloud street and downwind showers in the same manner as do small islands. There is little doubt that this would work. It is only a question of how often conditions will occur in a given region where the amount of heat available is sufficient to overcome the ambient stability. In almost any region there will be times when the heating will produce clouds. Whether there are regions where both coating with asphalt is geographically feasible and climatic conditions are favorable for causing clouds to develop into showers on a significant number of occasions is still to be determined. In order to tip the balance and contribute to the manner in which nature will distribute energy and rainfall by cloud seeding or by altering surface characteristics, we are faced with a need for more precise knowledge of the spatial and temporal distribution of atmospheric structure and dynamics. The areas and times when the atmosphere is in a metastable state with respect to any of the aforementioned treatments cannot now be readily assessed.

Obviously, over the mountainous landforms of the earth there are places where such large topographic features exist as to focus all convective phenomena over the higher elevations. Conversely, over large oceanic areas there are almost undetectible differences in the character of the underlying surface, yet we still observe a great degree of organization and orientation in shower and rainfall phenomena. In the latter case, intense perturbations are infrequent, although the atmosphere can frequently achieve a high state of instability with respect to any disturbance which presents itself, primarily because of the large amount of energy produced when the moist lower levels are lifted to release the latent heat of condensation.

It is not surprising then that Simpson[9] finds very large amounts of growth possible by seeding clouds in this region. Obviously, there must be many situations over the surface of the earth where the magnitude of the disturbance necessary to create a local concentration of convection would vary considerably. In mid-latitudes the large-scale vertical motion exerts a profound effect on the stability of the atmosphere, and day-to-day changes in stability are great. In the extremely stable cases with large-scale subsidence, it is obvious that even the large naturally available perturbing influences can do nothing to induce cloud formation on a scale which would produce precipitation, and the best they can do is to form small cumulus-humilis clouds. On the other hand, when large-scale uplift proceeds for a long time, the atmosphere becomes so moist and unstable that many diverse surface influences become capable of inducing convective clouds. In these situations showers will be widespread, but gradations in intensity may still result from the large perturbing influences. There is a significant time interval when the atmosphere is in transition between stability and instability. The air is still too stable for existing influences to release the instability, but additional energy released through cloud seeding might trigger mesoscale circulations that would persist into the period when the instability becomes more general.

Conclusion

It remains for the cloud physicists and dynamicists to push for observational systems which will enable us to monitor the atmosphere on a time and space scale which would permit us to assess and immediately diagnose those times and places where atmospheric stability is marginal and where the addition of an amount of energy such as can be triggered by cloud seeding would make large and predictable changes in cloud circulations within the clouds. Even existing sounding data could well be examined to obtain a climatological summary of the times and places in which existing crude, but apparently effective, cloud models would predict that cloud seeding could have significant effects on cloud growth. It must also be recognized that in modifying individual clouds and cloud systems we are in many cases not discussing a net increase in rainfall, but simply a redistribution of rainfall and energy within an existing large-scale synoptic system. This redistribution is accomplished by concentrating upward vertical motion in some areas in preference to others, while at the same time causing compensating downward motion elsewhere.

Placement of rainfall in an economically important or useful region—or in a watershed where it can be effectively collected, stored, and utilized—as opposed to an area where rainfall has little economic importance, is the salient point. Some relatively simple reorientation of lines of showers or the selection of clouds in the most favorable position to drop precipitation in a desired area could readily bring this about. Until recently, looking at the coarse data network on synoptic weather maps prevented many people from realizing that most precipitation occurs in the fine structure of a storm not visible on a synoptic scale but readily visible by both radar and satellites.

These discussions have been restricted to alteration of what the meteorologist would call mesoscale or convective scale phenomena, or modification of precipitation processes within cloud systems produced by larger atmospheric motions on a scale presumably not alterable at this point in time. I would feel remiss if I did not point out that the large-scale systems which control weather over the continents and oceans are not insensitive to the schemes described. Modification of the vertical transport of heat, momentum, and moisture on the mesoscale may effect important energy and moisture balances in the large-scale disturbances. If the individual cumulus can be made to grow larger or smaller, thousands can be made to do so, and energy could be redistributed on a scale which would alter the entire circulation. We are not yet prepared to state what the detailed result would be, or whether, after all the feedback and second-order effects have been considered, the result will be desirable.

Slowly but surely current research is answering the questions posed by probing this indescribably complex atmospheric system. It is not a matter of *whether* it will yield to man's will, but rather *when.*

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College News Notes

Robert Scholten, professor of geology, and Dr. L. D. Ramspott, Lawrence Radiation Lab, Livermore, Calif., are the authors of a paper entitled "Tectonic Mechanisms Indicated by Structural Framework of Central Beaverhead Range, Idaho-Montana," which appears in the *Geological Society of America Special Paper 104*, 70 pp., 1969.

Robert Stefanko, head of the department of mining, attended an electro-hydraulic training seminar at Franklin, Pa., on February 25. The seminar was sponsored by the Joy Manufacturing Company. In the afternoon he was a member of a panel on which he discussed the role of Penn State in mining education and training. In the evening at the graduation banquet, Dr. Stefanko gave the main address entitled "Key to Success." There were 156 industrial members in attendance.

Dr. Stefanko also appeared before a Congressional General Subcommittee on Labor on April 16 to testify on coal mine safety and health legislation. Three principal bills are presently under consideration by the U.S. House of Representatives, and many prominent industrial, education, and governmental people have been invited to present their views on the subject.

Arnulf Muan, professor of mineral sciences and head of the department of geochemistry and mineralogy, addressed the monthly colloquium of the Inorganic Materials Division of the National Bureau of Standards in Gaithersburg, Md., on March 21.

C. D. Stahl, head of the department of petroleum and natural gas engineering, presented lectures entitled "Maraflood Research at Penn State" and "An Overview of Petroleum Production Research" at the Denver Research Center, Denver, Co., March 13-14.

Dr. Stahl was also recently appointed to the Research Committee of the Interstate Oil Compact Commission.

H. Reginald Hardy, Jr., associate professor of mining engineering and Director of the Rock Mechanics Laboratory, presented a lecture at the Gulf Research and Development Company, Pittsburgh, Pa., on March 24. Dr. Hardy's lecture dealt with the development of the Rock Mechanics Laboratory and outlined the wide variety of basic and applied research presently being carried out on geological materials in the College of Earth & Mineral Sciences.

Industrial Location—Theory and Practice: An Italian Experiment

ALLAN RODGERS, *Professor of Geography and Head, Department of Geography*

Southern Italy is a classic area of subnational underdevelopment—one with a long development experience involving the expenditure, since 1950, of well over $3½ billion by the state in an attempt to narrow the huge economic and social gap between it and the far more prosperous North. However, throughout the fifties, the policy in practice was one of unplanned growth, which, aside from an attempt to build up the infrastructure of the region, relied heavily on the market mechanism, and there was no meaningful allocation of resources on either a sector or a locational basis. Responsible officials considered location to be of secondary importance in industrial development because of modern advances in industrial and transport technology. Essentially, they minimized the importance of the relative position of the various southern centers with respect to northern and foreign markets as well as the nature and location of demand within the South itself.

By 1959, however, a more rational policy began to emerge, and the current loan and subsidy program, which is one of the more attractive in Europe, reflects three elements: sector, size of investment, and location. The locational policy adopted called for the creation of planned industrial "areas" and "nuclei." These would receive support for the improvement of the economic fabric, and plants locating in such zones could obtain higher subsidies than those sited elsewhere in the Mezzogiorno. To date, however, there have been excessive delays in the implementation of this locational design. Relatively few of the designated areas are fully operational, and the location pattern of loans and subsidies still does not reflect the new policy.

Effects of this program on the economy of the South have been mixed. Manufacturing employment in Italy increased by more than one million from

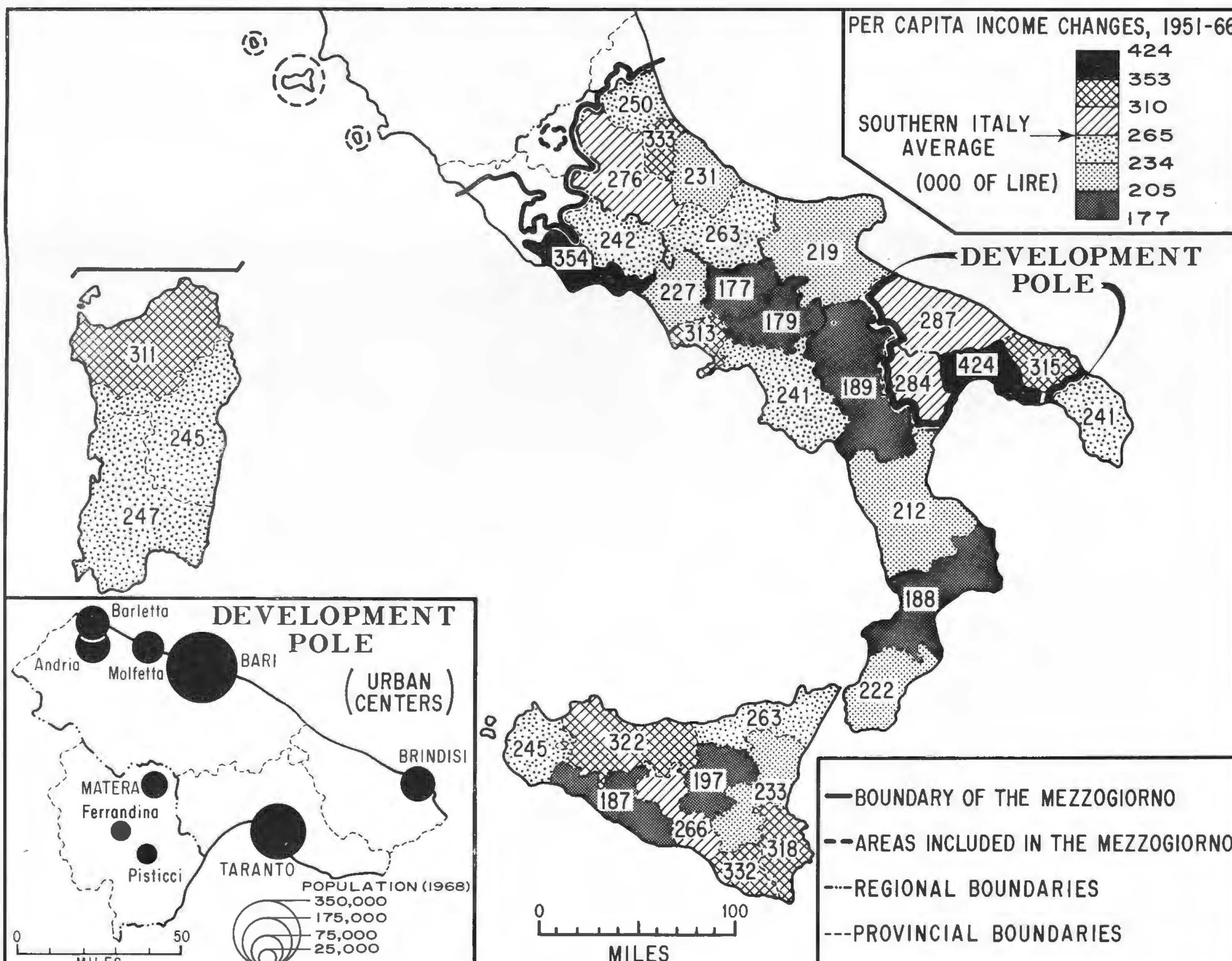

Fig. 2. Growth in per capita income in southern Italy from 1951 to 1966. (Inset: Urban Centers of the Development Pole).

1951 through 1966, or approximately 28 per cent. In contrast, employment in the Mezzogiorno increased by about two-thirds of the level of the North, i.e. 30 per cent. In all, only 150,000 workers were added to those already engaged in manufacturing in southern Italy (Figure 1). Thus, despite heavy subsidies, the industrial gap has apparently widened. This is also true in the case of per capita income in the region, which has increased notably but is still well below the growth in the rest of the country (Figure 11).

Faced with this failure to achieve the objectives set by the development program, Italian authorities have placed increased emphasis on building state owned facilities in the Mezzogiorno, such as the Alfa Romeo automobile works under construction near Naples. Secondly, and perhaps more important in the long run, the investment program has taken a new direction, which is in accord with modern industrial location theory.

This experiment is probably unique in industrial location projects outside the "socialist" world. It arose from recommendations by the European Economic Commission to the Italian government in 1965. Disappointed with the results of their development effort, the planning authorities had asked for technical advice on future programs, and the recommendations of the EEC are currently in process of implementation. The basic thesis of the report was the need to use new criteria to promote industrial development in the South. It cites the fact that the current program, which provides a 2 to 5 per cent subsidy for new plants in the South, was insufficient to offset the 10 per cent profit margin that the North already possessed because of existing "external economies" in that region. This term means the benefits that accrue to modern multiple-cycle industrial establishments from linear and circular linkages with associated industries, which supply materials and components to such firms, service their equipment, or purchase their products.

Thus, the development of integrated industrial complexes, in an appropriate economic environment, should reduce the time and cost of operations, lower inventory requirements, and hopefully improve the range and quality of industrial output. The plan calls for an investment of $166 million for the simultaneous insertion of a series of machinery and metal fabrication plants into a "development pole" in the Mezzogiorno, one with an existing infrastructure, an industrial tradition, and a potential labor pool. These plants would be assisted by heavy state investments designed to improve the port facilities and the transport network of the region and to create vocational and apprenticeship facilities. In addition, they would be eligible for the subsidies already available in all "approved industrial areas."

The site ultimately selected lies in the southeastern portion of the mainland in the provinces of Bari, Brindisi, and Taranto in Puglia, and the adjoining province of Matera in Basilicata (Figure 1). This zone, which accounts

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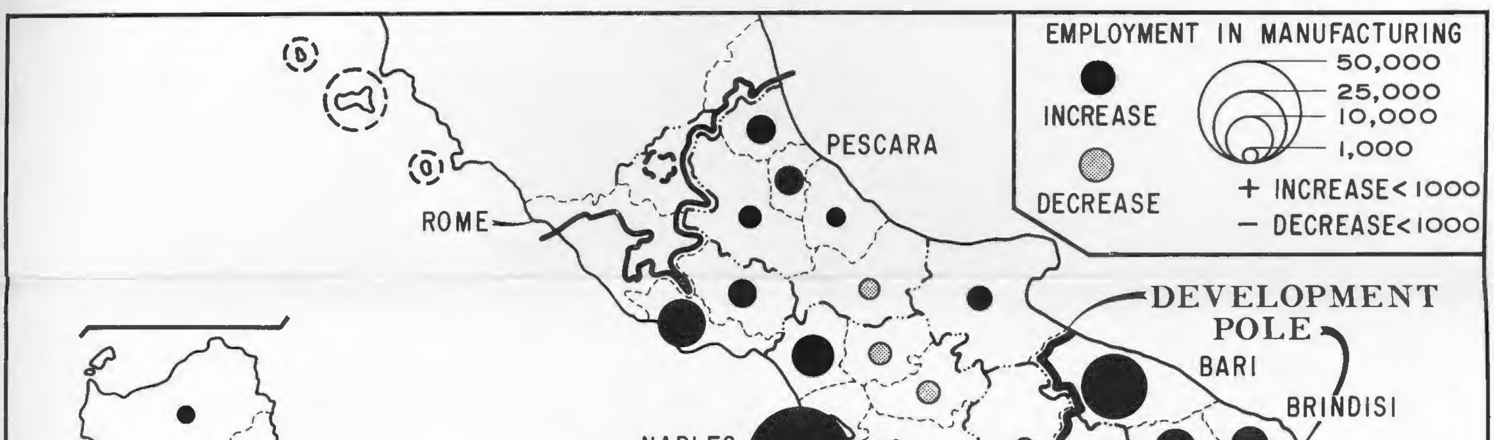

Fig. 1. Changes in manufacturing employment in southern Italy from 1951 to 1966. (Inset: Transport Network of the Development Pole).

The Role of Weather Modification *(Cont'd.)*

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Industrial Location

(Cont'd.)

for roughly one-tenth of the area and population of the South, has been a region of relatively rapid economic development. Its manufacturing growth, which has been heavily subsidized, has increased by nearly one-half since 1951, and employment in this sector now totals over 100,000 workers. This period has witnessed the building of a two million-ton integrated steel plant at Taranto, which is scheduled to triple in capacity within the next few years, as well as a major Shell refinery. Brindisi has been the site of a massive Montecatini-Edison petrochemical facility, while a number of medium sized machinery works have gone into operation at Bari. The most notable development in the province of Matera has been the use of natural gas for petrochemical production at Pisticci and Ferrandina. As a result of these investments and increased employment in manufacturing and tertiary activities, per capita income in the region is well above the average in the South.

Major investments are now in process for implementation of this development effort; they involve improvement of the region's transport network. By 1970 Bari is to be linked with Naples by an autostrada. Another superhighway is currently under construction along the Adriatic Coast to link Bari with Pescara, so ultimately there will be two major connections to the North. In addition, a projected link is planned to tie the region to the toll-free autostrada that will link Salerno with Reggio Calabria in the south. Also, these ties will be complemented by new and improved roads within the region, expansions in port facilities, building of natural gas pipelines, and construction of electric power facilities. Thus, there will be a simultaneous improvement in infrastructure and the development of linked industries envisaged by the EEC.

Four groups are currently committed to the program: Fiat and Ignis in the private sector, and Efim-Breda and I.R.I., which are state controlled. The number and character of plants have been altered because of reevaluations of cost estimates and changed market conditions. Some facilities which do not fit the original concept are now planned, such as plate glass and cold rolled steel, but key investments for plants which will produce compressors, pumps, automobile parts, agricultural machinery, etc. are in accordance with the original proposal. There is also discussion of further expansion of linked facilities in the petrochemical field. Aside from the anticipated employment of 10,000 additional workers, there should be multiplier effects in other manufacturing branches as well as in the tertiary sector. In sum, an experiment is now underway which may provide the impetus for comparable investments in other potential development poles in Italy. Indeed, this experiment may well have an impact on industrial investment programs in other depressed and underdeveloped regions of the world.

McFarland Award Banquet

Members of the Penn State chapter of the American Society for Metals, and all other interested persons, are reminded that the banquet to honor the twenty-first recipient of the David Ford McFarland Award, Dr. Jack H. Wernick, will be held on May 3 at 6:30 p.m. at the Centre Hills Country Club, State College, Pa. Individual tickets for the banquet are $6.50, with tax and gratuity included, and may be obtained from Dr. R.W. Lindsay, 221 Mineral Industries Building, University Park, Pa. 16802.

Reprints Available

Recent publications of the College of Earth & Mineral Sciences are listed below. Those desiring reprints should address their requests to the author whose name appears in italics (if there is more than one), 5 Mineral Industries Building, University Park, Pa. 16802.

Title, Author, and Source

The Elastic Constants of Polycrystalline $HoZn_2$. D. J. Michel, *Earle Ryba* and Z. P. Chang. ~~J. Appl. Phys., 39, 12, 5547-5548, Nov. 1968.~~

Frequency Distribution of Elements in Rensselaer Graywacke, Troy, New York. C. W. Ondrick and *J. C. Griffiths*. Geol. Soc. of Amer. Bull., 80, 509-518, March 1969.

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