HOT WATER IN UNDERGROUND MINING

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ABSTRACT : This paper will discuss high temperature water in underground mining at a location in Central America. The water referred to shows a maximum temperature of 77° C and owes its origin or is directly related to recent volcanic action. The case history here presented will review methods of control and working under such adverse conditions.

RESUME : Cette communication discutera des eaux à haute température dans les mines souterraines d'une localité d'Amérique Centrale. Cette eau atteint une température maximum de 77° C et doit son origine ou est directement liée à une action volcanique récente. Le cas historique ici présenté passera en revue des méthodes de contrôle et de travail sous de telles conditions adverses.

RESUMEN : Esta comunicación se refiere a la presencia de aguas con elevada temperatura, en las minas subterráneas de una localidad de América Central. Este agua alcanza una temperatura máxima de 77° C, y tiene su origen o está directamente ligada a una acción volcánica reciente. El caso histórico aquí presentado revisará métodos de control y trabajo bajo tales condiciones adversas.

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HOT WATERS IN UNDERGROUND MINING

Hot waters in subterranean workings is not something that is new. Such waters have been encountered and dealt with at numerous locations, and the mere fact of a geothermal gradient means that temperatures increase automatically with depth.

Temperature gradients vary from about 0.9°C per 100 meters to about 5.1°C per 100 meters of depth (Loofbourow, 1966). In general, older sedimentary and metamorphic rocks exhibit the lowest gradients, while younger intrusives and volcanics show much higher gradients. Of the latter, typical examples are found at Butte, Montana and Magma, Arizona. At the last location, the temperature gradient is reported to be about 2.8°C per 33 meters of depth (Hartman, 1961), hence for workings that are located some 1500 meters below the surface (where the surface temperatures are abnormal), this condition obviously becomes severe, and such mines can operate only with the benefit of air conditioning (Short, 1957). Finally, although investigated to the relatively shallow depth of only about 400 meters, a record or near record thermal gradient is found in the Furnace Creek Formation of Death Valley, California (1977) where a logged drill hole shows a temperature increase of 5.7°C per 100 meters of depth.

Examples of other mining areas that have moderate gradients are the Coeur d'Alene District of Idaho and the gold reef mines of South Africa. Despite the moderate temperature increase with depth, both of these regions suffer from extreme depths (especially the latter) and limited size of openings which create major ventilation problems.

Elevated rock temperatures mean elevated water temperatures and hence higher than normal air temperatures when air is introduced into openings developed. The water, being highly migratory, can have a severe direct and indirect effect on working conditions and worker efficiency.

Where orebodies and mine workings or potential mine workings occur above a potential adit tunnel level, or for some engineering construction projects, then such a drainage tunnel is an obvious way of removing waters irrespective of whether they are neutral, acidic, hot, or cold. This is illustrated by the Tecolote Tunnel near Santa Barbara, California where water at 47°C was removed by gravity flow and shallow-head pumping (Dominy and Bloodgood, 1959). On the other hand, if water must be pumped from underground workings, then several options may be considered including (for moderate depths) large diameter drill holes with deep well pumps, special pumping shafts, and combinations of such.

When flat-lying water-bearing geologic members occur above a bedded orebody, such as in the potash mines of Saskatchewan, the aquifier may be isolated

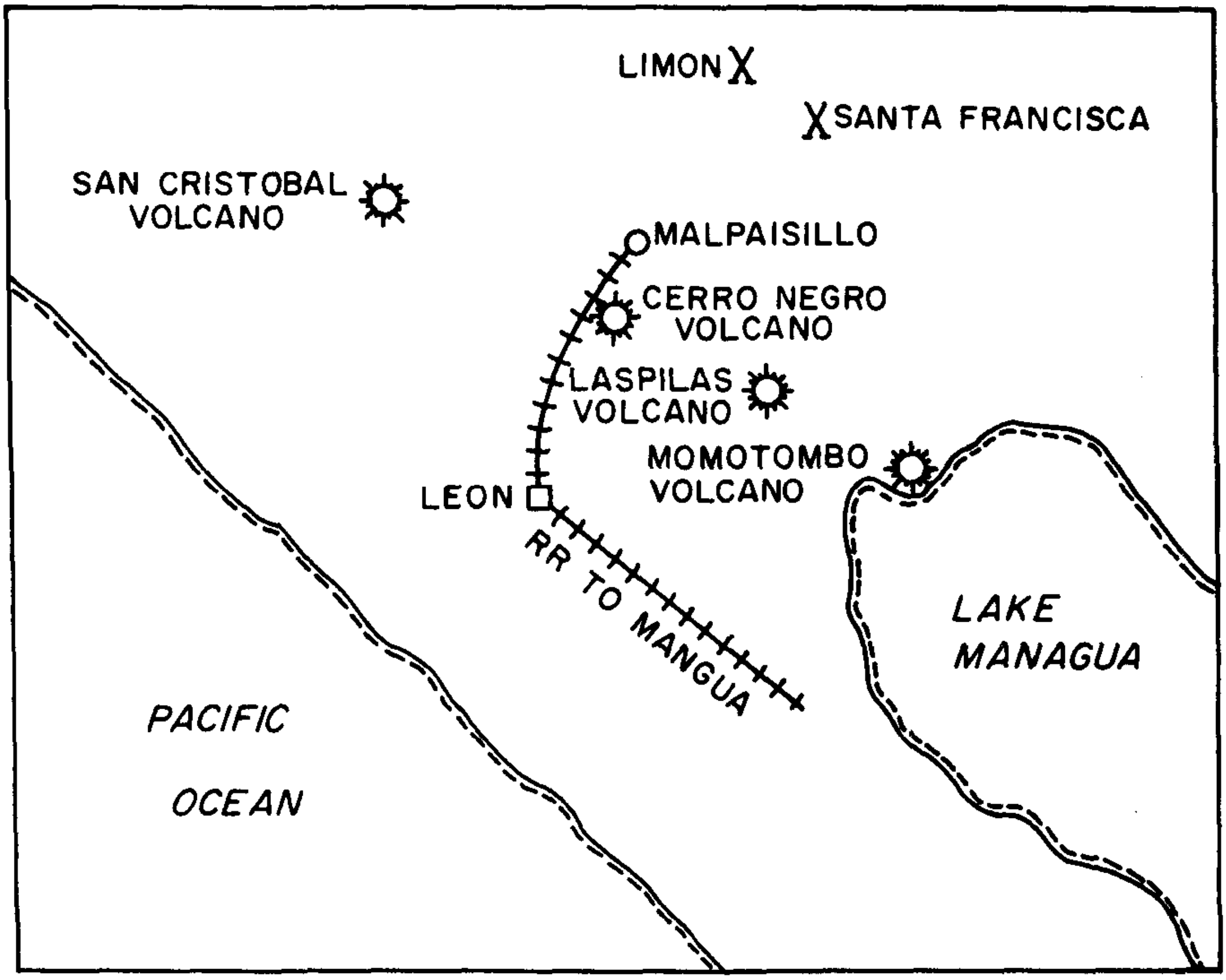
LIMON
SANTA FRANCISCA
SAN CRISTOBAL VOLCANO
MALPAISILLO
CERRO NEGRO VOLCANO
LASPILAS VOLCANO
MOMOTOMBO VOLCANO
LEON
RR TO MANGUA
LAKE MANAGUA
PACIFIC OCEAN

FIG. 1

by penetrating it with a concrete or steel lined shaft. Such an orebody is continuously isolated by controlled mining on a horizontal plane. However, when an orebody is on an inclined or vertical plane and if the orebody is semi-fractured and contains water, then the problem can be severe, and the water level must be coned and lowered to or below the bottom working level. Should the waters encountered be neutral and cool, then it becomes a matter of standard pumping, either under low or high heads and low or high volumes. As opposed to the above, if the waters are hot and corrosive, then problems are compounded, and special measures must be taken to cope with the situation.

In summation, warm waters and severe pumping conditions exist in many areas throughout the world, but only in a few locations such as Casapalca, Peru (Editor, ENR, 1970) and Mina Limon, Nicaragua, do waters exist that are directly related to volcanic or late volcanic action. It is this latter location that is dealt with in this instance.

The Limon Mine of Empresa Minera de el Setentrion is a 400-ton gold-silver mine that was brought into production in the early 1940's. The mine is located some 100 kilometers northwest of Managua, Nicaragua, Central America (see Fig. 1). Limon is further described as being relatively close to a chain of active and semi-active Tertiary volcanoes. At the mine, the rock mass is predominantly andesite with accompanying rhyolite. The volcanic mountains are not particularly high in this section of Central America with San Cristobal showing the highest local elevation of about 1800 meters. From the volcanic peaks and ridges, there is a sloping trend to the northeast and at the mine, the original main shaft collar shows an elevation of less than 100 meters.

Although not the highest, the most prominent volcanic cone is Momotombo. It has an elevation of 1200 meters and is a geographical landmark for the surrounding countryside and the air approaches to Managua. Momotombo has been quiescent for decades, although it is common to see slight vapors rising from its crater. Current investigations are now underway to determine whether elevated water temperatures along the flanks of the cone can be developed as a source of geothermal energy.

The most active volcano is the lowly Cerro Negro whose history of eruptions include 1947 and 1950. Over this period, the cone increased in altitude by over 100 meters and during the eruptions spread volcanic ash over a wide area towards the Pacific Ocean. Fortunately, the mine was on the windward side of Cerro Negro (see Fig. 1).

Apart from isolated reservoirs, hot water was first encountered on the 634 (Anderson, 1959) level of the main shaft, about 20 meters below sea level, when the main vein was intersected by crosscutting from the shaft.
A diamond drill hole penetrated the ore vein, a collar was grouted to the hole, and a pressure gage installed. Hydrostatic pressure was only about

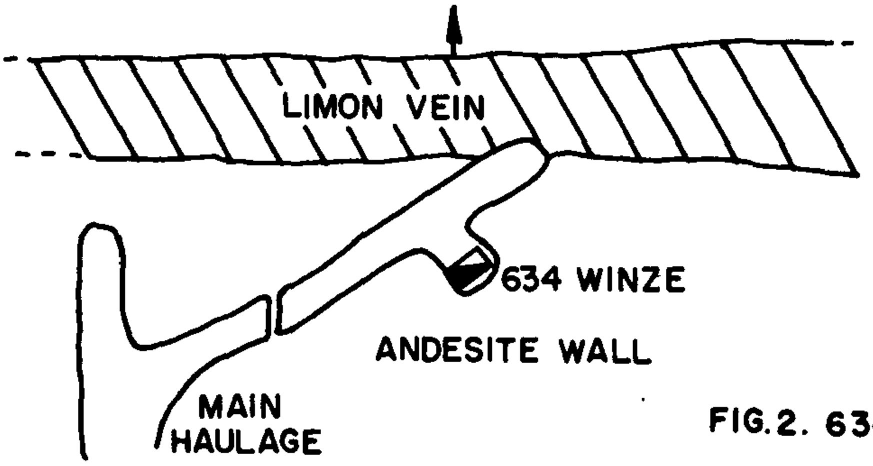

FIG. 2. 634 LEVEL

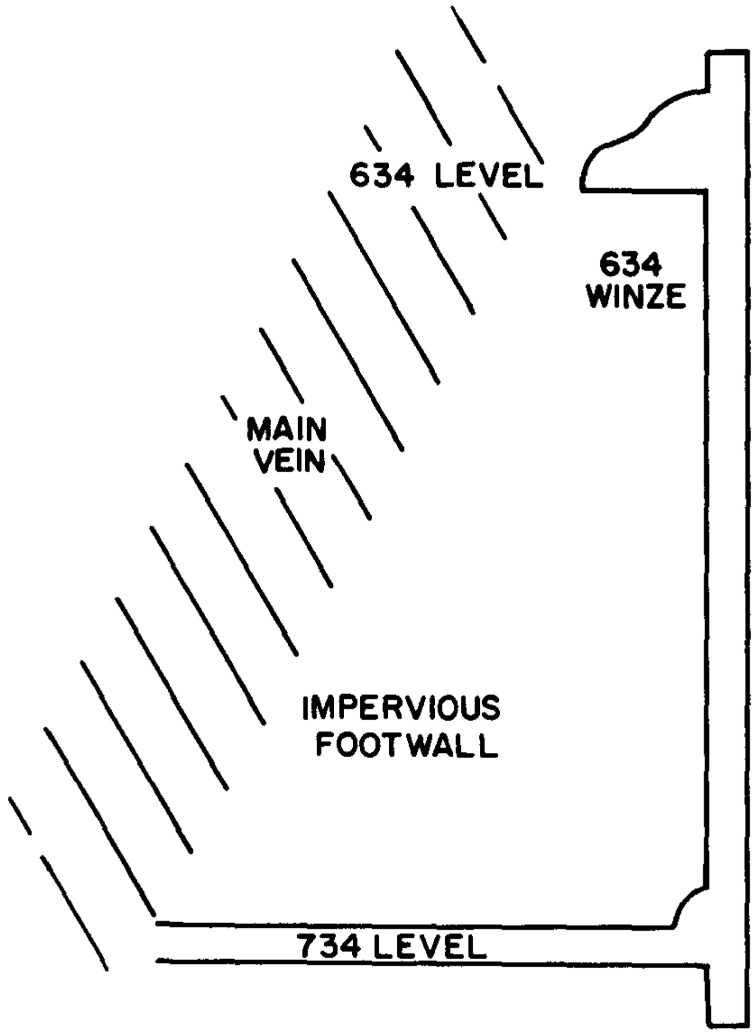

FIG. 3. WINZE AND 734-LEVEL CROSSCUT

10 meters of head, but the water showed a temperature of about 48°C. Since this was to be the main haulage level, it was decided to sink a shaft in the impervious footwall andesite and crosscut to and through the vein at 30 meters below the main level. The objective was to lower the water level and permit drifting on the 634 level under more favorable conditions. The small winze was sunk as planned with provision for a sump at the bottom to be serviced by a low-head deep well pump. The crosscut towards the footwall of the ore yielded a few isolated quartz stringers with a nominal amount of water in the range of 49°C (see Figs. 2 and 3).

The vein, about 6 meters wide, was crosscut with difficulty, but fortunately the inflow of water was limited and with controlled drilling and blasting did not exceed 300 liters per minute. Water occurred mostly in fractures which paralleled the strike and dip of the vein, and after one or two days of draining, it diminished enough to permit a further advance. Water at 49°C can be endured on the hands, but care had to be exercised to keep it off the backs and feet of the miners. Adequate ventilation was maintained by a 15 h.p. axial flow fan located near the winze collar that forced air through a 45-centimeter diameter flexible vent tube down the small shaft and up to the face. After the vein had been crosscut, the water level on the upper level dropped, permitting normal operations on that upper horizon.

The hot water so far released was clear in appearance, had a maximum temperature of 50°C, and had a slight odor of hydrogen sulfide.

Shortly after completing the 734 winze, work was initiated on a new vertical shaft to the southeast of the main orebody and somewhat nearer the volcanic chain. This area includes the Santa Francisca and San Luis veins (see Fig. 4), and hot water was known to exist here from verbal reports of early 20th century mining and from hot drill rods during exploration drilling. Diamond drilling showed irregular values, but little was known of any underground workings and even less about potential waters at elevated temperatures.

Prior to shaft sinking, consideration was given to placing one or more large-diameter drill holes in the hangingwall of the orebody, then installing deep well pumps to lower the water table. This tentative plan was not put into effect because of concern that the water might not migrate to the drill hole, and hence draw-down would be limited.

The Santa Francisca shaft was collared at an elevation of 75 meters above sea level and was sunk 237 meters to an elevation of 163 meters below sea level. It was a two-compartment vertical opening (see Fig. 5) with standard timber sets; the andesite rock was relatively firm with bearer sets at 20-meters, and most of the timber sets were unlined. The rock was cool, and nominal amounts of water in sinking were cool; drilling was done with lightweight sinkers and all mucking by hand. In effect, this was a routine shaft sinking job, and the final level was cut on the 212-meter level (700 level).

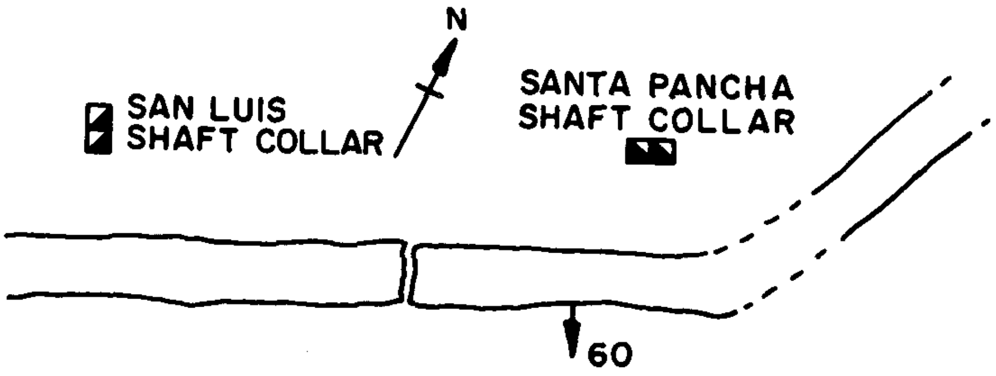

FIG. 4. SANTA FRANCISCA SHAFT

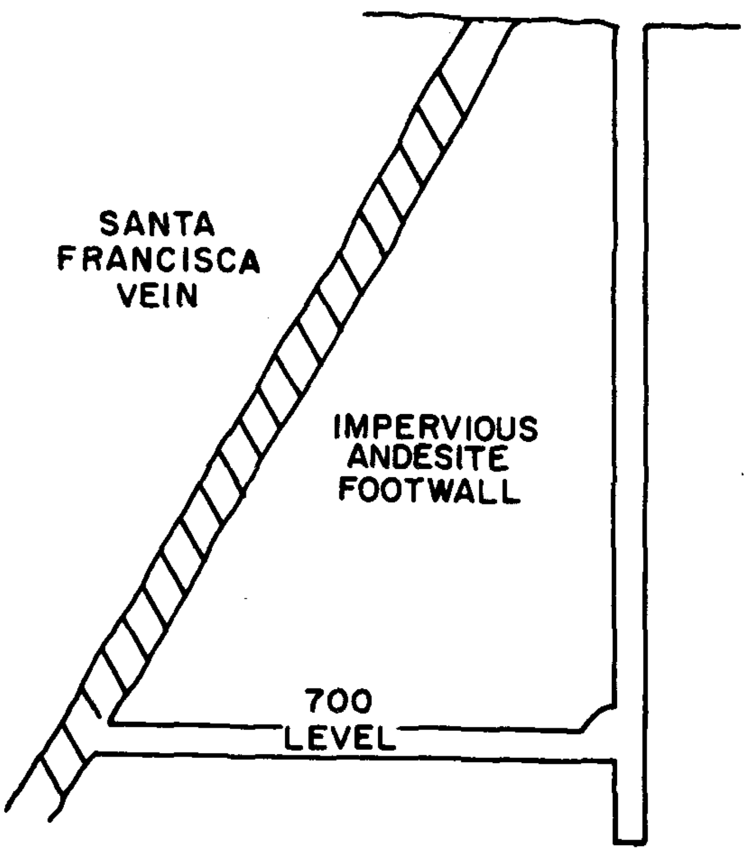

FIG. 5. SANTA FRANCISCA SHAFT AND 700 LEVEL

During shaft sinking in the cool footwall rock, no ventilation problem existed, but after the stations and loading pocket were completed, provision was made for ventilation in anticipation of adverse conditions ahead. One 15 h.p. axial flow fan was installed on surface and delivered 225 cubic meters per minute of air through a 45-centimeter diameter metal vent tube to the crosscut below. A second similar fan was installed on the level in series with the first one. This combination delivered fresh air through a flexible vent tube to within 5 meters of the face.

Upon completion of a conventional below-grade type of sump with a centrifugal pump installed, the crosscut was pushed towards the ore zone. As in the main Limon shaft, a deep ditch was carried to drain off and keep any water below track level.

In this instance, a diamond drill pilot hole was not drilled in advance of the face. It was feared that such a hole, if it encountered hot water under high pressure, would prohibit work at the face. In retrospect, these fears were justified, and if such a hole had been drilled, it would have been utterly impossible to approach the face until and if the hole so drilled was able to drain off enough water to lower the pressure sufficiently to gain access to the tunnel heading.

Each round on the 212 level of the Santa Francisca shaft was drilled with caution to avoid any sudden inflow of water. A few stringers of quartz were cut as the level progressed. These were parallel in strike and dip to the main Santa Francisca vein. Nominal amounts of hot water were developed at a temperature in the range of 50°C. There was thus every indication that water temperatures and flows were following a pattern similar to the main Limon shaft.

The footwall of the quartz vein was entered, and crosscutting of the mineralized body proceeded with no change in water flow or temperature. This sitation persisted until the entire 20 meters of vein was traversed. (It proved to be unusually wide at this point.) On a final round that presumably broke into the hangingwall, hot water at 75°C and at an estimated flow of 2200 liters per minute gushed from the face. The temperature was measured at a later date from pump discharge at the surface, and hence it is safe to say that initially, this water approached a record 77°C. The quantity of water in itself was not too great a problem. The mine staff was experienced in handling water, and the sister mine La India was at that time draining 40,000 liters per minute through its San Lucas drainage tunnel. However, water at only 23°C below the boiling point presented special difficulties that proved impossible to cope with at the time, and the shaft flooded almost immediately to within 25 meters of the collar.

When the initial impact of these events had subsided, a deep well pump was installed at the shaft collar for draw-down tests. Over a period of time additional pumps were placed in operation until a cluster of four were concentrated in one of the shaft compartments. This permitted lowering the water to within 30 meters of the bottom level. Insofar as only limited values were found on this bottom level and in this shaft as a whole, no working re-entry was made, and the Santa Francisca shaft in effect became a high cost sump even though its drainage characteristics were only indirectly related to subsequent adjacent underground workings.

Origin of this water is a matter of some speculation. Corrosion tests showed it to be high in sodium and calcium sulfates and contrary to what might be expected, a pH in the range of 5. The presence of boron, carbon dioxide, and hydrogen sulfide was established with the inference from these latter of a magmatic source (Lindgren, 1933). A probable safe assumption is that it is a mixture of magmatic and meteoric waters. However, it needs only a glance across the broad valley floor to Cerro Negro to verify the cause of the high temperatures. In addition, at the base of Cerro Negro, a hot water "spring" yields water at 93°C.

Following the extreme conditions cited at Santa Francisca, a new vertical shaft was sunk in the footwall of the San Luis vein some 3-400 meters to the west. Here again, shaft sinking was routine and temperatures normal. However, upon intersecting the vein about 75 meters above the bottom of the previous shaft, water at 60°C was encountered. To excavate an opening under such conditions was, to say the least, difficult. A procedure adopted was to drill a bottom hole first to relieve some pressure and to effect some drainage. The rest of the round was then drilled and blasted with less water and under less pressure than originally found. As previously done, a deep drainage ditch was excavated prior to reaching the vein, and this drained water to a below-drift sump. The sump had two standard centrifugal pumps, one operating and one standby. The pump motors were kept from burning out by the discharge from a 45-centimeter duct blowing air directly from the surface.

The vein was crosscut using a technique of placing sheet metal on stulls along the back of the tunnel to keep hot water from coming in contact with the workers. After driving the crosscut into the hangingwall, a vertical raise was driven to surface as a main exhaust shaft. Hence this operation was now set up for mine development with the shaft as an intake and the ventilation raise as an upcast. Lateral development of the mine then proceeded with the lowest level (at water level) being driven with some difficulty, but the upper level development was routine.

(At Santa Francisca, the water was concentrated in the hangingwall and not within the quartz vein. As a contrast, when the vein in the San Luis shaft was crosscut, hot water was confined to the ore vein and not in the hangingwall andesite. The inference here is that there is a cross-strike feeder channel that has conduited the water selectively to the Santa Francisca shaft area.

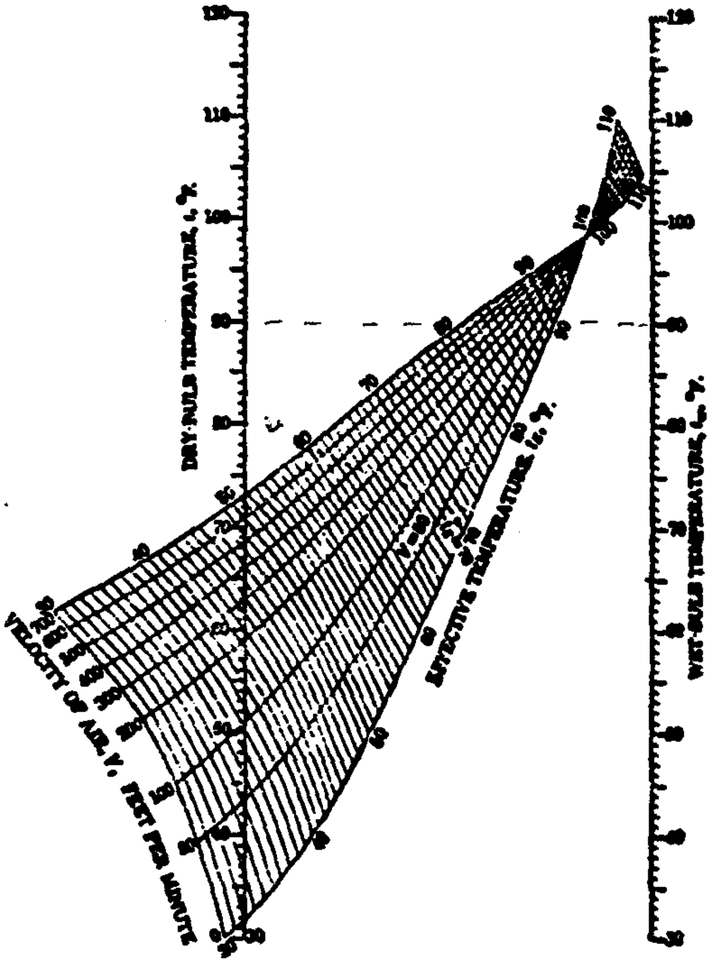

FIG. 6. EFFECTIVE TEMPERATURE CHART
(U.S. BUREAU OF MINES BULL. 385 (1935), p. 33)

This has never been directly confirmed, since more hot water was the last thing in the world that any staff member wanted to develop.)

On opening a new hot zone, an early objective was to establish a ventilation raise. The raises driven were conventional with vent tubes close to the face or in some instances with a drop cage. (The raise borers developed in the 1960's would be excellent in certain conditions for this type of development.) Upon completion of the ventilation shaft, an exhaust fan was placed at the surface over the vent shaft, and the operating shaft became a downcast. From there, auxiliary fans forced the air to the working faces throughout the mine. As mentioned, vent tubing had to be carried to within 5 meters of the face to make working conditions tolerable. Ventilation in raises was particularly difficult because of their inherent tendency to capture the hot and lighter air. This called for flexible expendable ducts to be carried close to the face, and constant maintenance and repair were required.

Hot waters at 100% or near 100% humidity produce working conditions that are difficult to cope with. Since the body loses heat by radiation, evaporation, and convection, if temperatures approach body temperature and if the humidity is 100%, then convection must play an important part. For the situation here cited, this is why large volumes of air had to be carried to within a short distance of the face.

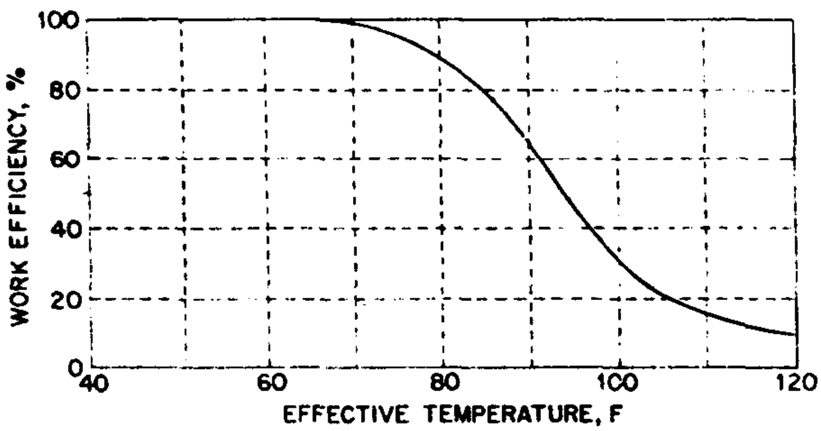

FIG. 7. EFFECTIVE TEMPERATURE AND WORK EFFICIENCY. (W. H. CARRIER, "PRINCIPLES OF AIR CONDITIONING," HEATING, PIPING AIR COND. (AUGUST, 1950): 108)

It is apparent from the foregoing charts that efficiency is low when opening a new hot water area. With air blowing at the face, temperatures were kept to about 90°F. This means that efficiency falls to about 50%. Fortunately, this situation is found only during initial development directly within the hot water zones before any draw-down is effected. Nevertheless, the effect of the hot water is felt continuously throughout the mine, and the overall efficiency is considerably less than what would be expected under normal temperature conditions.

Mining on the San Luis vein was followed by the development of other veins including Las Mercedes which fortunately did not produce hot water. At the present time (1978), most production comes from El Panteon vein. This ore zone was first found by an exploration drill hole put down in 1962.

Hot water at Panteon approaches 76°C, and volumes have now increased to about 3000 g.p.m. Production shafts at this part of the mining complex are sunk in the hangingwall, since the HW rock is more competent and requires less shaft support and maintenance. At Panteon, a combination of horizontal drill holes and crosscuts below the lowest working level are used for dewatering.

In 1953, about 20% of all power produced by the diesel electric plant was used for ventilation; today this figure has increased. As mentioned, fan installations consist of main exhaust fans on surface coupled with auxiliary fans underground. Axial flow fans are principally used, since emphasis is on large volumes of air rather than high heads.

In conclusion, hot water of volcanic or near volcanic origin in underground mining makes for disagreeable workings and high costs, including lower than normal efficiencies and excess ventilation. Technically, however, the problem can be handled by sinking initial openings either in hanging or footwall formations, whichever is more impervious. From such impervious host rock, bottomed below the lowest operating level, crosscuts or drill holes can tap the hot waters and by special pumping techniques, lower the water level and drain the orebody. However, like most unusual problems in mining, it can best be overcome by proper advance planning coupled with beforehand knowledge of conditions that may be encountered.

ACKNOWLEDGMENT

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