Minerals Beneficiation

Mill men continue their search for process improvements that will give lower costs and better performance

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THE less than favorable economic weather prevailing in the business world has continued to hold the damper on advancements in milling and minerals research. Toward year's end came announcements of strike settlements and cuts in prices of copper, zinc and lead. Anaconda's six week shutdown at Chuquicamata was ended November 14 with the New Jersey Zinc settlement being announced a few days later. The Bunker Hill strike ended near the close of the year. Earlier, settlement of the strike at White Pine was effected.

Despite the presently retarded economic outlook, new plants were put into production, construction proceeded on schedule at other properties, and ambitious undertakings involving multi-million dollar expenditures were announced, particularly in the iron and steel industries. Mill men have not neglected improvements in milling circuits favoring automation and automatic controls in the continuing search for lower costs and optimum performance.

As usual, the greatest activity appears centered in the iron and steel industry with plant expansions announced for Reserve and Republic, a new taconite project being planned in Wyoming for Columbia-Geneva, and announcement of plans for three commercial installations based on the Strategic-Udy direct iron process, two of these in Canada and one in the U. S. Vigorous activity was also afoot in the base metal industry, notably the announcement of construction of integrated copper-lead smelting facilities at Tsumeb in South-West Africa, Asarco's 15,000-tpd Mission project near Tucson, and bringing into production Southern Peru's Toquepala mill and smelter and Inco's Thompson project in Canada.

Autogenous Grinding Under Intensive Study

Efforts to reduce grinding costs have spurred interest in the possible benefits to be derived from autogenous grinding with attendant savings for crushing circuits. Extensive theoretical and pilot plant studies of the dry-grinding Aerofall mill were made and reported on in two papers at the International Mineral Processing Congress in London in April. Results tend to indicate that metallurgical advantages, in addition to low power and wear, may also be possible due to disintegration of the ore along grain boundaries to its natural grain size. This would seem to be of particular importance for the dry processing of specular hematite or magnetite ores having a moderately coarse liberation size. Iron ore metallurgists, being well abreast of developments, have had this mill under investigation for some time.

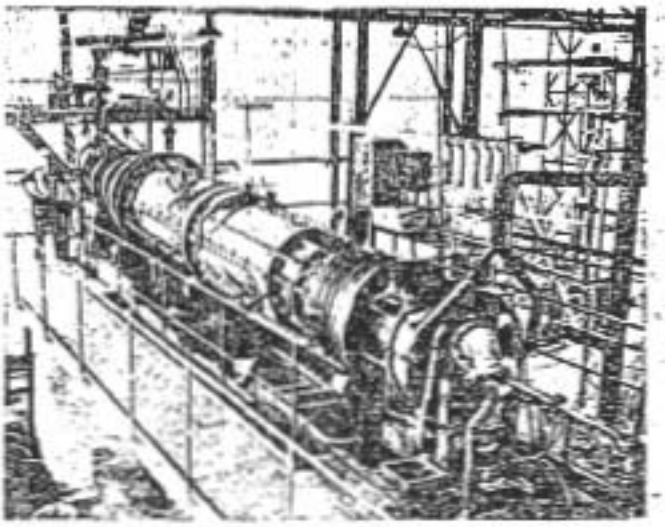
Extensive testing is also well under way with the Hardinge Cascade mill. The Quebec-Cartier installation at Lac Jeannine, employing twelve 12-ft. diam Cascade mills and due to commence grinding in December will be watched with interest by all mill men.

Every flotation operator is well aware that his grinding mill effects changes in surface chemistry as well as performing the purely physical task of comminution. These chemical changes are often unpredictable, sometimes detrimental, and sometimes beneficial. Often deliberate attempts are made to enhance or to retard the chemical effects. As autogenous grinding finds more application in sulfide flotation plants, it will be of considerable interest to observe and compare the chemical phenomena with that of conventional methods.

Iron Ore Beneficiation

The past year has seen the active resumption of the steady technological progress in mineral preparation that has come to be expected of the iron ore industry. The increasingly keen competition from high grade foreign ores and "manufactured" blast furnace burdens is forcing domestic operators to bend every effort to prepare chemically and physically enhanced materials having improved digestibility in the blast furnace.

After many years of lying dormant, the technically sound process of magnetic reduction has been dusted off and is being carefully scrutinized for processing semitaconite such as that found on the west end of the Mesabi range. A wealth of development work has gone into this process over the years and now it appears the next step to commercial reality will be taken as illustrated by the M. A. Hanna Co. announcement of a $2,000,000 expenditure for pilot plant



Two semitaconite processing pilot plants that will utilize Dravo-Lurgi magnetizing roasting kilns, similar to the one-half tph test model pictured, are under construction on the Mesabi Range. These plants will convert semitaconite to a synthetic magnetite which can subsequently be recovered using conventional magnetic equipment

* The author was assisted by W. C. Heller and E. C. Pittyman, metallurgists on the staff of Newmont Exploration Ltd., in the preparation of this article.

facilities in the Nashwauk-Cooley area. The favorable tax structure for semitaconites created by the Minnesota legislature in 1959 is reported to have influenced the decision for this expenditure. In some cases, a break on costs might be realized in grinding due to increased friability after heat treatment. Many different types of furnaces have been investigated over the years for the magnetic roasting step and at present the Lurgi kiln appears to be finding the most favor.

Expansion in the capacity of its E. W. Davis works to 9,000,000 tons of pellets per year was announced by Reserve Mining Co. during 1960. This represents a 50 percent increase over present tonnage and reportedly would involve new crushing, concentrating and pelletizing equipment as well as rail and power facilities.

The expansion of Cleveland-Cliffs' Humboldt plant on the Marquette range to an annual capacity of 650,000 tons of pellets was completed in 1960. This plant has the first commercial Allis-Chalmers Grate-Kiln system of concentrate agglomeration and heat treatment of pellets. Plans were also announced by Cleveland-Cliffs to expand the capacity of the Republic low grade mine to 1,600,000 tons of iron ore concentrates per year. Both Republic and Humboldt employ flotation for the concentration of iron minerals from the low grade jasper, and together with M. A. Hanna Company's Groveland operation, also on low grade jasper, will provide a source of some 3,000,000 tons of highly beneficiated concentrates per year from the upper Michigan peninsula. Adding to this, Erie Mining Company's production of pellets and the new goal of Reserve gives the phenomenal total of 20,000,000 annual tons of "manufactured" high grade product from the Minnesota-Michigan ranges.

Other Developments in Iron Ore Concentration

Other processes continue to be examined closely to improve quality of product and to reduce costs. Improvement of quality of dense media through control of particle shape is a move in this direction. The rotary scrubber is also being re-examined to obtain a better understanding of the improvements to be expected by this method of removing loosely adhering silica from ore particles.

Development of dry methods of iron ore concentration continues to be of interest, spurred by the activity in the Wabush area of Labrador. Low

Pouring steel into an electric furnace during test run of the Strategic-Udy process

and high intensity magnetic separators, principally of foreign origin, appear to be attracting the most interest. But wet methods of separation have not been ignored. At least one company has experimented with a new type of gravity separation device which has produced remarkable results in the extreme fine size range; this equipment is still in the experimental stage.

Of considerable interest is the expansion of Inco's iron ore recovery plant at Copper Cliff, Ont., to triple its present capacity. This novel process, which converts nickeliferous pyrrhotite into agglomerated pellets of 68 percent Fe content and recovers by-products of nickel and sulfur, is a tribute to the determination and ingenuity of Inco personnel. The high quality pellets are reported to be finding use as open hearth lump.

Economics of Direct Reduction Still Controversial

A great deal of information on direct reduction of iron ore was published during 1960. While there is still considerable controversy over the economics of D-R in the U. S., there is little doubt but that in specialized instances a commercial operation can be mounted. The Kellogg engineered HyL process at Monterey, Mexico, has been well described in the literature and is a case in point. More recently, a 500-tpd addition to this plant was announced.

L. J. Bechaud, Jr., is one of the world's foremost authorities on extractive metallurgy of germanium and is a holder of several patents. For the past eight years he has been associated with Newmont Exploration Limited and is currently director of its Metallurgical Department. Bechaud has been in his present post for three years, prior to which he was at Newmont's Grass Valley, Calif., operations. Before that, he was chief research metallurgist for M. A. Hanna Co. on the iron ranges of Minnesota, pioneering in the development of magnetic taconites and Michigan jaspers. He came to Hanna from Pan American Mining Co. and the goldfields of California.

The well publicized Strategic-Udy process, while not yet commercialized, is being planned for installation at Anaconda, Mont. This plant will produce steel from current and stockpiled slag. Canadian projects employing the Strategic-Udy process have also been announced. One of these is for a 150,000-tpy plant for New Mylamaque Exploration at Kingston, Ont. The other is for Quebec South Shore Steel at Varennes, Que.

Other D-R processes of commercial stature include H-Iron, Krupp-Renn, Höganäs, and the classic Wiberg-Söderfors. All but H-Iron have been in operation a number of years. More recently, the H-Iron process for producing low-carbon iron powder was put into operation by Alan Wood Steel Co. at Conshohocken, Pa., and Bethlehem Pacific has engineered a second plant at its Vernon steel works. The product from the latter plant will reportedly be charged to an electric steel-making furnace.

Two newcomers on the scene during the latter part of the year were the Dwight-Lloyd McWane and the Allis-Chalmers Agglomeration-Reduction processes, both in the development stage. The D-LM process employs pre-reduction of a prepared and pelletized feed on a traveling grate followed by introduction of the pre-reduced pellets directly to an electric furnace for steel making. This process appears to have the advantages of simplicity, close control, and flexibility, and should appeal to operators who tend to shy away from the complexities of more sophisticated equipment. The Allis-Chalmers process is a unique combination of two concentrically aligned kilns, the inner kiln providing for reduction by means of catalytically cracked hydrocarbon gas, with excess gas being burned in the annular space between the kilns to provide the heat.

Interest in Automation Grows

Interest in automatic control of mill processes in the mineral industries continues to grow. Although the fully automated push-button mill, controlled by a computer, is still some-

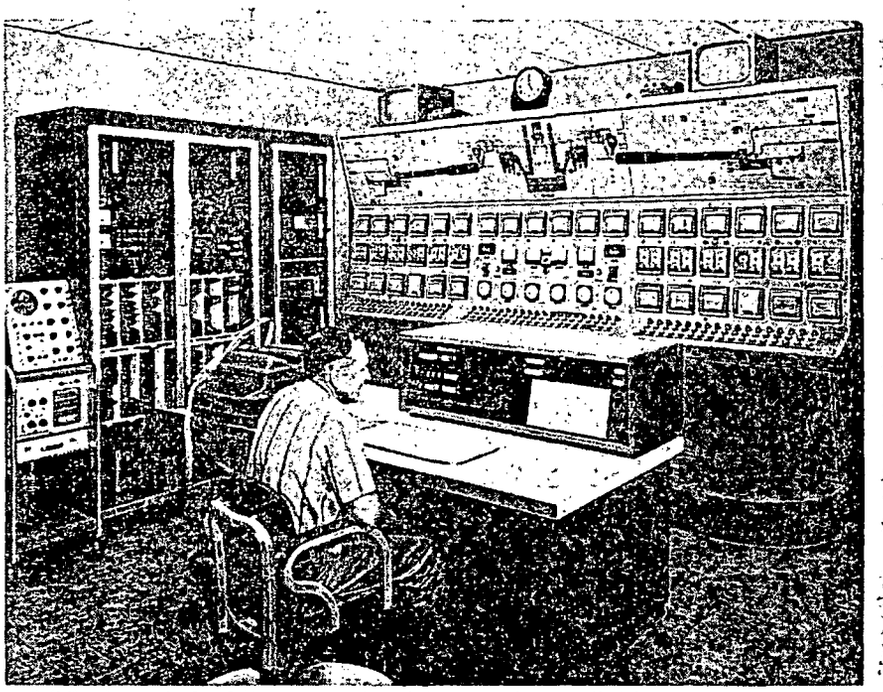
where in the future, advances have been made in applying mechanical and electronic controls to a number of unit operations involved in milling practice.

True automation with its implication of sensing and control devices, which are integrated by means of feedback systems with a sophisticated control center, is probably closest to reality in those mineral industries where efficient materials handling contributes largely to economy of operation and process variables are reasonably uncomplicated. These areas include pimarily such operations as cement plants and coal cleaning units where great progress in automatic control has been reported recently. Among the cement manufacturers reporting such advances in automatic control are the Dundee, Mich., plant of the Dundee Cement Co., the Ada, Okla., plant of Ideal Cement Co., and Riverside Cement Co.

The Dundee operation, while not under the direct control of a computer, utilizes an IBM electronic computer set-up for extremely rapid evaluation of data to achieve optimum operating conditions. The use of automatic control of burners on the kilns, clay and limestone preparation, and closed circuit TV observation of transfer points are just a few of the devices reported to be incorporated in the Dundee plant. Other cement plants are understood to be attempting to incorporate more direct control of unit operations into the electronic computer center.

The Moss No. 3 preparation plant of Clinchfield Coal Co. has put practically all materials handling and operation of dense media separation under centralized control. Rail cars move by gravity and are controlled remotely by target and limit switches and compressed air operated retarders. Handling, storage, and charging of the magnetite heavy medium to the separators is also under remote control. Gamma ray absorption devices are used to measure, report and record the specific gravity in each of nine dense media units. Under such control, product quality is reported to be better and more consistent, and significant economy in labor costs have resulted.

In the field of metallic minerals, the iron ore processing plants continue to lead in the field of automatic control of unit processes, particularly that of sintering. In addition, the application of computers to the problem of optimizing the operation and burdening of blast furnaces has been widely reported.



While the goal of a fully-automated push-button mill controlled by a computer is still in the future, mineral processers are making more and more use of both computers and automatic controls

Instrumentation in the Nonferrous Industry

Operators in nonferrous mills are plagued with the ancient problem of having to tailor-make control devices to fit each and every situation. A few novel approaches to the control of pulp density and grinding mills have been reported recently.

Asarco has two schemes under consideration for control of the grinding circuit for the new 15,000 tpd Mission copper concentrator. The first method is based on a determination of the difference in the temperature of the feed water and the ball mill discharge. A large temperature difference indicates the mill is underloaded and the electronic control system calls for an increase in the rate of feed.

The second system depends upon measuring and constantly controlling pulp density of the ball mill discharge at a predetermined value by automatically adjusting the rate of feed of water to the mill. The water flow rate is measured in turn and this information is used to automatically compensate for fluctuations by adjusting the rate of ore feed so that the water and ore are in balance.

The new Levack mill of Inco is reported to be extensively instrumented. Water addition to the classifiers is regulated by pulp density measuring devices based on gamma ray absorption. In the flotation circuit, pulp density, pH and temperature are measured automatically and controlled from a central point. Thickeners and filters are instrumented and operated from another centralized control point.

Much of the over-all problem associated with more complete automation of mineral beneficiating plants is involved in the lack of suitable sensing devices for measuring process variables. Considerable progress has been made recently in the application of such techniques as gamma ray absorption to determine pulp density as mentioned above. X-ray fluorescence is being employed by Anaconda to yield essentially continuous analyses for a number of elements in mill feed, concentrates and tailings. Kennecott is reported to be installing similar units at Utah Copper. While these extremely rapid assay tools are not automatic control devices, they do give the operator a more up-to-the-minute picture of the performance of his mill, and certainly these techniques represent one more advance toward automatic process control.

Hydrometallurgy Confined Largely to Uranium and Rare Earths

Significant new activity in the field of hydrometallurgy is still confined in large scale to the uranium extraction field. Several new mills went into operation or were approved for AEC contracts, principally in the Gas Hills district of Wyoming. Extraction techniques in the new mills are standard acid-leach or carbonate-leach followed by liquid-liquid extraction and stripping units.

The status of buying contracts between yellow-cake producers and

AEC for the 1962–1966 period continued to be cloudy. General policies announced by AEC are, by apparent necessity, broad and somewhat nebulous so that each operator's position during the forthcoming period must be individually established. By the end of the year, the major portion of the established uranium mills were reported to have reached new agreements with AEC regarding price for and amounts of yellow cake to be produced.

From a production standpoint, the application of hydrometallurgical techniques continued to be confined mainly to the rare-earths and nuclear products sectors of the industry. In the area of base metal production, an amine leaching process for producing high purity lead from mixed sulfide ores was developed at the University of British Columbia in cooperation with Sherritt Gordon Mines and was received with a good deal of interest.

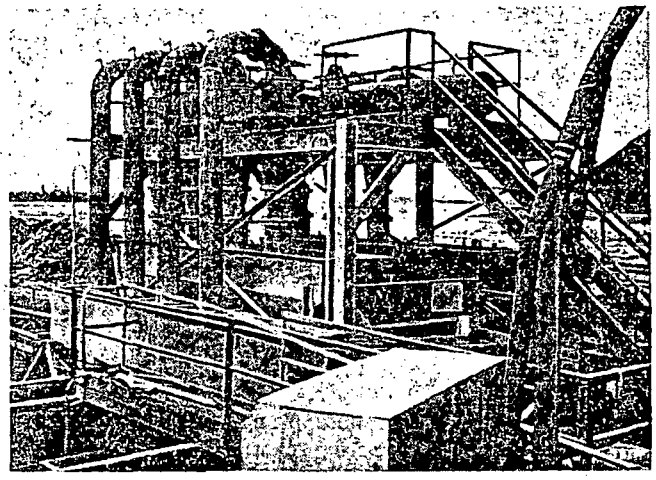
Briefly, the process consists of a pressure oxidizing leach in acid medium to convert PbS to $PbSO_4$. The resulting lead sulfate is selectively leached at room temperature with a 15 percent solution of diethylene triamine which forms a lead complex. Lead is precipitated from the amine as a basic carbonate by the addition of CO_2. Silver free lead is produced from the carbonate by reduction. The amine leach solution is regenerated with CaO producing gypsum as a waste by-product.

In this process reagent consumption appears to be quite low. All steps, except for the initial oxidation and final reduction of lead, are conducted at room temperature and pressure. This appears to be a practical process having application to non-separable base metal bulk concentrates. Lead purity is said to be four nines.

Wet Processes for GeO_2 and Cu Recovery

At Tsumeb in South-West Africa a new wet process plant for production of germanium dioxide went on stream in the latter part of the year. Sulfide concentrates are roasted for selective oxidation of arsenic and germanium. Calcines are acid leached and pregnant solution is concentrated in a submerged combustion evaporator. Evaporator sludge and liquor is distilled with hydrochloric acid to produce germanium tetrachloride which is subsequently hydrolyzed to GeO_2.

Empressa Minera de Matos Blancos S.A., has initiated a project in Northern Peru designed to recover copper occurring predominantly in the form of basic copper chloride, atacamite. The patented process consists of percolation leaching with sulfuric acid followed by sulfur dioxide absorbtion to precipitate insoluble copper chloride. The pure chloride is then pelletized with limestone and coke and is smelted in three 4 by 3-meter Lurgi rotary furnaces. Two additional furnaces are used to produce wire bars. Plant is designed to handle 3000 tpd of ore.



In recent years, the use of hydrocyclones in mineral processing systems has grown steadily

Although specific details are lacking, it is reported that a new technique is under investigation by the British Department of Industrial and Scientific Research involving the use of napthenic acid in liquid-liquid extractions. Priced more cheaply than alkyl-phosphoric acid, napthenic acid is reported to be equally effective.

Segregation Process Revived

The process of copper segregation is an example of an apparently dead horse which has recently shown surprising signs of life. While the exact mechanism of copper segregation has not been well defined, the over-all process consists of roasting oxidized copper ore with salt and carbonaceous material under controlled atmosphere conditions at 700–750° C. Simultaneous chloridization and reduction of the copper mineral apparently occurs such that metallic copper is produced in the form of separate well defined particles outside the ore matrix. This metallic copper is recoverable by standard flotation techniques.

Interest in the segregation process lagged after two experimental plants in the Congo and Southern Rhodesia closed in the early 1930's due to economic and mechanical difficulties. The U. S. Bureau of Mines at Tucson recently undertook a renewed evaluation of the process. Partly as a result of this work and the natural interest in a process for recovering copper from oxide and silicate minerals, pilot plants have been built in Mexico at Santa Rosalia and d'Akjoujt in Mauretania.

The first commercial segregation plant in the U. S. was recently put into operation by Trans-Arizona Resources near Tucson. The reactor in this plant is reported to be a 54-in. by 42-ft long indirect fired rotary kiln.

A pilot plant of particular interest is that of the Berenguela mine in Peru which is built to handle one tpd of ore. Here the older technique of roasting in rotary kilns under a relatively static atmosphere has been replaced by pelletizing the ground ore with coke and salt followed by roasting in a shaft furnace. Both copper and silver are segregated and recovered by flotation from a manganiferous ore containing from one to two percent copper and five to twenty oz of silver per ton. An interesting feature is the departure from the rotary or hearth type furnaces of previous plants.

New Separation and Classification Methods

A new and unique process developed at Battelle, which is used to upgrade rock salt at the Detroit mine of International Salt Co., makes use of a differential in radiant heat absorbtion to cause one fraction of "ore" to adhere to a heat sensitive belt. Other applications are possible.

Dorr Oliver, Inc., introduced a new dense-media process claimed to be capable of treating the full size range from 2½-in. to 65-mesh. The process includes DorrClone cyclones, dense media ore classification units, and DSM screens. Feed is introduced under gravity head thus eliminating pumping of ore with media. Media losses are claimed to be drastically reduced.

A double-drum, concurrent style permanent ceramic magnet, wet-drum separator has been developed by Stearns Magnetic Products, Milwaukee. The high strength ceramic material is said to provide savings in weight, operating and maintenance costs. Stainless steel is used for feed box and collection tank.

Successful application of the Buell developed Gravitational-Inertial classifier was reported on limestone and phosphate rock processing. This high efficiency dry classifier makes use of aerodynamic principles not previously utilized in classification. There are no moving parts in the separating chamber proper, hence maintenance costs should be low. Once the cut point has been set it is claimed no further attention is required. The classifier makes its separation by entraining fine dust particles in an induced eddy current which exhausts from the top of the unit. The coarser particles, which cannot make the turn into the eddy chamber, fall by gravity through an opening in the bottom. A secondary air current is directed onto the falling coarse particles and removes adhering fines.

Russians Dominate Flotation Research

Advances in flotation practice and research in the free world were at a modest level. New mills were designed but the flotation circuits reported rely mainly on the cut and dried standard techniques which have served the industry so well in the past.

Probably the most significant development in flotation was the domination of the Soviets in the fields of both basic and applied research. At the International Mineral Processing Congress held in London during April, six of thirteen papers concerned with flotation were of Russian origin among a total of seven nations whose representatives gave papers. A cursory check of published articles reveals that a large and steadily increasing amount of work in flotation research is being conducted behind the Iron Curtain.

During the past year in the Soviet Union, a large scale production plant was put into operation employing the L-P-F process on a copper ore. Sodium sulfide is used as the precipitant, it being claimed that this is simpler, cheaper, and gives better grade of concentrate than does sponge iron. One Soviet paper again emphasized the role and possible significance of gas precipitation in flotation. Indications are that losses of slimed mineral might be reduced by making more effective use of this phenomenon.

In North America, evidence of a growing interest in columbium was given by announcement from four different companies of the development of a flotation process for concentrating columbium minerals. Long chain amines, di-amines, and wetting agents is one combination; hydroxyquinoline chemicals for collector is used in another instance.

On a laboratory scale, interesting results were obtained at Washington State University on flotation of autunitic uranium ores with an aqueous emulsion of stearic acid, soap, and kerosene. The reagent also floats uraninite, uranophane, monozite, apatite, and with a soluble phosphate, chrysocolla is also reported to be floated. The only catch is that selectivity is not good.

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convincingly. If adequate favorable case history does exist, one of the most useful things that can be done is to pull it together and make it available.

In the modern scene, on-the-job training is necessary unless work-study cooperative programs are developed. Few companies offer it. Both educators and industry spokesmen hold that the job of the schools is to give a broad fundamental training, leaving much of the detail and most of the practical applications to industry. To be adequate in this context, on-the-job training consists of more than just learning the jobs and psychology of labor. It involves experience in various departments of the company, reports from the trainee and from his immediate supervisor, correction, and periodic interviews with local top management.

Nothing can be accomplished by retreating into the viewpoint that the young fellows are too soft or too desirous of made-to-order careers. To the extent that they may be found wanting in these respects it is the fault of conditions created by their elders. Anyway, we have to work with people as they are, not as they might have been. Furthermore, anyone who will take the trouble to learn the viewpoints of young men will find that they lack neither intelligence, manhood or valid philosophies. Can they be blamed for taking advantage of the offers of better competitors for their services?

Mining is a necessary, useful field. For people who thrive on challenges, it is continuously fascinating in its diversity, opportunity, geographic spread and incessant change. Until it regains status as a field of unusual opportunity and a home for an elite class of humanity we have no cause to be complacent. Meanwhile, there is much to be done involving cooperation between the industry and educators.

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the ore was deposited from a concentrated brine high in Na and Cl, and lower in K, Ca, Mg, B and SO_4, containing only small amounts of the ore minerals, perhaps as little as ten ppm.

A geologic therometer, that may be of great range and precision, has tentatively been established by R. N. Clayton of the University of Chicago and H. L. James of the Geological Survey. Using the O^{18}/O^{16} ratios of iron oxides, calcite and quartz, temperatures ranging from 80° C (Iron River, Mich.) to 700° C (Iron Springs, Utah) have been estimated. Further data suggest that iron oxides of the main ore bodies in the Lake Superior region were formed from solutions isotopically similar to present-day fresh water.

The year 1960 witnessed a continuation of the debate concerning basic theories of ore genesis. Many papers presenting discussions on this subject have been carried in *Economic Geology*. The conflict between the syngenetic and epigenetic schools is sometimes heated, but these debates, spurred by papers and discussions of such men as C. L. Knight, G. M. Schwartz, J. L. Kulp, R. H. Sales, H. L. James and many others, are a valuable contribution to geological science.

Difficult Problems Ahead

In conclusion, it can be stated that the mining industry has entered a period requiring considerable adjustment, both economic and technical. There will be difficult problems to solve in the immediate years ahead. Strong leadership and decisive action are needed to cope with rising costs, increasing taxes, restrictive legislation, and competition from the Communist world. At the same time, the industry is confronted with the task of constantly replacing and even expanding diminishing reserves in order to supply the free world with its vital mineral requirements.