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James Doyle Sell Mining Collection

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Table 7.—Time-price relationship for molybdenum in concentrate,[1] 1954–77

Year	Average annual price, dollars per pound: Actual price	Based on constant 1977 dollars
1954	1.05	2.49
1955	1.10	2.55
1956	1.18	2.66
1957	1.18	2.57
1958	1.25	2.68
1959	1.25	2.62
1960	1.25	2.58
1961	1.40	2.86
1962	1.40	2.81
1963	1.40	2.77
1964	1.55	3.02
1965	1.55	2.95
1966	1.55	2.86
1967	1.62	2.90
1968	1.62	2.78
1969	1.72	2.81
1970	1.72	2.67
1971	1.72	2.54
1972	1.72	2.44
1973	1.72	2.30
1974	2.02	2.47
1975	2.48	2.76
1976	2.94	3.11
1977	3.68	3.68
1978[p]	4.52	4.21
1979 June	6.50	
1980 - oct	8.25	
1981 -		

[p] Preliminary.
[1] Prices are weighted averages for each year. Price changes in 1977 and 1978: Aug. 1, 1977, $4.01; March 7, 1978, $4.41; Sept. 1, 1978, $4.95; Dec. 29, 1978, $5.19 (calculated based on 4.75-percent increase from previous price).

istration (GSA). However, since 1963, these materials have been sold from the stockpile because domestic reserves and production capacity were considered adequate to supply national emergency needs. By yearend 1977, no molybdenum remained in the stockpile. Revised stockpile goals announced in October 1976 and reaffirmed in 1977 by the Federal Preparedness Agency (FPA) of GSA did not include molybdenum materials.

Although adequate to supply potential increased needs in wartime, capacity is concentrated in relatively few mines and conversion plants. Interruption of normal operations at the major mines and plants due to accidents or labor problems would significantly reduce availability.

ECONOMIC FACTORS AND PROBLEMS

Pricing

Table 7 shows the time-price relationship since 1954 for molybdenum contained in concentrate in actual dollars and based on constant 1977 dollars. Actual prices are based on the published price of the major producer, Climax Molybdenum Co. Historically, prices quoted by the other large producers have not varied appreciably from the Climax price, although byproduct producers generally have listed their concentrate at prices slightly lower than that of Climax. The lower price was due to either lower molybdenite grade or higher impurity content than that of Climax concentrate. However, in response to strong worldwide demand during 1978, other producers began to list prices for concentrate and other products higher than the Climax price quotes. In addition, U.S. producers initiated a two-tiered price system in which prices for exported materials were set higher than for domestic sales.

The prices of other molybdenum products are also quoted on a contained-molybdenum basis and reflect, at least partially, the cost of conversion. Technical-grade oxide, the major form of molybdenum sold commercially, varies in price among the major producers depending on purity, type of packaging, and whether it is briquetted. Over the last 5 years, producer oxide prices have ranged from 7 to 12 percent over the concentrate price.

As of January 1979, Climax Molybdenum Co. listed oxide, in cans, at $5.55 and ferromolybdenum at $6.38 (both per pound of contained molybdenum) for domestic sales. A domestic price for concentrate was no longer listed, but an approximate price of $5.19 was calculated based on the percent increase in domestic prices on other materials for the last price change in December 1978. Climax's export prices were as follows: Concentrate, $5.86; oxide, $6.56; and ferromolybdenum, $7.71. Other major U.S. producers listed prices for oxide and ferromolybdenum above the Climax price quotes.

Although the bulk of producer sales are made at listed prices, it has been reported that during periods of oversupply in past years some discounting prevailed, particularly for byproduct concentrate and oxide. In contrast is the current situation of somewhat restricted supplies and byproduct oxide prices that exceed the Climax list price. The strength of the 1978 market was also attested to by dealer prices for oxide, which have been listed as considerable premiums over producer prices since 1976. Materials supplied by dealers represent, however, a relatively small fraction of total domestic consumption.

Prior to 1974, producer prices for molybdenite concentrate and other products were characterized by marked stability. Particularly noteworthy was the 5-year interval from 1969 to 1973 during which listed prices remained unchanged. The 1973 average price for molybdenum in concentrate, when adjusted for inflation, was lower than it had been for the previous 20 years. During this period, the applications and demand for molybdenum were considerably expanded.

The presently prevailing market of generally tight supply-demand balance and rising prices began in 1974. Since early 1974, the price per

FTC

ASARCO

J. H. C.

ASARCO Incorporated

OCT 19 1979

OCT 18 1979

SW Exploration

Exploration Department
T. C. Osborne
Vice President

October 16, 1979

Mr. J. H. Courtright
Tucson Office

Molybdenum

Dear Mr. Courtright:

Thanks for your memorandum of October 4.

I have no trouble with the concept that the Amax current molybdenum market price has a good chance of keeping up with inflation over the long-term. As pointed out in "Moly Study", molybdenum could be subject to periodic disruptions in the general pattern because a single new major molybdenum mine can readily produce 10%-25% of present world demand. (Compare this with copper, wherein a major new copper producer of first rank might produce 2% of current world demand). "Lumpiness" of the molybdenum supply stream has been a factor in prices in the past and will likely affect prices in the future from time to time over relatively short-term periods.

For practical purposes in evaluating possible new molybdenum investments at any particular time, I think we should use the current Amax molybdenum price at that time and current capital and operating costs. As far as I know, this has been our consistent policy in the past.

I think we also all agree we should not use spot molybdenum prices (although these may be very substantially higher than the Amax price as they have for the past several years) because to do so for investment decisions would be frankly speculative. Speculation in commodities is a perfectly good way to make money but it is not a business Asarco knows much about. Further, one rule in commodity speculation is to stay liquid, and a mine is of course about the least liquid way of tying up money there is. I realize your memorandum in no way suggests that we should use spot prices for long-term investment decisions, and am just throwing this discussion in because it is hard for everyone including myself not to be impressed with the current molybdenum profits we are making on what normally is a relatively minor by-product.

Very truly yours,

T. C. Osborne

cc: WLKurtz DMSmith
JCBalla FTGraybeal
REGale
(all w/copy of Mr. Courtright's Memo)

ASARCO Incorporated 120 Broadway New York, N.Y. 10005 (212) 732-9500
Telex: ITT 420585 RCA 232378 WUI 62522 Cables: MINEDEPART Telegrams: WU 1-25991

ASARCO — Exploration Department

JAC

Copy this — (single spacing)

October 4, 1979

MEMO FOR: T. C. Osborne

FROM: J. H. Courtright

MOLY

~~Perhaps you have seen~~ the recent USBM publication ----- "Molybdenum" by John T. Kummer, May 1979, ~~In any case,~~ Some of the more important aspects of are summarized below.

In contrast to "Moly Study" (my memo of 6/1/79), "Molybdenum" contains the results of research on demand which is broken down into six end-use categories for consumption in the USA:

	Lbs Mo x 1,000	
	1977	Forecast year 2000
Transportation	13,000	46,000*
Machinery	21,000	42,000*
Oil & Gas Industries	9,100	34,000*
Chemicals	7,100	24,000*
Electrical	5,200	12,000*
Other	6,000	12,000*

As may be noted, the most rapid growth rates forecast is in transportation, chemicals, and the oil and gas industries. In respect to the latter, the author states: "Increased activity in oil and gas production, refining, (and pipeline transportation), and the possibility of molybdenum use in coal gasification and liquification plants could combine to produce the high of the forecast range, 41 million pounds, (in contrast to the "probable" figure of 34 million pounds).

Production figures and demand forecast given are:

	Lbs Mo x 1,000		
	1977	1980 (capacity)	2000
World production	206,000	284,000	
World demand	205,000		630,000
USA demand	61,400		170,000
(1977-2000 compounded annually)			4.5%
Rest of world			
(" " " ")			4.8%

---

* "probable" - which is a conservative figure between "high" and "low" figures in Table 10, page 20 of text.

According to the above projections, world consumption in the year 2000 will require tripling of 1977 production. However, other than a tabulation of world reserves and possible resources in pounds of moly (total 42,500 million ----- 65% recoverable), the author makes essentially no attempt to analyse production potential, particularly of undeveloped deposits and prospects, but concludes: "The currently prevailing world supply and demand patterns are expected to continue at least into the mid-1980's, and probably for the remainder of this century."

According to "Moly Study," western world production forecasts (based on data for 30 deposits ----- operating mines, plus prospects with established potential) show that an over-supply could occur by 1987-1990. However, this assumes optimum production rates and a decline in demand to 3.4% per annum by 1983 ----- and does not take into account the possibility that development of some of the large-potential prospects listed, such as Quartz Hill and Mt.Emmons, may be stymied by the environmentalists.

Thus, in view of projected demand, it appears reasonably possible, if not probable, that the moly market price will keep up with inflation over the long term.

J. H. Courtright

J. H. Courtright

JHC:jlh
no encls
c.c. WLKurtz/FTGraybeal

ASARCO

Exploration Department

June 1, 1979

MEMO FOR: T. C. Osborne

FROM: J. H. Courtright

MOLY

Thanks for the loan of "Moly Study", which I found to contain the results of a fairly thorough investigation of current and potential production in the Western World. Data on present producers appear fairly accurate, but some erroneous grade figures are shown for potential future producers; for instance, Mt. Tolman, Washington State, is listed as .16% Mo, rather than .08% Mo (published grade), and Thompson Creek .09% Mo instead of .15% Mo (published? grade). Nevertheless, in general their projections of possible future supply appear reasonable.

Assessment of supply, however, is only half the picture. The other half, demand, is of equal or greater importance, but it is stated (page 23), "We have not attempted to detail the future moly consumption market by end-use markets.....". Yet this type of research is precisely what is required, I believe, to properly evaluate the future of moly, particularly from the standpoint of exploration.

In the matter of price forecasting, they state (page 5) "Moly concentrate pricing could reach $6.50 per pound by 1983, with the spot market at times in the $9.00 to $11.00 range." All are aware, of course, that the Climax quote has been around $6.80 for the past month, with dealer prices as high as $27.00.

As stated in my memo of 2-3-78, "One of the principal uses of moly is in large diamter steel pipe for oil and gas transmission." The "Moly Study" forecasts moly consumption growth as declining from 7.5% (yearly increase) in 1978 to 3.4% in 1983. Not being based on research, this should be rated as nothing better than a "guesstimate." In my opinion, the current high demand growth could last as long as the "energy crunch" persists ---- the end of which is certainly not now in sight.

The Moly Study will be returned under separate cover.

J. H. Courtright

J. H. Courtright.

JHC:jlh
c.c. W.L.Kurtz/F.T.Graybeal

ASARCO

Exploration Department

February 3, 1978

MEMO FOR: T. C. Osborne

FROM: J. H. Courtright

MOLYBDENUM

Our somewhat negative attitude in respect to moly exploration in the past few years has hinged largely on the "Henderson threat", a large, relatively high-grade deposit with a projected production of 50 million lbs/yr. However, after a sharp drop in 1971, consumption increased dramatically and is expected to grow at 7% per year (Amax annual report, 1976). World consumption in 1976 was estimated at 182 million lbs ------ 14 million lbs greater than production.

Henderson is expected to reach full capacity by 1980. Although this would approximately equal the 7% per year increase in consumption (in 4 yrs), the long term outlook is still very favorable according to an article in the January 13, 1978 issue of Mining Journal (excerpt attached).

Of particular note is the statement that one of the principle uses of moly is in large diameter steel pipe for oil and gas transmission. "Demand in this area appears likely to remain strong for some time to come". Among other items of significance in this article: (1) "The Communist World is expected to become even more dependent on imports", (2) "Another increase in prices of 8% to 10% early in the current year has been forecast....".

I believe the foregoing justifies a more aggressive stance in moly exploration and also points up the need for more literature search, particularly statistics, in an attempt to anticipate medium to long term markets in non-ferrous metals as well as other commodities.

J. H. Courtright

J. H. Courtright.

JHC:jlh
attmt
c.c. S.VonFay

ASARCO

J. H. C.

FEB 21 1978

Exploration Department
T. C. Osborne
Director of Exploration

February 13, 1978

file

Mr. J. H. Courtright
Tucson Office

Molybdenum

Dear Mr. Courtright:

Thanks for your short memorandum of February 3. I agree we should update our information and this procedure has already started.

As I recall it, our "somewhat negative attitude" in the early '70s was essentially toward the question of deep wildcat drilling for "stacked" deposits. This was the result not only of potential oversupply, but also the problems associated with trying to maintain low mining costs at depths of 3000 and 4000'. In fairness, I think if a reasonable open pit exploration proposition had come along we would have taken it.

The question of how far we should go in drilling deep wildcat holes for molybdenum is still a troublesome one. At the moment this may be largely academic since we don't have the drilling money, but this could be the time we should be accumulating prospects. I have in mind sending out a general memorandum on this subject but wish to wait until my thoughts crystallize a little more. From past experience, one must be very careful about sending out any kind of general instruction which too often is treated as divine revelation by the staff with consequent overreaction one way or the other.

Very truly yours,

T. C. Osborne

cc: SVonFay
WLKurtz

PROPOSALS FOR DEVELOPMENT OF U.S. MOLYBDENUM DEPOSITS IN COLORADO AND ALASKA; GOLD-COPPER DEPOSIT AT Ok TEDI IN PNG GAINS DEVELOPMENT APPROVAL; NICKEL PLANT AT RUSTENBURG, SOUTH AFRICA; MINERAL OUTPUT OF RWANDA.

PANORAMA

Molybdenum developments in Colorado and Alaska

WHAT is described as a 'very challenging' undertaking is being pursued by Amax Inc. in order to bring to production its Mount Emmons molybdenum prospect in Colorado, U.S.A. Such is the planning and thought which has gone into the proposed development of this prospect to a producing mine by 1989 that it is confidently expected that Mount Emmons will serve as a model for development of future mines, according to a recent issue of Climax Molybdenum Co.'s *Molybdenum Mosaic.*

Increases in molybdenum supply to meet the ever-growing demand for the metal must be met by increased production at existing mines, or output from new ones. One such potential producer of major importance is Mt. Emmons, located in Gunnison County, southwest Colorado. It is one of the world's larger Mo deposits, grading 0.44% MoS_2 before dilution by mining. Its reserves (including those of Amax's operating mines and other prospects) are given in Table 1. The Climax and Henderson mines are also in Colorado, Kitisault is in British Columbia, Canada and Mt. Tolman in Washington state, U.S.A.

The Mount Emmons deposit lies roughly 365m (1,200ft) below the surface on the south flank of the mountain, beneath a depression known as Red Lady Basin. Like the Henderson and Climax deposits, it is approximately circular in plan view and looks much like an inverted tea cup. The orebody is about 760m (2,500ft) in diameter and roughly 90m (300ft) in average thickness. Exploratory drilling programmes thus far, both from the top of Mount Emmons and from the old Keystone Mine tunnels, have identified molybdenite reserves of 155 million tons at an average grade of 0.44% MoS_2. At an annual production rate of from 10 to 14 million kg (23 to 30 million lb) of molybdenum, the mine would have a useful life of about 25 years.

Plans for the mine and mill sites are shown in Fig. 1. The location and configuration of the deposit are such that underground rather than open pit mining methods are most appropriate. A panel cave method of mining, similar to that used at Climax and Henderson, will be used. The ore will be transported by gravity down to a gathering level, and moved to the primary crusher at the mine site. Crushed ore then will be sent by either rail or conveyor belt to the mill site approximately 19 km (12 miles) away where MoS_2 will be extracted by conventional grinding and flotation methods. The ore haulage corridor will include an 8 km (5 mile) tunnel beneath 3,700-m (12,000-ft) high Mount Axtell, and an 11 km (7 mile) surface ore haulage system. The entire facility is being planned so that it will minimize any negative impacts, environmental and otherwise, on Gunnison County.

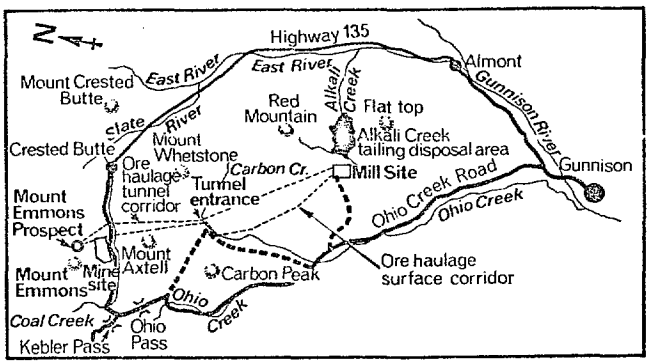

Fig. 1 The Alkali Creek plan showing proposed development of the Mount Emmons molybdenum deposit in Colorado, U.S.A.

The Alkali Creek area was tentatively chosen for the tailing disposal system because it is an off-stream unforested region with little visibility from Colorado State Highway 135, the principal road between Gunnison and Crested Butte (Fig. 1). The Ohio Creek Road will be improved to provide access to the mill and mine sites from Gunnison where it is anticipated most of the project's work force would live. The mill water system will be a closed-loop system to avoid any discharge of process water into the East and Gunnison Rivers. A tailing storage capacity of 100 to 300 million tons has been designed in such a way that probable floods will be controlled and the integrity of the tailing dam assured.

It will require more than 700 million dollars in investment and more than ten years of planning and development before the Mount Emmons Mine can be brought into production, probably around 1989.

Amax Environmental Services, Inc., is carrying out an extensive, comprehensive baseline study of areas which might be affected by mine or mill facilities.

Another molybdenum deposit known to be among the world's largest is that called Quartz Hill in Alaska. Discovered in 1974 by the U.S. Borax and Chemical Corp., and lying some 45 miles east of the town of Ketchikan in the southeast of the state (map p.312), drilling to date has shown the deposit to contain at least 700 million tonnes grading 0.15% MoS_2 with the ultimate size and depth of the deposit as yet undetermined. A drilling programme initiated last year had the objective of providing a more complete picture of geology, structure and grade.

This project, too, is nearing the end of the exploration phase

Table 1 — AMAX's Molybdenum Mines and Prospects

Mine	Start Up	Estimated Reserves* million tons	average grade	Projected Annual Production (million lb Mo)
Climax — Open Pit	1973	160	0.299% MoS_2	17-20
— Underground	1918	292	0.313% MoS_2	36-44
Henderson — Underground	1976	254	0.419% MoS_2	50
— Underground	—	154 (possible)	0.362% MoS_2	—
Kitsault — Open Pit	1981**	105	0.192% MoS_2	9-10**
Mount Tolman — Open Pit	1984**	900	0.10% MoS_2	20**
Mount Emmons — Underground	1989**	155	0.44% MoS_2	23-30**

*as of November 30, 1979
**estimated

89

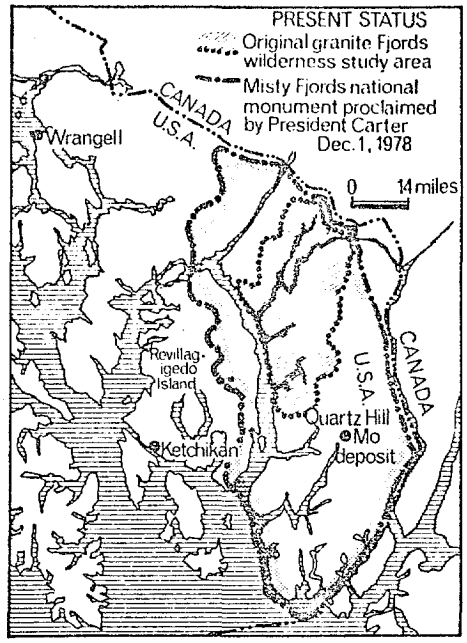

Fig. 2. U.S. Borax & Chemical Co.'s Quartz Hill Mo deposit is situated in the Tongass National Forest in southeast Alaska.

and is now in the initial stages of development planning; it is, however, at least three years away from being sufficiently well delineated to make a final decision on economic feasibility. One of the key factors relating to this is the need for bulk sampling to provide sufficient ore for pilot plant metallurgical tests. Should a go-ahead decision be a made, mine/plant construction would require a further 3 years and the mine's productive life is currently put at ±40 years.

A key factor in this development (as also with Mount Emmons) is the environmental impact assessment. This is particularly pertinent in this part of Alaska as the mine lies in a National Park. A baseline environmental study is already underway. The mine itself would be opencast, but as the ore is near-surface a minimum of overburden would be removed. Two alternative tailings disposal methods are being considered: on land, or by pipelining into the deep waters of Boca de Quadra fjord.

For the proposed 40-60,000 tonne/day ore mining-milling capacity, a capital investment of some $400 million is needed.

Government approval for PNG's Ok Tedi Au-Cu deposit.

THE Papua New Guinea government has formally announced its conditional approval for the development of the gold-copper deposits at Ok Tedi, in the remote Star Mountains in the centre of New Guinea close to the border with Irian Jaya.

The deposit was initially discovered and investigated by Kennecott, which however withdrew in 1975 when it considered itself unable to agree development terms with the PNG Government. The latter then set up the Ok Tedi Development Company so as to continue investigation and a programme of exploratory drilling involving 18 holes totalling 4,037m was completed in 1976, indicating reserves of 200-250 million tonnes grading 0.8% Cu (*Mining Magazine*, July 1976, p. 6). Preliminary investigations of gold content and metallurgical testwork were also carried out, and following these the PNG Government entered into discussions with Dampier Mining Co., a subsidiary of The Broken Hill Proprietary Company (BHP) of Australia with a view to the latter carrying out further investigations.

Late in 1976 BHP succeeded in establishing a consortium to develop the property, which has been carrying out more detailed studies since that time. BHP has a 37.5% holding in the

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Moly dealer quotes in four-month slide; static market likely to persist

The speculative boom in molybdenum came to an end in the first quarter. Spot moly oxide prices, which held at between $20 and $30 per lb throughout most of 1979, have plummeted in the last few months, dropping to $9.60 this week. The 68% decline from the record high of $32 per lb last June has not come as a surprise, but it does seem to foreshadow some major changes in the moly market.

Analysts predict that for the first time in seven years moly supplies may exceed demand in 1980. Last year's shortage was aggravated by a nine-month strike at the fourth-largest moly mine in the world, Placer Development's Endako project, and by a one-month strike at Brenda Mines. In addition, production at Kennecott's Magna, Utah, mine was less than expected, and Molycorp's Questa, NM, operation was plagued by production problems.

The gradual reduction of the *force majeure* at Endako—from 50% in November, to 30% in December, to 10% in March, to zero in April—and the planned development and expansion of several moly deposits have eased worries about shortages and depressed free market prices. According to a source at the US Bureau of Mines, "Consumption seems to have reached a plateau, and we don't see much indication of change."

Meanwhile, several companies have committed themselves to increasing production. In 1979, Duval and Cyprus Mines reopened their Esperanza and Pima copper mines in Arizona for moly production. Codelco began a project to increase its moly recovery from 52% to 70%, and Amax started evaluation of a 900-million-ton deposit in Mount Tolman, Wash., and a 165-million-ton deposit at Mount Emmons, Colo. Amax also hopes to have its Kitsault, BC, project contributing 9- to 10-million ppy by 1981. In addition, US Borax has been studying Alaska's Quartz Hill moly mine, estimated to contain at least 2-billion lb of recoverable moly. Teck Corp's copper-moly mine in British Columbia should add another 35-million lb to world output between 1981 and 1984. And, if developed by Cyprus mines, the Thompson Creek deposit in Idaho will supply 15- to 20-million ppy by mid-1983.

Undercutting the spot market

The plans to increase capacity cannot be blamed for the precipitous drop in moly prices last quarter, however. Analysts and merchants say that judicious buying by the Japanese, agressive selling and discounting by the Chileans, and the forced unloading of low-grade material have all pushed moly prices downward. In addition, the strike at British Steel Corp. allowed producers who usually supply the company to ship early to other customers, thereby undercutting a large portion of spot market activity. The retrenchment of European steel production has further depressed the market.

The outlook for moly, according to most traders, is bleak. They insist that prices have bottomed out but expect a static market well into the second half. While they are hoping free market prices will not fall below current producer prices of $9-9.50 per lb, they point out that only a long copper strike this summer can revitalize the market.

Elsewhere in ferroalloys . . .

Buyers waiting for cobalt prices to slump along with those of other metals are being advised by both traders and producers not to hold their breath. While the cobalt market has been quiet during the last two months, there are no reports of producers discounting from their $25-per-lb list price. Similarly, spot prices of around $23-23.50 per lb have remained firm since the start of the year. A few producers have noted a slight downturn in demand, but they point out that it began to show up only in April. Meanwhile, there is speculation among traders that the recent increase in inquiries from cobalt buyers has been caused by producers sitting on supplies rather than discounting. Few dealers however, have much cobalt on hand for prompt delivery, however, and granules are in particularly short supply.

GSA awarded regular-grade tungsten from its Apr. 22 auction to Kennametal and Li International. Kennametal bought 5,945.796 stu of Category A synthetic scheelite at $130.167 per stu, and Li International purchased 5,916.06 stu of synthetic scheelite for export at $130.18. Meanwhile, the US spot ore market was virtually lifeless, with no sales reported. The LMB quote continued to slip, dropping $1 on the low to $138-144 per mtu.

Climax's molybdenum concentrate roaster in Rotterdam shut down on Apr. 22 as a result of mechanical difficulties, and a company spokesman said repairs will take two to three weeks. In the meantime, Climax's US conversion facilities will increase their production to cover lost output. The Rotterdam roaster reportedly produces 14-million ppy.

In brief: Seltrust Holding plans to raise production capacity at its Agnew nickel project in western Australia by 60%, from the present 10,000-mtpy level to 15,000-mtpy over the next five years. Production at the mine, owned 60% by Seltrust and 40% by MIM Holdings, began last July. . . . The **MW dealer moly oxide** price, which seemed to be firming during the third week of April, resumed its downslide last week, dropping to $9.60-10.35 per lb from $10-10.65, based on transactions of 165 tons. Ferromoly mimicked the downward trend, causing the quote to widen to $11-12 per lb from $11.50-12.

Cadmium producers move to $3 list price

US cadmium producers last week followed New Jersey Zinc's Apr. 21 price cut to $3 per lb from $3.25. Asarco, Bunker Hill, and National Zinc lowered their cadmium metal prices on Apr. 28, while Amax moved the next day. Asarco also announced 25¢-per-lb decreases for cadmium oxide, cadmium powder, and cadmium sulfide, lowering them to $3, $3.75, and $3.40, respectively.

Meanwhile, the free market **cadmium** price dropped to $2.35-2.50. Analysts generally attribute the 20% decrease in spot prices during the past month to stale-bull liquidation—in other words, the drying-up of sales and the failure of higher metal prices to materialize has caused speculators to liquidate stocks. Some observers, however, point out that private speculators, who had never before invested in cadmium, bought up substantial positions late last year and have recently been forced to liquidate holdings because margin calls on their other investments, notably silver, are coming due.

Bismuth prices, which usually drop in sympathy with cadmium, held last week at $2.70-2.85, but traders are not optimistic about the future. **Antimony** showed signs of weakening, especially because of a falloff in demand from Eastern Europe. The quote fell 3¢ to $1.55-1.62 from $1.58-1.65. The MW **mercury** price was unchanged at $405-415 per fl.

Elsewhere in minor metals . . .

African Metals raised its germanium dioxide and germanium metal prices Apr. 28 because of further weakening of the dollar against the Belgian franc. Germanium dioxide rose to $371.50 per kg from $359, and germanium metal increased to $652 per kg from $630.25.

Minera Mexico Internacional raised the price of its San Luis arsenic trioxide by 3¢ per lb, to 35¢, effective May 1.

ASARCO

Southwestern Exploration Division

May 3, 1979

TO: W. L. Kurtz

FROM: F. T. Graybeal

Lead-Zinc Mineralization as a Guide to Porphyry Molybdenum Targets

The relationship of Pb-Zn mineralization, either in veins or massive sulfide replacements of limestone, to the Mt. Emmons (Colo.), Mt. Hope (Nev.), and Pine Grove (Utah) molybdenum deposits is well known. In these areas the Pb-Zn occurs primarily above the porphyry-associated molybdenum mineralization and the occurrence of other Pb-Zn deposits in known molybdenum provinces must be regarded as a potentially useful vertical zoning guide to underlying molybdenum targets. Small Pb-Zn deposits are exceedingly common in the western United States and often come to Asarco as submittals. These have been generally assessed on their merit as potential Pb-Zn mines. In the future, the potential for deeper mineralization should be considered.

I suspect that certain geochemical criteria exist which may indicate whether or not the prospect is related to a concealed molybdenum-bearing porphyry such as anomalous Mo, F, Sn, and W. Unfortunately Mo and W are common in skarns, but are they common in massive sulfide replacements of limestone where lime silicate alteration is absent? This may be an important distinction.

I was interested last Summer in the emission spectrographic analyses reported by Jim Sell during his reconnaissance for replacement mineralization in the Leadville Dolomite in Colorado. Frequently, anomalous Mo values were noted. At the time I assumed that this was simply part of the overall anomalous metal suite, but now I wonder whether these anomalous values might be related to a deep-lying porphyry molybdenum target. To my knowledge we did not get F in the emission spectrographic analyses, although it is known to be somewhat widespread around porphyry molybdenum deposits. As I recall there were only limited or no anomalous W and Sn values reported, but the emission spec. detection limit of 50 ppm for W may be too high. In addition, the dispersal of Mo-W-Sn around porphyry molybdenum targets is reportedly very restricted. It is possible that some of the Pb-Zn limestone replacement districts in the Colorado Mineral Belt may be the vertical expression of deeper porphyry molybdenum mineralization. Such zones would be concealed by the widespread nature of the Pb-Zn mineralization and the relative absence of quartz porphyry stocks even though quartz porphyry sills may be abundant.

The tendency for molybdenum deposits in the Colorado Mineral Belt to cluster in the 25-30 million year age range puts constraints on which limestone replacement districts might be favorable for porphyry molybdenum exploration, regardless of the geochemical expression. The attractiveness of these targets would only be diminished to the extent the geologist believed that all molybdenum deposits were confined to a specific age range.

If there is a porphyry molybdenum target under the Leadville District it is probably quite large. The fact that Climax is only 10 miles distant is intriguing. I would be most interested in a geochemical grid sampling

program in the Leadville District and other selected limestone replacement districts which emphasized detection of elements in addition to Pb and Zn that commonly occur as anomalous halos around and above molybdenum deposits. The difficulty of applying this concept to the Leadville District involves our relationship with Newmont to whom we would not want to reveal an intent to look for anything other than Black Cloud mineralization.

I have recently discussed this subject with several people in greater or lesser detail and put my thoughts on paper to perhaps generate additional thought and discussion. Although we are talking about relatively deep, vertically-zoned targets the exploration risk is reduced by the relatively high grade of porphyry molybdenum targets.

F. T. Graybeal

F. T. Graybeal

FTG:lb

cc: JDSell
GJStathis

Markets METALS/ORES

No Clear Direction

With the year well into its final quarter, conjecture on base metal prices in 1980 is now of more immediate interest to both consumers and producers. The latest forecast from Metals and Minerals Research Services Ltd., predicts lower prices in real terms in 1980 compared with 1979 with the possible exception of zinc. Despite the dramatic increase in oil prices however, a return to the deeply depressed price levels experienced in the wake of the 1973-74 oil crisis is not envisaged.

Speaking at a conference on commodity investment in London this week, the director of MMRS, Dr. Wyn Davies, said that where producers can exert a degree of control on supplies as in the case of aluminium, nickel and zinc, prices should be more stable. Higher production and a fall in consumption could see prices for copper, lead and tin weaken but aluminium prices are expected to remain strong. A firm zinc price is predicted, as despite an anticipated consumer decline, smelters are now believed to be in a better position to hold back zinc and hence bring it back into balance with demand.

While the balance between supply and demand will continue to exert the fundamental control on price levels, increasing investment interest in metals as an inflation hedge is assuming greater significance, and in the case of copper, the substantial premiums now developing for good quality metal is also of growing importance.

Uptrend for Copper

Copper closed on a strong note on the LME last Friday and in line with the firm tone in New York, cash wirebars gained £13.50 to close £48 up on the week at £975/tonne. The market strength was sustained initially this week but by Wednesday, profit-taking and a general lack of consumer interest aided to some extent by news that Zambian copper exports will not be affected by the recent Rhodesia-Zimbabwe Government ban on maize supplies to Zambia, saw cash metal slip back to around £956/tonne with a contango of £20.

Tin Rides High

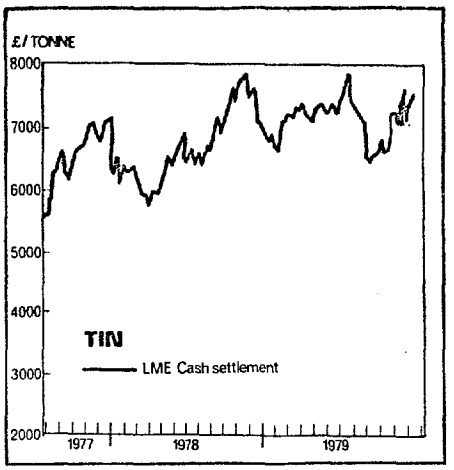
The coup last Thursday in Bolivia and the failure thus far, of Congress to give a go-ahead for the sale of U.S. stockpiled tin, were the key factors which produced a late surge in LME tin prices last week. Cash metal gained £180 on Friday to close at £7,890/tonne and in Penang, the Straits price climbed to $M2,071/picul. This week, fresh shipments of tin have arrived in Europe and the nearby supply squeeze in London has eased somewhat with the result that cash metal has now fallen back to around £7,630/tonne.

Mixed Fortunes for Lead and Zinc

In spite of a recovery last Friday, lead prices slid further this week and by Wednesday cash metal had retreated to £564/tonne. Recent producer price decreases to around 57 cent/lb have had little positive impact on buying interest and with the market price still considerably in excess of the producer price, dealers are reported to be switching to zinc which is holding steady at around £340/tonne.

Bright Future for Moly

Notwithstanding a weakening of free market molybdenum prices in recent weeks, the premiums over producer prices still exceed 100%, and with current demand likely to remain strong and stock levels at practically zero, the outlook for molybdenum is bright. Amax chairman Pierre Gousseland said in Frankfurt this week that the near boom in demand for alloyed steel experienced since the end of last year had led to supply bottlenecks in molybdenum. The company expects worldwide consumption to rise by 6% annually over the next few years and hopes to increase it own production by 50% within five years, aided by the opening of three new mines in North America (*MJ*, October 26, p.367).



LME Prices and Turnovers

Closing Prices	November 1 Buyers	November 1 Sellers	November 9 Buyers	November 9 Sellers
COPPER	tonne basis		tonne basis	
Wirebars				
Cash	£954.5	£955	£964	£965
Three months	£969.5	£970	£979.5	£980
Cathodes				
Cash	£941	£942	£945	£948
Three months	£953	£954	£960	£963
TIN				
High grade				
Cash	£7,745	£7,755	£7,650	£7,660
Three months	£7,480	£7,490	£7,490	£7,500
Standard				
Cash	£7,740	£7,745	£7,650	£7,660
Three months	£7,460	£7,470	£7,490	£7,495
Straits	$M2,030		$M2,058	
LEAD				
Cash	£594.5	£595.5	£568	£568.5
Three months	£585	£585.5	£565	£566
ZINC				
Cash	£319	£320	£333	£335
Three months	£329	£330	£343	£343.5
SILVER*				
Cash	783p	784p	789p	791p
Three months	798p	800p	806p	807p
ALUMINIUM				
Cash	£825	£830	£825	£830
Three months	£795	£796	£790	£792
NICKEL				
Cash	£2,730	£2,760	£2,770	£2,780
Three months	£2,810	£2,820	£2,815	£2,820
*p/Troy oz			$Malaysian/picul	

LME warehouse stocks on November 2 and turnovers for the week ending that date:

	Stocks (tonnes)	Stocks (previous)	Turnovers (tonnes)
COPPER			
Wirebars	113,500	114,825	89,500
Cathodes	32,150	32,225	3,900
TIN			
High grade	715	940	20
Standard	875	1,005	4,635
LEAD	20,850	20,800	41,600
ZINC	46,175	46,275	11,725
SILVER	11,310,000 oz	12,360,000 oz	9.970.000 oz
ALUMINIUM	14,900	13,400	26,025
NICKEL	5,538	5,574	1,830

London Prices NOVEMBER 8

Metals

Aluminium (99.5%) $1,725-$1,745/tonne cif
Free market $1,750-$1,800
Antimony
Free market (99.6%) $3,150-$3,200/tonne cif
Arsenic (U.K. 99% lumpy) £2,775/tonne
Bismuth (U.K. producer 99.99%) $5.00/lb
Free market $2.40-$2.70/lb cif
Cadmium (Commonwealth 99.95% sticks) $3.00/lb cif
Free market (sticks) $2.20-$2.30/lb cif
Free market (ingots) $2.20-$2.30/lb cif
Cerium (U.K. 99%) £35/kg d/d
Chromium (U.S. 99% lump) £3,300-£3,450/tonne d/d
Cobalt (U.S. producer) $25/lb cif
Copper (U.S. producer wirebar) 95.625-98.250c/lb
Gold £187.30 ($392.50)/troy oz
Indium (U.K. bars 99.97%) $16.50/troy oz d/d
Iridium (sponge and powder) $235-$255/troy oz d/d
Lead (U.S. producer) 57-63c/lb d/d
Magnesium (8kg ingots) £1,369/tonne d/d
Manganese (U.K. electro 99.95%) £650-£655/tonne d/d
Mercury Free market (99.99%) $305-$315/flask
Molybdenum (U.K. powder) £16.00-£18.00/kg
Nickel (U.K. producer price) $3.00-$3.05/lb
Free market $2.58-$2.80/lb
Osmium (U.K.) $120-$150/troy oz
Palladium (U.K. producer) £66.00-£70.75/troy oz d/d
Free market £67.55/troy oz
Platinum (U.K. & Commonwealth refined)
£185.50-£195.00/troy oz d/d
Free market £247.30/troy oz d/d
Rhodium (U.K.) $800/troy oz d/d
Selenium (Canadian 99.5%) $15/lb d/d
Free market $9.90-$11.00/lb cif
Tellurium (U.K. lump and powder 99-95%) $20-23/lb d/d
Titanium (U.K. sponge 99.3%) £3,400-£3,600/tonne cif
Tungsten (U.K. powder 90.99%) £12.57/kg d/d
Zinc (Eur. producer) $780/tonne gob
(U.S. producer) 35.00-£37.50c/lb d/d

Ores & Oxides

Antimony ore (60%) $23.00-$24.75/tonne unit cif
Beryl (10% BeO) $36.00-$40.00/s. ton unit BeO cif
Chrome
Russian (lumpy min. 48% Cr_2O_3) $100-$110/tonne cif
Transvaal (friable lumpy, basis 44%) $55-$65/tonne cif
Turkish (lumpy 48%) $95-$105 tonne fob
Columbite (min. 65% comb. oxides) $10.00-$13.00/lb cif
Ilmenite (Malaysian 52-54% TiO_2) $A17-$A19/tonne fob
Manganese ore
(48-50% Mn max. 0.1% P) $1.34-$1.36/tonne unit cif
Molybdenite
(conc. min. 85% MoS_2) $8.84/lb contained Mo cif
Rutile
(Australian 95-97% TiO_2) $A335-$A365/tonne fob
Vanadium (Highveld fused min 98% V_2O_5) $2.75/lb cif
Wolfram/Scheelite (65%) $140-$144/tonne unit
Zircon Sand (Australian 66-67% ZrO_2)
(standard) $A80-$A85/tonne fob packed
(premium) $A85-$A95/tonne fob packed

Moly Study - Nov. 1978

J.H.C.

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SUMMARY FINDINGS ON MOLY PRICING AND BY-PRODUCT CAPACITY

Moly Pricing:

The outlook to 1983 is very favorable, barring any major economic downswing. Moly concentrate pricing could reach $6.50 per pound by 1983, with the spot market at times in the $9.00 to $11.00 per pound range.

However, after 1983 the moly supply/demand situation could become critical, either one way or the other. The possibility of too many prime units coming on-stream too fast could cause substantial oversupply and significant price deterioration (down to the $3.00/lb. area in the posted market and $2.00/lb. in the spot market. On the other hand, the lack of any new prime units, would lead to prolonged shortages and rapidly rising prices. We have reviewed these alternatives under Options #1 through #4. (Please refer to MOLY PRICING section in this study and the Supply/Demand section).

Co/By-Product Moly:

We believe up to 30 million pounds of annual co-and-by-product moly can be added to the Western World market by 1983. From 1983 to 1990, another 20 million pounds could theoretically be added. In many cases, this by-product moly can be added both quickly and cheaply. Although this incremental by-product poundage is not too large, do not discount its effect on the market since its theoretical total by 1990 does add up to the potential size of the Henderson prime project (50 million lbs.). (Please refer to the section on Co/By-Product moly capacity additions).

SUPPLY/DEMAND IN THE WESTERN WORLD

Up to 1983:

We have projected Western World moly supply/demand to 1983 in Table #4 . The consumption growth rate assumption is as follows:

	Growth in Western World Consumption
1978	7.5%
1979	7.0%
1980	6.5%
1981	5.7%
1982	5.4%
1983	3.4%

Eastern bloc-imports are assumed to rise to 20 million pounds by 1981 and then level-off at 15 million ppy. Western World mine production by 1983 assumes a moly production increment of 75.9 million pounds. (Please refer to Table #7). Under these assumptions, we foresee a favorable moly supply/demand picture in the Western World up to 1983.

After 1983:

We have set-out a series of four options that the Western World molybdenum industry could take in their future moly mine development programs. These four options are presented in Tables #5 & 6 and can be altered using other assumptions. Obviously, if the industry trends toward Option #1 and #2, shortages will develop, and yet Option #4 would probably be the mirror image of the nickel industry of the 1970's.

TABLE #4

SUMMARY

WESTERN WORLD MOLYBDENUM SUPPLY/DEMAND FORECASTS
(millions of pounds of contained MO)

	1975	1976	1977	1978	1979	1980	1981	1982	1983
Western World Supply									
Mine Production	159.6	176.2	183.9	195.7	207.9	220.1	236.6	250.6	259.8
G.S.A. Sales (stockpile)	3.0	1.0	-	-	-	-	-	-	-
TOTAL	162.6	177.2	183.9	195.7	207.9	220.1	236.6	250.6	259.8
Western World Demand									
Consumption (1)	155.0	169.0	173.0	186.0	199.0(1)	212.0	224.0	236.0	244.0
Eastern-bloc Imports (2)	15.0	15.0	15.0	17.0	18.0(2)	18.0	20.0	15.0	15.0
TOTAL	170.0	184.0	188.0	203.0	217.0	230.0	244.0	251.0	259.0
- Shortage, + Surplus	-7.4	-6.8	-4.1	-7.3	-9.1	-9.9	-7.4	-0.4	+0.8

(1) Consumption: We have not adjusted our consumption forecasts for possible recession years (1979, 1983?) and leave this up to individual assumptions. However, our consumption forecasts do include our assumption on future moly demand growth (strong for next several years - pipelines, catalysts, H.S.L.A., - and then followed by slow growth in 1983-90 period.

(2) Eastern-bloc Imports: We have assumed that demand by Eastern-bloc countries continues strong over next several years. However, we again assume that this trend is reversed as possible copper-moly projects are brought on-stream in the Sino-Soviet area (i.e. Erdenet Obo).

TABLE #5

POSSIBLE FUTURE MINE DEVELOPMENT SEQUENCES
By 1987 and By 1990

OPTION #1

Option #1 - Assumption: No new major moly mining units come on-stream after 1983.

	By 1987	By 1990
Projected Annualized Consumption	284 mm lbs.	316 mm lbs.
Annualized Eastern-bloc Imports	10	10
Projected Moly Demand	294	326
Mine Production under Option #1	260	260
Annualized SHORTFALL - Option #1	34 mm lbs. SHORTFALL	66 mm lbs. SHORTFALL

OPTION #2

Option #2 - Assumption: A total of 10 by-product copper operations start producing moly @ rate of 2 million ppy each - no new prime capacity.

	By 1987	By 1990
Projected Moly Demand	294 mm lbs.	326 mm lbs.
Mine Production under Option #2	280	280
Annualized SHORTFALL - Option #2	14 mm lbs. SHORTFALL	46 mm lbs. SHORTFALL

OPTION #3

Option #3 - Assumption: A total of 10 by-product copper operations start producing moly @ rate of 2 million ppy each; Plus 2 new prime units come on-stream at rate of 20 million pounds each.

	By 1987	By 1990
Projected Moly Demand	294 mm lbs.	326 mm lbs.
Mine Production under Option #3	320	320
Annualized SURPLUS/SHORTFALL-Option #3	26 mm lbs. SURPLUS	6 mm lbs. SHORTFALL

OPTION #4

Option #4 - Assumption: Every planned project and prospect individually tabulated in this study (some of which are tenuous at best) comes on-stream by 1987 or by 1990.

	By 1987	By 1990
Projected Moly Demand	294 mm lbs.	326 mm lbs.
Mine Production under Option #4	399	477
Annualized SURPLUS UNDER Option #4	105 mm lbs. SURPLUS	151 mm lbs. SURPLUS

TABLE #6

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INDEPENDENT METALS RESEARCH

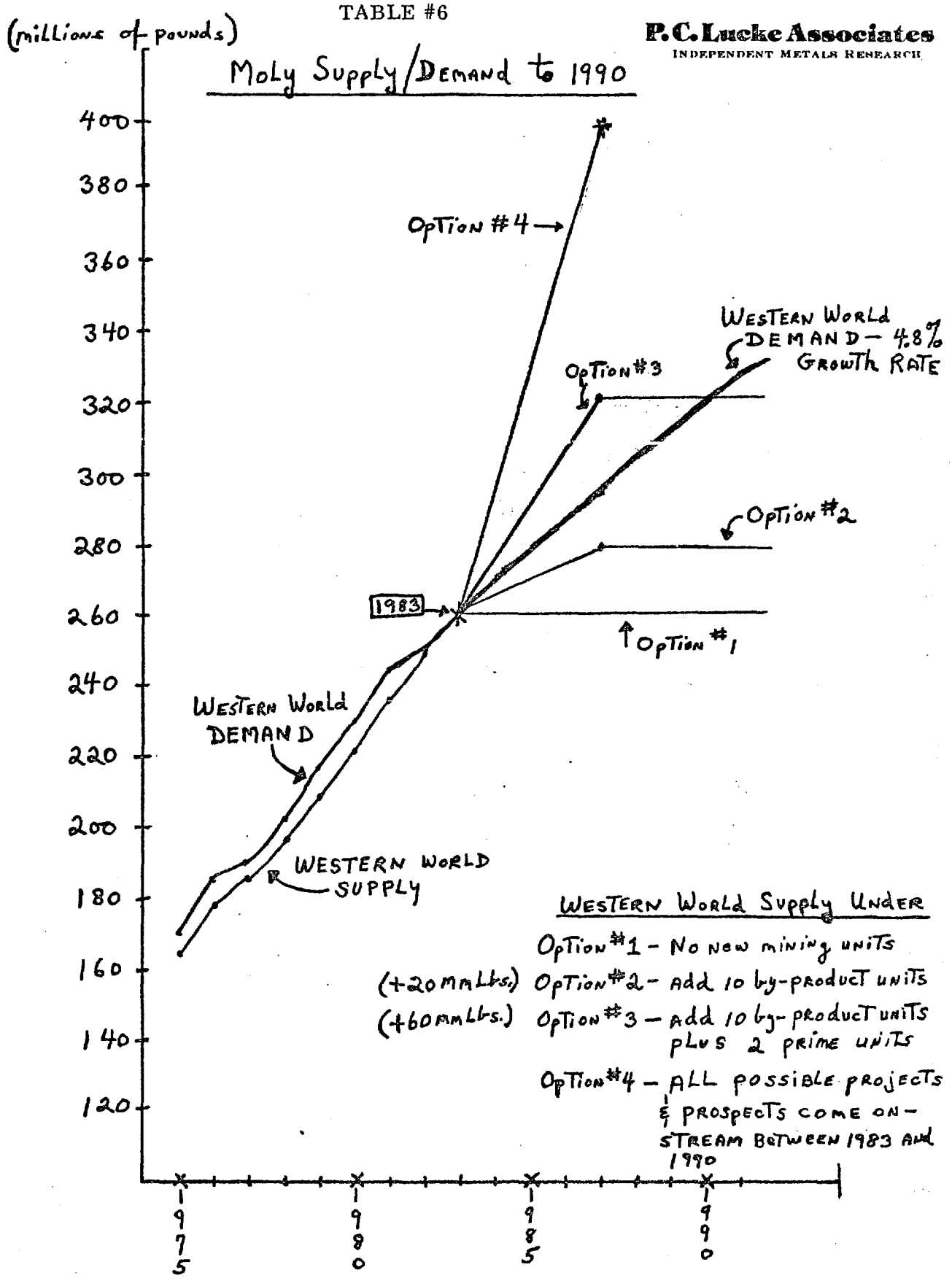

TABLE #7

ASSUMED INCREMENTAL MOLY PRODUCTION BY 1983 OVER 1977

Mining Unit	1977	By 1983 Planned	By 1983 Probable	By 1983 Possible	Probable Increment
Bingham	6.7	10.0	10.8	12.0	4.1
Climax (O/P)	14.7	-	20.9	-	6.2
Hall	0	-	0	17.8	-
Henderson	23.6	50.0	50.6	-	27.0
Morenci	0	-	1.5	-	1.5
Paradise Peak	0	-	0	7.2	-
Quartz Hill	0	-	0	28.4	-
Questa (U/G)	11.1 (O/P)	20.0	6.9 (U/G)	20.0	(4.2)
Thompson Creek	0	-	0	8.1	-
Kitsault	0	10.0	9.9	-	9.9
Chuquicamata	15.2	-	20.1	-	4.9
El Teniente	5.6	-	7.4	-	1.8
Cuajone	0	-	3.0	-	3.0
La Caridad	0	-	3.4	-	3.4
Sar Cheshmeh	0	-	4.0	-	4.0
Other Units	107.0	-	121.3	-	14.3
TOTAL	183.9		259.8		75.9

Continued . . . . . .

TABLE #8

Estimated Theoretical Moly Mine Units Increments from 1983 to 1990

(not included in probable increment by 1983)

Hall	17.8	
Paradise Peak	7.2	—
Quartz Hill	28.4	?
Thompson Creek	8.1	
Mt. Emmons	28.2	?
Mt. Tolman	15.0	?
Pine Grove	28.9	?
Questa (U/G)	13.3 (increment over 1983)	
Nordisk)		
Trout Lake)		
Copaquire)		
Los Pelambres)	70.0	
Toromocho)		
Pachon)		
Cerro Colorada)		
Other Units)		
Total Theoretical	216.9	

15 mi SE of Cobb's

new W.V discovery no potential

Western World

Assumed to 1983 and Theoretical by 1990 Capacity Additions
(millions of pounds)

Western World Production 1977	183.9
Assumed by 1983	259.8
Increment by 1983	75.9
Theoretical by 1990	476.6 (under Option #4)
Increment by 1990 (over 1983)	217.0

MOLY CONSUMPTION:

The standard forecasts for future moly consumption growth rates are in the 5.5% to 6.0% range. We have used in our future projections an overall 4.8% compound annual growth rate from 1977 to 1990 for the Western World. However, we have segmented the time-period to 1990 as follows: 1977 to 1983 and 1983 to 1990. Please refer to Table # 9. For example, we have assumed a 7.0% growth rate in the U. S. between 1977 and 1983, followed by a 2.5% growth rate from 1983 to 1990.

In this study, we have not attempted to detail the future moly consumption market by end-use markets and yet we fully realize how important the demand factor is in the supply/demand and pricing equations for all metals. Nevertheless, we were guided in our future consumption growth rate assumptions by some of the following factors which we believe will be in store for the moly industry in the future.

(a) The steel industry will make every attempt to control their raw-material cost structure. For example, in Type 317 stainless steel, there is presently about $300 per ton of moly.

(b) Some of moly's end-use markets are in the "one-shot" category (i.e. a natural gas pipeline with H.S.L.A. lasts 40 years). This is presently a very good growth market for moly, but what about the mid to late 1980's. favorable!

(c) Developing new markets for something that costs $6.00 per pound is ever so much more difficult than a product at $2.00 per pound. In the automotive market (presently a good developing market for moly), we have the future possibility of that nemesis of the metal's industry - plastics.

Continued . . . . .

MOLY PRICE FORECASTS

In Table #10, we project our moly pricing expectations under Option's #1, #2, #3 and #4. Obviously, the big question-mark is the post 1983 time-period which, of course, is the most important factor to current mine development planning. Our pricing forecasts are in 1978 U. S. dollars. Up until 1983, the critical time-period, we would estimate moly pricing to be as follows:

(Per pound of MO in Concentrates)

---yearly averages---

	Posted (1)	Spot (1)
1978	$ 4.46	6.00
1979	5.25	6.75
1980	5.60	7.50
1981	5.75	7.25
1982	6.00	7.50
1983	6.25	7.00

Table #10 presents our estimates of moly price ranges in the 1984 to 1987 period and from 1988 to 1990 under the various options.

(1) Special Note: As in our consumption and supply/demand forecasts recessionary economic cycles are not factored into the forecasts. This is left open to individual assumptions.
In addition, individual assumptions on "government pricing regulations" can be used to modify the above forecasts.

Capital Costs for Moly Mine/Mill Development

The chart on page 29 shows the relatively high capital costs per annual ton for new prime moly capacity as compared to not only other sectors of the metals industry, but also to that of by-product moly capacity ($20,000 vs. $2,500).

Some recent examples of these capital costs are as follows:

Moly Type	Mine Unit	Capital Costs ($ millions)	Annual Capacity (short tons)	Capital Costs Per Annual Ton
Prime	Henderson	$500	25,000 tons	$20,000/ton
Prime	Questa (U/G)	$200	10,000 tons	$20,000/ton
Prime	Kitsault	$100 +	5,000 tons	$20,000/ton +
By-Product	Iona (Bethlehem)	- $1 million	375 tons	$ 2,667/ton

The table below demonstrates why capital can be recovered so quickly in a good by-product moly operation at today's moly prices. It also shows that at today's ~~nickel~~ moly prices, capital recovery would be difficult.

Moly Capital Costs vs. Multiples of Metal Prices

	Capital Costs Per Ton	Capital Costs Per Pound	Metal Price	Capital Cost to Price Multiple
Prime Moly	$20,000	$10.00	$4.85/lb.	2.06 X
By-product Moly	$ 2,667	$ 1.33	$4.85	0.27 X
Aluminum	$ 3,750	$ 1.88	$0.56	3.36 X
Copper	$ 5,100	$ 2.55	$0.72	3.54 X
Nickel	$15,000	$ 7.50	$1.90	3.95 X

Estimated Moly Credit Per Pound of Copper Produced @ Selected Co/By-Product Moly Mining Units

In the 66 tables at the back of this study, we have listed our estimates of possible moly production to 1983 of the Western World prime and co/by-product moly producing units. Among the co/by-product mine units, we have attempted in most cases to show our estimates of copper costs and moly credits. In all cases, we assumed moly "rides-free". This assumption can be adjusted for individual needs either by a pro-rationing of costs, especially in the case of co-product units, or by assigning an arbitrary cost factor to the moly (i.e. $0.50 per lb.). Some examples of these moly credits are as follows: (1977 basis)

operating?

too low?

Mine Unit	Estimated Copper Costs/lb.	Est. Moly Credit in that Cost Structure/lb.	Costs/lb. before Moly Credit
Chuquicamata	$0.48/lb.	$0.053/lb.	$0.533
Esperanza (1)	$0.70	$0.455	$1.155
Lornex	$0.48	$0.098	$0.578
Mineral Park (1)	$0.58	$0.450	$1.03
Mission	$0.70	$0.032	$0.732
Pima (2)	$0.90	$0.042	$0.942
Mission	$0.65	$0.051	$0.701
Sierrieta (1)	$0.48	$0.317	$0.797
El Teniente	$0.54	$0.035	$0.575

(1) Co-product moly unit.

(2) Shut-down in September, 1977.

EXAMPLES of How Much Moly Reduces Copper Costs By

	1977
Sierrieta	40%
Lornex	17%
Mission	4%

Nov 1978 Moly Study #

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P. 3. (a) Capital per ~~lb~~ ton by product - $20,000 - new $25,000
(per annual ton — or $10/lb — 10.50/lb

(b) "we believe the age of "massive size" is about to end" — for prime mo producers — suggest 10 to 15 mil lb rather than 25 to 50 sized units

P. 5 After 1983 — supply/demand situation uncertain

		1975	1983	1987
P6 Production:	USA	105 M	168 M	300 M
	Canada	30	44	45

P 17. Growth in Western World Consumption
1978 - 7.5% (accelerating gradual decline) 1983 — 3.4%
1981 - 5.7%

Demand Growth strong for next several years (pipelines catalysts etc (H.S.L.A ?)

P-19 Option #3 — 10 by prod (copper op) at 2 m lbs each plus 2 prime new ones at 20 m lbs each.

projected moly demand	by 1987	by 1990
	294 m lbs	326 m lbs
minus prod.	320	320
	26 surplus	6 shortfall

Pine Grove, Utah – PD - Ge Hg
+200 M? at .20% mo

Quartz Hill – .15% mo +250 M tons
Quest – .20 110
Thompson cr. ~~.09~~ .15 120 HC

recov.
220 M

MINING

production is entirely from the state-owned 85 million to 51 million acres the land that 19,300 tonnes in 1977. This trend seems

3-1-79

FROM: J. H. COURTRIGHT

TO: Scott Burrill

In reference to our recent discussion re poor moly recovery at Mission and Silver Bell I am attaching copies of correspondence concerning "the amorphous moly mineral jordisite".

JHC

cc DEC
WLK/FTG

2/4/71 - Copy made for R. B. Meen

Mr. J. Cameron

S-2.2.1

JHC

AMERICAN SMELTING AND REFINING COMPANY
SILVER BELL UNIT
Silver Bell, Arizona

February 3, 1971

MINING DEPT
FEB 5 1971
TUCSON

MINERAL
FEB 5 1971
BENEFICIATION DEPT

R. B. M.
FEB 5 1971

J. J. S
FEB 5 1971

MEMORANDUM TO: Mr. J. W. Cameron, Resident Geologist

SUBJECT: OCCURENCE OF JORDISITE (AMORPHOUS MoS_2) IN PORPHYRY COPPER DEPOSITS

REPORT NO: 71-3

Attached are copies of a letter from Mr. Stephen Von Fay to Mr. J. H. Courtright with a description of Jordisite from Memoir 15, N.M.B.M., and an excerpt from R. U. King's text to his map MR 55, Molybdenum in the United States, sent to me by Mr. G. W. Bossard.

In his letter , Mr. Von Fay mentions that jordisite (amorphous MoS_2) differs considerably from normal molybdenite in its behavoir. Because of this difference, Mr. Von Fay feels that, if a significant part of the molybdenum content of porphyry copper deposits is in the form of jordisite, this mineral should be given special attention in the milling of copper-molybdenum ores.

Mr. Von Fay also mentions the possibility of zoning of jordisite in the orebody, resulting in a variation in recovery of molybdenum, depending on which portion of the orebody is being milled.

As you know, we sometimes encounter ores which give us very erratic molybdenum recoveries in the dextrin circuit. This part of the moly circuit consists of a two-stage refloat of the second copper cleaner concentrate with addition of lime and dextrin to the flotation feed. The high pH, combined with a dextrin coating of the molybdenite particles, usually is effective in depressing about 85-87 percent of the molybdenite into the combined tailings from the two refloat stages. Occasionally the molybdenite recovery in the dextrin circuit will drop to less than 30 percent when using the normal conditions of flotation in this circuit.

During these periods of poor moly recovery we have made microscopic examinations of the dextrin cleaner concentrate and found that it contains a black spongy type of molybdenite which I have referred to previously as "amorphous" molybdenite. The description of jordisite given in the N.M.B.M. paper sounds very much like this mineral present in the dextrin cleaner concentrate during poor Mo recovery, since this mineral is jet-black and appears to be amorphous. The occurence of the "amorphous" moly is also spotty, indicating possible zoning in certain areas of the orebody.

It seems probable that the amorphous molybdenite that sometimes occurs in our dextrin circuit may be this jordisite, and I believe this should be investigated. Mr. Von Fay refers to the occurence of a blue molybdenum oxysulfate, "ilsemannite" as an indication of the presence of jordisite. I believe we should look for this in areas of the ore-body which give us poor moly metallurgy to determine whether the moly may be in this mineral form.

T. D. Henderson, Jr.
T. D. Henderson, Jr.
Chief Metallurgist

TDH:jca

cc: GWBossard w/o attach.
DRJameson with attach.
BLRickman " "
MTMason " "
FHLightner " "
KKDeter " "
TDHenderson w/o attach.
File

AMERICAN SMELTING AND REFINING COMPANY
ROCKY MOUNTAIN EXPLORATION DIVISION
1805 SOUTH BELLAIRE STREET, SUITE 301
DENVER, COLORADO 80222
303-757-5107

J. H. C.

JAN 22 1971

January 8, 1971

J. H. C.

JAN 11 1971

JAN 1 . 1971

JAN 25 1971

G W B

READ AND FILE
PREPARE ANSWERS HANDLE
FILE WRITING

Mr. J. H. Courtright, Chief Geologist
American Smelting and Refining Company
P. O. Box 5747
Tucson, Arizona 85703

Dear Sir:

Enclosed herewith are two copies of a brief description of Jordisite (MoS_2), from Memoir 15, N.M.B.M., and the first page of R. U. King's text to accompany his map MR55, Molybdenum in the United States. The mineral was formally described in the American Mineralogist by L. W. Staples in 1951.

Our interest in this, from the standpoint of molybdenum recovery, centers around the fact that jordisite (MoS_2) is sharply different than molybdenite (MoS_2) in its "behavior". We therefore, of course, wonder if it should also not be expected to react in a quite different manner than molybdenite in the chemical environment of a flotation cell.

In the post mine, oxidizing, acid(?) environment where ground water is present, at least intermittently; jordisite apparently oxidizes readily, and molybdenum is easily transported by mine water. The blue oxysulfate "ilsemannite" is a common mineral on drift walls in Grants, and open pit walls of uranium deposits in Wyoming, and rapidly appears after mining is initiated. It seems to us that this behavoir is in such contrast to that of molybdenite, that the mineral deserves metallurgical attention, if it is in fact present as a significant fraction of the Mo assay in a supergene porphyry copper, or a deposit such as San Martin. We would also expect zoning of this mineral in relation to the oxidation-reduction contact, which implies to us a likelihood of considerable actual variation in "molybdenite" recovery depending on the relation of the milled ore to the contact.

Very truly yours,

Stephen Von Fay

Stephen Von Fay

SVF/jlk
Encl.

ASARCO

J. H. C.

FEB 2? 1978

Exploration Department
T. C. Osborne
Director of Exploration

February 13, 1978

File

Mr. S. Von Fay
ASARCO Incorporated
Denver Office

Molybdenum

Dear Mr. Von Fay:

I refer to Mr. Courtright's memorandum of February 3.

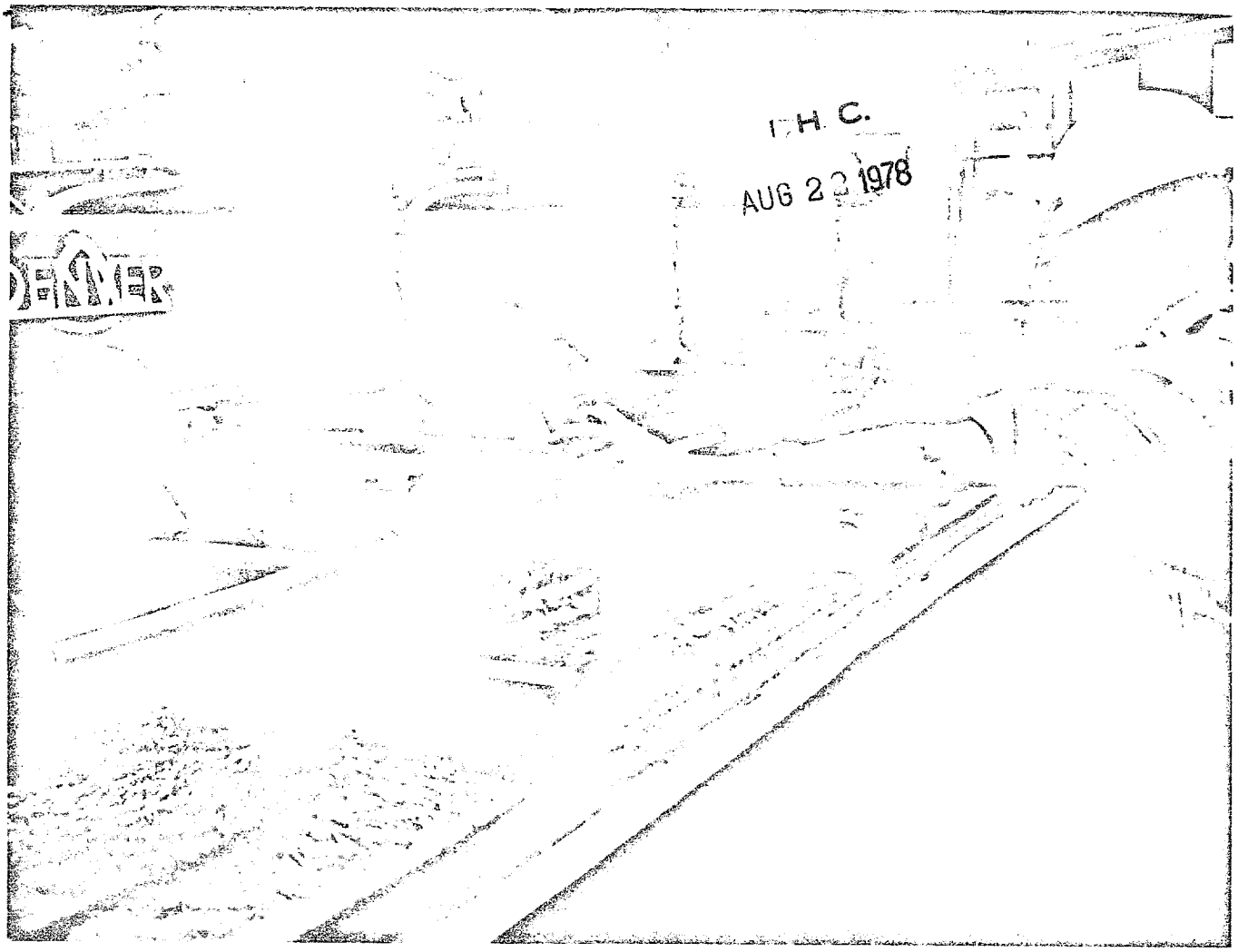
Earlier in January, I had asked our Corporate Development Department to review the long-range molybdenum picture. For their general information I gave them a copy of your excellent report prepared 7 or 8 years ago which is now substantially out-of-date.

Assuming that the people here will give us the demand side, I think it would be worthwhile for you to investigate and report on the potential supply. I suppose what we need basically is a listing of where the resources are, who owns them, what the grades are, plus estimates of possible capital costs and operating costs. This will require you to get some up-to-date block caving mining costs and mill construction costs, and I am sure the Southwestern Mining Department will cooperate in giving you horseback figures. Neglecting financing problems, I would like to see you rank the undeveloped and developing properties in the order in which they might be expected to come into production on a theoretical basis that the most profitable will be developed first. It would be also interesting to take a stab at determining what the cost of production per pound is for various operating mines and potential producers. Please call me if you have any questions.

Very truly yours,

T. C. Osborne

cc: WHCourtright
WLKurtz



I.H.C.
AUG 22 1978

MOLY FLOTATION: with the changing comparative economics of copper and molybdenum, the byproduct molybdenum flotation section is gaining more importance.

It is time to look at moly again: optimizing the byproduct circuit

With a very strong molybdenum market and a very weak market for copper, managements of the large copper producers should be taking a closer look at improving their molybdenite recoveries. Many mills could improve their primary molybdenite recovery, simply by adding an oil type collector to their primary grinding circuit. In the past, these same mills have refused to take this action due to adverse effects on the recovery of copper and/or the grade of the copper concentrates.

With byproduct molybdenum selling at a premium above the published price of the primary producers ($4.41), there certainly is a case for trying to recover more molybdenite at the expense of a minor loss in copper recovery. The economic copper equivalent for molybdenum contained in an ore is about 4 to 1, taking into consideration an 85 percent recovery of copper at $0.64 a pound and an overall recovery of molybdenite at 50 percent, at the current selling price of $4.41 per pound of contained molybdenum. In other words, if the molybdenum content in the tailing could be lowered by 0.005 percent there would be an economic trade off, if the copper in the tailing increased by 0.02 percent. This, of course, is not the complete picture because of the following factors:

By **Joseph F. Shirley**
Metallurgical Consultant
Mountain States Research
& Development
P. O. Box 17960
Tucson, Arizona
United States

Shirley has had fifteen years experience in the mining industry in metallurgical research, mill operations, and plant design. He has specialized in byproduct molybdenite recovery, having designed eight byproduct plants, four of which are now in production.

1. The copper in the concentrate form is not worth $0.64 per pound. If a plant does not have a captive smelter, the value of the copper would be worth only about $0.36 per pound.

Henderson
$4.41 / lb m.

Say, 450,000 incl
interest during constr.

Say cash flow of 90 mil

Cap cost per $1.00 annual earning

$$90\overline{)450} = \$5.00$$

= 19.4% ROI

20 yr life

J. H. C.

APR 3 - 1978

MINING DEPT
MAR 30 1978
TUCSON

New York, March 28, 1978

MEMORANDUM FOR: Messrs. J. C. Balla
D. P. Cadwell
J. V. Desvaux
J. H. G. Fuchter
R. E. Gale
R. S. Gray
F. T. Graybeal
J. J. Merz
D. M. Smith
R. B. Sprague
H. C. Williamson

Molybdenum

Herewith for its general interest is a copy of a memorandum dated March 21 by Mr. Davis of our Corporate Development Group, giving results of a molybdenum study which he initiated at my request.

I think the memorandum in general supports my view which is that in evaluating potential molybdenum prospects for exploration or development, we should normally use in calculations the current Amax price for molybdenum, coupled with our own best estimate of current construction and operating costs for the potential prospect in question. It may be assumed that future inflationary increases in construction and operating costs will be covered by increases in the price, and vice versa.

In general, any molybdenum prospect offering the possibility of producing the metal at a lower cost than Amax's would be highly interesting. Conversely, a prospect which would appear only to offer the possibility of being a higher cost producer than Amax would be approached cautiously even though pro forma calculations might seem to show an adequate rate of return.

As a matter of policy, we continue to be interested in the exploration for molybdenum on the above basis.

Original Signed By
T. C. Osborne

T. C. Osborne

Encl.

cc: WLKurtz - w/encl.
SVonFay "

bcc: RLHennebach - w/encl.
SAAnzalone "
BLDavis w/o encl.

Blind Note for Mr. Anzalone - Thanks for the help. If you have time and want to take a crack at it please feel free to calculate Amax's cost of production per pound molybdenum at Climax, at Henderson, plus a stab at Crested Butte. The numbers would be interesting.

TCO

March 21, 1978

Molybdenum, 1978
A Position Paper

This paper is being written at the request of the ASARCO Exploration Department. It will be used as part of the input they need to make a decision on how much, if any, effort they should expend on searches for molybdenum deposits.

An understanding of the molybdenum business needs to start with the awareness that the business is international in scope and it must be dealt with on such basis. The United States and Canada together produce some 85% of the free world supply of molybdenum. The United States has exported more molybdenum than it has consumed for eight out of the past ten years. Therefore, this paper will deal with the subject on a world-wide basis rather than limiting it to the U.S. and Canada.

Background

Besides the U.S. and Canada significant quantities of molybdenum are produced only in Chile and the Soviet Union. World Mine production and reserves by country are shown in the following table.

World Mine Production and Reserves
Thousands of Pounds of Contained Molybdenum

	1977 Estimated Mine Production	Reserves
United Stated	120,000	7,600,000
Canada	32,000	1,600,000
Chile	26,000	5,500,000
Peru	1,000	1,200,000
Other Western Bloc	700	1,400,000
Central Economy Countries	21,000	2,500,000
World Total	200,000	19,800,000

Figure 1

MOLYBDENUM MINE PRODUCTION BY COUNTRY

MILLIONS OF POUNDS OF CONTAINED MOLYBDENUM

* = UNITED STATES

\# = CANADA

% = CHILE

" = PERU

. = OTHER

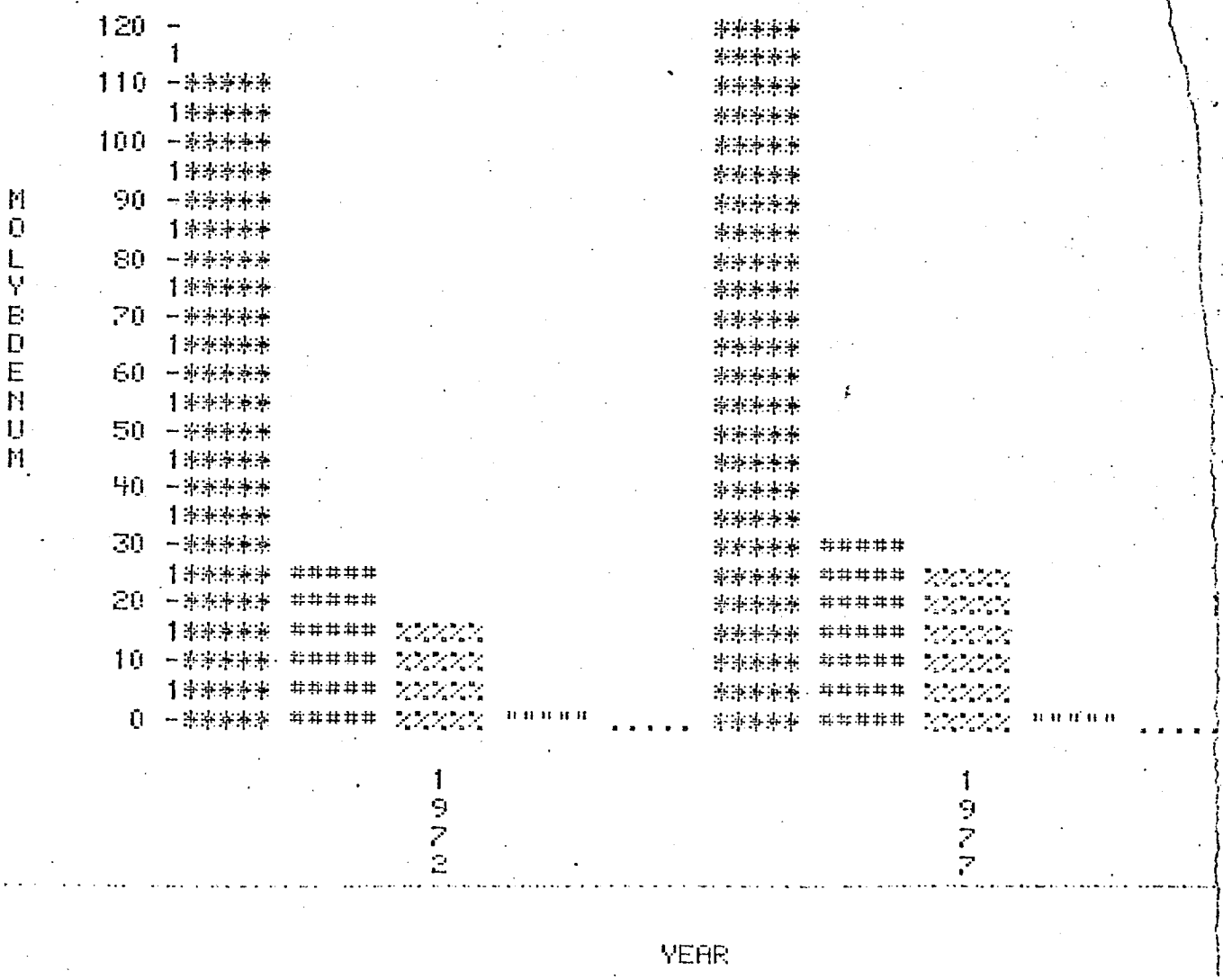


Fig. I shows free world mine production in 1972 and 1977. Notice that United States dominates the world market with Canada and Chile about tied for a distant second.

Since Amax dominates the U.S. markets a thorough understanding of Amax is important to an understanding of the molybdenum business. A brief description of their operation follows.

Amax Operations

Amax operates two molybdenum mines, Climax and Henderson, in the Colorado Rockies about 50 miles west of Denver. Climax is producing in excess of 60 million pounds per year of molybdenum from an average ore grade of 0.3% MoS_2. Climax has proven reserves of 30 years at the current operating rate.

The Henderson mine is a new underground mine just brought on stream in 1976. It is the largest privately financed work ever undertaken in the State of Colorado. It is estimated that Amax will have in excess of $500 million invested in the mine and mill by the time it reaches its rated capacity of 50 million pounds of moly production in 1980. Henderson average ore grade is 0.49% MoS_2 and proven reserves here will last until 2010 at this proposed mining rate some 30,000 tons per day.

The concentrate from these two mills, about 90% MoS_2, is sold to a limited extent, in the concentrate form. Most, however, is shipped to one of five roasting and conversion plants also owned by Amax. Two of these plants are located in the United States, an older plant being located in Langeloth, Pa. and a recently constructed one at Ft. Madison, Iowa. Other locations include plants in Great Britain, Italy and the Netherlands. The combined conversion capacity of all of these plants is in excess of 100 million pounds of molybdenum.

The MoS_2 is first roasted at these plants to form a technical grade oxide. This is sold as is and also converted by reaction with iron to ferromolybdenum. Ammonium molybdate is produced from tech grade which is the starting point for moly-containing catalysts or further reduction to the metal. Amax also purifies the sulfide which finds use as a lubricant.

Amax has for years carried out an extensive research, market development and technical service effort to expand and diversify the usage of molybdenum in all of its various forms. Amax has research expenditures in excess of $50 million annually and a good share of this is devoted to molybdenum application research.

The effort has paid off handsomely for Amax. By 1980 molybdenum will probably be generating a half a billion dollars in sales for Amax. Amax obviously sets the producer prices for all molybdenum products and they have conducted themselves in a very statesmanlike manner in this regard in the past. Producer prices have never decreased in the past 15 years, certainly an unusual phenomenon in the non-ferrous metals business. Through the sixties, prices rose very gradually from $1.40 to $1.70 for concentrates. Since 1972 prices have risen rather precipatously, 22% per year, to a current level of $4.41. This has been caused by a combination of factors, the very high inflation rate of past years, the spending by Amax of such large sums of capital on their Henderson property and also, and in no small part, because the market can bear it. Amax has done such a good job in finding unique uses for moly that it has become an indispensable ingredient for many metallurgical and catalyst applications. The Amax price history of molybdenum

Figure 2.

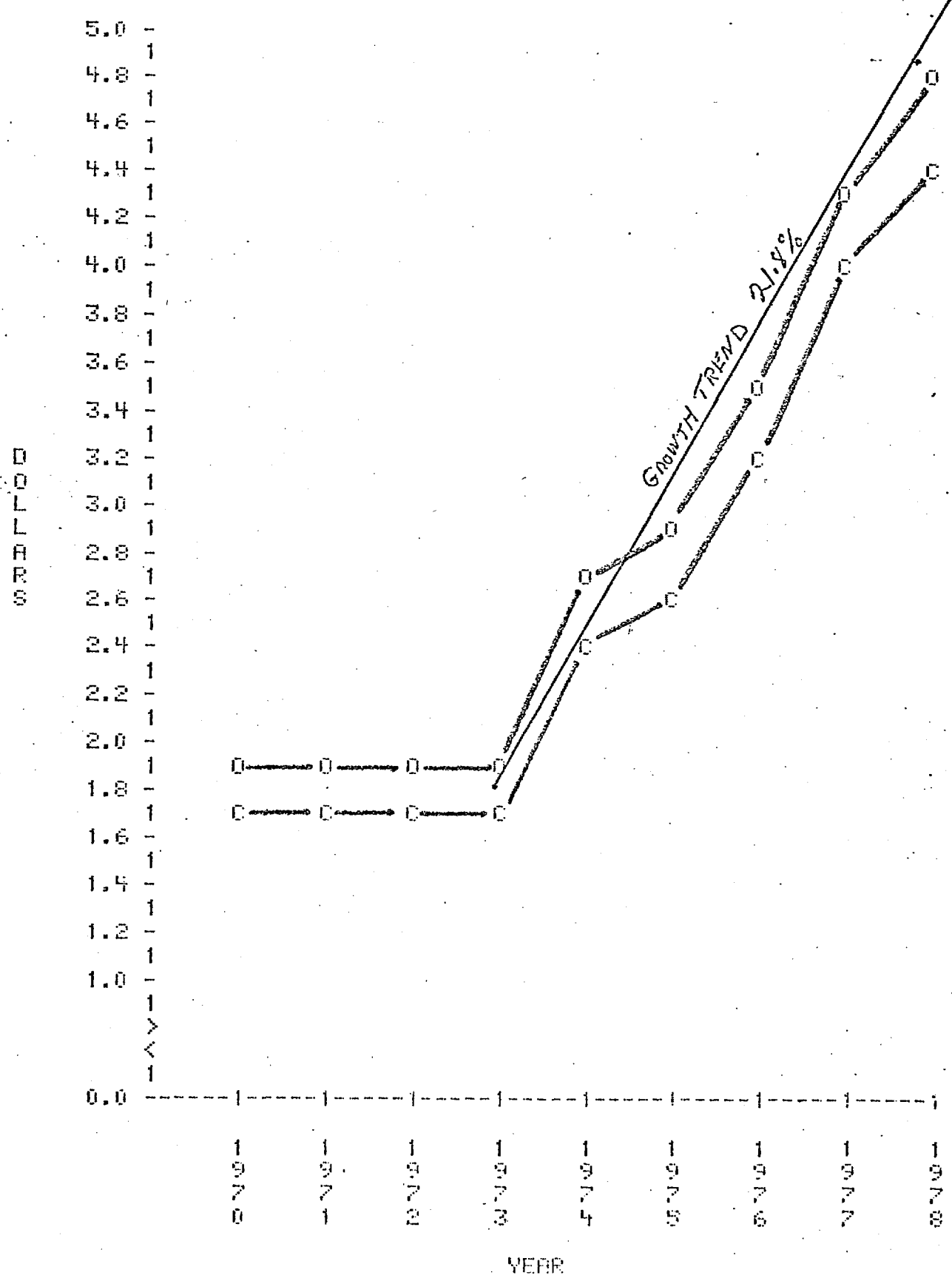
MOLYBDENUM PRICE HISTORY

AMAX PRICES AT YEARS END

$/LB OF CONTAINED MOLYBDENUM

C = CONCENTRATE

O = TECH GRADE OXIDE



is shown in Figure 2.

Another interesting item of pricing strategy followed by Amax is that they keep a constant price differential in effect between the prices of concentrate and tech grade. This difference which used to be 20¢ per pound, is now 35¢ which increase reflects inflation and pollution control costs. This is, in fact just about the actual cost of roasting the concentrate in a large and efficient plant. What Amax is doing is encouraging people to buy finished products rather that buy concentrate and make their own end products. With only a limited number of moly roasters available, Amax can make life difficult for small by-product producers such as ASARCO to find customers or for larger by-product producers such as Kennecott to operate roasters that are much more costly than are Amax's, due to economics of scale. This tends to help ensure competitors willingness to keep the prices up on the oxide product.

Other producers of molybdenum are shown in the following table:

Corporation	Installed Capacity MM lbs. of Mo	Reserves MM lbs. Mo
Codelco (Chile)	24	2,400
Kennecott	12	560
Noranda	27	550
Duval	21	300
Moly Corp.	11	330
Magma	4.5	240
Cyprus	3.8	92
ASARCO	2.0	200
Misc. Other	5	250
Soviet Union	20	450
Other Communist	4	400

Amax Costs

In considering what the future may hold for molybdenum pricing an analysis of Amax costs at their new Henderson mine should be helpful. A rough financial analysis of this operation follows:

In calculating the profitability of the Henderson Mine project the following assumptions were used:

1. Capital Expenses of 500,000 depreciated over 20 years on a straight line basis.

2. At the beginning of 1977 Amax long term debt was $630,000,000. It is assumed that 200,000,000 of this was invested in the Henderson mine and that the average interest rate was 7%. This gives a service-on-debt cost of 14,000,000 at start of project. Assuming a 20 yr. sinking fund type debt this would give an average service on-debt figure of $7,000,000 over the 20 year ge period.

3. Sales, administration and research costs are assumed to be 8% of gross sales value.

4. It is assumed that the mine and mill operate at capacity of 50,000,000 lbs. per year of contained molybdenum for the 20 years of the project.

5. Costs of mining and milling were supplied by T.C. Osborne and are assumed to be $8.33 per ton of ore.

6. Recovery rates are 9% as reported by Amax. typo.

7. Total tonnage mined and milled is 10,800,000 tons per year as reported by Amax, to produce 50,000,000 lbs. of contained molybdenum in a 90% MoS_2 concentrate.

Based on various assumed selling prices of molybdenum in concentrate the profitability of the project (Internal Rate of Return on Investment) is shown in Table I:

Table I

All Figures in Thousands of Dollars
Except When Noted

Sales Price $/lb.	$5.00	$4.41	$/lb. Mo	$3.50	$2.80
Sales Income	250,000	220,000	4.41	175,000	140,000
Direct Costs	90,000	90,000	1.80	90,000	90,000
Debt Service	14,000	14,000	.28	14,000	14,000
SAR	20,000	17,000	.34	14,000	11,000
Gross Profit	126,000	98,900	1.98	57,000	25,000
Depreciation	25,000	25,000	.50	25,000	25,000
Net Profit	101,000	73,900	1.48	32,000	0
Depletion	50,500	36,950	.74	16,000	0
Profit, B.T.	50,500	36,950	.74	16,000	0
Taxes @ 48%	24,200	17,740	.35	7,700	0
Profit, A.T.	26,300	19,210	.17	8,300	0
Depreciation	25,000	25,000		25,000	25,000
Depletion	50,500	36,950		16,000	0
Cash Flow	101,800	81,160	1.62	49,300	25,000
IROI %	19.8	15.3		7.6	0

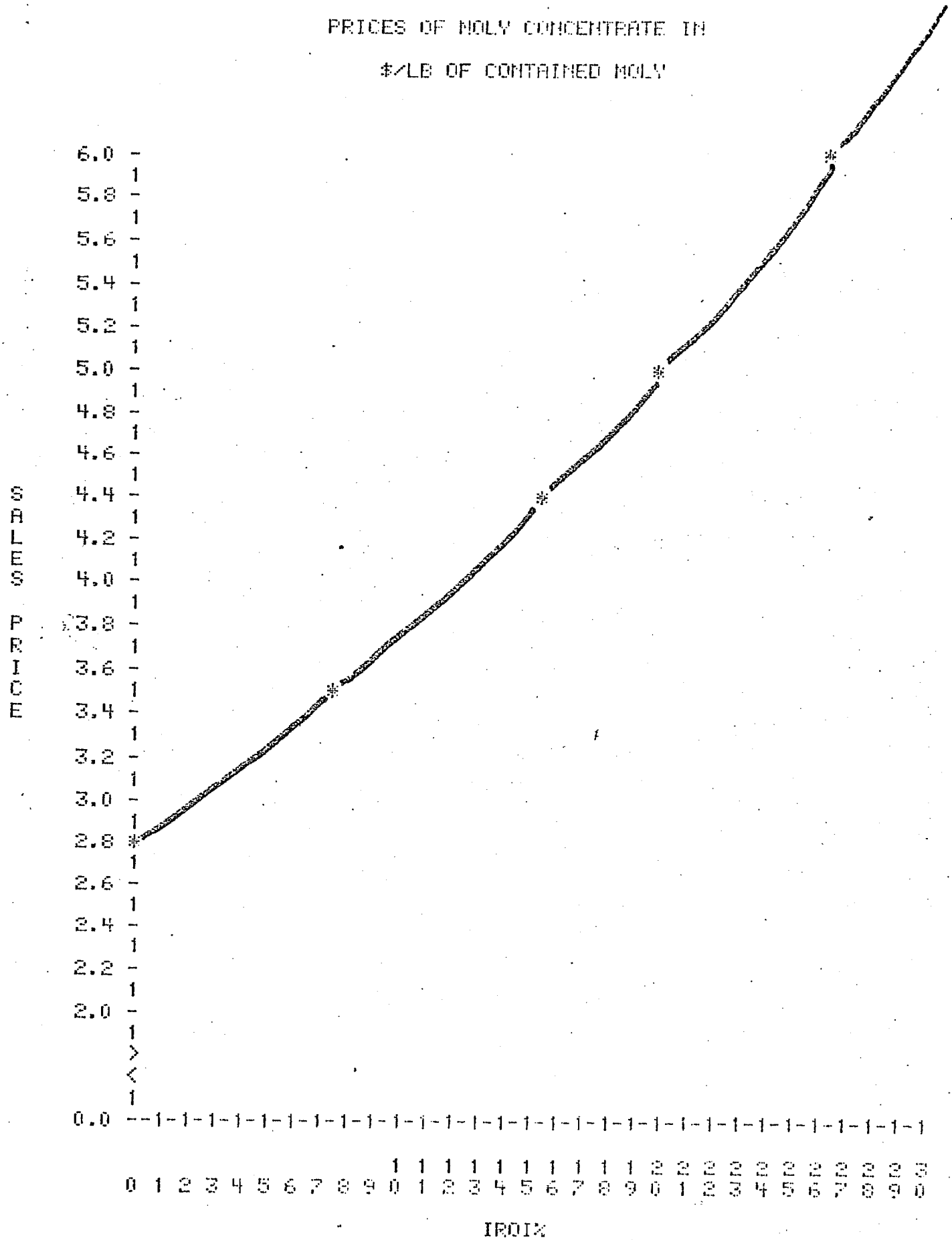
Fig. 3 shows in graphic form the return on investment at various selling prices of concentrates. At the current price it would appear that Amax is realizing a 15% after-tax return which seems a fair figure. We have been told that Amax expects to lower their mining and milling costs as they become more familiar with the new operation and approach capacity production. Offsetting this trend will be continuing inflationary pressures of increasing labor and energy costs. Amax has good reasons not to want the price of molybdenum to become unreasonably high. This would tend to discourage the use of the metal, spur search for alternate materials and also encourage marginal producers and exploration for new ore bodies.

Figure 3.

PROFITABILITY OF HENDERSON MINE PROJECT

PRICES OF MOLY CONCENTRATE IN

$/LB OF CONTAINED MOLY



In view of Amax's dominant position and their past history of pricing policies it would seem likely that the price of molybdenum will remain firm or increase somewhat over the next five years.

The only circumstances which would seem to be able to threaten this projection would appear to be the development and production of a major new ore body with substantially better economics that the Henderson mine or a collapse of market demand for molybdenum.

It has to be remembered that more than half of Amax's molybdenum is produced at the Climax mine and is probably somewhat cheaper to produce than the Henderson product. The Climax mining and milling costs are lower than Henderson, being reported as about $6.55 per ton of ore. However, due to the lower grade more ore must be mined so that the direct costs per pound of moly are probably about the same. The capital investment in the mine has certainly been much less than at Henderson however, so that depreciation and debt service have to be less.

One would have to view Amax's willingness to cut prices to be based on the average cost of their total production and not on that at either mine alone.

We are not aware at this date of any major new competative molybdenum ore bodies that are under development and it would undoubtedly take 5 to 10 years to bring any such mine into production after its discovery.

Markets

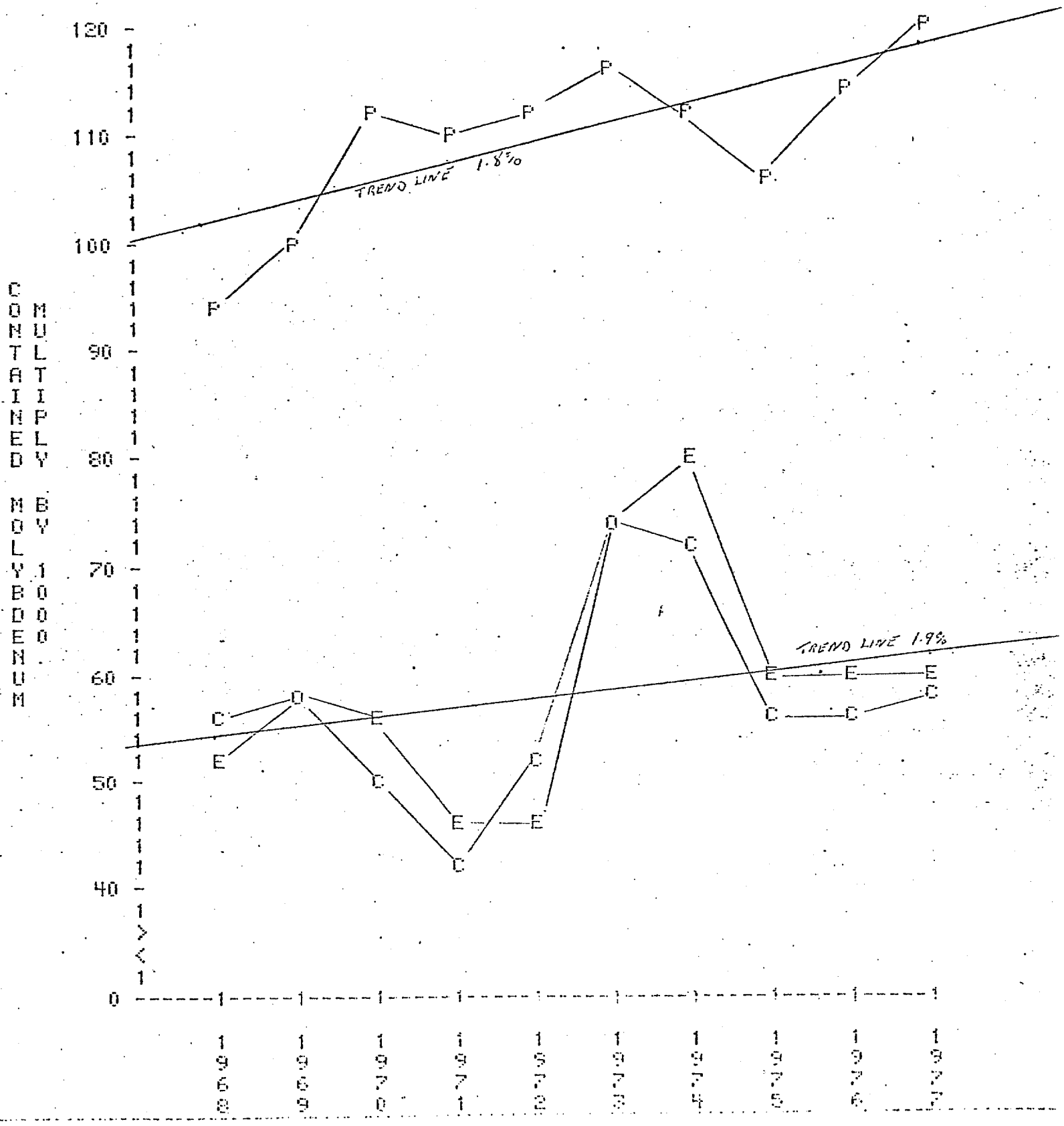
The final item then to consider is the future of the markets for molybdenum.

U.S.MOLYBDENUM STATISTICS, 1968-77, POUNDS X 1000

P = MINE PRODUCTION

E = NET EXPORTS

C = APPARENT CONSUMPTION



As is shown by Table II below, 88% of the usage of molybdenum in steel or steel related applications.

Table II

World Consumption of Molybdenum
By End Use Area

Application	% of Total Usage
Alloy Steel	44
Stainless Steel	24
Tool Steel	10
Chemicals Adn Lubes.	8
Cast Iron and Steel Mill Rolls	6
Superalloys	4
Moly Metal	3
Misc.	1
	100

While it may be true that the U.S. Steel Industry has shown little growth over the past years the same can not be said to be true of the world wide production of steel. As shown in Fig. 4 world steel production is growing at 4% and is now pushing the 700 million ton mark having grown from less that 500 million tons in 1965. This must be coupled with the fact that the market remains excellent for those steels in whose manufacture the use of molybdenum is imperative such as large diameter pipe-line for use in the Arctic, construction steels used in deep oil well drilling, high temperature steels for energy generating plants as well as light weight steels for transportation applications.

Much talk has been put forth about a 7% "average" growth rate for molybdenum consumption in the United States. As Fig. 5 shows this is an overstatement and in fact the average rate of growth over the past 10 years has been just under 2% for U.S. consumption and a little less for U.S. production.

It does not seem likely that much will change with the U.S. Steel Industry over the next 5 to 10 years that will cause a substantial change in the consumption of molybdenum so that we

03/17/78

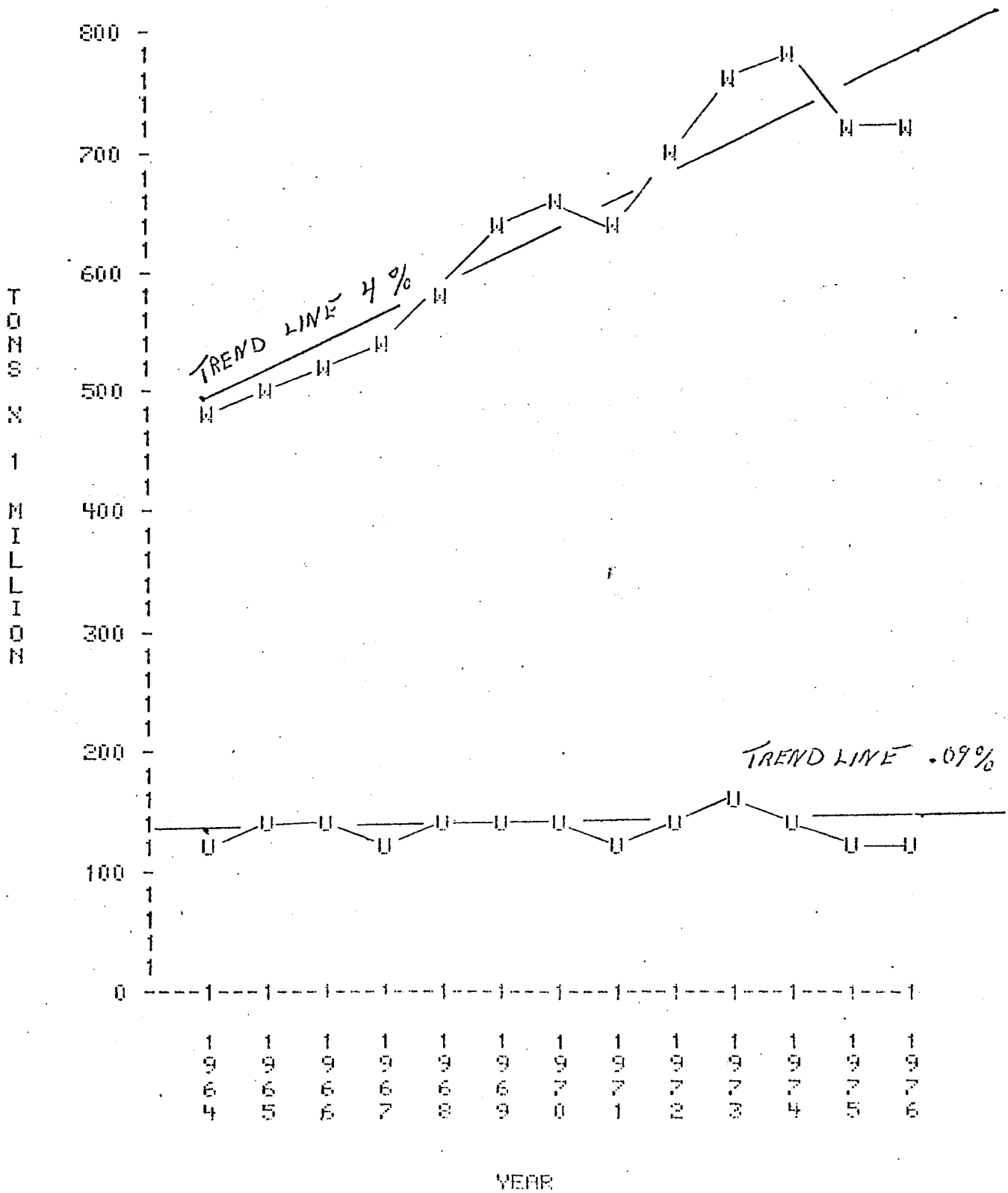
Figure 5

US AND WORLD PRODUCTION OF RAW STEEL

MILLIONS OF SHORT TONS

U = U.S. PROD

W = WORLD PROD



can look to the U.S. market for molybdenum to continue along at a 2% to 4% growth rate.

The export market however, should show a growth rate in excess of 4%, perhaps as high as 7%. The reasons for this are that the demands for steel being made by developing and third world countries will continue to grow. Much of this steel demand will be for the higher performance products which require molybdenum as an alloying agent. Also, the communist countries only have about 10% of the world reserves of recoverable molybdenum. They are already importing some 15 to 20 million pounds per year of moly from free world sources. It seems likely that as steel production in Communist countries continues to increase they will have increasing demand for imported supplies of molybdenum. We can therefore look to a continuing strong export market for molybdenum from the United States with a growth rate of some 4% to 7% for the next ten years.

In summary, it would appear that demand for molybdenum will continue to grow and that prices will remain firm and increase with inflationary pressures. It does not seem likely that molybdenum prices will drop over the next five years.

It also seems likely that Amax will continue to be the dominant factor in the U.S. and World markets for molybdenum and that any serious challenge to this dominance would depend on the discovery of a high quality ore body which would be cheaper to mine than is the average cost concentrate from the Amax mines.

Barry L. Davis

Moly

from Mineral Industry Survey
USBM — 12-27-77

1977 — U.S. production — 120 M lbs — 6% increase over 1976
U.S. Consumption 54 M — increase of 7 to 8% over 1976
World wide demand, same increase

Questa — 90 — 100 M tons at .33 MoS_2

Crested Butte 130 M tons @ .4 MoS_2

Henderson — 20 M lbs in '77, projected 50 M by '79 or '80

from Jim Hastings
Dec '72

TABLE I

COMPARISON OF GEOLOGIC FACTORS

Questa - Climax - Henderson

	Questa	Climax	Henderson (1)
Original Reserve (2) - Tons	150 Million (2)	+895 Million (2)	303 Million
Grade (% MoS_2), Undiluted	0.17	±0.35	0.49
Production	17,000 tpd-open pit	40,000 tpd-block cave	30,000 tpd (planned)-panel cave
Grade	0.17	0.33	0.45
Cutoff Grade	0.10	0.20	0.30
Maximum Plan Dimensions of Ore (ft.)	8,000 x 3,000 (3)	3,600 x 2,700	3,000 x 2,000
Ore Thickness (ft.)	400 to 1,200	800±	400 to 1,000
Number of Separate Ore Bodies	1	3	1
Geologic Environment	Shallow volcanic	Volcanic (?)	Shallow volcanic
Overall Classification of Ore-Related Intrusives	Aplite and qtz porphyries	Qtz rhyolite porphyries	Qtz feldspar porphyries
Number of Ore-Related Intrusives	3	3	3 (?)
Major Forms of Molybdenite Occurrence	Stockwork, veins	Intense Stockwork	Intense Stockwork
Important Accessory Minerals	Qtz, py, fl, cpy, hem, gyp, rhod, sph, gal	Qtz, py, fl, topaz, rhod, cpy, sph, gal, hueb, cass, monazite	Qtz, py, fl, topaz, rhod, mag, sph, gal, hueb
Most Diagnostic Alteration Products	Silicif., K-Spar and Biotization	Silicif., K-Spar	Silicif., K-Spar
Alteration Phases Recognized (Arranged in approximate corresponding order from outermost zone in)	Propylitic Argillic (?) Qtz-Sericite --- Potassic (?)	? Argillic (?) ? --- Potassic Intense Silicif.	Propylitic Argillic Sericite-qtz-py Qtz-mag-topaz Potassic Intense Silicif. (?)

Notes: (1) Urad-omitted. (2) "Original" reserve refers to estimates of total tonnage above cutoff prior to any significant mining. In the case of Questa, the figure listed is only the open pit reserve. For Climax, a conservative estimate of 200 million tons of open-pit ore @ 0.26% MoS_2 is included. (3) These dimensions encompass the presently known outline of +0.10 MoS_2. Much of this material is not presently economic reserve, but higher grade portions of this zone reportedly could be mined underground at some future date.

MINERAL INDUSTRY SURVEYS

U. S. DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
WASHINGTON, D. C. 20240

Rogers C. B. Morton, Secretary John D. Morgan, Jr., Acting Director

For information call Andrew Kuklis
Telephone: 703-557-0500

Annual, Preliminary

MOLYBDENUM IN 1973

Domestic output of molybdenum in concentrate approximated that produced in 1972, according to the Bureau of Mines, U.S. Department of the Interior. Industrial stocks, the highest on record at yearend 1972, dropped about 35 percent during 1973 because domestic consumption and exports exceeded U.S. production. Domestic consumption rose because of an increase in requirements by the steel industry, the largest consumer of molybdenum material.

Exports of molybdenum concentrate and oxides were the highest on record. The Nation shipped to foreign markets an equivalent of over 60 percent of the 1973 output, principally to industrialized countries of the free world. Exports relative to domestic production dropped to 41 percent in 1972 from a record high of 52 percent in 1970. The new record high in exports was due to an increase in world demand and relatively low price on foreign markets caused by the devalued and downward floating dollar.

At yearend, molybdenum in various materials in the national stockpile were as follows: Molybdenum disulfide, 28.6 million pounds; ferromolybdenum 5.5 million pounds; and molybdic oxide, 9.6 million pounds. At current published prices, the value of the material in the stockpile was $82 million.

Published prices for high quality molybdenum concentrate and products were unchanged, but at yearend, a major producer announced resumption of selling molybdenum materials at the list price established in May 1969. Molybdic oxide and ferromolybdenum prices were modified in 1971 to provide quantity differential and more lenient delivery terms.

The domestic molybdenum industry enjoyed continuous operation during 1973 as no serious labor problems interrupted production schedules. A marked improvement in the world demand for molybdenum resulted in an increase in activities associated with expanding current production facilities and/or increasing exploration and exploitation of new molybdenum deposits. The following are some of the more significant developments pertinent to the molybdenum industry.

American Metal Climax Inc. (AMAX) continued development of the Henderson mine near Empire, Colo. Major work projects underway in 1973 were driving a haulage tunnel through the Continental Divide and construction of a concentrator. Approximately one-half of the 9.3 mile-long tunnel was completed at yearend. Satisfactory progress was made on the concentrator, but its completion was not expected until late 1974. Production at the Henderson mine was scheduled to commence in 1976 at a rate of about 30,000 tons of ore per day.

Prepared December 26, 1973 in the Division of Ferrous Metals

Development of the Climax open pit mine by AMAX was nearing completion at yearend, considerably ahead of schedule. Output during 1974 was expected to rise to approximately 60,000 tons of ore per day, an increase of about 50 percent over that of 1973. AMAX reportedly mined the 300 millionth ton of molybdenum ore at the Climax operation on January 11, 1973. Records indicate that more ore has been produced at the Climax mine than at any underground mine in North America. According to production data, the record "ore ton" came from the Phillipson level of the mine, a producing area in operation for over 40 years. It is of interest to note that the 200 millionth "ore ton" was reached on January 27, 1966, almost 7 years ago. The estimated ore reserves at Climax are considered sufficient to operate the mine for an additional 30 to 40 years.

AMAX Specialty Metal Corp., a division of AMAX, announced plans for construction of a molybdenum conversion plant at Fort Madison, Iowa, and modernization of the existing facility at Langeloth, Pa. An estimated $25 million was authorized for expenditures on both projects. AMAX also was conducting feasibility studies on increasing roasting capacity at existing plants in the United States and Europe.

The Endako molybdenum mine of Placer Development Ltd. reached designed production capacity of 28,000 tons of ore at midyear, after operating at reduced capacity since 1971 because of an oversupply of molybdenum. Reaching full production resulted in employment of 70 new workers, increasing the work force to around 415 employees. Additional production equipment costing $4 million also was purchased to improve metallurgical recovery and increase roasting and mining capacity. The company negotiated a contract with a Japanese consumer to supply 12 million pounds of molybdenum annually.

Bethlehem Copper Corp. Ltd. was spending $3 million for a detailed engineering study of the J-A copper-molybdenum mineralization in British Columbia. The ore deposit contains proven reserves totaling 286 million tons having an average grade of 0.43 percent copper and 0.017 percent molybdenite.

Cyprus Mines Corp. was spending $1.3 million on an economic feasibility study and continuation of exploratory development of the Thompson Creek molybdenum deposit in Central Idaho. The ore body has proven reserves totaling 100 million tons averaging 0.148 percent molybdenite. To date, an incline and considerable footage of crosscuts and drifts have been mined in the deposit. The company was expected to invest about $75 million for a mining facility having a capacity to produce and process 20,000 tons of ore per day.

Highmont Mining Corp. Ltd. was expected to commence development of a copper-molybdenum deposit in the Highland Valley area of British Columbia. An estimated $70 million would be spent on a mining facility to produce and process ore at a rate of 25,000 to 27,000 tons of ore daily. The deposit contains an estimated 145 million tons of ore grading 0.37 percent copper and 0.045 percent molybdenite. Very little overburden covers the mineralized zone. Pilot plant testing on the ore resulted in metallurgical recoveries of 92 percent for copper and 83 percent for molybdenum.

Hecla Mining Co. continued exploration and metallurgical studies on the Shaft Creek copper-molybdenum deposit in northwestern British Columbia. Work projects underway during 1973 included drilling, bulk sampling, and metallurgical testing of the ore. Also, a road was constructed to the property. The deposit contains 300 million tons of ore grading 0.40 percent copper and 0.036 percent molybdenite. A feasibility study was conducted to determine the economical potential of the deposit at mining rates of 25,000 to 40,000 tons per day.

D Daly
~~JHC~~
GJS,
JRK.

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MOLYBDENUM IN SEPTEMBER 1973

Domestic molybdenum output in concentrate in September approximated that produced in August, according to the Bureau of Mines, U.S. Department of the Interior. The 9-month production of molybdenum totaled 79.9 million pounds compared with 79.7 million pounds for the same period in 1972. Molybdenum in stocks at mines and plants declined 3 percent in September compared with the previous month. For the 9-month period, stocks at mines and plants decreased 17.9 million pounds.

Exports of molybdenum concentrate, including roasted concentrate, approximated that of August. The Netherlands and Japan were the recipients of 52 percent of the molybdenum exports.

King Resources Company Operators Ltd. suspended operations at the Mt. Copeland mine near Revelstoke, British Columbia. Development and construction of a mine and a 200 ton-per-day concentrator was completed early in 1970 at a cost of $7 million. A sizable mineral deposit having an average grade about 1 percent molybdenite was discovered in 1964. Since the start of production, a total of 182,000 tons of ore was processed at the mill. Molybdenum recovered from the ore totaled nearly 3 million pounds.

Cyprus Mines Corp. reported having about 100 million tons of ore averaging 0.148 percent molybdenite at the Thompson Creek deposit in Idaho. To date, an incline in the orebody and considerable footage of drifts and crosscuts have been completed. Final studies were underway to determine feasibility of operations. Directors of Cyprus Mines Corp. approved additional expenditures totaling $1.3 million for continuation of development of the ore deposit. The company expects to invest about $75 million for a mining facility having a capacity to produce and process 20,000 tons of ore per day.

Prepared in the Division of Ferrous Metals, November 23, 1973.

'72 stocks 45 mil — Sept '73 - 27 mil

from Tim Hastings

file

J. H. C.

DEC 5 – 1972

TABLE V

MOLYBDENUM STATISTICS (1)
(Millions of Pounds Mo)

	1965	1970	1980	2000
Free World Mine Production				
U.S.	77.4	111.4		
Canada	9.6	35.4		
Chile	7.9	12.6		
Other	3.4	4.4		
Total F.W.	98.3	163.8		
Free World Consumption				
U.S.	53	53(2)	105	180
Other	47	84	160	341
Total F.W.	100	137	265	521
Free World Reserve				
U.S.		6,300		
Canada		1,000		
Chile		1,800		
Other		317		
Total F.W.		9,417		
U.S. Export	26.4	55.7		
Price: (Per # Mo in concentrate, f.o.b. Climax)	$1.55	$1.72		
U.S. Stocks (Mo in concentrates only)	4.2	9.7(3)		
U.S. Stockpile	79.9	±47.1		

Notes: (1) Data from U.S.B.M. Commodity Data Summaries, Jan., 1972; E.M.J., Mar., 1972; Mining Journal (London) 1971.
(2) U.S. consumption in 1970 reflects sharp drop from 4% average growth rate due to business decline. Based on past trends, this figure would normally be 61-62 million pounds.
(3) Does not include Mo in oxide form, ferromolybdenum, etc. Preliminary estimates of total Mo inventory indicate an excess well above 50 million pounds at the end of 1970, and still accruing.

please zero for SVF

S-10.10

5B-3.0

Jordisite (Amorphous MoS_2)

MINERAL

FEB 24 1971

BENEFICIATION DEPT

From: Min Benef Dept

To:	Init	File	Retn	Hdle
TAS				
JEAM				
RBM				
JJS	✓			
DEC	✓			
HBT				
ARR	✓			

AMERICAN SMELTING AND REFINING COMPANY
SILVER BELL UNIT
Silver Bell, Arizona

February 23, 1971

G.W.B.
FEB 24 1971

MEMORANDUM TO: Mr. T. D. Henderson, Jr. Chief Metallurgist

J. H. C.

Re: Your Memorandum "Occurance of Jordisite (Amorphous MoS_2) In Porphyry Copper Deposits" - Dated February 3, 1971.

FEB 25 1971

Research at the University Library has turned up no new information on jordisite or ilsemannite. Apparently the paper by Staples (1951) is the most recent publication on these two "minerals". The purpose of this memorandum is to discuss the likely-hood of jordisite and ilesemannite at Silver Bell and the possibilities and methods of detecting jordisite in any deposit.

The megascopic characteristics of jordisite include: dominantly jet-black(2), sometimes brown (2), possibly associated with carbonaceous material (2), submetallic (3) and sectile (3). Microscopic characteristics under reflected light include: lacks cleavage (3), submetallic, and grey black to lead grey (which nearly includes the complete spectum of reflectives) appearance (3). Microscopic characteristics under transmitted light include: "tiny, ragged-looking grains less than 0.001 mm in diameter" (2) (0.001 mm equal 1 micron, which is getting near or is below the lower limit of resolution for transmitted light work), opaque black to dark brown (2), "In many phases, jordisite cannot be distinguished unequivocally from carbonaceous material ...." (2). Chemical characteristics of jordisite include: "areas where pyrite impinges on the sand grains" (or an oxidizing enviornment) "seems to be free of jordisite." (2), oxidizes easily, probably amorphous (3), jordisite alters more readily to ilsemannite than does molybdenite (3), is soluble in concentrated HNO_3 (3), very slightly soluble in HCl (3), insoluble in H_2SO_4 and H_2O (3), 59.8% Mo and 40.2% S (3) and it appears to be an epithermal mineral.

1. King, R. U., Molybdenum in the United States, USGS with map #MR55.
2. New Mexico Bureau of Mines, Memoir 15.
3. Staples, L. W., Ilsemannite and Jordisite, Am. Min. V.36, p 609, 1951.
4. M. H. Hay, Index to Minerals ("last-word" on minerals).

From reading the available printed matter, one can say that there is some question of the validity of jordisite either as a mineral or a mineraloid. But, assuming jordisite is a valid mineral or mineraloid, there are some problems involved in identification. First, if jordisite is non-crystaline, one cannot use XRD, TK or DTA for identification. Second, if jordisite has the same chemical formula as molybdenite, one cannot use electron beam microprobe, XRF or "wet-chemical" (included AA, etc.) methods to identify jordisite. This leaves only microscopic techniques to identify jordisite, but, jordisite has not been described sufficiently enough for one to differentiate it from molybdenite. Jordisite is also apparently variable - at times assuming carbonceaous characteristics. Indeed it has been stated that the two minerals appear very similar under the microscope.

If jordisite oxidizes readily and if ilsemannite is very soluble (observed only above the water table or in open stopes), then these two minerals probably don't occur in our mill run material since both ore bodies at Silver Bell, especially El Tiro, have undergone partial oxidation and solution. However, if these minerals, especially jordisite, do occur at Silver Bell we still face the problem of segregation and identification before we can do amenabilities testing.

While working for Kennecott in Salt Lake City, I had the opportunity to study materials from the Ray Mines Division in Nevada with which they had metallurgical problems very similar to the ones you describe. I did detailed microscopic and electron beam microscope work on these samples. The only difference I could see in the samples was "that some of the molybdenite grains appeared to be 'dirty' or tarnished." Perhaps this affect was caused by a submicroporosity or "spongy" texture.

Summary

There does seem to be a difference in molybdenite grains or MoS_2 grains in some of the porphyry copper deposites. My guess is that the problems involved are more likely caused by limited oxidation and/or solution of molybdenite which is "notably" stable (in an acid enviornment) rather than caused by jordisite, etc, which has been noted as being "relative rare" (Staples, p 614) and readily oxidizes. I think additional studies of the physical and chemical characters of molybdenite are warranted, even though I can't suggest any definite methods of study. In my work here I have not identified any jordisite or ilsemannite.

J. W. Cameron

J. W. Cameron
Resident Geologist

JWC:jca

cc: GWBossard
DRJameson
BLRickman
MTMason
FHLightner
KWDeter
File

ILSEMANNITE AND JORDISITE

LLOYD W. STAPLES, *University of Oregon, Eugene, Oregon.*

ABSTRACT

Ilsemannite, a molybdenum mineral of uncertain composition, was identified in Oregon for the first time by the writer in 1939, in an ore specimen from the Kiggins mine on the Oak Fork of the Clackamas River. The occurrence is different from any previously described in that the ilsemannite is associated with cinnabar, the latter being of good enough grade to permit profitable mining during periods of high prices.

The ilsemannite occurs as a coating and alteration product of a fine-grained, black, sectile, submetallic material. Chemical and *x*-ray analyses of the original black material prove it to be an amorphous molybdenum disulfide. It is recommended that the name "jordisite," suggested by Cornu in 1909, be used for this material. Höfer and other writers have assumed ilsemannite was derived from wulfenite, other molybdates, or molybdenite.

Jordisite, possibly because of its amorphous state, alters more readily to ilsemannite than does molybdenite. This, together with the relative scarcity of jordisite in mineral deposits, probably accounts for the few known occurrences of ilsemannite in molybdenum districts.

INTRODUCTION

The Kiggins mine on the Oak Fork of the Clackamas River, located about 50 miles southeast of Portland, Oregon, has been a small intermittent producer of quicksilver. In 1939, when the writer was engaged as geologist in charge of developing this property, he had an opportunity to collect several interesting suites of minerals from the mine. One of the gangue minerals associated with the cinnabar was identified as ilsemannite. Laboratory work later confirmed this field identification. A further study of the ilsemannite showed that it occurred as a coating on a black sectile material from which it was obviously derived. As the origin of ilsemannite has never been satisfactorily explained, a study of this material was undertaken in the hope of obtaining further information leading toward the solution of the problem.

ACKNOWLEDGMENTS

Data for this paper were obtained in part from the chemical analyses made by Mr. K. C. Peer of San Francisco, and Mr. H. C. Frye of the Department of Chemistry, University of Oregon, and from the *x*-ray diffraction photographs obtained under the direction of Dr. J. D. H. Donnay of The Johns Hopkins University and Mr. A. J. Kaufmann, Jr., of the U. S. Bureau of Mines, Albany, Oregon. Two spectrographic analyses were made by Mr. T. C. Matthews of the Oregon State Department of Geology and Mineral Industries. The writer also wishes to acknowledge financial assistance from the Graduate School of the

University of Oregon which helped defray the expense of some of the analyses.

ILSEMANNITE

Andesites, probably of Miocene age, form the country rock in the region of the Kiggins mine. They are highly fractured, the most prominent trend of fractures being N. 45° W. Veins filling these fractures and related fissures contain cinnabar in commercial amounts. Calcite, pyrite, and stilbite are the principal gangue minerals.

The ilsemannite is found as veinlets and irregular lenses or pods closely associated with the cinnabar. Although ilsemannite is found in small amounts in many places in the mine, the richest occurrence is in the main tunnel (adit #1), 45 to 60 feet from the portal. Here the ilsemannite is in a calcite vein which varies in dip from 60° N. E. to almost vertical, and extends in a N. 45° W. direction along the adit. An underhand stope 6 feet deep, was put down on the calcite vein at this point and showed a concentration of both cinnabar and ilsemannite on the footwall.

Stilbite frequently occurs as a fissure filling with well-developed comb structure, the subhedral crystals often exceeding 5 cm. in length. In addition, fine-grained stilbite is intimately mixed with cinnabar, in the calcite veins. This close association of stilbite and cinnabar, although not common in quicksilver mines, is not anomalous since both minerals are characteristic of low temperature, epithermal deposits. The ilsemannite when first found has a dark blue-black color and often stains the calcite light blue. On exposure to sunlight the ilsemannite turns blue-green and fades. Some of the mineral was furnaced along with the cinnabar and the calcined product emerged a purplish pink in color. Ilsemannite is soluble in water, first producing a greenish blue solution which later deepens to a typical molybdenum blue.

Although ilsemannite is not a common mineral, there are several known occurrences of it. It was first described by Höfer (1871) from Bleiberg, Carinthia. Since then it has been described from more than a dozen localities, but in spite of this there is still uncertainty regarding its origin and chemical composition.

Hess (1925, p. 9) has shown that Höfer in his original discussion of ilsemannite confused two substances, one a black material and the other a blue substance derived from the first. Hess remarks, "The black mineral that forms with water first a greenish-blue and then a blue solution may be a different mineral having perhaps some such relation to ilsemannite as anhydrite ($CaSO_4$) has to gypsum ($CaSO_4 \cdot 2H_2O$)." Strunz (1941) describes ilsemannite as amorphous, and corresponding to the so-called blue molybdenum oxide. Dana (1944, pp. 602-603) well summarizes the situation by stating, "Possibly several different substances are repre-

sented among the natural occurrences." In general, most mineralogists seem to have applied the name "ilsemannite" to any molybdenum compound or mixture which is water soluble and turns the solution a typical molybdenum-blue color.

No method was worked out whereby the very thin coating of ilsemannite, often existing only as a stain on other water soluble minerals like halotrichite, could be separated from them. Consequently chemical analyses of this material were not obtained.

Underneath the coating of soluble sulfates and ilsemannite there was discovered a black, submetallic, sectile mineral which was first thought to be metacinnabar. Microchemical tests, however, proved it to be a molybdenum compound rather than a mercury mineral. It is obvious that the ilsemannite is derived from this black mineral, since the ilsemannite occurs as bluish spots, coatings, or along cracks where there was opportunity for ready alteration.

Ilsemannite is usually considered to be a secondary mineral and there has been considerable uncertainty concerning the primary or earlier mineral from which it was derived. Höfer (1871) believed the Bleiberg ilsemannite to be derived from wulfenite, as no other molybdates were known from the locality, but he had no positive evidence and based his conclusions on the fact that a molybdenum-blue coloration may be obtained by the action of concentrated sulfuric acid on wulfenite. Cook (1922), in studying ilsemannite from Shasta County, California, suggested molybdenite as the source mineral. Likewise, Lindgren and Ransome (1906, p. 124) believed that ilsemannite from Cripple Creek, Colorado, was a direct product of the oxidation of molybdenite. Hess (1925, p. 16) concluded that, "Ilsemannite, like wulfenite, is probably formed from some unknown mineral, perhaps a sulfide." The fact that molybdenite deposits so seldom are accompanied by ilsemannite makes it doubtful that molybdenite is usually the source of ilsemannite.

A study of the black mineral in polished sections and in fragments indicates that it is not molybdenite. It lacks cleavage, is dull black except where scratched, and then it has a submetallic gray black to lead gray appearance. It is soluble in concentrated HNO_3, very slightly soluble in HCl and insoluble in H_2SO_4 and H_2O. In the Clackamas occurrence it was deposited about the same time as the cinnabar and later than the calcite and stilbite. Figure 1 shows veinlets of the black mineral following the rhombohedral outlines of the calcite.

Chemical Data

Because the Clackamas material is an intimate mixture of molybdenum minerals with quartz, cinnabar, stilbite, pyrite, opal, halotrichite, and

calcite, separation for analysis is very difficult. Purification of the black mineral was accomplished first by removing the water-soluble minerals and then discarding all the other remaining minerals by hand-picking under the microscope. Two spectrographic analyses were made on this material, the first[1] showing Si and Ca greater than 10%; Al, Fe, Mo, ranging from 10% to 1%; Mg, As from 1% to 0.1%; Na, K, Mn, Ti, Ba, Sr, from 0.1% to 0.01%, and Cr, V, Cu, Bi, B, less than 0.01%. A second

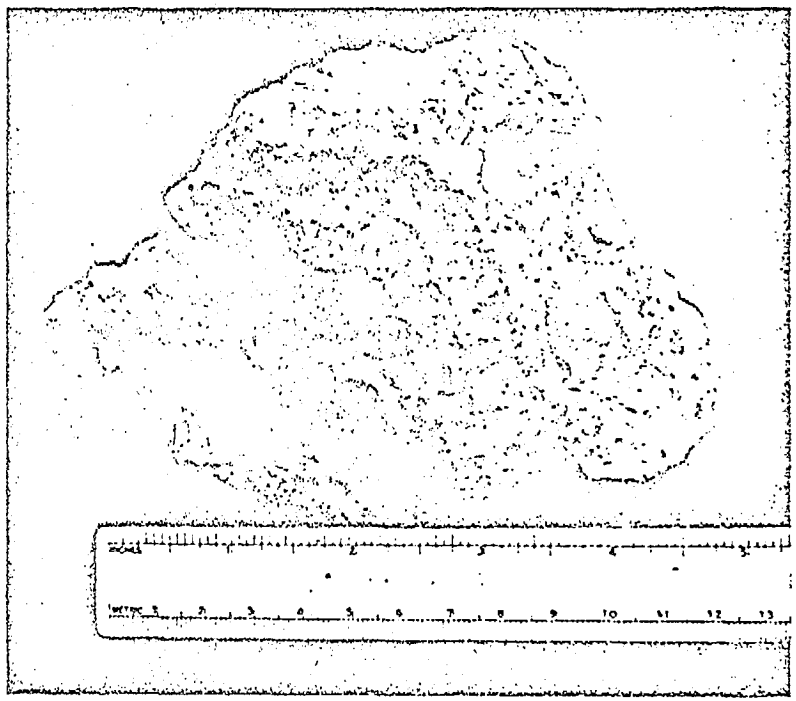

Fig. 1. Jordisite veinlets (black) with rhombohedral pattern outlining calcite.

spectrographic analysis on slightly purer material[2] obtained Si as the major constituent; Mo from 20% to 10%; Fe from 6% to 3%; Al from 0.5% to 0.1%; and smaller amounts of Ca, Na, Ba, Cu, Mn, Ni, Sr, Ti, and V. The question raised by these analyses was whether the black mineral was a complex salt such as a silicomolybdate of iron or aluminum, or whether most of the reported elements were due to impurities that were not removed.

[1] Analysis by Oregon State Department of Geology and Mineral Resources, T. C. Matthews, analyst.

[2] Analysis by Multiphase Laboratories, San Francisco, K. C. Peer, analyst.

Two small samples of the purified material were analyzed[3] and the following was determined to be the composition of the material:

Silica (SiO_2)	57.0
Molybdenum sulfide (MoS_2)	20.5
Iron sulfide (FeS_2)	9.3
Alumina (Al_2O_3)	1.2
Calcium compound (CaX)	0.6
Heavy metal sulfides (as HgS) also undetermined and traces	1.2
Total water	10.2
	100.0%

It was evident that the analyzed sample contained impurities of pyrite, stilbite, and cinnabar, so the presence of iron sulfide, alumina, calcium, and heavy metal sulfides was to be expected in the above analysis. The analysis indicated only a trace of sulfate sulfur, practically all of the sulfur appearing as sulfide sulfur. On distributing the sulfur between the iron and molybdenum, there was almost exactly the correct amount to yield the formula MoS_2, making it evident that although the material did not have the properties of molybdenite it was a molybdenum disulfide.

It was found possible to make a satisfactory bromoform separation of the material, thereby removing almost all of the cinnabar, pyrite, and calcite. As a further check for the presence of molybdenum disulfide an analysis[4] was made of some material purified in this manner. This showed only a trace of iron and when all the sulfide was applied to the molybdenum present it gave a ratio of 59.8% molybdenum to 40.2% sulfur, as compared with an ideal ratio of 60.0% to 40.0% for MoS_2, leaving no doubt that the compound is molybdenum disulfide.

X-ray Analysis

X-ray diffraction patterns were made on the material by Dr. J. D. H. Donnay and Mr. A. F. Rekus of The Johns Hopkins University. These exposures indicated the presence of considerable quartz which yielded the predominant pattern, and corroborated the chemical analysis. No additional match could be made from the weaker lines and a comparison with molybdenite from Haddam, Conn., and Ogden Mine, N. J., indicated that the black mineral was not molybdenite. Dr. Donnay[5] made the interesting observation that colloidal matter might be present as indicated by several broad bands in some of the films. These

[3] Analysis by Multiphase Laboratories, San Francisco, K. C. Peer, analyst.
[4] H. C. Frye, Dept. of Chem., Univ. of Oregon, analyst.
[5] Personal communication.

results were confirmed by x-rays[6] on material further purified by bromoform separation and the only pattern obtainable was that of quartz, with no evidence of the presence of any molybdenite. From these analyses it is concluded that the black mineral is an amorphous molybdenum disulfide.

Jordisite

Cornu (1909) stated that ilsemannite is derived from a black powdery colloidal molybdenum sulfide which he called "jordisite." He gave no proof of this derivation nor did he describe jordisite. Hess (1925, p. 16) in commenting on this reference stated, "It does not convince one that his material was really a sulphide of molybdenum." So far as known no one has confirmed the occurrence of jordisite since Cornu's brief description. The present study on material from the Clackamas locality indicates that Cornu was correct in his statement that ilsemannite is derived from a black colloidal molybdenum sulfide, and although Cornu did nothing to establish the name "jordisite," the occurrence in Oregon should confirm the name as a valid one for the mineraloid. Furthermore, unlike the most common occurrence of molybdenite, jordisite appears to be a low temperature product as indicated by its association with cinnabar and zeolites. This, together with the relative rarity of jordisite, may explain the scarcity of ilsemannite in most molybdenite deposits. In those few cases where ilsemannite has been reported as associated with or derived from molybdenite, it is likely that some jordisite was also present.

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Manuscript received Oct. 4, 1950

[6] Diffraction pattern by U. S. Bureau of Mines, Albany, Oregon.

2/4/71 - Copy made for D. B. Meen

Mr. Jameson

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AMERICAN SMELTING AND REFINING COMPANY
SILVER BELL UNIT
Silver Bell, Arizona

MINERAL
FEB 5 1971
BENEFICIATION DEPT

February 3, 1971

J. H. C.
FEB 8 1971

MEMORANDUM TO: Mr. J. W. Cameron, Resident Geologist

SUBJECT: OCCURENCE OF JORDISITE (AMORPHOUS MoS_2) IN PORPHYRY COPPER DEPOSITS

REPORT NO: 71-3

Attached are copies of a letter from Mr. Stephen Von Fay to Mr. J. H. Courtright with a description of Jordisite from Memoir 15, N.M.B.M., and an excerpt from R. U. King's text to his map MR 55, Molybdenum in the United States, sent to me by Mr. G. W. Bossard.

In his letter , Mr. Von Fay mentions that jordisite (amorphous MoS_2) differs considerably from normal molybdenite in its behavoir. Because of this difference, Mr. Von Fay feels that, if a significant part of the molybdenum content of porphyry copper deposits is in the form of jordisite, this mineral should be given special attention in the milling of copper-molybdenum ores.

Mr. Von Fay also mentions the possibility of zoning of jordisite in the orebody, resulting in a variation in recovery of molybdenum, depending on which portion of the orebody is being milled.

As you know, we sometimes encounter ores which give us very erratic molybdenum recoveries in the dextrin circuit. This part of the moly circuit consists of a two-stage refloat of the second copper cleaner concentrate with addition of lime and dextrin to the flotation feed. The high pH, combined with a dextrin coating of the molybdenite particles, usually is effective in depressing about 85-87 percent of the molybdenite into the combined tailings from the two refloat stages. Occasionally the molybdenite recovery in the dextrin circuit will drop to less than 30 percent when using the normal conditions of flotation in this circuit.

During these periods of poor moly recovery we have made microscopic examinations of the dextrin cleaner concentrate and found that it contains a black spongy type of molybdenite which I have referred to previously as "amorphous" molybdenite. The description of jordisite given in the N.M.B.M. paper sounds very much like this mineral present in the dextrin cleaner concentrate during poor Mo recovery, since this mineral is jet-black and appears to be amorphous. The occurence of the "amorphous" moly is also spotty, indicating possible zoning in certain areas of the orebody.

It seems probable that the amorphous molybdenite that sometimes occurs in our dextrin circuit may be this jordisite, and I believe this should be investigated. Mr. Von Fay refers to the occurence of a blue molybdenum oxysulfate, "ilsemannite" as an indication of the presence of jordisite. I believe we should look for this in areas of the ore-body which give us poor moly metallurgy to determine whether the moly may be in this mineral form.

T. D. Henderson, Jr.
Chief Metallurgist

TDH:jca

cc: GWBossard w/o attach.
DRJameson with attach.
BLRickman " "
MTMason " "
FHLightner " "
KKDeter " "
TDHenderson w/o attach.
File

ASARCO

AMERICAN SMELTING AND REFINING COMPANY
ROCKY MOUNTAIN EXPLORATION DIVISION
1805 SOUTH BELLAIRE STREET, SUITE 301
DENVER, COLORADO 80222
303-757-5107

J. H. C.
JAN 11 1971

J. H. C.
JAN 22 1971

January 8, 1971

JAN 1
JAN 2 1971

G W B
READ AND RETURN
PREPARE ANSWERS ..... HANDLE .....
FILE ..... INITIALS .....

Mr. J. H. Courtright, Chief Geologist
American Smelting and Refining Company
P. O. Box 5747
Tucson, Arizona 85703

Dear Sir:

Enclosed herewith are two copies of a brief description of Jordisite (MoS_2), from Memoir 15, N.M.B.M., and the first page of R. U. King's text to accompany his map MR55, Molybdenum in the United States. The mineral was formally described in the American Mineralogist by L. W. Staples in 1951.

Our interest in this, from the standpoint of molybdenum recovery, centers around the fact that jordisite (MoS_2) is sharply different than molybdenite (MoS_2) in its "behavior". We therefore, of course, wonder if it should also not be expected to react in a quite different manner than molybdenite in the chemical environment of a flotation cell.

In the post mine, oxidizing, acid(?) environment where ground water is present, at least intermittently; jordisite apparently oxidizes readily, and molybdenum is easily transported by mine water. The blue oxysulfate "ilsemannite" is a common mineral on drift walls in Grants, and open pit walls of uranium deposits in Wyoming, and rapidly appears after mining is initiated. It seems to us that this behavoir is in such contrast to that of molybdenite, that the mineral deserves metallurgical attention, if it is in fact present as a significant fraction of the Mo assay in a supergene porphyry copper, or a deposit such as San Martin. We would also expect zoning of this mineral in relation to the oxidation-reduction contact, which implies to us a likelihood of considerable actual variation in "molybdenite" recovery depending on the relation of the milled ore to the contact.

Very truly yours,

Stephen Von Fay

Stephen Von Fay

SVF/jlk
Encl.

Table 6.--Authigenic minerals in deposits in the Dakota Sandstone

	Mirsky, 1953	Gruner, Gardiner, Smith, 1954	Gabelman, 1956a	Hilpert and Corey, 1955	Weeks and Truesdell, 1958b	Thaden and Santos, 1959
Uraninite, UO_2			X			X
U adsorbed on carbon			X			
Carnotite, $K_2(UO_2)_2(VO_4)_2 \cdot 1\text{-}3H_2O$			X	X	X	X
Tyuyamunite, $Ca(UO_2)_2(V_2O_4)_2 \cdot 5\text{-}8H_2O$			X	X		X
Metatyuyamunite, $Ca(UO_2)_2(V_2O_4)_2 \cdot 3\text{-}5H_2O$	?	X				
Uranophane, $Ca(UO_2)_2SiO_3(OH)_2 \cdot 5H_2O$		X				
Meta-autunite, $Ca(UO_2)_2(PO_4)_2 \cdot 6H_2O$		X				
Pyrite, FeS_2				X		
Limonite, $Fe_2O_3 \cdot XH_2O$			X	X		
Gypsum, $CaSO_4 \cdot 2H_2O$			X			
Jarosite, $KFe_3(SO_4)_2(OH)_6$			X			
Calcite, $CaCO_3$			X			

SUMMARY

As stated in the introduction, there is considerable diversity among the mineral assemblages from deposit to deposit in the Grants mineral belt. There is also, however, an overriding similarity among all the deposits, and it may be more informative, in summary, to consider these similarities than the differences.

Primary unoxidized uranium in all the deposits occurs principally as either coffinite or uraninite associated with pyrite and generally with some type of organic material. Other minerals that may or may not be present include montroseite, fluorite, jordisite, and base-metal sulfides.

Oxidation of these primary minerals before mining and in an environment with a low vanadium content can result in the formation of uranium silicates or phosphates such as uranophane and autunite. In such an environment, however, it may be more common for most of the uranium to be leached from the rocks.

If abundant vanadium is present under oxidizing conditions, the uranium enters into uranium vanadate minerals, such as carnotite and tyuyamunite, of low solubility. The excess vanadium or uranium is probably leached out of the system.

In the oxidizing environment, such minerals as native selenium, barite, calcite, gypsum, and cryptomelane may also be formed.

After mining is commenced, oxidation is locally rapid, and the ground-water and capillary solutions are likely to contain at least local concentrations of such metals as uranium, vanadium, molybdenum, sodium, calcium, and iron with sulfate, carbonate, and bicarbonate anions. These form a large variety of evaporite or efflorescent minerals on the mine walls. Among them, andersonite, zippeite, thenardite, pascoite, and ilsemannite are probably the most common.

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MOLYBDENUM IN THE UNITED STATES
(Exclusive of Alaska and Hawaii)

by
Robert U. King

INTRODUCTION

The accompanying map shows the principal deposits and many minor occurrences of molybdenum in the conterminous United States. Six types are distinguished by shapes of the symbols used, and three size categories indicate the relative importance of the deposits.

The six types are (1) disseminated or stockwork molybdenum deposits in which molybdenite (MoS_2) is the chief or sole economic mineral present, (2) disseminated or "porphyry"-type copper-molybdenum deposits from which molybdenite is recovered as a byproduct or co-product of the mining of copper, (3) vein or simple fissure fillings, (4) contact-metamorphic (pyrometasomatic) deposits and replacements, (5) pegmatites, and (6) bedded deposits in sedimentary rocks.

The sizes are based on molybdenum content; both production, if any, and estimated reserves were considered in assigning categories. Cutoffs between large and medium are 100,000,000 pounds and between medium and small 100,000 pounds of molybdenum, respectively. These categories indicate only order of magnitude, however, and no pretense of precision is intended. Deposits for which insufficient data are available to estimate size are shown as being of the smallest category.

The map symbols are plotted to the nearest minute and do not necessarily distinguish between individual deposits, groups of deposits, or districts; about 445 symbols represent many more deposits because some are more closely spaced than plotting at the scale used will allow with clarity.

Where the principal molybdenum mineral is other than molybdenite an identifying letter is added beside the symbol for that deposit: J, jordisite (amorphous molybdenum disulfide, MoS_2); I, ilsemannite (molybdenum oxy-sulfate); W, wulfenite (lead molybdate, $PbMoO_4$); P, powellite (calcium molybdate-calcium tungstate, $Ca(MoW)O_4$); F, ferrimolybdite (hydrous ferric molybdate, $FeMoO_3.nH_2O$).

Deposits or localities are numbered consecutively by States and are identified in the locality index. Both published and unpublished information was used in compiling the map, and at least one reference is given for each locality if reports concerning the area are published.

GEOLOGY

Molybdenite is the most common naturally occurring molybdenum mineral, and, with the possible exceptions of ferrimolybdite, jordisite, and molybdenum-bearing iron oxides, is the only one of present commercial importance in the United States. Wulfenite was an important source of molybdenum during the first two decades of this century, and recently molybdenum has been recovered from bedded uranium ores in North and South Dakota and New Mexico that contain jordisite and from ferrimolybdite and molybdenum-bearing iron oxides at the Climax deposit. More than a dozen other minerals are known that contain molybdenum as an essential element or in trace amounts; however they have not been found to occur in deposits sufficiently large to be of economic importance.

Although molybdenum deposits are widely scattered across the nation, having been recorded in 29 of the States, 99 percent of the known reserves are contained in a few large disseminated deposits in the Rocky Mountain region of Colorado and New Mexico and in a few large porphyry copper deposits of the Basin and Range region of Arizona, Nevada, and Utah. Most molybdenum produced in the United States has come from such deposits, either ones in which molybdenum is the only or primary mineral sought or from deposits in which molybdenum is recovered as a byproduct of copper mining operations. Some molybdenum is produced as a co-product with tungsten.

Historically, molybdenum has been obtained in relatively small tonnages from pegmatites, quartz veins, and contact-metamorphic deposits, as well as from near-surface oxidized portions of base-metal deposits. The economics of mining, extraction, and refining today relegate most of these deposits to the category of specimen or geologic interest.

The disseminated or porphyry-type molybdenum deposit is widespread over the western part of the United States, from Washington and Montana on the north to Arizona and New Mexico on the south. These deposits seem to be closely related to intrusive stocks or plugs of rhyolite or quartz monzonite porphyry of Late Cretaceous to mid-Tertiary age. Pervasive hydrothermal alteration and metallization of large volumes of intensely fractured rock are the most conspicuous features of these deposits. The deposits are of relatively large dimensions but have low metal content; at Climax, the world's largest molybdenum mine, "more than 2,000 lbs. of ore must be mined to recover some 4 lbs. of molybdenum."* These deposits are of major economic importance only because they are peculiarly amenable to large-scale low-cost mining techniques and relatively simple extractive processes.

*Five minutes with molybdenum, Climax Molybdenum Company Division AMAX, 1966.

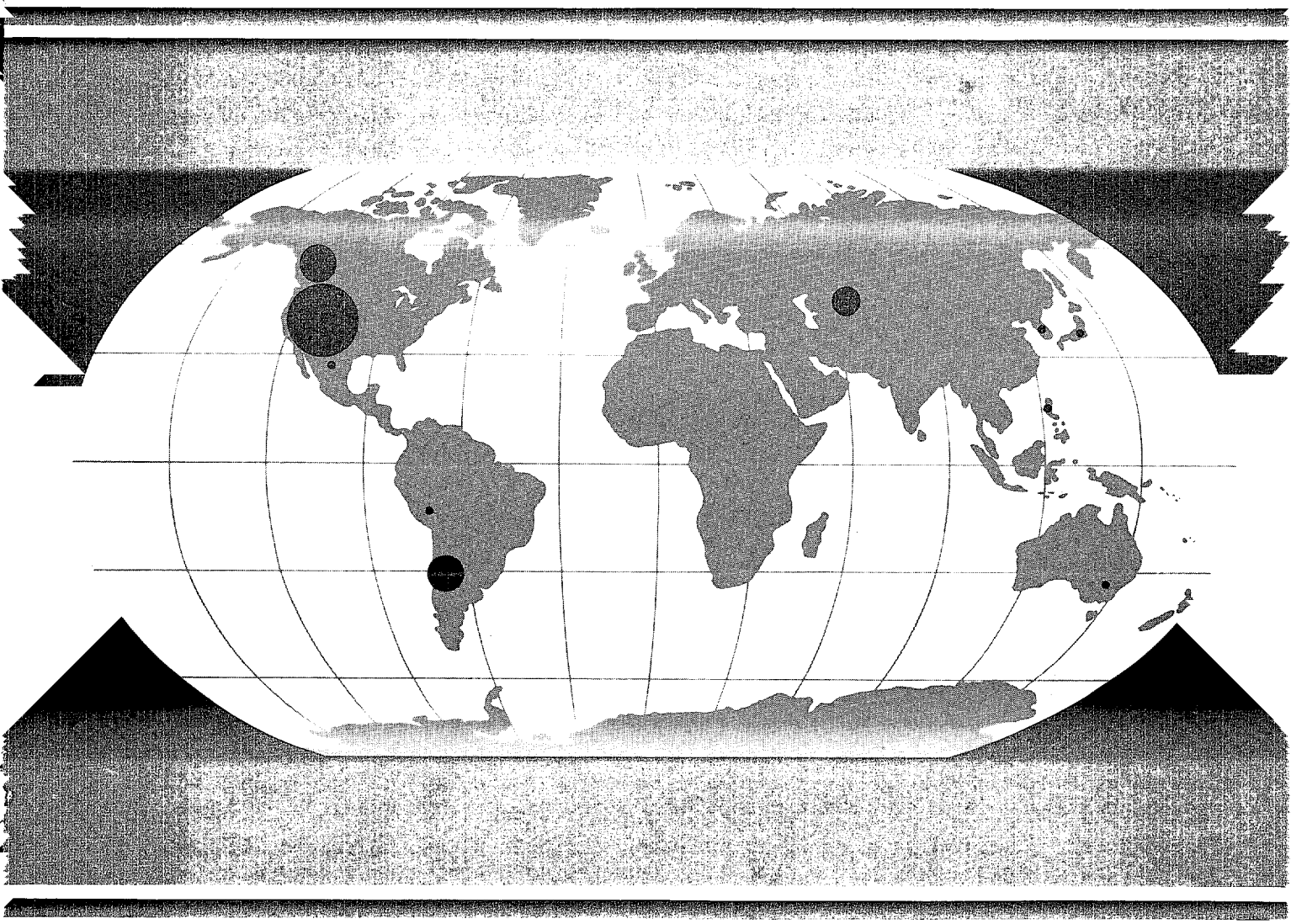
Molybdenite in quartz veins is probably the most common mode of occurrence of molybdenum in the United States. Deposits of this type are known throughout the Cascade and Sierra Nevada Ranges from Washington to California, and in the Rocky Mountains from Idaho and Montana to New Mexico; they are also scattered along the Appalachian Mountains from Maine to Alabama. The vein deposits are in intrusive rocks of granitic to dioritic composition and in associated metamorphic rocks. Molybdenite most commonly occurs with pyrite in quartz gangue, often associated with chalcopyrite, fluorite, and base-metal sulfides, and in some places with graphite, scheelite, or beryl; many gold- and silver-bearing vein deposits also contain small amounts of molybdenite. In the oxidized upper parts of some base-metal veins wulfenite is the molybdenum mineral, as at the Shenandoah mine in Nevada and at the Mammoth-St. Anthony and Rowley mines in Arizona. Vein-type deposits of molybdenum ordinarily are not profitably minable due to their limited dimensions or small reserves. The most notable exception was the Questa mine in New Mexico, from which more than 20 million pounds of molybdenum was obtained during the period from about 1920 to 1955 when high-grade veins were worked; the present operation is confined to a very large disseminated deposit.

In the contact-metamorphic deposits common to the Basin and Range Province of the western United States, molybdenum occurs as molybdenite or powellite commonly

MCP
mineral commodity profiles

J.H. Courtright
Copy

MOLYBDENUM



BUREAU OF MINES ★ UNITED STATES DEPARTMENT OF THE INTERIOR
MAY 1979

Explanation of Cover

The circles and dots on the map on the cover are roughly proportional to the production of molybdenum in various areas of the world as listed in table 3 of the text

MOLYBDENUM

MINERAL COMMODITY PROFILES
May 1979

This current report on molybdenum has been prepared by the Bureau of Mines, U.S. Department of the Interior to:

1. Provide the latest available data and information on molybdenum.

2. Invite comment, revisions, or additional information on the subject.

Please direct communications to the author:
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UNITED STATES DEPARTMENT OF THE INTERIOR

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MOLYBDENUM

by John T. Kummer[1]

Molybdenum is a refractory metallic element used principally as an alloying agent in steels, cast irons, and superalloys to enhance hardenability, strength, toughness, and wear and corrosion resistance. Primarily added in the form of molybdic oxide or ferromolybdenum, it is frequently used in combination with chromium, columbium, manganese, nickel, tungsten, or other alloy metals to achieve desired metallurgical properties. The versatility of molybdenum has assured it a significant role in contemporary technology and industry, which increasingly require materials that are serviceable under higher stresses, greater temperature ranges, and more corrosive environments. Moreover, molybdenum finds significant usage as a refractory metal and in numerous chemical applications, including catalysts, lubricants, and pigments. The variety of uses for molybdenum materials, few of which afford acceptable substitution, has resulted in a strong current demand that is expected to grow at a greater rate than most other ferrous metals.

Almost all molybdenum is recovered from low-grade deposits of the mineral molybdenite (MoS_2). Deposits mined primarily for molybdenum provide 65 to 70 percent of U.S. output and about 55 percent of world output. The remainder is obtained mainly as a byproduct from mining of large, low-grade copper porphyry deposits. Primary deposits generally grade 0.2 to 0.5 percent molybdenite; copper ores from which byproduct molybdenum is recovered contain 0.02 to 0.08 percent molybdenite.

Distribution of molybdenum reserves and productive capacity is concentrated in a few countries of the world. World mine output was an estimated 206 million pounds (molybdenum contained in concentrate) in 1977, of which the United States, Canada, and Chile provided 89 percent; the United States, historically the world's leading producer of molybdenum, supplied nearly 60 percent. An estimated 10 percent of the world output came from the U.S.S.R. These four countries, led by the United States, are expected to continue as the principal mine producers for the rest of this century.

The same four countries possess about 90 percent of the estimated 17.3 billion pounds of molybdenum in world reserves. The United States, Chile, and Canada account for 7.5, 5.4, and 1.3 billion pounds, respectively. The U.S.S.R. is estimated to have 1.5 billion pounds in reserves. Although exploration for new sources is likely to be successful in other areas, the aforementioned countries probably have the greatest potential for future additions to reserves and, ultimately, to mine output.

As a result of the concentration of production capability, international trade in molybdenum materials consists primarily of exports from the United States, Canada, and Chile to industrialized nations that lack mine production. The major importers are the countries of Western Europe and Japan. The United States has exported about half of its mine output, mostly as concentrate or oxide, in recent years and currently supplies about 55 percent of the molybdenum consumed in other market economy countries. Because of the considerable excess of production over domestic demand, the United States should continue as the leading supplier of molybdenum to the rest of the world. *

Based on contingency assumptions for various end uses, U.S. demand for molybdenum is forecast at between 150 and 200 million pounds in 2000. From a demand of 61.4 million pounds in 1977, the low and high of the projected demand range corresponds to growth rates of 4.0 and 5.3 percent annually to 2000. The probable demand in 2000 is forecast at 170 million pounds, corresponding to a growth rate of 4.5 percent annually from 1977. Cumulative requirements for 1977 to 2000 will range between 2.3 and 2.8 billion pounds at the projected growth rates. Current mine output and antici-

[1] Physical scientist, Division of Ferrous Metals.

pated increases in the 1980's should continue to provide molybdenum in excess of domestic demand for the remainder of this century. The ratio of domestic reserves to U.S. cumulative demand to 2000 is approximately 3 to 1.

Rest-of-world demand for molybdenum was an estimated 155 million pounds in 1977 and is forecast to range between 400 and 520 million pounds in 2000. The projected demand range corresponds to growth rates of 4.2 and 5.4 percent annually to 2000. Probable demand for the rest of the world is forecast at 460 million pounds in 2000, corresponding to an annual growth rate of 4.8 percent from 1977. Cumulative demand for the rest of the world from 1977 to 2000 should range between 6.1 and 7.1 billion pounds.

Although the ratio of current world reserves to probable cumulative world demand to 2000 (9.1 billion pounds) is approximately 2 to 1, production capacity will have to be appreciably increased to meet projected annual requirements after the early 1980's. Compared with the world production of about 206 million pounds in 1977, probable world demand is projected at 336 million pounds in 1985 and 630 million pounds in 2000. World production capacity should approach 300 million pounds annually by 1982 or 1983. Numerous deposits are currently being evaluated, but the potential output from these sources is not expected before the mid 1980's. Thus, given the forecast for world demand, the possibility exists that molybdenum availability will be restricted through 1985.

INDUSTRY STRUCTURE

Background

From the period of the Greek and Roman civilizations to the late 18th century, terms such as "molybdos" or "molybdaena" were applied to minerals that were soft and "leadlike" in character, probably including minerals now known as galena, graphite, and molybdenite. This confusion was resolved in 1778 when the Swedish chemist, Karl Scheele, demonstrated that molybdenite, the principal molybdenum mineral, was a discrete mineral sulfide. Four years later, P. J. Hjelm of Sweden reduced the acid-forming oxide of the element by heating with charcoal, thereby producing an impure powder of the metal, which he named molybdenum. Various properties of the element and its compounds were determined during the 19th century, and, in 1893, German chemists produced a 96-percent pure metal by reducing calcium molybdate. The impure metal was reported to have been used experimentally as a substitute for tungsten in tool steels.

Molybdenum-bearing armor plate was produced in France in 1894; this was the first recorded use of the metal as an alloying element in steel. Soon thereafter, Henri Mossian, a French chemist, succeeded in producing a 99.98-percent pure metal by reduction of molybdenum in an electric furnace. Mossian then conducted studies to establish the element's atomic weight and to determine its physical and chemical properties. These studies stimulated interest in the metal and its compounds and investigations of commercial applications. By the late 1890's, molybdenum was used in certain chemicals and dyes and, in 1898, a self-hardening molybdenum tool steel was marketed.

The first mine production of molybdenite was probably from the Knaben mine in southern Norway in the late 18th or early 19th century. Since essentially no commercial use for the metal existed, output from the mine remained insignificant until about 1880. By the end of the century, molybdenum ore was also mined intermittently in Australia and the United States. Molybdenite and wulfenite concentrates were produced from ores in Arizona and New Mexico, but U.S. output was small and ceased entirely in 1906 due to lack of demand.

World War I generated the first appreciable utilization of molybdenum when it was substituted for tungsten in high-speed steels and used as an alloying element in certain steels for military armament. From 1912 to 1920, small output was recorded from several additional countries, and U.S. production was resumed. The flotation process for separating molybdenite from its ores was developed during these years. The Climax deposit in Colorado and the Questa deposit in New Mexico were initially exploited from 1917 to 1919. Development of the Climax deposit, the world's largest, later proved the viability of high-tonnage extraction of relatively low-grade ore and established the United States as the leading producer of molybdenum.

Output terminated in 1920 in the United States and most other countries because nonmilitary consumption of molybdenum was insufficient to support continued production. However, industrial efforts to develop peacetime applications, primarily as an alloy in steels and cast irons, were successful and, by the mid 1920's, demand exceeded that of the war years. Operations resumed at the Climax deposit in 1924. By 1930, world output of molybdenum totaled 4.2 million pounds, of which the United

States and the Climax mine accounted for about 89 and 73 percent, respectively.

In 1933, the Greene Cananea Copper Co., a Mexican subsidiary of the Anaconda Co., initiated the recovery of molybdenite as a byproduct of copper mining operations. Three years later, Kennecott Copper Corp. began byproduct recovery at its Bingham open pit in Utah. Since that time, molybdenite recovery circuits have been installed at numerous copper concentrating plants, notably in the United States, Chile, and Canada. These sources have supplied 40 to 50 percent of the world molybdenum output in recent years.

Since the early 1930's, world production and consumption of molybdenum have increased about fiftyfold to more than 200 million pounds in 1977. During this period, industrial research and marketing programs have considerably expanded the range of metallurgical materials in which molybdenum is a preferred or essential alloy ingredient. The use of molybdenum as a refractory metal and in a variety of chemical applications has also experienced significant growth.

Table 1.—Principal world molybdenum mines in 1978, by country

Country	Company	Mine
Bulgaria	Government	Medet.
Canada	Brenda Mines Ltd. (Noranda Mines, Ltd.)	Brenda.
	Lornex Mining Corp. Ltd. (Rio Algom Ltd.)	Lornex.
	Noranda Mines Ltd	Boss Mountain.
	do	Copper Mountain.
	do	Needle Mountain.
	Placer Development Ltd	Endako.
	do	Gibraltar.
	Utah Mines Ltd. (Utah International Inc.)	Island Copper.
Chile	Corporación Nacional del Cobre de Chile (CODELCO)	Chuquicamata.
	do	El Teniente.
	do	El Salvador.
	do	Andina.
Peru	Southern Peru Copper Corp. (SPCC)	Toquepala.
United States	ASARCO Inc	Mission.
	do	Silver Bell.
	Anamax Mining Co	Twin Buttes.
	Cities Service Co	Pinto Valley.
	Climax Molybdenum Co. (AMAX Inc.)	Climax.
	do	Henderson.
	Cyprus Mines Corp	Bagdad.
	do	Pima.
	Duval Corp. (Pennzoil Co.)	Esperanza.
	do	Mineral Park.
	do	Sierrita.
	Inspiration Consolidated Copper Co	Inspiration.
	Kennecott Copper Corp	Bingham.
	do	Chino.
	do	Nevada mines.
	do	Ray.
	Magma Copper Co. (Newmont Mining Corp.)	Magma.
	Molycorp Inc. (Union Oil Co. of California)	Questa.
	Union Carbide Corp	Pine Creek.
U.S.S.R	Government	Kalmakyr.
	do	Balkhash (Kounrad).
	do	Umaltinsk.
	do	Tyrny Auz.
	do	Kadzharan.

Size, Organization, Geographic Distribution

About 60 percent of the world output of molybdenum is provided by U.S. mines. Four large corporations have accounted for 89 to 94 percent of the domestic mine output in recent years. Two of these firms mine deposits primarily for molybdenum, the other two recover molybdenum as a byproduct or coproduct of copper ore. The four firms also operate plants to convert sulfide concentrate to technical-grade oxide and other molybdenum products. The remainder of domestic mine output is provided by eight companies, all of which produce molybdenum as a byproduct of copper, tungsten, or uranium mining, and none of which possesses conversion facilities. Table 1 shows the principal world molybdenum mines, and table 2 lists the principal U.S. producers of molybdenum products.

Climax Molybdenum Co., a division of AMAX Inc., is the world's leading producing firm. The firm mines primary molybdenite ore at the Climax and Henderson mines, both located in Colorado. Capacity output at the Climax mine is 60–63 million pounds of molybdenum annually, although in some years output has fallen to 51–55 million pounds due to milling of lower grade ore. The Henderson mine, from which concentrate was initially produced in 1976, is expected to reach capacity output of 50 million pounds per year in 1980. With a capacity output totaling about 110 million pounds by 1980, Climax Molybdenum Co. should account for nearly 70 percent of the domestic output and about 45 percent of the world's production of molybdenum. The company converts concentrate to oxide, ferromolybdenum, and chemical products at plants in Pennsylvania and Iowa. The two plants have a combined annual conversion capacity of about 70 million pounds of molybdenum. Concentrate is also shipped to roasting facilities operated by the company in the Netherlands, Italy, and England. AMAX produces molybdenum metal powder and metal products at a plant in Michigan and lubricant-grade molybdenum disulfide at a plant in Pennsylvania.

Primary molybdenite ore is also mined by Molycorp Inc., which was acquired by Union Oil Co. of California in 1977, at the Questa mine in New Mexico. The mine produced a record 11.5 million pounds of molybdenum in concentrate in 1976, but is currently producing at a considerably lower rate. The ore presently being mined may be depleted in the early 1980's, after which surface mining operations would terminate. Substantial underground reserves have been outlined at the Questa property since 1974. The company recently announced plans to mine

Table 2.—Principal U.S. producers of molybdenum products in 1978

Company	Plant location	Major products
AMAX Inc.:		
AMAX Specialty Metals Corp	Coldwater, Mich	Metal powder (pellets).[1]
Climax Molybdenum Co	Fort Madison, Iowa	Molybdic oxide, ammonium molybdate.
	Langeloth, Pa	Molybdic oxide, ferromolybdenum sodium molybdate, purified molybdenum disulfide.
Duval Corp. (Pennzoil Co.)	Sahuarita, Ariz	Molybdic oxide, ferromolybdenum.
General Electric Co	Cleveland, Ohio	Metal powder.[1]
GTE Sylvania Inc	Towanda, Pa	Ammonium molybdate, metal powder (pellets).[1]
Kennecott Copper Corp	Magna, Utah	Molybdic oxide.
Molycorp Inc. (Union Oil Co. of California)	Washington, Pa	Molybdic oxide, ferromolybdenum.
M&R Refractory Metals Inc	Winslow, N.J	Molybdic oxide, metal powder (pellets).
North Metal and Chemical Co	York, Pa	Sodium molybdate.
Philips Elmet Corp	Lewiston, Me	Metal powder.[1]
S. W. Shattuck Chemical Co	Denver, Colo	Molybdic oxide; ammonium, sodium, and calcium molybdate.
Teledyne Wah Chang Corp	Huntsville, Ala	Metal powder.[1]
Westinghouse Electric Corp	Bloomfield, N.J	Metal powder.[1]

[1] Wire, rod, sheet, or other mill products are also produced.

the underground ore and estimated an output of 18 to 20 million pounds of molybdenum annually by 1984, after expansion of processing facilities. Molycorp operates a conversion plant in Pennsylvania at which technical grade oxide and ferromolybdenum are the principal materials produced.

Duval Corp., a subsidiary of Pennzoil Co., and Kennecott Copper Corp. are the other major domestic producers of molybdenum. Both firms recover molybdenum from surface mining of large copper porphyry deposits. Duval Corp. annually produces 20–24 million pounds of molybdenum at its Sierrita, Mineral Park, and Esperanza properties in Arizona, although in late 1977, the Esperanza operations were shut down for an indefinite period because of the depressed copper market. The Sierrita property, at which copper and molybdenum are considered coproduct values, is the largest domestic source of molybdenum from copper ores, with recent annual output totaling 16–18 million pounds. Duval also operates roasting and ferromolybdenum plants at its mining properties in southern Arizona.

Kennecott Copper Corp. mines four copper-molybdenum deposits located in Utah, Arizona, New Mexico, and Nevada. Combined molybdenum output from these properties has ranged from 7 to 11 million pounds annually since 1974, a considerable decrease from nearly 17 million pounds produced in 1970. Declining molybdenum grades and recovery at its large Bingham mine in Utah are chiefly responsible for Kennecott's lower output levels. A roasting facility near Salt Lake City, Utah, processes a portion of the molybdenum concentrate produced by the Kennecott mining operations.

Six other mining firms recovered molybdenum as a byproduct of copper mining during 1978. The combined output of these firms contributed about 8 percent of the domestic production in 1978; their mines are all located in Arizona. The firms include Magma Copper Co. (a subsidiary of Newmont Mining Corp.), Anamax Mining Co. (an equal partnership of the Anaconda Co. and AMAX Inc.), Cyprus Mines Corp., Cities Service Co., Inspiration Consolidated Copper Co., and ASARCO Inc. For the most part, these firms sell their concentrate output to domestic or foreign firms with roasting facilities, or to dealers. During 1978, byproduct molybdenum recovery was resumed, with minor output, at the Inspiration mine of Inspiration Consolidated Copper Co. and the Silver Bell mine of ASARCO Inc., both located in Arizona.

Molybdenum is also recovered from tungsten ore by Union Carbide Corp. at a mine in California. A small quantity of molybdenum is recovered in the processing of uranium ore by Kerr-McGee Corp. in New Mexico. These two sources combined provide less than 0.5 percent of the domestic output.

In addition to the four major producing firms, roasting plants are operated by the S. W. Shattuck Chemical Co. in Colorado and M&R Refractory Metals Inc. in New Jersey. Their combined roasting capacity is small compared with the major producers. These two firms and several others have the capability to convert oxide to molybdenum chemicals and/or metal powder.

Canada, the second leading producer of molybdenum, accounted for nearly 18 percent of the world output in 1977. Almost all Canadian output is obtained from molybdenum and copper-molybdenum porphyry deposits in British Columbia. The Endako mine, a primary molybdenum source owned by Placer Development Ltd., supplies nearly 50 percent of Canadian output. Another 25 percent of Canadian output is obtained from the Brenda mine, a copper-molybdenum coproduct source, in which Noranda Mines Ltd. holds a 50.9-percent interest. Noranda, Placer Development, Lornex Mining Corporation Ltd. (a subsidiary of Rio Algom

Ltd.) and Utah Mines Ltd. (Utah International Inc.) control the six other producing mines in Canada. In late 1978, molybdenum recovery was initiated at the concentrating plant of Bethlehem Copper Corp.'s copper property in the Highland Valley area of British Columbia. Anticipated capacity output from the plant was up to 1 million pounds of molybdenum in concentrate annually. In September 1978, AMAX Inc. announced plans to reopen the Kitsault (Lime Creek) mine and mill in the Alice Arms area of British Columbia. The facility last produced molybdenum in 1972. The company anticipates output to resume in 1982 at a rate of 9 to 10 million pounds of molybdenum annually.

Roasting plants are operated by Placer Development at its Endako property in British Columbia and by Fundy Chemical International Ltd. in Quebec. The Endako roaster converts concentrate produced at the Endako mine, and Fundy primarily processes concentrates on a toll basis. Fundy and Masterloy Products Ltd., in Ontario, have ferromolybdenum production facilities. Canada exports 85 to 90 percent of its domestic output, primarily as concentrate or oxide to western European countries and Japan.

Chile, the only other significant producer of molybdenum among market economy countries, accounted for 12 percent of the world output in 1977. All of Chilean output is recovered as a byproduct of copper mining by the State-owned Corporación Nacional del Cobre de Chile (CODELCO) from the Chuquicamata, El Teniente, El Salvador, and Andina mines. The Chuquicamata and El Teniente deposits are among the largest copper porphyries in the world and are the source of most of Chile's molybdenum. The Molibdenos y Metales S. A. (Molymet) company converts about a third of the mine concentrate output to oxide and ferromolybdenum. Almost all Chilean molybdenum products are exported, mainly to Western Europe and Japan.

All other market economy countries account for less than 1 percent of the world output. Peru is currently the only significant producer among these minor sources, with output of 1 to 2 million pounds of molybdenum annually since 1970. Most of the Peruvian output is recovered as a byproduct from the Toquepala copper mine, which is operated by Southern Peru Copper Corp. (SPCC), jointly owned by ASARCO Inc., Cerro-Marmon Corp., Phelps Dodge Overseas Capital Corp., and Newmont Mining Corp. Addition of a molybdenum recovery plant at the recently developed Cuajone copper mine, also operated by SPCC, could increase Peru's molybdenum output to nearly 4 million pounds per year in the near future.

Table 3.—World molybdenum mine production for 1977 and capacity for 1977, 1978, and 1980

(Thousand pounds)

	Production in 1977	Capacity[1] 1977	1978	1980
North America:				
United States	122,408	146,000	156,000	170,000
Canada	[2]36,225	40,000	41,000	42,000
Mexico	[e]40	200	200	200
Total	158,673	186,200	197,200	212,200
South America:				
Chile	24,250	26,000	28,000	30,000
Peru	1,021	1,500	3,000	5,000
Total	25,271	27,500	31,000	35,000
Europe:				
U.S.S.R.	[e]21,400	22,000	24,000	26,000
Bulgaria	([3])	500	500	500
Norway	0	500	500	500
Total	21,400	23,000	25,000	27,000
Asia:				
China	([3])	5,000	5,000	5,000
Japan	330	500	500	500
Republic of Korea	222	500	500	500
Iran	0	0	0	4,000
Philippines	10	200	200	200
Total	562	6,200	6,200	10,200
Oceania	[e]25	200	200	200
World total	205,931	243,100	259,600	284,600

[e]Estimated.
[1] Capacity data are estimations based on recent or anticipated output.
[2] Shipments.
[3] Unknown.

Among central economy countries, the U.S.S.R. and China are the only significant molybdenum producers. U.S.S.R.'s contribution was estimated at about 10 percent of world output in 1977. Information is inadequate to make a reliable estimate of output for China.

World molybdenum production and capacity for 1977 and projected capacity for the years 1978 and 1980 are shown in table 3.

Countries that are major producers of steel and other metallurgical materials are the principal consumers of molybdenum. The estimated total world demand for molybdenum was 210 to 220 million pounds in 1977. The approximate percentages of total demand, by major geographical regions, were as follows: United States, 28; Western European countries, 33; Japan, 12; U.S.S.R. and Eastern European countries, 21; others, 6. Since the European countries and Japan have little or no mine output of molybdenum, these countries import all of their requirements. Major conversion plants in Europe and Japan process imports of concentrate to oxide, ferromolybdenum, and other commercial products.

Definitions, Grades, Specifications

Molybdenum is a silver-white metallic element with an atomic number of 42, atomic weight of

95.95, and a density of 10.2 grams per cubic centimeter. The chemistry of molybdenum is complex: It exhibits oxidation states from −2 to 6, coordination numbers from 4 to 8, and forms compounds with most inorganic and organic ligands (*13*).[2] Molybdenum is a strong carbide-forming element, and much of its alloying effect in steel is imparted through the formation of carbides. It has a melting point of about 2,610° C; among the metallic elements, only tungsten, rhenium, osmium, and tantalum have higher melting points. Other significant physical properties of molybdenum metal are good thermal conductivity (about one-half that of copper), the lowest coefficient of thermal expansion of the pure metals, high strength at elevated temperatures, and resistance to corrosion in a wide variety of mediums. Molybdenum metal is stable in air or water at moderate temperatures, but above about 500° C, it oxidizes readily.

Molybdenite (MoS_2) is the principal mineral from which molybdenum is obtained. Crude ore containing molybdenite is beneficiated to produce molybdenite concentrate. The concentrate generally contains about 90 percent molybdenite; the grade may be somewhat lower, particularly if produced at copper byproduct concentrating plants. Technical-grade molybdic oxide (MoO_3) is produced by the roasting of molybdenite concentrate. Typically, the oxide has a MoO_3 content of 90 percent, or 60 percent contained molybdenum. Other raw materials, including ferromolybdenum, purified molybdic oxide, ammonium and sodium molybdate, and molybdenum metal powder are produced from technical-grade oxide. The production of these materials is described in the section entitled "Products for Trade and Industry."

Although molybdenum materials are no longer maintained in the Government stockpile, purchase specifications issued by the General Services Administration (GSA) list the approximate chemical requirements for molybdenite concentrate, technical-grade oxide, and ferromolybdenum suitable for use by industry. According to National Stockpile Specification P–74–R5, July 15, 1963 (superseding issue of July 21, 1959), the chemical compositions of these materials are as follows:

Constituents of molybdenum disulfide (molybdenite concentrate)		Weight-percent (dry basis)
Molybdenum disulfide (MoS_2)	Minimum	90.00
Copper (Cu)	Maximum	0.45
Lead (Pb)	Maximum	0.15
Phosphorus (P)	Maximum	0.04
Tin + Arsenic (Sn + As)	Maximum	0.15

Free moisture content not to exceed 4 percent.

Constituents of molybdic oxide		Weight-percent (dry basis)
Molybdenum (Mo)	Minimum	60.00
Copper (Cu)	Maximum	0.50
Lead (Pb)	Maximum	0.15
Phosphorus (P)	Maximum	0.05
Sulfur (S)	Maximum	0.25

Free moisture content not to exceed 0.5 percent.

Constituents of ferromolybdenum		Weight-percent (dry basis)	
		Grade A	Grade B
Molybdenum (Mo)	Minimum	60.00	60.00
Carbon (C)	Maximum	2.50	0.10
Carbon (C)	Minimum	2.00	—
Copper (Cu)	Maximum	0.50	0.50
Phosphorus (P)	Maximum	0.10	0.10
Silicon (Si)	Maximum	1.00	1.00
Sulfur (S)	Maximum	0.20	0.20

The above specifications are generally met or exceeded for materials marketed by the major domestic producers. Standards set by ASTM (American Society for Testing and Materials) for molybdic oxide and ferromolybdenum do not vary appreciably from the specifications issued by GSA.

USES

Metallurgical applications, which include the use of molybdenum in steels, cast irons, superalloys and other alloys, and as a refractory metal, account for about 90 percent of domestic consumption; chemical and other nonmetallurgical applications account for the remaining 10 percent.

About 70 percent of consumption is attributable to the production of molybdenum-containing steels. Technical grade molybdic oxide and ferromolybdenum are the principal forms added to steel melts. Depending on type and specifications, the molybdenum content of steels ranges from less than 0.1 percent to nearly 10 percent, and it is used as the sole alloy agent or, more often, in combination with other ferrous alloys. The role of molybdenum as an alloy is versatile; because it imparts or enhances a variety of desired physical properties, molybdenum-containing steels are being utilized in increasing quantities.

Molybdenum is added to the general class of alloy steels to improve hardenability and toughness, to increase resistance to temper embrittlement, abrasion, and corrosion, and to enhance hardness and strength, especially at elevated temperatures. These steels are used in all major segments of industry, including the manufac-

[2] Italicized numbers in parentheses refer to items in the list of references at the end of this report.

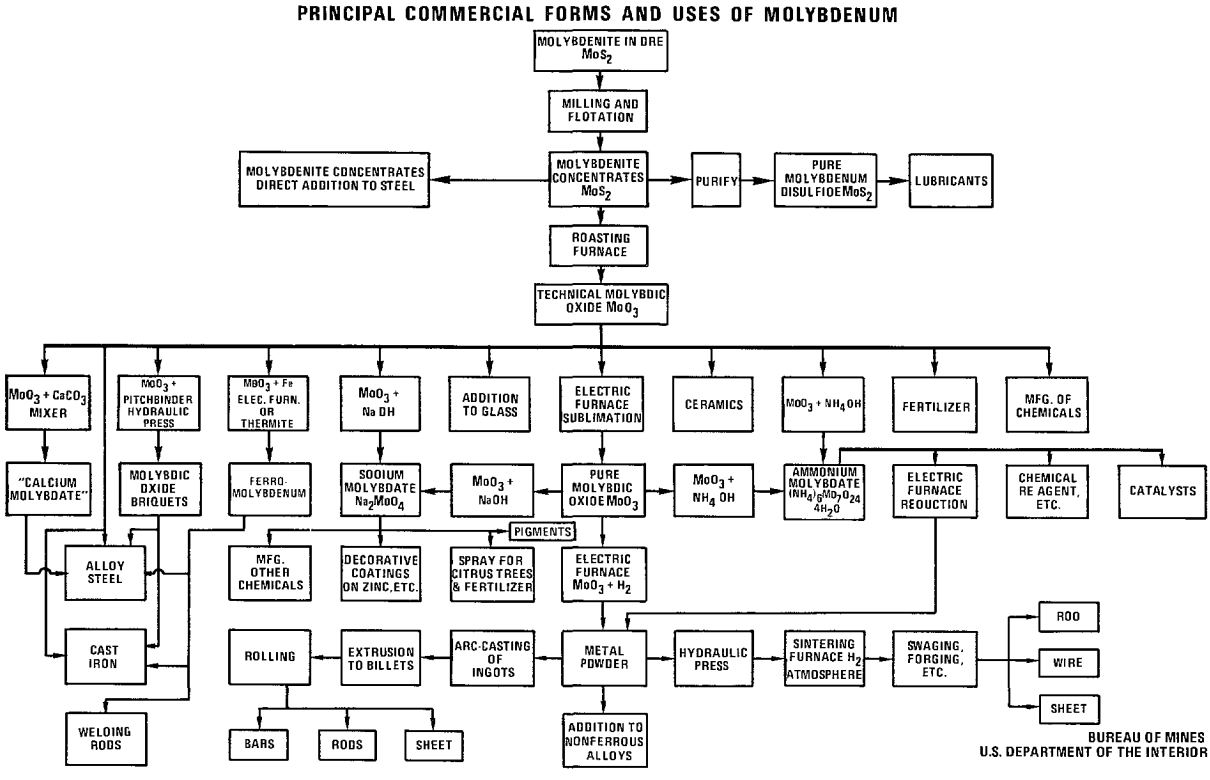

Figure 1.—Principal commercial forms and end uses of molybdenum.

turing of transportation equipment and vehicles, industrial machinery and tools, and equipment used in agriculture, mining, electrical power generation, food and chemical processing, and oil and gas production. Certain grades of stainless steels contain up to 4 to 5 percent molybdenum to improve general corrosion resistance. Newly developed ferritic stainless steels containing molybdenum are increasingly utilized in severe chemical and seawater environments. Molybdenum-containing alloy and stainless steels are used in the production of a wide variety of piping, tubing, and tubular assemblies that are used extensively in boilers, superheaters, heat exchangers, condensers, and distillation and refining equipment. Molybdenum is used in significant quantities in high-strength, low-alloy (HSLA) steels used in structural applications and the production of oil and gas transmission pipelines. Varieties of these linepipe steels exhibit the strength, toughness, and weldability required particularly in low-temperature (Arctic) regions and offshore environments. Tool and high-speed steels containing 4 to 9.5 percent molybdenum have captured a significant, and growing, share of the market for these types of steels. The wide and expanding applications of molybdenum-containing steels, as briefly outlined above, have established molybdenum's importance in modern industry.

Molybdenum is employed in cast irons to improve tensile strength, toughness, and resistance to chipping and spalling. Numerous nickel- and cobalt-based superalloys and other high-performance alloys contain appreciable percentages of molybdenum; these materials are employed for strength at high temperatures or for corrosion resistance to acidic and alkaline solutions. Molybdenum-based alloys are used in diecasting equipment and in materials exposed to molten glasses or salts, high-temperature chemicals, and liquid metals.

As a refractory metal, molybdenum is utilized in a wide variety of electrical and electronic components, for resistance elements in electric furnaces, in equipment used for nuclear powerplants, and in numerous other applications requiring materials serviceable under extremely high temperatures. Applied as a powder, molybdenum is used to provide a wear-resistant surface coating to machine and engine parts

subject to continued abrasion. Other important metallurgical uses of molybdenum include welding and alloy hard-facing rods and materials, permanent magnet alloys, and metal-to-glass seal materials.

Among nonmetallurgical uses, the principal applications of molybdenum are in lubricants, catalysts, and pigments. The lubricating properties of molybdenum disulfide are a function of its lamellar crystal structure and surface chemistry. It performs well under severe pressure and temperature conditions and is widely used as an additive to oils and greases, in aerosal sprays applied to reduce surface friction, and in plastic and metal composites as an antiwear or antifriction agent. The use of molybdenum disulfide in automotive engine oils may increase substantially in the future.

Molybdenum is an ingredient of catalysts used for hydrotreating, desulfurization, and other petroleum-refining processes. Molybdenum catalysts are also employed in oxidation-reduction reactions to produce alcohols, formaldehyde, and petroleum-based chemicals. Molybdenum orange is an important paint pigment, and molybdenum chemicals are widely used in dyes, inks, color lakes, and corrosion-resistant primers. Soluble molybdates are experiencing increasing use as corrosion inhibitors in cooling water systems because of their low or negligible toxicity. Molybdenum compounds are also employed as flame retardants and smoke suppressants, as a micronutrient in fertilizers, as chemical reagents, in the glass and ceramic industries, and in numerous other minor chemical applications.

RESERVES—RESOURCES

Available information on world reserves and resources of molybdenum varies widely in reliability. For certain countries such as Canada, Chile, and the United States, company reports or other published materials enable a reliable inventory of minable ore reserves. For most other countries, reserves must be estimated from fragmentary or preliminary data on ore tonnage and grade of known or anticipated sources. In particular, the reserve figures listed in table 4 for the U.S.S.R. and China should be considered order-of-magnitude estimates.

Reserve data, for the most part, are restricted to quantities of molybdenum in ore deposits of producing mines or deposits under development. In a few cases, deposits judged as reasonably certain for future production were included in the reserve category. Because of the difficulty in ascertaining the economic viability of undeveloped deposits or deposits currently being evaluated, such potential sources have been placed in the "Other" resource category of table 4. "Other" resources listed for most countries should be regarded as somewhat speculative.

Table 4.—Identified world molybdenum resources

(Million Pounds)

	Reserves	Other[1]	Total
North America:			
United States	7,500	8,100	15,600
Canada	1,300	2,100	3,400
Mexico	300	800	1,100
Other[2]	----	1,300	1,300
Total	9,100	12,300	21,400
South America:			
Chile	5,400	6,600	12,000
Peru	500	1,000	1,500
Other	----	600	600
Total	5,900	8,200	14,100
Europe:			
Bulgaria	10	20	30
U.S.S.R.	1,500	1,500	3,000
Other	----	1,400	1,400
Total	1,510	2,920	4,430
Africa:	----	100	100
Asia:			
China	500	500	1,000
Iran	300	300	600
Other	10	390	400
Total	810	1,190	2,000
Oceania:			
Australia	----	50	50
Other[3]	----	400	400
Total	----	450	450
World total[4]	17,300	25,200	42,500

[1] Derived in consultation with U.S. Geological Survey.
[2] Includes Greenland, Central America, and Puerto Rico.
[3] Includes Antarctica.
[4] Data do not add to totals shown because of rounding.

It should be noted that the reserve data in table 4 refer to molybdenum contained in ore. The recovery of molybdenum after milling approximates 80 to 90 percent of the in-place ore content at primary molybdenum sources. Recoveries achieved at byproduct sources vary markedly from mine to mine, but average an estimated 55 percent of the molybdenum in ore processed. Overall, an estimated 65 percent of the total world molybdenum reserves can be considered as recoverable.

Most of the world reserves of molybdenum occur in the western mountain regions of North and South America, extending from Alaska and British Columbia through the United States and Central America to the Andes Mountains of Chile. These regions, roughly bordering the western margin of the Pacific Basin, are also regarded as most promising for future discoveries and additions to reserves.

The United States has 43 percent of the world molybdenum reserves, estimated at 17.3 billion pounds. About 70 percent of the U.S. reserves

occurs in large porphyry or disseminated deposits mined, or anticipated to be mined, primarily for molybdenum. These deposits are located in Alaska, Colorado, and New Mexico. The remaining reserves are almost entirely in porphyry copper ores in Arizona, Nevada, New Mexico, and Utah. Other molybdenum sources contribute insignificantly to U.S. reserves.

Canadian reserves of molybdenum are primarily located in British Columbia (*8*), including nearly 30 percent of the total in the Endako primary deposit. Other Canadian reserves are associated with molybdenum and copper-molybdenum porphyry deposits in British Columbia except for one relatively minor source in Quebec.

Molybdenum reserves in Central and South America are in large copper porphyry deposits. Of several such deposits in Chile, the Chuquicamata and El Teniente deposits are among the world's largest and account for 85 percent of the total molybdenum reserves in Chile (*20*). Although Mexico and Peru have substantial reserves, the Toquepala deposit in Peru is the only significant producer. Numerous other copper porphyries that may contain recoverable quantities of molybdenum have been identified in Central and South America. Many of these deposits are actively being explored and evaluated and could add substantially to reserves in the future.

Reserves of molybdenum in the U.S.S.R. and China are estimated to be substantial, but definitive information about the current sources of supply or prospects for future development in the two countries is lacking. Molybdenum production and reserves in Bulgaria are presumed to be small. Other European countries, particularly Yugoslavia, probably possess molybdenum resources. Some production has been reported from Australia, Japan, the Philippines, and the Republic of Korea in recent years, but ore reserves in these countries are relatively small. Copper ores are being investigated on the islands of New Guinea and Bougainville in the southwest Pacific, but whether these contain economically recoverable molybdenum awaits further evaluation. The recent development of the Sar Cheshmah copper deposit in Iran, from which recovery of byproduct molybdenum is planned, has coincided with the exploration of similar prospects in Iran, Pakistan, and Afghanistan.

Development of a Minerals Availability System (MAS) by the Bureau of Mines, which will include information on molybdenum supply available to the Nation, has been underway for several years. The system involves the evaluation and classification of worldwide mineral resource data for automated storage and retrieval. MAS provides a mechanism for analyzing long- and short-term supply positions, contingencies and alternatives, mineral-related land-use issues, environmental issues, and a variety of economic and technological problems associated with mining, processing, and transporting molybdenum. The Bureau of Mines completed minerals availability studies on two molybdenum-containing deposits in the United States in 1977—the Heddleston deposit, Lewis and Clark County, Mont., and the BrenMac-Sunrise property, Snohomish County, Wash.

Geology

Mineralogy.—The average crustal abundance of molybdenum is 1 to 2 parts per million (ppm). The molybdenum content of igneous rocks tends to increase with increasing silica content. Molybdenum does not occur in nature in its free or native state, but is found only chemically combined with other elements. Small deposits of molybdenum-bearing minerals occur throughout the world, but the only molybdenum mineral of commercial importance is molybdenite. Wulfenite, powellite, and ferrimolybdite are common but have supplied very little molybdenum.

Molybdenite (MoS_2) is a lead-gray, metallic mineral that characteristically occurs in thin, tabular, commonly hexagonal plates and also disseminated as fine specks. The plates have a basal cleavage and may split into thin flakes which bend readily although they are not elastic. It has a specific gravity of 4.6 to 4.7, a hardness of 1 to 1.5, a greasy feel, and it soils the fingers. Superficially it resembles graphite, for which it commonly has been mistaken.

Wulfenite ($PbMoO_4$), a molybdate of lead, is a metallic mineral characterized by red, orange, yellow, gray, and white colors. The mineral has a resinous or adamantine luster, a hardness of 2.75 to 3, a specific gravity of 6.5 to 7, and a white streak. It generally occurs in well-formed crystals, chiefly square and tabular, ranging in size from microscopic to more than an inch along the edge. Deposits are found almost entirely in veins, mostly in the oxidized parts of lead deposits. Occurrences of wulfenite are numerous, but none is of economic importance.

Powellite ($Ca(Mo,W)O_4$), a calcium molybdate, is usually formed from the alteration of molybdenite. It is nearly always impure; tungsten substitutes for molybdenum up to about 10 percent. The mineral has a hardness of 3.5, a

specific gravity of 4.3, and a variable color which includes dirty white, gray, straw yellow, greenish yellow, pale greenish blue, and brown. Powellite is found with scheelite, and this association helps to identify the mineral because it fluoresces a golden yellow.

Ferrimolybdite ($Fe_2Mo_3O_{12}\cdot 8H_2O$) is a very soft, hydrous mineral of distinctive canary-yellow color. It occurs as fine, needlelike crystals and has a hardness of 1.5 and a specific gravity of 2.99 to 4.5.

Other molybdenum minerals include chillagite, ilsemannite, koechlinite, lindgrenite, eosite, and jordisite.

Should demand for molybdenum continue to rise, wulfenite, powellite, and ferrimolybdite may become economically important source materials.

Type of Deposits.—Molybdenum deposits are of five genetic types: (1) porphyry or disseminated deposits including stockworks and breccia pipes in which metallic sulfides are dispersed through relatively large volumes of altered and fractured rock, (2) contact-metamorphic zones and tactite bodies of silicated limestone adjacent to intrusive granitic rocks, (3) quartz veins, (4) pegmatites and aplite dikes, and (5) bedded deposits in sedimentary rocks.

The first three genetic type deposits are hydrothermal in origin and as such represent nearly all the known molybdenum resources currently mined in the world. The remaining types do not represent a great volume of molybdenum but are of certain economic importance only when molybdenum is associated with other minerals.

In the hydrothermal deposits, metallic minerals are precipitated from high-temperature aqueous solutions either by changes in temperature and pressure or by evaporation of the liquid. Minerals are deposited in the cavities, cracks, or interstices of the matrix rock. Favorable host intrusive rocks with which the metallic minerals are genetically related range from intermediate to acidic and include diorite, quartz monzonite, granite, and their porphyritic equivalents. Metallization commonly takes place both in the host intrusive and in the surrounding or overlying country rock. The following are specific examples of hydrothermal mineralization at deposits currently mined.

The most important stockworks deposit at Climax, Colo., was formed by an intrusion of a quartz-monzonite magma into granite, schist, and porphyry rocks. The aqueous solutions penetrated the smallest fractures and deposited quartz-molybdenite in the form of small veinlets, which made the host rock appear like a breccia.

Molybdenite occurs in veins and stringers of porphyry-type rock at the Questa deposit of New Mexico. The vein filling is quartz and molybdenite with minor amounts of pyrite, chalcopyrite, and chlorite. The veins vary from a fraction of an inch to several feet wide. The mineral content varies widely; most of the molybdenite is fairly fine grained and appears to be concentrated along the vein walls or along joints and seams.

Most of the porphyry coppers in the Western United States contain small quantities of molybdenite disseminated with the copper minerals through large bodies of granitic rock. The chief minerals are chalcopyrite and chalcocite, with pyrite and small amounts of other sulfides including molybdenite. In addition, minor amounts of other base-metal minerals, specular hematite, fluorite, and secondary silicate minerals are present. Chalcocite replaces pyrite and chalcopyrite in the zone of secondary enrichment. The copper-to-molybdenum ratio ranges from about 10:1 to perhaps 150:1.

Small quantities of molybdenite are widely distributed in lime-silicate deposits along the contacts between granitic intrusive rocks and lime-rich sedimentary rocks. Molybdenite is commonly associated with scheelite, bismuthinite, or copper sulfides in zones of silicated limestone near granitic intrusive rocks. The only domestic production from this type of mineralization has been as a byproduct from the Pine Creek tungsten deposit in California. The mineral formation is metasomatic since it originates by replacement of the rock with additional material transported from the intruding magma.

In the pegmatite-type and aplite-type deposits, the principal geological process is igneous intrusion with subsequent solidification of the magma and crystallization of its mineral components. The pegmatities are coarsely crystalline and consist almost exclusively of quartz and feldspar. Molybdenite occurs as an accessory mineral, and the individual crystals are generally large and usually euhedral. Many pegmatites contain magnetite, ilmenite, cassiterite, wolfram, columbite, zircon, apatite, rutile, and beryl. The average grade of these types of deposits is low, hence, they are not important potential producers of molybdenum. Pegmatite-type deposits that contain disseminated molybdenum associated with bismuth were mined in recent times in Val d'Or and Preissac, Quebec, Canada.

Molybdenum minerals occur in coal, shale, phosphorite, lignitic sandstone, and some arkosic sandstone. The molybdenum in these sedimentary rocks has not been included in the

estimates of reserves because economic and technical problems prevent exploitation at present. A small quantity of molybdenum has been recovered from uraniferous lignites in North and South Dakota, but output from these sources ceased in 1968.

TECHNOLOGY

Exploration and Development

Prospecting and exploration for molybdenum is basically the same as that for deposits of other metals. Areas generally considered favorable for molybdenite mineralization are those metallogenic provinces that encompass known occurrences of molybdenum stockwork deposits (*5*) and copper-molybdenum porphyry deposits (*10*). An understanding of regional geology, mineral associations, and known patterns of molybdenite mineralization is essential to identify potential sites for field investigation. Sites for detailed study may be selected on the basis of geologic mapping of rock units and structures, geochemical analyses of sediments and soils, and ground geophysical surveys. An intensive drilling and sampling program is then required to estimate the size, grade, and continuity of the discovery. Exploration drifts may be driven into the ore body to provide more specific geologic information and bulk samples for metallurgical testing.

The evaluation of a deposit may require 2 to 5 years from the time of discovery. During this time, the technical, economic, and environmental aspects of mine development must be evaluated. An additional 3 to 8 years may be required to prepare the deposit for production. Long development times are indicative of the complex planning and considerable capital needed to develop the large, low-grade stockwork and porphyry deposits that are expected to remain the significant sources of molybdenum. As a general rule, development of underground molybdenum deposits would require more time and capital than that of surface deposits.

Mining

Molybdenum ore is mined by underground and open pit methods, the choice of method being determined by the size, configuration, grade, and depth of the ore body. Underground and surface operations accounted for about 55 and 45 percent, respectively, of the domestic molybdenum output in 1978. The Climax deposit of AMAX Inc. is the sole U.S. property mined by both underground and surface techniques.

Underground deposits of molybdenum ore are mined by block or panel caving methods modified to suit the characteristics of the particular ore body being worked. In these methods, large masses of ore are undercut and blasted at the base to induce the collapse and fragmentation of the ore under its own weight. The broken ore may be drawn off from the caved mass by gravity through finger raises into slusher drifts. The ore is then scraped to draw holes where it falls into ore cars on a haulage level located beneath the slusher drifts. Alternatively, the broken ore may be funneled by gravity to crosscut drifts located at intervals between production drifts. Ore is moved from the ends of the crosscuts along the production drifts to ore passes where it is dumped and collected in loading pockets on a deeper main haulage level. Ore is then transported from the main haulage level to the site of the inital milling operations. Caving methods are used to mine underground deposits of molybdenum because the low grade of the ore necessitates extraction of large tonnages of rock at a minimum of cost. However, caving of the ore most be carefully controlled to avoid ore dilution and excessive ground stresses to mine openings.

In open pit mining operations, the ore is exposed by removal of waste rock. The cut in the ore takes the form of benches which vary in height and width from mine to mine. The cycle of open pit extraction consists of drilling, blasting, loading, and haulage. Primary drilling consists of driving a vertical blasting hole into the ore. Secondary drilling and blasting may be required to break large boulders. Ore is loaded by mechanical shovels into rail cars or trucks and haulage is by large trucks for short distances or by train for long distances. Skipways and belt conveyors are used at some mines for transporting ore to the mill site.

Beneficiation

Because of their low molybdenum content, all molybdenum-bearing ores require beneficiation. After crushing and grinding to a suitable size, both primary molybdenite and copper sulfide ore containing molybdenite are beneficiated by flotation. With primary ores, a final concentrate of 90 to 94 percent molybdenite is produced by subjecting the ore to several stages of grinding and reflotation. Copper, iron, and lead minerals are generally the critical impuri-

ties that must be minimized in the final concentrate product. Overall recovery of molybdenite at primary-ore concentrating plants ranges from 75 to 90 percent of the in-place ore content.

Production of molybdenite concentrate from copper ores is more difficult, however, because molybdenite constitutes less than 0.1 percent of the ore. As a byproduct value, molybdenite recovery is generally given less priority than recovery of copper values. In some cases, improved molybdenite recovery may be attained only at the expense of reduced copper recovery or lower grade of copper concentrate produced.

Recovery from copper ores begins with the bulk flotation of copper minerals and molybdenite as the first separation from gangue materials. Molybdenite in the bulk flotation product is then separated from the copper minerals in a selective flotation process, which usually involves the flotation of molybdenite and depression of copper minerals. The separatory flotation requires close control of pH, reagent mix, and several flotation steps. Processing of copper-molybdenum ore varies from plant to plant depending on the grade of mineralization and impurities in the ore. Concentrate produced as a byproduct contains 70 to 90 percent molybdenite, although most approaches the higher end of the range in content. The yield of molybdenite from cooper ore varies from less than 20 to about 80 percent; the average for U.S. byproduct operations is approximately 55 percent.

Products for Trade and Industry

Some commercial-grade molybdenite concentrate is treated with additional grinding and flotation steps to produce lubricant-grade molybdenum disulfide. Oil and water are volatilized by passing an upgraded concentrate through an inert-gas-swept kiln. The oil-free product is about 99 percent molybdenum disulfide and suitable for use in lubricant applications.

Molybdenite concentrate is converted to technical-grade molybdic oxide (MoO_3), the major form of molybdenum used by industry and the base material for production of ferromolybdenum, chemicals, and molybdenum metal powder. The technical-grade oxide is produced by roasting molybdenite concentrate in a multiple-hearth furnace at temperatures of up to 650° C. Careful regulation of concentrate feed, hearth temperature, and airflow is necessary to promote efficient oxidation of the sulfide and to prevent sublimation of molybdic oxide. Typically the roasted product contains 90 percent MoO_3 and a maximum of 0.1 percent sulfur. Technical-grade oxide is used to add molybdenum to steels, cast irons, and other alloys.

Molybdic oxide briquets are prepared by compaction of a mixture of technical-grade oxide and air-floated pitch as a binder. Briquet composition is approximately 78 percent molybdic oxide and 12 percent carbon, with the balance principally silica. Briquets are used to add molybdenum to iron and steel furnaces under conditions in which use of finely divided or granular oxide would result in excessive mechanical losses.

Pure molybdic oxide (approximately 99.95 percent) is produced by sublimation of technical-grade oxide at temperatures of 1,100° to 1,200° C in a circular, sand-hearth electric furnace. After cooling, the fine, volatized oxide is densified with distilled water and dried. The pure oxide is used in chemical applications or to produce sodium and ammonium molybdates and molybdenum metal powder.

Ferromolybdenum is typically produced by reduction of technical-grade oxide and iron oxide with a conventional metallothermite process, using silicon and/or aluminum as the reductant. The metallic mass formed by the thermite reaction is crushed and marketed in a number of sizes. The molybdenum content ranges from 58 to 64 percent. Ferromolybdenum is used as an alternate additive in producing alloy steels, cast irons, and nonferrous alloys.

Ammonium molybdate is produced by reacting pure molybdic oxide with ammonium hydroxide and crystallizing out the pure molybdate. Sodium and calcium molybdate are made in a similar manner using sodium hydroxide and calcium chloride. All are used commercially in chemical applications. In the past, a mechanical mixture of technical-grade oxide and pulverized limestone, termed "calcium molybdate," was used as an alternate material for alloy additions of molybdenum.

Molybdenum metal powder is manufactured by reducing pure molybdic oxide or ammonium molybdate with hydrogen. The purest metal powder (99.95 percent molybdenum minimum) is produced from ammonium molybdate. Metal powder is pressed and sintered into small metal ingots which are converted into rod, wire, or sheet by hot rolling, swaging, or forging. Large ingots are produced by arc-casting powder in a vacuum or inert-gas atmosphere. The powder is also pressed and sintered into small pellets and corrugates for alloy additions in which high-purity metal is required.

Figure 1 illustrates the principal commercial forms and uses of molybdenum from ore to end products.

Current Research and Applications

Research and development programs span the entire range of the molybdenum industry from extractive metallurgy to product development. Producing firms are engaged in continuous work to enhance recovery of molybdenite at concentrator plants by refinements in grinding and flotation procedures. Processes have been devised to recover molybdenum from concentrates and ores that present special problems in processing owing to certain gangue materials or impurities. New methods for the production of molybdic oxide, molybdenum chemicals, and ferromolybdenum have been developed and may be used on a commercial basis in the future. The degree of research activity concerned with ore beneficiation and conversion technology is underscored by the numerous patents granted in recent years in these areas.

Considerable research is carried out in physical metallurgy directed toward the development of new steels and alloys which take advantage of molybdenum's alloying properties. Much of this work is conducted in metallurgical laboratories of the Climax Molybdenum Co. A partial listing of recently developed metallurgical materials containing molybdenum includes (1) corrosion-resistant ferritic stainless steels with better weldability than established ferritic grades; (2) a constructional steel that combines high strength and resistance to sulfide stress cracking, suitable for use in deep oil and gas wells where hydrogen sulfide is encountered; (3) nickel-based alloys with 7 to 15 percent molybdenum, which exhibit high strength and superior corrosion resistance; (4) a low-alloy, high-strength chromium-molybdenum rail steel; (5) dual-phase, low-alloy steels with high strength and good formability, which permit weight reduction of automotive components; and (6) carburizing steels with high hardenability and greater toughness, and available at lower cost than standard grades. The development and commercial application of these and other metallurgical products are expected to have considerable impact on the molybdenum market.

Basic and applied research is furthering understanding of the behavior and utilization of molybdenum chemicals in a variety of applications. Papers presented at the Second International Conference on the Chemistry and Uses of Molybdenum (7) covered aspects of the structures, bonding, and reactions of inorganic molybdenum compounds, molybdenum catalytic mechanisms, and molybdenum biochemistry. Industrial research has been concerned with expanded applications for molybdenum catalysts, lubricants, corrosion inhibitors, and flame and smoke retardants. A cemented molybdenum monocarbide has recently been produced that exhibits properties and performance similar to those of conventional cobalt-bonded tungsten carbide.

Over the past several years, Bureau of Mines' metallurgists have developed an electrooxidation process to recover molybdenum and rhenium from offgrade concentrates. The process was successfully demonstrated in pilot-plant scale and has been made available to industry for feasibility studies. Other recent investigations by the Bureau of Mines include work on flotation separation of molybdenite from copper concentrates using steam injection, the development of investment shell molds suitable for casting of molybdenum and molybdenum-based alloys, molybdenum-containing alloys suitable for use in high-temperature applications and geothermal brine environments, the electrodeposition of coatings to retard oxidation of molybdenum metal, and the removal of molybdenum from metallurgical process water.

SUPPLY–DEMAND RELATIONSHIPS

Components of Supply

Molybdenum supply-demand statistics for the United States for the years 1969–78 are shown in table 5. The data for 1977, with the principal molybdenum-producing countries shown, are displayed in figure 2. Since 1969, the United States has supplied approximately 62 percent of the total world mine output of molybdenum. Roughly two-thirds of the U.S. output in recent years has been obtained from primary molybdenum mines; most of the remainder was recovered as a byproduct of copper mining. With the Henderson mine approaching capacity production, the U.S. share of world output should increase over the next 2 to 3 years, as will domestic output from primary mines. Canada, Chile, and the U.S.S.R. provide most of the mine production from the rest of the world. Mainland China is probably a noteworthy producer (greater than 1 percent of world output), but information is inadequate to make a reliable estimate of its output.

The U.S. Government stockpile of molybdenum materials was entirely depleted in 1977 and ceased to be a factor in the domestic supply-demand picture. Nearly 85 million pounds of molybdenum contained in concentrate, oxide,

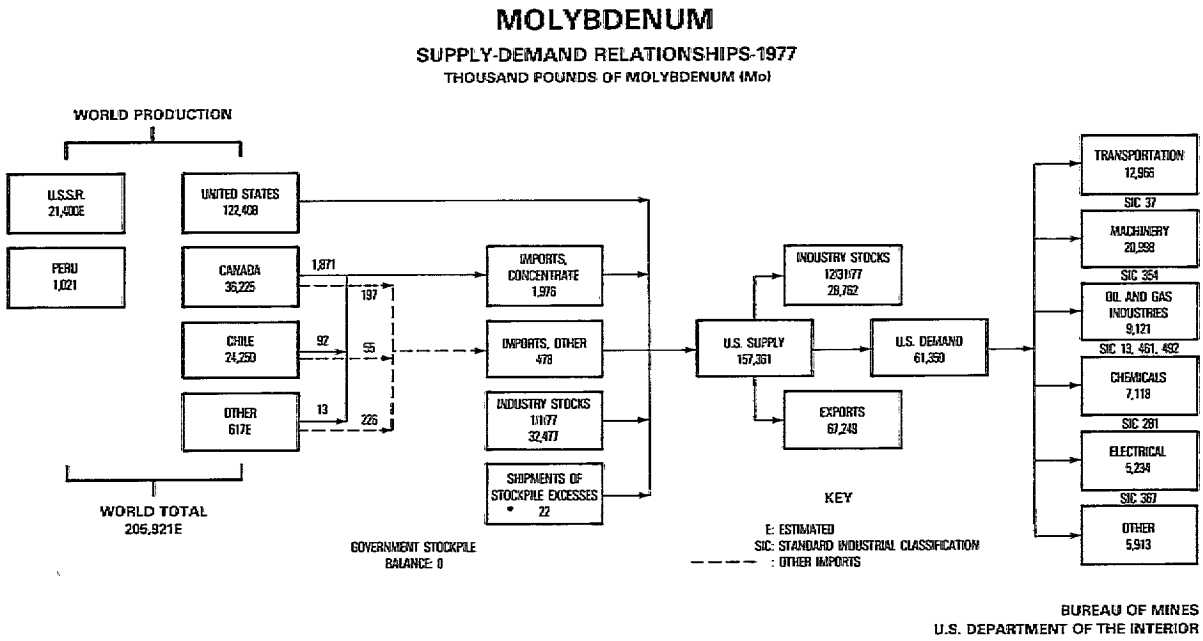

Figure 2.—Supply–demand relationships for molybdenum, 1977.

and ferromolybdenum were shipped from stockpile excesses from 1963 through 1977. In 1974, stockpile shipments totaled 35.1 million pounds of molybdenum and provided an appreciable portion of the U.S. supply during a year of high demand.

Although the United States is self-sufficient in molybdenum, imports provide part of the total domestic supply. The quantity imported was minor previous to 1975, but since that year has averaged about 2.6 million pounds of molybdenum, or about 4 percent of U.S. demand from 1975 to 1978. Nearly 80 percent of imports of the last 3 years have been as concentrate from a Canadian producer. Numerous countries supply small amounts of other imported material in various metallic or chemical forms.

Industry stocks of molybdenum materials constitute a significant component of U.S. supply. During the last 6 years, domestic inventories decreased markedly from 79 million pounds at yearend 1972 to 25.9 million pounds at yearend at 1978. The downward trend in stocks reflects the strong worldwide demand of recent years and underscores the tenuous supply-demand balance that currently prevails. At the close of 1978, domestic molybdenum inventories were divided among industry segments as follows in million pounds: Concentrate at mines and plants, 8.6; molybdenum materials at conversion plants, 8.0; molybdenum materials at consumer establishments, 9.3. These quantities represented a 1- to 2-month supply based on average monthly consumption.

U.S. and World Consumption

U.S. industrial demand for molybdenum increased from 29 million pounds in 1950 to 36.8, 49.2, and 61.4 million pounds in 1960, 1970, and 1977, respectively. Based on linear regression analysis, domestic demand increased at an average rate of 3 percent per year from 1960 to 1977. Demand growth has not been steady, however. For example, domestic demand reached peak levels in 1973 and 1974, each year exceeding 70 million pounds. Most recently, demand has grown at an annual rate of 5.4 percent from 1975 to 1977.

World consumption is difficult to ascertain because of the lack of information on changes in inventory levels outside of the United States. However, assuming that foreign inventories of molybdenum remain stable over a relatively long period, annual world consumption and demand growth rates can be estimated. Based on this assumption, apparent consumption of molybdenum in market economy countries increased from about 74 million pounds in 1960 to 156 million pounds in 1970 and to 188 million pounds in 1977. Demand was calculated to increase at a 6.9-percent annual rate from 1960

Table 5.—Molybdenum supply-demand relationships, 1969–78

(Thousand pounds)

	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978[p]
World mine production:										
United States	99,807	111,352	109,592	112,138	115,859	112,011	105,980	113,233	122,408	132,482
Rest of the world	59,663	66,777	57,862	62,675	64,229	73,557	70,733	78,054	83,523	83,000
Total	159,470	178,129	167,454	174,813	180,088	185,568	176,713	191,287	205,931	215,482
Components of U.S. supply:										
Domestic mine production	99,807	111,352	109,592	112,133	115,859	112,011	105,980	113,233	122,408	132,482
Shipments of Government stockpile excesses	2,832	4,756	319	81	5,752	35,142	4,344	1,594	22	----
Imports	25	48	985	411	1,156	534	2,776	2,235	2,454	3,129
Industry stocks, Jan. 1	37,879	31,716	41,325	64,135	79,037	52,511	46,852	40,364	32,477	28,762
Total U.S. supply	140,543	147,872	152,220	176,765	201,804	200,198	159,952	157,426	157,361	164,373
Distribution of U.S. supply:										
Industry stocks, Dec. 31	31,716	41,325	64,135	79,037	52,511	46,852	40,364	32,477	28,762	25,866
Exports	58,553	57,381	47,278	46,130	75,844	81,734	64,286	65,000	67,249	70,030
Industrial demand	50,274	49,166	40,807	51,598	73,449	71,612	55,302	59,949	61,350	68,477
U.S. demand pattern:										
Transportation	10,445	9,844	8,488	10,466	15,591	14,708	11,610	13,140	12,966	14,472
Machinery	17,901	17,582	13,961	17,751	25,876	25,866	20,181	21,024	20,998	23,437
Oil and gas industries	7,937	7,665	6,053	7,544	11,041	11,090	8,838	8,935	9,121	10,181
Chemicals	4,028	4,381	4,489	6,307	7,403	6,418	4,781	5,927	7,118	7,945
Electrical	4,511	4,400	3,533	4,438	6,482	6,384	4,931	5,256	5,234	5,842
Other	5,452	5,294	4,283	5,092	7,056	7,146	4,961	5,667	5,913	6,600
Total U.S. demand	50,274	49,166	40,807	51,598	73,449	71,612	55,302	59,949	61,350	68,477

[p] Preliminary.

to 1977. The actual growth rate is slightly lower because some molybdenum has been exported from market economy countries to centrally planned economy countries.

Total world consumption (including the U.S.S.R. and other centrally planned economy countries) in 1977 was estimated at 216 million pounds of molybdenum, or about 5 percent greater than the world output of 206 million pounds. World demand exceeded output each year from 1973 to 1977.

World Trade

The United States is the major exporter of molybdenum to other industrialized countries of the world. For the period 1973–78, total exports averaged nearly 71 million pounds of molybdenum and exceeded domestic demand each year. In 1978, exports amounted to about 53 percent of the domestic mine output. An estimated 58 percent of molybdenum consumption in other market economy countries of the world was supplied by exports from the United States from 1973 to 1978.

About 97 percent of U.S. exports of molybdenum are in the form of concentrate or technical-grade oxide. The principal destinations are the Netherlands, Japan, Belgium-Luxembourg, the Federal Republic of Germany, Sweden, and the United Kingdom. Exports directly to the U.S.S.R. began in 1977. A substantial portion of the exported concentrate went to the Netherlands for conversion into technical grade oxide and reshipment largely to other European countries.

Other materials exported include ferromolybdenum, molybdenum wire and powder, and other metallic forms and scrap. Japan and Western European countries are the principal recipients of these materials.

Canada and Chile are the only other producing countries that are major exporters of molybdenum. Canada exports about 85 to 90 percent of its mine output, mostly as concentrate or oxide, to Japan and Western European countries. Chile exports almost all of its mine output as concentrate, oxide, or ferromolybdenum, also primarily to Japan and Western European countries. Among other countries, international trade is primarily in products such as technical-grade oxide, ferromolybdenum, and molybdenum metal and chemicals.

Secondary Sources or Recycling

Some secondary molybdenum is recovered in the production of alloy steels, superalloys, and metal, but data on quantities are incomplete and inconclusive. Most of this recycled material is generated and reused directly at metal-forming or fabricating plants (runaround scrap) or shipped to plants that reclaim it (prompt industrial scrap). Very little molybdenum-containing obsolete scrap is processed for its molybdenum content. Although some molybdenum is recycled as a minor constituent of scrap alloy steels, the use of such scrap does not generally depend on its molybdenum content. An increasing but indeterminate quantity of molybdenum is being reclaimed from spent catalysts and chemical residues.

Substitutes

Historically, molybdenum has been a relatively inexpensive alloying agent used primarily in specialty steels and alloys and, in the United States, it has been readily available. As a result, metallurgical applications for molybdenum were broadened, and its utility as an alloy ingredient became well recognized. The substitution for molybdenum by other alloy metals had little impetus. Recently however, the potential for substitution has received attention owing to the substantial rise in price of molybdenum raw materials since 1974.

Several factors mitigate the possible replacement of molybdenum to the degree that its overall demand would be significantly affected. First, there is no acceptable substitute in numerous metallurgical and chemical uses. Second, it is commonly added to steels and alloys to enhance several desired properties (such as hardenability, strength, corrosion resistance, etc.), often in synergistic effect with other alloy metals. In such cases, molybdenum could be replaced for particular effects, but at a sacrifice in overall performance. Moreover, the molybdenum content of alloy and specialty steels ranges from less than 1 to a few percent. Therefore, costs of molybdenum raw materials have to increase substantially to appreciably affect the cost of the finished product, thereby stimulating substitution. Finally, the United States is self-sufficient in molybdenum, a situation that does not prevail for other ferrous metals. Significant replacement would entail increases in the imports of substituted metals.

Nevertheless, possible alternatives exist in most applications of molybdenum. Steels and alloys containing less or no molybdenum might be used in place of those with higher molybdenum content. In most cases, such substitution would result in lowered or unacceptable performance. Boron, chromium, and manganese can replace molybdenum in steels where hardenability is the only desired effect. In certain low-alloy steels, columbium, manganese, and vanadium act in similar fashion to molybdenum. Chromium, nickel, and tungsten are possible substitutes in steels and other alloys. Molybdenum has substantially replaced tungsten in commonly used high-speed tool steels; a return to tungsten grades is possible, but with a reduction in economy and performance. Nonmetallurgical materials, such as plastics and ceramics, can replace steels and alloys containing molybdenum in certain applications.

Tungsten and tantalum can be substituted for molybdenum in certain refractory metal uses, but at a cost disadvantage. Molybdenum can be replaced by graphite for refractory elements in electric furnaces in the range of 1,000° to 1,600° C, but at the expense of slightly greater difficulty in operation and control. Chrome orange, cadmium red, and organic orange pigments are possible substitutes for molybdenum orange. Acceptable substitutes for molybdenum are not found in most of its major catalytic applications. Graphite and other solid lubricants generally do not perform as well as molybdenum disulfide, especially under high-pressure and high-temperature conditions.

Table 6.—Domestic molybdenum byproduct and coproduct relationship in 1977

Source	Product	Unit	Quantity	Percent of total output
Molybdenum	Tin	Long ton	W	W
Do	Tungsten	1,000 pounds	2,253	37.5
Do	Pyrite	do	W	--
Do	Rhenium	do	--	--
Do	Molybdenum	do	82,870	67.7
Copper	do	do	39,186	32.0
Tungsten	do	do	W	W
Uranium	do	do	W	W

W Withheld to avoid disclosing individual company data.

BYPRODUCTS AND COPRODUCTS

Tin, tungsten, and a very minor quantity of pyrite are recovered as byproducts from the molybdenum ore at the Climax deposit. Rhenium is extracted from flue gases and dust produced during the roasting of molybdenite concentrate. Although rhenium was not produced from domestic ores in 1977, its recovery was resumed in 1978.

Molybdenum is recovered as a byproduct primarily from copper ores. A very small amount is also obtained from tungsten and uranium ores. At the Sierrita mine of the Duval Corp., copper and molybdenum are considered coproduct values.

The relative quantities of molybdenum recovered from molybdenum and other ores and of the byproducts recovered from molybdenum ores in the United States in 1977 are shown in table 6.

STRATEGIC CONSIDERATIONS

Molybdenum is a strategic element used in steels and alloys that have important applications in the manufacturing and production of military armament. As with other ferrous metals, demand has increased during times of war. In the past, molybdenum materials have been maintained in the U.S. Government stockpile administered by the General Services Admin-

Table 7.—Time-price relationship for molybdenum in concentrate,[1] 1954–77

Year	Average annual price, dollars per pound: Actual price	Based on constant 1977 dollars
1954	1.05	2.49
1955	1.10	2.55
1956	1.18	2.66
1957	1.18	2.57
1958	1.25	2.68
1959	1.25	2.62
1960	1.25	2.58
1961	1.40	2.86
1962	1.40	2.81
1963	1.40	2.77
1964	1.55	3.02
1965	1.55	2.95
1966	1.55	2.86
1967	1.62	2.90
1968	1.62	2.78
1969	1.72	2.81
1970	1.72	2.67
1971	1.72	2.54
1972	1.72	2.44
1973	1.72	2.30
1974	2.02	2.47
1975	2.48	2.76
1976	2.94	3.11
1977	3.68	3.68
1978[p]	4.52	4.21

[p] Preliminary.
[1] Prices are weighted averages for each year. Price changes in 1977 and 1978: Aug. 1, 1977, $4.01; March 7, 1978, $4.41; Sept. 1, 1978, $4.95; Dec. 29, 1978, $5.19 (calculated based on 4.75-percent increase from previous price).

istration (GSA). However, since 1963, these materials have been sold from the stockpile because domestic reserves and production capacity were considered adequate to supply national emergency needs. By yearend 1977, no molybdenum remained in the stockpile. Revised stockpile goals announced in October 1976 and reaffirmed in 1977 by the Federal Preparedness Agency (FPA) of GSA did not include molybdenum materials.

Although adequate to supply potential increased needs in wartime, capacity is concentrated in relatively few mines and conversion plants. Interruption of normal operations at the major mines and plants due to accidents or labor problems would significantly reduce availability.

ECONOMIC FACTORS AND PROBLEMS

Pricing

Table 7 shows the time-price relationship since 1954 for molybdenum contained in concentrate in actual dollars and based on constant 1977 dollars. Actual prices are based on the published price of the major producer, Climax Molybdenum Co. Historically, prices quoted by the other large producers have not varied appreciably from the Climax price, although byproduct producers generally have listed their concentrate at prices slightly lower than that of Climax. The lower price was due to either lower molybdenite grade or higher impurity content than that of Climax concentrate. However, in response to strong worldwide demand during 1978, other producers began to list prices for concentrate and other products higher than the Climax price quotes. In addition, U.S. producers initiated a two-tiered price system in which prices for exported materials were set higher than for domestic sales.

The prices of other molybdenum products are also quoted on a contained-molybdenum basis and reflect, at least partially, the cost of conversion. Technical-grade oxide, the major form of molybdenum sold commercially, varies in price among the major producers depending on purity, type of packaging, and whether it is briquetted. Over the last 5 years, producer oxide prices have ranged from 7 to 12 percent over the concentrate price.

As of January 1979, Climax Molybdenum Co. listed oxide, in cans, at $5.55 and ferromolybdenum at $6.38 (both per pound of contained molybdenum) for domestic sales. A domestic price for concentrate was no longer listed, but an approximate price of $5.19 was calculated based on the percent increase in domestic prices on other materials for the last price change in December 1978. Climax's export prices were as follows: Concentrate, $5.86; oxide, $6.56; and ferromolybdenum, $7.71. Other major U.S. producers listed prices for oxide and ferromolybdenum above the Climax price quotes.

Although the bulk of producer sales are made at listed prices, it has been reported that during periods of oversupply in past years some discounting prevailed, particularly for byproduct concentrate and oxide. In contrast is the current situation of somewhat restricted supplies and byproduct oxide prices that exceed the Climax list price. The strength of the 1978 market was also attested to by dealer prices for oxide, which have been listed as considerable premiums over producer prices since 1976. Materials supplied by dealers represent, however, a relatively small fraction of total domestic consumption.

Prior to 1974, producer prices for molybdenite concentrate and other products were characterized by marked stability. Particularly noteworthy was the 5-year interval from 1969 to 1973 during which listed prices remained unchanged. The 1973 average price for molybdenum in concentrate, when adjusted for inflation, was lower than it had been for the previous 20 years. During this period, the applications and demand for molybdenum were considerably expanded.

The presently prevailing market of generally tight supply-demand balance and rising prices began in 1974. Since early 1974, the price per

Table 8.—U.S. import duties

TSUS No.	Material	Rate of duty, Jan. 1, 1979[1]
601.33	Molybdenum ore	12 cents per pound on molybdenum content.
603.40	Material in chief value molybdenum	10 cents per pound on molybdenum content plus 3% ad valorem.
607.40	Ferromolybdenum	Do.
	Molybdenum:	
628.70	Waste and scrap	10.5% ad valorem.[2]
628.72	Unwrought	10 cents per pound on molybdenum content plus 3% ad valorem.
628.74	Wrought	12.5% ad valorem.
	Molybdenum chemicals:	
417.28	Ammonium molybdate	10 cents per pound on molybdenum content plus 3% ad valorem.
418.26	Calcium molybdate	Do.
419.60	Molybdenum compounds	Do.
420.22	Potassium molybdate	Do.
421.10	Sodium molybdate	Do.
423.88	Mixtures of inorganic compounds, chief value molybdenum	Do.
473.18	Molybdenum orange	5% ad valorem.

[1] Not applicable to countries that have centrally controlled economies.
[2] Duty on waste and scrap temporarily suspended.

pound of molybdenum in concentrate has more than tripled from $1.72 to $5.19 as of January 1979. During the same period, technical grade oxide increased from $1.92 to $5.55 per pound of contained molybdenum. Twelve price increases have occurred since early 1974; in each instance prices on molybdenum products were raised from 5 to 16 percent over their previous level. Higher operating costs, the need to recover the cost of expanding production capacity, and the tight supply-demand balance have been cited as factors in the recent price escalations. If supply-demand relationships do not change appreciably, further price increases are expected, but at what frequency or level is uncertain.

Taxes and Tariffs

No special taxes are imposed on the domestic molybdenum industry. Producers are granted a depletion allowance of 22 percent on domestic and 14 percent on foreign production. Tariff rates for molybdenum materials are shown in table 8.

OPERATING FACTORS AND PROBLEMS

The mining and milling of both primary molybdenum ore and copper ore containing molybdenum are high-tonnage operations. The largest domestic molybdenum mine has an ore-processing capacity of about 48,000 tons per day; processing capacity at the largest copper-molybdenum surface mine exceeds 100,000 tons per day of ore. Ore grade is low; therefore, open pit and underground block caving methods are required to extract the ore profitably.

The costs involved in producing molybdenite concentrate vary according to mining methods used (underground or surface), the physical characteristics of the ore body, and the difficulty in beneficiation of the ore. In mining, the principal nonlabor operating expenses involve consumption of explosives, utilization of fuel and electricity for operating equipment, and replacement parts for servicing of equipment. Costs of ore beneficiation are dependent on the use of grinding materials, flotation reagents, electricity to operate milling and concentrating equipment, and general plant maintenance. Operating variables are monitored, and adjustments are made when necessary to maximize efficiency and economy of operation.

The mining of primary molybdenum ore and disposal of ore tailings disturb land areas. In the future, land reclamation will probably become increasingly necessary as mines become inactive. The problem is relatively localized because few primary mines are expected to be in operation. Copper mining that yields byproduct molybdenum entails the disturbance of significantly larger land areas. Development of new mine-mill complexes presents local socioeconomic and land-use problems. Since new potentially economic sources are likely to be found in relatively unpopulated regions with little other industry, development of a major mine can have significant impact on established occupational patterns. Interaction between mining firms and local and State agencies is expected to increase to assure that mine development proceeds in as orderly and environmentally sound a manner as possible.

The conversion of molybdenite concentrate to technical-grade molybdic oxide involves roasting, which releases sulfur oxides into the atmosphere. Producing firms have modified roasting facilities or installed sulfuric acid recovery equipment to reduce emissions and thereby comply with more stringent pollution control restrictions. Because the molybdenum-processing industry is relatively small, raw materials and energy needs generally are not critical concerns.

Although some concentrate is converted in

Table 9.—Summary of forecasts of U.S. and rest-of-world molybdenum demand, 1977–2000

(Thousand pounds)

	1977	2000 Forecast range		Probable		Probable average annual growth rate, 1977–2000[1] (percent)
		Low	High	1985	2000	
United States:						
Total	61,350	150,000	200,000	93,000	170,000	4.5
Cumulative	----	2,300,000	2,800,000	620,000	2,500,000	
Rest of the world:						
Total	[2]155,000	400,000	520,000	243,000	460,000	4.8
Cumulative	----	6,100,000	7,100,000	1,600,000	6,600,000	
World:						
Total	[2]216,350	550,000	720,000	336,000	630,000	4.8
Cumulative	----	8,400,000	9,900,000	2,200,000	9,100,000	

[1] Calculated from demand in 1977.
[2] Estimated.

Western States, most is shipped by rail from mines in the West to conversion plants in the East and Midwest. Some is also shipped to the gulf and west coasts for export. Transportation costs are reflected in the price of molybdenum products, but the high unit value of the products makes shipping costs relatively insignificant when compared with the total value of the product.

An estimated 4,500 people were employed in 1978 in the mining and milling of primary molybdenum ore in the United States. Several hundred are also employed at domestic conversion plants. A number of additional employees associated with the molybdenum industry are engaged in exploration and resource evaluation, basic research, product control and development, and marketing activities.

Compared to other industrial metals, molybdenum exhibits low or negligible toxicity. No significant toxic effects in human beings have been identified in the mining and processing of molybdenum materials (*3*). As an environmental trace element, molybdenum is an essential micronutrient and has been shown to be related to copper metabolism in certain animal species. Deficiencies or excesses of molybdenum can affect the normal growth and development of numerous plant and animal species (*9*).

OUTLOOK

Demand

Domestic demand for molybdenum in 2000 is forecast to range between 150 and 200 million pounds, corresponding to average growth rates of 4.0 and 5.3 percent annually and based on the demand of 61.4 million pounds in 1977. Within this range, the probable level of demand in 2000 is forecast at 170 million pounds, corresponding to an annual growth rate of 4.5 percent for the period 1977–2000. Cumulative domestic demand to 2000 is forecast to range from 2.3 to 2.8 billion pounds; probable cumulative demand is 2.5 billion pounds. Domestic demand is expected to reach 93 million pounds in 1985. These forecasts are shown in table 9.

Demand for molybdenum in the rest of the world is forecast to range from 400 to 520 million pounds in 2000, corresponding to average annual growth rates of 4.2 and 5.4 percent from the 1977 demand level. The probable level of demand for the rest of the world is forecast at 460 million pounds, giving an annual growth rate of 4.8 percent. Cumulative requirements for the period 1977–2000 were calculated to range from 6.1 to 7.1 billion pounds. Rest-of-world demand should grow at a slightly higher rate than that for the United States because the increase in production of molybdenum-containing steels and alloys is expected to be more pronounced in foreign industrialized and developing nations. Table 9 shows the forecasts for rest-of-world and total world demand in 1985 and 2000.

The forecasts for domestic demand were partially based on time series data of the estimated demand for molybdenum in major end-use industrial classifications for the period 1965 to 1977. Regression analysis was applied to each end use to determine which economic indicator (such as gross private domestic investment or the Federal Reserve Board index of iron and steel production) best correlated with the historical end-use data. Projections of the appropriate economic indicator were then used to derive statistical projections for demand by end use in 2000; the projections are shown in table 10. Except for the "chemicals" end-use sector, correlations with economic indicators were poor. In addition, the projections of demand were judged to inadequately reflect the expectation of growing molybdenum consumption in the "transportation" and "oil and gas industries" sectors.

Using the statistical projections as a base, a

Table 10.—Projections and forecasts for U.S. molybdenum demand by end use, 1977 and 2000

(Thousand pounds)

End use	1977	2000			
			Contingency forecasts for the United States		
			Forecast range		
		Statistical projections[1]	Low	High	Probable
Transportation	12,966	28,491*	42,000	53,000	46,000
Machinery	20,998	48,927*	38,000	49,000	42,000
Oil and gas industries	9,121	20,329*	29,000	41,000	34,000
Chemicals	7,118	23,850	21,000	28,000	24,000
Electrical	5,234	12,157*	10,000	14,000	12,000
Other	5,913	11,319*	10,000	15,000	12,000
Total	61,350		150,000	200,000	170,000

[1] Statistical projections are derived from regression analysis based on historical time series data, and forecasts of economic indicators such as gross national product, Federal Reserve Board index, etc. Projection equations with a coefficient of determination (R-squared) less than 0.70 are indicated by an asterisk (*).

contingency analysis was then undertaken to evaluate the economic, technological, and other factors that might influence molybdenum consumption in the future within the end-use sectors. In applying this analysis, forecasts were made for the low, high, and probable level of demand for molybdenum in the various end-use sectors. The forecasts were based on qualitative information concerning recent and anticipated trends in molybdenum demand, modified by the specialist's judgment. The summary of these contingency forecasts, also shown in table 10, determined the forecast range and probable total demand for molybdenum in the United States in 2000.

The underlying presumption in establishing the forecasts was the expectation that demand will experience considerable growth primarily because of the increasing applications for molybdenum as an alloying element in steels, cast irons, superalloys, and other alloys. Since about 70 percent of molybdenum consumption is in full alloy, stainless, and other steels, molybdenum demand should broadly follow the demand for these specialty steels. Moreover, the strong demand for molybdenum in recent years has been stimulated by increased utilization of those grades of alloy steels containing molybdenum, and the outlook is for growing usage of these specific grades. It was also expected that demand for molybdenum in catalyst, lubricant, pigment, and other nonmetallurgical applications will exhibit appreciable growth. A brief discussion of the contingency analyses for the forecasted demand in each end-use category follows.

Transportation.—The probable forecast of 46 million pounds for molybdenum demand in transportation in 2000 was based on the expectation of significant growth in the use of molybdenum-containing steels and high-temperature alloys for the manufacture of automobiles, railroad equipment, aircraft, and aerospace systems. The high of the forecast range, 53 million pounds, reflects the possibility of greater-than-anticipated applications of molybdenum to produce materials of higher strength and lower weight necessary for the increased efficiency of transportation systems. Factors that could reduce demand to 42 million pounds, the low of the forecast range, include the continuing trend to smaller size automobiles, a general decline in travel by the population due to higher costs brought on by increased fuel costs, and the possible replacement of molybdenum by other elements in certain alloys.

Machinery.—The probable forecast of 42 million pounds for demand in 2000 for this end use reflects anticipated growth in molybdenum use in stainless and alloy steels and irons for industrial machinery and in high-speed, hot work, and other tool steels. Included in this sector is equipment used for mining, construction, food and chemical processing, and numerous other industrial processes, all of which should contribute to growth in usage of molybdenum-bearing steels and alloys of high strength and wear and corrosion resistance. Growth in population and demand for consumer goods would effect the overall demand for industrial machinery. Changes in machining techniques, such as the trend toward higher speeds that make carbide inserts preferable to molybdenum tool steels, and the possible substitution of tungsten in tool steels could reduce molybdenum demand in this sector. With these contingencies in mind, the high and low of the forecast range were set at 49 and 38 million pounds of molybdenum, respectively.

Oil and Gas Industries.—Probable requirement of molybdenum in this sector was forecast at 34 million pounds in 2000. Demand should grow for molybdenum in alloy and stainless steel tubular products employed in oil and gas drilling, refining, and processing equipment. Use of molybdenum in low-alloy steels for oil and gas pipelines is also expected to experience consid-

erable growth. Increased activity in oil and gas production and refining and the possibility of molybdenum use in the construction of coal gasification and liquefaction plants could combine to produce the high of the forecast range, 41 million pounds of molybdenum. On the other hand, a lesser growth in petroleum production and utilization owing to declining rates of discovery could limit molybdenum demand to 29 million pounds in 2000.

Chemicals.—The probable forecast of 24 million pounds of molybdenum demand in 2000 in the chemicals sector is equal to the calculated statistical projection, which was derived from the good historical correlation between molybdenum use in chemicals and gross private domestic investment. The growth in demand should be primarily in catalyst, pigment, and corrosion-inhibiting applications. Should greater need for molybdenum catalysts in petroleum refining occur, or the possible use of molybdenum in catalysts for coal gasification and liquefaction materialize, then demand may reach 28 million pounds. Diminished production and refining of petroleum by 2000 could result in lower requirements for catalysts and leads to the forecast of 21 million pounds as the low of the forecast range.

Electrical.—The anticipated growth in use of molybdenum alloys and metals in electrical generation and transmission equipment established the probable forecast of 12 million pounds for demand in 2000. Higher requirements for electrical power and the possibility of molybdenum utilization in the production of nuclear and solar power equipment could increase demand to 14 million pounds. The possibility of substitution for molybdenum in certain electrical and electronic components and lower than expected demand for electricity are contingencies that could diminish demand in this sector to about 10 million pounds.

Other.—Requirements for this end-use sector were forecast to range from 10 to 15 million pounds of molybdenum in 2000. Most of the increase in demand should be accounted for by expanded use of molybdenum in lubricating applications, although other diversified uses, such as in welding and hardfacing equipment, magnetic alloys, fertilizer, and consumer products, should experience growth in molybdenum utilization. The probable forecast, 12 million pounds, was set near the median of the forecast range.

Table 11.—Comparison of domestic molybdenum production and demand, 1954–78, 1985, and 2000

(Thousand pounds)

Year	Demand	Production	
1954	26,443	58,668	
1955	34,987	61,781	
1956	37,450	57,462	
1957	29,053	60,753	
1958	25,347	41,069	
1959	33,760	50,956	
1960	36,758	68,237	
1961	34,179	66,563	
1962	36,162	51,244	
1963	42,455	65,011	
1964	46,377	65,605	
1965	54,460	77,372	
1966	61,870	90,532	
1967	54,848	90,097	
1968	56,199	93,447	
1969	50,274	99,807	
1970	49,166	111,352	
1971	40,807	109,592	
1972	51,598	112,138	
1973	73,449	115,859	
1974	71,612	112,011	
1975	55,302	105,980	
1976	59,949	113,233	
1977	61,350	122,408	
1978[p]	68,477	132,482	
1985	[1] 93,000	[2] 160,000	[e] 200,000
2000	[1] 170,000	[2] 220,000	[e] 350,000

[e] Estimate. [p] Preliminary.
[1] Probable forecast from table 9.
[2] 20-year trend.

Supply

Domestic molybdenum demand and production for the period 1954–77 and forecasts for 1985 and 2000 are shown in table 11. The statistical projection of the 20-year trend (1958–77) in domestic output extrapolates to production forecasts of 160 and 220 million pounds in 1985 and 2000, respectively. The extrapolations, however, do not take into account sources that are currently under development or that have a reasonable probability of development in the future. Potentially significant deposits are currently being evaluated and exploration can be expected to lead to additional discoveries that may be producing mines by 2000. If worldwide demand increases at the projected rates, the need for new output is certain and should provide the stimulus for increased exploration and development. With these considerations in mind, domestic output is forecast to reach 200 million pounds in 1985 and 350 million pounds by 2000.

Producing mines and committed capacity increases in sources under development should provide 150 to 160 million pounds of U.S. output by the early 1980's. One or two additional primary mines and/or increased output as a byproduct of copper mining could bring production up to the estimate of 200 million pounds per year by 1985. An additional 150 million pounds of annual output would be required between 1985 and 2000 in order to reach 350 million pounds by 2000. One-third of this ad-

ditional output could be provided by copper mining, assuming projected increases in domestic copper output and improved recovery of byproduct molybdenum. The remainder would be provided by new primary mines with combined annual output roughly equivalent to 100 million pounds.

For the years 1967–77, the ratio of domestic mine output to industrial demand ranged from 2.7:1 to 1.6:1. A ratio approximating 2:1 should prevail at least through the 1980's, given the estimated increases in U.S. mine production and the forecasts of domestic demand. Consequently, the United States should continue as the major supplier of molybdenum to the rest of the world.

Rest-of-world output of molybdenum is also expected to increase and add to total world supplies. However, it is difficult to estimate future levels of foreign production because most of the possible sources now being evaluated are copper deposits from which byproduct molybdenum may be recovered. Development of these deposits would depend primarily on expectations of demand and profitability in the copper market. Nonetheless, the need for increased production is pronounced. Subtraction of the forecasted U.S. output from the forecasts of probable total world demand gives the approximate requirements for rest-of-world annual output—136 million pounds by 1985 and 280 million pounds by 2000. Compared with an estimated rest-of-world output of 84 million pounds in 1977, the additional productive capacity that would be required by 2000 appears prodigious. Even assuming lower growth rates in world demand (3 or 4 percent annually rather than the forecast 4.8 percent), significant new production will be required.

Possible Supply-Demand Changes.

The currently prevailing world supply and demand patterns are expected to continue at least into the mid 1980's and probably for the remainder of this century. The United States should continue as the world's leading producer and exporter of molybdenum, and domestic output will be more than adequate to supply domestic requirements. Canada, Chile, and the U.S.S.R. should continue as the other major producing nations unless large primary deposits are discovered and brought into production elsewhere. Output of byproduct molybdenum from copper mining is foreseen in other countries, but these sources probably will not add significantly to future supplies. As at present, about 55 to 60 percent of the world output should be obtained from primary deposits. Although developing nations will account for a greater share of demand in the future, the bulk of demand will still be divided among the highly industrialized nations.

The essential problem concerning the molybdenum market is whether annual production capacity can be increased to meet the anticipated growth in demand. Although known reserves exceed cumulative demand to the year 2000, both for the United States and the world, the bulk of these reserves are contained in a relatively few large deposits that are mined at rates which probably will not be increased appreciably in the future. To parallel the forecasted increases in demand, annual world output would have to increase by about 130 million pounds from 1977 to 1985, and by 425 million pounds in the interval 1977–2000. Committed capacity increases announced to date amount to only an additional 60 to 70 million pounds of annual output over the 1977 production level. These capacity increases should keep supplies in approximate balance with demand into the early 1980's.

In the longer term, the middle 1980's and beyond, a shortfall in world molybdenum supply could occur without additional mine output. The additional output would come primarily from the discovery and development of new reserves, rather than increased production from existing reserves. Several promising deposits are currently being evaluated in the United States and elsewhere; these could add materially to world supply by the middle or late 1980's. Exploration is likely to reveal other undiscovered sources, some of which should prove to be economically minable.

Possible Technological Progress

Advances in ore beneficiation and the development of new end-use applications are expected to have the greatest impact on the future supply and demand of molybdenum. Ongoing efforts to improve the efficiency of flotation techniques should result in increased recoveries of molybdenum, particularly for that obtained as a byproduct of copper mining. More efficient beneficiation methods would increase the quantity of recoverable ore reserves and possibly convert some low-grade byproduct resources to reserves.

The application of new geochemical and geophysical exploration techniques could increase the probability of finding additional molybdenum deposits. It is not considered likely that types of occurrences other than molybdenum or

copper-molybdenum stockwork and porphyry deposits will contribute significantly to supplies, at least for the remainder of this century. Molybdenum is known to occur as a minor element in seabed nodules, but the economical recovery of molybdenum from these nodules is speculative.

As has been noted previously, the development and application of new molybdenum-containing steels and alloys is anticipated to increase the demand for molybdenum considerably. Use of molybdenum metal or molybdenum-based alloys would be stimulated if a coating, alloying, or surface-diffusion technique were developed that improves molybdenum's resistance to oxidation at high temperatures. Nonmetallurgical applications for molybdenum compounds are expected to be broadened because of their desirable properties and relatively low toxicity. As overall demand grows and the economics prove justified, recycling of molybdenum in both metallurgical and chemical forms will probably be increased.

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Molybdenum. Ch. in Minerals Yearbook, annual.
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Metals Week.
Mining Congress Journal.
Mining Engineering.
Mining Journal (London).
Skillings' Mining Review.
The Northern Miner (Canada).
World Mining.

Current Bureau of Mines Publications

Single copies of the following can be obtained free from the Branch of Publications Distribution, Bureau of Mines, 4800 Forbes Avenue, Pittsburgh, PA 15213:

"Mineral Commodity Summaries"

"Status of the Mineral Industries"

"Mineral Commodity Profiles" (a series presenting timely data on selected mineral raw materials).

"Chromium," May 1977
"Copper," June 1977
"Nickel," July 1977
"Cobalt," July 1977
"Asbestos," September 1977
"Manganese," October 1977
"Vanadium," December 1977
"Lead," December 1977
"Columbium," January 1978
"Potash," February 1978
"Zinc," May 1978
"Iron Ore," May 1978
"Aluminum," May 1978
"Iron and Steel," July 1978
"Tin," July 1978
"Stone," July 1978
"Titanium," August 1978
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"Fluorine," August 1978
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"Platinum Group Metals," September 1978
"Sand and Gravel," September 1978
"Silver," September 1978
"Gold," October 1978
"Cement," November 1978
"Phosphate," January 1979
"Silicon," February 1979
"Barite," February 1979
"Cesium," May 1979
"Rare-earth Elements and Yttrium," May 1979
"Molybdenum," May 1979

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

Work file Molybdenum

1982

TABLE 40

HISTORICAL RECORD OF WORLD MOLYBDENUM PRODUCTION

(in metric tons of molybdenum content)

YEAR	PARTIAL	CUMULATIVE	YEAR	PARTIAL	CUMULATIVE
1778-1900	200	200			
1901	22	222	1941	20,719	125,603
1902	46	268	1942	24,832	155,435
1903	148	416	1943	32,236	187,671
1904	48	464	1944	22,037	209,708
1905	62	526	1945	16,773	226,481
1906	86	611	1946	10,703	237,184
1907	58	669	1947	13,948	251,132
1908	117	786	1948	13,460	264,592
1909	77	863	1949	11,805	276,397
1910	85	948	1950	15,241	291,638
1911	63	1,011	1951	22,060	313,698
1912	180	1,191	1952	24,585	338,283
1913	91	1,282	1953	30,968	369,251
1914	132	1,414	1954	30,994	400,245
1915	223	1,637	1955	32,540	432,785
1916	416	2,053	1956	30,675	463,460
1917	499	2,552	1957	32,242	495,702
1918	728	3,280	1958	22,630	518,332
1919	280	3,560	1959	28,660	546,992
1920	194	3,754	1960	36,899	583,891
1921	31	3,785	1961	36,319	620,210
1922	33	3,818	1962	30,469	650,679
1923	96	3,914	1963	38,444	689,123
1924	250	4,164	1964	40,046	729,169
1925	644	4,808	1965	46,871	776,040
1926	776	5,584	1966	59,878	835,918
1927	1,065	6,649	1967	62,699	898,617
1928	1,670	8,319	1968	63,135	961,752
1929	1,959	10,278	1969	70,245	1,031,997
1930	1,831	12,109	1970	80,727	1,112,724
1931	1,571	13,680	1971	79,328	1,192,052
1932	1,344	15,024	1972	76,131	1,268,183
1933	3,160	18,184	1973	77,616	1,345,799
1934	5,193	23,377	1974	81,668	1,427,467
1935	6,733	30,110	1975	81,864	1,509,331
1936	10,002	40,112	1976	87,243	1,596,574
1937	14,854	54,966	1977	93,044	1,689,518
1938	16,868	71,834	1978	100,066	1,789,684
1939	15,672	87,506	1979	103,456	1,893,140
1940	17,378	104,884	1980	114,746	2,007,886

TABLE 48

MOLYBDENUM MINE PRODUCTION CAPACITIES OF OTHER COUNTRIES

(in metric tons)

MINE	LOCATION	OWNERSHIP	ORE CONTENT % Cu	ORE CONTENT % Mo	PRODUCTION 10^6 tpy ore	PRODUCTION tpy copper	PRODUCTION tpy molybdenum
Peru							
Toquepala	Tacna	Southern Peru	1.0	0.02	14	120,000	1,700
Cuajone	Moquegua	Southern Peru	1.2	0.02	16	170,000	1,300
Philippines							
Sipalay	Negros Occid.	Marinduque	0.5	0.015	6	25,000	100
Kennon	Luzon	Blacl Mountain	0.4	0.04	1	3,000	200
Biga-Toledo	Cebu	Atlas	0.4	0.005	11	45,000	200
Mexico							
Cumobabi	Sonora	Frisco	0.25	0.2	0.7	1,500	1,200
South Korea							
Daegu	Kyang Bung	Korea Tungsten	-	0.035	0.5	-	200
Iran							
Sar Chesmeh	South-East	NICIC	1.12	0.027	14	145,000	1,800
Finland							
Matasvara		Outokumpu Oy					350
			Total				7,050
			WORLD TOTAL				149,810

TABLE 15

WORLD MOLYBDENUM MINE PRODUCTION: 1961 - 1970

(in metric tons of molybdenum content)

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
UNITED STATES										
CLIMAX	21,776	14,795	21,481	21,286	22,804	25,490	26,337	23,452	23,719	26,528
URAD	-	-	-	-	-	-	620	3,656	3,388	3,687
QUESTA	-	-	-	-	-	3,533	4,258	4,122	4,938	4,575
UTAH	5,590	5,542	4,767	4,742	6,866	6,403	4,097	4,854	6,495	6,916
CHINO	268	337	276	325	450	410	248	278	389	323
MCGILL	154	156	182	60	97	245	110	134	130	94
RAY MINES	-	-	-	3	-	-	7	139	197	359
SAN MANUEL	1,050	1,129	1,286	1,350	1,554	1,925	1,087	1,248	1,494	1,510
ESPERANZA	579	565	516	637	657	648	662	1,000	915	948
MINERAL PARK	-	-	-	35	978	1,119	1,279	1,596	1,448	1,354
SIERRITA	-	-	-	-	-	-	-	-	-	2,014
MORENCI	235	178	100	188	189	106	45	27	-	-
BAGDAD	72	36	101	125	206	212	239	276	204	182
SILVER BELL	129	143	213	225	200	141	200	135	176	195
MISSION	-	-	-	7	320	289	169	248	355	351
COPPER CITIES	-	-	-	-	-	15	48	46	88	89
INSPIRATION	87	53	215	266	162	113	62	95	160	199
TWIN BUTTES	-	-	-	-	-	-	-	-	-	120
PIMA	-	-	-	-	-	-	382	657	783	673
UNION CARBIDE	193	260	313	371	387	270	204	274	253	352
SUB-TOTAL	30,133	23,194	29,450	29,620	34,870	40,919	40,054	42,237	45,132	50,469

TABLE 15 (Continued)

WORLD MOLYBDENUM MINE PRODUCTION: 1961 - 1970

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
CANADA										
Mo CORP. OF CAN.	349	370	335	340	309	251	272	-	162	263
GASPE MINES	-	-	43	210	224	241	222	232	123	170
BOSS MOUNTAIN	-	-	-	-	664	1,620	1,433	1,089	1,062	1,124
ENDAKO MINES	-	-	-	-	-	5,242	6,481	5,480	8,530	8,274
BC MOLYBDENUM	-	-	-	-	-	-	-	1,860	2,526	2,786
RED MOUNTAIN	-	-	-	-	-	150	343	249	335	266
BRENDA MINES	-	-	-	-	-	-	-	-	-	3,675
CADILLAC	-	-	-	-	187	780	467	343	331	-
SUB-TOTAL	349	370	378	550	1,384	8,284	9,218	9,253	13,069	16,558
CHILE										
EL TENIENTE	1,011	876	799	1,171	1,358	1,070	1,595	1,342	1,625	2,764
CHUQUICAMATA	449	874	1,363	1,717	1,567	2,751	2,303	1,191	2,161	2,338
EL SALVADOR	442	679	891	1,042	912	914	979	1,332	1,056	1,596
SUB-TOTAL	1,902	2,429	3,053	3,930	3,937	4,735	4,877	3,865	4,842	5,700
KNABEN	238	257	250	229	224	225	290	221	353	331
TOQUEPALA	-	-	538	639	680	672	924	806	222	608
RUSSIAN MINES	3,130	3,300	3,950	4,180	4,580	4,580	4,880	5,150	5,500	5,750
ALL OTHERS	567	859	825	898	1,383	1,987	3,266	3,222	1,458	1,311
WORLD TOTAL	36,319	30,469	38,444	40,046	46,871	59,878	62,699	63,135	70,245	80,727

TABLE 16

WORLD MOLYBDENUM MINE PRODUCTION: 1971 - 1980

(in metric tons of molybdenum content)

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
UNITED STATES										
CLIMAX	23,453	23,923	23,040	26,922	27,112	27,497	23,153	23,456	22,242	23,604
HENDERSON	-	-	-	-	-	1,359	10,704	14,623	19,397	22,671
URAD	3,302	3,180	2,419	1,685	-	-	-	-	-	-
QUESTA	4,575	4,983	4,938	5,074	5,028	5,209	3,669	2,491	2,265	1,689
SIERRITA	4,460	5,290	6,477	5,138	6,124	7,977	7,363	7,401	7,358	7,937
MINERAL PARK	1,296	1,587	1,692	1,285	1,239	1,200	1,752	2,044	1,719	1,790
ESPERANZA	1,189	-	1,552	1,161	1,456	1,353	1,047	-	944	944
UTAH COPPER	5,609	6,111	5,803	4,193	3,649	2,923	3,108	4,403	4,626	3,320
CHINO MINES	192	179	275	125	191	86	72	120	121	9
RAY MINES	232	14	276	309	149	337	266	287	373	315
MCGILL	15	27	118	46	11	-	44	59	-	-
SAN MANUEL	1,439	2,252	2,456	1,910	1,440	1,203	1,474	1,605	1,501	1,149
TWIN BUTTES	582	963	1,470	659	156	554	1,648	1,418	2,122	1,394
BAGDAD	204	206	226	166	197	177	154	1,168	1,481	939
PIMA	650	525	850	786	822	864	525	-	192	769
MISSION	512	860	364	295	198	124	129	172	782	632
SILVER BELL	237	58	-	-	-	-	-	61	195	89
COPPER CITIES	94	97	119	49	9	-	-	-	-	-
PINTO VALLEY	-	-	-	-	72	200	153	204	324	269
MORENCI	21	-	-	-	-	-	-	-	241	128
INSPIRATION	105	13	47	-	-	-	-	28	94	84
UNION CARBIDE	324	330	288	195	131	128	133	137	121	122
AMBROSIO LAKE	-	200	74	-	25	103	56	47	50	53
SUB-TOTAL	48,491	50,798	52,484	49,998	48,009	51,294	55,450	59,724	66,148	68,251

TABLE 16 (Continued)

WORLD MOLYBDENUM MINE PRODUCTION: 1971 - 1980

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
CANADA										
ENDAKO MINES	6,526	4,190	5,388	5,466	6,849	6,838	6,905	6,363	2,697	7,294
BOSS MOUNTAIN	912	906	-	826	1,094	1,033	980	752	639	758
BC MOLYBDENUM	2,313	481	-	-	-	-	-	-	-	-
BRENDA MINES	4,355	4,557	3,786	3,466	3,937	3,636	3,930	3,210	2,532	2,300
RED MOUNTAIN	365	-	-	-	-	-	-	-	-	-
LORNEX	-	264	1,579	1,832	1,399	1,710	1,670	1,805	2,010	2,170
ISLAND COPPER	184	214	582	532	816	472	919	924	1,079	1,201
GASPE	185	211	126	25	142	528	1,039	1,888	430	805
GIBRALTAR	-	-	224	338	35	-	141	129	538	780
BETHLEHEM	-	-	-	-	-	-	-	197	263	260
SUB-TOTAL	14,840	10,823	11,685	12,485	14,272	14,217	15,584	15,268	10,188	15,568
CHILE										
EL TENIENTE	1,030	1,489	1,267	2,231	2,431	2,321	2,174	2,771	2,581	2,312
CHUQUICAMATA	3,727	3,370	2,430	6,144	5,319	7,049	6,960	8,930	9,258	9,330
EL SALVADOR	1,324	1,032	1,191	1,382	1,341	1,462	1,453	1,227	1,212	1,335
ANDINA	-	-	-	-	-	67	351	264	508	691
SUB-TOTAL	6,081	5,891	4,888	9,757	9,091	10,899	10,938	13,192	13,559	13,668
MATASVARA	-	-	-	-	-	-	-	-	104	340
KNABEN	357	255	131	-	-	-	-	-	-	-
CUAJONE	-	-	-	-	-	-	-	-	-	1,311
TOQUEPALA	810	768	722	750	650	449	462	730	1,181	1,359
RUSSIAN MINES*	6,350	6,550	6,750	6,850	8,750	9,100	9,300	9,700	10,800	11,670
ERDENEITYN OBO	-	-	-	-	-	-	-	-	-	340
ALL OTHERS	2,399	1,246	1,030	1,828	1,117	1,387	1,366	1,499	1,630	2,340
WORLD TOTAL	79,328	76,131	77,616	81,668	81,864	87,243	93,044	100,066	103,456	114,746

* Estimates

NEW PROJECTS

CUMOBABI MINE : This project is another example what the thriving metal markets can do for a fast development of mineral properties. Like in the case of Highmont Mine in British Columbia, high molybdenum prices since 1978 speeded up a fast development of this relatively recently discovered mineral district, converting Mexico overnight, again into an important molybdenum producer, like Canonea did it almost 50 years ago, in 1933, by starting first by-product recovery at its copper plant in the state of Sonora.

Minera Cumobabi SA de CV is a wholly owned subsidiary of Frisco SA de CV, located in mountainous district of La Verde, over 1,000 mts above sea level, 27 kms southwest of Cumpas in the state of Sonora and 43 kms southwest of the large porphyry copper of La Caridad, also a potential by-product molybdenum producer. Cumobabi got its name from two metals CU and MO it contains and the local word for "source" which is BABI.

This district is a combination of porphyry and breccia-type deposits which were discovered at old mining works carried out already in 1800's but systematically explored only since 1966, when Cia Minera Hermosillo acquired several claims in the area and started a diamond drilling program and underground exploration which continued into 70's. Minera Cumobabi acquired these claims in 1978 and started development of an open pit mine, which was brought into production in September of 1980.

The Cumobabi topographically rugged area consists of cretaceous andesite, volcanoclasic rock and Tertiary rhyolite. Diorite and granodiorite plugs intruded these volcanic formations, and pipes of collapse breccia formed at the contacts of the intrusives and the volcanics. The breccias and the intrusives were subsequently mineralized, giving origin to the higher grade breccias and lower grade porphyries.

The initial project of Cumobabi was based on a 4.7 million tons San Judas orebody, which assayed 0.25% Cu and 0.2% Mo. This orebody should provide the basis for a 600 tpd open pit and concentrator which should be able to produce about 300 tpy of Mo, plus a similar amount of copper. However, further exploration rapidly increased these reserves to about 18 million tons and, moreover, discovered three additional orebodies : the Transvaal and Transvaal West, a few hundred meters west of San Judas and the Molybdeno breccia, 700 mts south of San Judas Pit. According to the latest geological estimates, the Cumobabi mineral district today accounts for approximately 70 million tons of ore assaying an average of 0.25% Cu and 0.1% Mo. It is believed, however, that further exploration will bring these reserves to up to 200 million tons.

In view of these new findings and booming molybdenum markets of 1979 and 1980, the original plans of building a 600 tpd operation rapidly changed and expanded the project to 2,000 tpd, with an idea that, if necessary, this operation can be expanded to 15,000 or even 30,000 tpd by mid 80's. Obviously, with the present market situation it is more likely that the constructed 2,000 tpd plant will suffice for several years to come.

The San Judas orebody is 300 mts long, 70 meters wide and at least 300 mts deep. Mineralization is found in the upper level of the orebody, which is dome shaped and has a clearly defined lower level. In this deposit molybdenite is disseminated in quartz veins, with notable enrichment areas. The breccia itself consists of quartz, biotite and orthoclase with some apatite, zircon and calcite,which appear in smaller proportion. The development of the open pit started over the San Judas orebody and this open pit will also permit mining of San Judas-Transvaal poprhyry. Some other claims of Minera Penacobre, a subsidiary of Cananea, may be also included in this pit (some claims of Transvaal and Transvaal West are jointly owned by Cumobabi and Penacobre) if expansion of operations to 15 or 30,000 tpd are considered. The San Judas breccia contains around 0.4% Mo while the average for the San Judas porphyry is only 0.12% Mo. Breccia to porphyry ratio is 3 : 7 - this for 14 million tons of reserves with a cutoff grade of 0.05% Mo.

The other important orebody is Molibdeno, on the opposite side of the mountain, 700 mts to the south. Molibdeno's ore reserves, so far, are put at about 25 million tons. Some 15 million tons belong to breccia and the other 10 million tons to stockwork. Molibdeno breccia is apparently an apex on top of the stockwork, and this orebody may be mined both by open pit and underground methods, in two separate operations. The stockwork consists of zones of intense fracturing and alteration in andesite. Molybdenum mineralization appears in quartz-orthoclase, with veins 25 to 50 mts thick and with almost no copper mineralization. The average grade of the ore is 0.10% Mo, although higher grade areas also exist. However, where molybdenum content is the highest, is in breccia, where the average grade is 0.18% Mo and where one 1.5 million tons section caries 0.25% Mo.

Stripping operations at San Judas started in early 1979. This open pit has 10 mt benches and the initial stripping ratios are about 1.15 : 1. The ore is drilled with Atlas Corpco Rotamec-1300 drills which produce 11 m deep holes, 16 cm in diameter. Blasting is with Detomex and ANFO, with a powder consumption of 200 gms/t. The ore is loaded with 5.5 cu mt bucket Eaton Yale frontend loaders which feed a fleet of six Wabco 35 metric tons capacity mechanical drive trucks.

The Cumobabi concentrator was designed with prevision for further expansion. It has thus an oversized 10,000 tpd crushing plant, with a 36x55 in. Allis Chalmers gyratory crusher and a 5.5 ft Short Head Symons crusher. Crushing plant discharges a minus 10 mm product to a covered 26,000 metric tons storage facility.

Grinding and flotation plants are designed for a 2,000 tons per day capacity , although the concentrator building has spare space for future expansions. This plant was built in a record time of some 18 months thanks to the possibility of use of older equipment from San Francisco del Oro mill. The grinding section consists of four 7 x 11 ft ball mills which grind the ore to 100% minus 45 mesh. Each mill is driven by a 250 HP motor. These mills work in a closed circuit with 5 x 30 ft spiral classifiers, which overflow is floted in two banks of 16 Agitair No 48 cells, with eight roughers and two sets of four scavangers in each bank.

The bulk concentrate is thickened and re-ground to 70% minus 200 mesh in a 5 x 8-ft Marcy ball mill, then , again, thickened in an 18-ft thickener and conditioned for copper-molybdenum separation. Flotation of molybdenite is carried out with Diesel Oil and T.F.A. while depression of copper and gangue materials is achieved by sodium hydrosulphide and sodium silicate. Flotation is carried in 44 Agitair No 48 and 32 Agitair No 36 cells. Several re-treatment circuits are used to obtain 57% Mo standard grade concentrate which is dewatered and trucked to Cumpas, where it is converted into molybdenum threeoxide in a 10-hearth Nicols roaster. This 18-ft dia unit has a capacity of 18 metric tons of concentrates per 8-hrs shift. Off-gases from the roaster are cleaned in multiclones and electrostatic precipitators. The company has a production capacity of 3 million pounds of Mo per year, as well as of 1,300 tpy of Cu. which is sent for custom smelting.

The tailings from this operation are discharged at a dam, 600 mts away, where water for milling operation is reclaimed and pumped back to the mill.The water supply comes from two wells, 23 kms away and amounts to 60 liters per second. It should be complemented with reclaimed water from the tails. The electric energy comes from the Nacozari power substation 46 kms away.

The whole project was executed at a cost of US $ 23 million. Operations were started in last quarter of 1980 and some difficulties were reported in 1981. A part of production is supposed to be shipped to Japan, but relatively little has been known about production figures.

ERDENETYIN OBO MINE - which in Mongolian means Treasure Mountain is located in north central Mongolia about 330 kms northwest of the Mongolian capital Ulan Bator and about 270 kms, by road, south of the Soviet border. The mining potential of this area was known from pre-historical times because of outcrops of turquoise and native copper and ancient works in numerous surface pits, as well as the name of the area itself. However, the modern exploration and consideration of this area for production started only in 1963 by a mixed Mongolian-Czechoslovakian exploration , which soon established that Erdenetyin Obo is a rather extensive mineral belt, 25 kms long and 1.5 to 3 kms wide, which extends from northwest to southeast and which consists of several mineralized orebodies. After 10 years of exploration, during which also some Soviet geologists got involved, it was established that the most promissing area is located in the Northwestern and Central orebodies. The first orebody is of elliptical shape, is 2,800 mts long, 1,000 mts wide and at least 500 mts deep. The adjacent Central orebody is separated from the Northwestern orebody by a fault and is considerably smaller - 1,400 mts long and only 50 to 400 mts wide. Alltogether mineral resources of this area were estimated at 367 cu.m of mineralized mass with about 136 cu m. of overburden and with an average grade of between 0.8 to 0.96% Cu and 0.016% Mo. Based on these data, a cooperation agreement between Mongolian and the Soviet governments was signed in 1973, by which a joint-venture in developing this property into a 14 million tons per year operation was established. This included financing of an open pit 2,500 mts long, 1,150 mts wide and 270 mts deep; construction of a 40,000 metric tons per day concentrator able to produce some 100,000 tpy of copper in form of 35% Cu concentrates and about 1,300 tpy of Mo in form of 51% Mo concentrate. The project did not contemplate erection of a smelter and refinery because concentrates would be exported to the Soviet Union. However, it considered numerous other infrastructures such as a 164 kms railroad from Erdenet to Salhit to connect Erdenet with the main Ulan Bator - Trans-Siberian railroad; a modern highway between Erdenet and Darkhan (close to Salhit) and a 270 kms 220 kV power line, which would connect Erdenet with the Soviet electric power supply. The execution of this contract was given to the Soviet Giprotzvetmet agency, which contracted several dozens of other technical, engineering, construction etc. agencies. These programs also called for construction of a modern 50,000 people city consisting of 12 large apartment blocks and adequately supplied with water and all other services. Tentative plans for this project were to put on stream the first stage of operations at an annual capacity of about 4 million tpy in December of 1978 and to have this project finished at full capacity of 14 m tpy in 1982. Depending on the higher or lower grades of the ore annual copper output could vary between 100,000 and 125,000 tpy, while molybdenum production would be around 3 million pounds of contained Mo.

The Erdenetyin Obo deposit, as a classical copper porphyry, consists of a leached cap, 20 to 40 mts deep and with a copper content of between 0.01 and 0.4% Cu. This material is rather refractory to leaching and although stockpiled apart for possible future processing, so far was not used.

NEW PROJECTS

Underneath the leached cap is the secondary enrichment zone which consists of bornite, chalcocite, covellite and minor amounts of pyrite and chalcopyrite. The thickness of this zone in the main, Northwest, orebody is up to 300 mts and in the Central Orebody only about 85 mts. The mineralized area is lens-like, i.e. thicker at the center and thinner to the peryphery where it is only 15 to 60 meters thick. Copper mineralization of this zone is very intense and assays anywhere from 1% to 7% copper. About 85% of the calculated reserves of this orebody are located in the secondary enrichment zone.

Underlying the secondary enrichment zone is the primary mineralization, which is principally in form of chalcopyrite and pyrite and which extends to at least 500 mts below ground level. The average assay of this zone is between 0.4 and 0.5% and it also decreases towards the periphery where it amounts to only 0.2 - 0.3% Cu. Contrary to the copper mineralization, molybdenum mineralization is more intense toward the periphery, where it reaches up to 0.025% Mo, as compared with an average grade of 0.012% in the center. Molybdenite is accompanied by rhenium values, as well as the copper ore has minor amounts of gold, silver, lead, zinc, bismuth, tellurium and arsenic but quantities of which are not reported. However, it seems, that they fall within a normal range of usual impurities, i.e. are present only in traces.

Pre-stripping of the mine was started in 1977 for development of a pit, as mentioned above, 2,500 mts long, 1,150 mts wide and 270 mts deep. Work benches are 15 mts high and 50 mts wide and in first few years the pit floor will descend at a rate of 20 to 30 mts per year, but as the pit grows the rate of descent will average about 15 mts per year. In mining, the most advanced and the largest Soviet equipment is being used : EKG-8I showels with 8 m^3 buckets SBSH-250MN drills, 350 to 540 HP buldozers and BeLAZ -548 and 549, 40 t and 75 t trucks.

Concentration of ore includes a three-stage crushing; one step grinding to 65% minus 200 mesh; bulk flotation of copper and molybdenum into a concentrate which is then treated for molybdenum separation by depression of copper sulphides with sodium sulphide and other reagents.

All milling equipment is of the Soviet origin and the different operations are fulfilled as follows : crushing is carried out in KKD-1200/130GRIS, KCD-2200T and KMD-3000T crushers, which are respectively gyratory, standard and short-head crushers. Gyratory crushers receive 1,000 mm heads and deliver 250 mm product, which is then crushed to a maximum size of 15 mm, in a closed circuit, and then fed to the ball mills. Coarse ore bins can store some 165,000 tons of ore while the fine ore bins have a capacity of 370,000 tons - almost a 10 days production!

Grinding is accomplished in 5.5 x 6.5 m MSHTZ ball mills, 140 m^3 each. These work in a closed circuit with 1400 mm diameter hydrocyclones to produce a flotation feed of 65% minus 200 mesh. Flotation is carried out in 12.5 m^3 FPM flotation cells, which, in the first stage, produce a bulk concentrate of 12 to 14% Cu and

0.2% to 0.3% Mo. This concentrate is thickened, conditioned with sodium sulphide depressor and kerosene for molybdenite flotation and sent for by-product molybdenum recovery. A rougher molybdenite concentrate obtained from this flotation is refloated several times to obtain a final molybdenite concentrate assaying between 47% and 51% Mo. The overall recovery of molybdenum is 50 percent.

Meanwhile molybdenum circuit tails, which is the copper concentrate, are combined with the scavenger products and retreated for concentrate upgrading. A final copper concentrate, assaying 35% Cu and about 0.1% Mo is obtained with an overall recovery of 86 percent.

Flotation concentrates are dewatered in a standard way by DU-100-2.5-2 filters, dried and shipped to consumers. Meanwhile tailings of these operations are pumped 4.5 kms away to a pond, with a 21 mts high dam, which can accomodate about 200 million tons of solids.

Since Mongolia is a rather undeveloped country and these mining operations are located in a desertic region without their own infrastructures, this project contemplated construction of a number of mechanical, electric and foundry shops able not only to repair and maintain all existing equipment, but also to fabricate the most necessary parts as well. These shops also take care of heavy mining and transportation equipment and have their own oxygen-acetilen and compression stations, laboratories and all equipment for most diversified maintenance and service jobs. Also, control of these operations is based on third generation EC-1033 computers.

This mine has a very favorable stripping ratio of 0.6 : 1, which certainly will be reflected in lower mining costs and with an average copper content in the heads of between 0.8% and 1% Cu is probably one of the better copper porphyries in the Communist World. Its 300 million tons ore reserves assure about 22 years of continued operation at the designed production capacity of 14 million tons per year, with a copper output of between 100,000 and 125,000 tpy and molybdenum by-product of some 1,300 tpy. These operations were started by the end of 1979 on a 4 million tpy basis and in 1980 a second section was added. It is expected that in 1981 copper production totaled some 50,000 tons while the molybdenum output was about 650 tons. It is expected that in 1982 the whole project will be on stream and that for 1983 a 100,000 tons of copper and 1.300 tons of molybdenum will be produced. Later, these production figures may be improved on account of better grade ores, reaching somewhat higher levels, but from early 90's production is likely to decrease to the present and even lower levels.

NEW PROJECTS

HIGHMONT MINE : This low-grade copper-molybdenum porphyry located in the Highland Valley of British Columbia, some 200 kms Northeast of Vancouver was recognized by explorers already since 30's and staked in 1955 and 1956. This property was owned and optioned by several large companies, including ASARCO, Kennecott, Anaconda, Rio Algom Mines and several others before it was developed by Teck Corporation between 1979 and 1981 and put on stream in February of 1981. First serious studies of this property were started in mid 60's, when Highmont Corporation Limited was formed in 1966. This was after the Anaconda Group in 1964 and 1965 optioned the property and did some reconnaissance work. Subsequently, Rio Algom Mines group carried out some persussion drilling and Nippon Mining Co. financed underground bulk sampling for metallurgical and feasibility studies. However, Nippon Mining withdrew early from this venture and the program was completed with founds obtained by equity sale to the public. First feasibility studies for this property were made in 1971 by Chapman, Wood & Griswold Ltd. in association with Wright Engineers Ltd. but gave negative results because of the prevailing economic conditions in early 70's, affected by a recession and low metal prices. During the 70's some additional exploration work was done and new claims were purchased by the company, which now amalgamated with Torwest Resources Ltd in 1977. In 1978, in view of higher copper and molybdenum prices a new feasibility study was made, now in association with Teck Corporation Ltd, which since 1969 entered into financial agreement with Highmont for rights to finance development of this property. After 1978 and 1979 marketing and financing arrangements for a credit of C$ 150 million to develop this property were obtained, the development of this project was officially announced in April of 1979. Subsequently, late in 1979, Highmont and Teck Corporation merged and later Metallgesellschaft of West Germany acquired from Teck a 14% interest for C$ 14.4 million. The construction of mining and milling facilities was started in May of 1979 and finished in a record time by the end of 1980. First testing of one of two circuits started in December of 1980 and the second circuit was on stream by March of 1981. Already in January of 1981 this plant, built for a 25,000 tpd (short tons) capacity was working at 15,000 tpd and by mid-year, with two milling sections in operation, the designed capacity was overcome by 20 percent.

Highmont property consists of seven mineralized areas, of which only two are considered to be of economic importance. The largest, 100 million tons deposit, occurs in quartz diorite and assays an average of 0.26% Cu and 0.023% Mo. The smaller one has reserves of 21 million tons of ore assaying an average of 0.25% Cu and 0.047 percent molybdenum. The copper-molybdenum ratio in both deposits varies considerably from one area to another. Copper mineralization is principally in form of chalcopyrite and bornite, with pyrite mineralization on the outer edges of the deposits.

This mine is open pit mined, with a stripping ratio of 2 : 1. The East Pit, first to be developed, will be 100 mts deep, 450 m. wide and 975 m. long. The West pit will be 90 m deep, 430 m wide and 610 m long. It will also have a waste to ore ratio of 2 : 1, with a 0.35% Cu equivalent cut-off (combined value for Cu and Mo). Both pits will be worked simultaneously with 9 m.benches and the overall pit slope of 40°. Blasthole drilling is carried out by

two Gardner Denver 100 rigs, drilling 250 mm holes on a 7m x 7m pattern. Powder factor is about 0.175 kg/t and drill performance is about 152 m per drill shift. Waste and ore are escavated by 3P&H 1900 AL electric shovels with 9.4 cu m dippers. The truck fleet consists of 15 Lectra-Haul 120 s.ton trucks powered by KTA 2300-C Cummins 1200 hp engines.

The overall open pit mining rate is about 54,500 tpd, seven days a week, 24 hrs per day. This will increase to 69,000 tpd to sustain concentrator capacity at 22,700 tpd.

The concentrator is for a daily capacity of 22,700 tpd at a 92% operating time. It is supposed to produce, on an annual basis,between 45 and 50 million pounds of copper (20,000 to 23,000 metric tons) and 4 to 5 million pounds of Mo (1,800 to 2,300 tpy). Projected recoveries on copper are 90% and those on molybdenum are 78%.

The ore from the open pit is, first, crushed in an Allis Chalmers 54in x 74in gyratory crusher, powered by a 450 kW motor, which works at a 2,200 tph capacity and produces a minus 250 mm discharge. The ore is withdrawn by a 2,240 mm wide belt feeder and discharged to a 1,370 mm conveyor which delivers it to the 68,000 tons live load coarse ore stockpile. Stockpile is feeding two milling sections, each consisting of one 10.4 m x 4.3 m autogenous mill driven by 3280 kW motors and one 5 m dia by 8.8 m long ball mill, with a 4,400 kW motor. The autogenous mills produce a 6.3 mm discharge (the plus 6.3 mm material being sent to a shorthead cone crusher for additional crushing to minus 12.7 mm, which returns it to the primary mill) which is being fed to the secondary ball mills. These mills work in a closed circuit with cyclones and produce an overflow of 65% minus 200 mesh, which is then sent for bulk flotation.

Each of two parallel flotation sections consists of 2 banks of 12 Denver 36 cu mts cells, which work at 32% solids and have retention time of 18 minutes. An average of 2,870 m3 of pulp is treated per hour producing a rougher concentrate, which is then sent to first cleaners consisting of 2 banks of 12 cells Denver machines of 2.8 m3 each. The cleaner concentrate is then recleaned another two times in similar flotation machines but with 8 cells per bank. Bulk flotation is carried out in an alcaline circuit of pH of 8.5 which is obtained without addition of lime but is rather the natural alcalinity of the ore. Potassium amyl xanthate and Aero 3302 are used as collectors and MIBC as a frother.

The cleaner bulk concentrates from two circuits are combined, thickened and conditioned with sodium hydrosulphide for copper depression and sent to copper-molybdenum separation circuit consisting of one bank of 16 cells Denver 2.8 m3 machines. Fuel oil is used for molybdenum flotation while copper depression in last stages is helped with cyanide. Recleaning of molybdenite requires 10 stages by which a standard molybdenite concentrate is obtained. The final molybdenite concentrate should be,however,leached to eliminate excess of copper and to obtain a premium product. The

first four stages of cleaning are done in 1.4 m3 Denver cells and the last 6 stages in 0.68 m3 cells. Percent solids varies from 16% in the first separation down to 6% in the last re-cleaning stage.

Water for the milling operation is brought from three wells, 8 kms from plant, and is stored in head tanks. Tailings from the concentrator are being discharged at a tailings pond, 5 kms away from the plant, and which is designed for a 2.3 million m3 capacity of water storage. More than 70 percent of water used in operation is reclaimed from this pond. Special measures were taken to control long term seepage rates from the dam.

This operation occupies a working force of some 360, most of whom live in Logan Lake, 14 kms away, or at Ashcroft and Kamloops. The metallurgical process was designed and pilot plant tested at Lakefield Research of Canada Ltd.

Details for operation of by-product molybdenum flotation plant are as follows :

	Cu-Mo Separation	Mo first cleaners	Mo 2-4 cleaners	Mo 5-10 cleaners
Cells Make	Denver	Denver	Denver	Denver
Cell size m^3	2.8	1.4	1.4	0.68
No banks	1	1	1	1
Cells per bank	16	20	12	20
Total vol m^3	45	28	5.7 x 3	13.6
Pulp % Solids	16	10	13/10/6	6
Pulp m^3/hr	130	95	36/39/85	47
Ret.time-min	21	18	10/ 9/ 4	17.5
Air, m^3 per min/m^3	1.0	1.8	1.8	-
Imp.speed rev/min	194	219	219	370
Imp. diameter, mm	686	559	559	406
Imp. speed, m/s	3.5	3.2	3.2	3.9

QUARTZ HILL PROJECT : This article has been compiled from a variety of the US Borax publications and particularly including papers on Economic Geology by P.R. Smith and exploration staff and a paper on The Intricacies of Developing New Production Capacity for Molybdenum by George Griggs, Manager of New Business Development of US Borax & Chemical Corporation.

The Quartz Hill molybdenite deposit was discovered in 1974 by US Borax & Chemical Corporation as a direct result of a stream sediment, geochemical reconnaisance program in Southeastern Alaska. Quartz Hill is located approximately 45 air miles east of Ketchikan. It is a small multiphase igneous stock which intruded the Coast Range Batholith approximately 30 million years ago. The stock of this deposit is made up of a complex suite of quartz monzonites, quartz latites and associated breccias. The mineralization occurs primarily as a quartz-molybdenite stockwork within the stock. The development of this stockwork can be attributed to multiple degassing episodes of the Quartz Hill stock, resultant fracturing of the host rock and subsequent quartz-molybdenum flooding. Mineralization was followed by intrusion of late stage dikes. Faulting has affected all rock types present. The most prominent structural feature is the NW-SE trending Stephens Fault, which has at least six hundred feet of right literal movement and an undetermined amount of vertical slip.

Ore reserves based on 1979 data, which were calculated by computer, indicate 2.2 billion tons mass at 0.12% MoS_2. Manually derived reserves based on the same data were roughly 1.3 billion tons of 0.13 MoS_2. The major area of difference is that the computer included undrilled areas that were mathematically averaged above the cutoff grade by kriging, while hand calculations used geologic cross sections with reserves rigidly defined by drill hole grade intercpts and limited to half distance to the next section. Because manually calculated reserves adhered to interpolation and extrapolation of 250 feet, it is felt that these reserves can be considered proven, probable and possible categories. Higher grade reserves occur within this orebody and have been manually calculated at approximately 300,000,000 tons of 0.201% MoS_2 using a 0.150 MoS_2 cutoff. The hand calculated reserves, including 1980 drill hole data are as follows :

1,550,059,000 tons of 0.125% MoS_2	at 0.05% MoS_2 cutoff
969,182,000 tons of 0.150% MoS_2	at 0.10% MoS_2 cutoff
308,100,000 tons of 0.201% MoS_2	at 0.15% MoS_2 cutoff

Quartz Hill molybdenum deposit was discovered by a group of geologists directed by J.E.Stephens, who took stream samples at the junction of White Creek and Hill Creek rivers and found 168 ppm of Mo in it. Claimstaking took place in October of 1974 and since January 1975 four drillers and one geologist returned to drill the first hole. A comprehensive shallow drilling program was initiated in the spring of 1975 and continued during the 1976 and 1977 seasons. The shallow drill holes ranged in depth from 100 to 300 ft and were located on a 500-ft grid pattern. Due to the

very limited outcrop availability and the near or at surface mineralization, this method of exploration proved to be very useful in determining target areas for deeper, 1,500 ft. drilling. Deep drilling began in 1976 and has continued through 1980. As of October 1980, 138 deep "NX" cored diamond drill holes have been completed, totaling 144,444 feet. Also, 220 shallow "AX" cored diamond drill holes have been completed totaling 25,872 feet. This drilling program was carried out at a cost of around $ 10 million.

Molybdenite is the only mineral of economic importance in this orebody. Although tin, tungsten, copper, lead, zinc and silver are present also, they are in traces and have no economic importance. Molybdenite occurs in the quartz-rich quartz monsonites and quartz latites. Under the microscope molybdenite appears as uniform six-sided crystals and flakes; grain size varies from 0.008 mm to 0.09 mm normally, and avergaes about 0.05 mm. The molybdenite crystals are generally discrete but they also occur in clots of crystals closely spaced and locally overlapping. Large masses of molybdenite are rare. The molybdenite occures in five ways :

1. Within quartz veinlets - fine to coarse-grained
2. At the edge of quartz veinlets
3. Along fractures and/or fault zones
4. Included in or related to secondary alteration minerals
5. As a cementing material with quartz fault breccias.

The most common occurence of molybdenite is directly related to quartz veinlets, either within the quartz veinlet or more commonly along the perimeter of the veinlet. It tends to be concentrated just inside the veinlet boundary or just outside the boundary within the surrounding fine-grained, locally altered, quartz monzonite matrix.

The second most common occurence is along the fractures and faults. The molybdenite-rich veinlets are very dark (blue-black) and typically occur as "moly-paint" on joint fracture surfaces. Many, however, have features that distinguish them from the typical joint surface. These veinlets are "tight" filled wall to wall, have highly irregular to sutured courses, and in places, clots of essentially pure molybdenite several centimeters across. In spite of the purity in the veinlet material, the habit of the veinlets suggests replacement rather than the open-space filling as the dominant process in ore formation. This type of mineralization has also been described at the Henderson orebody (Wallace, 1978).

In the field, areas of intensely sheared rock will display strong argillic zones with related favorable molybdenite mineralization. High grade zones of molybdenite mineralization may be found locally within major shear zones. Grades of 2% to 3% MoS_2 have been found locally over short intervals in drill core associated with zones of shearing. The grade of mineralization is directly related to structurally prepared zones where host rock has been intensely shattered, allowing permeability for the molybdenum rich solutions

Locally some molybdenite may be found related to secondary alteration minerals, primarily K-feldspar. In rocks that contain molybdenite, 86% also contain minor pyrite and 50% contain magnetite.

The pyrite content averages about 1% and slightly increases with higher MoS_2, while FeO assay is also around 1%. The other impurities are as follows :

Sn	less than 10 ppm	
W	less than 10 ppm	- with local assays up to 30 ppm
Cu	30 ppm	- with up to 1,000 ppm
Pb	less than 5 ppm	- locally in veinlets up to 3,000 ppm
Zn	5 -30 ppm	- locally up to 800 ppm
Au	not detected	
Ag	less than 0.2 ppm	- locally in places up to 40 ppm
U	between 3 and 10 ppm	

Initial US Borax production at Quartz Hill is expected to be in the range of between 40 and 50 million pounds of Mo per year. Operations at Quartz Hill will be open pit mining with a very low stripping ratio. While this suggest low operating costs and low initail investment for mine developing, the remote location of the deposit will require a great deal of infrastructure, which is rather costly and which thus will make investment per pound of installed capacity rather at a higher bracket level. To produce 40-50 million pounds of Mo processing of 60,000 to 80,000 tpd of ore will be necessary, which with the presently known reserves will give the property at least about 40 years of life.

Development of this mine was conditioned by approval of a number of permissions, which are included in 31 major categories and which require 89 major permits and involve 25 different state and federal government agencies. This apart from special ecological objections rised by different private and official agencies.

Metallurgical studies carried out in 1979 and 1980 determined that the open pit mined ore will be processed in the following way : after primary crushing to minus 12 inches, it will be conveyed to an ore storage pile for coarse ore by a conveyor. Coarse ore will be then screened to remove fines, prior to the secondary crushing, which will reduce the ore to 3/8" material, which will be stored in fine ore bins. Finely crushed ore will be then conveyed to two-stage grinding, first, in rod mills and then in ball mills. At this stage the ore will be diluted with water to about 65 percent of solids. After grinding, the ore will be conditioned with more water and flotation reagents and then sent to a flotation circuits, where a molybdenite concentrate will be separated from the gangue material. Molybdenite concentrate, assaying probably no les than 90% MoS_2 will be then dewatered, first, by filters and then by driers and then stored and fed into shipping containers for delivery to the customers. The waste rock tailings from flotation circuit will be thickened and conveyed by a pipeline to a tailings disposal area. Two alternate disposal methods are being considered : disposal on land and submarine disposal in the deep waters of Boca de Quadra. In the case of land disposal, the tailings will be stored in basins created by construction of dams. Channels would be constructed to divert surface water runoff around the disposal area. These channels and the disposal dams would be disigned to handle the heavy rainfall of the area to State and Federal permit requirements. The tailings placed in

disposal will be settled out and water overflow will be recycled to the mill or discharged. The recycled water will be monitored and treated as necessary to meet recycle requirements or, if discharged, to meet Federal and State water quality standards.

In the case of tailings disposal in Boca Quadra, they will be placed in a deep submerged valley carved out of the rock and glacial action. Comprehensive oceanographic and marine biologic studies are in progress to evaluate this disposal alternative. If the placing of tailings in Boca de Quadra is enviromentally feasible and acceptable to the permitting agencies, the tailings would be conveyed by pipeline to fjord mixed with sea water and piped to a discharge outfall at a depth of 150 feet or more. At this depth the dense tailings slurry would flow gradually to the bottom of the fjord where the rock particles would deposit in the same manner that natural sediments are being deposited today. Based on present knowledge, the tailings would be insoluble and stable in the cold saline water of the fjord.

It is obvious that such a large molybdenum producer, which will become the second after Climax, on a world scale, will necessarily have to convert its own molybdenite concentrates into molybdic oxide both for sale and further processing into ferro-molybdenum and molybdenum salts. So far no much information exists in this respect, but it has been considered that roasting operations will be probably carried out near Seatle in the State of Washington. This maybe also the place for a chemical products plant.

US Borax considers that with about 2 billion pounds of resources in form of recoverable molybdenum it has every chance to become a major molybdenum producer, in fact, the second largest after Climax. A recent communication indicates that, after all legal and ecological objections were solved, the company gave a green light for development of this project at an estimated cost of US $ 870 million, expressed in 1980 currency. So far the company already spent some $ 20 million on exploration and other studies and testing. Construction of access roads will start in the spring of 1982 and first operation is expected to start in 1987. Actually, it is not clear if production will be started in 1987 at full capacity, but depending on the market conditions it may be developed in two or even three stages, according to the demand.Construction of the mine and mill was previously determined as a three-year affair, so probably first stripping of the mine and actual erection of the mill may wait until 1984. This gives a tremendous flexibility to the timing of the project itself.

QUESTA NEW PROJECT : This project came as a necessity for replacement of the old open-pit Questa operation, which after a major slide was shut down and never reopened again. Instaed it was considered more practical to develop a new underground Goat Hill mine, which is immediately near to the Questa outlines, and which permits the use of the old Questa concentrator, which for this purpose will be expanded and revamped.

previous to this Molycorp Inc. has been engaged for a number of years in successful exploration of this region for new molybdenum resources in a partnership with the Kennecott, which was also looking for a primary molybdenum mine. However, since 1977, when Molycorp was acquired by Union Oil of California, this partnership was dissolved and Union Oil decided to go on this $ 200 million project all alone. Incidently, Union Oil was the original discoverer of Pima Mine in Arizona, but then sold equity to Cyprus and Utah International, holding now only a quarter of the total interest.

The new underground orebody at Goat Hill will be mined by gravity block caving method. The mine will have three outisde entrances: one of them is a 24 ft diameter shaft, which goes to the depth of 1,300 feet and which will contain the main hosting cage for underground employees and transportation of equipment and supplies. This service shaft will also serve for fresh air intake and for waste hoisting. The other, 14 feet diameter shaft will be used for exhaust ventilation, air supply for underground mine and to transport concrete to the mine. Initially, it has been used for development work enabling tunneling activities before the service shaft was completed. It is also 1,300 feet deep. Finally, the third outside entrance to the mine is 6,641 feet, 17.6% grade (10°) decline, 19 feet wide and 15 feet high, which contains a 4 foot wide conveyor belt and which serves to bring ore from the mine to the coarse ore stockpile. Mine air will be also exhausted through this decline.

The underground orebody is a disseminated porphyry-type molybdenite deposit, impregnated through a weak and highly fractured andesite located about 1,200 feet below the surface. These conditions favor an efficient low-cost mining method - block caving. The orebody is almost a flat lying cylinder, 4,500 feet long and from 375 to 750 feet wide. Molycorp will develop an extensive network of access drifts and crosscuts into and below the orebody. Two working levels will be established, the lower serving as a haulage level and connected to the upper grizzly level by 54 feet long transfer raises 4 feet wide. From drifts on the temporary undercut level, above the grizzly level, a series of holes are drilled in a fanlike pattern. The holes are filled with explosives which shatter the bottom 15-feet wide. The ore will be flown down raises to the grizzly level drifts. A grizzly is a set of steel bars that regulate the size of rocks that can enter the transfer raises. The material that has been withdrawn leaves the remainder of the rock in that panel without support and it caves into the void. The process steadily continues as ore is drawn out at the loading stations at the bottom of transfer raises and loaded into electric trains on the houlage levels for the trip to the conveyor and then to the mill. More than 32 kms of track will be needed over the next 20 years to exhaust this orebody.

The surface buildings include two hoist houses for the vertical shaft elevators, transfer conveyor belts, compressor house, change house, maintenance shop and main office building. The double-drum hoist for the service shaft will have a 25 metric ton load capacity.

The transfer conveyor belts on the surface will be used to bring the ore to the existing crushing facilities from the portal of decline. The installation of the conveyor belts, instrumentation and electrical work is being completed.

The concentrator is being now modernized and expanded. The modified plant consisting of crushing, grinding, flotation, filtering, drying and packaging sections will have a capacity to process daily 16,400 metric tons with an average grade of 0.174% Mo. This is a good grade ore, according to the international standards, since it will yield more than 3 lbs of Mo per ton of ore.

This project will cost some $ 200 million and is planned to start operations already in 1983. The concentrating plant was already finished and modernized in January of 1982 and will be able to treat ore from the stockpile and the open pit, which has been now expanded in the north-eastern side. This material has less than 0.1% Mo and is being processed to meet contract obligations and the work force employed until the underground mine starts production in 1983. However, the full production from the underground mine of 20 million pounds of Mo per year will be reached only in 1984. The present mine and mill personnel of 526 is expected to grow to 1,153 by the end of 1983.

Extracted from a Molycorp pamphlet
on Molybdenum Operations, Nov.1981

THOMPSON CREEK MOLYBDENUM PROJECT : Cyprus Mines Corporation, a subsidiary of Amoco Minerals Corporation (Standard Oil of Indiana) is currently developing a large open pit mine and constructing a processing plant near Thompson Creek in central Idaho. The project is scheduled to commence operations in 1983, with an annual production rate of 18 to 20 million pounds of Mo per year. This project is located in Custer County, Idaho, approximately five miles southwest of county's seat of Challis.

At Thompson Creek, mining will be conducted by drilling and blasting with Ingersoll-Rand T-5 and Marion M-4 rotary drills and digging and loading with 25 cubic yard capacity 4 P&H 2300 XT shovels and 15 cubic yard Dart 600E front loaders. Ore will be delivered by a fleet of 22 WABCO 170-tons trucks from the open pit to the primary crusher, located near the mine. Crushed ore will be then transported overland by belt conveyor to a concentrator, which will process about 22,500 metric tons per day of ore. Tailings from the concentrator will be flown by gravity pipeline about 7,000 ft north-east of the concentrator to the tailings pounds located in the upper reaches of Bruno Creek watershed. The land area which will be directly affected by the proposed facilities is approximately 2,500 acres or nearly four square miles.

The process proposed to recover molybdenite at Thompson Creek will involve the following four basic steps :

(1) Mining
(2) Crushing and conveying
(3) Grinding and flotation
(4) Concentrate drying and packaging

About 45 metric tons per day of molybdenite concentrate will be dried and packaged for shipment by truck and rail to the market. The pertinent parameters and miscelaneous project data for Thompson Creek Molybdenum Project are as follows :

Ore reserves - in metric tons	175,000,000 tons
Average grade in ore, percent molybdenum	0.112
Production rate - metric tpd	22,500
metric tpy	8,070,000
Molybdenum recovery, percent	90
Molybdenum production - lbs/year	18-20,000,000
Grade of molybdenite in concentrate	90% +
Daily tonnage of concentrate - met.tons	45
Ratio of concentration	1 : 500
Overburden removal prior to operation	118 million tons
Stripping ratio	3 : 1
Employment during construction	600
Employment during operation	550
Operating days per year	355
Operating shifts per week - mine	21
- crusher	10
- mill	21
Electric power demand - peak demand	46 megawatts
- average	30 megawatts
Fresh water make-up - maximum	12,000 gpm
- average	1,000 gpm

The Thompson Creek molybdenum deposit was discovered about 1966 and immediately recongnized as a medium-size low grade molybdenum deposit. The claims on this deposit were staked by Cyprus Corporation, who at one time thought to develop it at around $ 75 million investment, but which had to face low molybdenum prices of early 70's and also some ecological objections of local authorities. In those days the known reserves were around 80 million tons. However, better exploration increased ore reserves to around 200 million tons, assaying an average of 0.112% Mo and after an exhaustive study on overall impact of this project on Custer County, carried by an independent consulting firm, a favorable resolution by US Forest Service and the Bureau of Land Management was issued. This coinceded with the acquisition of Cyprus by Amoco Minerals, which was helpful for molbilization of all investment capital necessary.

Overburden mining began in early 1981, after the government agencies gave formal approval to this project in December of

1980. The actual mining and milling operations are scheduled to start in mid-1983. The preproduction overburden removal will take over 2 years and will involve a daily removal of some 180,000 tons of steril rock for a total of over 130 million tons in two years.

The ore crushed in the primary crusher and transported to the surge stockpile will be fed to two semiautogenous SAG mills and then reground in primary ball mills, which work in a closed circuit with 6 hydrocyclones. The cyclones overflow, conditioned already with all necessary flotation reagents will be conducted to rougher flotation circuit and, after a cleaning flotation and regrinding of the cleaner concentrate, will be refloated four additional times, with a regrinding operation between the third and fourth flotation step, in order to obtain a final molybdenite concentrate assaying over 90% MoS_2 and with a 90% molybdenum recovery.

The final concentrate will be thickened, leached from impurities, filtered, dried and packed into drums for shipment. In view of relatively large output of this plant, which is expected to reach 20 million pounds per year, and in view of the recent Anaconda experience, this operation may consider very soon its own roasting facility for converting molybdenite into molybdic oxide and thus gain an easy access to the market.

For power supply this operation will depend on a 90-mile 230 kV production power line from the Moore Substation near Moore, Idaho, scheduled to be completed by December of 1982. Maximum water plant requirements will be around 12,000 gpm and will depend on two production wells with a supply capacity of 6,000 gpm each. Both of these wells are already constructed.

The scheduled completion of the different phases of this project are as follows :

Mine equipment	- October 1981
Overland conveyor	- November 1982
Crusher	- April 1983
Concentrator	- June 1983
Ancillary facilities & systems	- June 1983

Plant start-up is scheduled for July 1983, with limited production continuing through October 1983. Full plant production is scheduled to begin in November of 1983. A recent official communication of this company indicated that essentially the scheduled program is up to date and that the company has firm intentions to start operations as programmed in spite of the weakened molybdenum prices, because the present range of prices was considered in the feasibility studies of this project.

The cost of this project is estimated over $ 330 million.

DEVELOPMENT OF NEW RESOURCES : A combination of two factors - high molybdenum prices since 1977 and the gradual takeover of the traditional metal mining companies by the energy sector had an extraordinarily strong impact on the development of new resuources. Practically every major company sent exploration groups all around the world, to Arizona, Nevada, Colorado, New Mexico, British Columbia, Ontario, Chile, Peru, South East Asia, Oceania, Australia and everywhere else in search of base and alloy metals, molybdenum and gold being the principal ones. No wonder that this resulted in the discovery of new deposits, some of them of considerable importance.

In Nevada, AMAX and Rocky Mountain Energy, a subsidiary of Union Pacific, continued a joint-venture effort in the exploration of the relatively little known Buckingham deposit to discover that this low grade orebody may contain as much as 1 billion tons of 0.06 % molybdenum ore. EXXON successfully drilled at Eureka and Mt. Hope to find a major molybdenum orebody in rhyolite porphyry. Full evaluation of the potentiality of this prospect is in progress and it is believed that it falls in the 100 million tons category or more. In south western Nevada, an important molybdenum mineralization was found at Paradise Peak, in Nye County, about 25 miles from Gabbs. The drilling is carried out by UV Industries and mineralization was found at depths from 50 to 700 feet. Nearby is another called Buzzard Peak and belonging to Colby Mines, with a complex molybdenum-copper-tungsten mineralization. Apart from Buckingham, AMAX was also drilling at Pine Nut in Mineral County near Gardnerville, while US Borax explored the Barcelona district in Nye County, east of Round Mountain. There were also drilling teams in Nevada from Molycorp, Louisiana Land and Development Company, Phillips Petroleum Company, Union Carbide Corporation and some other minor companies, which only indicates that Nevada is considered a high potential area for copper and molybdenum porphyries. This, along with the fact that molybdenum is already being recovered by Kennecott at McGill in the Robinson District and by Anaconda at Tonopah, on the western slope of San Antonio Mountains in Nye County, indicates that in this or the next decade, Nevada may become a large molybdenum producer.

Arizona is better explored than Nevada and, with operations established as early as 1880, is on record for molybdenum production since the beginning of this century. In fact, it was the first molybdenum producer in USA and its large copper porphyries at San Manuel, Bagdad, Mission, Mineral Park, Sierrita, Esperanza, Silver Bell, Inspiration, Pinto Valley, Morency and Ajo and Rey account already for over 25 % of the national production capacity. In spite of this, new exploration programs carried out by Newmont and Getty Oil lead to the discovery of a major copper porphyry at Casa Grande with reserves over 500 million tons grading 1 % Cu and 0.012 % Mo. This is at present the best copper porphyry in the US and probably will be considered for production before the end of this decade. Lake Shore mine, now taken over by Noranda, also prove to contain an interesting mineralization in moly. Its 250 million tons reserves contain an average of 0.9 % Cu and 0.008 % Mo. This state has also substantial potential for new production development at Vekol Hills, where over 100 million tons of 0.6 % Cu and 0.014 % Mo reserves exist and at the Copper Basin district where reserves amount to about 150 million tons of 0.55 % Cu and 0.2 % Mo. In some areas of this districts, high-grade sections with up to 3 % Mo were found. An Additional potential has been found in numerous molybdenum quartz veins in Mohave, Pima, Pinal and Santa Cruz Counties, such as Leviathan mine, where in the past 3 to 5 % Mo ore was extracted, or Santa Nino mine, with a high grade ore coming-

up to 0.5 % Mo and several percent of copper. The other possibility are the molybdenum stockworks found at Squaw Peak and Ventura mine.

Nevertheless, Alaska, along with the Yukon and northern British Columbia are the prime areas for development of the new resources. Apart from fabulous Quartz Hill deposit discovered by US Borax important deposits were found in South Eastern Alaska, near Yukon and the BC border. The most promising of them are the copper porphyries of Orange Hill and Bond Creek. Bond Creek, just along the Canadian border, is reported to have some 500 million tons of ore assaying 0.3% Cu and 0.018 % Mo, while Orange Hill, in the same location, has about 300 million tons of ore assaying 0.35 % Cu and 0.12 % Mo. Somewhat to the north of this region is the Tauris Bluff deposit, with about 150 million tons of 0.5 % Cu and 0.05 % Mo ore. North East of Quartz Hill, also close to the Canadian border, are other two minor porphyries, that of Nunatak, with approximately 100 million tons of 0.07 % Mo, and Boundary Creek, North East of Juneau, with a substantial mineralization, which volume has not been determined yet. Additional molybdenum mineralization has been found at Lawrence Island in the Bering See region, at Pyramid Mountain in the Alaskan Peninsula and molybdenum quartz veins in the Katichikan (Kosciusko Island, Baker Island), and Juneau Districts (Lower Brady Glacier).

Just across the border, in the Yukon, important mineralization was found at Red Mountain, 25 miles from the Alaskan Highway. This property was originally drilled by Boswell River Mines and Tintina Silver Mines. Since 1978 it has been drilled by Amoco Canada Petroleum Ltd. which found mineralization over a length of 2 miles and so far proved 60 million tons of ore grading 0.12 % Mo. On the border of the Yukon and BC, Amax Minerals Exploration Ltd. has successfully drilled the Longtung Deposit, where it proved about 160 million tons of ore containing 0.1 % Wo and 0.033 % Mo. The other important deposit in this area is the Casino Deposit, located between Dawson City and Whitehorse, which consists of about 180 million tons of ore assaying 0.37 % Cu and 0.014 % Mo.

The British Columbia was the other area exceptionally active for molybdenum exploration in the last years. Placer continued the exploration of the Ruby-Creek Deposit, owned by Adanac, and found over 100 million tons of ore assaying an average of 0.1 % Mo. Newmont Mining and Esso Minerals of Canada, on the other hand, concentrated on their Trout Lake property which according to some estimates should be in the range of 100 million tons of ore assaying probably as much as 0.24 % Mo and some additional tungsten values. Another important find was Moly-Taku, on Mt. Ogen, 15 miles from the Alaskan border. This deposit, explored by Omni Resources, has very promising resources of about 200 million tons assaying an average of 0.2 % Mo but will be difficult to work because of the rugged environment and the abundance of ice. Otherwise BC is, of course, famous for such important deposits as Endako, Boss Mountain, Kitsault, Gibraltar, Island Copper, Lornex, Highmont, and others in the Highland Valley now in operation or in active development. The other deposits; such as Mt. Thomlison, with 40 million tons of 0.055 % Mo reserves, or Mt. Haskins, near Cassiar, with 15 million tons of 0.1 % Mo content, have to wait for the appropriate time and conditions for investment. Teck, which holds a 70 % interest in Shaft Creek, reportedly increased the resources of this deposit to 1 billion tons averaging 0.3 % Cu and 0.02 % Mo.

The British Columbia has virtually dozens of very promising copper-molybdenum and molybdenum porphyries or other types of deposits. Its potential has been developed only in the last 15-20 years and certainly has great for growth. In this context, it is interesting the recent purchase of Bethlehem Copper by Cominco.

which will certainly contribute to an intensification of exploitation of the Highland Valley deposit, such as the Jona, and J.A. and Maggie deposits, with an important molybdenum potential. British Petroleum and Utah Mines were exploring the Salal property, located 200 kms north of Vancouver, with a promising porphyry molybdenum potential.

Elsewhere in Canada and the United States, active exploration programs were carried out at Pine Grove, Utah, by Getty Oil and Phelps Dodge where well over 100 million tons of ore assaying and average of 0.12 % Mo were found. In New Mexico, US Geological Survey reported the discovery of a potentially economic mineralization at South Four Pean, just about 10 miles South of Questa Mine.

In Australia, exploration drilling by CSR Limited brought to discovery of a major primary molybdenum orebody at Mudgee, in New South Wales. The individual ore samples assay up to 0.4 % Mo but the extention of the deposit has not been determined yet.

In Latin America new exploration programs were set in Mexico, Chile and Peru. Argentina and Brazil have also shown some promising conditions for the molybdenum mineralization. In Mexico the main exploration effort has been concentrated in the state of Sonora, which is the continuation of the porphyry belt from Arizona and where such important deposits as Cananea and La Caridad were found. Cumobabi developed into an important national producer, while an exploration by AMAX and Mexicana de Cobre was in progress at the Meztli-Creston Deposit, near Opodepe, about 110 kms northeast of Hermosillo. So far 135, million tons of reserves, assaying an average of 0.05 % Mo were proved.

In Chile a new porphyry copper desposit, containing probably as much as 400 million tons of ore, was discovered south of Chuquicamata in the desert of Atacama. Utah International and Getty Oil announced, late in 1981, the discovery of Escondida, with copper grades between 1 and 2.3 % and with-likely molybdenum mineralization of 0.012 % Mo.

Elsewhere in the world, new molybdenum deposits were found in South Korea and China. In South Korea a joint-venture agreement has been subscribed between AMAX and Hyunday Corporation in exploration and development of a new orebody at Sangdong with 80 million tons of ore reserves assaying an average of 0.25 % Mo. On the other hand, the Chinese reported a new molybdenum find in the Shanxi Province. It is rumored that AMAX and Duval have sent their geologists to China and that both companies are considering joint ventures with the Chinese in the development of their molybdenum resources.

DEEP SEA RESOURCES : Molybdenum has been found not only in manganese nodules, which apart from copper, nickel and cobalt also contain minor but probably still recoverable amounts of molybdenum in the order of several hundred parts per million. Recent reports indicate that deep sea explorations of the ocenan floor led to the discovery of sulphide deposits just off the coast of Ecuador along a fault at the Galapagos Rift. The theory goes that mineral-laden hot water solutions, like those which form hydrothermal deposits, break through the ocean floor at great depths and in contact with near-zero cold water precipitate polymetallic sulphides that they carry with. This hot solutions seeping through the floor may continue for thousands of years, and materialize in substantial depositions. The recently discovered polysulphide deposit at the Galapagos Rift was found at

depths of some 2,400 mts, covering a surface of roughly 1,000 by 200 meters and was at least 45 mts thick. It is located about 500 kms west of Ecuador and contains substantial metallurgical values such as 10 % each of Cu and Fe, 0.1 % Mo and similar quantities of lead and vanadium, as well as 0.03 % each of silver and tin; plus 0.01 % each of zinc and cadmium. The volume of reserves was estimated at about 22.5 million metric tons and the estimated value of metals was about US $ 2 billion. Similar deposits are expected to be found in Pacific Ocean just off the US coast, at Gorda Ridge in Oregon and Juna de Fuca Ridge off the Washington State coast. This type of deposits will only increase the interest of consortia already engaged in the exploration and preparation for deep-sea mining of manganese nodules. Of particular interest are very high copper content of these minerals and the substantial silver and molybdenum credit which they may carry. Also, while the nodules have to be processed by costly hydrometallurgical methods to recover and separate their polymetallic content, these minerals, being sulphides, can be easily concentrated by a flotation process, which is considerably cheaper. Nevertheless, it is considered that at this time insufficient information exists on this type of deposits to actively consider their active exploration. The exploration has been carried out by US Department of Commerce scientists in a submergible vessel called Alvin, and the principal main data for this deposit were reported by the US National Ocean Survey.

SUMMARY OF MOLYBDENUM RESOURCES IN 1982

(in metric tons of molybdenum content)

	Primary Deposits	Co-Product Deposits	By-product Deposits	Total
UNITED STATES	1,532,000	137,000	616,000	2,285,000
SOVIET UNION	100,000	200,000	107,000	407,000
CANADA	177,500	40,000	122,000	339,500
CHILE	-	-	1,777,000	1,177,000
ALL OTHERS	30,500	-	169,000	199,500
TOTAL RECOVERABLE MOLYBDENUM - MT	1,840,000	377,000	2,791,000	5,008,000
INSTALLED PLANT CAPACITY - MT/year	77,810	22,300	38,890	139,000
PRODUCTION IN 1980	58,533	19,771	22,863	101,167

UNITED STATES

its world leadership in molybdenum production. While in 1978 the US molybdenum output amounted to 59,725 metric tons of Mo, or 59,7% of the world output, in 1980 it reached 68,251 tons or about 60% of the world total. This was due to a number of important projects which were expanded or in development. Had it not been for a great copper strike in 1980, the US share in world production would be even higher; the United States lost, due to this strike, an estimated 1,300 to 2,000 metric tons of molybdenum. This situation will become apparent in 1981 and 1982 when, apart from an extra recovery of molybdenum, a new production capacity will be developed.

The United States obtains its molybdenum output from 3 primary mines, Climax, Henderson and Questa, and about 17 by-product mines operated by 10 companies. The Climax and Henderson mines account for 68% of the national output, while Questa is now running down because of exhausted reserves; however, it will soon be replaced by a brand-new underground mine at Goat Hill, near the present Questa operation. Thus, its production, which in 1980 amounted to only 1,689 metric tons, will be expanded to about 9,000 tpy by 1984. Among the by-product mines, substantial gains were made by the Duval properties, which increased their combined production from 9,446 tons in 1978 to 10,671 tons in 1980. Duval, a subsidiary of Pennzoil, is the largest by-product producer in the United States and the second largest in the world, after CODELCO-Chile. All the other by-product mines operated more or less under standard conditions, with certain losses due to the copper strike. Particularly affected was Kennecott which in 1980 produced only 3,644 tons of Mo as compared to 5,120 tons in 1979. Kennecott's production capacity is expected to increase in the next few years, thanks to renovation and expansion programs at its Bingham and Chino properties. This is now particularly possible, after Kennecott merged, in 1981, with Standard Oil of Ohio (SOHIO). The Twin Buttes property of Anamax and the Mission Mine of ASARCO benefited from additional feed from a newly developed mine at Eisenhower, which split in equal parts its mining output, to be processed by both companies. This resulted in about 1,000 metric tons of additional molybdenum, which helped particularly Mission's falling molybdenum production. In addition to revamping the molybdenum production at its Morenci concentrator since 1979, Phelps Dodge now inaugurated a moly circuit at its Ajo plant. The production is relatively small, but high in rhenium content.

Apart from developing the new Goat Hill property at the old Questa mine, several other projects are now under consideration. In the first place, there is the expansion of the Henderson concentrator, by the addition of the fourth grinding circuit, which will bust the originally planned production of 22,600 tpy to an estimated 29,000 tpy. AMAX is also conducting extensive studies at Mt. Tolman for which it plans a 60,000 tpd operation with a potential output of 9,000 to 10,000 tpy of molybdenum. The other very promising project

is Mt. Emmons, with a visualized 30,000 to 33,000 tpd underground mine and a 10,000 to 13,500 tpy molybdenum output. Mt. Emmons is being programmed to be in operation by the end of this decade, while Mt. Tolman can be developed in 3 to 4 years depending on the market conditions. The next large project to enter operation is the Tonopah mine in Nevada, which was developed by Anaconda, a subsidiary of Atlantic Richfield at a cost of $ 200 million. This mine is already being given preliminary testing and will be in operation by October of 1981, producing an estimated 3,000 to 4,000 tpy of Mo, 1,800 tpy of copper and 200 to 250 tpy of silver. At the current silver prices, this precious metal seems to be the principal product of the mine. Anaconda is also installing a new by-product circuit at its property in Butte, Montana, at the Weed concentrator. This mine is expected to produce between 2,200 and 3,600 tpy of Mo depending on the ore mineralization in a new section of the orebody under development. This plant started its operation by mid 1981. The development of another new primary molybdenum mine was announced by US Borax in the beginning of 1981, when problems with the Alaskan Lands Act were satisfactorily solved. This mine, at Quartz Hill, is expected to be developed by 1987, with a milling capacity of 54,000 tpd, for an annual output of 18,000 metric tons of molybdenum. The project cost is expected to be about $ 870 million. In the by-product category, Philipp Brothers and Quintana Minerals Corporation are developing a 15,000 tpy operation in New Mexico, which is expected to enter into production in 1982 with 18,000 tpy of copper and 450 tpy of molybdenum.

With these new properties in production, the United States is going not only to mantain but even to improve its position in the world's molybdenum output.

The domestic uses of molybdenum in the United States are shown in attached tables prepared by the US Bureau of Mines. By comparing the molybdenum consumption in 1980 with that of 1979, it becomes apparent a 12% drop of the same because of recessive conditions in the American economy in 1980. Simultaneously, this produced, for the first time since 1972, a significant increase in the domestic producers and consumers stocks. This situation was also reflected in the exports, which dropped due to the recessive conditions in Western Europe. Although the 1980 molybdenum exports amounted to 31.985 metric tons of contained molybdenum as compared to 32,566 tons in 1979, much of this molybdenum remained unsold and stored in converting plants. The United States makes its exports in the form of molybdenite concentrate which accounts for about one half of all the molybdenum exports; in the form of technical molybdic oxide, which accounts for another 47%, and in the form of other primary products such as ferro-molybdenum, chemical compounds containing molybdenum, molybdenum wire and semi-fabricated parts which all together account for only 3% of all the molybdenum exports. The exports in the form of molybdenite concentrates

tion may cost around $ 31 million. (For more details see Sect.II).

TONOPAH (HALL) MINE - This mine, located in the San Antonio Mountains in Nye County, Nevada, about 20 miles north of Tonopah, is the property of Anaconda, a wholly owned subsidiary of Atlantic Richfield. The orebody was drilled for several years to prove some 250 million of low grade material containing an average of 0.05% Mo and 0.05% Cu. Only 100 million tons are considered ore, and they assay an average of 0.1% Mo and 0.07% Cu. In general, the molybdenum grade of the orebody varies between 0.015 and 0.15% Mo. There is about 28 million tons of material which should be pre-stripped before operations start in the last quarter of 1981. The iniciation of project was postponed due to ecological observations posted by the Land Management Bureau, but after these were remedied an investment of US $ 200 million was quickly approved and the project developed in a record time. The initial break-in operation started in August of 1981, and the plant will be in full operation by the end of the year. This project consists of an open pit mine and a 20,000 tpd concentrator able to produce between 5,500 and 6,800 metric tons of contained molybdenum per year in the form of molybdenite concentrate, assaying 90% MoS_2. The recoverable molybdenum reserves amount to about 85,000 tons of Mo, enough for about 15 years of operation. The open pit will have a stripping ratio of 1:3. Low grade material will be stockpiled separately for future consideration, and only ore which allows a reasonable income will be processed. Alternatives for US $ 5 and $ 7 per pound prices were considered. Although a production capacity of at least 5,500 metric tons per year of Mo can be achieved, present plans forsee the following output for the next six years, expressed in metric tons:

	1981	1982	1983	1984	1985	1986
Molybdenum	1,350	4,100	3,170	3,170	3,170	3,170
Copper	900	2,700	1,800	1,800	1,360	1,360
Silver	93	254	171	217	217	217

It should be observed, that at present prices revenue from silver may be 50% higher than from molybdenum, which makes this mine essentially a silver mine. Revenues from copper are of minor importance since they amount only to about 2 to 3 percent of total revenue.

TOQUEPALA - a subsidiary of the northern Peru Copper Corporation (51.7% ASARCO, 21.9% Cerro-Marmon Corporation, 16.1% Phelps Dogde and 16.1% Newmont), which started its operations in 1960 and molybdenum recovery in 1963 and experienced in the last few years considerable improvements in molybdenum metallurgy and recovery, which can be appreciated from the following figures:

WLK file Molybdenum

ASARCO

Rocky Mountain
Exploration Division

RECEIVED
JAN 28 1981
EXPLORATION DEPARTMENT

January 23, 1981

TO: W. L. Kurtz

FROM: D. M. Smith, Jr.

F, Mo, Pb Geochemistry
El Plomo Au Deposit
Costilla County, Colorado

Emission spectrographic (31-element) and chemical (F) analyses (Appendix) were performed on 138 samples collected by D. A. Wolfe (1979) from abandoned drill-hole cuttings at El Plomo. The results confirm our suspicion that F, Mo, and Pb are anomalous in the deposit. Individual results are described below:

F The bell-shaped histogram (Att. A) of the assays suggests that nearly all of the samples come from within an area anomalous in F. Values may be considered highly anomalous above 1600 ppm with a threshold (interval between background and anomalous) falling at 1200 ppm.

Mo A plot of Mo assays (Att. B) shows a more traditional background-to-anomaly relationship with a threshold at 10 ppm and anomalous values commencing at 50 ppm.

Pb Use of the 50 ppm emission-spec detection interval to prepare a histogram of Pb assays (Att. C) proved totally unsatisfactory. The unusual pattern thus produced probably reflects the inherent sensitivity biases of the instrumentation rather than any unique geochemical distribution of Pb in the deposit. A coarser plot of the data (Att. D) using 500 ppm intervals shows Pb to be anomalous above 1000 ppm.

Other elements commonly included in the indicator suite for Mo deposits behave in singularly unspectacular fashion:

Sn All samples <10 ppm.

W Only 7 of 138 samples assayed >50 ppm.

Zn All samples <200 ppm.

WLK - Is this to be refiled or do you want in your office? -S Refile

The remainder of the group of elements often found associated with low-grade

xc PGV 3/10/82

Au deposits also failed to register:

As All samples <500 ppm.

Sb All samples <100 ppm.

Ag Values exceeding the detection limit of 1 ppm were found in 48 of the 138 samples, but only 6 assays of 5 ppm or better were obtained.

Hg Not assayed.

The geochemistry of the El Plomo deposit compares quite favorably with the data available for buried molybdenum deposits located elsewhere in the southern Rocky Mountain and eastern Great Basin regions. This is especially true when it is remembered that few of the deposits appear to contain the entire suite of indicator elements. Brief descriptions of the surface geochemistry associated with several established and rumored ore bodies follows:

Mount Emmons, Gunnison County, Colorado: 165×10^6 + @ 0.43% MoS_2. Amax geologists (Smith, 1978, A, B) report that Pb, Zn, Cu, F, W, Rb/Sr and Rb/K are anomalous in rock chip or stream sediment samples at the surface 1300 ft. above the ore body, but specific values are not available. Mo is not found at the surface except in a single dike of intrusive breccia which assays 200 to 240 ppm. Outward distance from 0.2% MoS_2 to "background" Mo is about 700 ft. Approximately coinciding with the surface projection of the ore zone is the 1500 ppm F contour. The Keystone base-metal vein system is located adjacent to the east side of the Mo ore body, but does not penetrate it. During the period of 1955 to 1967 the veins produced a total of 473,822 tons of ore averaging 5.60 oz Ag, 0.70% Cu, 5.60% Zn, and 2.60% Pb (Smith, 1978A).

Redwell Basin, Gunnison County, Colorado: 29×10^6 + @ .18% MoS_2 and 100×10^6 + @ 0.16% MoS_2. Molybdenite zones occur at 2600 ft. and 4000 ft. below the surface outcrop of two nested breccia pipes of latitic composition. The larger of the two mineralized bodies is the deeper. Sharp (1978) describes the geochemistry of the deposit: Mo values >20 ppm are seldom found at the surface and assays >500 ppm are not encountered until 1800 ft. below the outcrop. WO_3 values >100 ppm first appear at a depth of about 1700 ft. Sn >50 ppm and averaging 86 ppm is found from the surface to 2100 ft. below outcrop and again from 2400 ft. to 4700 ft. Pb values >500 ppm and averaging 3256 ppm are found at the surface, extending to a depth of 1000 ft. Zn values >500 ppm, averaging 4813 ppm extend from the surface to a maximum depth of 2500 ft. Cu values >100 ppm and averaging 528 ppm occur at the surface and reach to a depth of 3000 ft. Petrographic estimates of fluorite contents "range as high as 10%" and "quantitative measurements were as much as 3% fluorite for 10-foot core samples."

No quantitative data are presented for the vertical distribution of fluorite; however, its presence is reported from outcrop to a depth of at least 4500 ft. An average Ag content of 30 to 60 ppm is reported by sources other than Sharp to exist in the Pb-Zn zone.

Henderson, Clear Creek County, Colorado: 300×10^6 + @ 0.49% MoS_2. The geochemical picture at Henderson is somewhat obscured by the presence of the older Urad ore body, remnants of which are located only a few hundred feet below the surface of Red Mountain. Directly below the Urad ore zone at a depth of about 4000 ft. from the surface is the top of the Henderson ore body. In a manuscript submitted to Economic Geology, Bright and White (1975) describe primary trace element dispersion associated with the Henderson molybdenum deposit: The top of the Henderson-related 10 ppm Mo halo is located 2300 ft. below the top of Red Mountain and 1500 ft. above the top of the 1000 ppm Mo zone. An anomaly of 2000 ppm F is nearly pervasive at the surface, but the 5000 ppm zone is not reached until a depth of 2500 ft. Pb is not anomalous at the surface. The 500 ppm Pb zone begins at a depth of 800 ft, 2800 ft. above the top of 1000 ppm Mo, and continues intermittently to a depth of 4200 ft. The 1000 ppm Pb zone is found only between depths of 800 ft. and 2700 ft. W values >50 ppm occur only within the 60 ppm Mo zone. The outer edge of the >50 ppm zone is located from 500 ft. to 1500 ft. out from the 60 ppm Mo zone. Zn >500 ppm extends 2000 ft. to 3000 ft. outwards from the 60 ppm zone. In general the elements Be, F, Mo, and W increase towards ore. Elements which tend to form halos around the ore zone are Ag, Bi, Cr, Cu, La, Mn, Pb, Sn, V, and Zn.

Cave Peak, Culberson County, Texas: no published reserves. The Cave Peak breccia pipe complex described by Sharp (1979) contains at least 3 individual molybdenite zones. The shallowest molybdenite mineralization is exposed at the surface and the 60 ppm contour of the deepest tops out at a depth of 2100 ft. Distances between the 1500 ppm Mo and 60 ppm Mo contours vary between 30 ft. and 250 ft. W values >400 ppm are restricted to a zone which closely parallels the 60 ppm Mo contour and generally occurs within 200 ft. of it. Sn assay values for 5-foot core samples range from 125 to 540 ppm and are restricted to areas within the W and Mo zones. A "low intensity zone" of +1.3% to 3% CaF_2 completely overlaps the molybdenite zones and extends up to 200 ft. beyond the 60 ppm Mo boundary. Values exceeding +3.1% CaF_2 are coextensive with the upper 600 ppm Mo zone. Apparently absent from the system are Pb, Zn, and precious metals, perhaps due to the deep level of erosion suggested by the presence of +0.25% MoS_2 at the surface.

Pine Grove, Beaver County, Utah: 55 to 135×10^6 + @ 0.29 to 0.38% MoS_2. Vein and limestone replacement deposits occur at the surface. Welch (1939) estimated the grade of vein ore occurring in the Wah Wah mine at Pine Grove to be 0.05 oz Au, 6.62 oz Ag, and 8.25% Pb per ton with Zn <1%. Courtright (1979) reports values in latite of up to 500 ppm

Pb and Zn with up to 15 ppm Ag, but <2 ppm Mo, down to a depth of ± 1500 ft. Mo is anomalous at the surface only in pebble dikes. Mo mineralization extends from 2950 ft. to 7050 ft. below the surface (Abbot and Williams, 1981). Fluorite is a gangue constituent of the vein and replacement deposits. Information about the geochemistry of other elements is not available.

Mount Hope, White Pine County, Nevada: rumored discovery. A redimentary graphic log of Phillips Petroleum Corp's 1971 ddh-15 (SWED files) shows ZnS reported below a depth of 600 ft, but only a single occurrence of PbS, at about 1175 ft., was noted. Molybdenite and fluorite are logged as appearing concurrently at 1315 ft. and persisting to the bottom of the 2000-foot hole. The interval from 1476 ft. to 1968 ft. (492 ft.) assayed 0.075% MoS_2 which is equivalent to 450 ppm Mo. Two rotary holes drilled in 1974, MH-1 and MH-2, on the TIA claim group at Mount Hope (SWED files) contained interesting geochemical values which may relate to the rumored discovery, but spacial relationships are not known and unlike the Phillips hole, no intrusive rocks were reported:

	MH-1 (735 ft.)	MH-2 (397 ft.)
Pb	28 ppm, 0 to 735 ft.	121 ppm, 0 to 40 ft. 26 ppm, 40 to 397 ft.
Zn	7400 ppm, 0 to 430 ft. 60 ppm, 430 to 735 ft.	2076 ppm, 0 to 230 ft. 52 ppm, 230 to 397 ft.
Mo	7 ppm, 0 to 150 ft. 35 ppm, 150 to 190 ft. 5 ppm, 190 to 320 ft. 30 ppm, 320 to 735 ft.	46 ppm, 0 to 397 ft.
Ag	<1 ppm, 0 to 90 ft. 2.3 ppm, 90 to 260 ft. <1 ppm, 260 to 330 ft. 1.6 ppm, 330 to 430 ft. <1 ppm, 430 to 570 ft. 1 ppm, 570 to 650 ft. <1 ppm, 650 to 735 ft.	5.8 ppm, 0 to 230 ft. <1 ppm, 230 to 397 ft.
Au	<1 ppm, 0 to 735 ft.	<1 ppm, 0 to 397 ft.

Questa, Taos County, New Mexico: 20.5×10^6 + @ 0.297% MoS_2 (original open pit reserve). Data concerning the geochemistry of the three major ore bodies at Questa (open pit, Goat Hill, Flag Mountain) have not been published. Carpenter (1968) refers to fluorite - base-metal fillings in re-opened quartz-molybdenite veins within the deposit, but provides no further details.

Several generalizations about the geochemistry of molybdenum deposits can be made from the capsule descriptions provided above. Mo values >20 ppm seldom persist for more than 1500 ft. outward from molybdenite ore zones and often the dispersion is much less. Anomalous Sn and W values are closely tied in space to the higher grade portions of the Mo zones, although Sn does tend to get further away than W. F values >1500 ppm appear to be common at distances of more than 3800 ft. above the tops of ore bodies. Pb and/or Zn with or without detectable amounts of precious metals form anomalies at the intermediate levels of porphyry Mo systems. Pb values >500 ppm may range from the ore zone outward to a distance of at least 3000 ft., but seem to be most prevalent in the interval of 1200 to 2800 ft. Zn values >500 ppm are reported to occur as close as 100 ft. to ore-grade Mo and to extend as far away as 3400 ft. The average >500 ppm Zn zone is located from 1400 ft. to 3000 ft. out from ore.

Applying the data from the preceding paragraph to the anomalous values obtained for El Plomo it can be inferred that 1500 ppm F indicates that the distance to a molybdenite zone should be less than +3800 ft., while 1000 ppm Pb indicates a distance of 1200 to 2800 ft., and 50 ppm Mo suggests that the distance is less than 1500 ft. Metal anomalies are certainly not sure-fire guides to ore, but the experience of the last decade dictates that all Mo-F-Pb-Zn anomalies should be very carefully evaluated before they are discarded. In the case of El Plomo the geochemical indications are good. An important detracting aspect, however, is the lack of any associated intrusive (perhaps eruptive) feature of the magnitude of those recognized at virtually all of the established molybdenite deposits.

D. M. Smith Jr.

Douglas M. Smith, Jr.

DMS:cej

cc: FTG
LDJ
DAW

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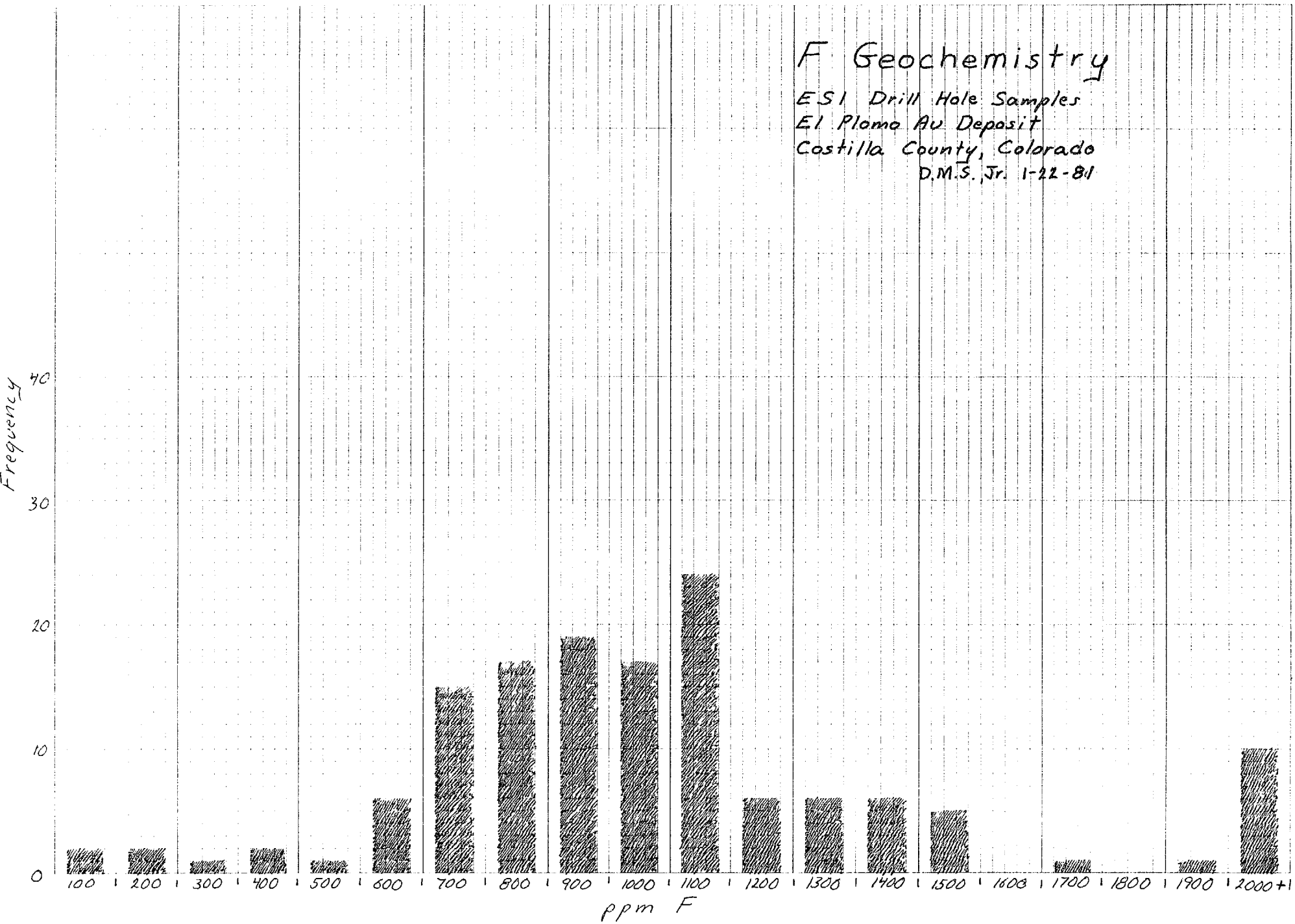
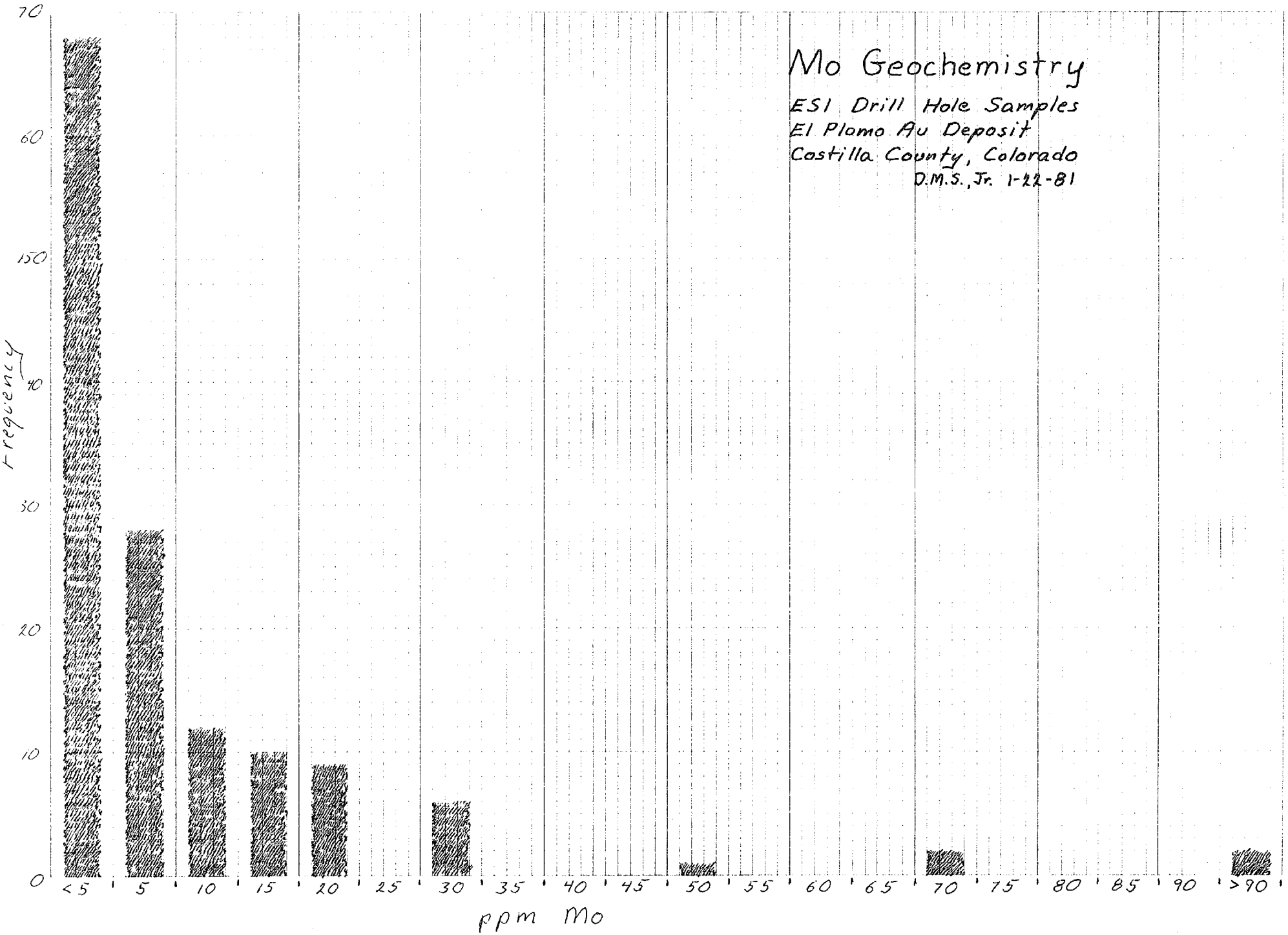
KEUFFEL & ESSER CO. MADE IN U.S.A.



Attachment A

10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.



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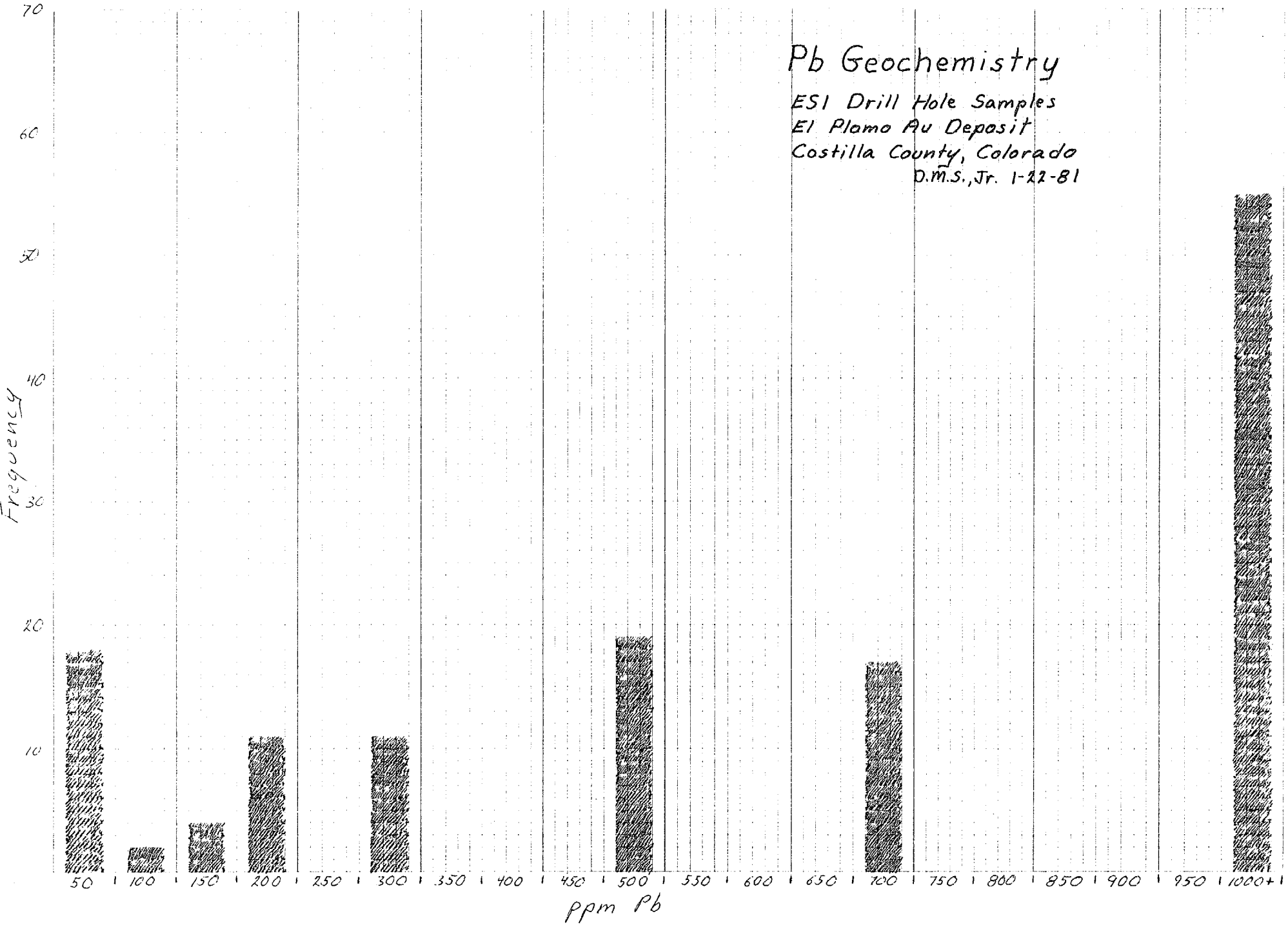

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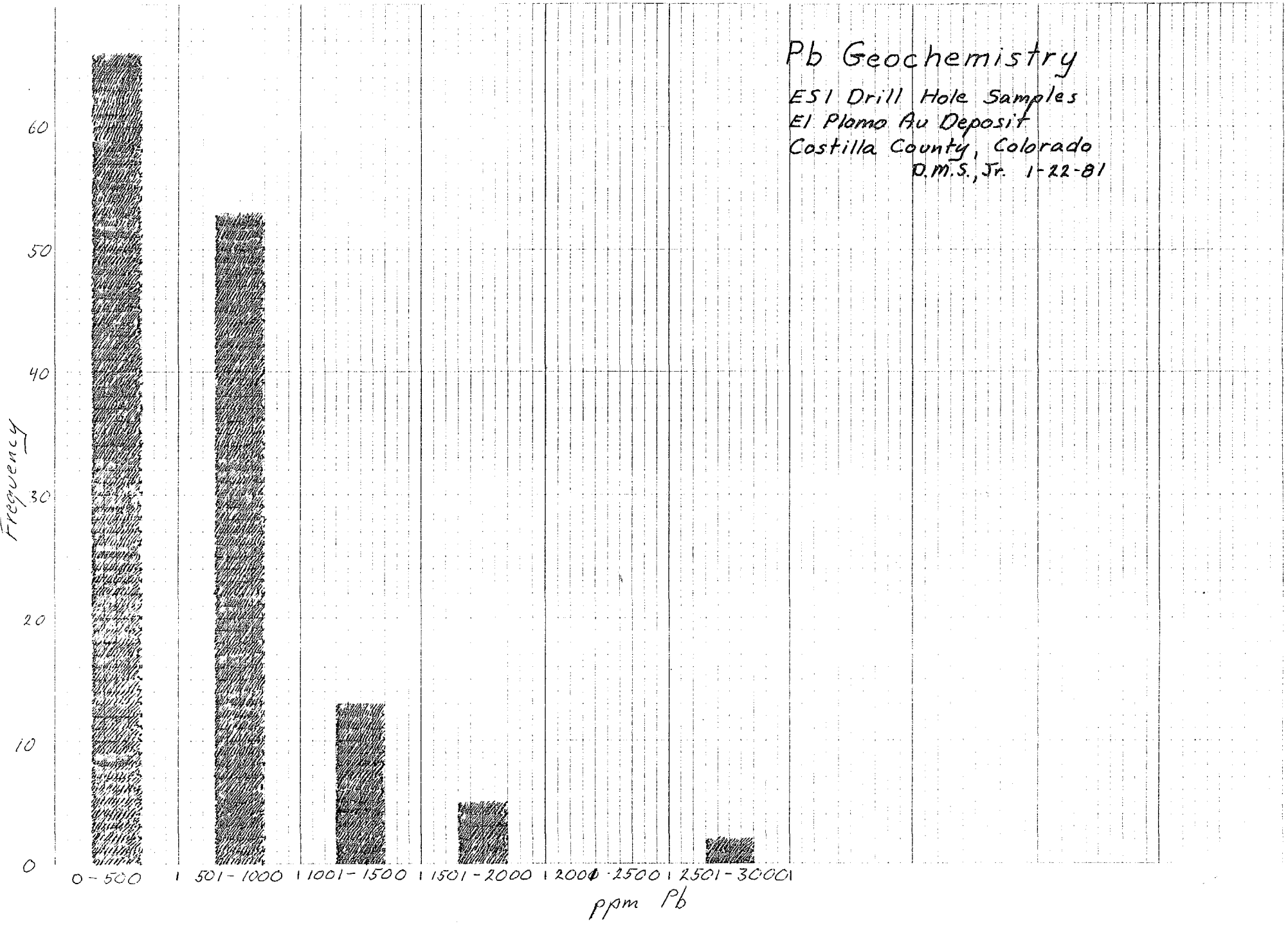

Attachment D

TAB

Appendix

JOB NO. DCR 110
January 7, 1981
PAGE 3

ITEM	SAMPLE NUMBER	F (%)
10	ELP 01	.054
11	ELP 02	.044
12	ELP 03	.190
13	ELP 04	.066
14	ELP 05	.092
15	ELP 06	.072
16	ELP 07	.080
17	ELP 08	.027
18	ELP 09	.016
19	ELP 10	.037
20	ELP 11	.016
21	ELP 12	.130
22	ELP 13	.110
23	ELP 14	.068
24	ELP 15	.080
25	ELP 16	.048
26	ELP 17	.026
27	EP 01	.130
28	EP 02	.540
29	EP 03	.110
30	EP 04	.086
31	EP 05	.360
32	EP 06	.260
33	EP 07	.170
34	EP 08	.100
35	EP 09	.100
36	EP 11	.068
37	EP 13	.098
38	EP 15	.090
39	EP 17	.110
40	EP 18	.092
41	EP 19	.078
42	EP 20	.110
43	EP 21	.120
44	EP 22	.130

ITEM	SAMPLE NUMBER	F (%)
45	EP 23	.200
46	EP 24	.100
47	EP 25	.110
48	EP 26	.072
49	EP 27	.064
50	EP 28	.400
51	EP 29	.150
52	EP 30	.082
53	EP 31	.100
54	EP 32	.270
55	EP 33	.100
56	EP 34	.100
57	EP 35	.110
58	EP 36	.110
59	EP 38	.110
60	EP 39	.130
61	EP 40	.150
62	EP 41	.110
63	EP 42	.110
64	EP 43	.110
65	EP 44	.110
66	EP 45	.082
67	EP 46	.080
68	EP 47	.092
69	EP 48	.100
70	EP 49	.082
71	EP 50	.092
72	EP 52	.086
73	EP 53A	.090
74	EP 53B	.060
75	EP 54	.100
76	EP 55	.096
77	EP 56	.110
78	EP 57	.100
79	EP 58	.140

ITEM	SAMPLE NUMBER	F (%)
80	EP 59	.110
81	EP 60	.092
82	EP 61	.086
83	EP 62	.068
84	EP 64	.084
85	EP 65	.070
86	EP 66	.072
87	EP 67	.092
88	EP 68	.092
89	EP 69	.086
90	EP 70	.072
91	EP 71	.072
92	EP 72	.084
93	EP 73	.076
94	EP 74	.110
95	EP 75	.080
96	EP 76	.072
97	EP 77	.078
98	EP 78	.070
99	EP 79	.100
100	EP 80	.110
101	EP 81	.086
102	EP 82	.110
103	EP 83	.150
104	EP 85	.078
105	EP 86	.100
106	EP 87	.076
107	EP 89	.092
108	EP 90	.100
109	EP 93	.110
110	EP 94	.098
111	EP 95	.130
112	EP 96	.096
113	EP 97	.110
114	EP 98	.086

ITEM	SAMPLE NUMBER	F (%)
115	EP 100	.078
116	EP 101	.120
117	EP 103	.100
118	EP 104	.100
119	EP 105	.098
120	EP 106	.130
121	EP 107	.110
122	EP 108	.080
123	EP 109	.100
124	EP 110	.100
125	EP 111	.110
126	EP 112	.092
127	EP 113	.090
128	EP 114	.120
129	EP 115	.110
130	EP 116	.110
131	EP 117	.110
132	EP 118	.120
133	EP 119	.150
134	EP 120	.140
135	EP 121	.120
136	EP 122	.140
137	EP 123	.200
138	EP 124	.140
139	EP 125	.096
140	EP 126	.120
141	EP 127	.140
142	EP 128	.140
143	EP 129	.036
144	EP 130	6.000
145	EP 131	.072
146	EP 132	.260
147	EP 133	.150

Gordon H. VanSickle
Manager

SKYLINE LABS, INC.
SPECIALISTS IN EXPLORATION GEOCHEMISTRY
12090 WEST 50TH PLACE • WHEAT RIDGE, COLORADO 80033 • TEL.: (303) 424-7718

REPORT OF SPECTROGRAPHIC ANALYSIS

JOB NO. DCR 110
January 7, 1979

ASARCO, Inc.
Attn: David A. Wolfe
9305 W. Alameda Parkway, #202
Lakewood, Colorado 80226

Analysis of 138 Pulp Samples

The attached pages comprise this report of analysis. Values are reported in parts per million (ppm), except where otherwise noted, to the nearest number in the series 1, 1.5, 2, 3, 5, 7, 10, etc. within each order of magnitude. These numbers represent the approximate boundaries and midpoints of arbitrary ranges of concentration differing by the reciprocal of the cube root of ten. The 'accepted' value is considered to be within + or - 1 step of the range reported at the 68 % confidence level and within + or - 2 steps at the 95 % confidence level.

Gordon H. VanSickle
Manager

JOB NO. DCR 110
PAGE 1

ITEM NO.	SAMPLE NO.
10	ELP 01
11	ELP 02
12	ELP 03
13	ELP 04
14	ELP 05
15	ELP 06
16	ELP 07
17	ELP 08

ITEM	10	11	12	13	14	15	16	17
ELEMENT								
Fe	1.5%	2%	3%	2%	3%	2%	1.5%	1%
Ca	<0.02%	0.02%	7%	0.02%	0.02%	0.02%	<0.02%	0.03%
Mg	0.1%	0.07%	1%	0.1%	0.15%	0.15%	0.15%	0.05%
Ag	<1	<1	<1	20	1	2	<1	<1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	<10	<10	10	<10	<10	<10	<10	<10
Ba	200	50	300	700	150	500	700	1000
Be	<2	<2	2	<2	<2	<2	<2	<2
Bi	<10	<10	<10	20	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	20	20	<5	<5	<5	<5	<5
Cr	150	150	70	100	200	150	100	50
Cu	3	20	30	20	10	30	2	3
Ga	<10	<10	20	10	10	<10	10	10
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	<20	<20	20	20	20	100	20	30
Mn	20	20	2000	50	50	50	50	500
Mo	30	100	<2	15	10	30	<2	<2
Nb	<20	<20	20	20	20	20	<20	<20
Ni	5	10	20	<5	7	5	5	<5
Pb	10	10	15	100	10	15	20	15
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	10	<10	<10	<10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	150	<100	<100	<100	<100	100
Ti	700	700	3000	2000	1500	1500	1000	700
V	10	15	100	10	20	20	10	<10
W	<50	<50	<50	<50	<50	<50	<50	<50
Y	<10	<10	10	10	20	10	<10	10
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	70	100	30	200	50	200	150	100

JOB NO. DCR 110
PAGE 2

ITEM NO.	SAMPLE NO.
18	ELP 09
19	ELP 10
20	ELP 11
21	ELP 12
22	ELP 13
23	ELP 14
24	ELP 15
25	ELP 16

ITEM	18	19	20	21	22	23	24	25
ELEMENT								
Fe	0.2%	3%	0.2%	2%	1.5%	1%	2%	2%
Ca	<0.02%	0.03%	<0.02%	2%	0.7%	0.02%	0.03%	0.02%
Mg	0.02%	0.15%	0.02%	0.7%	0.2%	0.2%	0.3%	0.2%
Ag	<1	<1	<1	<1	<1	<1	<1	<1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	<10	<10	<10	10	10	10	10	10
Ba	<10	2000	1000	500	700	700	5000	1500
Be	<2	<2	<2	2	3	2	2	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	<5	<5	<5	<5	<5	5	<5
Cr	200	100	150	70	70	70	70	70
Cu	2	2	3	5	2000	15	10	7
Ga	<10	15	<10	10	10	10	10	10
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	<20	50	<20	20	100	20	20	70
Mn	100	700	100	5000	1000	150	1500	1000
Mo	<2	2	<2	<2	<2	<2	20	70
Nb	<20	20	<20	20	20	30	20	20
Ni	<5	5	5	15	10	5	7	5
Pb	<10	10	<10	10	10	200	20	10
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	<10	<10	<10	<10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	<100	100	<100	<100	<100	<100
Ti	20	1500	50	2000	1500	500	1000	1500
V	<10	10	<10	70	10	<10	15	10
W	<50	<50	<50	<50	<50	<50	<50	<50
Y	<10	20	<10	10	50	<10	<10	10
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	<20	150	<20	50	200	100	200	200

JOB NO. DCR 110
PAGE 3

ITEM NO.	SAMPLE NO.
26	= ELP 17
27	= EP 01
28	= EP 02
29	= EP 03
30	= EP 04
31	= EP 05
32	= EP 06
33	= EP 07

ITEM	26	27	28	29	30	31	32	33
ELEMENT								
Fe	5%	2%	1%	3%	3%	3%	2%	3%
Ca	<0.02%	0.5%	0.15%	0.02%	0.05%	0.2%	0.5%	0.07%
Mg	0.1%	0.5%	0.1%	0.15%	0.05%	0.2%	0.2%	0.05%
Ag	<1	<1	<1	1	1	1	<1	1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	<10	10	<10	10	10	10	10	<10
Ba	700	700	700	200	500	300	200	50
Be	<2	2	<2	<2	<2	<2	2	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	20	5	100	10	50	30	70
Cr	200	70	50	100	30	70	50	100
Cu	5	100	70	200	100	200	200	20
Ga	<10	10	10	10	10	10	10	<10
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	<20	50	20	20	<20	20	20	<20
Mn	200	700	200	30	30	50	200	30
Mo	<2	<2	<2	7	20	15	15	5
Nb	20	<20	<20	20	20	<20	<20	<20
Ni	5	10	5	20	5	15	10	15
Pb	<10	1000	1000	300	1000	200	200	200
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	<10	<10	<10	<10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	<100	<100	100	<100	<100	<100
Ti	3000	2000	1000	1500	700	1000	1500	300
V	50	20	10	20	20	15	30	<10
W	<50	<50	<50	50	<50	<50	<50	100
Y	<10	10	<10	<10	<10	<10	<10	<10
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	<20	20	100	150	100	150	150	70

JOB NO. DCR 110
PAGE 4

ITEM NO.	SAMPLE NO.
34	EP 08
35	EP 09
36	EP 11
37	EP 13
38	EP 15
39	EP 17
40	EP 18
41	EP 19

ITEM	34	35	36	37	38	39	40	41
ELEMENT								
Fe	2%	2%	5%	2%	1.5%	2%	1.5%	7%
Ca	0.02%	0.03%	0.02%	<0.02%	0.03%	0.07%	0.02%	0.05%
Mg	0.2%	0.15%	0.15%	0.2%	0.15%	0.2%	0.3%	0.15%
Ag	1	1	3	1	2	<1	<1	<1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	10	10	10	10	10	10	10	15
Ba	1000	1500	700	1000	1000	1000	500	300
Be	<2	<2	<2	<2	<2	<2	2	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	5	5	<5	5	7	<5	20
Cr	30	50	70	50	70	100	70	70
Cu	150	200	200	150	300	20	50	100
Ga	15	15	10	10	10	10	20	10
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	50	70	<20	20	50	70	<20	<20
Mn	70	70	50	50	50	300	200	50
Mo	2	2	20	10	10	<2	<2	150
Nb	20	20	20	<20	20	<20	100	20
Ni	<5	<5	5	<5	<5	7	5	7
Pb	300	200	1000	700	300	2000	1000	500
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	<10	<10	<10	<10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	<100	<100	<100	<100	<100	<100
Ti	1500	1500	1500	1500	2000	1000	200	700
V	<10	<10	<10	10	10	10	<10	10
W	<50	<50	<50	<50	50	<50	<50	<50
Y	10	15	10	15	20	20	30	10
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	200	500	500	300	200	150	100	150

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ITEM NO.	SAMPLE NO.
42	EP 20
43	EP 21
44	EP 22
45	EP 23
46	EP 24
47	EP 25
48	EP 26
49	EP 27

ITEM	42	43	44	45	46	47	48	49
ELEMENT								
Fe	1.5%	3%	2%	3%	3%	3%	3%	2%
Ca	0.03%	0.3%	0.3%	0.5%	0.15%	0.02%	0.03%	0.02%
Mg	0.2%	0.2%	0.15%	0.3%	0.15%	0.2%	0.1%	0.15%
Ag	<1	<1	<1	<1	1	1	1	<1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	10	10	10	10	10	10	<10	10
Ba	1500	500	500	700	300	700	500	500
Be	<2	2	<2	2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	7	5	10	<5	<5	<5	<5
Cr	70	70	50	50	100	70	150	100
Cu	20	70	50	70	150	100	20	30
Ga	10	10	10	15	10	10	<10	<10
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	50	20	30	30	<20	<20	20	<20
Mn	100	500	300	700	150	50	20	30
Mo	3	<2	2	2	50	15	20	15
Nb	20	20	20	20	20	20	<20	20
Ni	5	5	5	7	10	10	5	7
Pb	1000	200	500	500	1000	1000	300	300
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	<10	<10	<10	<10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	<100	<100	<100	100	<100	<100
Ti	1000	1500	1000	2000	700	1500	1000	1000
V	10	30	10	30	20	50	30	20
W	<50	<50	<50	<50	<50	<50	<50	<50
Y	10	<10	<10	20	<10	<10	<10	<10
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	150	150	150	200	100	100	100	100

ITEM NO. SAMPLE NO.
50 = EP 28
51 = EP 29
52 = EP 30
53 = EP 31
54 = EP 32
55 = EP 33
56 = EP 34
57 = EP 35

ITEM	50	51	52	53	54	55	56	57
ELEMENT								
Fe	3%	5%	3%	5%	3%	3%	3%	3%
Ca	0.15%	0.07%	0.02%	0.05%	0.2%	<0.02%	0.02%	0.03%
Mg	0.05%	0.07%	0.1%	0.15%	0.2%	0.15%	0.15%	0.15%
Ag	1.5	3	2	2	<1	<1	<1	<1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	10	10	10	10	10	10	10	10
Ba	100	100	150	100	300	700	700	1000
Be	<2	<2	<2	<2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	30	150	70	150	10	15	15	10
Cr	70	150	70	150	70	70	70	100
Cu	50	150	70	150	10	20	50	50
Ga	<10	<10	<10	10	15	10	10	15
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	<20	<20	<20	20	20	30	50	100
Mn	10	30	20	100	300	50	50	70
Mo	20	20	30	20	2	3	3	5
Nb	20	20	20	20	20	20	20	20
Ni	7	50	20	30	10	5	5	5
Pb	150	1000	200	700	1000	1000	1000	2000
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	<10	<10	<10	<10	10	10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	<100	<100	<100	<100	<100	<100
Ti	700	700	1500	1500	2000	2000	2000	1500
V	20	20	20	50	50	10	10	10
W	<50	100	<50	50	<50	<50	<50	<50
Y	<10	<10	<10	<10	<10	20	15	20
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	70	50	70	70	200	200	300	300

ITEM NO.	SAMPLE NO.
58	EP 36
59	EP 38
60	EP 39
61	EP 40
62	EP 41
63	EP 42
64	EP 43
65	EP 44

ITEM	58	59	60	61	62	63	64	65
ELEMENT								
Fe	2%	5%	3%	3%	5%	3%	3%	3%
Ca	0.5%	0.05%	0.03%	0.1%	<0.02%	0.1%	0.03%	0.05%
Mg	0.15%	0.2%	0.3%	0.15%	0.2%	0.2%	0.2%	0.2%
Ag	<1	<1	<1	<1	1	<1	3	<1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	10	10	10	10	10	10	10	10
Ba	1000	1500	1000	1500	700	1000	1500	1500
Be	<2	<2	<2	<2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	15	<5	<5	<5	<5	<5	<5
Cr	50	70	70	50	50	100	100	100
Cu	7	10	70	10	10	15	10	15
Ga	10	15	15	10	10	10	20	15
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	100	20	20	50	70	50	70	70
Mn	700	100	50	200	50	200	100	150
Mo	2	5	3	2	10	5	5	2
Nb	20	20	20	20	20	20	20	20
Ni	7	5	7	5	5	7	5	7
Pb	3000	500	1000	500	2000	700	2000	1000
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	10	10	10	<10	10	<10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	100	<100	<100	<100	<100	<100
Ti	1500	2000	2000	1500	2000	1500	2000	2000
V	10	15	20	<10	20	10	10	10
W	<50	<50	<50	<50	<50	<50	<50	<50
Y	20	30	20	20	20	20	30	20
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	200	300	200	200	200	300	500	500

ITEM NO.	SAMPLE NO.
66	EP 45
67	EP 46
68	EP 47
69	EP 48
70	EP 49
71	EP 50
72	EP 52
73	EP 53A

ITEM	66	67	68	69	70	71	72	73
ELEMENT								
Fe	2%	5%	5%	3%	3%	5%	2%	3%
Ca	0.02%	0.02%	0.03%	0.03%	0.5%	0.5%	<0.02%	0.02%
Mg	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.15%	0.2%
Ag	<1	<1	<1	<1	<1	<1	<1	<1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	10	10	10	10	10	10	10	10
Ba	1000	1500	1500	1500	2000	1500	1000	1500
Be	<2	<2	<2	<2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	10	20	5	<5	<5	<5	<5
Cr	200	150	50	100	70	70	70	150
Cu	200	30	15	100	20	30	7	50
Ga	<10	15	10	10	15	20	10	15
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	50	100	70	100	100	150	20	50
Mn	50	70	70	100	700	700	50	50
Mo	2	7	7	3	2*	2*	10	3
Nb	20	20	20	20	30	30	<20	<20
Ni	5	5	5	5	5	5	5	5
Pb	1000	1500	150	700	500	1000	500	500
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	<10	<10	10	10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	<100	<100	100	100	<100	<100
Ti	1500	2000	2000	2000	3000	5000	1000	1500
V	10	10	<10	20	10	15	15	10
W	<50	<50	<50	<50	<50	<50	<50	<50
Y	20	30	20	20	50	50	<10	10
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	500	200	700	500	500	700	150	300

ITEM NO.	SAMPLE NO.
74	EP 53B
75	EP 54
76	EP 55
77	EP 56
78	EP 57
79	EP 58
80	EP 59
81	EP 60

ITEM	74	75	76	77	78	79	80	81
ELEMENT								
Fe	2%	3%	3%	3%	3%	5%	2%	2%
Ca	1%	0.03%	0.7%	0.03%	0.05%	0.1%	0.02%	0.03%
Mg	0.2%	0.3%	0.2%	0.3%	0.3%	0.2%	0.2%	0.2%
Ag	<1	<1	<1	<1	<1	1	<1	<1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	10	10	10	10	10	10	10	10
Ba	2000	2000	2000	2000	2000	2000	2000	2000
Be	<2	<2	<2	<2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	20	<5	5	<5	<5	20	<5	<5
Cr	70	70	100	100	70	100	100	100
Cu	30	300	20	150	50	50	100	7
Ga	15	10	15	20	20	15	15	15
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	<20	70	50	50	100	100	70	70
Mn	1000	70	700	100	200	200	70	70
Mo	3	2	2	7	5	15	5	2
Nb	20	20	20	30	30	30	20	20
Ni	15	<5	5	5	5	5	5	<5
Pb	1000	500	2000	300	500	500	300	700
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	10	<10	10	<10	10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	200	<100	<100	<100	<100	<100	<100	100
Ti	1500	3000	2000	3000	2000	2000	2000	1500
V	10	20	10	15	10	10	10	10
W	50	<50	<50	<50	<50	<50	<50	<50
Y	20	20	30	20	20	50	15	15
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	100	500	300	500	200	500	300	200

ITEM NO. SAMPLE NO.
82 = EP 61
83 = EP 62
84 = EP 64
85 = EP 65
86 = EP 66
87 = EP 67
88 = EP 68
89 = EP 69

ITEM	82	83	84	85	86	87	88	89
ELEMENT								
Fe	2%	3%	2%	3%	3%	2%	2%	2%
Ca	0.07%	0.02%	0.03%	0.02%	0.02%	0.03%	<0.02%	0.05%
Mg	0.2%	0.15%	0.2%	0.15%	0.15%	0.2%	0.15%	0.15%
Ag	<1	<1	<1	<1	<1	1	2	<1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	10	10	10	10	10	10	10	10
Ba	1000	1000	1500	1000	1000	1000	700	700
Be	<2	<2	<2	<2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	<5	<5	20	7	<5	<5	<5
Cr	100	150	70	100	100	70	70	100
Cu	10	30	20	300	100	15	15	15
Ga	10	10	15	10	10	10	10	10
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	100	50	70	70	70	100	20	50
Mn	150	70	100	2000	200	70	50	100
Mo	<2	10	<2	20	15	<2	<2	<2
Nb	20	20	20	20	20	20	20	<20
Ni	<5	5	<5	5	5	5	5	7
Pb	150	1500	1000	1000	500	200	700	700
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	<10	<10	<10	<10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	<100	<100	<100	<100	<100	<100
Ti	2000	2000	2000	1000	2000	2000	1000	1500
V	10	10	10	10	10	10	10	15
W	<50	<50	<50	<50	<50	<50	<50	<50
Y	20	20	30	20	20	15	<10	<10
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	700	300	300	20	300	300	100	200

ITEM NO.	SAMPLE NO.
90	= EP 70
91	= EP 71
92	= EP 72
93	= EP 73
94	= EP 74
95	= EP 75
96	= EP 76
97	= EP 77

ITEM	90	91	92	93	94	95	96	97
ELEMENT								
Fe	2%	2%	2%	3%	2%	3%	3%	3%
Ca	0.02%	<0.02%	<0.02%	0.5%	0.03%	0.5%	0.7%	0.1%
Mg	0.15%	0.15%	0.2%	0.2%	0.2%	0.15%	0.15%	0.15%
Ag	1	<1	<1	<1	1	<1	<1	<1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	10	10	10	<10	10	10	10	10
Ba	1000	700	1000	1000	1500	1500	1500	1000
Be	<2	<2	<2	<2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	5	7	<5	<5	<5	<5	<5	<5
Cr	100	150	70	50	70	70	70	50
Cu	20	20	10	50	70	30	15	70
Ga	20	15	20	20	20	20	20	20
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	100	70	50	100	50	100	100	70
Mn	50	50	70	1000	100	1000	1000	200
Mo	<2	5	2	5	20	2	5	<2
Nb	<20	20	20	20	20	20	20	20
Ni	5	5	5	5	5	5	5	5
Pb	1500	500	1500	1000	1000	1000	700	500
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	<10	<10	<10	<10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	<100	100	<100	100	100	<100
Ti	2000	1500	1500	2000	1500	2000	3000	2000
V	10	15	15	15	10	10	10	10
W	<50	<50	<50	<50	<50	<50	<50	<50
Y	15	10	10	30	20	30	50	20
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	150	200	200	200	300	300	500	200

ITEM NO.	SAMPLE NO.
98	= EP 78
99	= EP 79
100	= EP 80
101	= EP 81
102	= EP 82
103	= EP 83
104	= EP 85
105	= EP 86

ITEM	98	99	100	101	102	103	104	105
ELEMENT								
Fe	3%	2%	2%	2%	2%	2%	3%	2%
Ca	1%	0.02%	0.05%	0.05%	0.02%	0.2%	0.5%	0.02%
Mg	0.3%	0.2%	0.2%	0.15%	0.2%	0.2%	0.15%	0.2%
Ag	<1	1.5	<1	<1	<1	<1	1	1.0
As	<500	<500	<500	<500	<500	<500	<500	<500
B	10	10	10	10	10	10	10	10
Ba	1500	1500	700	1000	1000	1000	1000	1000
Be	<2	<2	<2	<2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	<5	<5	<5	<5	<5	<5	<5
Cr	70	100	150	100	100	70	100	100
Cu	10	100	50	300	30	10	20	150
Ga	30	30	10	10	15	15	10	10
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	70	20	100	30	70	70	30	30
Mn	1500	100	70	50	500	1000	50	70
Mo	2	2	7	<2	<2	<2	5	<2
Nb	20	<20	20	20	<20	<20	<20	20
Ni	5	<5	5	<5	5	<5	<5	5
Pb	3000	1000	1500	500	1000	300	300	700
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	10	<10	<10	<10	<10	<10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	200	<100	<100	<100	<100	<100	<100	<100
Ti	5000	1500	1500	1500	1500	2000	1500	1000
V	10	10	15	10	10	15	10	15
W	<50	<50	<50	<50	<50	<50	<50	50
Y	50	15	20	10	30	20	15	<10
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	300	200	300	100	200	300	300	150

ITEM NO. SAMPLE NO.
106 = EP 87
107 = EP 89
108 = EP 90
109 = EP 93
110 = EP 94
111 = EP 95
112 = EP 96
113 = EP 97

ITEM	106	107	108	109	110	111	112	113
ELEMENT								
Fe	3%	3%	5%	3%	3%	3%	5%	3%
Ca	<0.02%	0.02%	0.5%	0.02%	0.05%	0.05%	0.02%	0.5%
Mg	0.15%	0.2%	0.3%	0.5%	0.2%	0.3%	0.2%	0.2%
Ag	2	1	5	1	<1	20	<1	1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	10	10	10	10	10	10	10	10
Ba	1000	1000	500	1500	700	1000	1000	1000
Be	<2	<2	<2	<2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	<5	<5	<5	<5	<5	<5	<5
Cr	70	50	200	70	50	100	100	50
Cu	100	50	20	15	10	100	50	200
Ga	15	10	15	15	10	15	20	20
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	30	20	20	50	50	50	30	50
Mn	100	70	50	100	50	300	200	1000
Mo	7	<2	70	5	10	30	7	5
Nb	20	<20	20	20	20	20	20	20
Ni	<5	<5	5	5	5	5	7	5
Pb	1000	1500	700	500	1000	1000	1000	1000
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	10	<10	<10	<10	<10	10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	<100	<100	<100	<100	<100	<100
Ti	1500	1500	3000	2000	2000	2000	2000	2000
V	10	10	50	10	15	10	15	15
W	<50	<50	<50	<50	<50	<50	<50	<50
Y	10	<10	20	20	10	30	10	30
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	200	[illegible]	300	300	500	300	300	300

ITEM NO. SAMPLE NO.
114 = EP 98
115 = EP 100
116 = EP 101
117 = EP 103
118 = EP 104
119 = EP 105
120 = EP 106
121 = EP 107

ITEM	114	115	116	117	118	119	120	121
ELEMENT								
Fe	3%	3%	3%	3%	2%	2%	3%	2%
Ca	1%	1%	1%	1%	2%	0.05%	0.7%	0.1%
Mg	0.2%	0.2%	0.2%	0.5%	0.2%	0.2%	0.2%	0.15%
Ag	<1	<1	<1	3	<1	1	<1	<1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	<10	10	10	10	<10	<10	10	<10
Ba	1500	1500	2000	2000	1500	1500	1000	1000
Be	<2	<2	<2	<2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	<5	<5	<5	<5	<5	5	<5
Cr	100	50	30	50	50	70	30	30
Cu	10	20	10	50	30	30	20	10
Ga	15	20	15	15	10	15	15	10
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	50	50	70	50	50	30	50	50
Mn	1000	1000	1000	1000	1000	150	700	500
Mo	2	2	2	<2	5	7	5	3
Nb	20	<20	<20	20	20	20	20	20
Ni	5	5	<5	<5	5	5	5	5
Pb	1000	1500	1000	500	700	1000	500	300
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	10	10	<10	<10	10	<10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	100	100	100	100	<100	<100	<100	<100
Ti	2000	2000	2000	3000	2000	2000	1500	1000
V	15	10	15	10	10	15	10	10
W	<50	<50	<50	<50	<50	<50	<50	<50
Y	30	30	20	20	20	10	15	<10
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	300	300	500	300	300	300	300	[illegible]

JOB NO. DCR 110
PAGE 15

ITEM NO.	SAMPLE NO.
122	EP 108
123	EP 109
124	EP 110
125	EP 111
126	EP 112
127	EP 113
128	EP 114
129	EP 115

ITEM	122	123	124	125	126	127	128	129
ELEMENT								
Fe	2%	3%	2%	2%	3%	2%	2%	2%
Ca	0.15%	0.7%	0.5%	0.7%	0.05%	0.07%	0.07%	0.05%
Mg	0.15%	0.2%	0.2%	0.2%	0.3%	0.2%	0.2%	0.2%
Ag	1	1	<1	<1	<1	7	<1	<1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	10	<10	<10	<10	<10	10	<10	<10
Ba	1000	1500	1500	1000	1000	500	1500	1000
Be	<2	<2	<2	<2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	5	<5	<5	<5	<5	<5	<5
Cr	70	50	150	50	70	100	100	50
Cu	15	7	20	10	30	100	200	500
Ga	15	20	10	15	20	10	10	10
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	50	30	50	100	50	20	50	50
Mn	200	700	700	700	500	100	150	200
Mo	10	5	3	2	2	15	3	2
Nb	20	20	20	20	20	20	20	20
Ni	<5	<5	<5	<5	5	5	<5	5
Pb	200	700	200	200	1500	1500	1000	1000
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	10	<10	<10	<10	<10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	<100	<100	<100	<100	<100	<100
Ti	1500	2000	1500	1500	1500	1500	2000	1500
V	10	10	15	15	15	20	10	10
W	<50	<50	<50	<50	<50	<50	<50	<50
Y	10	30	15	20	10	<10	20	10
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	300	500	300	200	150	200	200	100

ITEM NO.	SAMPLE NO.
130	EP 116
131	EP 117
132	EP 118
133	EP 119
134	EP 120
135	EP 121
136	EP 122
137	EP 123

ITEM	130	131	132	133	134	135	136	137
ELEMENT								
Fe	2%	1.5%	2%	5%	2%	3%	2%	3%
Ca	0.02%	0.02%	0.05%	0.2%	0.02%	0.02%	0.02%	0.5%
Mg	0.2%	0.2%	0.2%	0.5%	0.2%	0.2%	0.2%	0.3%
Ag	<1	<1	1	<1	1.5	1	2	1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	10	10	10	<10	10	10	<10	10
Ba	1500	1500	1500	1500	1500	1000	1000	700
Be	<2	<2	<2	<2	<2	<2	<2	2
Bi	<10	<10	<10	<10	<10	<10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	<5	<5	<5	<5	<5	<5	7
Cr	70	50	100	30	30	100	100	70
Cu	150	200	500	200	50	30	70	500
Ga	15	10	15	15	20	10	10	15
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	20	20	30	50	30	30	20	20
Mn	70	70	100	500	70	100	70	500
Mo	30	10	10	2	10	7	15	5
Nb	20	20	20	20	20	20	20	20
Ni	<5	<5	<5	5	<5	5	<5	10
Pb	700	1500	1500	700	700	1500	700	700
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	<10	<10	10	<10	<10	10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	100	<100	<100	<100	100	<100
Ti	2000	2000	1500	3000	1500	1500	1500	5000
V	10	10	10	20	10	10	10	70
W	<50	<50	<50	<50	<50	<50	<50	<50
Y	10	10	15	20	10	15	15	15
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	300	300	150	200	200	300	500	300

ITEM NO.	SAMPLE NO.
138	EP 124
139	EP 125
140	EP 126
141	EP 127
142	EP 128
143	EP 129
144	EP 130
145	EP 131

ITEM	138	139	140	141	142	143	144	145
ELEMENT								
Fe	2%	2%	2%	2%	2%	2%	1.5%	0.7%
Ca	1%	0.1%	1%	0.02%	0.2%	0.02%	10%	0.15%
Mg	0.2%	0.2%	0.3%	0.3%	0.2%	0.03%	0.15%	0.1%
Ag	<1	2	1	<1	<1	<1	5	1
As	<500	<500	<500	<500	<500	<500	<500	<500
B	<10	10	<10	10	<10	<10	<10	<10
Ba	1000	700	1500	1500	2000	10	500	2000
Be	<2	<2	<2	<2	<2	<2	<2	<2
Bi	<10	<10	<10	<10	<10	10	<10	<10
Cd	<50	<50	<50	<50	<50	<50	<50	<50
Co	<5	<5	<5	<5	<5	30	<5	<5
Cr	50	70	50	100	70	150	150	100
Cu	20	50	100	100	100	10	1000	30
Ga	15	10	15	15	15	<10	<10	10
Ge	<20	<20	<20	<20	<20	<20	<20	<20
La	50	20	50	70	150	<20	20	<20
Mn	1000	300	1000	70	500	20	100	700
Mo	2	15	2	10	<2	5	30	2
Nb	20	20	20	20	20	<20	20	<20
Ni	<5	5	<5	<5	<5	7	5	5
Pb	500	300	1000	700	1500	20	150	70
Sb	<100	<100	<100	<100	<100	<100	<100	<100
Sc	<10	<10	<10	10	<10	<10	<10	<10
Sn	<10	<10	<10	<10	<10	<10	<10	<10
Sr	<100	<100	100	100	<100	<100	<100	<100
Ti	2000	1500	1500	2000	1500	200	700	500
V	10	20	<10	15	10	<10	20	10
W	<50	<50	<50	<50	<50	<50	<50	<50
Y	20	<10	20	20	20	<10	15	<10
Zn	<200	<200	<200	<200	<200	<200	<200	<200
Zr	300	200	300	500	200	<20	70	50

ITEM NO. SAMPLE NO.
146 = EP 132
147 = EP 133

ITEM	146	147
ELEMENT		
Fe	5%	3%
Ca	7%	0.07%
Mg	2%	0.5%
Ag	<1	<1
As	<500	<500
B	15	10
Ba	500	1000
Be	2	2
Bi	<10	<10
Cd	<50	<50
Co	15	5
Cr	150	100
Cu	15	2
Ga	20	10
Ge	<20	<20
La	<20	50
Mn	7000	2000
Mo	<2	5
Nb	20	20
Ni	70	10
Pb	20	10
Sb	<100	<100
Sc	30	<10
Sn	<10	<10
Sr	300	<100
Ti	5000	2000
V	150	20
W	<50	<50
Y	10	15
Zn	<200	<200
Zr	50	200

Celk fce Moty Sdenovo

WWC file Molybdenum

Burnham — Source rocks —

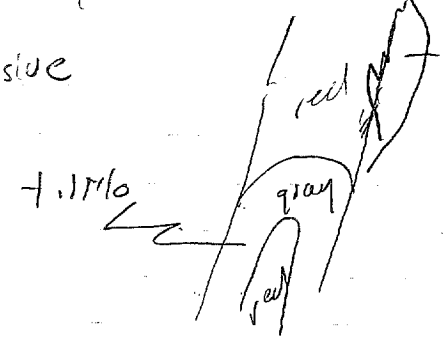
S = <1.1 Al_2O_3 - K, Na, Ca

Pine Grove — Pb-Zn-Ag veins 5,000 tons ore
1950-70's
1974 PD —
1975 first hole
three more
1978 Getty
Now total 125,000' drilling
1981 completed pilot hole for shaft

Picacho Mineral Belt — Sevier orogenic belt

24 my age ; Basin Range title range-t deposit

Two intrusive



+ cast end pu-pM post Pine Grove

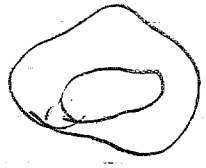
+ 1.1 Mo

unexplored x-section

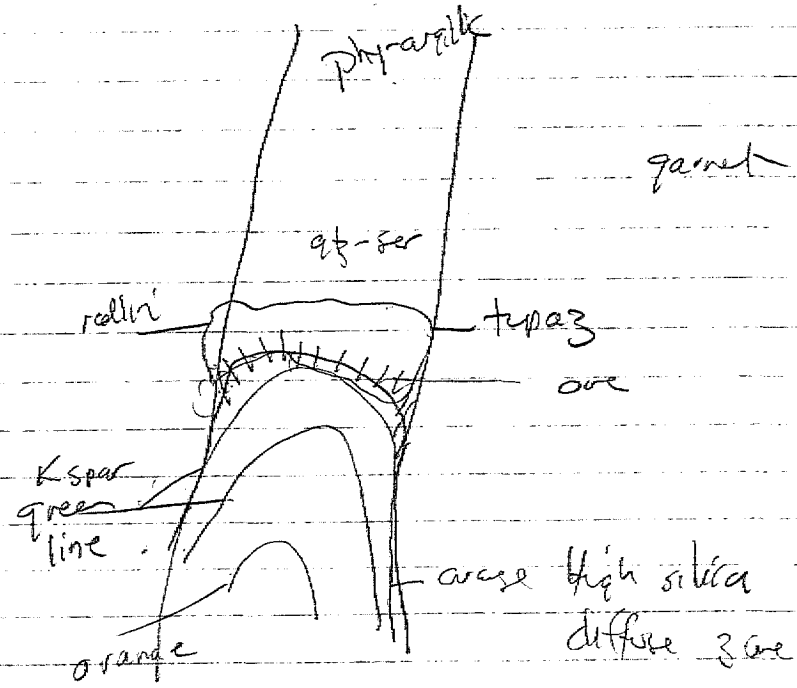
intruded by pebble dikes — on dump at old vein mine contains Mo

early tonalite as frags in rhyolite
Pine Grove porph

4,000' el



2,000 elevation



base metal
Anyesen ore and connected
hydrothermal with Mo

2500' first occurrence
of moly below
surface

various stages of porphyry not yet worked out

WK file Moly

From Bill Paque

Cave Creek study

			capital	ROR
		strip		
19 MT	.15 Mo	Gil	$160	13%
14 MT	.20	underground	110	13%

2,000' deep shell not explored

Not include Texas portion.

WLK file
Molybdenum

WLK

RECEIVED
OCT 29 1980
EXPLORATION DEPARTMENT

10/27/80

FROM: DOUGLAS M. SMITH, JR.

TO: JDS

I stumbled onto the attached article while researching another topic. What intrigues me is the presence of Bi in base-precious metal veins above carbonate beds which the authors feel are worthy of exploration. The occurrence of cassiterite is also somewhat unusual I think.

Bismuth has been related to feeder channels in mineralizing fault-veins at Leadville (Chapman, 1941) and I've heard that it

is anomalous in the small limestone replacement ore bodies above the Pine Grove MoS_2 deposit. Have you any knowledge of unusual quantities of Bi in veins or replacements in the Tintic area? My next question is, does an exploration target exist at Marysvale that may have perhaps been overlooked in the gold rush and is it Pb-Zn-Ag-Au replacement or MoS_2, and is it even worth thinking about?

Many thanks for the goodies from the Tintic of yore.

Stay in touch
Tony

Chapman, E.P. 1941, Newly recognized features of mineral paragenesis at Leadville, Colorado: A.I.M.E. Trans. v. 144, p. 264-275.

cc: WLK ✓

BISMUTH AND TIN MINERALS IN GOLD- AND SILVER-BEARING SULFIDE ORES, OHIO MINING DISTRICT, MARYSVALE, UTAH

By ARTHUR S. RADTKE, CHARLES M. TAYLOR [1], and JOHN E. FROST [2],
Menlo Park, Calif., Palo Alto, Calif., Houston, Tex.

Abstract.—Large amounts of cuprobismutite and bismuthinite are present in gold- and silver-bearing sulfide ores in the Tunnel Extension Number Two mine near Marysvale, Utah. Significant amounts of cassiterite in small grains are concentrated in the quartz gangue. Most of the silver is present in cuprobismutite, and gold occurs as the native metal. Carbonate beds below the mine, mineralized elsewhere in the district, offer potential exploration targets.

The Ohio mining district, a precious-metal producer, is located on the east flank of the Tushar Range, about 6 miles west-southwest of Marysvale (fig. 1) in Piute County, Utah. Samples collected by J. E. Frost from the 400 level of the Tunnel Extension Number Two mine contain several abundant metallic minerals, and the ore contains abundant bismuth and copper. Bismuth and tin minerals in these ores were not reported in either the early work by Butler and others (1920), or in the recent compilation of minerals in Utah (Bullock and others, 1960). Dasch (1964), in summarizing certain mineral resources for Utah, including bismuth, did not mention the occurrence of this metal in the Ohio district.

Semiquantitative spectrographic analyses by C. M. Taylor and A. S. Radtke, at Stanford University, confirmed the presence of abnormally large amounts of bismuth and copper, in addition to lesser amounts of iron, zinc, arsenic, silver, tin, antimony, gold, lead, and tellurium in ore from the Tunnel Extension Number Two mine.

This paper presents the results of a preliminary study of the mineralogical and chemical associations in this ore and gives a new mineral occurrence for bismuthinite, cuprobismutite, and cassiterite.

[1] Materials Analysis Co.
[2] Humble Oil and Refining Co.

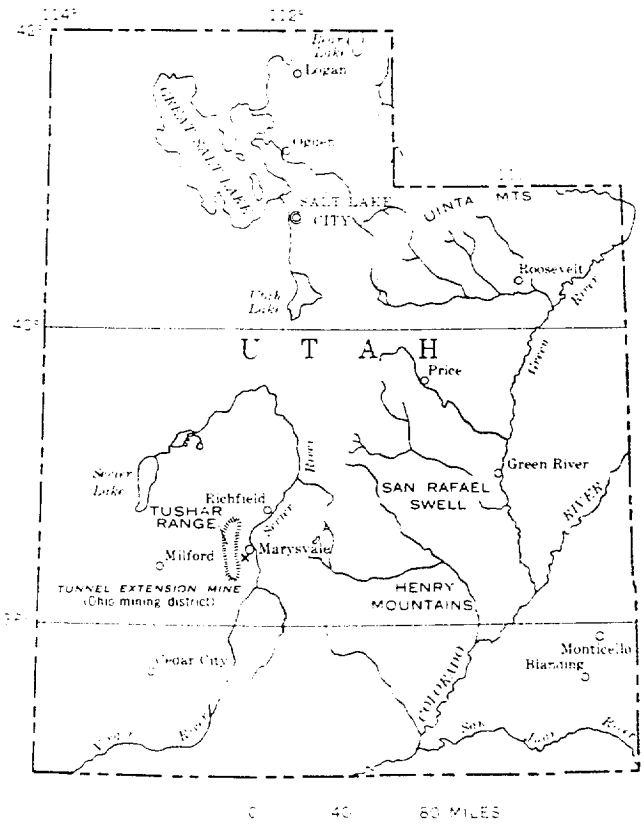


FIGURE 1.—Index map of Utah, showing location of the Tunnel Extension mine (Ohio mining district).

DESCRIPTION OF THE DEPOSIT

Ore bodies in the Tunnel Extension Number Two mine occur in steeply dipping tabular-shaped masses along and in faults or shear zones. Although small amounts of ore locally replace the wallrock, most of the mineralization is confined to the faults or shear zones and the deposits are classified as "fissure-filling type."

U.S. GEOL. SURVEY PROF. PAPER 575-D, PAGES D127-D130

The wallrocks are of the Bullion Canyon Volcanics of middle Tertiary (Miocene?) age. In sequence, underlying the volcanics, although not exposed in the present mine workings, are (1) indurated rocks of the Navajo Sandstone, (2) shale and sandstone of the Chinle Formation with its basal Shinarump Member (conglomeratic sandstone), and (3) siltstone and sandstone of the Moenkopi Formation.

Limestone, dolomite, and interbedded quartzite of the Kaibab Limestone, host rocks for gold-silver ores of the Deer Trail and several other mines in the Tushar Range, underlie the thick sequence of sandstones and shales. Because the ore of the Tunnel Extension mine is believed to be hypogene and because it is possible that the ore-controlling structures extend to depth, the carbonate beds below the mine may be worth exploring for additional gold-silver deposits.

ORE MINERALOGY AND CHEMISTRY

The results of mineralogic studies which included examination of polished sections and thin sections of the ore are described in this report. All polished sections were prepared following the methods described by Taylor and Radtke (1965).

The results of the semiquantitative spectrographic analysis of one specimen of massive sulfide ore (table 1) show that the most abundant elements in the ore are bismuth (>10 percent), silicon (10 percent), copper (7 percent), tin (1.5 percent), and silver (1 percent). Gold content, determined as 0.003 percent, is equal to approximately one ounce per ton. Zinc, arsenic, and tellurium, identified by Taylor and Radtke in previous spectrographic analyses, were not detected in the analysis shown in table 1.

The ore is made up of subhedral to euhedral interlocked grains of quartz and fine-grained intergrowths of sulfide minerals (fig. 2). In hand specimen, only cuprobismutite, bismuthinite, and quartz are sufficiently abundant to be distinguishable. All minerals identified in the ore and their relative abundance are given in table 2.

Primary ore minerals include cuprobismutite, bismuthinite, tetrahedrite, emplectite, chalcopyrite, native gold, and tetradymite. Secondary or alteration minerals include covellite, chalcocite, and a new hydrated bismuth sulfate. Most of the gangue is composed of quartz. Although calcium content is low in the analyzed ore (0.001 percent, table 1), very small amounts of calcite are present.

Cassiterite in two distinct forms is closely associated with and dispersed through the quartz gangue.

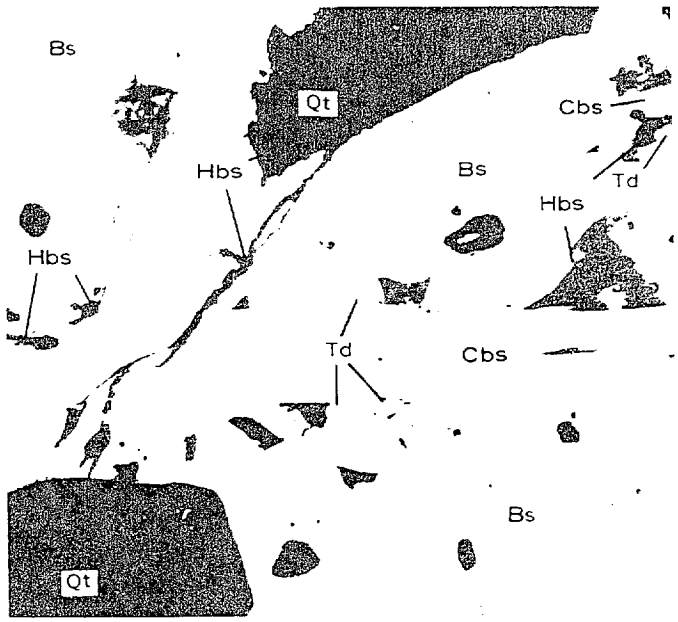


FIGURE 2.—Photomicrograph showing intergrowths of medium-gray bladed cuprobismutite (Cbs) and small white grains of tetradymite (Td) in pale-gray bismuthinite (Bs). Darkest areas are euhedral quartz (Qt) grains. Note alteration of primary bismuth minerals to hydrous bismuth sulfate (Hbs) along fractures and grain boundaries. × 370.

TABLE 1.—*Semiquantitative spectrographic analysis of massive sulfide ore, Tunnel Extension Number Two mine, Marysvale, Utah.*

[In weight percent. M, major constituent, greater than 10 percent. Analyst: Chris Heropoulos, U.S. Geological Survey]

Element	Amount	Element	Amount	Element	Amount
Si	10	Ag	1	Ni	0.001
Al	0.02	Au	0.003	Pb	.3
Fe	.015	Ba	.001	Sb	.1
Mg	.0003	Bi	M	Sn	1.5
Ca	.001	Cr	.0002	V	.005
Ti	.007	Cu	7	W	.01
Mn	.07	Mo	.001		

Other elements looked for but not found: As, B, Be, Cd, Ce, Co, Eu, Ga, Ge, Hf, Hg, In, K, La, Li, Na, Nb, P, Pd, Pt, Re, Sc, Sr, Ta, Te, Th, Tl, U, Y, Yb, Zn, and Zr.

TABLE 2.—*Mineralogy of massive sulfide ore, Tunnel Extension Number Two mine, Marysvale, Utah*

Mineral	Abundance [1]	Mineral	Abundance [1]
Cuprobismutite	~50	Tetrahedrite	1
Quartz	25	Emplectite(?)	<1
Bismuthinite	15	Chalcopyrite	<1
Bismuth-bearing alteration mineral.[2]	5	Gold (electrum ?)	<1
Covellite	2	Tetradymite	<1
Chalcocite	1	Calcite	<1

[1] Visual estimate of percentage of total sample.
[2] New mineral (hydrated bismuth sulfate).

The bulk of the cassiterite is found as small anhedral grains scattered randomly through quartz with lesser amounts as large elongate subhedral grains along the contacts between quartz and sulfide veinlets (fig. 3).

The ore specimens studied show the initial development of extensive oxidation and alteration (fig. 4). Although both bismuthinite and cuprobismutite show alteration, the former is apparently less stable and oxidizes more readily. Along crosscutting microfractures both minerals show alteration to and replacement by secondary phases. In areas with fine-grained intergrowths of both primary sulfides, the alteration may be confined to the binary bismuth sulfide (fig. 4). This is supported by the chemistry and abundances of the secondary or alteration minerals. Cuprobismutite is far more common than bismuthinite; yet secondary copper minerals, including covellite and chalcocite(?), are very scarce. The hydrated bismuth sulfate phase is very common and apparently formed directly from bismuthinite and cuprobismutite. Minor amounts of secondary copper sulfides in submicron particles intergrown with the secondary bismuth sulfate are present near cuprobismutite.

Of specific mineralogical interest is the nature and distribution of gold and silver in the ore. Native gold

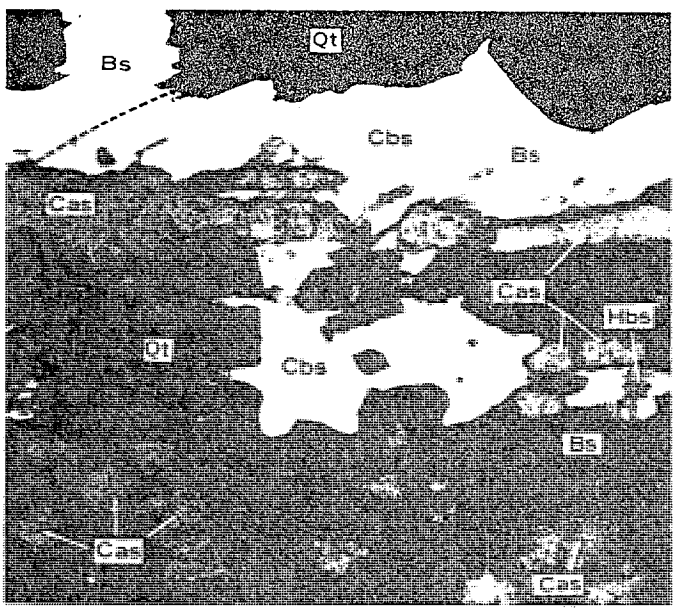


FIGURE 3.—Photomicrograph showing veinlet of white cuprobismutite (Cbs) and bismuthinite (Bs) in dark-gray quartz (Qt). Boundary between the two primary bismuth minerals is marked by dashed line. Note long prismatic subhedral grains of cassiterite (Cas) in quartz along margin of veinlet and small anhedral cassiterite grains scattered through quartz. Slight alteration of primary bismuth minerals to hydrous bismuth sulfate (Hbs) controlled by grain boundaries and microfractures within the grains is apparent. × 180.

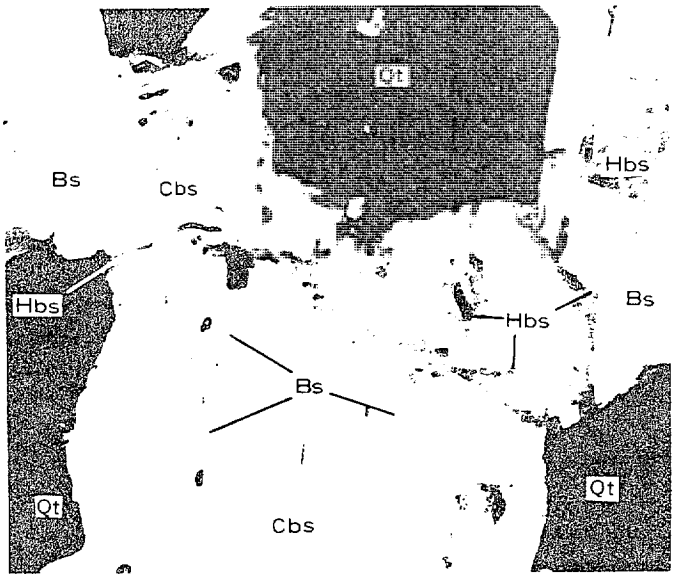


FIGURE 4.—Photomicrograph showing preferential and extensive alteration of pale-gray bismuthinite (Bs) to hydrated bismuth sulfate (Hbs). Cuprobismutite (Cbs), slightly darker than bismuthinite, is altered only along microfractures. Large, dark-gray-black euhedral grains are quartz (Qt) gangue. × 370.

in the ore is virtually confined to small late(?) microfractures cutting large sulfide intergrowths. A photomicrograph of native gold and secondary alteration minerals along a microfracture through cuprobismutite is shown in figure 5. Numerous electron microprobe analyses showed no substitution of gold for other elements in any of the ore minerals. No gold or gold-silver tellurides were recognized. Cuprobismutite, which makes up approximately +50 percent of the samples studied (table 2), contains the bulk of the silver; electron microprobe analyses show that this mineral contains over 1 percent silver. Tetrahedrite, relatively uncommon in the samples studied, is apparently not an important ore mineral of silver. Owing to the extreme small particle size of the gold and the high silver content in surrounding cuprobismutite, quantitative electron microprobe analyses of gold were not attempted. On the basis of color comparisons against known alloys of gold-silver, the gold-bearing phase in the ore is apparently deficient in or virtually free of silver.

In ore from the nearby Bully Boy mine, Butler and others (1920, p. 544) describe a primary unidentified silver mineral with "silvery-white metallic luster * * * coated by a dark grey material of dull luster, apparently an alteration product. The mineral contains free gold in minute fissures." They also reported that cerargyrite forms thin films in the fissures. Although cerargyrite was not recognized in our study, this min-

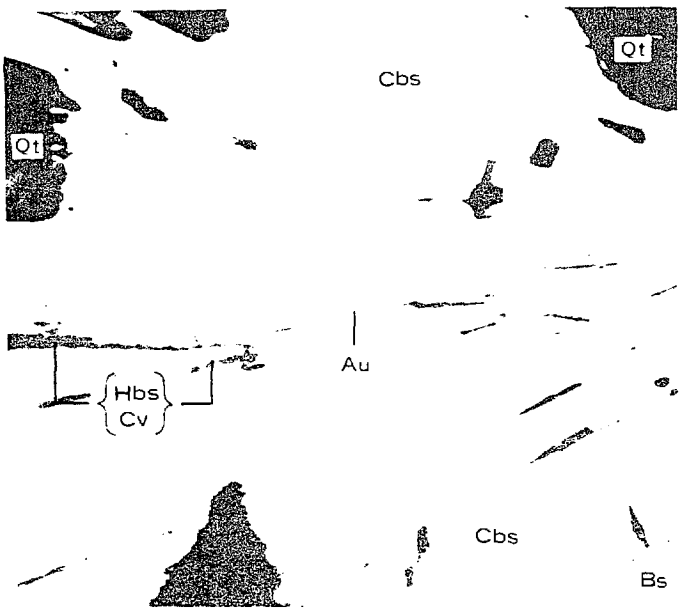


FIGURE 5.—Photomicrograph showing white native gold (Au) in a small microfracture in massive pale-gray cuprobismutite (Cbs). Other minerals in microfractures include admixed covellite (Cv) and hydrous bismuth sulfate (Hbs). Note general lack of alteration of cuprobismutite. Lighter gray mineral in lower right corner is bismuthinite (Bs); dark-gray-black areas are quartz (Qt) gangue. × 370.

eral would account for the silver released from cuprobismutite during alteration.

Butler and others (1920) also suggested that tetrahedrite in the ore was not an important silver mineral. They stated (1920, p. 544), "Material containing several percent of this mineral is said to contain only small quantities of precious metals and is ore only when it contains sufficient copper to be valuable for that metal." This conclusion is supported by the now-recognized concentration of silver in cuprobismutite (copper bismuth sulfide) rather than in tetrahedrite.

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Butler, B. S., Loughlin, G. F., Heikes, V. C., and others, 1920, The ore deposits of Utah: U.S. Geol. Survey Prof. Paper 111, 672 p.

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RECEIVED
MAR 16 1981
EXPLORATION DEPARTMENT

ASARCO

Geochemical Office

March 10, 1981

To: J. C. Balla

From: L. D. James

~~Molybdenum~~
South Central Idaho

Some 10-11 years ago the Spokane office carried out a geochemical reconnaissance stream sediment survey for Cu/Mo deposits along intrusive-sediment contacts in South Central Idaho (reports by J.J. Jones, January 27, 1971; and L. D. James, May 12, 1971). A number of malybdenum anomalies located in the course of this study were later substantiated by preliminary follow-up study (my memorandum November 3, 1971). As far as I can determine from my files these anomalies were never investigated, presumably because attention was concentrated on the White Cloud Prospect. Admittedly, these anomalies could well be related minor vein type sulfide occurences but the strength and extent of several is such as to merit source location and examination?

L. D. James.

Lloyd D. James

LDJ:cej

cc: RLB
WLK

ASARCO

cc to file
Moly

WLK

RECEIVED
FEB 25 1981
EXPLORATION DEPARTMENT

Rocky Mountain Exploration Division
Douglas M. Smith, Jr.
Manager

February 19, 1981

TO: R. L. Brown

FROM: D. M. Smith, Jr.

Missouri, Molybdenum in
Cambrian Carbonate Rocks

Reports of anomalous quantities of Mo in carbonate rocks associated with Pb-Zn mining districts are not new. Sell (1979) notes that Mo values are generally < 3 ppm outside limestone-replacement districts, but increase to >10 ppm in the ore zone. Similar Mo contents are found in the ore-bearing dolomite at the root zone of the Silesian-Cracovian Pb-Zn deposits (Haranczyk, 1967). The 0.1% Mo (0.167% MoS_2) rumored to have been discovered in the Potosi and Eminance formations of Missouri is, however, anomalously anomalous.

Black shales, which may contain between 10 and 300 ppm Mo (Hawkes and Webb, 1962), are present in the Paleozoic section of the mid-continent region and could have provided a source for the Mo found in the Cambrian carbonates. Oil field brines (Carpenter et al, 1974) and expelled formation waters (Billings et al, 1969) are capable of transporting metals, although I am not aware of any Mo analyses quoted in the literature for these media. The presence of jordisite (colloidal MoS_2) in many roll-front uranium deposits demonstrates that Mo is soluble in low-temperature weakly-alkaline solutions and is subject to precipitation by reduction in the presence of carbonaceous material and/or hydrogen sulfide (Hostetler and Garrels, 1962).

The preceding suggests that both source and transport might be contrived for the Mo now occurring in the Potosi and Eminance formations, but unless these rocks are sooty and fetid, it is difficult to explain the necessary reduction and precipitation of the metal. Indeed, I am aware of no Mo anomalies in limestone near the molybdenum deposits of the Colorado Mineral Belt. In the Grants district Mo is present in sandstone- and shale-hosted uranium deposits, but absent from those occurring in the Todilto Limestone (Granger, 1963).

D. M. Smith, Jr.

Douglas M. Smith, Jr.

DMS:cej

Att: References cited

cc: LDJ
WLK, w/cc. of incoming

References Cited

Billings, G.K., Kesler, S.E., and Jackson, S.A., 1969, Relation of zinc-rich formation waters, northern Alberta, to the Pine Point ore deposit: Econ. Geol., v. 64, no. 4, -. 385-391.

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Haranczyk, C., 1967, Ore-bearing dolomite of the root-zone of Silesian-Cracovian Pb-Zn ore-deposits in Problems of hydrothermal ore deposition (Prouba and Stemprok, eds.): International Union Geol. Sci. Ser. A, no. 2, p. 384-392.

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February 6, 1981

Mr. D. D. Harper, Manager
Knoxville Office

Missouri
Molybdenum in Cambrian
Carbonate Rocks

Dear Mr. Harper:

I don't quite know what to make of Lloyd James' report that ore grade moly was intersected in the Cambrian Potosi and Eminance formations by the U.S.G.S. in a diamond drill hole drilled in Ozark County, Missouri.

Steve Von Fay reported a few years ago on some "roll front" type occurrences in sandstones, but the Missouri occurrences appear to be in carbonate rocks which presumably are chemically reactive.

Obviously we should try to see the physical core if at all possible but beyond that suggestion I have no good ideas. However, I am curious to know what all the people whom I have copied on this letter think about the occurrence.

Very truly yours,
Original signed by
R. L. Brown

R. L. Brown

cc: PRDingess
LDJames
DMSmith/DWolfe

Mina La Encantada (La Prieta), Coahuila

1-15 & 16 76

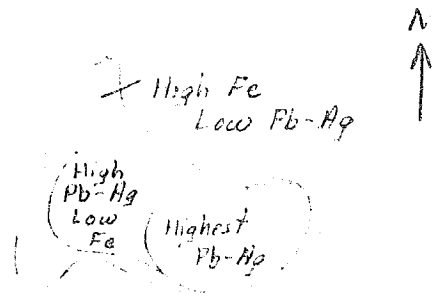
Now manager @ Tayoltita

Now Ch. Geol. of St. Joe's El Indio in Chile

Gerente: L. Chapoltan Sr.
Geologo Residente: Miguel P. Lojan S.
Geologo de Mina: [illegible]

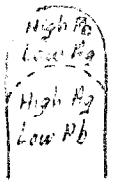
La Prieta Ore Body

Horizontal Zonation



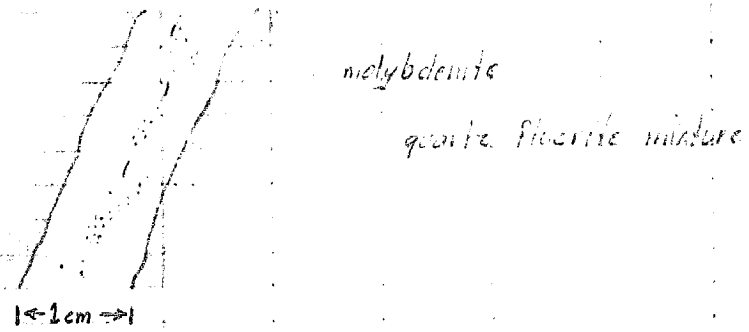
Difference in Fe contents of the two zones is a relatively constant 5%

Vertical Zoning

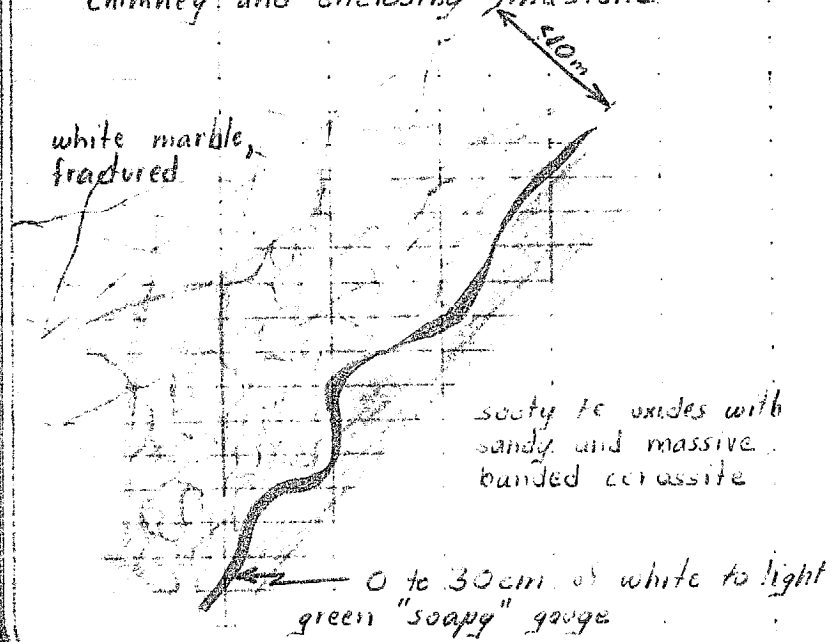


Host: Aurora Limestone

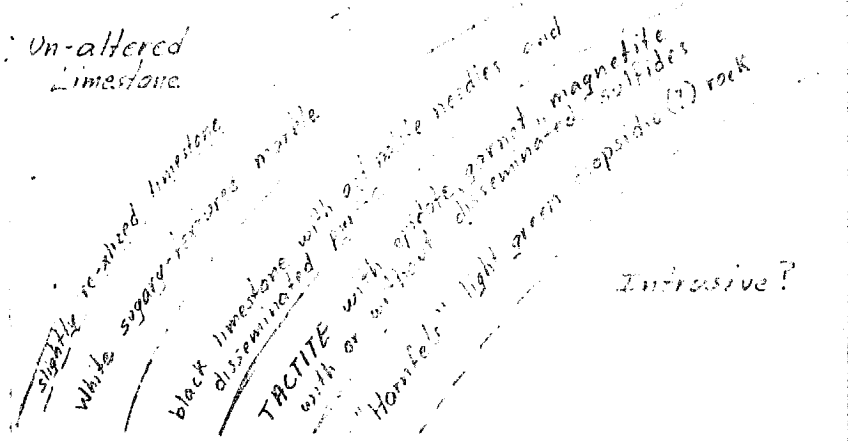
Detail: Quartz - fluorite - molybdenite vein



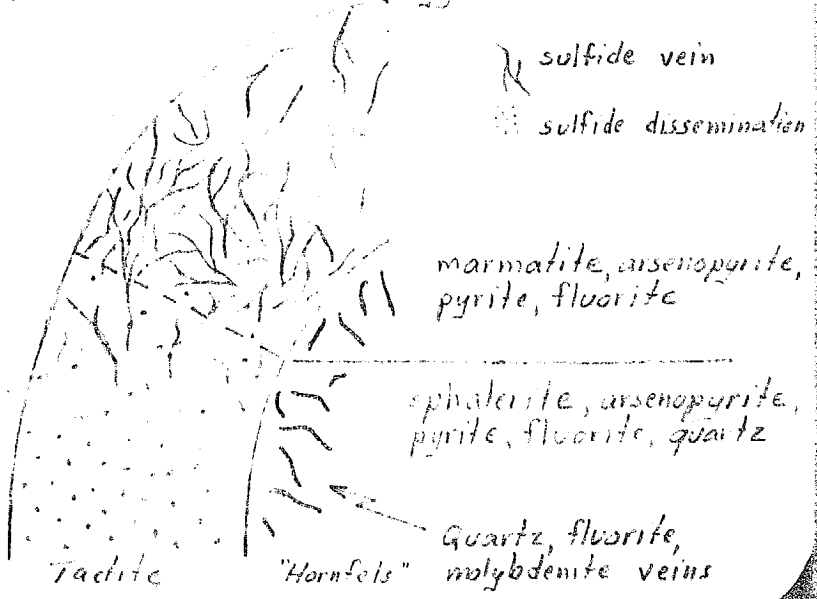
Detail of contact between La Prieta chimney and enclosing limestone



Schematic Cross-Section of the Tactite Zone



Distribution and Mineralogy of Veins in Tactite



WLK file Molybdenum

ASARCO

RECEIVED
JAN 30 1981
EXPLORATION DEPARTMENT

Rocky Mountain Exploration Division
Douglas M. Smith, Jr.
Manager

January 27, 1981

Mr. Darby Fletcher
2456 W. Bayshore Rd. #6
Palo Alto, California 94303

Dear Darby:

A Stanford student whose name I failed to record called me during September 1979 to chat about porphyry molybdenum deposits. He was accumulating information for a group research project dealing in part or, perhaps, totally with the geochemistry of said deposits. Although I was promised a copy of the final product, one was never forthcoming. Are you familiar with the project and can you obtain a copy for me? I will be more than happy to foot the bill for reproduction.

Hope the probe is probing again. I really enjoyed my tour of the Stanford facilities and truly appreciate the time that you, Paul, and Tim took out from your studies and thesis work.

Very truly yours,

Doug

Douglas M. Smith, Jr.

DMS:cej

cc: WLK *see attached memo*

DAW - LDJ

WhK: At long last I have discovered the source of my Bi rumour.

9/4/79

FROM: DOUGLAS M. SMITH, JR.

TO: D. J. K.

A Stanford research project has shown galena found near porphyry Mo deposits to be anomalously high in Bi. Recognition of this feature (prior to the Stanford study) by PD geologists was reportedly instrumental in leading them to drill deep below the Pb-Zn deposits at Pine Valley in southwestern Utah.

ASARCO

RECEIVED

JAN 30 1981

EXPLORATION DEPARTMENT

Northwestern Exploration Division
John C. Balla
Manager

January 28, 1981

File Title Sediment 2, and Goat Creek

Mr. W.L. Kurtz, Manager
Western U.S.A.
ASARCO Incorporated
P.O. Box 5747
Tucson, AZ 85703

Goat Creek Prospect
Sanders County, Montana

Dear Sir:

The Goat Creek prospect is located five miles northeast of Thompson Falls. ASARCO drilled the property in the period October, 1969 - August, 1970, when the project was dropped. During the course of exploration on the property, the potential for "... several hundred million tons of low grade (approx. 0.08% MoS_2) mineralization" was recognized (see Goat Creek Project report, December, 1971).

I have just learned that during the course of discussion on the proposed Montana severance tax on minerals that Noranda has reported a reserve of 100,000,000 tons with a grade of 0.15% MoS_2. I do not have any additional information.

Very truly yours,

John C Balla

John C. Balla

JCB/dt

cc: R.L. Brown

FTG - ~~SD~~ - ~~SPD~~

ASARCO

Rocky Mountain
Exploration Division

January 31, 1980

RECEIVED
FEB 7 1980
EXPLORATION DEPARTMENT

TO: W. L. Kurtz

FROM: D. M. Smith, Jr.

Mineral Zoning Related to MoS_2 Deposits

In doing my research for the Morristown Exploration Meeting I have encountered an interesting anomaly: The main production from mines above the Pine Grove discovery was Pb-Ag rather than Pb-Zn or Pb-Zn-Ag. At Mount Emmons the Keystone mine produced Zn (5.6%)-Pb (2.6%)-Ag (5.6 oz.) ore, but the occurrence is not analogous to Pine Grove since it is located lateral and closer to the molybdenite zone (i.e. deeper in the system). Samples of base metal veins I collected several years ago from around the Henderson-Urad deposit yielded multi-ounce Ag assays, but I do not recall the Pb to Zn ratios.

All this makes me wonder if Pb-Ag occurrences should receive special attention on our reconnaissance of base metal deposits for moly targets. More specifically, this awareness points directly at the Cactus pipe-Frisco area located 20 miles northwest of Pine Grove: The Carbonate, Horn Silver, Indian Queen, and Golden Reef properties were all mined for Pb-Ag ores. While the Cactus pipe area previously has been drilled for Cu, it is conceivable that the penetration was too shallow to have stumbled into a deep moly system —if it exists. Here in Colorado the Sherman, Alma, Hilltop-Peerless, and Kokomo Pb-Ag deposits are all peripheral to Climax and Galena Mountain has a strong Pb (+10,000 ppm)-Ag (+5.6 oz.) anomaly in the veins.

GJS correct

Maybe Leadville is the near-surface Pb-Ag-Zn geochem anomaly over a mega-Mo deposit!!

FTG.

D. M. Smith

Douglas M. Smith, Jr.

DMS:cej

cc: LDJ
DJK
DAW

ASARCO

RECEIVED
OCT 18 1979
EXPLORATION DEPARTMENT

Exploration Department
T. C. Osborne
Vice President

October 16, 1979

Mr. J. H. Courtright
Tucson Office

Molybdenum

Dear Mr. Courtright:

Thanks for your memorandum of October 4.

I have no trouble with the concept that the Amax current molybdenum market price has a good chance of keeping up with inflation over the long-term. As pointed out in "Moly Study", molybdenum could be subject to periodic disruptions in the general pattern because a single new major molybdenum mine can readily produce 10%-25% of present world demand. (Compare this with copper, wherein a major new copper producer of first rank might produce 2% of current world demand). "Lumpiness" of the molybdenum supply stream has been a factor in prices in the past and will likely affect prices in the future from time to time over relatively short-term periods.

For practical purposes in evaluating possible new molybdenum investments at any particular time, I think we should use the current Amax molybdenum price at that time and current capital and operating costs. As far as I know, this has been our consistent policy in the past.

I think we also all agree we should not use spot molybdenum prices (although these may be very substantially higher than the Amax price as they have for the past several years) because to do so for investment decisions would be frankly speculative. Speculation in commodities is a perfectly good way to make money but it is not a business Asarco knows much about. Further, one rule in commodity speculation is to stay liquid, and a mine is of course about the least liquid way of tying up money there is. I realize your memorandum in no way suggests that we should use spot prices for long-term investment decisions, and am just throwing this discussion in because it is hard for everyone including myself not to be impressed with the current molybdenum profits we are making on what normally is a relatively minor by-product.

Very truly yours,

T. C. Osborne

cc: WLKurtz
JCBalla
DMSmith
FTGraybeal
REGale
(all w/copy of Mr. Courtright's Memo)

ASARCO

RECEIVED
OCT 9 1979
EXPLORATION DEPT.

Exploration Department

October 4, 1979

MEMO FOR: T. C. Osborne

FROM: J. H. Courtright

MOLY

C. O.
OCT 16 1979

Perhaps you have seen the recent USBM publication ----- "Molybdenum" by John T. Kummer, May 1979. In any case, some of the more important aspects are summarized below.

In contrast to "Moly Study" (my memo of 6/1/79), "Molybdenum" contains the results of research on demand which is broken down into six end-use categories for consumption in the USA:

	Lbs Mo x 1,000	
	1977	Forecast year 2000
Transportation	13,000	46,000*
Machinery	21,000	42,000*
Oil & Gas Industries	9,100	34,000*
Chemicals	7,100	24,000*
Electrical	5,200	12,000*
Other	6,000	12,000*

As may be noted, the most rapid growth rates forecast is in transportation, chemicals, and the oil and gas industries. In respect to the latter, the author states: "Increased activity in oil and gas production, refining, (and pipeline transportation), and the possibility of molybdenum use in coal gasification and liquification plants could combine to produce the high of the forecast range, 41 million pounds, (in contrast to the "probable" figure of 34 million pounds).

Production figures and demand forecast given are:

	Lbs Mo x 1,000		
	1977	1980 (capacity)	2000
World production	206,000	284,000	
World demand	205,000		630,000
USA demand	61,400		170,000
(1977-2000 compounded annually)			4.5%
Rest of world			
(" " " ")			4.8%

---

* "probable" - which is a conservative figure between "high" and "low" figures in Table 10, page 20 of text.

According to the above projections, world consumption in the year 2000 will require tripling of 1977 production. However, other than a tabulation of world reserves and possible resources in pounds of moly (total 42,500 million ----- 65% recoverable), the author makes essentially no attempt to analyse production potential, particularly of undeveloped deposits and prospects, but concludes: "The currently prevailing world supply and demand patterns are expected to continue at least into the mid-1980's, and probably for the remainder of this century."

According to "Moly Study," western world production forecasts (based on data for 30 deposits ----- operating mines, plus prospects with established potential) show that an over-supply could occur by 1987-1990. However, this assumes optimum production rates and a decline in demand to 3.4% per annum by 1983 ----- and does not take into account the possibility that development of some of the large-potential prospects listed, such as Quartz Hill and Mt.Emmons, may be stymied by the environmentalists.

Thus, in view of projected demand, it appears reasonably possible, if not probable, that the moly market price will keep up with inflation over the long term.

J. H. Courtright

J. H. Courtright

JHC:jlh
no encls
c.c. WLKurtz/FTGraybeal

ASARCO

Exploration Department

October 4, 1979

MEMO FOR: T. C. Osborne

FROM: J. H. Courtright

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Thus, in view of projected demand, it appears reasonably possible, if not probable, that the moly market price will keep up with inflation over the long term.

J. H. Courtright

J. H. Courtright

JHC:jlh
no encls
c.c. WLKurtz/FTGraybeal

ASARCO

Southwestern Exploration Division

May 3, 1979

fie 7-10-79

TO: W. L. Kurtz

FROM: F. T. Graybeal

Lead-Zinc Mineralization as a Guide to Porphyry Molybdenum Targets

The relationship of Pb-Zn mineralization, either in veins or massive sulfide replacements of limestone, to the Mt. Emmons (Colo.), Mt. Hope (Nev.), and Pine Grove (Utah) molybdenum deposits is well known. In these areas the Pb-Zn occurs primarily above the porphyry-associated molybdenum mineralization and the occurrence of other Pb-Zn deposits in known molybdenum provinces must be regarded as a potentially useful vertical zoning guide to underlying molybdenum targets. Small Pb-Zn deposits are exceedingly common in the western United States and often come to Asarco as submittals. These have been generally assessed on their merit as potential Pb-Zn mines. In the future, the potential for deeper mineralization should be considered.

I suspect that certain geochemical criteria exist which may indicate whether or not the prospect is related to a concealed molybdenum-bearing porphyry such as anomalous Mo, F, Sn, and W. Unfortunately Mo and W are common in skarns, but are they common in massive sulfide replacements of limestone where lime silicate alteration is absent? This may be an important distinction.

I was interested last Summer in the emission spectrographic analyses reported by Jim Sell during his reconnaissance for replacement mineralization in the Leadville Dolomite in Colorado. Frequently, anomalous Mo values were noted. At the time I assumed that this was simply part of the overall anomalous metal suite, but now I wonder whether these anomalous values might be related to a deep-lying porphyry molybdenum target. To my knowledge we did not get F in the emission spectrographic analyses, although it is known to be somewhat widespread around porphyry molybdenum deposits. As I recall there were only limited or no anomalous W and Sn values reported, but the emission spec. detection limit of 50 ppm for W may be too high. In addition, the dispersal of Mo-W-Sn around porphyry molybdenum targets is reportedly very restricted. It is possible that some of the Pb-Zn limestone replacement districts in the Colorado Mineral Belt may be the vertical expression of deeper porphyry molybdenum mineralization. Such zones would be concealed by the widespread nature of the Pb-Zn mineralization and the relative absence of quartz porphyry stocks even though quartz porphyry sills may be abundant.

The tendency for molybdenum deposits in the Colorado Mineral Belt to cluster in the 25-30 million year age range puts constraints on which limestone replacement districts might be favorable for porphyry molybdenum exploration, regardless of the geochemical expression. The attractiveness of these targets would only be diminished to the extent the geologist believed that all molybdenum deposits were confined to a specific age range.

If there is a porphyry molybdenum target under the Leadville District it is probably quite large. The fact that Climax is only 10 miles distant is intriguing. I would be most interested in a geochemical grid sampling

program in the Leadville District and other selected limestone replacement districts which emphasized detection of elements in addition to Pb and Zn that commonly occur as anomalous halos around and above molybdenum deposits. The difficulty of applying this concept to the Leadville District involves our relationship with Newmont to whom we would not want to reveal an intent to look for anything other than Black Cloud mineralization.

I have recently discussed this subject with several people in greater or lesser detail and put my thoughts on paper to perhaps generate additional thought and discussion. Although we are talking about relatively deep, vertically-zoned targets the exploration risk is reduced by the relatively high grade of porphyry molybdenum targets.

F. T. Graybeal

F. T. Graybeal

FTG:lb

cc: JDSell
GJStathis

Wilk Fig. Fledysdemm

GEOLOGY, v. 6, p. 236-238, APRIL 1978

PRINTED IN U.S.A.

PRINTED IN U.S.A.

copy for FT Graybeal
JC Ballou
DOW
9/10/79

W.L.K.
wck file Moly

9/4/79

FROM: DOUGLAS M. SMITH, JR.

TO: D. J. K.

A Stanford research project has shown galena found near porphyry Mo deposits to be anomalously high in Bi. Recognition of this feature (prior to the Stanford study) by PD geologists was reportedly instrumental in leading them to drill deep below the Pb-Zn deposits at Pine Valley in southwestern Utah.

source of info.

ASARCO

Exploration Department

F.T.G.

June 1, 1979

MEMO FOR: T. C. Osborne

FROM: J. H. Courtright

MOLY

Thanks for the loan of "Moly Study", which I found to contain the results of a fairly thorough investigation of current and potential production in the Western World. Data on present producers appear fairly accurate, but some erroneous grade figures are shown for potential future producers; for instance, Mt. Tolman, Washington State, is listed as .16% Mo, rather than .08% Mo (published grade), and Thompson Creek .09% Mo instead of .15% Mo (published? grade). Nevertheless, in general their projections of possible future supply appear reasonable.

Assessment of supply, however, is only half the picture. The other half, demand, is of equal or greater importance, but it is stated (page 23), "We have not attempted to detail the future moly consumption market by end-use markets.....". Yet this type of research is precisely what is required, I believe, to properly evaluate the future of moly, particularly from the standpoint of exploration.

In the matter of price forecasting, they state (page 5) "Moly concentrate pricing could reach $6.50 per pound by 1983, with the spot market at times in the $9.00 to $11.00 range." All are aware, of course, that the Climax quote has been around $6.80 for the past month, with dealer prices as high as $27.00.

As stated in my memo of 2-3-78, "One of the principal uses of moly is in large diamter steel pipe for oil and gas transmission." The "Moly Study" forecasts moly consumption growth as declining from 7.5% (yearly increase) in 1978 to 3.4% in 1983. Not being based on research, this should be rated as nothing better than a "guesstimate." In my opinion, the current high demand growth could last as long as the "energy crunch" persists ---- the end of which is certainly not now in sight.

The Moly Study will be returned under separate cover.

J. H. Courtright

J. H. Courtright.

JHC:jlh
c.c. W.L.Kurtz/F.T.Graybeal

FROM: W. L. KURTZ

Aug 12, 1970

TO: JC Bulla
DM Smith

Attached for your general info.
Hollister will never quit publishing

WLK F64

General Info —
USGeo. Regulations —
Permits

Copy for SAA DMS done 5/30/78

put to: ~~DMS~~ ~~FOC~~ ~~JHC~~

ASARCO

RECEIVED
MAY 22 1978
EXPLORATION DEPARTMENT

Northwestern Exploration Division
John C Balla
Manager

May 19, 1978

Mr. W.L. Kurtz, Manager
Western USA
ASARCO Incorporated
P.O. Box 5747
Tucson, Arizona 85703

WLK File — Mdy

Quartz Hill
S.E. Alaska

Dear Sir:

While you were here, you asked about U.S. Borax's Quartz Hill prospect in SE Alaska. Attached is a copy of a newsclipping out of the May 11, 1978 Wallace Miner, which gives you an idea of what they are planning on doing. Note the 24 separate permits they need to build that first road into the property.

Also enclosed is a copy of an article out of the May 1978 issue of Alaska Construction & Oil on the same subject.

Yours very truly,

John C. Balla/mc

John C. Balla

JCB/mc
Enclosure

cc: TCOsborne

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als including the Purple Heart. He came to Kellogg in 1949 and worked at the Sunshine mine as a pumpman. He had

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JHC → our file Moly

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MAR 30 1978
EXPLORATION DEPARTMENT

New York, March 28, 1978

MEMORANDUM FOR: Messrs. J. C. Balla
D. P. Cadwell
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Molybdenum

Herewith for its general interest is a copy of a memorandum dated March 21 by Mr. Davis of our Corporate Development Group, giving results of a molybdenum study which he initiated at my request.

I think the memorandum in general supports my view which is that in evaluating potential molybdenum prospects for exploration or development, we should normally use in calculations the current Amax price for molybdenum, coupled with our own best estimate of current construction and operating costs for the potential prospect in question. It may be assumed that future inflationary increases in construction and operating costs will be covered by increases in the price, and vice versa.

In general, any molybdenum prospect offering the possibility of producing the metal at a lower cost than Amax's would be highly interesting. Conversely, a prospect which would appear only to offer the possibility of being a higher cost producer than Amax would be approached cautiously even though pro forma calculations might seem to show an adequate rate of return.

As a matter of policy, we continue to be interested in the exploration for molybdenum on the above basis.

T. C. Osborne

Encl.

cc: WLKurtz - w/encl.
SVonFay "

March 21, 1978

Molybdenum, 1978
A Position Paper

This paper is being written at the request of the ASARCO Exploration Department. It will be used as part of the input they need to make a decision on how much, if any, effort they should expend on searches for molybdenum deposits.

An understanding of the molybdenum business needs to start with the awareness that the business is international in scope and it must be dealt with on such basis. The United States and Canada together produce some 85% of the free world supply of molybdenum. The United States has exported more molybdenum than it has consumed for eight out of the past ten years. Therefore, this paper will deal with the subject on a world-wide basis rather than limiting it to the U.S. and Canada.

Background

Besides the U.S. and Canada significant quantities of molybdenum are produced only in Chile and the Soviet Union. World Mine production and reserves by country are shown in the following table.

World Mine Production and Reserves
Thousands of Pounds of Contained Molybdenum

	1977 Estimated Mine Production	Reserves
United Stated	120,000	7,600,000
Canada	32,000	1,600,000
Chile	26,000	5,500,000 ?
Peru	1,000	1,200,000
Other Western Bloc	700	1,400,000
Central Economy Countries	21,000	2,500,000
World Total	200,000	19,800,000

Figure 1

MOLYBDENUM MINE PRODUCTION BY COUNTRY

MILLIONS OF POUNDS OF CONTAINED MOLYBDENUM

* = UNITED STATES

= CANADA

% = CHILE

" = PERU

. = OTHER

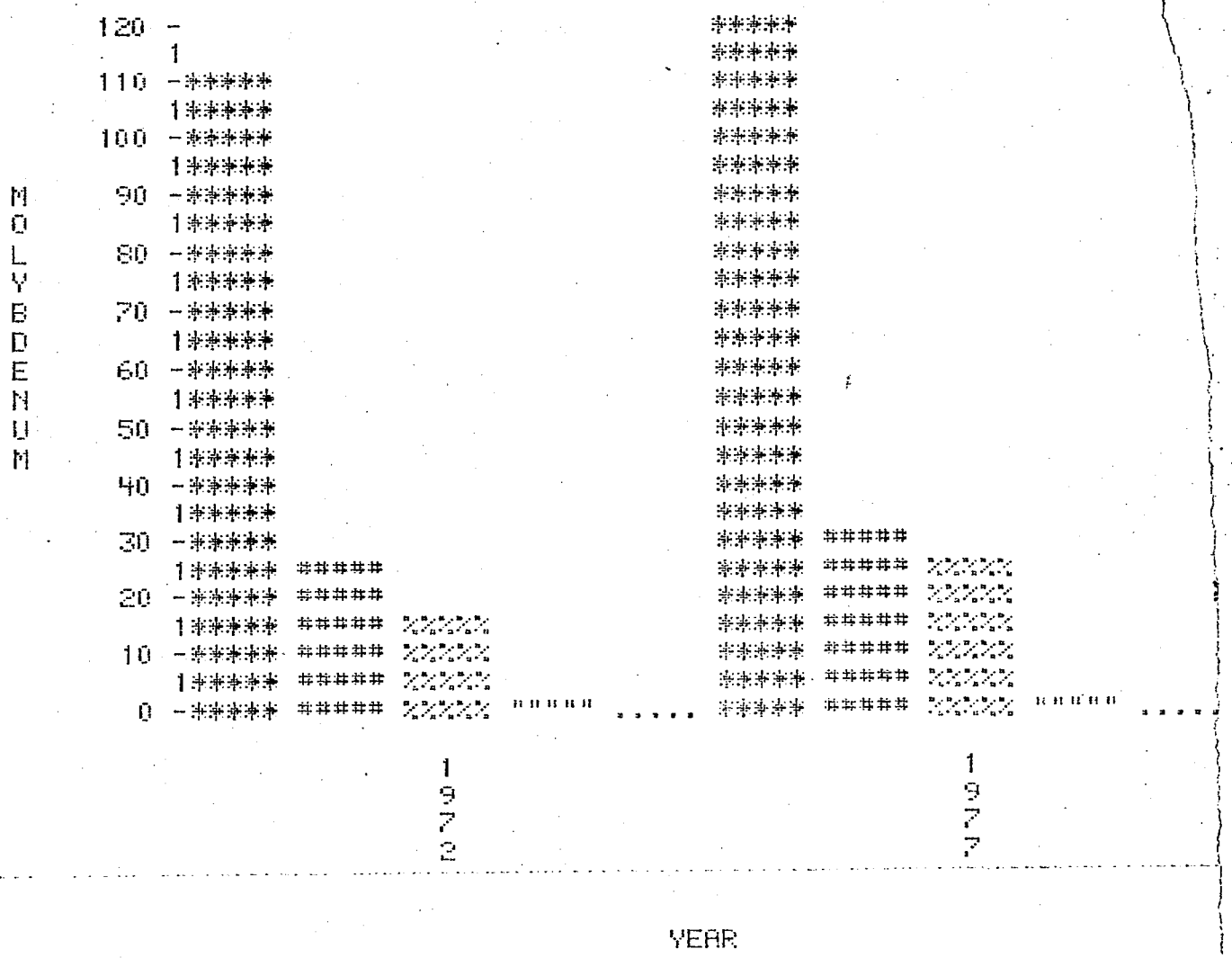

Fig. I shows free world mine production in 1972 and 1977. Notice that United States dominates the world market with Canada and Chile about tied for a distant second.

Since Amax dominates the U.S. markets a thorough understanding of Amax is important to an understanding of the molybdenum business. A brief description of their operation follows.

Amax Operations

Amax operates two molybdenum mines, Climax and Henderson, in the Colorado Rockies about 50 miles west of Denver. Climax is producing in excess of 60 million pounds per year of molybdenum from an average ore grade of 0.3% MoS_2. Climax has proven reserves of 30 years at the current operating rate.

The Henderson mine is a new underground mine just brought on stream in 1976. It is the largest privately financed work ever undertaken in the State of Colorado. It is estimated that Amax will have in excess of $500 million invested in the mine and mill by the time it reaches its rated capacity of 50 million pounds of moly production in 1980. Henderson average ore grade is 0.49% MoS_2 and proven reserves here will last until 2010 at this proposed mining rate some 30,000 tons per day.

The concentrate from these two mills, about 90% MoS_2, is sold to a limited extent, in the concentrate form. Most, however, is shipped to one of five roasting and conversion plants also owned by Amax. Two of these plants are located in the United States, an older plant being located in Langeloth, Pa. and a recently constructed one at Ft. Madison, Iowa. Other locations include plants in Great Britain, Italy and the Netherlands. The combined conversion capacity of all of these plants is in excess of 100 million pounds of molybdenum.

The MoS_2 is first roasted at these plants to form a technical grade oxide. This is sold as is and also converted by reaction with iron to ferromolybdenum. Ammonium molybdate is produced from tech grade which is the starting point for moly-containing catalysts or further reduction to the metal. Amax also purifies the sulfide which finds use as a lubricant.

Amax has for years carried out an extensive research, market development and technical service effort to expand and diversify the usage of molybdenum in all of its various forms. Amax has research expenditures in excess of $50 million annually and a good share of this is devoted to molybdenum application research.

including exploration?

The effort has paid off handsomely for Amax. By 1980 molybdenum will probably be generating a half a billion dollars in sales for Amax. Amax obviously sets the producer prices for all molybdenum products and they have conducted themselves in a very statesmanlike manner in this regard in the past. Producer prices have never decreased in the past 15 years, certainly an unusual phenomenon in the non-ferrous metals business. Through the sixties, prices rose very gradually from $1.40 to $1.70 for concentrates. Since 1972 prices have risen rather precipatously, 22% per year, to a current level of $4.41. This has been caused by a combination of factors, the very high inflation rate of past years, the spending by Amax of such large sums of capital on their Henderson property and also, and in no small part, because the market can bear it. Amax has done such a good job in finding unique uses for moly that it has become an indispensable ingredient for many metallurgical and catalyst applications. The Amax price history of molybdenum

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Figure 2

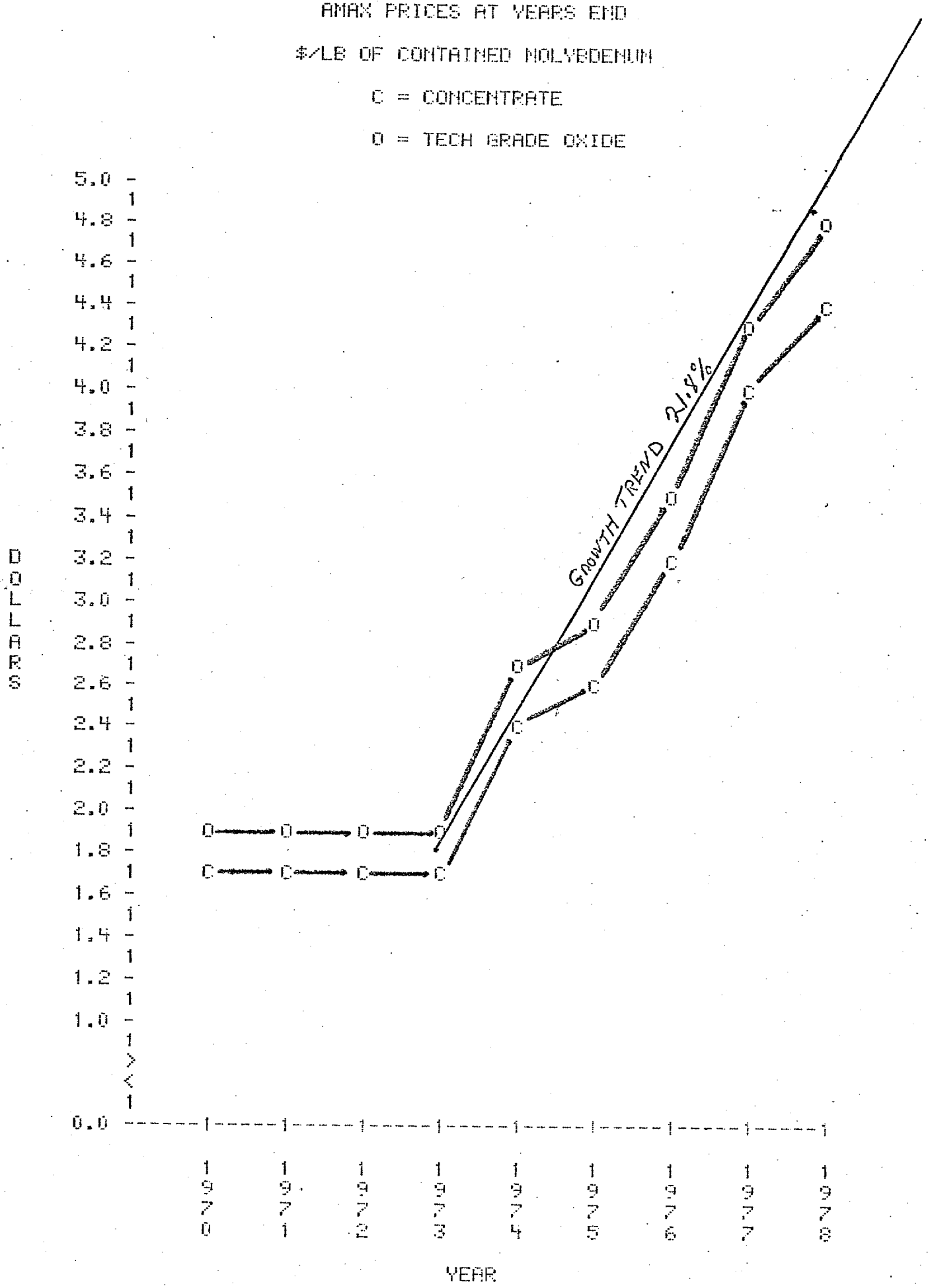
MOLYBDENUM PRICE HISTORY

AMAX PRICES AT YEARS END

$/LB OF CONTAINED MOLYBDENUM

C = CONCENTRATE

O = TECH GRADE OXIDE



is shown in Figure 2.

Another interesting item of pricing strategy followed by Amax is that they keep a constant price differential in effect between the prices of concentrate and tech grade. This difference which used to be 20¢ per pound, is now 35¢ which increase reflects inflation and pollution control costs. This is, in fact just about the actual cost of roasting the concentrate in a large and efficient plant. What Amax is doing is encouraging people to buy finished products rather that buy concentrate and make their own end products. With only a limited number of moly roasters available, Amax can make life difficult for small by-product producers such as ASARCO to find customers or for larger by-product producers such as Kennecott to operate roasters that are much more costly than are Amax's, due to economics of scale. This tends to help ensure competitors willingness to keep the prices up on the oxide product.

Other producers of molybdenum are shown in the following table:

Corporation	Installed Capacity MM lbs. of Mo	Reserves MM lbs. Mo
Codelco (Chile)	24	2,400
Kennecott	12	560
Noranda	27	550
Duval	21	300
Moly Corp.	11	330
Magma	4.5	240
Cyprus	3.8	92
ASARCO	2.0	200
Misc. Other	5	250
Soviet Union	20	450
Other Communist	4	400

Amax Costs

In considering what the future may hold for molybdenum pricing an analysis of Amax costs at their new Henderson mine should be helpful. A rough financial analysis of this operation follows:

In calculating the profitability of the Henderson Mine project the following assumptions were used:

1. Capital Expenses of 500,000 depreciated over 20 years on a straight line basis.

2. At the beginning of 1977 Amax long term debt was $630,000,000. It is assumed that 200,000,000 of this was invested in the Henderson mine and that the average interest rate was 7%. This gives a service-on-debt cost of 14,000,000 at start of project. Assuming a 20 yr. sinking fund type debt this would give an average service on-debt figure of $7,000,000 over the 20 year period.

3. Sales, administration and research costs are assumed to be 8% of gross sales value.

4. It is assumed that the mine and mill operate at capacity of 50,000,000 lbs. per year of contained molybdenum for the 20 years of the project.

5. Costs of mining and milling were supplied by T.C. Osborne and are assumed to be $8.33 per ton of ore.

6. Recovery rates are 9% as reported by Amax.

7. Total tonnage mined and milled is 10,800,000 tons per year as reported by Amax, to produce 50,000,000 lbs. of contained molybdenum in a 90% MoS_2 concentrate.

Based on various assumed selling prices of molybdenum in concentrate the profitability of the project (Internal Rate of Return on Investment) is shown in Table I:

Table I

All Figures in Thousands of Dollars
Except When Noted

Sales Price $/lb.	$5.00	$4.41	$/lb. Mo	$3.50	$2.80
Sales Income	250,000	220,000	4.41	175,000	140,000
Direct Costs	90,000	90,000	1.80	90,000	90,000
Debt Service	14,000	14,000	.28	14,000	14,000
SAR	20,000	17,000	.34	14,000	11,000
Gross Profit	126,000	98,900	1.98	57,000	25,000
Depreciation	25,000	25,000	.50	25,000	25,000
Net Profit	101,000	73,900	1.48	32,000	0
Depletion	50,500	36,950	.74	16,000	0
Profit, B.T.	50,500	36,950	.74	16,000	0
Taxes @ 48%	24,200	17,740	.35	7,700	0
Profit, A.T.	26,300	19,210	.17	8,300	0
Depreciation	25,000	25,000		25,000	25,000
Depletion	50,500	36,950		16,000	0
Cash Flow	101,800	81,160	1.62	49,300	25,000
IROI %	19.8	15.3 ?		7.6	0

Fig. 3 shows in graphic form the return on investment at various selling prices of concentrates. At the current price it would appear that Amax is realizing a 15% after-tax return which seems a fair figure. We have been told that Amax expects to lower their mining and milling costs as they become more familiar with the new operation and approach capacity production. Offsetting this trend will be continuing inflationary pressures of increasing labor and energy costs. Amax has good reasons not to want the price of molybdenum to become unreasonably high. This would tend to discourage the use of the metal, spur search for alternate materials and also encourage marginal producers and exploration for new ore bodies.

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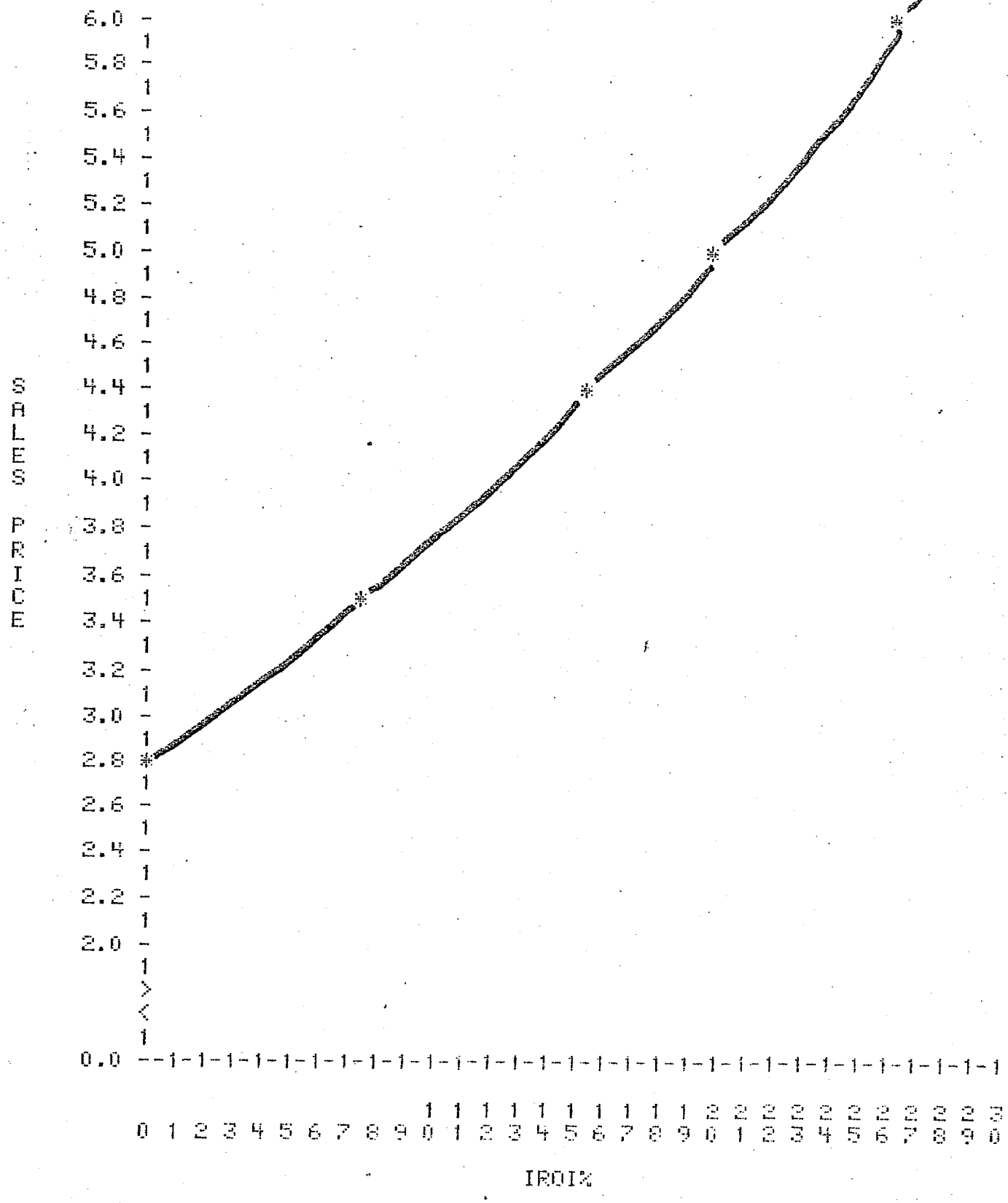
Figure 3

PROFITABILITY OF HENDERSON MINE PROJECT

PRICES OF MOLY CONCENTRATE IN

$/LB OF CONTAINED MOLY



In view of Amax's dominant position and their past history of pricing policies it would seem likely that the price of molybdenum will remain firm or increase somewhat over the next five years.

The only circumstances which would seem to be able to threaten this projection would appear to be the development and production of a major new ore body with substantially better economics that the Henderson mine or a collapse of market demand for molybdenum.

It has to be remembered that more than half of Amax's molybdenum is produced at the Climax mine and is probably somewhat cheaper to produce than the Henderson product. The Climax mining and milling costs are lower than Henderson, being reported as about $6.55 per ton of ore. However, due to the lower grade more ore must be mined so that the direct costs per pound of moly are probably about the same. The capital investment in the mine has certainly been much less than at Henderson however, so that depreciation and debt service have to be less.

One would have to view Amax's willingness to cut prices to be based on the average cost of their total production and not on that at either mine alone.

We are not aware at this date of any major new competative molybdenum ore bodies that are under development and it would undoubtedly take 5 to 10 years to bring any such mine into production after its discovery.

AMAX MT EDMONDS

Markets

The final item then to consider is the future of the markets for molybdenum.

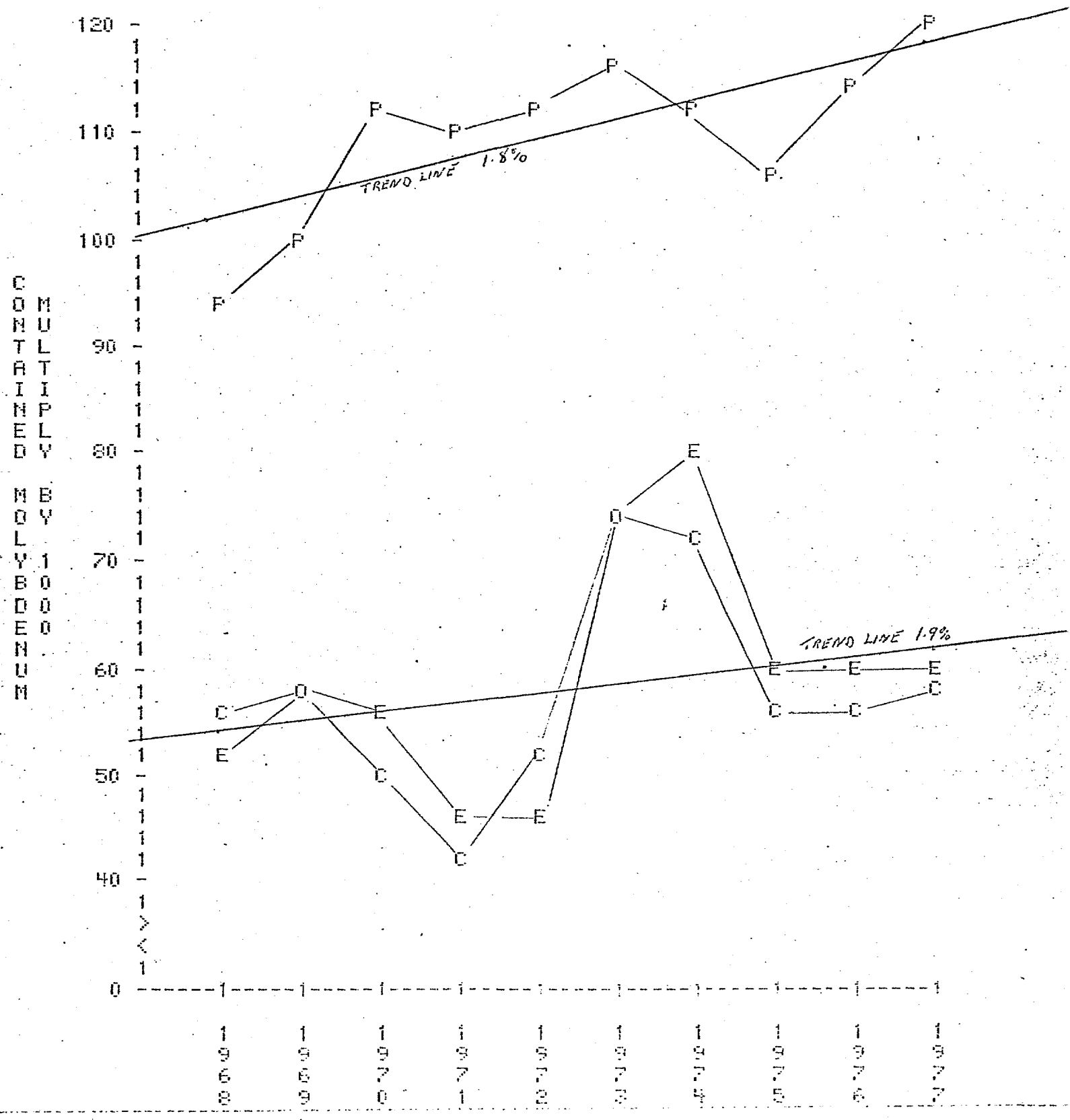
Figure 4

U.S.MOLYBDENUM STATISTICS, 1968-77, POUNDS X 1000

P = MINE PRODUCTION

E = NET EXPORTS

C = APPARENT CONSUMPTION



As is shown by Table II below, 88% of the usage of molybdenum in steel or steel related applications.

Table II

World Consumption of Molybdenum
By End Use Area

Application	% of Total Usage
Alloy Steel	44
Stainless Steel	24
Tool Steel	10
Chemicals Adn Lubes.	8
Cast Iron and Steel Mill Rolls	6
Superalloys	4
Moly Metal	3
Misc.	1
	100

While it may be true that the U.S. Steel Industry has shown little growth over the past years the same can not be said to be true of the world wide production of steel. As shown in Fig. 4 world steel production is growing at 4% and is now pushing the 700 million ton mark having grown from less that 500 million tons in 1965. This must be coupled with the fact that the market remains excellent for those steels in whose manufacture the use of molybdenum is imperative such as large diameter pipe-line for use in the Arctic, construction steels used in deep oil well drilling, high temperature steels for energy generating plants as well as light weight steels for transportation applications.

Much talk has been put forth about a 7% "average" growth rate for molybdenum consumption in the United States. As Fig. 5 shows this is an overstatement and in fact the average rate of growth over the past 10 years has been just under 2% for U.S. consumption and a little less for U.S. production.

It does not seem likely that much will change with the U.S. Steel Industry over the next 5 to 10 years that will cause a substantial change in the consumption of molybdenum so that we

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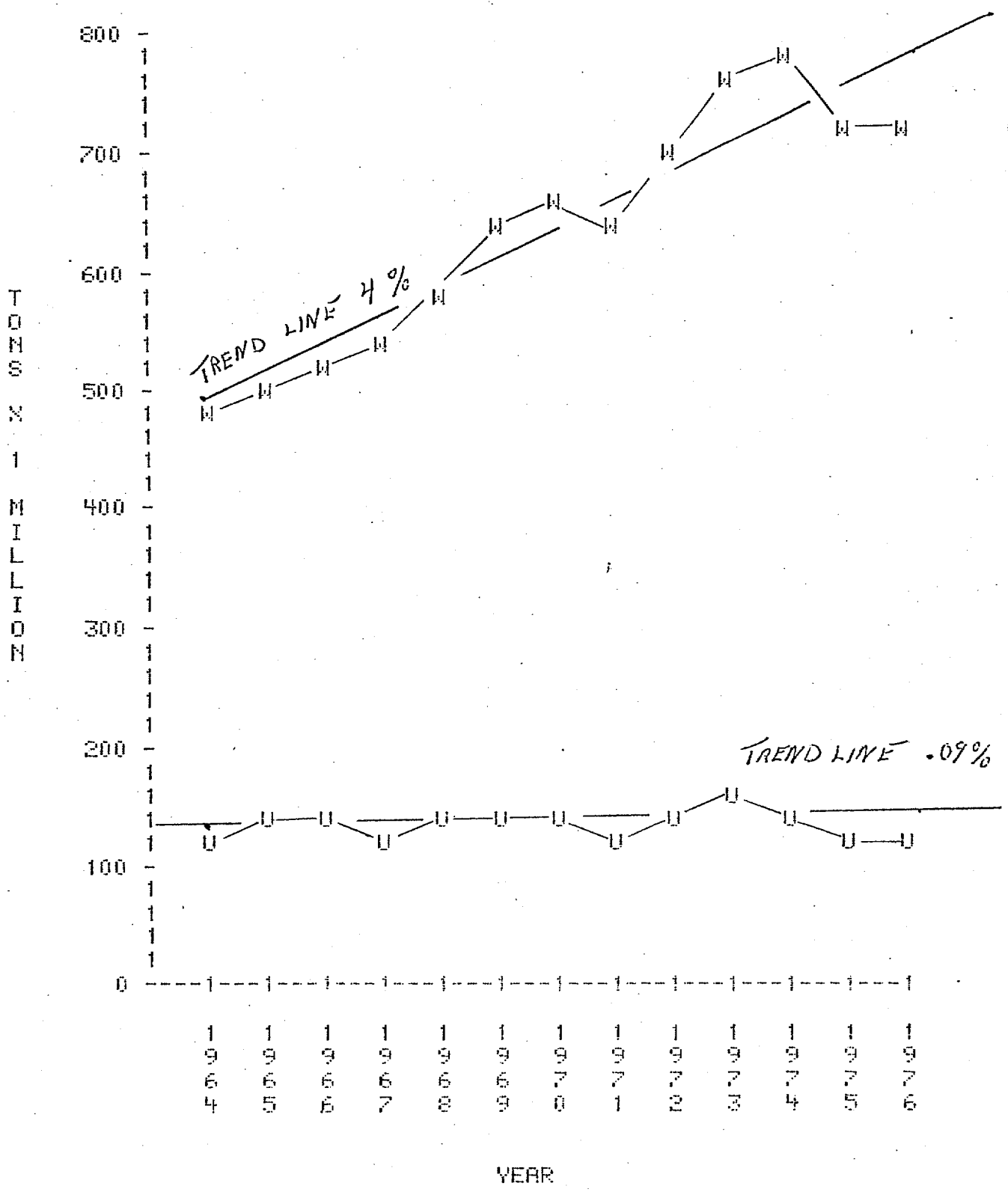
Figure 5

US AND WORLD PRODUCTION OF RAW STEEL

MILLIONS OF SHORT TONS

U = U.S. PROD

W = WORLD PROD



can look to the U.S. market for molybdenum to continue along at a 2% to 4% growth rate.

The export market however, should show a growth rate in excess of 4%, perhaps as high as 7%. The reasons for this are that the demands for steel being made by developing and third world countries will continue to grow. Much of this steel demand will be for the higher performance products which require molybdenum as an alloying agent. Also, the communist countries only have about 10% of the world reserves of recoverable molybdenum. They are already importing some 15 to 20 million pounds per year of moly from free world sources. It seems likely that as steel production in Communist countries continues to increase they will have increasing demand for imported supplies of molybdenum. We can therefore look to a continuing strong export market for molybdenum from the United States with a growth rate of some 4% to 7% for the next ten years.

In summary, it would appear that demand for molybdenum will continue to grow and that prices will remain firm and increase with inflationary pressures. It does not seem likely that molybdenum prices will drop over the next five years.

It also seems likely that Amax will continue to be the dominant factor in the U.S. and World markets for molybdenum and that any serious challenge to this dominance would depend on the discovery of a high quality ore body which would be cheaper to mine than is the average cost concentrate from the Amax mines.

Barry L. Davis

file: Moly

North-Central Section 12th Annual Mtg.
May 1-2, 1978
University of Michigan at Ann Arbor

ASARCO

Exploration Department

WXK

February 3, 1978

MEMO FOR: T. C. Osborne

FROM: J. H. Courtright

MOLYBDENUM

Our somewhat negative attitude in respect to moly exploration in the past few years has hinged largely on the "Henderson threat", a large, relatively high-grade deposit with a projected production of 50 million lbs/yr. However, after a sharp drop in 1971, consumption increased dramatically and is expected to grow at 7% per year (Amax annual report, 1976). World consumption in 1976 was estimated at 182 million lbs ------ 14 million lbs greater than production.

Henderson is expected to reach full capacity by 1980. Although this would approximately equal the 7% per year increase in consumption (in 4 yrs), the long term outlook is still very favorable according to an article in the January 13, 1978 issue of Mining Journal (excerpt attached).

Of particular note is the statement that one of the principle uses of moly is in large diameter steel pipe for oil and gas transmission. "Demand in this area appears likely to remain strong for some time to come". Among other items of significance in this article: (1) "The Communist World is expected to become even more dependent on imports", (2) "Another increase in prices of 8% to 10% early in the current year has been forecast....".

I believe the foregoing justifies a more aggressive stance in moly exploration and also points up the need for more literature search, particularly statistics, in an attempt to anticipate medium to long term markets in non-ferrous metals as well as other commodities.

J. H. Courtright

J. H. Courtright.

JHC:jlh
attmt
c.c. S.VonFay

Continued, next page

JUN 11 1973

UNITED STATES MINERAL RESOURCES

MOLYBDENUM

By R. U. King, D. R. Shawe, and E. M. MacKevett, Jr.

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ABSTRACT OF CONCLUSIONS

Molybdenum, a rare metal widely dispersed in the rocks of the earth's crust, occupies an essential place in today's highly sophisticated industries.

World production of molybdenum is about 200 million pounds per year, of which about 60 percent is produced in the United States. Identified resources amounting to about 17.5 million tons of molybdenum in the United States and about 32 million tons in the world and occurring both as the primary metal sulfide in large low-grade porphyry molybdenum deposits and as a subsidiary metal sulfide in large low-grade porphyry copper deposits, seem adequate to supply world needs for the forseeable future.

To assure economic availability of these resources and to discover additional resources that surely will be needed if world demand continues to escalate and if environmental problems should tend to restrict the commercial development of resources, employment of our most sophisticated exploration techniques will be essential. Successful prediction of the location of undiscovered molybdenum resources will depend upon an understanding of the genetic relationship of molyddenum to associated magmatic rocks, the environments in which these magmatic rocks were emplaced, and the role of plate tectonics in developing favorable environments and mechanisms for the generation and emplacement of molybdenum-carrying rocks.

INTRODUCTION

Molybdenum, discovered in the last 1770's, is a metal of fairly recent entry into the commercial market, having come into significant use during the 1920's as a result of extensive metallurgical research into its alloying properties and as a result of the establishment at Climax, Colo., of proved reserves sufficient to supply world demand for many years at a reasonable price. Its importance as an alloying metal is due chiefly to the increase in hardness, toughness, and resistance to corrosion and wear at elevated temperatures that it imparts to iron, steel, and stainless steel.

Molybdenum is a silvery-gray metal having a high specific gravity (10.2)—slightly higher than copper—and a melting point of 2,620°C—the fifth highest melting point of all metals. It is ductile and has a hardness of about 200 V.P.N. (Vickers Pyramid Number) and its coefficient of thermal expansion is among the lowest of metals. It is resistant

to acids and oxidation at ordinary temperatures. It has a high thermal conductivity and good electrical conductivity.

The principal uses of molybdenum are in the iron and steel industries with 70 percent of the apparent consumption going into high-speed, tool, stainless, and low-alloy construction steels and 20 percent going into special alloys and castings; the remaining 10 percent is used as molybdenum metal and in pigment, catalysts, agriculture, chemicals, and lubricants.

It must be evident from the above list of uses that molybdenum is an essential metal in a highly sophisticated industrialized nation such as the United States and that it is equally essential in other industrially developed countries. The extent to which our present living standards depend on the ready availability and constant supply of molybdenum may be illustrated by an example of molybdenum utilization in the automotive industry: 10 million units yearly production consumes more than 2 million pounds of molybdenum, a significant consumption despite the small weight of molybdenum used per unit.

Without molybdenum as an alloying metal, superstrength steel as used in heavy construction such as modern skyscrapers and bridges would be more costly, and in some instances the increased weight needed for equivalent strengths would render certain construction patterns unmanageable.

Molybdenum can substitute for tungsten, vanadium, chromium, columbium, tantalum, nickel, and boron. Each substitution is a matter of cost-availability to obtain certain desired qualities in the finished product.

Molybdenum is virtually the sole metal commodity of which the United States is a net exporter. Domestic production in 1970 was just over 110 million pounds of molybdenum, or two-thirds of the free world production. Domestic consumption, on the other hand, is about 50 million pounds; the United States annually exports about 55 million pounds of molybdenum in various forms such as molybdenite concentrates, molybdenum trioxide, and ferromolybdenum to more than 20 other nations.

EXPLOITATION

Recorded world production of molybdenum began just after 1900, when about 100 short tons of the metal was produced, approximately half of which came from Australia and Norway and half from the United States (Fischer and King, 1964). Through the years, molybdenum has been produced, at one time or another, in some 30 countries around the world. The major part, however, has come from nine countries: the United States, Chile, Canada, Japan, Korea, Norway, Mexico, the U.S.S.R., and China.

The United States currently supplies about 60 percent of the world's total molybdenum; Canada, about 15 percent; the U.S.S.R. and China, about 15 percent; and all other producing countries, 10 percent.

World production of molybdenum increased from about 300,000 pounds per year in 1906 to 3 million pounds per year in 1932, a tenfold increase during this 26-year period. The next tenfold increase occurred within a 5-year period in the 1930's, as a result of a major increase in United States production brought about chiefly by the initiation of large-scale mining by block caving of the Climax ore body in Colorado. Production increased sharply during World War II to a high point in 1943 of 70 million pounds of molybdenum and then decreased rapidly to about 24 million pounds in 1946, remaining at this level until 1949 owing to the low level of demand that followed the end of hostilities. Since 1949 a relatively uniform and consistent increase in the annual rate of production, interrupted only by recession in 1958 and work stoppages in 1962, has continued to the present, at which time about 200 million pounds of molybdenum is produced annually.

Until 1936, domestic production of molybdenum was as a main product of molybdenum ores. In 1936, at the Bingham, Utah, porphyry copper mine, recovery of molybdenum as a byproduct was begun; today about one-quarter of the United States production of molybdenum is obtained as a byproduct of copper mining, and at least half of the world production of molybdenum is obtained as a byproduct or coproduct of copper mining operations.

For many years the famous Climax molybdenite mine in Colorado was the only known porphyry molybdenum deposit in the world; but in 1957, the Questa molybdenite deposit in New Mexico was recognized to have many characteristics of a stockwork-type ore body, and intensive exploration confirmed the presence of a large tonnage of low-grade molybdenite ore. In 1966, open-pit mining of the disseminated ore body at Questa began, and by 1969, the annual production of molybdenum was more than 10 million pounds. In British Columbia, several porphyry molybdenum and copper-molybdenum deposits were developed, and in 1966, molybdenum output from British Columbia's mines amounted to 20 million pounds.

Early in the 1960's, intensive exploration was

undertaken at the Urad-Henderson porphyry molybdenite deposits in Colorado. Production at the Urad mine began in 1967 at an annual rate of about 3 million pounds of molybdenum. In 1966, American Metal Climax, Inc., announced reserves of more than 300 million tons of ore in its Henderson deposit, some 2,000 feet below the Urad ore body, at a grade of 0.49 percent molybdenite. The company expects to put this mine into production by the late 1970's

Only at Climax, Colo., has the recovery of associated minerals in a porphyry-type molybdenum deposit so far been successful; tungsten (huebnerite), pyrite, topaz, uranium (brannerite), monazite, tin (cassiterite), and molybdenum oxide have been recovered as byproducts.

GEOLOGIC ENVIRONMENT

GEOCHEMISTRY[1]

Molybdenum is a metallic element of Group VIb of the periodic table and has atomic number 42, atomic weight 95.94, and occurs as six isotopes. In nature it has valences of +4 and +6 in molyhydrates and possibly rarely has valences in the +3 and +5 states. Molybdenum is a rare element, its abundance in continental crustal rocks being generally given as 1 to 1.5 ppm. It is rather uniformly distributed among the igneous rocks but averages slightly higher in basaltic rocks than in granitic rocks.

Chemically, molybdenum can function both as a metal and as a nonmetal. In the geochemical cycle it becomes concentrated in shales, clays, and phosphorites; in these rocks, there is a positive correlation between the content of molybdenum and the content of organic carbon. Molybdenum is also concentrated in coal and petroleum. Of the molybdenum that is supplied to ocean waters, virtually all is precipitated either mainly with the clay minerals or partly in hydrous manganese oxides.

Man's activities contribute molybdenum to the environment in mining, in metallurgical processing, in the addition of phosphate fertilizers to the soil, and in the conversion of coal and oil to provide for his various energy needs.

MINERALOGY

Molybdenum does not occur in nature in its free or native state but is found only in combination with other elements, such as sulfur, oxygen, tungsten, lead, uranium, iron, magnesium, cobalt, vanadium, bismuth, and calcium. The most common molybdenum minerals are molybdenite (molybdenum disulfide, MoS_2), powellite (calcium molybdate, $CaMoO_4$), wulfenite (lead molybdate, $PbMoO_4$), ferrimolybdite ($FeMoO_3 \cdot H_2O$), ilsemannite (molybdenum oxysulfate), and jordisite (amorphous molybdenum disulfide). Of these, only molybdenite, ferrimolybdite, and jordisite are of current economic importance. Some molybdenum has been recovered in the past, however, from wulfenite- and powellite-bearing ores. As the demand for molybdenum continues to rise, powellite, ferrimolybdite, and jordisite may be looked upon as possible source materials.

TYPES OF DEPOSITS

Molybdenum deposits are of five genetic types: (1) porphyry or disseminated deposits including stockworks and breccia pipes in which metallic sulfides are dispersed through relatively large volumes of altered and fractured rock, (2) contact-metamorphic zones and tactite bodies of silicated limestone adjacent to intrusive granitic rocks, (3) quartz veins, (4) pegmatites and aplite dikes, and (5) bedded deposits in sedimentary rocks.

PORPHYRY DEPOSITS

Probably more than 95 percent of the world's supply of molybdenum has been obtained from porphyry molybdenum or porphyry copper-molybdenum deposits. In these deposits primary copper sulfides and (or) molybdenite occur as disseminated grains and in stockworks of quartz veins and veinlets in fractured or brecciated, hydrothermally altered granitic intrusive rocks and in the intruded igneous or sedimentary country rocks.

Favorable host intrusive rocks with which the ore minerals are generally assumed to be genetically related range from intermediate to acidic and include diorite, quartz monzonite, and granite, and their porphyritic equivalents. Metalization commonly took place both in the host intrusive and in the surrounding or overlying country rock.

In the porphyry molybdenum deposits, molybdenite is characteristically the sole ore mineral. Molybdenite commonly is accompanied by pyrite, fluorite, and small amounts of tungsten, tin, lead, and zinc minerals. In contrast, the porphyry-copper or copper-molybdenum deposits contain only small amounts of molybdenum, and in these, the molybdenum is of economic significance only because of the recoverable copper content. The primary copper mineral is chalcopyrite, which is intimately associated with pyrite.

The porphyry or disseminated deposits are commonly considered to be pipe-shaped bodies, circular

[1] From material provided by Michael Fleischer, written commun., 1972.

or oval in plan and with steeply dipping sides. In nature, however, the deposits are more likely to be in complex forms, such as domal, funnel-shaped, arcuate, and annular bodies (Brown, 1969; James, 1971).

Almost invariably one or more major faults pass through or close to the ore bodies. Evidence of both preore and postore movement is abundant in these faults, and localization of the ore bodies along major faults is an accepted hypothesis. Intensive, widespread and continued fracturing of host intrusives and of enclosing country rocks is characteristic.

The average mineral content of porphyry-type deposits ranges from 0.1 to 0.5 percent molybdenite in molybdenum porphyries, and from about 0.015 to 0.1 percent molybdenite in copper-molybdenum porphyries. Currently minable porphyry deposits range in size from a few hundred feet to several thousant feet in horizontal dimension and may extend to depths of several thousand feet. Fractures and hydrothermally altered rocks extend many hundreds of feet outward beyond the limits of minable ore, decreasing in intensity outward from the central zone.

Three-fourths of the world's reserves of molybdenum are in the Western Cordillera of North and South America, the mountainous region along the western part of these continents. These reserves consist of large low-grade disseminated deposits of hydrothermal origin that occur in clusters throughout the length of the Cordillera. They are typical porphyry deposits, genetically associated with intrusive rocks of acidic to intermediate composition in areas of intense volcanism and complex tectonic history. The period of ore deposition extended from Late Triassic to middle Tertiary.

The remaining one-fourth of the world's reserves of molybdenum are distributed among the U.S.S.R., parts of Europe, southwestern Asia, and southeastern Asia including China, the islands of the South Pacific, and Australia; the U.S.S.R. reserves account for at least half of this fraction.

Porphyry or stockwork deposits that yield molybdenum alone or as the chief metal are known to occur principally in Alaska, British Columbia, and in the Rocky Mountain region of the United States (Clark, 1970); porphyry copper-molybdenum deposits from which molybdenum is obtained as a byproduct occur over the entire length of the Western Cordillera from Alaska to Argentina, and in other parts of the world (Eimon, 1970).

The Climax and Urad-Henderson deposits in Colorado and the Questa deposit in New Mexico are described here as three examples that illustrate the typical porphyry molybdenum ore deposits, their geological relationships, and the resources connected with this type of deposit. Comprehensive descriptions of the porphyry copper-molybdenum deposits in southwestern North America are given by Titley and Hicks (1966), and of those in the Western Hemisphere by Ridge (1972).

CLIMAX, COLORADO

For many years (1930–55), the Climax molybdenum deposit at Fremont Pass, about 100 miles west of Denver, Colo., was unique in that it was the only known porphyry molybdenum deposit in the world. Large-scale bulk mining of the disseminated ore body began in the mid-1930's, about 20 years after its discovery and after the mining from near the top of the deposit of small tonnages of high-grade zones that contained from ¾ to 1 percent molybdenite (Butler and Vanderwilt, 1933). The Climax mine, operated by the Climax Molybdenum Co. division of American Metal Climax, Inc., exploits one of the three largest known molybdenum stockwork deposits in the United States if not in the world. The two other deposits of equivalent size and character are the Questa molybdenum deposit in northeastern New Mexico (Molybdenum Corp. of America), and the Urad-Henderson molybdenum deposit at Empire, Colo. (Climax Molybdenum Co.). The Climax deposit has, according to the company's annual report, reserves amounting to about 500 million tons of molybdenum ore which contain over 2 billion pounds of molybdenum, sufficient to sustain the present rate of production through the remainder of this century.

The deposit consists of a complex dome-shaped mass of fractured, silicified, and mineralized Precambrian granite, gneiss, and schist that generally overlies a composite porphyry stock of quartz monzonite to granite composition, middle Tertiary in age. Molybdenite associated with quartz, pyrite, fluorite, topaz and lesser amounts of tungsten, scandium, titanium, and tin minerals is dispersed in fracture fillings, in veinlets, and as minute flakes throughout the fractured host rocks forming a low-grade (0.05 to 0.5 percent Mo) ore body of several thousand feet in smallest dimension. Several commodities, such as tungsten, pyrite, and tin, are recovered as byproducts. Climax has become a leading United States producer of tungsten in recent years. A small tonnage of monazite has been recovered in the past, as has a small amount of topaz. According to company reports, more than 150 million tons of ore had been mined from the Climax deposit by 1972. The ore deposit has not yet been

delineated completely and the possibility therefore exists that additional reserves may be discovered that will at least in part replace reserves currently being mined. Detailed descriptions of the geology of the Climax area and of the deposit were given by Vanderwilt and King (1955) and Wallace, Baker, Johnson, and MacKenzie (1960).

URAD-HENDERSON, COLORADO

The Urad-Henderson porphyry molybdenum deposit near Empire, about 50 miles west of Denver, is a prime example of the discovery and development of a huge deposit as a result of careful and exhaustive geologic study and the use of modern exploration techniques. The Urad ore body, known for many years, was first developed on high-grade quartz-pyrite-molybdenite fissures and fracture zones, from which about half a million pounds of molybdenum was produced during the early part of the century and in the 1940's. The Urad molybdenite ore body is localized in a zone of fractured and altered granite around the southern margin of a composite granite porphyry stock (Carpenter, 1960, p. 321) of middle Tertiary age. Molybdenite also occurs in veinlets and as disseminations in the altered and fractured granite between the fracture zones and fissures, forming a massive porphyry type body of many millions of tons of molybdenite ore containing from 0.3 to 0.5 percent molybdenite.

About 2,000 feet below the Urad ore body, and separated from it by altered rocks that contain only traces of molybdenite, is the Henderson molybdenite ore body. According to the Climax Molybdenum Co., reserves in the Henderson ore body amount to over 300 million tons at a grade of 0.49 percent molybdenite. Very few geological data have been published on the Henderson deposit, but it is a typical porphyry or stockwork deposit. The mine is expected to be brought into production late in the 1970's, with a planned milling capacity of 50,000 tons per day.

QUESTA, NEW MEXICO

Molybdenite at Questa occurs in massive quartz veins, in a stockwork of discontinuous veinlets, and as fine disseminated flakes in a hydrothermally altered and fractured zone several thousand feet wide. The quartz-molybdenite veins exploited during the earlier development period, as well as the stockwork molybdenite, lie along the contact of a composite intrusive body of granite and the overlying andesitic volcanic rocks. Molybdenite is the only mineral of economic importance in the deposit although rhodochrosite, fluorite, and a little chalcopyrite are present. The grade of the ore body is low, averaging only about 0.1 percent molybdenum. According to company reports, more than a quarter of a billion tons of ore has been developed at the property. Despite its low grade, the Questa deposit promises to be one of the major domestic sources of molybdenum for many years.

CONTACT-METAMORPHIC DEPOSITS

In the molybdenum-bearing contact-metamorphic deposits (tactites and skarns), molybdenite is commonly associated with scheelite, bismuthinite, or copper sulfides in zones of silicated limestone near granitic intrusive rocks. Molybdenite also occurs alone in contact-metamorphic deposits. The Pine Creek mine in California is an example of the contact type of deposit from which molybdenum and tungsten have been recovered as coproducts since 1939 (Bateman, 1956).

Significant amounts of molybdenum also occur in contact-metamorphic deposits in the northeastern Caucasus of the U.S.S.R., in China, and in Morocco (Kruschov, 1959). The molybdenite deposits of the Knaben mine in Norway are in quartz-rich amphibolitic gneisses of probable sedimentary origin and may be included in this category. The ore ranges from 0.1 to 0.2 percent molybdenite, and although production from the deposit has been persistent for many years, it has been relatively small.

QUARTZ VEINS

Quartz veins containing molybdenite are widely distributed throughout the world. Early production about 1900 was made from the relatively high grade deposits of this type. A prime example of vein type bodies is found at the Questa molybdenite deposit at Red River, N. Mex., where small tonnages of molybdenite were produced between the 1920's and the mid-1950's from high-grade quartz-pyrite molybdenite gash veins along the contact between a sodic granite and overlying andesitic volcanic rocks. The molybdenite content of the veins ranged from 1 to 30 percent molybdenite. Not until the late 1950's was it discovered that the veins were associated with mineralized rocks having the characteristics and potential for a large low-grade porphyry-type molybdenite ore body associated with a composite granite stock.

PEGMATITES

Commonly, pegmatite bodies and aplite dikes contain molybdenite among many other metallic and

nonmetallic constituents. The molybdenite is generally coarsely crystalline, occurring as rosettes or thick books and aggregates of flakes, which are erratically distributed in the host rocks. Although much specimen material of excellent quality can be obtained from this type of deposit, few deposits have been of economic interest owing to the characteristically small tonnage available and the erratic distribution of molybdenite. Notable among the pegmatite-type deposits that have yielded significant quantities of erratically disseminated molybdenum are those at Val d'Or and Preissac, in eastern Quebec, where molybdenite is associated with bismuth in pegmatite bodies and greisen zones (Vokes, 1963).

BEDDED DEPOSITS IN SEDIMENTARY ROCKS

Although molybdenum is concentrated in coals, shales, and phosphorites, no molybdenum of economic grade has been found in these rocks. Only in certain lignitic sandstone beds of southwestern North Dakota, northwestern South Dakota, and eastern Montana, and in some arkosic sandstone beds in the badlands of southwestern South Dakota and northeastern Utah, has the molybdenum content approached ore grade (0.1 to 0.2 percent Mo) in deposits thick enough to be minable.

In the United States, molybdenum is associated in significant amounts with some of the bedded sandstone uranium deposits in Arizona, Wyoming, South Dakota, New Mexico, and Utah, and in the Gulf Coast region of Texas. Similar occurrences undoubtedly exist in other parts of the world, but published data are not readily available on these deposits. The molybdenum is in the minerals jordisite and ilsemannite and is present in amounts ranging from a few parts per million to more than 0.5 percent. It is irregularly distributed with respect to the uranium ore bodies, commonly occurring along or some distance from the outer margins of the ore bodies rather than within them. Ordinarily the small amount of molybdenum present in this type of ore deposit is detrimental because the molybdenum interferes with the recovery of uranium and must be segregated out of the circuits during milling processes. However, where the uranium deposits are of sufficient size and the molybdenum content is significant, a valuable byproduct may exist. According to the U.S. Bureau of Mines, molybdenum has been recovered from composites of uranium ores and ash residues of some uranium-bearing lignites from South Dakota and New Mexico.

RESOURCES

IDENTIFIED AND HYPOTHETICAL RESOURCES

About half the world's identified resources of molybdenum are in the United States, and of these resources, about 75 percent occur in deposits where molybdenum is the principal metal sought. The other half of the world's identified resources are distributed among more than 30 countries around the world. These resources occur as large bodies of fairly uniformly mineralized rock containing more than 500 ppm (parts per million) (0.05 percent) of molybdenum if no other valuable metal is present in significant amounts, or more than 50 ppm (0.005 percent) of molybdenum if molybdenum is not the primary metal sought.

Most of the identified resources of molybdenum are in the disseminated or porphyry-type deposits of the Colorado Mineral Belt, the Sangre de Cristo Range in New Mexico, and the Basin and Range province of the southwestern United States; the Interior Belt of British Columbia, Canada; the Andean Cordillera of Peru and Chile; and the Ural and Altai Mountains of the U.S.S.R. (table 85). Many of these deposits have been explored only to a minimal extent, and the metal contents appear to be lower than current ore grades—molybdenum in porphyry molybdenum deposits in the order of 0.01 to 0.1 percent and copper in porphyry copper-molybdenum deposits in the order of 0.1 to 0.2 percent—too low to be profitably mined under present conditions.

The magnitude of the identified resources of molybdenum can only be partly estimated directly from published data and statistics, because of the large fraction that is associated with copper resources. Clearly a sizable part of the discussion of the resources of molybdenum must therefore be based on geologic and geochemical information.

Large quantities of molybdenum probably are still hidden in areas of known deposits, as extensions of mining districts or mineral belts, and occur in deposits similar in geologic character and grade to those already known. Such hypothetical resources are predicted on the basis of known distributions of geologic environments favorable for molybdenum deposits and on the basis of our current understanding of the processes of deposition of molybdenum deposits. The bulk of hypothetical resources thus estimated amounts to about 1 billion tons of molybdenum, a large part of which appears to be equally divided between the United States and the U.S.S.R.

Table 85 is a summary of the estimated world resources of molybdenum.

TABLE 85.—*Estimated magnitude, in millions of pounds, of world resources of molybdenum*

Area	Identified resources [1]	Hypothetical resources [2]
North America:		
Canada:		
British Columbia	8,000	---------
Quebec	2,000	---------
Subtotal	10,000	10^6
Greenland	200	---------
United States:		
Alaska	1,000	---------
Arizona	2,000	---------
Colorado	20,000	---------
Idaho	1,000	---------
Maine	100	---------
Montana	1,000	---------
Nevada	500	---------
New Mexico	8,000	---------
North Carolina	100	---------
Texas	100	---------
Utah	1,000	---------
Washington	200	---------
Wyoming	100	---------
Subtotal	35,100	10^6
Puerto Rico	500	---------
Mexico	1,000	---------
Central America	1,000	---------
Total	47,800	10^4
South America:		
Argentina	100	---------
Columbia	100	---------
Ecuador	100	---------
Chile	5,500	---------
Peru	1,300	---------
Total	7,100	10^6
Europe:		
Bulgaria	100	---------
Rumania	100	---------
Spain	100	---------
Yugoslavia	1,000	---------
Total	1,300	10^4
Africa:		
Morocco	50	---------
Sierra Leone	50	---------
Total	100	10^2
Asia:		
Burma	100	---------
China	1,000	---------
India	50	---------
Iran	100	---------
Japan	100	---------
U.S.S.R.	5,000	---------
Thailand	50	---------
Vietnam	50	---------
Total	6,450	10^6
Antarctica	50	10^2
Australia	100	10^3
Oceania:		
Borneo	30	---------
Bougainville	40	---------
New Guinea	30	---------
Philippines	100	---------
Total	200	10^4
World total	[3] 63,100	[4] 2.2×10^6

[1] Identified resources are specific, identified mineral deposits that may or may not be evaluated as to extent and grade, and whose contained minerals may or may not be profitably recoverable with existing technology and economic conditions.
[2] Hypothetical resources are undiscovered mineral deposits, whether of recoverable or subeconomic grade, that are geologically predictable as existing in known districts.
[3] Equal to 31,550,000 tons.
[4] Equal to 1.1 billion tons.

SPECULATIVE RESOURCES

Speculation as to worldwide distribution and magnitude of molybdenum resources necessarily must be based on geologic relationships of the deposits that are best documented and most clearly understood. Domestic deposits offer the best information in this regard; consequently models based largely on occurrences in the United States and the Western Hemisphere as described under "Porphyry Deposits" are used to infer speculative resources.

World molybdenum resources are likely to be divided somewhat equally between deposits that contain molybdenum as the primary metal and those in which molybdenum is expected to be a byproduct or coproduct. Porphyry-molybdenum and porphyry-copper deposits are expected to contain by far the bulk of molybdenum resources.

Porphyry-molybdenum or porphyry-copper deposits are individual mineral deposits associated with stocklike intrusives, breccia structures, and faults. Distribution of this type of deposit worldwide, therefore, should be related to the distribution of certain major geologic features:

1. The deposits are found in belts of Cretaceous-Tertiary tectonic activity that were disturbed by subsequent igneous activity (Eimon, 1970). They occur along the cordillera of North and South America, the Alpide belt (Sillitoe, 1972), the Iranian orogenic belt, the south Pacific Arc, and in the Ural and Altai Mountains of the U.S.S.R.
2. They are associated mostly with intrusive activity that ranges in age from Triassic to mid-Tertiary (Sillitoe, 1972).
3. They occur in intrusive rocks of intermediate to acid composition; porphyry molybdenum deposits tend to be associated with granitic intrusives and porphyry copper-molybdenum deposits with instrusives of intermediate composition.
4. The molybdenum deposits commonly occur in clusters or groups of 5 to 20 miles in radius (King, 1970).
5. Porphyry deposits are commonly found in areas of gravity and magnetic lows; porphyry molybdenum deposits related to Tertiary silicic intrusives tend to occur in regional gravity lows.
6. Molybdenum deposits are commonly alined in major structural belts and at intersections of structural belts (Noble, 1970).
7. The intrusive rocks and commonly the intruded rocks show evidence of local and regional frac-

turing of an intense nature and of long duration (Rehrig and Heidrick, 1972).

8. The deposits are associated with intrusives of a complex nature showing evidence of multiple intrusion events (Wallace and others, 1968).
9. Intense hydrothermal alteration of host intrusive as well as of country rocks with an accompanying variety of accessory minerals is a trademark of porphyry deposits (Vanderwilt and King, 1955).

Using a combination of some of the geologic features just described, we have estimated speculative resources of molybdenum in and near the State of Colorado as an example.

The known molybdenum occurrences in and near Colorado occur in clusters that are shown in figure 52. These clusters of molybdenum deposits are closely associated with areas of principal middle Tertiary silicic intrusive activity. The molybdenum occurrences and associated intrusives are spatially related to major gravity lows, also shown in figure 52.

Three of the clusters of molybdenum occurrences contain the major porphyry molybdenum deposits at Henderson, at Climax, and at Questa. Some evidence suggests that the other clusters shown may

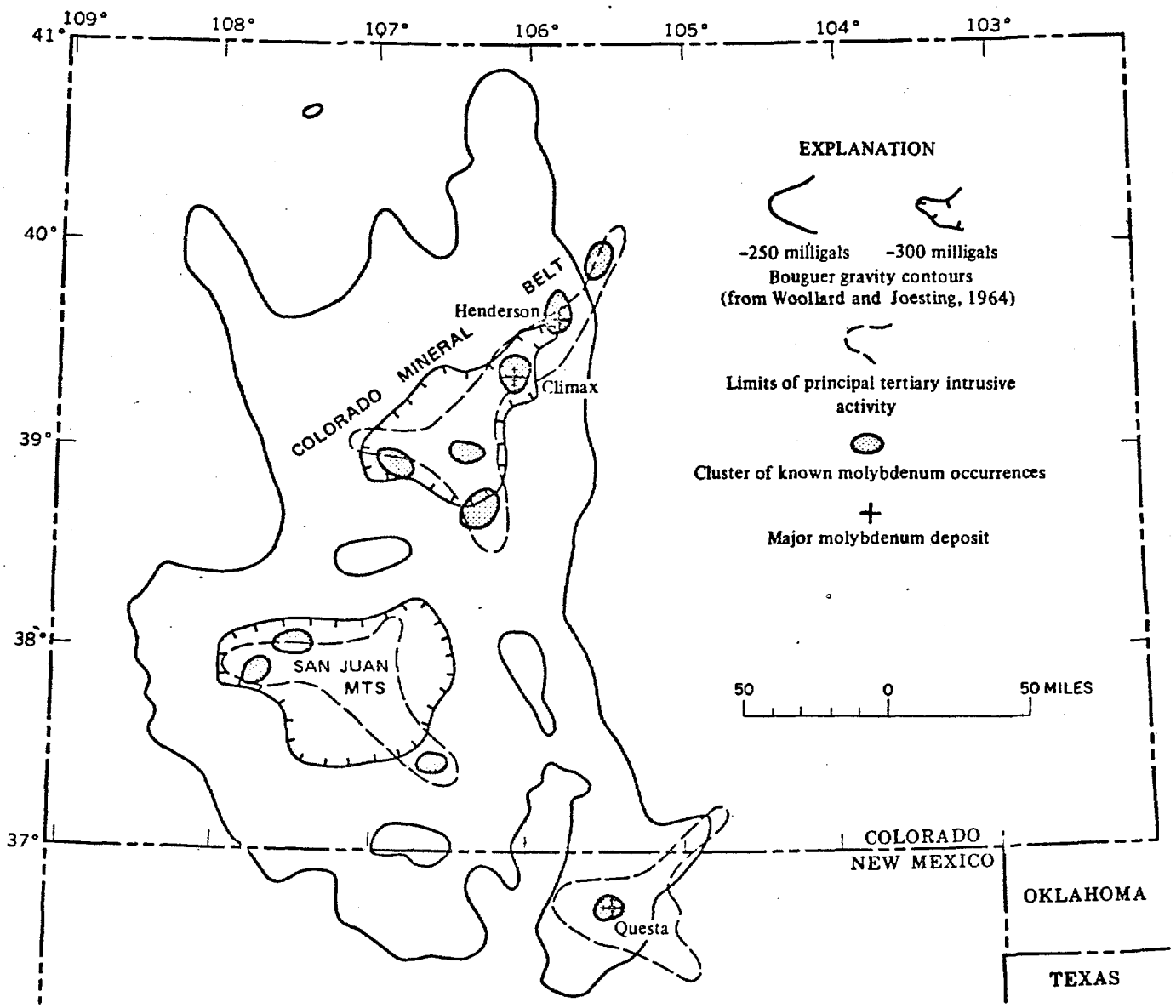

FIGURE 52.—Map showing location of molybdenum resources in Colorado and northern New Mexico in relation to various geologic parameters.

also contain major molybdenum deposits, though perhaps not all of minable grade. For example, the cluster of occurrences next southwest of the Climax cluster has been drilled by exploration companies for many years, and although no minable deposit has been discovered, a phenomenal amount of widely dispersed molybdenum has been revealed, probably greater in amount than is contained in the Climax deposit itself (Ogden Tweto, oral commun., 1972). From a geological standpoint, but not an economic standpoint at this time, this cluster contains a major molybdenum deposit.

Molybdenum deposits known in the San Juan Mountains in southwestern Colorado occur largely in the volcanic pile overlying the intrusive bodies that form the roots of the present San Juan volcanic field. Deposits in central Colorado in the main segment of the Colorado Mineral Belt are associated with intrusive bodies that represent the root-zone of a volcanic field now largely stripped away by erosion. If major molybdenum deposits occur in the San Juan field, presumably they lie at depth in the root-zone of the present volcanic pile, analogous to the central Colorado deposits. Occurrences known at the surface in the San Juan field are likely "leakages" from deeper seated deposits. The geological probability of major molybdenum deposits at depth in the San Juan Mountains seems good, although the economics of mining them, even if they could be found now, are at present unfavorable.

The three known major molybdenum deposits in and near Colorado have produced or contain unmined resources estimated at 5×10^9 lbs molybdenum each. Returning to the earlier conclusion that each of the 10 clusters of molybdenum occurrences shown on the map likely contains a major molybdenum deposit, we can estimate a total resource for the map area of roughly 5×10^{10} lb molybdenum, occurring in the vicinity of surface occurrences of molybdenum.

By making further assumptions that volcanic and other young rocks in the San Juan Mountains and in the vicinity of Questa may cover unknown clusters of molybdenum occurrences and that the spacing of clusters of molybdenum occurrences in the root-zone of a middle Tertiary igneous province is similar to that shown in the central Colorado part of the Colorado Mineral Belt where a root-zone is exposed, it is logical to infer the presence of additional unknown clusters in the San Juan Mountains and in the vicinity of Questa. Such unknown clusters may nearly equal in number those already known at the surface, judged from the areas of possible molybdenum occurrence implied by the outlines of gravity lows and of middle Tertiary intrusive activity shown on the map. If this assumption is correct, perhaps about 20 major molybdenum deposits exist in and near Colorado, representing a total resource of roughly 10^{11} lb molybdenum.

PROSPECTING

The search for molybdenum is facilitated by the physical properties of molybdenite as well as by the geochemical characteristics of the element. Molybdenite does not oxidize readily, and because of its bright silvery gray color and a strong platy crystal habit, it can be seen by eye in concentrations amounting to less than 100 ppm in light-colored rocks. Molybdenum is a mobile element and is both sulfophile and oxyphile. These characteristics work both for and against the prospector. In chemically acid environments, as in the presence of pyrite, molybdenite commonly is fixed in place, chiefly as ferrimolybdite, a recognizable molybdenum mineral, but also very commonly is attached to iron-bearing clay minerals, and to goethite and other limonitic minerals, in which forms it is not ordinarily recognizable. Fortunately, molybdenum in its six-valence oxidation state is amenable to inexpensive and rapid detection by qualitative and semiquantitative chemical and spectroscopic methods that have threshold sensitivities in the parts per million range, approaching and even reaching crustal-abundance values of molybdenum. In chemically less acid environments or in alkaline environments, molybdenite may convert to ilsemannite, a water-soluble blue efflorescence.

Because the economically significant molybdenum deposits of today, and probably of the foreseeable future, are the large volume stockworks and porphyry-type deposits related to fractured and hydrothermally altered granitic intrusive rocks, various geophysical techniques are useful prospecting methods (Sumner, 1969). Anomalously low magnetism may be detected as a result of the removal of magnetite during hydrothermal alteration of host intrusives, and low gravitational anomalies due to large intrusive stocks of granitic rocks may be measurable.

In terranes that are characterized by large volumes of silicic intrusive rocks as young as Tertiary in age, such as the Western Cordillera of the United States, low regional gravity values are closely correlated with distribution of the young silicic rocks; because molybdenum seems to be preferentially concentrated around silicic intrusives of Tertiary age in this region, major regional gravity lows reflect regions favorable for molybdenum deposits. In

terranes characterized by large volumes of silicic rocks older than Tertiary, such as Britich Columbia, low regional gravity values are not correlated closely with the distribution of the silicic rocks; inansmuch as molybdenum is associated principally with Mesozoic intrusives in British Columbia, major regional gravity lows do not correlate closely with regions of known molybdenum deposits.

Residual heat in intrusive rocks, heat from exothermal weathering of sulfides, and differences in vegetative cover due to metal concentration and alteration may be detected by airborne infrared imagery techniques, but these methods are not adequately developed to date to be highly useful in exploration. Geochemical and biochemical sampling of vegetative cover, soils, rocks, and water have been used to delineate general target areas of molybdenum concentration at and near ground surface.

PROBLEMS FOR RESEARCH

Because economic exploitation of molybdenum today requires that large tonnages of ore be mined and processed, large surface areas will be disturbed whether mining be done by underground methods or by open-pit methods; and because of the low mineral content of the ores, large surface areas will be needed for disposal of the residual waste materials. Molybdenum exploitation therefore is subject to the same or similar environmental problems as any large-scale operations, whether it be strip mining of coal, stone quarrying, mining of beach-sand deposits, or opencut mining of iron, aluminum, and copper.

Successful prediction of the location of presently unknown molybdenum deposits will come mostly from improved understanding of (1) the genetic connection between molybdenum (as well as associated elements) and the magmatic rocks around which molybdenum deposits formed, (2) the environments in which the magmatic rocks were generated and emplaced, and (3) the role of plate tectonics in developing favorable environments for generation and emplacement of molybdenum-carrying magmatic rocks.

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Thompson – Nogal Dist – Circ 123 Molybdenum (22)

Ore genesis and zoning of mineral deposits

Thirty-four polished ore sections from the fissure veins were examined during the present study. In addition, 26 polished sections of panned concentrates from cuttings of the Cleveland-Cliffs project were studied.

The mineral assemblage of the fissure veins is simple. The ore minerals are sphalerite and galena with subordinate amounts of chalcopyrite, pyrite, barite, and quartz. Gold, silver, and molybdenum occur in varying amounts as shown by assays; however, minerals with these elements in the Nogal District veins have not been recognized under the microscope.

Textures of the vein minerals indicate that the sequence of mineral deposition was quite consistent throughout the district. A paragenetic diagram (fig. 14) indicates galena to be the earliest-formed ore mineral. Replacement of wall rock is minor although hydrothermal alteration is extensive. The ore minerals were deposited in fractures that were repeatedly opened. Banding of ore minerals is common and comb texture is frequently exhibited. The last hypogene mineral formed, barite, is normally in the center of the vein. The Spur veins exhibit fracturing during the barite crystallization. Fractures in early-formed quartz host galena veinlets in the Old Abe veins, and crushing and fracturing of other minerals, indicate repeated opening of the faults.

The ores commonly are vuggy; colloform chalcedony around the vugs is not unusual. In the Renowned vein, which

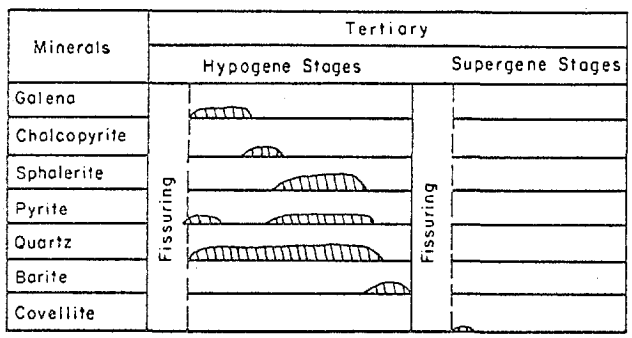

Figure 14
PARAGENETIC RELATIONSHIPS OF FISSURE-VEIN DEPOSITS OF NOGAL AND BONITO MINING DISTRICTS.

is typical, the minerals from the wall rock occur in the following order:

1) quartz, massive to euhedral with disseminated euhedral pyrite which may occur in several bands controlled by opening of fault,
2) massive galena which slightly corrodes some of the quartz crystals,
3) chalcopyrite and sphalerite with the chalcopyrite concentrated along the boundary with galena, and
4) barite as distinct bladed crystals along the center of the vein, crushed by repeated faulting.

The chalcopyrite-sphalerite textures suggest that the chalcopyrite exsolved from a homogeneous phase and diffused out of the unfavorable structure and concentrated at the grain boundaries of its former host. Laboratory studies (Edwards, 1954, p. 92) indicate that unmixing of chalcopyrite from a sphalerite host occurs in the range of 350° to 400° C. Because all of the chalcopyrite has migrated to the edge of the sphalerite and adjacent to galena, the temperature of crystallization must have been lower than 350° C. The last product of crystallization, barite, is normally accepted as a mesothermal to epithermal mineral. The depth of formation for the veins can be shown by a reconstruction of the Sierra Blanca Volcanics to be on the order of 6,000 feet. All these data support the classifying of the Nogal District mineral deposits as mesothermal of the Lindgren classification. Certainly the assemblage indicates an expected cooling of hydrothermal fluids with successive stages of crystallization.

Although the assemblage of minerals is the same within the district, percentages vary. A good example is the zinc to lead ratios. Fig. 15 shows a decrease in this ratio with increase in distance from the Rialto stock. Within the vein deposits molybdenum and copper mineralization is more prominent nearer or within the Rialto stock (Silver King mine). Neither of these elements is present in economic amounts, however.

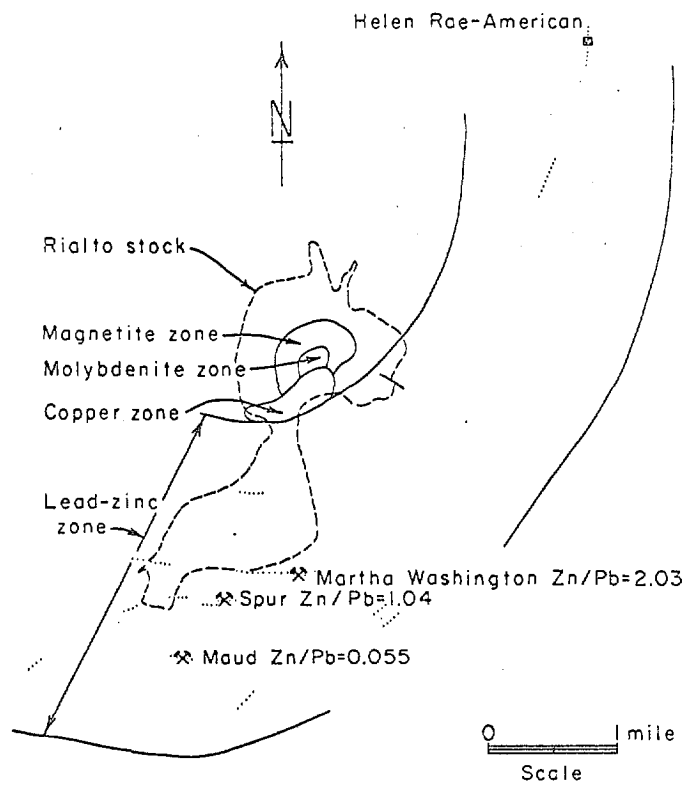

Figure 15
MINERAL ZONING AROUND RIALTO STOCK.

Within the Rialto stock disseminated mineralization occurs in zones that are nearly concentric with the lead-zinc zoning to the south. The magnetite, molybdenite, and copper zones are also closely related to the type of hydrothermal alteration, and, as a result, do not form complete circular zones rimming each other. Nevertheless, many of the deposits are apparently closely related to the Rialto intrusive, although some influence from the Bonito Lake stock might be expected.

STRUCTURAL CONTROLS

The vein systems of the area south of the Parsons mine trend generally east-west, parallel to the Bonito fault found

both east and west of the district. The Washington vein (fig. 2) splays northward, as does the fault, and adjoins the Bonito Lake stock on the east. Faulting occurred after intrusion of the stock. Elsewhere vein deposits either parallel or radiate outward from the hypabyssal intrusive boundaries. The amount of dip appears to be a factor on the presence of sulfide mineralization. If the vein dip is greater than 70°, sulfide mineralization is usually found. Sulfides in veins with dips less than 70° are limited to those systems in which strike deviates from east-west.

Disseminated mineralization within the Rialto stock appears to be related to fractures and breccia pipes whereas the disseminated mineralization of the two other large intrusives is closely related to intrusive borders or late-stage intrusive phases. More data are needed on the latter deposits.

CONCLUSIONS

The Nogal district appears to have considerable potential for low-grade high-tonnage deposits. Possibly one or more of this type deposit may exist, but exploration will require a company with sufficient capital to finance an extensive program.

The vein deposits are discouraging, due to their lenticularity and narrow widths. Transportation expenses to milling facilities are excessive. Small operations which have their own mills appear to be the only solution for this type of deposit in the Nogal district.

Availability of Water

In 1907 the Rio Bonito was partly diverted into a pipeline system by the El Paso and Southwestern Railroad (later the Southern Pacific Railroad). Today water is still diverted through a pipeline from Bonito Reservoir, owned by the City of Alamogordo. The pipeline also furnishes Carrizozo and Holloman Air Base from the 5 cfs-diversion from Bonito Reservoir. The story of the development of the mountain waters of the Sierra Blanca is realistically portrayed by Neal (1961).

In the Sierra Blanca many springs issue from perched water tables on top of massive andesitic flows. Many of these springs have been improved and water is collected in metal tanks for wildlife and stock. The flow of these springs is less than 1 gpm. Unit 34 of the Nogal Peak section is a particularly impermeable volcanic unit which localizes water flow from a perched water table. The springs issue in the re-entrants of the cliff-forming unit. Ground and surface waters have been studied in parts of the map area (Mourant, 1963).

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Ore deposits - Moly W. L. Kurtz

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CHARACTERISTICS OF DISSEMINATED MOLYBDENUM DEPOSITS IN THE WESTERN CORDILLERA OF NORTH AMERICA

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CHARACTERISTICS OF DISSEMINATED MOLYBDENUM DEPOSITS IN THE WESTERN CORDILLERA OF NORTH AMERICA

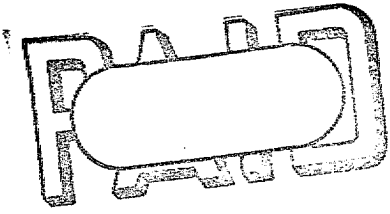
Introduction

Some 30 years ago Stevenson (1940) underscored the fact that most of the world's molybdenite production came from the Cordillera that comprise the western part of North America, and that the northern extension of the Cordillera into British Columbia is not essentially dissimilar to the United States section. Therefore, in view of the successful development of molybdenite resources in the United States, he concluded that prospecting in the Canadian section of the Cordillera should be encouraged. However, as recently as seven years ago Schneider (1963) remarks that no large economic deposits have been brought into production in British Columbia, although one important property was being evaluated.

World production of molybdenum ore was sporadic until 1900. Among the very early producing areas in North America were Arizona and New Mexico in the United States. World War I provided the stimulus that brought the Climax deposit into production, and in 1920 Questa, New Mexico followed, although the ore came from fissure vein deposits at that time. In the early part of this century high grade deposits in various parts of the world containing 5-20 percent MoS_2 were exploited. In Canada most production during World War I came from Quebec and Ontario. With the build-up of world tension and the inception of hostilities in 1939, British demand was satisfied by United States producers (Schneider, 1963).

At the end of World War II production slumped to 24 million pounds for the western world in 1946, but grew to 75 million pounds per year in 1964. In 1968 production has been estimated at 140 million pounds, a jump of 85 percent in four years (Scholz, 1968). Nowadays, molybdenum is primarily produced from large tonnage, low-grade disseminated deposits containing 0.20-0.5 percent MoS_2, or

70-1-50



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