Overburden Stripping From Deeply Buried Orebodies by Controlled Nuclear Explosive Casting

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Abstract

Previous schemes to strip the overburden from a deeply-buried orebody by nuclear explosives have been hampered by various constraints. These are the notions that surface topography should slope in the desired direction to facilitate casting; that the orebody should be stripped all at once, meaning that an unsafe and unnaturally high yield will be detonated; or that the overburden be broken and cast, in a manner akin to conventional blasting, with a series of explosions linked by milli-second delays, such delays being an unproven and, perhaps non-permissible technology; and, finally, that the schemes leave an excessive amount of overburden to be removed by conventional means.

It is proposed that deep orebodies, idealized by a 250-ft. thick copper porphyry under 600 feet of cover, be stripped in successive rows, using available row-charge technology. A first row, of greater magnitude than those succeeding, is used to expose the orebody. The second row is placed so as to throw overburden into the void created by the first. All rows are placed so as not to damage the ore. Except for the first row, all rows utilize directed throwing. After a row is detonated, the ore beneath it would be removed by conventional means. The void thus created would provide space for the successive row to fire into. Further, the additional free-face provided by the void imparts a major direction to the ejecta. Because of the directed nature of the throw, ore removal does not have to proceed directly beneath the row slope. Advantages to this scheme are its adaptability to terrain; its reduction in overburden to be removed by conventional methods; its increased speed in uncovering ore; its reduction of unit costs; and its adaptability to production rates.

An example, utilizing the idealized orebody shows that production of ore can begin within a year of project approval <u>versus</u> four or five years for the same orebody developed conventionally; that no more than eight percent of the overburden has to be handled conventionally; and that unit cost for overburden removal is about four cents per ton, which is a two to ten-fold reduction in present-day costs.

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Introduction

The world is experiencing an inflationary demand for metals that has created an almost impossible to ease pressure on mineral producers. An increasing per capita demand for durable goods, inside a generally increasing population, has placed a spiralling demand on materials producers. A further pressure, quite unrelated to the technical problems of production, is caused by the political instability in the developing nations, many of which contain large natural resource deposits. A consequence of this pressure is that producers are actively seeking new ore deposits. Deposits that are, without a doubt, going to be lower grade, or more difficult to extract, than present ones.

As existing orebodies are depleted, the producers are willing to extract metal from orebodies of consistently lower tenor. Generally, in order to maintain earnings, a low-grade orebody must be sufficiently large to allow a proper amortization of investment. This means, however, that large sums of money must be committed to an orebody that may or may not turn a profit. Consequently, success or failure may hinge on the reduction of a few cents from operating costs. For example, by investing in large-scale materials handling equipment, some of the newest southwestern copper producers can open-pit a ton of ore for eight to twelve cents. This figure represents a two-to three-fold reduction on the average per ton cost (27¢) given by Pfleider[15]* for fifteen open-pit copper mines in the American hemisphere. Thus, in face of rising demand, producers are turning to lower and lower grade orebodies. It is not implied that these orebodies have less total metal than the older, richer bodies, only that they have less metal per ton of rock. The lower grade results in lower unit profits and more difficult beneficiation.

Waste Removal from Open-pit Mines

In recent years, the extraction of large low-grade orebodies has been by open-pit methods. Briefly, this implies that the worthless, or waste, rock that covers the orebody is removed, or stripped, and dumped to one side and then the ore itself is removed. Open-pitting is different from underground operations, where selective mining takes only ore and leaves waste in place. The low unit cost of handling material in the open pit allows this handling of waste. The amount of waste, in tons, that must be handled for every ton of ore mined is called the stripping ratio; obviously, there are economic limits, dependent on the ore tenor, to stripping ratios.

Conventionally, there is little to distinguish waste mining from ore mining. Similar cycles of drilling, blasting, loading, and hauling are practised in both ore and waste.[15]* Therefore the deeper the ore is to be found the more expensive it will be to mine because of the added stripping costs. Stripping ratios reported for the fifteen copper mines ranged from one to four with one outlier at 8.5. Given the low unit operating cost that has been reported, it becomes apparent that

*Superscript numbers indicate references listed at the end of the paper.

further cost reduction can be achieved only by complete change of mining method. One possible variation is the removal of waste overburden by casting with nuclear explosives.

In using conventional high explosives, the engineer is aware that the explosive will break and then throw the rock. Ordinarily, explosive emplacement is designed to minimize throw; however, in some instances, the round is overloaded so that throw becomes appreciable.[16] This throw or casting may be necessary to get the rock into some better position, for example, for clean up by a shovel. The notion becomes apparent that if the round is overloaded, not with high explosives but with nuclear explosives, the throw may become of such a magnitude that the waste is spoiled directly into its storage areas without the intermediary help of shovels and trucks.

Nuclear Casting

Nuclear excavation schemes have been discussed for some time,[1,5,6,7,9,11,12,13,14] and it is not intended to review them here. In addition, several good reports have selectively covered nuclear stripping of ore bodies.[2,16] It is intended to review these reports and then to propose an extension of their methods so as to make the nuclear method more efficient and flexible. The reference to "nuclear" is understood to be a shortening of nuclear explosive excavation.

Originally, it was concluded in a report by P. L. Russell that an orebody should be relatively small to be amenable to nuclear stripping.[16] This was because it was conjectured that a crater from only one device could be used for stripping. Obviously, this report was written before the feasibility of nuclear row charges was generally known. The report stated that lack of control of throw was a disadvantage to nuclear stripping; and that sloping terrain, necessary to augment the throw, was desirable. With the conjecture of one crater for stripping the entire orebody, a further stipulation was made. In order to have sufficient crater diameter, without disturbing the ore, the minimum waste thickness had to be 200 feet. This report, like those subsequent, realized that a high-priority in its scheme was the need for no disturbance or dilution of the ore. The report had further use in that it catalogued some of the major copper orebodies in terms of their linear dimensions and depth of cover. Russell did propose an orebody of average dimensions, and it is this body that is used as a base for subsequent calculations.

It was also suggested in this report that it might be possible to bury the nuclear explosive such that the waste over the orebody would be ejected and the ore itself would be shattered or ruptured by the blast. This would mean careful placement of the explosive so that the ore would coincide with the plastic zone of the crater.[17] A savings of the conventional drilling and blasting cost in the ore removal is assumed to be effected. Present opinion, however, holds that any such savings would be more than offset by the hazards involved in trying to work around rock that has been rendered incompetent and radioactive.

The Anaconda Company, in a report from its research laboratory, recognized that unit cost reductions are best achieved in large-scale operations.[2] They, therefore, proposed a large stripping operation with some thirty nuclear explosives. These explosives were to be placed in an approximately square array and were to be fired with milli-second delays. The timing sequence would set off the outer ring first, followed by those explosives remaining in the center of the firing area. It was decided that a certain amount of ground slope would be necessary to augment the throw. The report concluded that approximately 65 percent of the broken waste would be thrown and the remaining 35 percent would be removed conventionally. Approximately 14 percent of the waste would be unbroken, and would also be removed conventionally. Thus only 57 percent of the waste is removed nuclearly. The report indicated the then common costs for many of these mining operations.

Unfortunately, the Anaconda scheme has many drawbacks. The notion of delay blasting, while common in high-explosive work, is probably unacceptable in nuclear work. The first, or zero-delay, blast would disrupt the communication lines to the subsequent blasts, causing the non-permissible situation of an armed but uncontrolled device. An array of devices, as suggested, with a total yield of 20 megatons would lead to impossible situations in respect to ground shock, air blast, and residual radioactivity. Finally, the dependence on ground slope limits the general applicability of the scheme.

Representative Orebody

The feasibility of the proposed system will be demonstrated on a sample orebody that is representative of some of the more deeply-buried ore masses in the copper porphyry district of the southwestern United States. The dimensions of this sample are similar to those suggested by Russell.[16] Horizontally, the ore zone is considered to be roughly square with an edge length of 5000 feet. Overburden thickness is taken at an average of 600 feet; the overburden, itself, is considered to consist of incompetent, fractured acid rock covered by a minor thickness of alluvium. The physical properties of the overburden are similar to those of granular material. To present the most difficult case for throwing, the surface is taken to be flat. The ore averages 250 feet of thickness, is relatively uniform, and has an average copper content of 0.45%. Considering a tonnage factor of 0.085 tons/ft.^{3}, 532 million tons of ore are present.

This orebody is similar to many of those in the copper district. Figure 1 depicts this deposit. Since the purpose of this paper is to demonstrate that nuclear blasting can turn a marginal property into a profitable one, it is assumed that the ore zone is mineable and is therefore uniform throughout its measured extent. Thus an orebody is proposed that, if the per ton of ore charges for waste removal were small, would be quite profitable. Deposits of similar grade and depth are now being considered for mining. The lakeshore property in Arizona,[8] although not flat, is one. Because of the depth of the lakeshore body and a zone of high-grade at depth, this deposit will be mined by both open-pit and underground methods. The Anaconda Company is currently bringing its Twin Buttes open pit into ore production. They stripped 200 million tons of overburden, with a thickness between 450 and 500 feet, in order to begin production. Twin Buttes has an ore zone that averages between 0.5 and 0.7 percent copper and is much thicker than that in the proposed sample. A last example is the San Manuel Orebody in Pinal County, Arizona.[18] Because of its depth and contorted shape, this deposit is currently being mined by block-caving methods. Nonetheless, it would be well-suited for nuclear stripping.

Proposed Method

Nuclear stripping has the desirable advantage that as overburden thickness increases, the per ton charge for waste removal decreases because the explosive cost does not increase proportionally with an increase in yield. There are, however, the undesirable elements of seismic shock, air blast, and radioactive pollution of the environment. It is for these reasons that the orebody is presumed to be relatively isolated and well above the ground water table. Some estimates of exclusion zones and re-entry times are given at the end of the paper.

The proposed method is an adaptation of the stripping methods used in surface coal mining. Essentially, a strip of overburden is removed and the coal beneath it is mined. A void then exists for the deposition of the next strip of overburden. Mining proceeds in this fashion until all the coal is removed. Since the waste has been spoiled almost in the same place that it came from, it is possible to level and reclaim the mined out property.

Row-charge nuclear blasting is utilized to strip and prepare for mining the hypothetical orebody. In this method, one row of charges is blasted at a time, thereby minimizing the concomitant hazards of the explosion. Carefully observing the depth of the orebody a first row of explosives is emplaced such that it creates a channel immediately adjacent to the orebody and sufficiently deep that it contains the overburden that is to be cast by the second row of explosives. Selecting a depth of cut for the first row enables the depth of burst, width of the cut, yield of explosives, and spacing to be read from Figure 2, which is plotted from the given data for explosives in alluvium.[17,20] Knowledge of device spacing allows calculation of the member of required explosives for this row.

Choosing 775 feet as the depth of cut for the hypothetical deposit, the remaining parameters are depth of burst, 1330 feet, width of cut, 2560 feet, explosive spacing, 1280 feet, and yield of each explosive, 2000 kt. To provide sufficient room at the ends of the channel, five charges are used. They are placed 720 feet from the vertical extension of the orebody limits so that the resulting crater is just tangent to the edge of the deposit as shown in Figure 3. Approximately 263 million tons of waste, more than the entire project at Twin Buttes, would be removed by this first blast.

In addition to providing a void, the first row provides a change in the geometry of the free face of an adjacent second row. Blasted material tends to move normally to the free face that has the lowest burden. Consequently, if the second row is properly placed, upon detonation most of the throw will be directed toward the first row. From row charge experiments, it is observed that the slopes of an ordinary row are stable;[4] also that the face configuration resulting from a directed blast is stable.[19] Therefore, it seems plausible to use a second row of explosives, buried just on the shallow side of optimum, to throw an amount of the overburden into the void of row one. If 80-kt explosives, buried at 525 feet, are used, then, from Figure 2, spacing is 470 feet and 13 devices are needed. The explosives are placed so that they are equidistant from the free surface measured vertically or horizontally. This position should give maximum throw to the overburden. Figure 4 is an idealized cross-sectional view of the effect of row 2; Figure 5 shows more detail of the cut and also of the method of ore extraction.

Although this report is solely of hypothesis, there appears to be good evidence for the supposition that row 2 will clean its cut as shown in Figure 5. Extension of high-explosive technology is one such reason; the evidence of land-slide dam experiments is another.[4] Additionally, if the shape of a surface crater is oriented so that its free surface is parallel to the slope of row 1, it is easily seen that the cut of row 2 results. Finally, the geologic plane between ore and waste, in many instances, will give a good breaking surface. Planimetric examination of Figure 5 shows that approximately 92 percent of the waste is directly spoiled. The expected slope angle is parallel to the original slope of row 1, and is close to 45 degrees.

After a suitable "cooling" time, the mine is re-entered and work on three jobs begins. Two crews start material handling operations, and a third crew starts to drill emplacement holes for row 3. Of those crews on material handling, one is, of course, cleaning up the remaining eight percent of the overburden, and the other is beginning to load ore. Loading is done with Quarry-Mine style shovels, and haulage is with trucks in the 100-ton range.[15] The shovels load directly, without drilling and blasting, as the nuclear blast has fractured much of this rock. As ore mining proceeds to depth, the possibility of insufficient fracturing for direct loading exists. If the signals of shovel tooth wear and bucket filling factors indicate this, then drilling for high-explosive blasting will commence. Benches are of 50-feet height and have working widths of not less than 100 feet. The final slope angle is maintained at 45 degrees. Although disastrous failure of the slope will not occur, it is quite possible that loose rock could work its way down the slope. Hence, one of the upper benches is maintained as a safety zone; that is, left purposely wide. A later section describes radiation shielding for the machine operators.

Once the ore beneath row 2 is removed, a void exists for blasting into by row 3. Therefore mining can proceed in an orderly fashion until the deposit is depleted. The hypothetical orebody requires eleven production rows to complete mining.

The only rehandling of material that is envisioned is for that from production rows which falls short and lands on the existing ore slopes. For the 250-foot thickness this is a minor problem that can be handled by clean up bulldozers. For greater thickness, however, the amount of rehandling could become

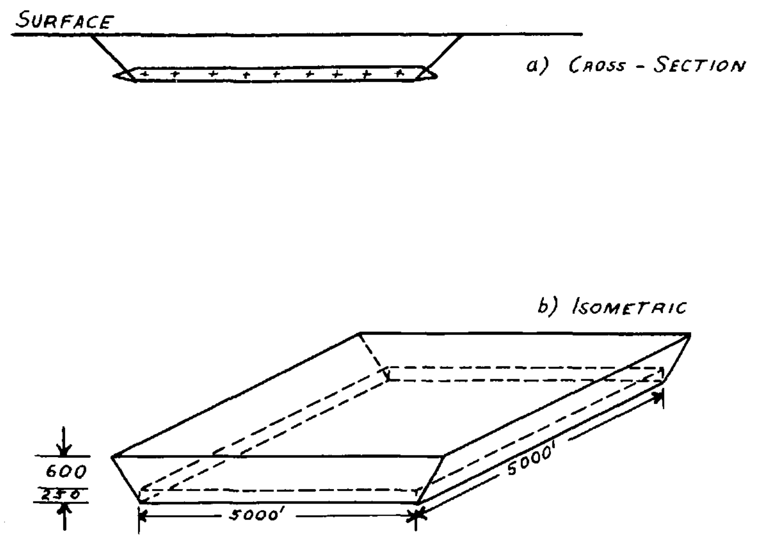

FIGURE 1: THE OREBODY AND ITS OVERBURDEN

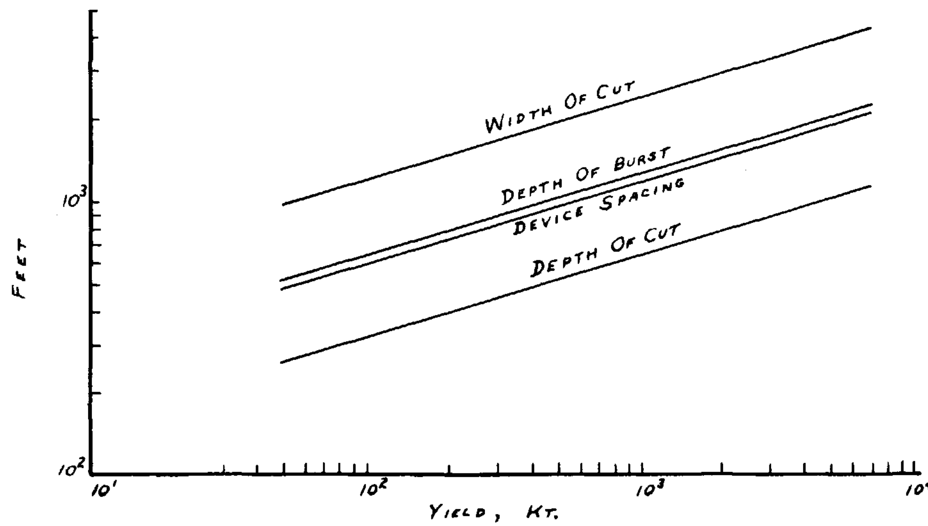

FIGURE 2: YIELD vs ROW PARAMETERS

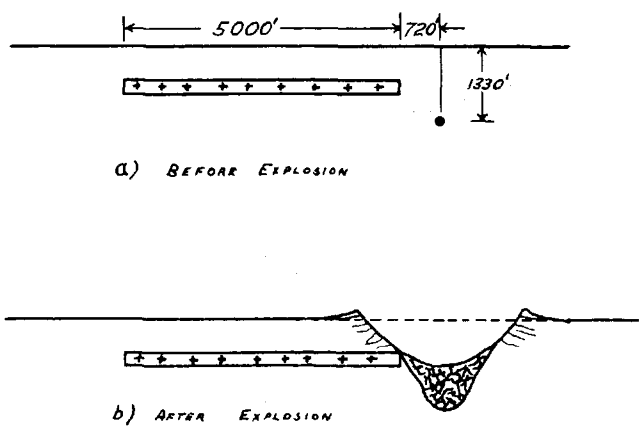

FIGURE 3: LOCATION OF SINGLE END CUT

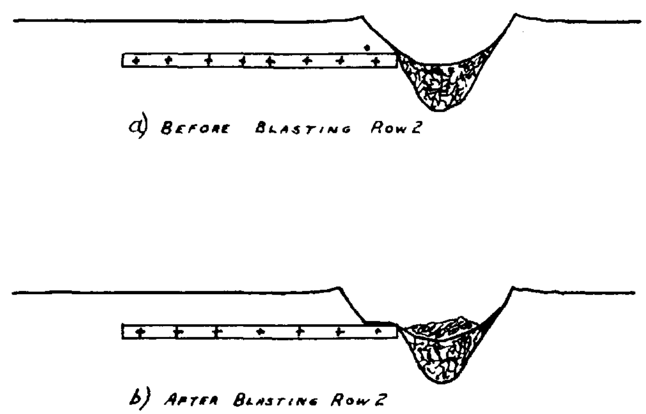

FIGURE 4: DIRECTED BLASTING

considerable enough to detract from the economy of the method. Individual project designs will have to consider this problem separately.

If greater production rates are desired, then the deposit can be attacked from two sides as shown in Figure 6. Working two faces has the advantage of maintaining more consistent production. Hence, when one face is "cooling" the other is feeding the mill. The double-face method casts approximately 94 percent of the overburden.

Comparative Costs and Completion Times

In order to begin this comparison, certain basic cost and profit information is presented. The recoverable value of copper, considering a price of 52 cents per pound,[21] a grade of 0.45 percent, and 90 percent metal recovery, is 2241 million dollars. The price of conventionally mining and removing a ton of rock, although placed at nearly 25 cents in Pfleider, [15] can be more realistically assumed to be 12 cents for this type of orebody. The given cost averages the lower cost of mining unconsolidated rock without blasting, and the higher cost of mining rock that needs blasting. Other standard costs, taken from the Anaconda report[2] include milling the ore at 60 cents per ton and smelting and refining at 80 cents per tons of ore. These costs do not include depreciation. Capital costs involved are 150 million dollars for a concentrator, 60 million for a smelter, and 60 million for one set of pit equipment.

Assuming a safe slope of 45 degrees, approximately 2 billion tons of overburden have to be removed at a cost of 240 million dollars, in order to conventionally mine this deposit. The pit equipment considered, approximately 150 trucks, fifteen shovels, 15 drills, and miscellaneous service equipment, has a daily production rate of 300,000 tons per day. With a 250-day work year, it will take 34 years to completely mine this deposit. For the first five years, no ore can be mined. Since the average life of this pit equipment is between 5 and 7 years, it will be replaced four times. The total cost of production is therefore 1560 million dollars, and the total profit -- not considering the time value of money -- is approximately 681 million dollars.

Using the Anaconda method[2] on the hypothetical orebody, which means that the need for a sloping land surface is ignored, a profit of 870 million dollars is created. It is doubtful that this system would work; but if it did, it would remove 57 percent of the overburden. Using the report's nuclear costs and 12 cents per ton for stripping the remaining 43 percent leads to an overburden removal cost of 171 million dollars. Pit equipment is only replaced twice; thus total cost is 1371 million dollars. Stripping can be completed in 15 years and ore production can begin within a year of project approval.

The proposed method, with one opening row, creates a profit of 1002 million dollars. Stripping costs are assessed with 8 percent removed conventionally and 92 percent by nuclear means. The nuclear operations involve drilling and explosive purchase as major items and safety and hazard evaluations as minor items. These items are detailed as five, 2000-kt ex-

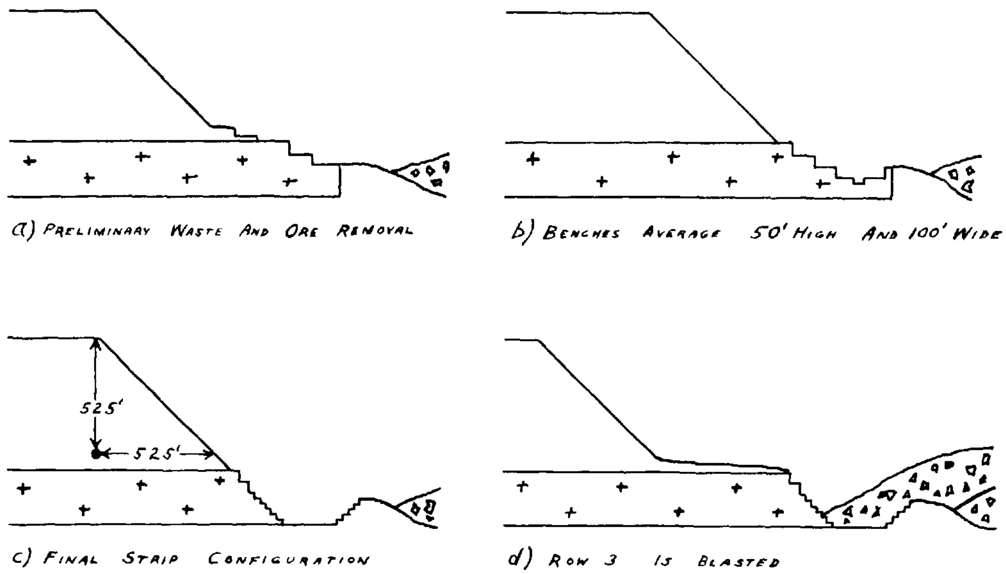

Figure 5: Details Of The Stripping Sequence

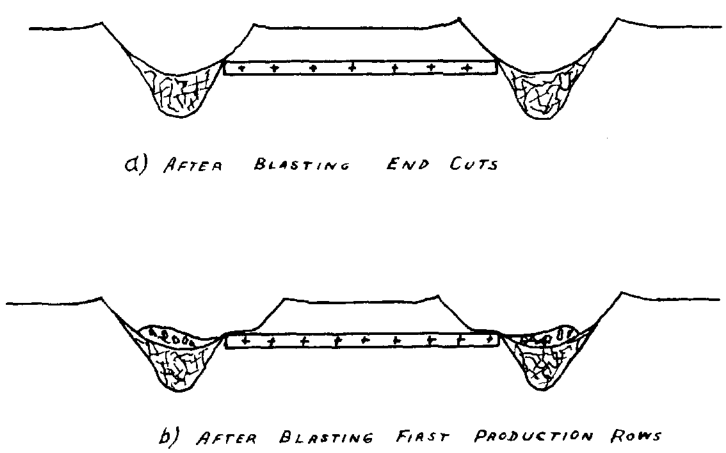

Figure 6: Double-Cut Method

plosives buried at 1328 feet, and 143, 80-kt explosives buried at 525 feet. The explosives cost 600,000 dollars apiece for the larger and 450,000 for the smaller.[10] The larger size require a 72-inch hole which, uncased, costs 90 dollars per foot. The smaller size goes in a 48-inch hole which costs 34 dollars per foot. These costs are for moderately soft material.[10] The total overburden removal cost becomes 97 million dollars, which includes 70 million for direct nuclear costs, seven million (10 percent) for contingencies, and 20 million for conventional stripping. In this scheme, the pit equipment is replaced only once and the total cost is 1237 million dollars. The beauty of this scheme is not only the high total value of the profit, but the fact that its present value is so much higher than in the other methods. This is because ore can be mined within four months of project approval. With an ore mining rate of 100,000 tons per day, the mine is depleted in 21 years of 250 work days.

The double-cut method gives much the same profit, the added nuclear costs being offset by the lowered conventional stripping costs, but halves the mining rate. Table 1 compares the four methods, giving per ton stripping costs and expected profits.

Table 1

Mining Methods Compared

Method	Total Nuclear Explosive, Mt.	Time to first ore production	Waste Stripping cost, ¢/ton	Percent Waste Conven. Removed	Profit Million $
Conventional	--	5 years	12	100	681
Anaconda[2] Nuclear	25	1 year	8.6	43	870
Nuclear Row Stripping: Single Cut	22	4 mos.	4.9	8	1002
Double Cut	30	4 mos.	4.7	6	1007

To conclude this section on costs, a few comparisons are made. Figure 7 is a plot of total expected profit vs the conventional per ton mining cost. Three methods are plotted: conventional mining, Anaconda nuclear, and nuclear row stripping. Not only does row stripping present the highest profits; but because it leaves the least overburden for conventional removal, its profits decline the least with an increase in per ton removal costs. Figure 8 is a plot of expected profit vs change in overburden thickness. All the other parameters, as presented here, remain constant. Again the nuclear method gives the highest profits for any depth, shows the least decline in profits with increasing depth, and has the greatest depth before break-even. Returning to the constant depth of 600 feet, the break-even ore grade for the three methods can be calculated. In conventional mining, zero profits are expected at 0.34 percent copper; the Anaconda method breaks even at 0.30 percent; and the proposed row stripping breaks even at 0.27 percent. Of course, the conventional break-even grade varies the most with a change in per ton removal costs. These figures are an added

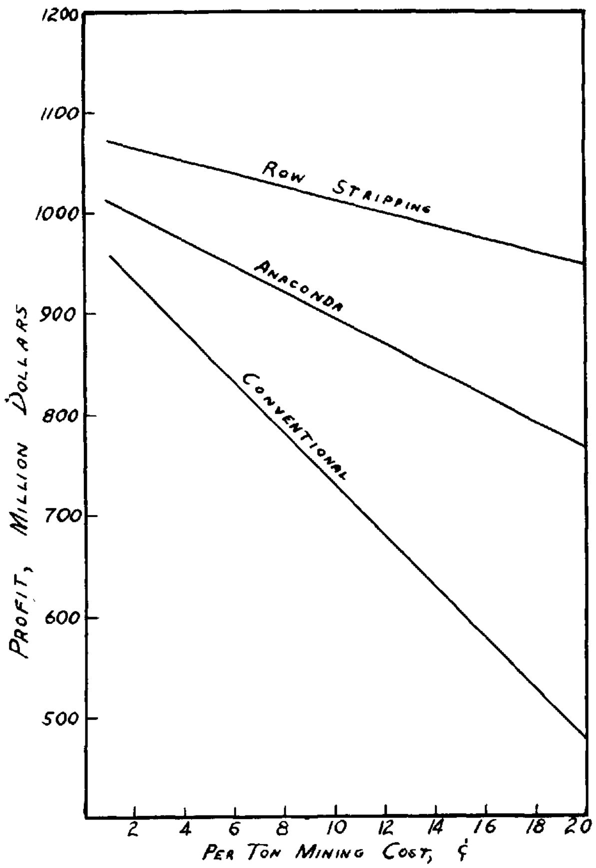

Figure 7: Profit vs Conventional Mining Cost

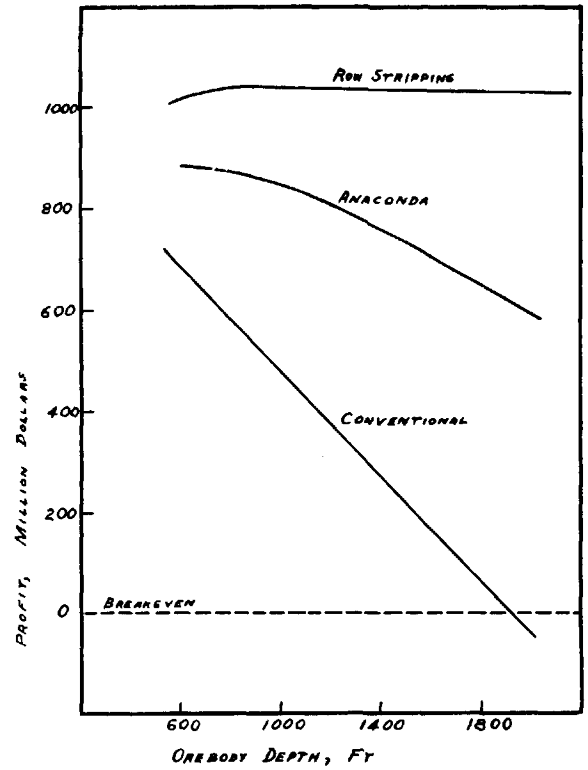

Figure 8: Profit vs Orebody Depth

indication that, in addition to engineering feasibility, the nuclear row method gives greatest profits in a deeply-buried orebody.

Safety

It is clearly understood that the greatest drawbacks to any nuclear method are the safety hazards attendant to such an explosion. Although it is stated that nuclear craters and rows are reasonably safe from radiation because the explosion zone is buried under fallback,[17] this assumption does not apply to nuclear stripping of orebodies. Precisely because this "hottest" material must be removed by machine does radiation become the greatest hazard in this scheme.

Fortunately, this problem is not insurmountable. Today, in the open-pit copper mines of the Southwest, operators are protected from the debilitating effects of heat, dust, and noise by placing them in air-conditioned and insulated cabs. In the modern open-pit mine all communications are done by radio and it is rare to see a man on foot. Thus, it seems relatively easy to protect the workers from the radiation hazards. Rather than depending upon "cooling" below maximum permissible dose rates, the workers would be actively protected by properly shielding their cabs, by insuring that the air they breathed was properly filtered, and by developing operating schemes such that no worker could leave his cab unless he was wearing protective clothes. The only large inconvenience foreseeable is for the geologists and surveyors who must spend long periods of time exposed in the pit.

The mine shoulb be separated into "hot" zones and safe zones and rigid control established for entry from one to another. For instance, no worker would be allowed to go from a safe zone to a "hot" zone unless he were shielded. A shielded cab would be a safe zone and a worker would not be allowed to enter it from a "hot" zone unless he were properly cleaned. Hence rules for returning into the safe zone would have also to be maintained. For example, a truck returning from the pit, "hot", to the shop, safe, would have to be thoroughly steam cleaned to remove radioactive debris.

It is assumed that the ore, shielded by 75 feet of waste at the shot point, is relatively "cool" or safe. Care must be taken to avoid contamination of the ore by the waste. The concentrater and smelter, assumed to be safe zones, should be built sufficiently upwind from the mine to avoid local fall-out. No shot would be permitted on a day when the wind was shifting from its prevailing direction.

There are methods for calculating exclusion zones[10,17] for seismic damage, airblast, and local fall-out, but these require input information from the shot area for their exact calculation. Typically, however, for the five 2000-kt shots fired simultaneously, an exclusion zone of 40 to 50 miles will insure no building damage claims and will also insure that the populace is not exposed to dose rates that are as high as maximum permissible. Consequently, a mining scheme is proposed that has engineering feasibility, economic viability, and that can meet the safety demands presently promulgated for near-surface nuclear explosions.

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