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ASSESSMENT OF THE EFFECTS OF POTENTIAL GROUND SUBSIDENCE ON A RECLAIMED TAILINGS PILE

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INTRODUCTION

The UMTRA Project involves remedial work at 24 abandoned uranium mill tailings piles. Remedial work is to be effective for a design life of 1000 years, where reasonably achievable, and at any rate for 200 years.

At the Ambrosia Lake pile in New Mexico, there are mine workings at about 174 to 180 meters below the southwest part of the pile. Potential subsidence, if it occurs, could impact the integrity of the remedial work to be undertaken at the pile.

This paper describes the evaluations and analyses done to assess the potential for and nature of subsidence of strata beneath the pile. Further, the paper describes the work done to assess the impacts, if any, of potential subsidence on the pile and in particular on the radon barrier - a cover of compacted silty clay placed over the pile.

The analyses show that even if the maximum theoretically predicted subsidence were to occur, there will be no significant effect on the integrity of remedial works at the pile.

SITE DESCRIPTION AND GEOLOGIC SETTING

The Ambrosia Lake site is in northwest New Mexico, within the Navajo section of the Colorado Plateau physiographic province (Figure 1). Terrain in this section of the plateau is generally flat-topped, gently sloping cuestas, broad steep scarped mesas, low-gradient pediment and fan surfaces, deeply incised canyons and arroyos, and strike valleys. Basalt flows and cinder cone fields cover large areas west and south of the Ambrosia Lake site.

Cenozoic tectonic and erosional processes have exposed rocks of Precambrian through late Quaternary age in the region. With the exception of Quaternary basalt flows, Precambrian igneous and Paleozoic sedimentary units outcrop south of the tailings site in the vicinity of the Zuni Uplift. Progressively younger strata are exposed in the central and northern portions of the area, terminating with deltaic deposits of the upper Cretaceous Fruitland Formation. Extrusive volcanic rocks primarily of Miocene and Pliocene age constitute the Mt. Taylor and Mesa Chivato physiographic features east and northeast of the existing tailings pile.

The Ambrosia Lake site lies in a northwest-trending strike valley cut into the upper Cretaceous Mancos Shale. Approximately 1000 meters of Permian to Cretaceous clastic sedimentary strata underlie the site. The sedimentary section dips northeast at approximately two degrees, forming a regional homocline of the southern San Juan Basin referred to as the Chaco Slope.

Tectonic faults are abundant in the study region and reflect multiple episodes of deformation. Most of the structures are Laramide, with north and northeast trends. Displacement is commonly down to the east and on the order of a few tens of meters. In addition to the regional uplifts and monoclinal elements forming the southern margin of the San Juan Basin, numerous small-scale domes, anticlines, and synclines locally deform the otherwise uniform regional bedding. Vertical displacement of the Laramide age local structures is generally less than 150 meters.

Unconsolidated alluvial and eolian deposits of late Quaternary age mantle extensive low-lying portions of the study region and site. Within the Ambrosia Lake valley, thicknesses of alluvium exceed 30 meters. Valley sideslope alluvial sediments in the immediate site vicinity range in depth from one to 15 meters.

THE PROPOSED REMEDIAL ACTION AND DESIGN FEATURES

The main feature of the design concept is the consolidation and stabilization in place of the Ambrosia Lake tailings, contaminated subsoils, and windblown contaminants. Mill buildings and foundation materials will also be demolished and buried.

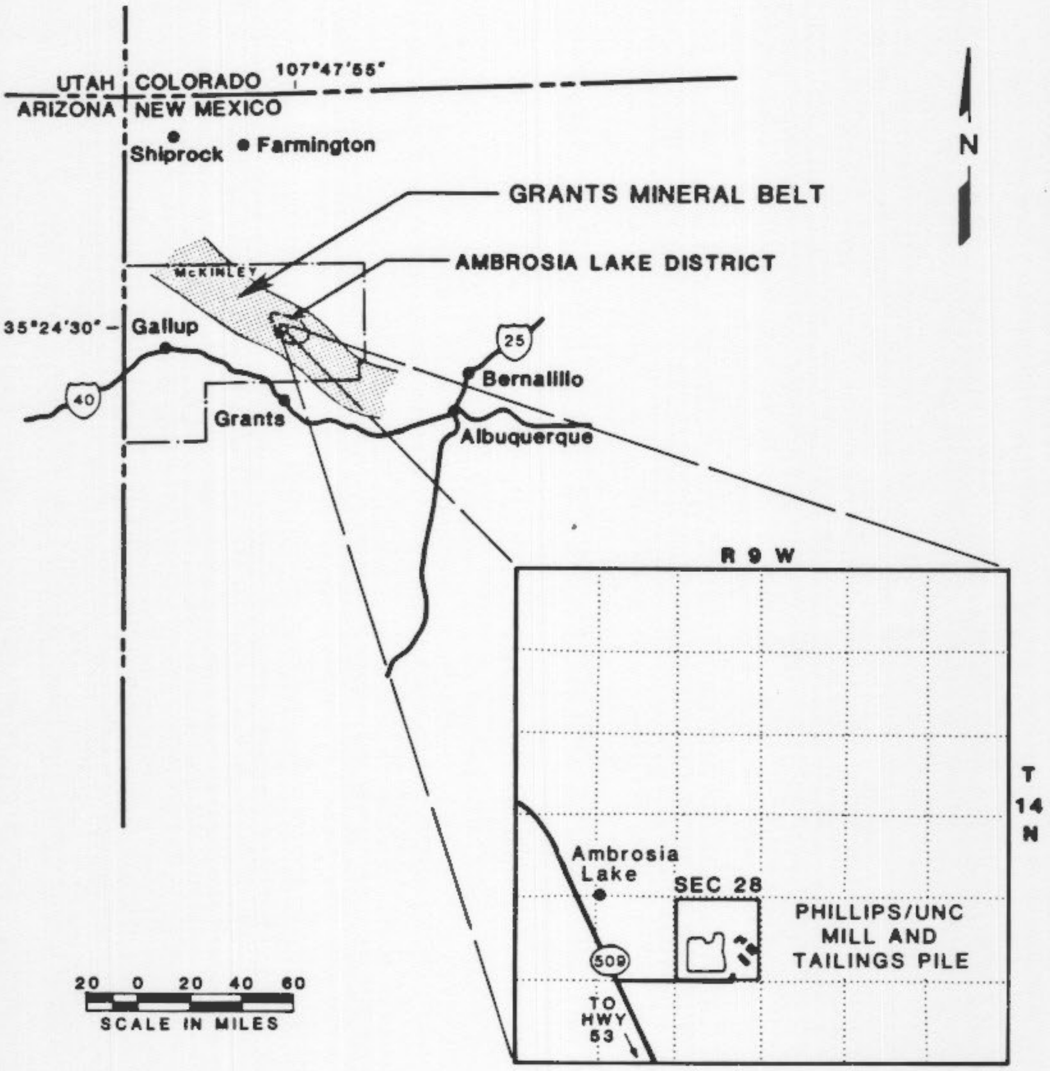

Figure 1. Vicinity map of Ambrosia Lake UMTRA site.

Figure 2 shows the cross-section of the pile and Figure 3 shows a layout of the pile after remedial work. Figure 3 also shows the zone of mine workings below the southwest corner of the pile which could lead to subsidence.

The radon barrier is compacted weathered Mancos Shale from the borrow site approximately 1.5 kilometers north of the pile. The radon barrier, which is at least one meter thick, is designed to reduce radon flux to 20 picocuries per square meter per second or less.

Pile erosion protection consists of rock and filter layers designed to withstand the Probable Maximum Precipitation (PMP) on the pile and the Probable Maximum Flood (PMF) flows around the perimeter of the pile.

The northern portion of the pile is to be relocated because it is more economical to move the tailings and incorporate them into the main portion of the pile, than it is to cover them with a radon barrier and erosion control layers. The tailings moved from the northern portion of the pile will be used to fill the existing pond on the pile surface and to shape the top of the pile to form slopes from which water will drain.

The southern portion of the pile, including the southwestern corner which is underlain by mine workings, will not be moved as it is more economical to stabilize this portion in place and cover it with a radon barrier and erosion control layer rather than to relocate it.

Tailings instability is another reason for not relocating the tailings in the southwestern part of the pile. The tailings in that part of the pile are soft and nearly saturated. If the surrounding sand tailings dike were to be removed, problems of instability would be encountered: the soft slimes tailings in the inner part of the pile could flow from a breach in the perimeter dikes.

REGIONAL SUBSIDENCE

Two principal mining methods were used in the extraction of the Ambrosia Lake ore. A technique referred to as "scram" stope mining was used to exploit the thickest ore bodies during the early years of activity in the Ambrosia Lake valley. Changes in mining industry regulations and the decreasing grade of ore prompted mining firms to develop ore bodies during the 1970s using the multiple level room and pillar method. Two levels of room and pillar type workings underlie the southwest corner of the tailings pile at a depth of approximately 174 to 180 meters.

Numerous occurrences of mine working-induced subsidence have been recorded in the Ambrosia Lake

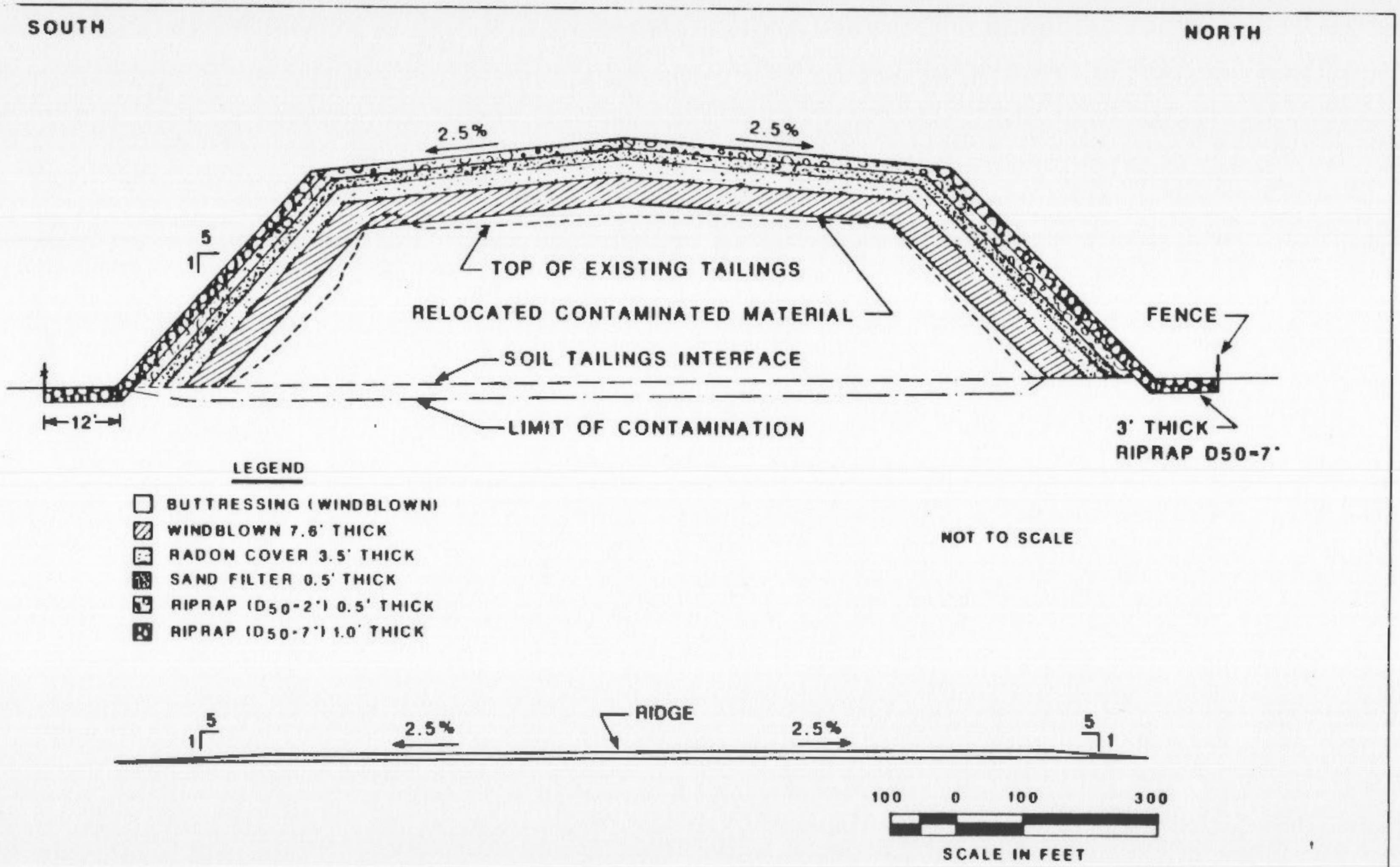

Figure 2. Typical embankment cross-section, Ambrosia Lake site.

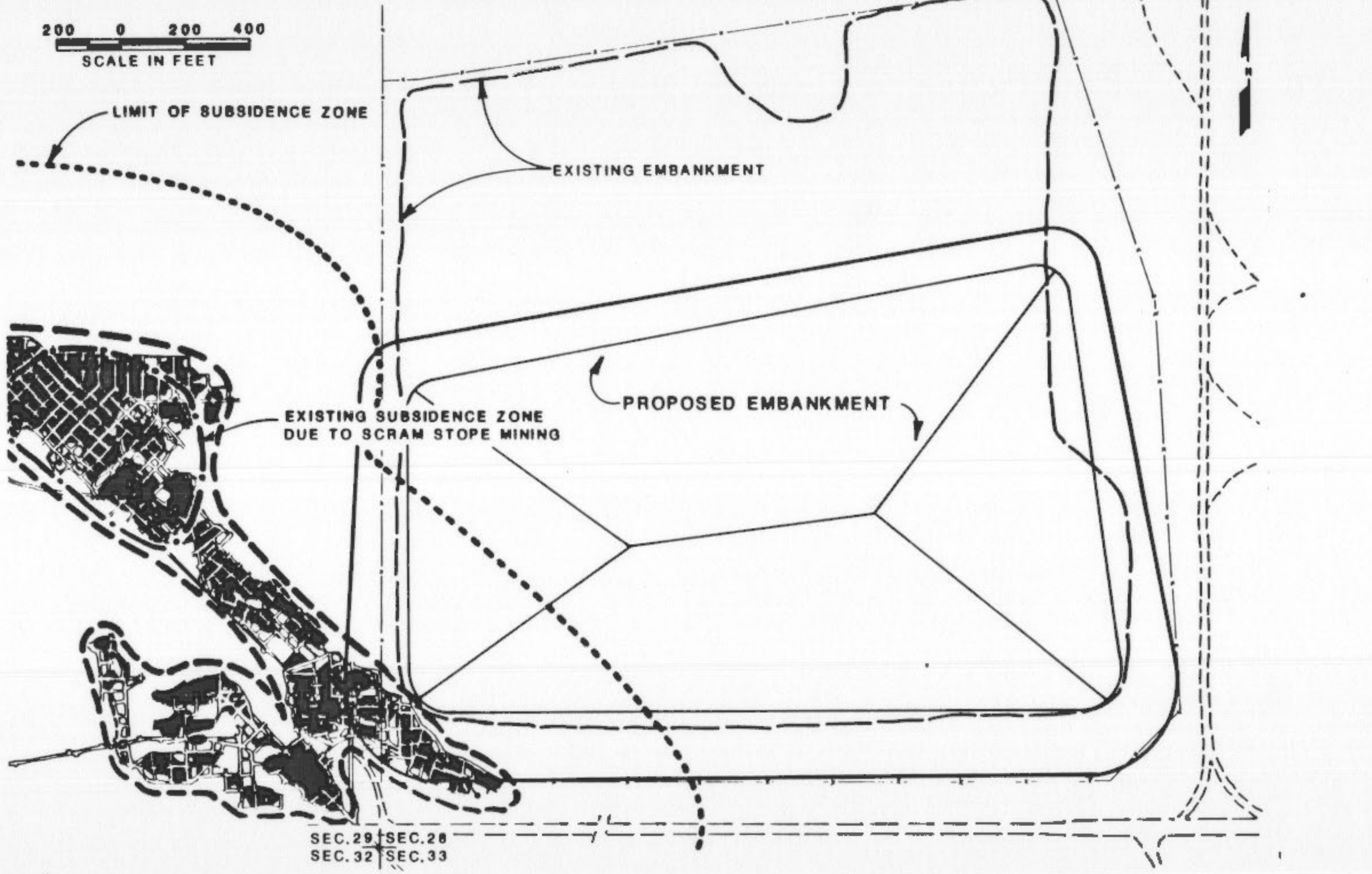

Figure 3. Map showing location of proposed embankment and subsidence zone

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mining district. Surface manifestation of the collapse of underground workings is evident approximately 250 meters west of the existing tailings pile (Figure 3).

Close examination of mine workings maps provided by firms operating in the Ambrosia Lake area indicates that surface subsidence is nearly always associated with "scram" stoping development of the underlying ore body. As the mining technique involved the use of the entire rock column overlying the ore bearing strata as a natural gravity crusher of the ore, failure of the ground surface was concurrent with mining activity. The depressions are circular or elliptical and range from a few to several meters deep. The zone of subsidence on the western edge of the existing tailings pile is a depression approximately 400 meters in diameter, and one meter deep at the lowest point. The subsidence zone is delineated by discontinuous subsidence cracks, piping holes, and enhanced vegetation growth along its perimeter. There are two concentric subsidence scarps of two- and one-meter widths along the north and east edges of the subsidence zone. Erosion and piping have developed troughs in the scarps exceeding a depth of one meter, although vertical offset of individual scarp features is not greater than 150 millimeters. Similar zones of subsidence are seen in airphotos of the Ambrosia Lake valley.

No recognized surface subsidence has occurred over any areas of multiple room and pillar development in the Ambrosia Lake area. Abel and Lee (1) in a study of the lithologic controls and subsidence observed that, in Pennsylvania, the negligible magnitudes of surface subsidence associated with the failure of room and pillar type workings were frequently undetectable. This appears to be true also for areas of room and pillar mining in the Ambrosia Lake ore district.

Sandstones, siltstones, and shale of Jurassic and Cretaceous age constitute the 200-meter-thick rock column overlying the sub-pile mine voids. No known tectonic structures disturb the uniformly dipping units. The ore-bearing strata are poorly to very poorly indurated, and presented a constant caving hazard in the workings during the years that mines were operating. Ground support of mine passages was typically placed on centers of two meters or less. Ceiling failure generally occurred in the form of localized arcuate slabs. It is possible, therefore, that collapse of the stopes has already occurred. Peele and Church (2) describe early studies in which the volumetric expansion that desegregated rock slabs underwent during the failure of successively shallower strata were characterized. The phenomenon, termed "swell factor," varies primarily with the lithologic character of the rock column and depth of workings being evaluated. Application of the values quoted by Peele and Church (2) suggests that complete infilling of the failure void would occur at a depth of 150 meters below ground surface. The analysis assumes a vertical dimension of mine opening roughly three times that beneath the tailings and is therefore a conservative approach.

VERTICAL MOVEMENTS AND EXTENT OF SUBSIDENCE

The methods used to analyze the subsidence are described by Abel & Lee (1) and the National Coal Board (NCB) (3). The mining under the pile consists of rooms and pillars. The geology overlying the underground openings is described above and shown in Figure 4. The characteristics of each opening are given in Table 1.

Table 1. Mine Openings Characteristics.

	Upper opening	Lower opening
Depth	174 m	180 m
Panel width	30 m	36 m
Panel length	245 m	245 m
Mining height	4.5 m	4.5 m
Pillar width	3.0 m	3.0 m
Extraction ratio	60%	70%

The maximum subsidence was calculated using the equation presented by Abel & Lee (1) as follows:

$$\text{Subsidence}\ (\%) = 8.469 + 11.95\ln(L_{max}\ (\frac{H}{W}))$$

$$L_{max} = \frac{KD}{1-R}$$

where:

- D = depth (m).
- R = extraction ratio.
- H = mining height (m).
- W = pillar width (m).
- K = A constant-the unit mass of rock-0.0226 MPa/ft.

The maximum percent subsidence was calculated to be 40.6 percent for the upper level and 44.5 percent for the lower level. This results in a critical subsidence for the upper and lower levels of 1.86 and 2.03 meters, respectively. Since the panels are fairly narrow with respect to the depth, the subsidence is sub-critical and a reduction in the critical subsidence may be made. NCB (3) quotes reduction factors to account for this;

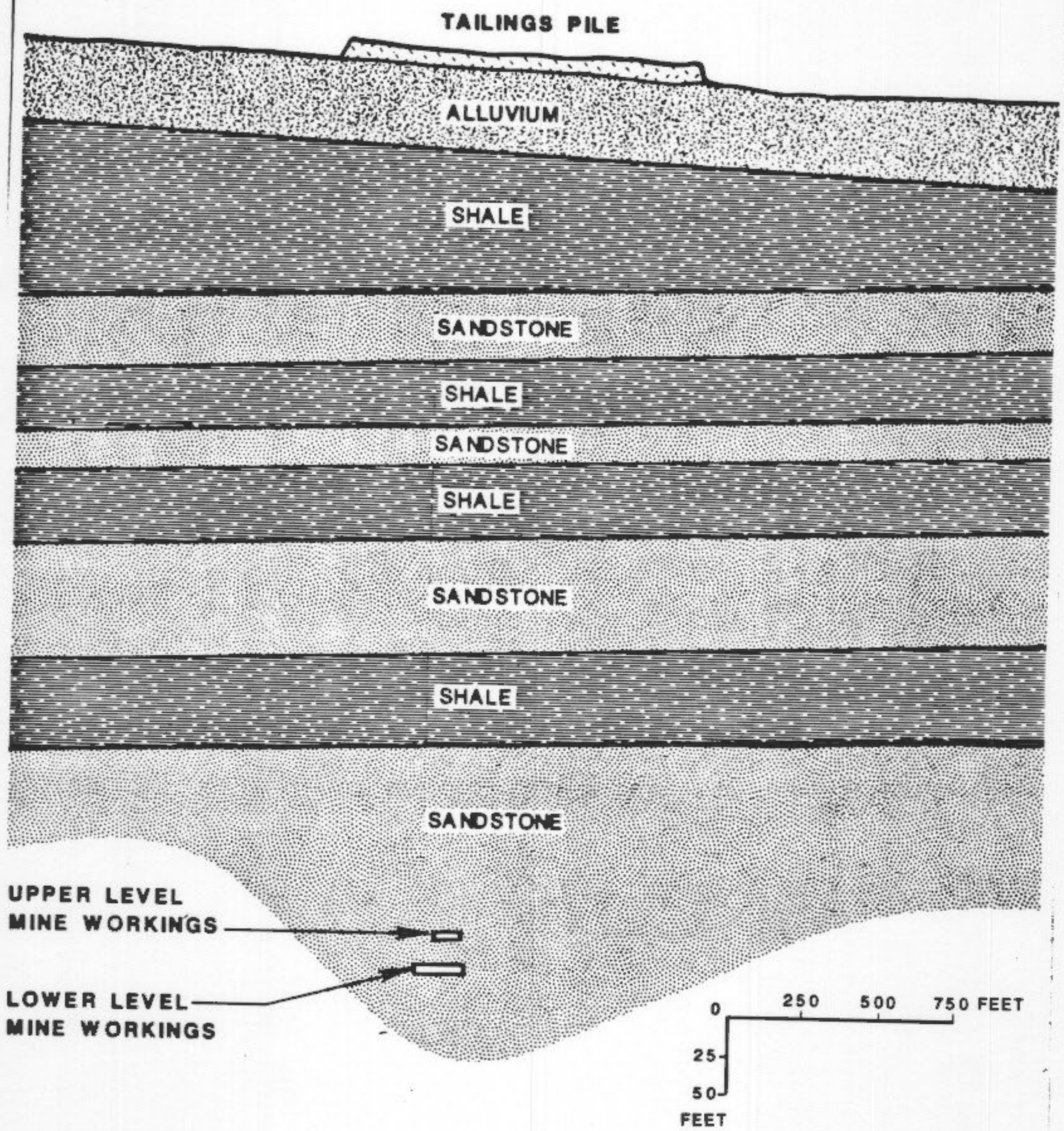

Figure 4. Geology above and location of underground mine workings.

values of 0.04 and 0.05 for the upper and lower levels, respectively, were used in the analysis. This produces an estimated settlement of 73 and 101 millimeters for for the upper and lower levels with a combined total subsidence at the surface of 174 millimeters (4).

In order to predict the profile of the subsidence, the angle of draw is determined using empirical relationships presented by Abel & Lee (1). The materials above the workings consist of about 52 percent shale and 48 percent sandstone. For this lithology, the angle of draw is 20°.

~~The subsidence profile was calculated and plotted~~ as described by the NCB and shown in Figure 5.

RADON BARRIER CRACKING

Subsidence itself is not necessarily harmful to the radon barrier but the amount of strain that the radon barrier experiences is critical because too much tensile strain could cause cracking. Compressive strain in the radon barrier would not necessarily be harmful because cracking would not occur and the radon barrier is very plastic; therefore, a shortening would be expected to occur but no buckling is likely.

Since the strain is the first derivative of the subsidence profile, the strain can also be plotted. The guidelines shown by the NCB were also used to plot the strain profile. Figure 6 shows the strain profile for the combined workings. The maximum tensile strain was calculated to be 0.05 percent.

This strain can be compared to values published for structural damage. Cracking of plaster occurs for strains of 0.1 percent, and cracking of reinforced concrete occurs at about 0.3 percent.

Leonards and Narain (5) report an extensive series of tests to measure the strains that actually cause cracking in soils subjected to tensile stresses. Some of the soils tested are similar to those to be used for the radon barrier at Ambrosia Lake. Their testing indicates that cracking does not occur in compacted earthen structures until strains of up to 0.3 percent are reached. This indicates that even the maximum strains that could potentially occur at the site are lower than those at which cracking is likely to occur.

Localized cracking or failure is not likely to occur at this site since no major faults or changes in lithology occur within the potential subsidence zone.

The discussion above is based on the approach that the subsidence will be expressed at the surface as a relatively uniform downward movement and smooth deformation profile. The basis for this is the presence of a layer of Mancos Shale above the workings and beneath the pile. The Mancos Shale is a relatively uniform material with no significant structure.

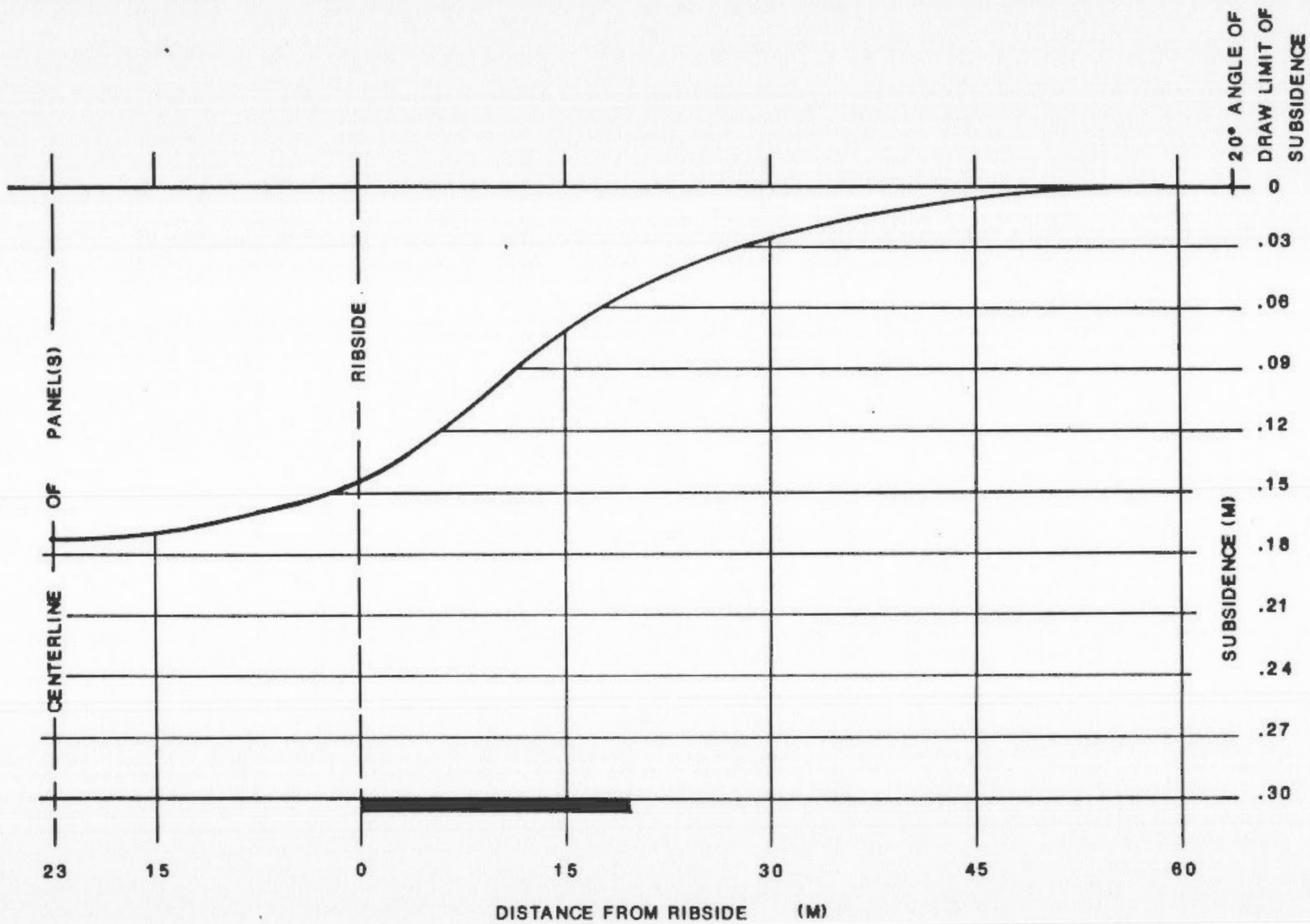

Figure 5. Subsidence profile

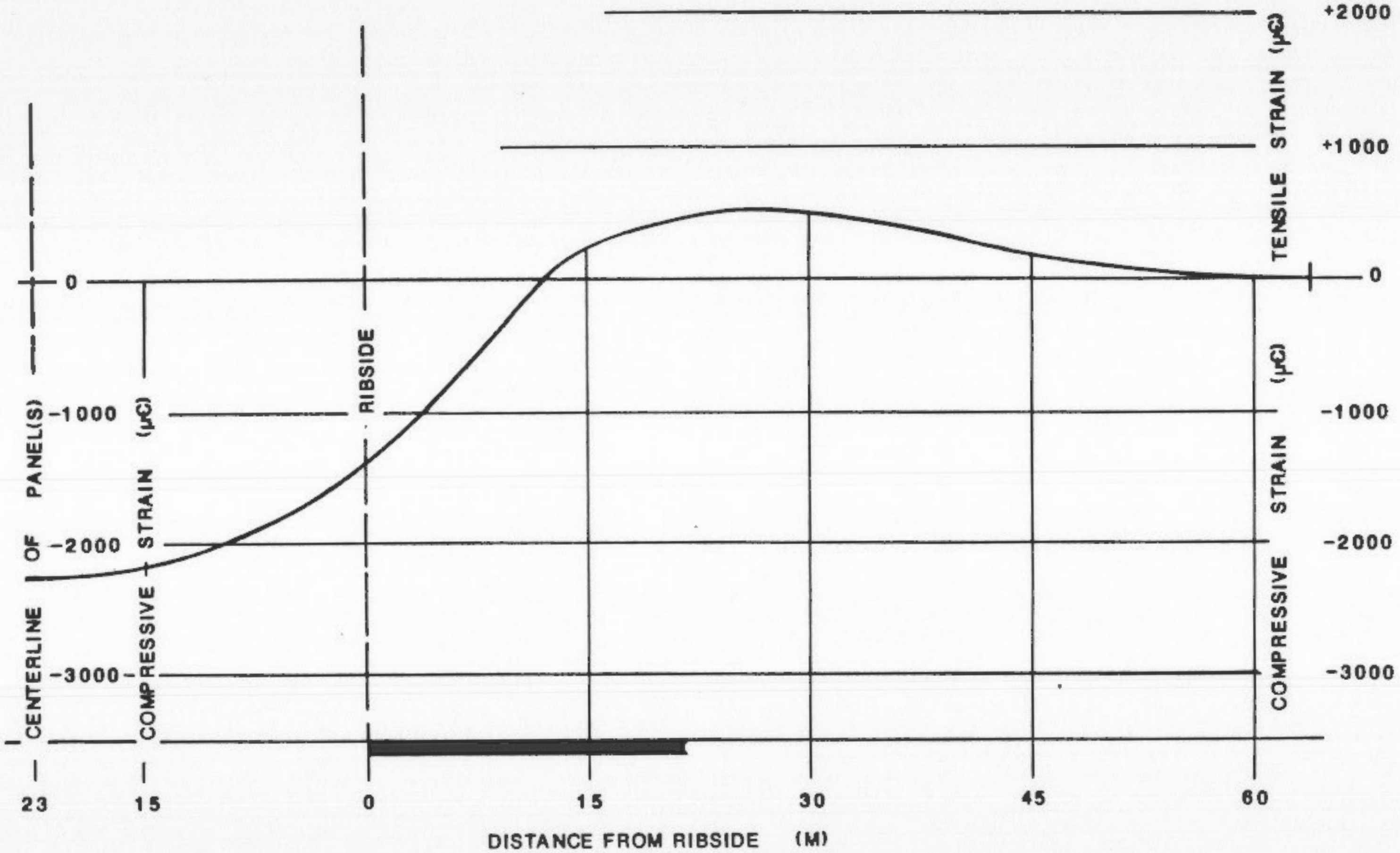

Figure 6. Strain profile

There is, however, a remote possibility that subsidence will occur as a distinct surface step at a specific location. The effect of this could potentially be a localized shear deformation of the cover. This would be manifest through the rock armor at the surface. A single or several shear and extensional cracks will have little effect on the intended performance of the radon cover. In addition, the rock armor that protects the pile from surface water runoff is not significantly affected since the subsidence scarp would be small and perpendicular to any runoff flow path.

CONCLUSION

Subsidence does not always occur over all mine openings. Localized collapse of roof strata can effectively seal a mine opening due to the increased volume of broken rock compared to in-situ rock. This change in volume is called the swell factor, and thus may prevent or reduce subsidence.

For the Ambrosia Lake inactive uranium mill tailings piles, the maximum vertical displacement, horizontal movement, and strain of the ground surface were calculated. The strains induced in the radon barrier, a silty clay cover placed over the pile, were calculated. The maximum predicted strain in the cover was compared to the established limits for compacted earthen structures, and found to be below the limit at which cracking will occur.

Accordingly the conclusion is that subsidence, even if it does occur, is unlikely to affect the integrity of the remedial works at the pile. Hence, it is not necessary to relocate the tailings at the southwest corner of the pile. This is a cost-effective solution and one that is also acceptable for practical reasons.

ACKNOWLEDGMENT

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