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PREPRINT

Aerial and Ground-Based Inspections of Mine Sites in the Western U.S.-Implications for On-Site Inspection Overflights, Under the CTBT

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CONTENTS

OVERVIEW

The verification regime of the Comprehensive Test Ban Treaty (CTBT) provides for the possibility of On-Site Inspections (OSI's) to resolve questions concerning suspicious events which may have been clandestine nuclear tests. Overflights by fixed-wing or rotary-wing aircraft, as part of an OSI, are permitted by the Treaty (CTBT Protocol, Part II E, paragraphs 71 to 85). These flights are intended to facilitate the narrowing of the inspection area, from an initial permissible 1000 km^2, and to help select the locations to deploy observers and ground-based sensors (seismic, radionuclides, ...)

Because of the substantial amount of seismicity generated by mining operations worldwide, it is expected that mine sites and mine districts would be prime candidates for OSI's. To gain experience in this context, a number of aerial and ground-based mine site inspections have been performed in the Western U.S. by Lawrence Livermore National Laboratory since 1994 (Figure 1). These inspections are part of a broad range of CTBT mining-related projects conducted by the U.S. Department of Energy and its National Laboratories [1, 2]. The various sites are described next, and inferences are made concerning CTBT OSI's. **All the mines are legitimate operations, with no implication whatsoever of any clandestine tests.**

MINE SITE INSPECTIONS

1. Mine Types

The sites described below represent both underground and surface mining.

- The Henderson mine in Colorado is an underground, block-caving operation in molybdenum ore.
- The Solvay mine in Wyoming is an underground, room-and-pillar operation in trona (an evaporite).
- The Twentymile mine in Colorado is an underground, longwall coal mine.
- The San Manuel mine in Arizona is an open-pit, copper operation.

- The Battle Mountain mine in Nevada is an open-pit, gold mine.
- The Barrick Gold Strike mine in Nevada is also an open-pit operation.
- The Newmont Gold mine in Nevada is an open-pit, as well.
- The Black Thunder mine in Wyoming is a large cast-blasting, open-pit coal mine.

2. The Henderson Mine, CO

The block-caving activities at Henderson have left a very large "glory-hole" which overlies the cave area. It is shown in Figures 2* and 3, as viewed from more than 10 km away. This is a much larger feature than would ever be created by a clandestine nuclear explosion. But block-caving mines can provide very large, open subsurface cavities, under the cave area, which may be considered for decoupling nuclear explosions. If such a mine became a candidate for an OSI it would be advisable to install radionuclide sensors in the cave area. As shown in Figures 2 and 3, this could only be done with transport by helicopters. The helicopters may not even be able to land. The instruments, as well as the operators, may have to be lowered with a harness and winch.

The same problem may arise in the deployment of sensors to monitoring seismic aftershocks. This is precisely what Figure 4 illustrates. The Lawrence Livermore National Laboratory (LLNL) deployed a series of passive seismometers on the flanks of the mountain to listen for caving activity [3]. Deployment was achieved by an arduous climb on foot. Figure 4 shows one of the listening sites. It is not adequate for helicopter landing, although a low-altitude hover could have been considered.

3. The Solvay Mine, WY

On February 3, 1995 a seismic event of magnitude M_L=5.1 originated from this mine site, upon the collapse of a 2 km^2 area of 3-meter high pillars, at a depth of 420 m [4]. An overflight of the site was performed on October 1995. A broad view of the site is given in Figure 5, where the scale is shown by the 2 km^2 hatched area overlying the underground collapse. The figure also shows in the distance the presence of other

* All figures are by the author, unless otherwise noted.

underground trona mining operations. This brings up the fact that the accuracy of seismic event location, particularly when they occur in active mining districts, may have an impact on the OSI process. It is conceivable that the OSI area that is proposed may not encompass the seismic source and may focus on the wrong mine. This prospect will be discussed further in the report.

The aerial inspection was repeated in October 1996. Figures 6 through 11 are from both inspections, at descending altitudes from 1000 m to less than 100 m. The trace of the underground caving is shown in each frame. Nowhere are there cracks on the ground that would be attributed to the subsidence due to the underground collapse, although a surface survey by the mine personnel indicated up to 90 cm of such subsidence. The sedimentary formations overlying the mine horizon were compliant enough not to show surface cracking.

However, from an OSI point of view the event did leave a significant mark. The levee, which dammed the retaining pond, shown in Figures 5 to 9, was broken by its subsidence. The fluids spilled out of the original pond and evaporated, thus leaving the extensive discoloration of the ground which can be seen from the air.

A note of caution is in order: some mine fluids may contain highly toxic materials (arsenic, cyanide, lead, mercury, etc.). It would not be wise to consider an on-foot inspection of a similar pond-spill area without first assessing its potential toxicity*. As shown in the air photographs, there is no practical road access to the spill area. This indicates, again, the potential value of helicopter-borne deployments for the observers and the sensors.

4. The Twentymile Mine, CO

When longwall coal panels are excavated the ground often is allowed to cave back from the moving face, because backfilling of the gob area is not economical and not necessary if surface subsidence is permitted. At Twentymile, LLNL seismically monitored the development of such a panel [5] and the seismic deployment was complemented by aerial observations in October 1995 and October 1996.

* This does not imply, nor is there any indication of, specific toxicity for the Solvay pond.

The results of the 1995 overflights are shown in Figures 12 to 14. Figure 12 gives an overview of the site and of the panel, at a depth of 420 m. By then the face had only progressed to the dashed line and was moving towards the observer. Figures 12 to 14 (1995) represent the baseline observations prior to the passage of the panel. Figures 15 to 17 (1996) show the extensive cliff collapses due to surface subsidence after panel passage. This is due to the fact that the thick-bedded Twentymile sandstone, shown also in Figures 13 and 14, could not accommodate being undermined without unraveling. On the other hand, Figure 18 shows that this particular location with less brittle rock beds did not reveal the passage of the panel under it. Clearly, the massive ground failures shown at Twentymile would provide guidance for narrowing the site of an inspection area.

5. The San Manuel Mine, AZ

That overflight is described in Figures 19 to 22. The peculiarity of this mine is that it combined open-pit and underground caving operations. The block-caving, in fact, undermined a portion of the pit. This can be clearly seen in the left-center portions of Figures 19 and 20, where a jumble of large rock blocks shows the surface effects of the cave. A side view is given in Figure 21.

Once again, access to that part of the site would be extremely hazardous by foot and the only possible deployment of sensors and observers would be by helicopters.

Figure 22 shows the rugged terrain surrounding the open-pit and a network of roads and man-made features. It is conceivable that a sizable underground excavation could have been hidden in the adjacent regions of a comparable open-pit and that the open-pit itself should not be the exclusive focus of attention during an OSI.

Figure 23 shows an examination of another part of the mine site from the ground. This area was a former block-caving zone. It created extensive fracturing of the ground. Large scarps can be seen on the left side, right side, and left foreground of the picture. Access by foot to those scarps appears readily available.

6. The Battle Mountain Mine, NV

A large (over 1000 km^2) area in north-central Nevada is pictured in Figure 24. A single very conspicuous open-pit mine (gold) appears in it and a close-up is given in Figure 25. There are no remarkable or unusual features to this site.

7. The Barrick Gold Strike Mine, NV

Also located in north-central Nevada, this open-pit gold mine is the site of active blasting as illustrated in Figures 26 and 27. The amount of explosive in any shot usually does not exceed 90 tons of ANFO. Such a pit would be an unlikely place for a clandestine nuclear test. However, because of its proximity to the Newmont Gold Quarry, 15 km to the south, an inspection may need to cover both sites.

8. The Newmont Gold Quarry, NV

The open-pit is shown from the air in Figure 28, and from the ground in Figures 29 and 30. Figure 29 shows some blast areas ready for firing and the center of Figure 30 shows an area of ore recently blasted. This mine was also monitored by LLNL [6]. Again, the pit does not seem to offer much opportunity for a clandestine nuclear test.

However, a **hypothetical situation*** is outlined in Figure 31. The figure is very similar, but not identical to Figure 28. It has 2 additional features, denoted by the arrows: they are subsidence craters from nuclear tests, which have been borrowed from a picture of Yucca Flats at the Nevada Test Site (Figure 32), and overlayed on to Figure 27. The wintry scene of Figures 28, 31 and 32 helps to subdue the ground features. Note that the crater in the center of Figure 31 would not necessarily be very conspicuous at the altitude of the picture (~3000 m), as it is near the large pond which is part of regular mining. At a lower altitude the difference may be clear.

These pictures also draw attention to the effect that snow cover may have on the ability of some OSI activities to detect unusual features.

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* This discussion is strictly for illustration purpose. There is no implication whatsoever of illegitimate activities at the Newmont Gold Quarry.

9. The Black Thunder Mine, WY

It is the largest producing coal mine in the U.S. (34 million tons in 1996). Blasts can be up to 3,600 tons of ANFO [1]. The ground pictures of Figures 33 to 35 give a sense of the scale of the operation. It is conceivable that a hole for a clandestine explosion could be buried under a large amount of rock thrown by cast blasting in a similar mine, as in Figure 35. Again, access to that rubble zone may only be practical through heliporting.

Because Black Thunder is in a large, active mining district with several coal mines all firing large shots of ANFO, another issue may appear concerning OSI's: the location of a suspect event may not be easily determined, thus making the selection and reduction in size of an inspection area quite difficult. This point is supported by some of the results of the GSETT-3 experiments, as shown in Figure 36.

Summary of Observations, and OSI Implications

- Legitimate mining generates numerous disturbances of the ground, some of which could equally well be due to clandestine nuclear tests. Overflights are essential to locate these features in a minimum amount of time. Then, additional diagnostics can be deployed to ferret out the illegitimate features.
- Access to areas of desirable deployment may be extremely difficult and very time consuming by foot or ground transportation, thus requiring additional air operations.
- Desirable deployment areas may be contaminated by other than nuclear products, thus making land access very hazardous, and again requiring aerial deployment.
- **All the mines discussed in this paper are legitimate operations which have been described solely for the purpose of illustrating conditions that may be encountered in possible future OSI's conducted in mining districts, worldwide.**

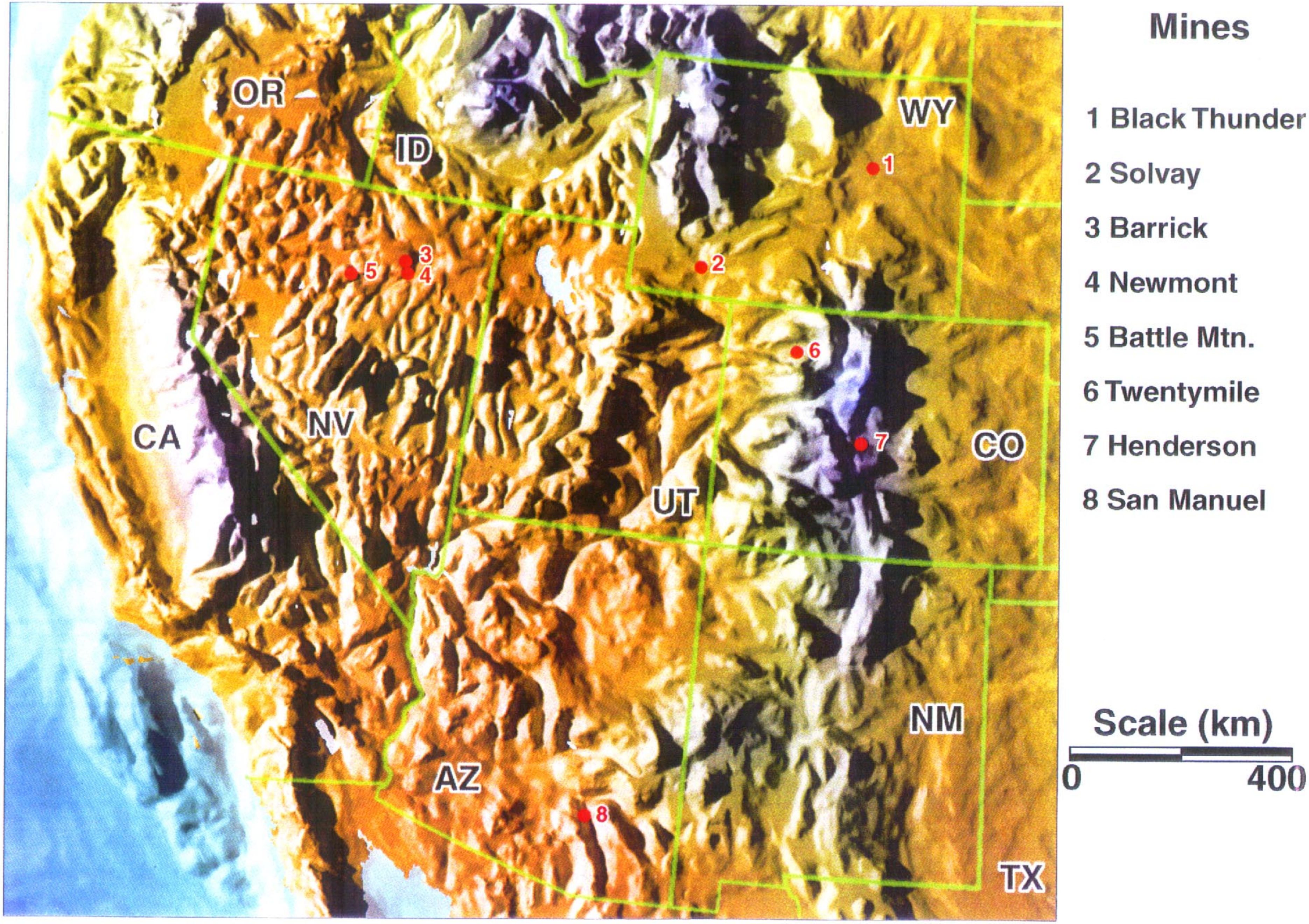

Figure 1: Locations of mines inspected by LLNL, in the Western U.S.

Figure 2: Cave above the Henderson Mine, CO, from 14 km away.

Figure 3: Close-up of cave above the Henderson Mine, CO.

Figure 4: Seismic station deployment at the Henderson Mine, CO. (Courtesy of A. Smith)

Figure 5: Solvay mine site, WY, looking north. Overview, with other mine sites.

Figure 6: The Solvay site looking north, with spillage of pond fluids in the foreground.

Figure 7: The Solvay site, WY, looking south.

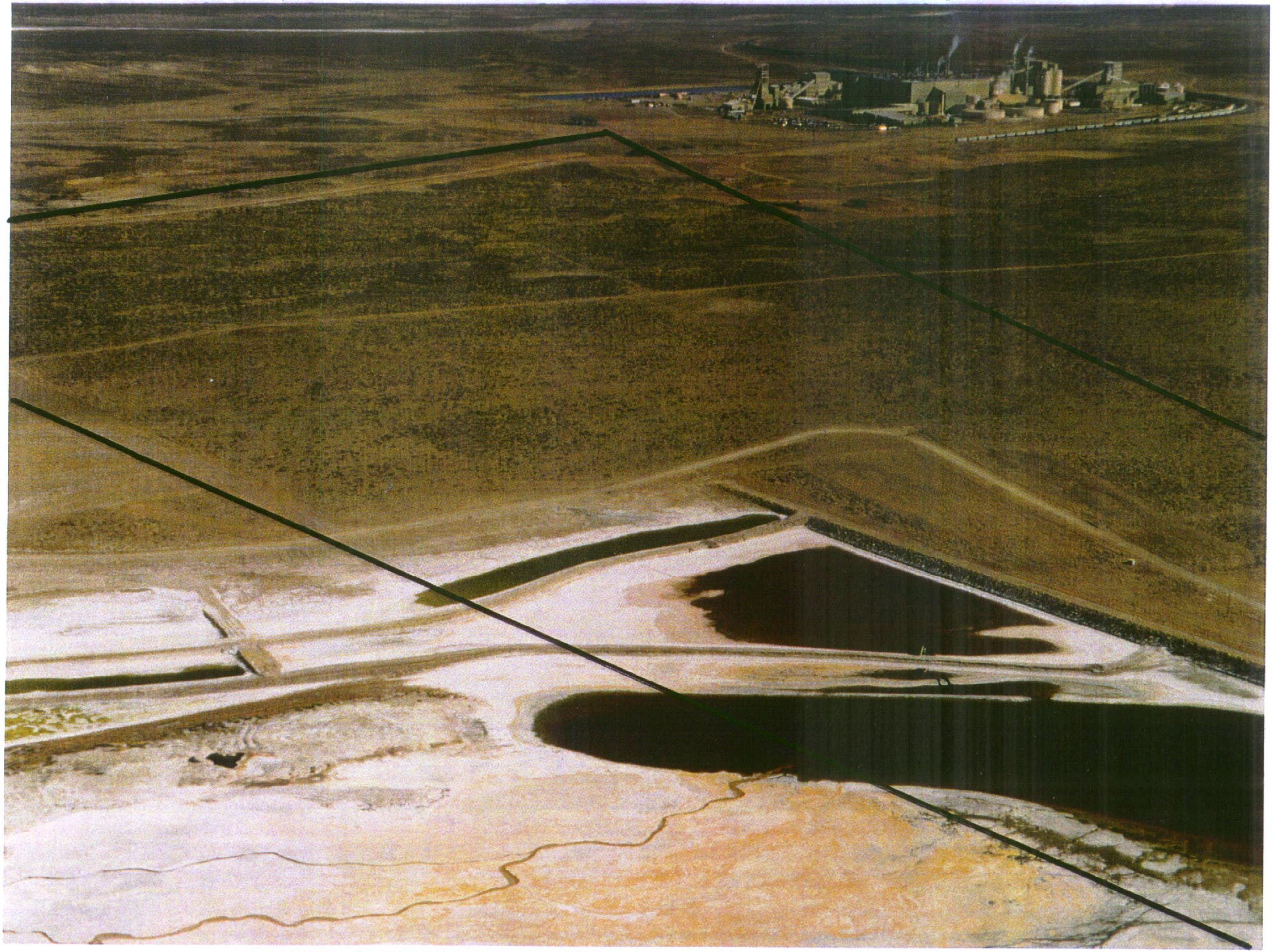

Figure 8: Solvay, WY. Close-up of the pond area, looking north.

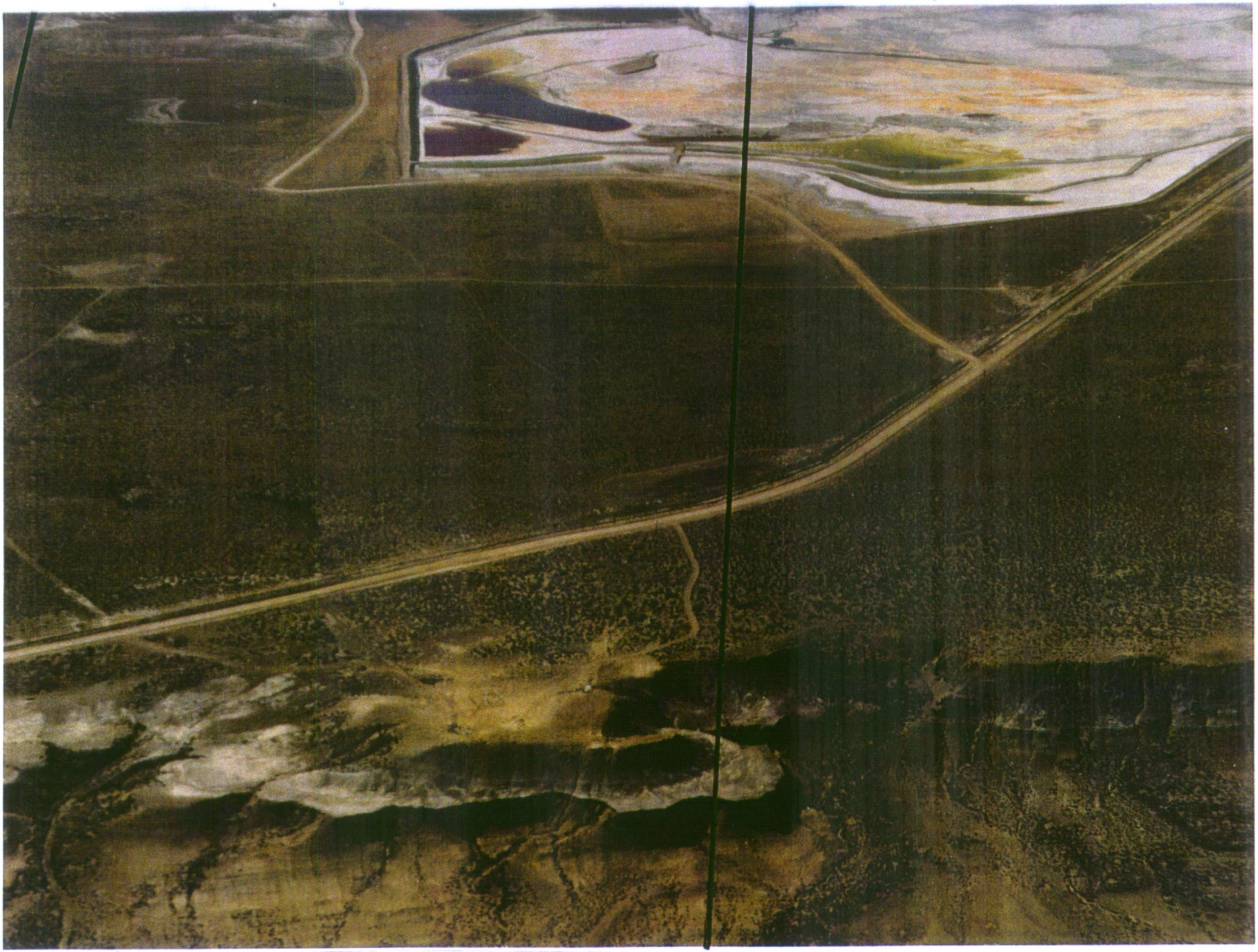

Figure 9: Solvay, WY. Pond and bluff area, looking south.

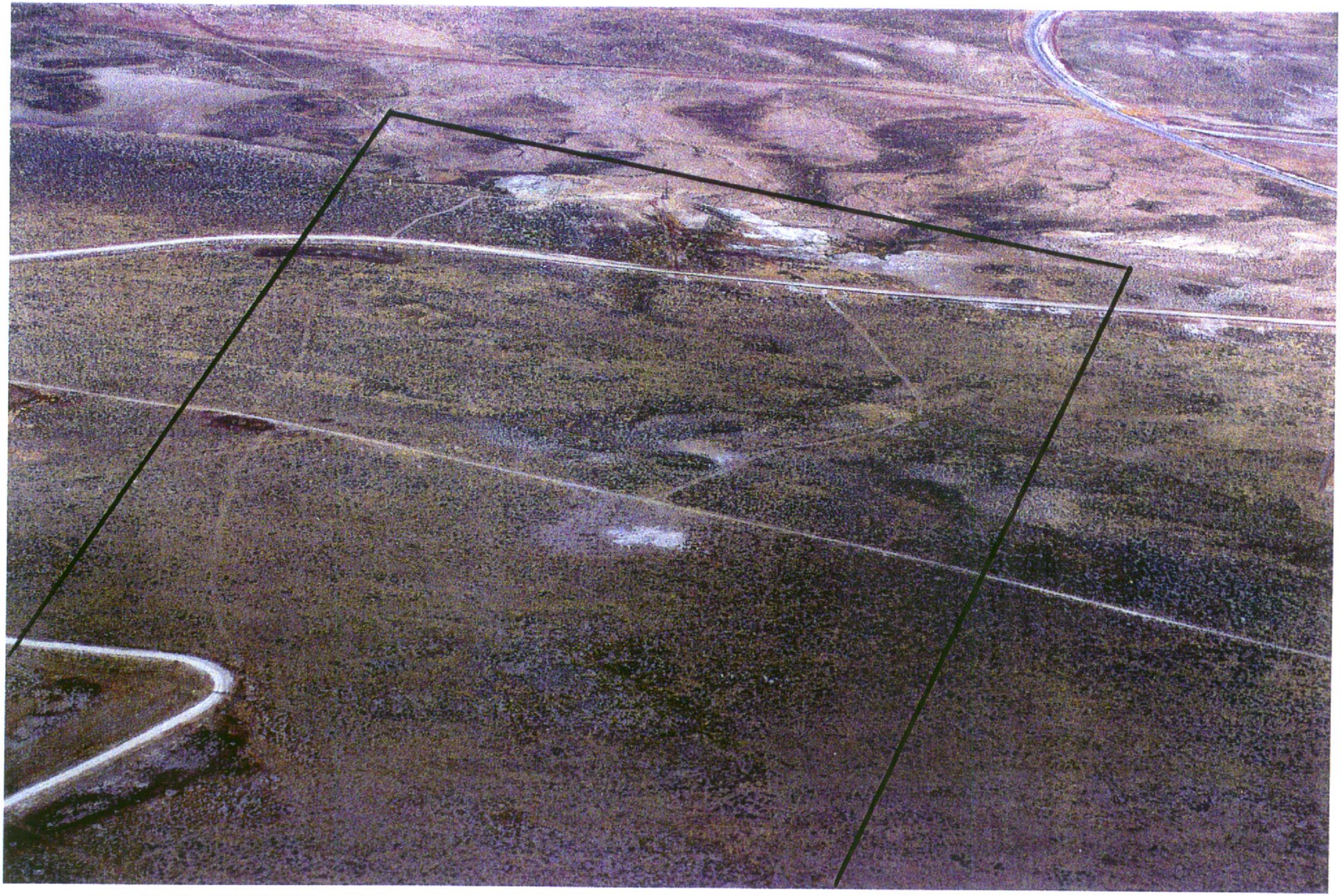

Figure 10: Solvay, WY. Close-up of the surface above the north end of the collapse area. No surface indications.

Figure 11: Solvay, WY. Ground surface between pond and plant. No visible subsidence feature from 300 m high.

Figure 12: Overview of Twentymile Coal mine site, CO, looking west.

Figure 13: Twentymile site, CO. Cliffs of the Twentymile sandstone; no failures, October 1995.

Figure 14: Twentymile site, CO. Twentymile sandstone cliffs close-up; no failure, October 1995.

Figure 15: Twentymile site, CO. Sandstone cliff failures, October 1996, looking northwest.

Figure 16: Twentymile site, CO. Close-up of Twentymile sandstone cliff failures looking northwest.

Figure 17: Twentymile site, CO. Sandstone cliff failures, looking north.

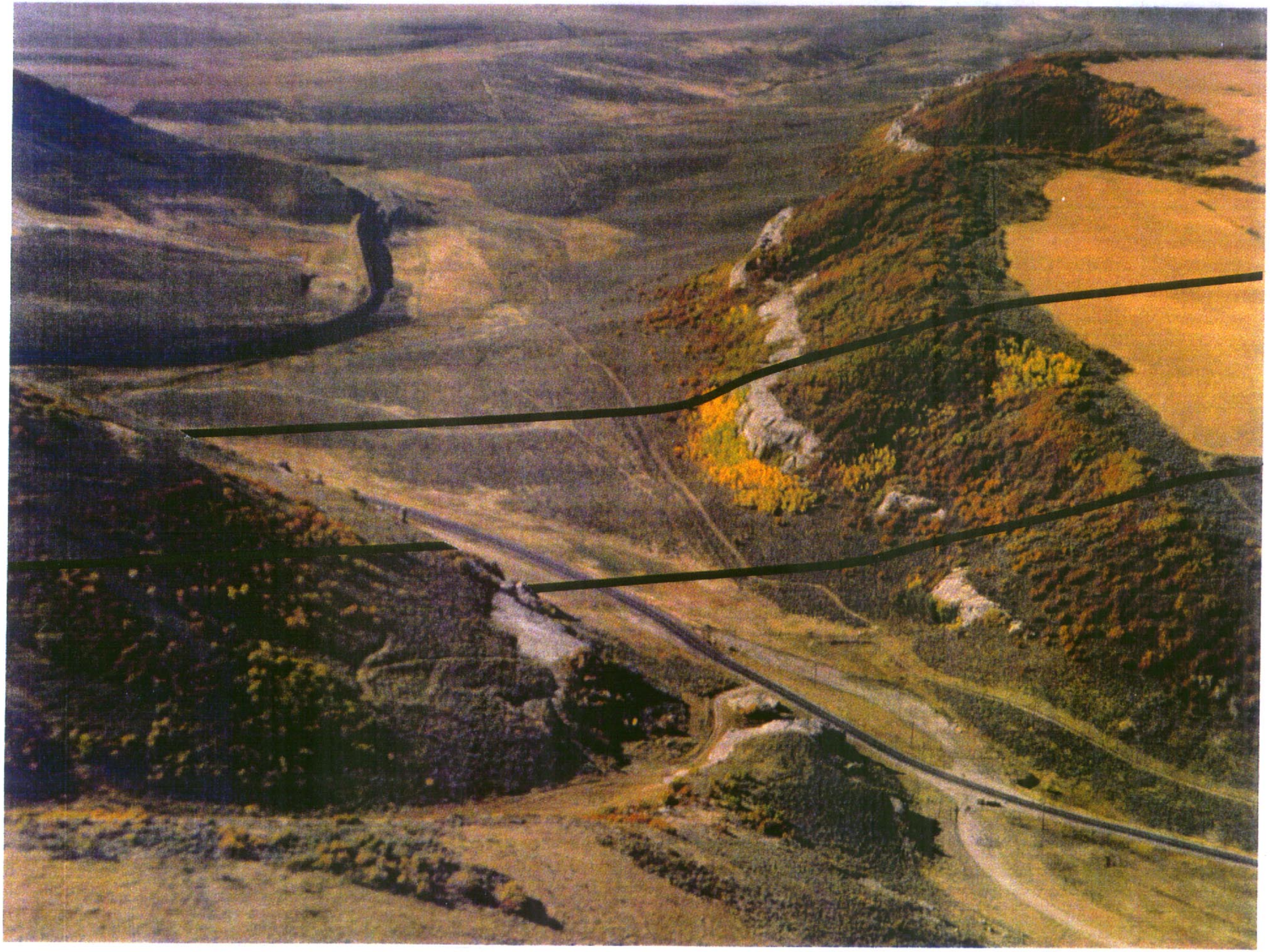

Figure 18: Twentymile site, CO. Ground above west-end of panel, between cliff areas; no failure, October, 1996.

Figure 19: San Manuel copper mine, AZ. Pit overview, looking west.

Figure 20: San Manuel site, AZ. Close-up of pit, with ground broken by undermining, on the left center.

Figure 21: San Manuel site, AZ. Pit, looking north. Note the broken ground in center.

Figure 22: San Manuel site, AZ. East-end of pit area.

Figure 23: San Manuel site, AZ. Note the pronounced ground failures over the large cave area.

Figure 24: Battle Mountain gold mine, NV. Overview, looking west.

Figure 25: Battle Mountain site, looking north.

Figure 26: Barrick Gold Strike mine, NV. Pit, looking south-east.

Figure 27: Barrick Gold Strike mine, NV. Close-up of pit and blasting areas.

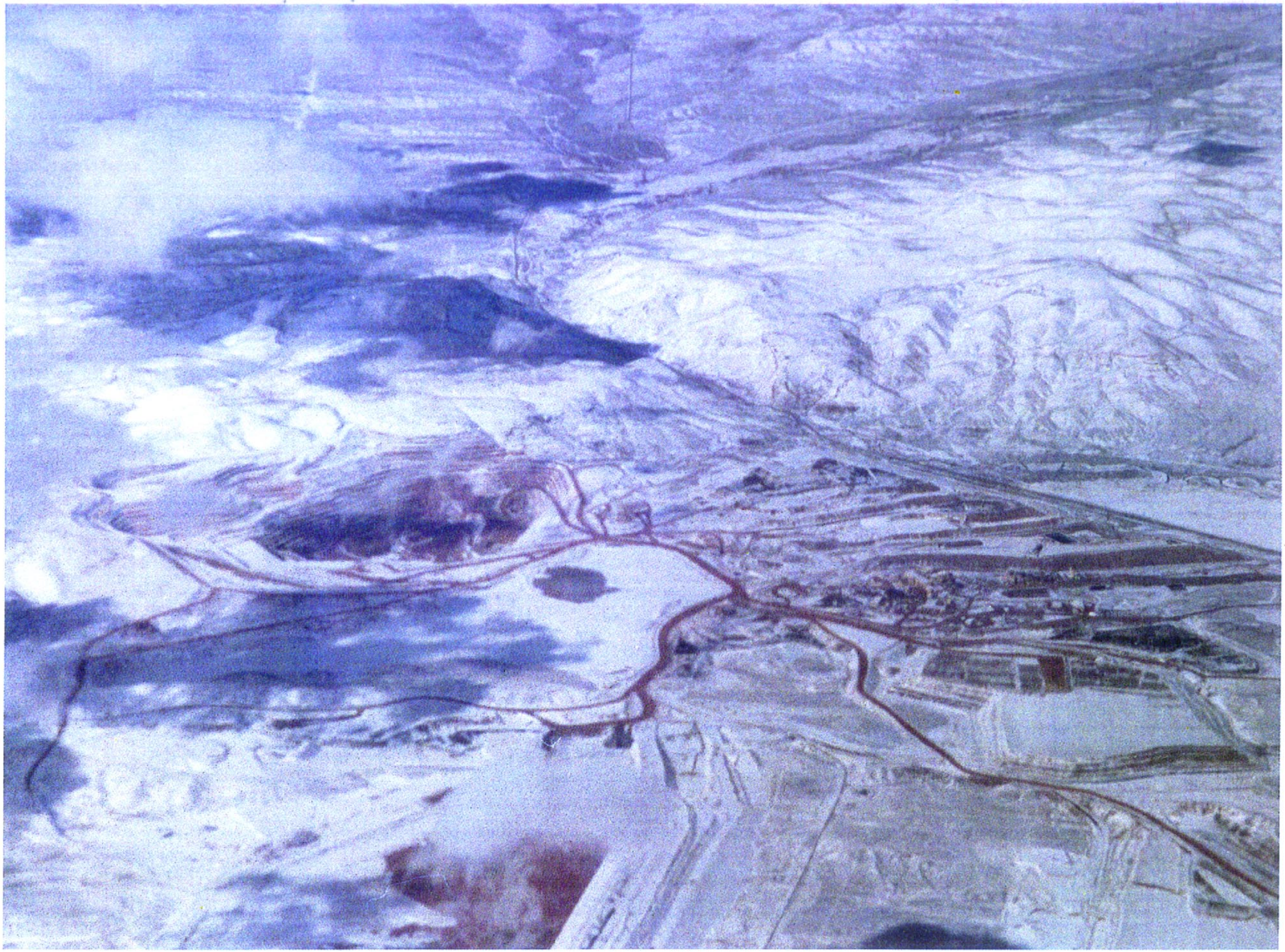

Figure 28: Newmont Gold Quarry, NV. Overview, looking north from 3000 m high.

Figure 29: Newmont Gold site, NV. Open pit, looking south-east.

Figure 30: Newmont Gold site, NV. Open pit, looking south, with blasted rock in center.

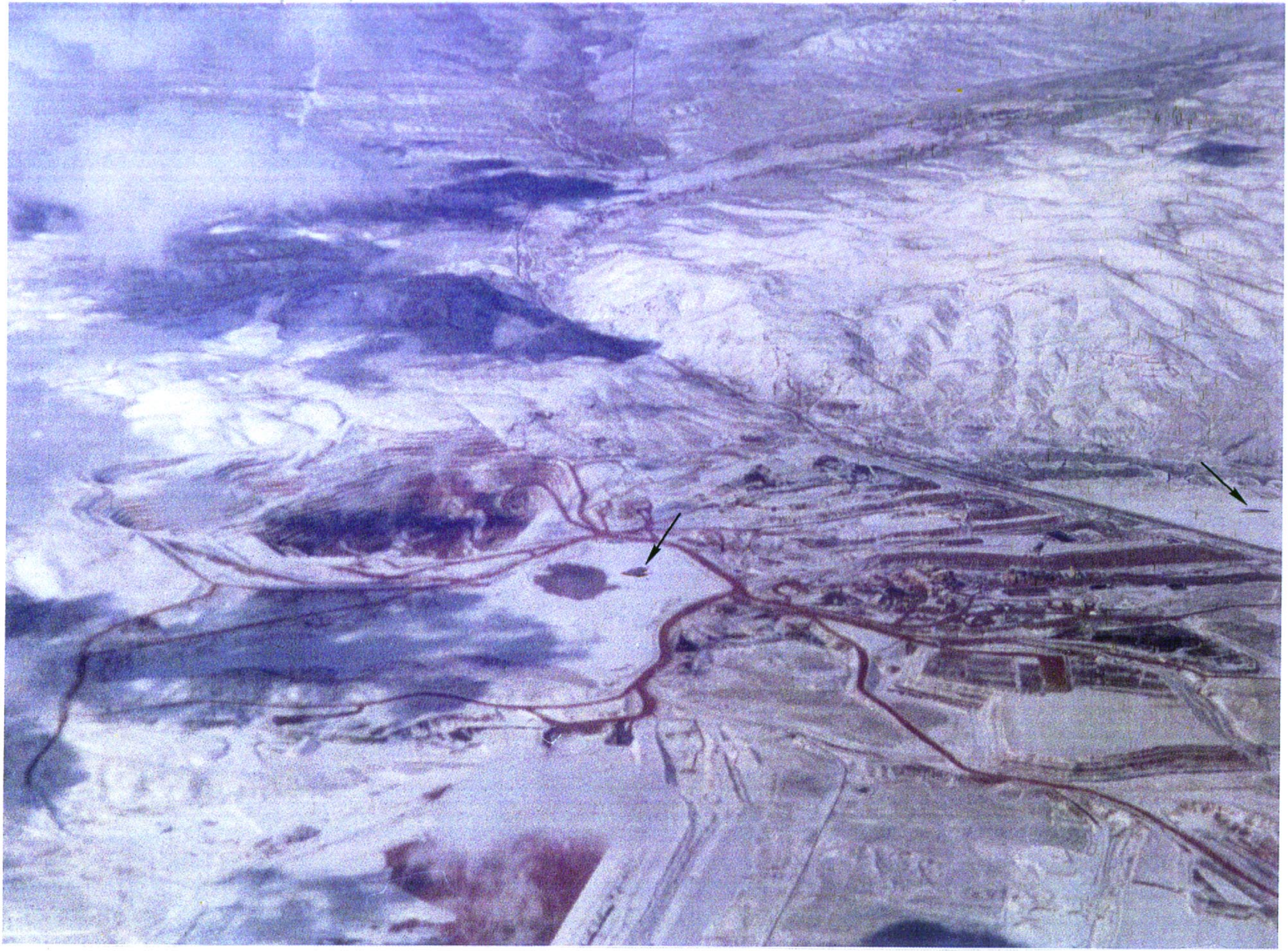

Figure 31: Newmont Gold site, NV, with two crater features added to it (a hypothetical situation).

Figure 32: Yucca Flats, Nevada Test Site. Nuclear subsidence craters.

Figure 33: Black Thunder Coal Mine, WY. Overview of a pit. The overburden rock is 45-m thick, above the coal.

Figure 34: Black Thunder site, WY. 21-m thick coal seam.

Figure 35: Black Thunder site, WY. Ground broken and thrown after a 1,600-ton ANFO cast shot.

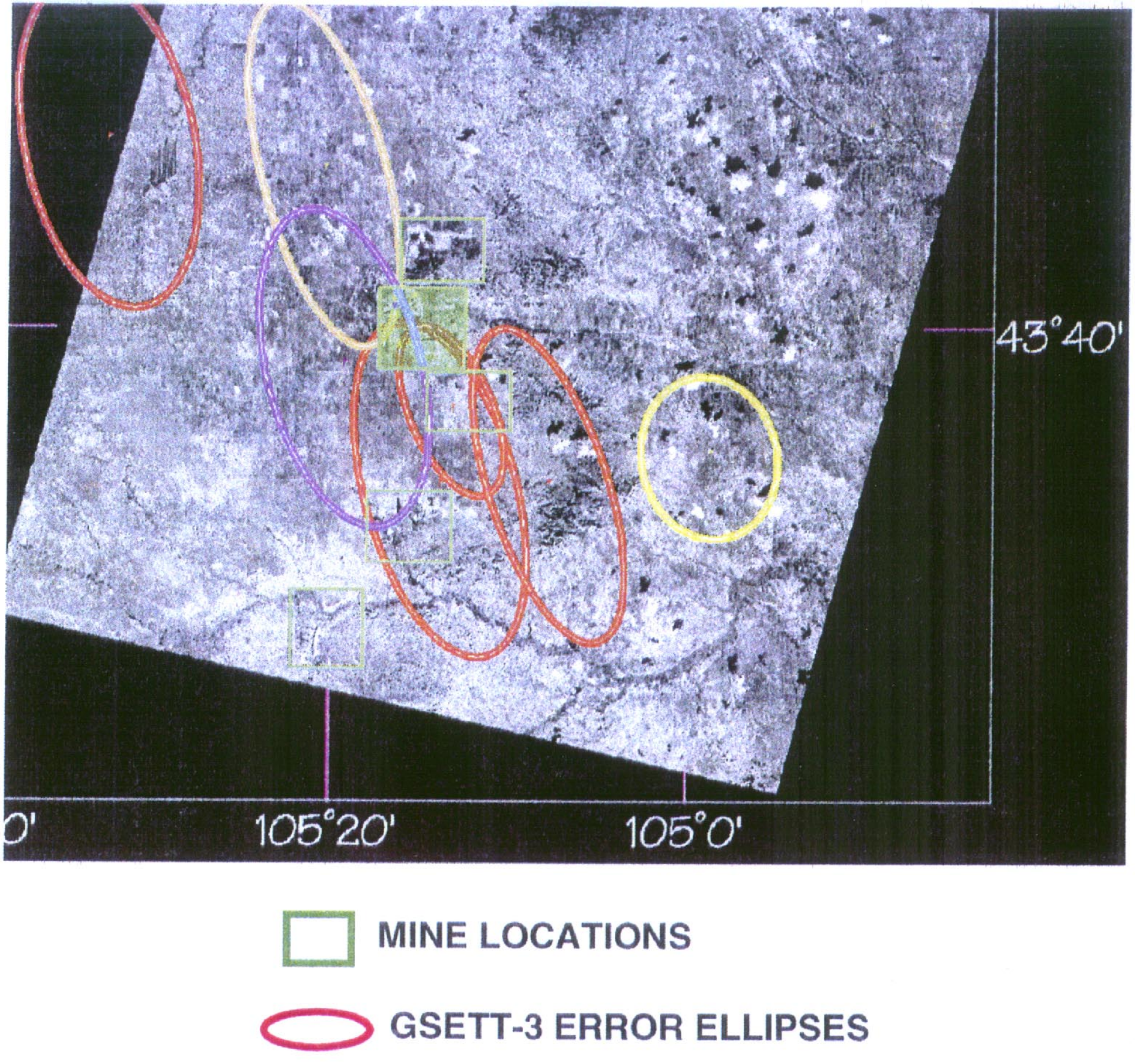

Figure 36: Powder River Basin, WY (after reference 1).

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