

MONITORING GASEOUS AND LIQUID FLUX IN SULFIDE WASTE ROCK¹

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ABSTRACT: A monitoring program was used to compare water migration, oxygen concentration, temperature, and solution chemistry in paired reclaimed and unreclaimed sulfide waste rock dumps in southwestern Montana. Slope regrading to a 2:1 gradient, addition of cover-soil, and revegetation appear to limit infiltration. In most locations, pyrite oxidation is only present in the upper 30 ft of the dump the region most affected by the wetting front to date. Waste rock in the lower 100 ft of the dump may be too dry to support microbial oxidation of pyrite.

Additional Key Words: acid mine drainage, hard-rock mining, waste rock, acid drainage abatement, environmental monitoring.

Introduction

Acid mine drainage (AMD) from waste rock disposal facilities is a prevalent concern at a number of Western U.S. hard rock mining sites. Relationships between waste rock geochemistry, internal water movement, and oxygen supply and their effect on surface and groundwater quality and on overall reclamation success are concerns of regulatory agencies. The dynamics of the sulfide oxidation reaction are closely related to waste rock mineralogy and hydrology. Infiltrating water may promote the migration of acidic and metal enriched pore water. While gaseous oxygen is usually abundant within a dump owing to the abundant porosity, heat produced during microbial pyrite oxidation may create a thermally driven advective circuit, in effect pumping oxygen to the reactive core of unreclaimed waste rock dumps (Harries and Ritchie 1987)(Fig. 1).

A number of facility engineering and reclamation practices may be used to minimize the risk of AMD for mine waste facilities in semi-arid areas (Schafer 1992). Regrading of the angle-of-repose dump slope may seal off the permeable "rubble zone" that forms at the base of end-dumped waste. In so doing, the advective oxygen supply may be limited. More importantly, placement of cover-soil and establishment of vegetation may promote surface runoff and increase evaporative consumption of water. In this way off-site AMD can be alleviated by reducing the rate of seepage through the facility. Other engineering practices such as dump construction in thin compacted lifts, and construction of waste cells within clay layers (Krauss 1990) have also been used.

The Golden Sunlight Mine is a large scale open-pit gold producer located in southwestern Montana. Gold is hosted in a breccia pipe system which is superimposed in a thick argillite sequence and quartz latite intrusives. Unoxidized waste rock typically contains 2% to 5% pyritic S and has negligible neutralization capacity. Over 100 million mt of waste rock have been placed in single stage dumps around the perimeter of the pit. Owing to the steep terrain, dump height exceeds 600 ft in some locations.

Reclamation techniques utilized at the Golden Sunlight Mine (Fig. 2) are designed to limit acid production and migration by (1) reducing infiltration of water and (2) reducing the supply of oxygen. Regrading of slopes from all angle of repose of 1.4:1 to 2:1 is designed both to reduce the slope steepness and to seal off rubble zones at the original dump toe, thus reducing the potential for advective air movement into the dump. Application of rock

¹Paper presented at the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, April 24-29, 1994.

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capping material and cover-soil limits water infiltration, increases runoff, and further reduces oxygen movement into the dump. As vegetation becomes established in the applied cover-soil, plant water use and evaporative water loss will increase. Information acquired in this study will enable the long-term effectiveness of waste rock reclamation to be evaluated at the Golden Sunlight Mine.

The objective of this on going investigation is to concurrently monitor the hydrologic conditions in a large unreclaimed angle-of-repose waste rock dump and a paired reclaimed dump. A combination of downhole monitoring techniques was used to measure differences in gaseous oxygen concentrations, temperature, water content, and pore water chemistry.

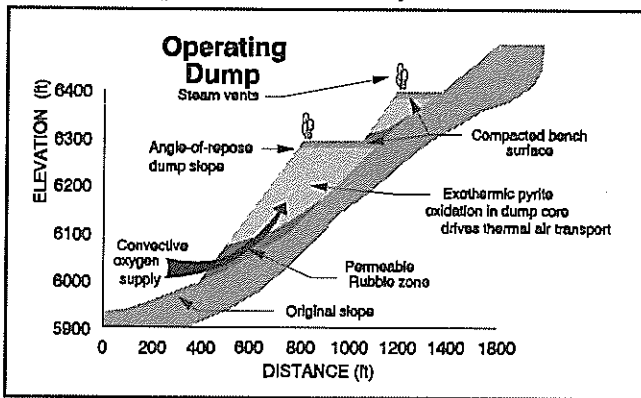


Figure 1. Characteristics of an operating high sulfide dump.

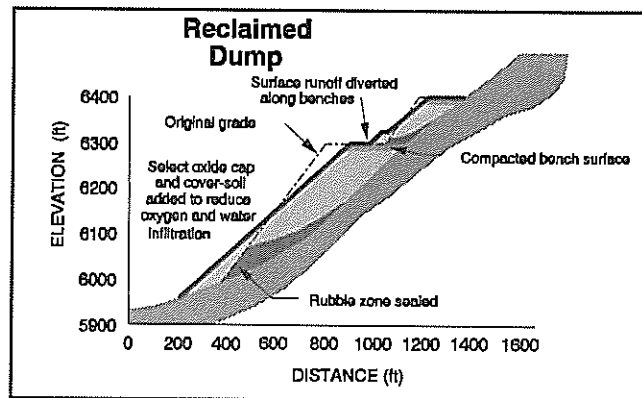


Figure 2. Reclaimed waste rock dump showing placement of soil cover and sealing of the rubble zone.

Methods

A large portion of the northwest dump complex at the Golden Sunlight Mine was regraded in 1991. Approximately 60 cm of oxidized waste rock and 50 cm of cover-soil were placed over the 2:1 regraded slopes. A mixture of dryland grasses and forbs were seeded in spring 1992. Monitoring installations were placed near the crest (site 1) and toe (site 3) of the reclaimed slope (section A-A' in Figs. 3 and 4). In addition, monitoring devices were installed on a prominent reclaimed bench (site 2) designed to direct runoff off the regraded slope. Similar monitoring devices were installed on the bench (site 6) and toe (site 7) of an unreclaimed angle-of-repose dump (section C-C', Figs. 3 and 4).

A climate station was installed at site 2 to provide daily rainfall and temperature data. Downhole devices included thermistors, heat dissipation units, neutron probe access tubes, gas sampling ports, and pore water samplers. Due to the cost of drilling in waste rock, most installations involved multiple-depth completion in the same hole. Neutron probe access tubes consisted of core steel augered into the waste rock. This installation technique maintained close contact with waste material to facilitate water content measurement. Gas-sampling ports were staggered throughout the depth of waste rock (Figs. 5 and 6) which varied from 40 to 170 feet. Shallow pore water samplers installed at depth of 3, 5 and 10 ft consisted of Soil Moisture model 1920 ceramic tip pressure-vacuum lysimeters. Lysimeters installed near the base of the dump (at over 100 ft) were BAT lysimeters which are more suitable for sample recovery from greater depths.

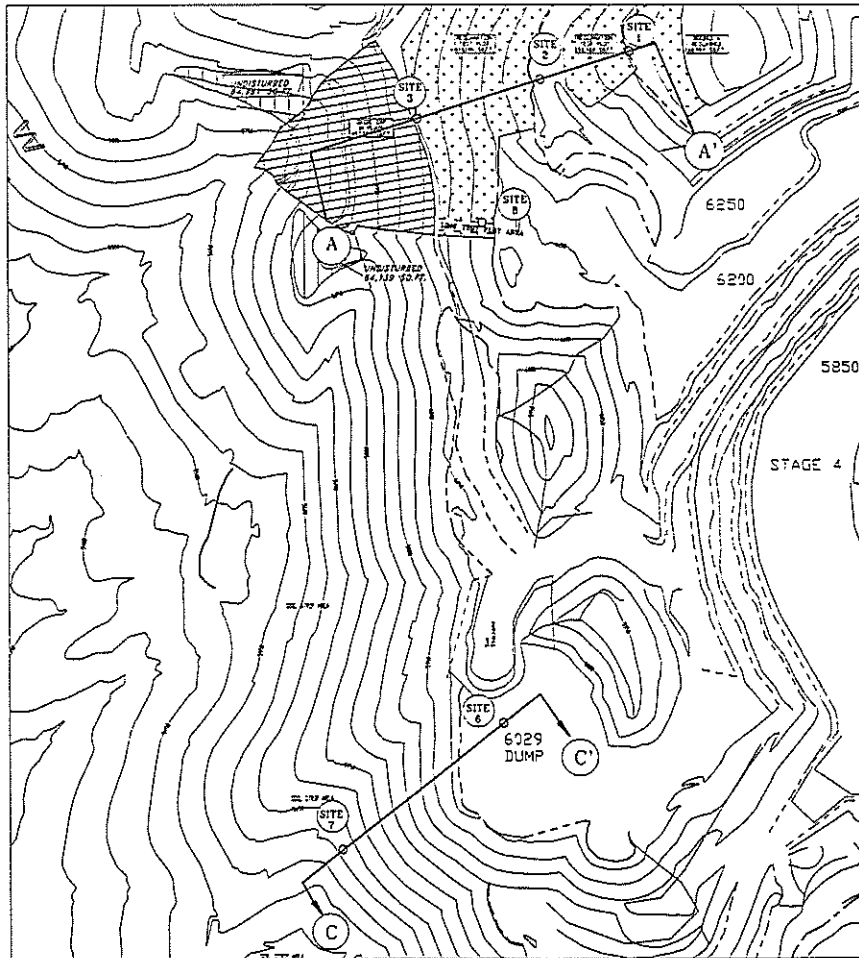


Figure 3. Plan view of Golden Sunlight Mine northwest dump showing reclaimed (north) and unreclaimed (south) test dumps.

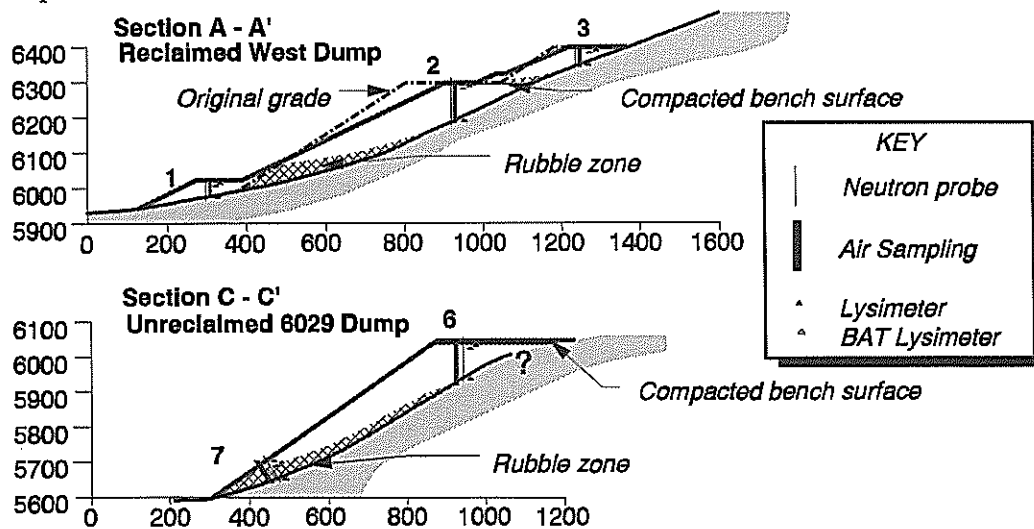


Figure 4. Cross-section view of monitoring devices installed in the northwest dump.

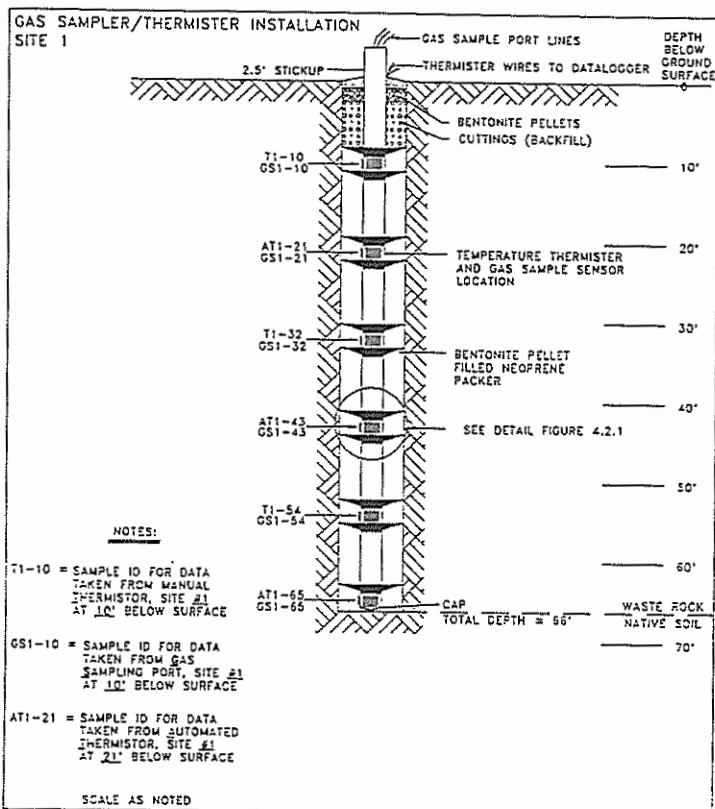


Figure 5. Typical multiple completion gas port assembly for site 1 in the reclaimed section of the Golden Sunlight Northwest Dump.

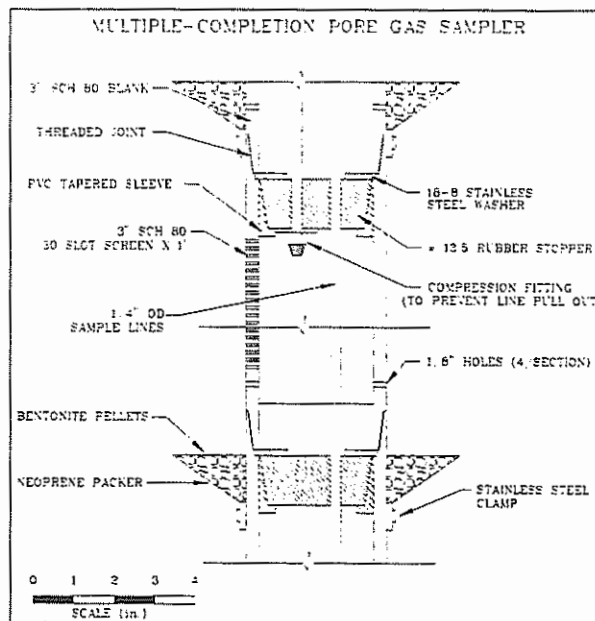


Figure 6. Detail of gas sampling port.

Routine monitoring of temperature, water content, oxygen levels, soil suction levels, and pore water chemistry began in mid-1992. The purpose of the hydrologic monitoring program was to identify differences in oxygen supply, water flux, and pore water chemistry in reclaimed and unreclaimed dumps.

Results

Water Content and Water Balance

Water content in waste rock at the Golden Sunlight Mine is a function of the average rock particle size, and prior saturation by rainfall infiltration. During placement, freshly shot waste rock typically has a volumetric water content of less than 6 percent. The rock particle size gradually increases with depth due to gravity sorting in the end-dumping sequence. As a consequence, residual saturation varies between 8 and 12 percent within the dump with residual saturation generally lower near the base of the dump where larger particles are deposited. Overall, the waste rock has a volumetric "wetting requirement" of 3 to 5 percent. Infiltration gradually wets the waste rock from its initial water content to residual saturation or field capacity. The upper 6 to 10 ft of each waste rock bench differs from the remaining waste rock due to vehicle compaction which pulverizes the material. The fines generated cause residual saturation levels to reach 15 to 20 percent. A 100 ft column of waste rock would retain 3 to 5 ft of solution before seepage could migrate out of the pile.

The overall water balance for each monitoring point is presented in Fig. 8. The cumulative precipitation from July 1992 to October 1993 is compared to the cumulative change in water within the vertical extent of the

dump. Essentially all of the incident precipitation appeared to infiltrate into the toe of the unreclaimed waste rock pile (site 7). The wetting front appears to have nearly reached the base of the dump at site 7. Both the reclaimed dump bench (site 2) and the crest of the unreclaimed dump (site 6) gained far more water than the cumulative rainfall. This apparent anomaly is probably due to run-on from natural hillslopes upgradient of the dump and lateral seepage along the dump foundation. The reclaimed 6300 bench (site 2) was located in a depression which collected a significant amount of runoff water from the 6400 slope in both 1992 and 1993. The control crest location appeared to decrease in water content between spring and late summer of 1993. This change in water content may represent flux of water below the base of the dump.

Both site 1 and site 3, the crest and toe of the reclaimed dump, exhibited a greatly reduced intake of water, averaging about 30 to 40 percent of the incident precipitation. As vegetation becomes better established, the performance of the revegetated soil cap in reducing infiltration is expected to improve. Rainfall received during 1993 was approximately double the long-term average rainfall at the site.

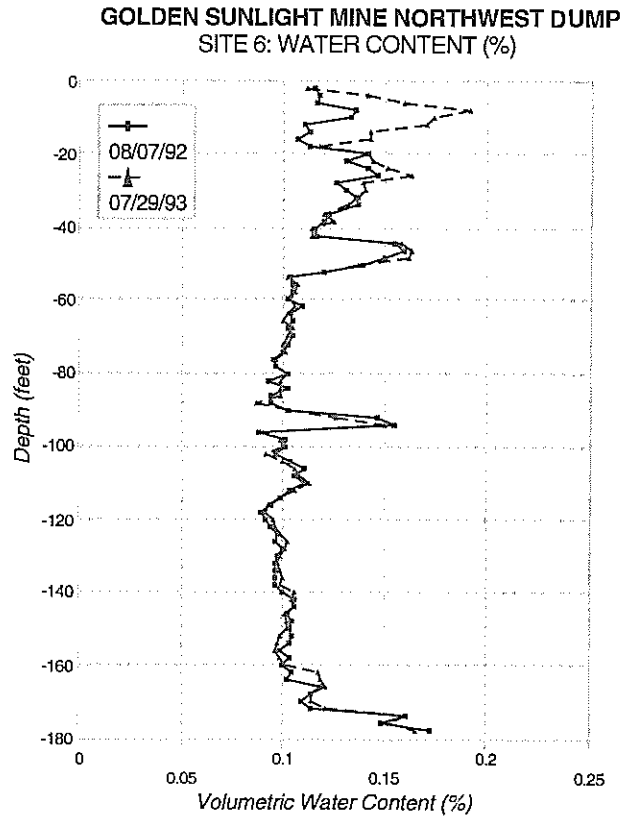


Figure 7. Water content variation with depth in the untreated dump crest. Natural soils were encountered at 175 feet.

Suction Levels

Heat dissipation units are automated devices used to measure soil water potential in soils. A data-logger is used to measure soil suction levels hourly. Long-term trends in suction at site 1 (Fig. 9) corroborated the soil water content data. The base of the dump remained extremely dry at the end of 1993 (water potential <-10 bars) because the wetting front had not reached this level. Soil water potential at 3, 5 and 10 feet generally ranged from -0.6 to -0.3 bars indicating that materials are at residual saturation at these depths. Minor increases in water potential occurred in response to rainfall events.

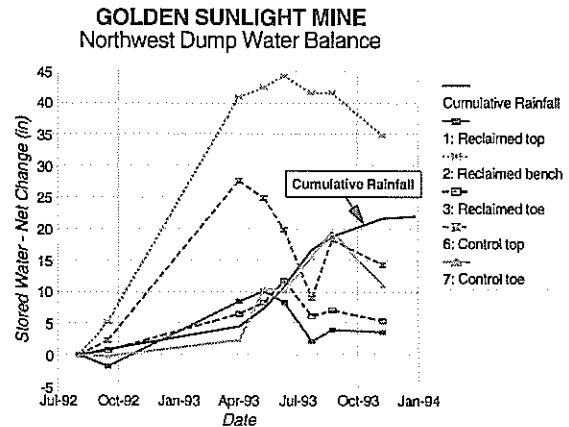


Figure 8. Site water balance for the reclaimed and unreclaimed Northwest Dumps.

Temperature

Temperature is particularly important in this investigation because pyrite oxidation is strongly exothermic. Hence, elevated temperatures provide a direct indication of the spatial extent of microbial pyrite oxidation. Temperature trends for numerous measurement depths at each site are presented in Fig. 10. Site 1 does not indicate significant pyrite oxidation. Temperatures average 8°C, the average annual air temperature. Seasonal temperature fluctuation is only pronounced at the three foot depth. Pyrite oxidation has been triggered between 40 and 75 feet at site 2, the reclaimed 6300 bench. Interestingly, heating is confined to the wetting front which has moved from 40 to 80 feet during the two years of monitoring. It appears that dry waste rock placed at water content below residual saturation (less than about 10%) may be too dry to support *Thiobacillus ferrooxidans* activity. Similarly, the upper 10 feet of the unreclaimed crest is just beginning to heat, and the 33 foot depth which was wetted in mid 1993 may be beginning to heat. The toe of the angle of repose dump had extremely cold temperatures indicative of cold air drainage within the pile. Water content measurements indicated that a large mass of ice developed at this location and melted in late summer.

Oxygen Levels in Waste Rock Pore Space

Oxygen concentrations were highly elevated at all depths in the reclaimed and unreclaimed waste rock at Golden Sunlight (Fig. 11). Minor decreases in O₂ were noted near the surface of reclaimed sites during the 1993 growing season. The applied cover-soil layer did not serve as an effective oxygen diffusion barrier, however. Reduced oxygen levels were only noted at 33 feet at site 2, the depth at which extreme heating was also noted. The high oxygen levels throughout most of the dump could be either attributed to rapid oxygen advection or diffusion rate or to a lack of oxygen consumption. For the drier, lower half of the dump, oxygen demand appears to be slight due to the apparent minor microbial pyrite respiration.

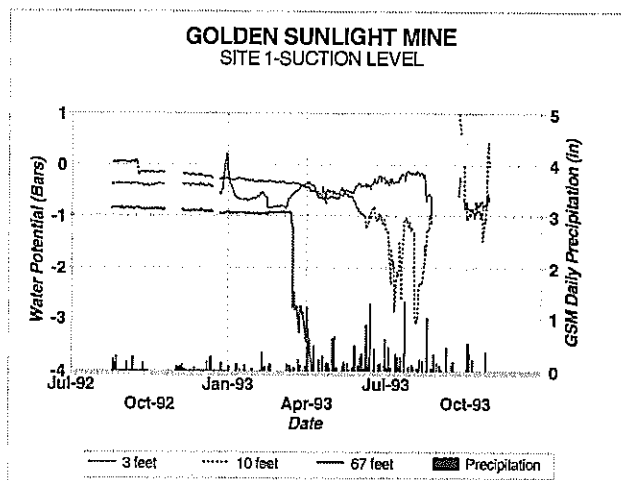


Figure 9. Seasonal variation in soil suction beneath the crest of the reclaimed dump.

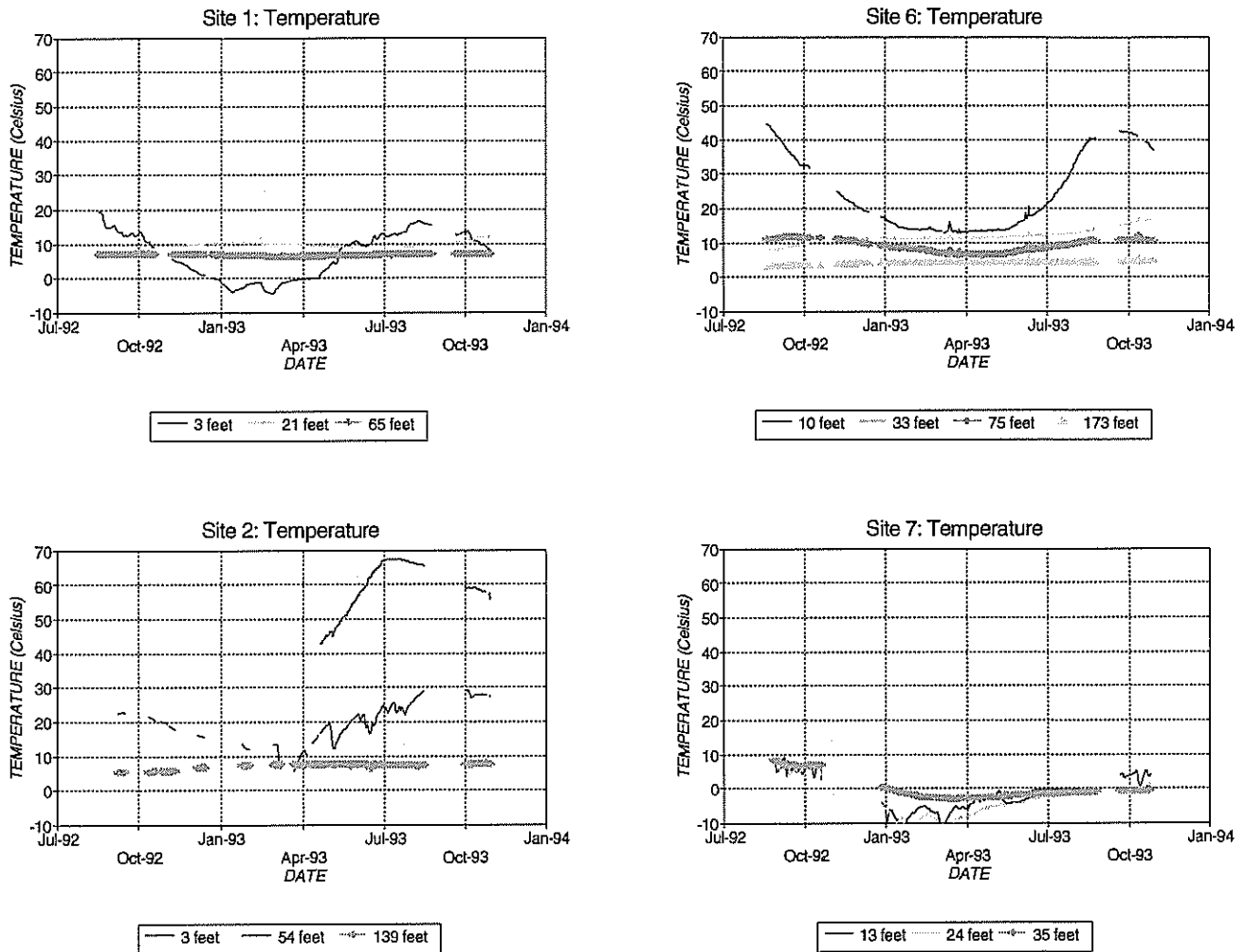


Figure 10. Soil temperatures at reclaimed and unreclaimed monitoring sites.

Pore Water Chemistry

Pore water samples were obtained from 3, 5 and 10 feet in depth at most sites. Samples of pore water could not be obtained from deeper lysimeters placed at the foundation of the dump either due to mechanical damage of the access tube from consolidation or due to very low soil suction levels. In general, pH of pore water ranged from 1.5 to 3 in sulfide waste rock and was from 4 to 7 in oxide waste rock and cover-soil layers.

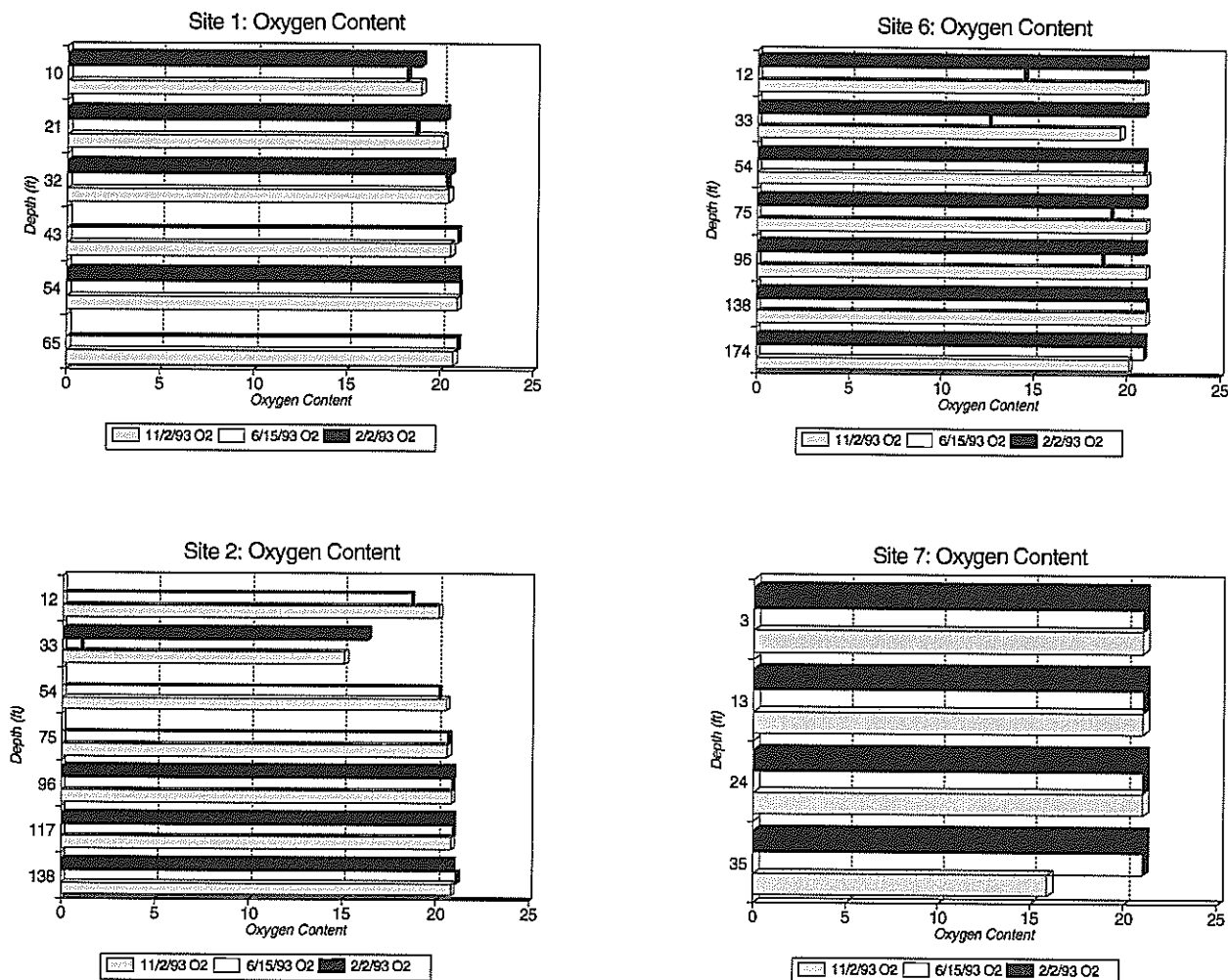


Figure 11. Oxygen levels in pore space at reclaimed and unreclaimed monitoring sites.

Conclusions

Regrading and addition of cover-soil to sulfide waste rock dumps appears to be effective in reducing infiltration of water into the dump. As vegetation becomes established, infiltration may decrease to the point that the rate of migration of the wetting front will be diminished.

Oxidation of pyrite is accompanied by evolution of heat. Although thermally-driven advection was thought to maintain an ample oxygen supply to reactive zones within the dump, the advective cells may be surficial rather than being fed from the coarse-textured dump foundation as originally hypothesized.

Migration of the wetting front, which is currently at around 30 feet through most of the dump, appears to trigger sulfide oxidation. Deeper materials that are relatively dry do not appear to be reacting at present. Pronounced hillslope effects also affect water movement within the dump. Run-on from upgradient areas, and ponding of water on erosion control benches has stimulated deeper water movement in few portions of the Northwest Dump at Golden Sunlight. The practice of concurrent reclamation, that is progressive regrading and revegetation during mining, may be particularly important for sulfide waste rock facilities in semi-arid climates.

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