

STATUS OF SITES WHERE FIRE CONTROL WORK HAS BEEN ACCOMPLISHED

Federal and state agencies have intermittently attempted control of underground fires at inactive mines in Colorado for approximately 50 years. The United States Bureau of Mines attempted to quell active fires at approximately 22 locations in Colorado from about 1952 through 1974. Their work focused on accomplishing limited drilling to determine the extent of the burning coal. Following determination of the burning area, a cover of non-combustible earthen material was placed on the overlying ground surface. The purposes of the surface seals were to prevent oxygen from being introduced to the fire, and to seal vents to help smother the fire.

Records from 20 surface sealing projects were located. Of the 20 sites where a surface seal or other similar method was employed, eight appear to be dormant, 10 are active and two exhibit very low activity. Table 4, *Status of Sites Where Underground Fire Control Work Has Been Accomplished*, tabulates the sites where abatement work has been attempted.

The main problem that the surface seals appear to have experienced are fracturing and failure as a result of being compromised by surface erosion, or as a result of subsidence. In either case, a breach in the seal provides an opportunity for the fire to breathe, and overcome the smothering effect of the seal. It appears that this method would be most useful at sites with low gradient slopes, little snow or rain fall, the ability to divert surface run-on, and that have limited opportunity for large scale subsidence. Regular inspections and the financial ability to accomplish periodic maintenance are vital components to an effective, long-term surface seal.

Table 4. Status of Sites Where Underground Fire Control Work Has Been Accomplished

County	Mine Name	Agency Attempting Control Project	Control Method Employed	Date Control Completed	Current Fire Status
Delta	Dugger-Rollins	Bureau of Mines	Surface Seal	1952	Dormant
	Minnesota Creek	Bureau of Mines	Surface Seal	1961	Low Activity
	States	Bureau of Mines, Division of Minerals and Geology	Surface Seal; Drilled And Instrumented	1950's, 1997	Active
Fremont	Double Dick	Office of Surface Mining	Surface Seal / Cut-Off Trench	1980's	Active West Of Trench
Garfield	Black Raven	Bureau of Mines	Surface Seal	1972	Dormant
	Harvey Gap	Division of Minerals and Geology	Water, Grout Injection	2003	Active; Subsurface Temperatures Being Monitored
	Haas	Bureau of Mines	Seal Entries; Surface Seal; Remove Coal,	1961	Active
	IHI No. 2	Bureau of Mines	Remove Coal; Backfill	1953	Dormant
	IHI No. 3 (D & H)	Bureau of Mines, Division of Minerals and Geology	Surface Seal; Barrier; Grout Injection	1973, 1995, 1999	Active
	New Castle No. 1	Division of Minerals and Geology	Safety Enclosure Constructed	1990	Active
	New Castle No. 3	Division of Minerals and Geology	Subsidence Feature / Vent Filled	2000	Active
	South Cañon No. 1	Division of Minerals and Geology	Entries Sealed, Safety Enclosure Constructed, Fire Characterization	1990; Ongoing	Active
	South Canyon Refuse Pile Fires (7) *	Division of Minerals and Geology (6), Office of Surface Mining (1)	Excavate And Quench	2002, 2003	Dormant
	W H Canyon	Bureau of Mines	Likely Surface Seal and Other Surface Method	1981	Dormant
Gunnison	Peanut Mine Refuse Pile*	Division of Minerals and Geology	Excavate And Quench	2001	Dormant
Jackson	Riach	Bureau of Mines	Surface Seal	1974	Active
	Rosebud No. 1	Bureau of Mines	Surface Seal	969	Dormant
	Rosebud No. 3	Bureau of Mines	Surface Seal	1963	Dormant
	North Park No. 1	Bureau of Mines	Trench And Barrier	1949	Dormant
Mesa	Farmers Mutual	Bureau of Mines	Surface Seal	1969	Assumed Active
	Garfield	Bureau of Mines, Division of Minerals and Geology	Surface Seal; Safety Enclosure Constructed	1969	Assumed Active
	Go Boy	Adjacent Active Mining Operation, Division of Minerals and Geology	Flooded Twice, Drilled And Instrumented	Presumed Early 1980's, 1985	Assumed Active
Moffat	Streeter / Collom	Bureau of Mines, Division of Minerals and Geology	Surface Seal, Grout Injection	1962 – 1972; 1998	Active
	Wise Hill / Hart	Bureau of Mines, Division of Minerals and Geology	Surface Seal, Seal Entries; Grout Injection, Irrigated	1976; 1997, 2004	Active
Ouray	Slagle	Bureau of Mines	Surface Seal	1954	Active
Routt	Kaspar	Bureau of Mines, Division of Minerals and Geology	Surface Seal; Safety Enclosure Constructed	1972	Active
Rio Blanco	Skull Creek	Bureau of Mines, Division of Minerals and Geology	Cut-Off Trench; Drill, Foam Injection	1951, 2004	Active
	Riley-Wesson	Bureau of Mines	Surface Seal	1954	Dormant

* Abated or extinguished coal refuse fires included here for ease of reference

The Division of Minerals and Geology has accomplished some abatement work at actively burning abandoned coal mines since about 1984. Some of the work has been directed toward preventing human interaction with the surface features of a fire. Exclusion fences have been constructed at some sites, such as South Canyon, New Castle Number 3 and Kaspar. Subsurface investigations of fire activity, surface sealing, mine flooding and grout injection have been attempted at other sites in an effort to control or contain subsurface fire activity. A brief summary of some of these abatement activities follows.

IHI Project

The IHI Project was accomplished at the D & H Coal Mine in Haas Canyon, north of Rifle in Garfield County by the Division of Minerals and Geology. See the Garfield County portion of the Active Fires Section of this report for a description of the site. The IHI Phase I and II Projects, completed in 1995 and 1999, respectively, attempted to control the D & H fire by applying a foaming grout product into the actively burning coal. This was done by drilling holes into the burning materials and injecting the foaming grout into the target zone. One of the properties of the grout is that it entrains air in micro-cells. These thousands of micro-cells act as insulation within the grout, thus cutting off the air supply to the burning material while suppressing heat transfer.

Initially, the Project was thought to have extinguished some portion of the fire, which has a large surface expression area. However, over time it has become apparent that the fire is active on a number of fronts within the burn zone. Likely, the fire was suppressed in some areas, generally the central portion of the burn zone. It is clearly active, exhibiting high surface heat values, at the margins of the affected area. This may indicate a bifurcation of the fire into westerly and southerly components.

Bovine Project

The Bovine Project was begun at Wise Hill/Hart Mine Fire in 2004. The goal of the project was to cool and potentially suffocate the fire. These goals were to be accomplished by providing water to the fire via the fractures located at the ground surface immediately above the fire. A series of small coffer dams were constructed using a dozer over the surface of the mine. Water, obtained from a nearby mining operation, was applied to the ground surface by a system of high volume sprinklers. Water addition continued at a pace so that the coffer dams were able to contain the volume of water applied, allowing the water to seep into the ground via natural percolation and through the fire and mining related fracture systems. The system was terminated for the winter months in the fall of 2004, with plans to resume operations in the spring of 2005.

Axial Project

The Axial Project was accomplished at the Streeter / Collom Coal Mine Fire by the Division of Minerals and Geology. See the Moffat County portion of the Active Fires Section of this report for a description of the site. The purpose of the Axial Project was to define the actively burning area and to then attempt to abate the fire. Drilling into the burning mine was accomplished to define the subsurface burn area, and to provide access for the foaming grout to be placed. The drilling portion of the project appears to have successfully delineated the aerial and vertical extent of the burn zone underground. Post-project reports indicate that the portion of the mine involved in the fire is extensive. The grouting portion of the project, the purpose of which was to isolate and cool portions of the fire, experienced many technical difficulties. This is not uncommon with a difficult technical problem in challenging topographic conditions.

Because the remaining thermocouples no longer function, it is difficult to determine what impact the project had on subsurface conditions. Surface activity, however, indicates that the subsurface fire is still extremely active.

Harvey Gap Project

The goal of this project, completed in the late summer of 2003, was to attempt to suffocate the fire by introducing large quantities of water and fly ash – based grout to the burning portions of the mine. Two burning mines and an intervening unmined, but burning, coal seam were treated during this project.

Water injection began on September 22, 2003, at a rate of approximately 100 gallons per minute, alternating from vent to vent. The pattern of steam indicated that there was no connection between the two coal seams mined, and the outcrop fire.

The amount of cement and fly ash utilized was approximately 95,700 pounds (47.9 tons) and 515,900 pounds (258 tons), respectively. These quantities, when mixed with water, made approximately 450 cubic yards of grout.

Table 5. Vent Temperatures* Measured at Harvey Gap Fire Before During and After Injection

Date Temp. Measured:	Feb.-24-03	May-09-03	Sep.-18-03	Sep.-25-03	Oct.-02-03	Oct.-07-03	Oct.-17-03	Oct.-23-03	Increase	Decrease
Vent Number 4	116	106	94	81	85	85	103	121	5	
Vent Number 5	692	716	715	575	423	325	477	500		-192
Vent Number 7	880	901	904	950	806	599	508	593		-287
Vent Number 9	781	824	811	852	909	737	715	843		-66
Vent Number 10	603	590	583	182	131	180	173	174		-429

* Temperatures in Degrees Fahrenheit

The overall result of the Harvey Gap Coal Mine Fire Project was cooling the fires and surrounding rock, closing the vents to prevent people from falling into or gaining access to, and smothering the fire by reducing the amount of air circulating through the fires.

The table on page 68 shows the effect of treatment at each vent. Immediately after beginning treatment, the temperature rises, only to fall, and then rise again. It appears that the temperatures will stabilize somewhere between 200° and 400° lower than the highest pre-project temperature.

States Mine and Go-Boy Mine Projects

The States Mine, located in Delta County, and the Go-Boy Mine, located in Mesa County, were both drilled and fitted with instrumentation by the Division of Minerals and Geology. This was done at both locations for the purpose of evaluating subsurface fire conditions over time. The timing of the Go – Boy Project coincided with the culmination of fire abatement activities undertaken by an adjacent active coal mining operation. No attempt at abating either of these fires was undertaken at the time of the drilling projects.

South Cañon Mine Fire Project

South Canyon, located about five miles west of Glenwood Springs in Garfield County, is host to one of the largest, and currently most active underground mine fires in Colorado. See the Active Mine Fires, Garfield County portion of this report for a site description. Since about 1992, the Division of Minerals and Geology has been involved in safeguarding the area so that the public does not come into contact with mine openings and the fire zone. Approximately five mine openings have been sealed, and fences have been erected near the County Road to exclude the public from the actively burning area. More recently, drilling has begun for the purpose of defining subsurface conditions in the various mines and intermediate coal rider seams. Drilling was completed on the east side of the canyon in the late spring of 2003, and began on the west side of the canyon in 2004. Initial abatement activities are scheduled to begin in 2006 and may continue for a number of years. These activities will likely include re-opening closed mine entries and some subsidence features and installing air tight seals to minimize oxygen supply to the fire. Other abatement activities are as yet undefined, pending completion of exploratory drilling operations. Likely, abatement would include injection of subsurface fire suppressant materials through drill holes.

South Canyon Coal Refuse Project

Seven historic coal refuse piles caught fire in South Canyon as a result of the Coal Seam Wildfire that occurred in 2002. These fires went largely undetected for a period of four to six months. As a result, some became fairly hot, and one grew to approximately one half acre in size. The others varied from a few hundred square feet to a few tens of square feet in aerial extent.

The Division of Minerals and Geology extinguished six of these fires between 2002 and 2003. The Office of Surface Mining extinguished one in 2003. Each was extinguished in a similar manner. A cut off trench was excavated around the perimeter of the fire to stop its ability to advance into un-burnt refuse. A large hole was excavated adjacent to the burning materials, and filled with water. The burning refuse was swept into the water filled trench using a track excavator. When the material had cooled to approximately 200 degrees, it was removed from the trench, and allowed to air-cool. It was then mixed with non-combustible materials and pushed back to approximate the original topography of the site.

Surface Fire Mitigation Project

The Surface Fire Mitigation Project was accomplished by the Division of Minerals and Geology in the spring and summer of 2003 at five mine fire locations. The original purpose of the project was to eliminate the cover of annual weeds and grasses at the eight sites where the risk of surface fires was evaluated at moderate or greater. Permission to complete the project was denied at three of these locations. As a result, the project was accomplished at the Rienau Number 2, Black Diamond, New Castle Number 3, Harvey Gap and South Cañon Number 1 mine fires.

The project was accomplished by using hand crews to remove the annual weeds and grasses from within a pre-defined perimeter. The cleared materials were generally tacked to the ground surface down hill of the cleared area to act as a natural sediment barrier. Following surface clearing, a pre-emergent herbicide was applied to the site in order to minimize the potential for weed seed germination. Approximately 15 acres were treated during the course of the project.

OUTCROP FIRE EVALUATIONS BY COUNTY

Three significant coal outcrop fires are known to exist in Colorado, one each in Mesa, Montezuma and Moffat counties. Each fire occurs on lands managed by the Federal government. Generally, these fires do not qualify for abatement funding by the annual grant that the State receives from the Office of Surface Mining, as these fires are unrelated to abandoned coal mines. Periodically, the Office of Surface Mining has funds available for the investigation or abatement of these fires; Colorado received one such grant in 2002. A portion of this grant was used to construct a surface seal at the Smokey Mountain Outcrop Fire in 2004. The remaining portion of the grant will be used to excavate the Horse Trap Outcrop Fire. This work is scheduled to begin in 2005.

Table 6. Coal Outcrop Fires By County

County	Outcrop Fire Name	Location	Estimated Surface Acreage Impacted
Montezuma	Horse Trap	37° 14' 53.6" North; 108° 24' 14.3" West	Less than 1 acre
Mesa	Smokey Mountain	39° 21' 02.7" North 108° 42' 21.2" West	15 acres estimated
Moffat	Sand Springs	40° 26' 38.5" North; 107° 47' 12.0" West	Less than 1 acre

Montezuma County

Horse Trap Outcrop Fire; Mesa Verde National Park

During the summer of 2002, the National Park Service discovered an underground coal fire within Mesa Verde National Park, located in Montezuma County, Colorado. In August of 2002, the Park Service contacted the Division of Minerals and Geology and requested that the Division evaluate the fire. The first site visit occurred in September, 2002, with subsequent visits in 2003 and 2004.

The fire is situated in an unnamed tributary drainage east of Morefield Canyon in the northerly portion of the Park. The center of the fire is located at approximately 37° 14' 53.6"; 108° 24' 14.3". The fire is readily accessed by foot from a dirt service road that approaches within approximately 450 feet of the burn zone.

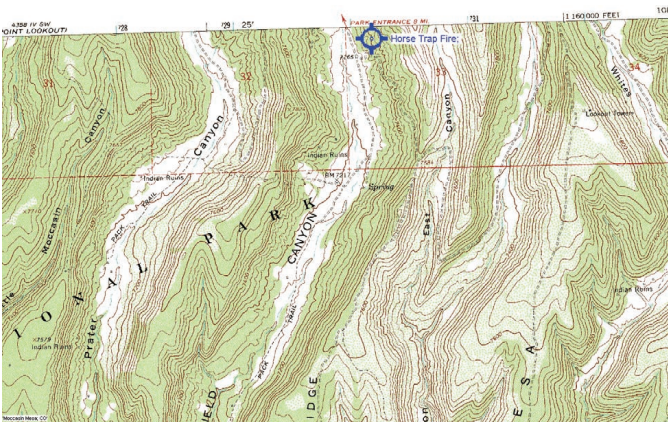
The fire zone is located on the nose of a small intermediate east to west trending ridge situated between two ephemeral drainages. These small drainages are located immediately north and south of the ridge and burn zone.

The surface expression of the fire presents itself as a westerly facing scarp, an interior slump and an overlying fracture zone on the nose of the small ridge. The burn zone trends about north to south, is approximately 50 feet in width at its base, and is approximately six feet in height. An overlying, or uphill, semi-circular fracture pattern characterizes the burn zone. An interior facial surficial slump exists within the burn zone below the uphill fracture pattern. This slump disrupts the interior fractures, and separates the fire into northerly and southerly segments. An approximately two feet tall by 12 feet long backwall of fractured and broken sandstone is present at the northerly portion of the active burn zone. Discontinuous parallel fractures occur within the burn zone. These fractures were observed to act as vents at the most northerly and southerly portions of the area.

Parallel fractures occur within the active burn zone, and are pronounced immediately uphill of the fire activity. Within the burn zone, the fractures culminate in the facial slump and the two feet tall backwall. These appear to be fire related features, venting the underlying fire. A small vent is located at the most northerly portion of the lower fracture zone. This vent was observed to be exhaling steam at the time of the site visit from a fracture in sandstone material. The temperature of the ground surface at the vent was measured at 120°. The vent exhaust was sampled using hand held multi-gas meters. Oxygen content was 19.2 percent, carbon monoxide was 120 parts per million, and hydrogen sulfide was 3 parts per million.



Horse Trap Outcrop Fire. North to left.



Horse Trap Outcrop Fire location. North at top.

A second vent was observed near the southerly margin of the burn zone. This vent appears to be on-strike, but discontinuous from the other interior fractures. The ground temperature at this location was measured at 200°. The vent exhaust at this location contained an oxygen content of 17 percent, carbon monoxide content of 93 parts per million and hydrogen sulfide at 3 parts per million.

Approximately six feet up slope from the active burn zone is located another set of parallel fractures. These upper fractures trend about north 65° west. These appear to be tension fractures, which may have developed as a result of the slump failure, located downhill within the burn zone. These upper fractures are relatively cold, having temperatures matching ambient ground temperatures of about 58° to 60°. Venting from these fractures was not observed.

It is likely that the surficial slump was caused by a lack of structural support after the underlying coal had burned. It is possible that the slump has helped to mitigate fire activity in the center of the area. This may occur as a result of the sloughed material acting as a blanket to seal oxygen-supplying fractures in the central portion of the burn zone.

Site observations and temperature measurements indicate that the fire is most active in the central and southerly areas. Venting and ground temperatures from the northerly area indicate a cooler fire at that location.

Observations indicate that the underground fire is located relatively near surface, and is thus far relatively contained laterally. However, they also indicate that continued burning and subsequent subsidence could easily cause escalated fire activity as oxygen is provided to heated, but not yet combusting, coal materials located behind the active burn front.

Although the extent of the combusting coal was limited in the test hole, it is likely that the fire has burned deeper into the ridge near the central portion of the area. A fire, which has resulted in a more significant loss of coal, would explain the surface slump observed at the central portion of the burn zone.

General Observations:

This is a near surface event that is not supported into the hillside for a great distance. The outcrop involved in the fire is likely limited in thickness.

It is possible that thin shale partings exist within the coal, thus the fire is probably not prone to rapid progression through adjoining coal measures.

This is a low activity fire, exhibiting low surface temperatures.

Due to its proximity to the ground surface, the fire is moderately efficient. No creosote or sulfur mineral deposition was observed on the ground surface.

Exposure to oxygen will likely result in a rapid increase in local fire intensity.

Human health and safety risk is low, as the fire is small, and well away from areas frequented by Park visitors.

Wildfire potential is low, as surrounding vegetation has been subjected to wildfire in the recent past.

Mitigation activities are scheduled to begin in 2005.

MESA COUNTY

Smokey Mountain Outcrop Fire

The Smokey Mountain Outcrop Fire is located north of Loma in Mesa County. The site is situated on lands managed by the U. S. Bureau of Land Management, and has been visited on numerous occasions since January 2001.

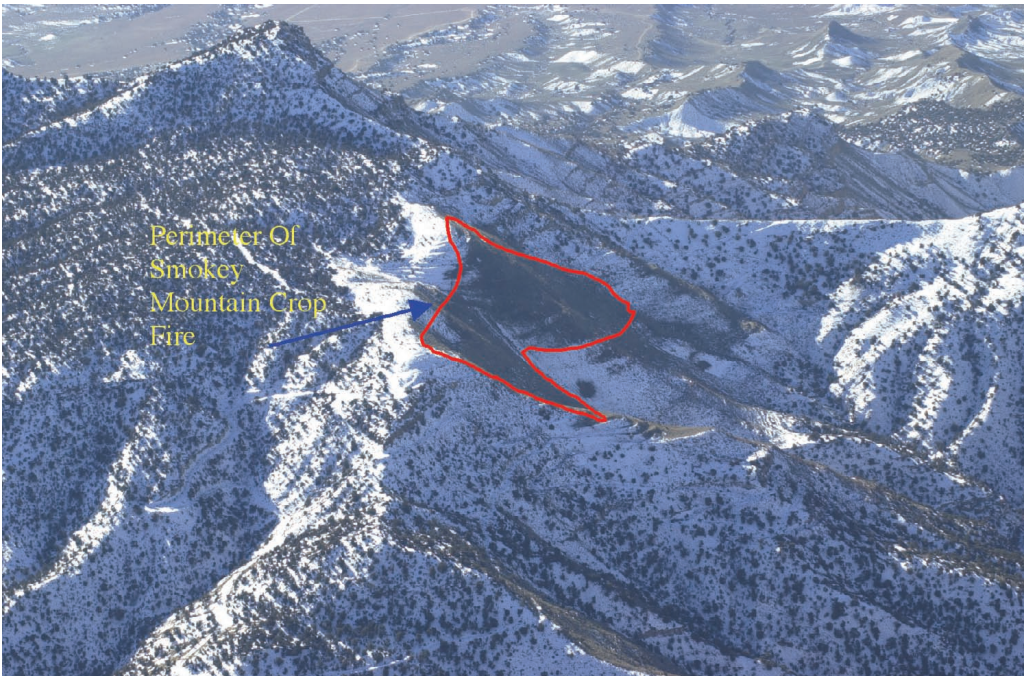
The fire is accessed by driving north from Highway 6 and 50 on 16 Road to Coal Gulch. An approximately one-mile hike or mountain bike ride toward the south from the Coal Gulch Road is required to reach the fire location.

Although there are several coal mines in the vicinity of Smokey Mountain, none appear to be connected to the fire. Anecdotal information indicates that a mine operating to the southeast of the Smokey Mountain fire encountered significant sections of burned coal as the mine advanced in the direction of the Smokey Mountain crop fire. Apparently, the mine had progressed approximately 800 feet underground mining a 22 foot thick coal seam. At this distance, the upper four feet of the seam was reduced to ash as a result of a pre-existing fire event. It is unknown whether the burnt coal is related to the Smokey Mountain crop fire, but there is some potential that the two events are related, given the proximity of the areas. This supports the theory that the Smokey Mountain fire has been burning for an extended period of time, and that it advances in discontinuous fingers as oxygen availability allows.

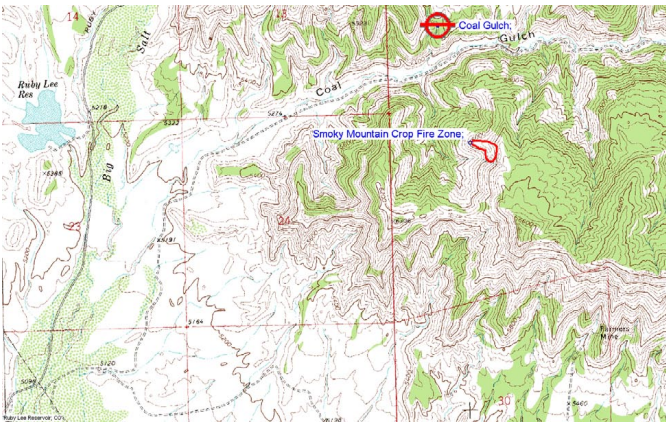
The surface expression of the fire is located in a north / south trending sub-canyon to Coal Gulch. The burn zone exists on a west-facing slope of this canyon from about mid-slope at the northern extent of the fire to near the canyon crest near the southeasterly extent of the fire zone.

The majority of the west facing canyon slope exhibits evidence of the underlying fire, generally due to vegetative changes from the surrounding piñon juniper forest. The canyon slope over the crop fire exhibits vegetative community dominated by annual grasses and weeds and grasses.

The area was subject to fire suppression activities in the 1960's. A surface seal was installed using cut and fill methods. Evidence of this activity includes at least two access road remnants and some benches from which material was generated to cover the fire zone.



Smokey Mountain Outcrop Fire. View toward Southeast.



Smokey Mountain Outcrop Fire location. North at top.

Three areas of venting present themselves at Smokey Mountain. The first is located near the northerly margin of the site, about mid-slope within the canyon. The second is located near the southeast margin of the canyon, higher on the canyon slopes. The third is located further south, at about the same elevation as the central area.

North Area

The active area at the northerly extent of the fire is a series of small circular vents and, more commonly, a series of venting fractures located at about $39^{\circ} 21' 06.2''$; $108^{\circ} 42' 25.0''$. These features are all located in an area that was heavily disturbed by the surface sealing activities. The venting fractures are discontinuous, but can be traced over a distance of about 50 feet. These fractures have an average width of about six inches, and are generally eight to ten feet in length. These features trend north, 75° east. Vent temperatures consistently measure at 225° to 250° over time. These features appear to occur predominately in cut benches

created during construction of the surface seal. A few small vents occur in the fill material immediately south of the larger linear features. The temperature of these vents varied between 95° and 180° . These features appear to have developed in fill material below the cut benches.

None of the vents exhibits any sulfur or creosote deposition. Neither has been observed to emit smoke or steam; however, coal combustion can be smelled on calm days.

Central Area

A single vent located higher on the canyon slope than the northerly area characterizes the central vent area. The vent, which is located at the base of a three-foot thick sandstone sequence, emits a large volume of water vapor. Condensate can be observed to drip from the overlying sandstone. This 125° vent is located at $39^{\circ} 21' 02.7''$; $108^{\circ} 42' 21.2''$.

Southerly Area

The southerly area exhibits a number of vents and venting fractures. These generally exhibit cooler temperatures, and a greater degree of water vapor and combustion by-products than what is observed at the northerly vent area.

The southerly area is located higher on the canyon slopes than either the central or northerly areas. The area is characterized by a series of small vents and a few venting fractures. These are located at approximately $39^{\circ} 20' 56.9''$; $108^{\circ} 42' 22.4''$. An upper (higher elevation) and lower set of vents exists in the immediate vicinity. The vents appear as a series of four, three inch diameter circular vents spread along an approximately 30 feet long alignment. Likely the intervening area between the circular vents is surficial

slough or partial healing of a fracture system. These vents are visible on a north, 15° west trend. The upper vents audibly exhale steam at a remarkable rate. These vents exhibit temperatures that vary from 160° to 210°, with visible steam.

Approximately 200 feet to the south west is an area approximately 75 feet long parallel with contour by 25 feet long perpendicular with contour that exhibits creosote deposition, with temperatures at less than 200°. Numerous small vents, generally one inch in diameter, are found throughout this area.

The Division of Minerals and Geology attempted to repair portions of the Bureau of Mines surface seal in 2004. Earthwork to bolster the seal and provide additional cover material was accomplished.

General Observations:

The northerly vent area appears to be venting from the underlying fire through the perimeter of the surface seal.

The north area appears to be relatively cool, possibly indicating that the fire is burning a great distance from the surface expression, and that the surface seal may be partially successful in reducing oxygen availability.

The central and upper portion of the southerly areas exhale a great volume of steam, perhaps indicating a more active and deeper fire near this location;

The lower part of the central area may be the remnants of a near surface rider seam fire that is either dormant, or inactive at this time.

The public health hazard is rated as low, given the relatively small nature of the vents, and the remoteness of the site. However, a nearby trail experiences some degree of hiker and mountain bike use. These users could be drawn to the area by the steam plume that rises from the central and southerly vents.

The wildfire hazard at this site is low, given the general lack of surface fuels in the area, and the relatively low temperatures of the vents.

MOFFAT COUNTY

Sand Springs Outcrop Fire

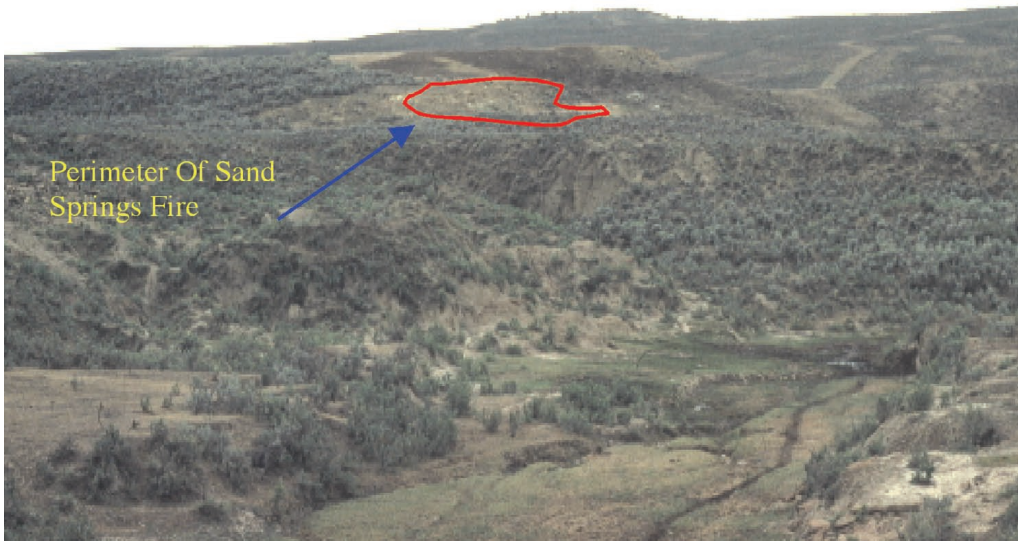
The Bureau of Land Management (BLM) requested that the Division evaluate an underground coal fire located approximately 12 miles southwest of Craig in Moffat County, Colorado. It was reported to the Division that the underground fire sparked a surface vegetation fire, which was suppressed by the BLM fire crew from Craig. The fire crew eliminated surface vegetation in the vicinity of the coal fire by burning an approximately one-acre area surrounding the underground fire.

The site was visited on August 7, 2002. The fire is accessed by traveling west from Craig to County Road 174, then south on County Road 90 to its end. Ranch roads provide access to within one mile of the fire. The fire was accessed by foot for the remaining mile.

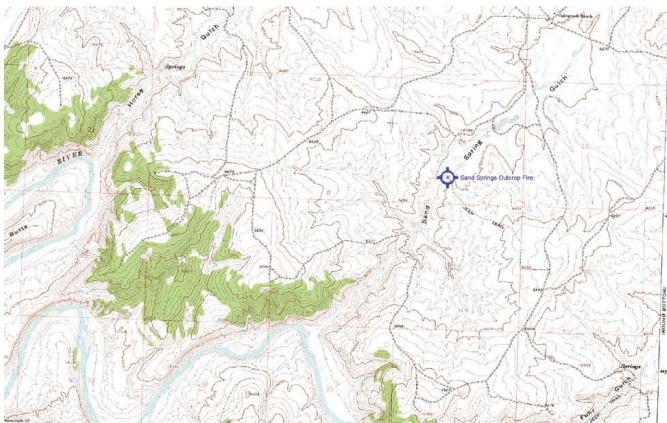
The surface expression of the underground fire occurs on a small north westerly facing ridge immediately east of Sand Springs Gulch. The fire zone is located at 40° 26' 38.5"; 107° 47' 12.0".

The surface expression of the fire zone is approximately 100 feet, north to south, by 75 feet, east to west. The fire zone is characterized by small, discontinuous subsidence fractures formed in a conical pattern uphill of what appears to be a small subsidence depression incised by a gully. These fractures generally trend easterly to westerly. The subsidence feature defines the westerly and most downhill extent of the fire zone. Additional fractures, generally oriented in a northwest to southeast pattern, were observed immediately north of the fire zone in a sandstone outcrop. Parallel jointing in the sandstone, rather than fire related subsidence, appears to be responsible for the fractures observed in this area.

Ground temperatures within fire related fractures were generally in the 1250° range. However, discreet vents within a few of the fractures were measured in the 180° range. These higher temperature vents were generally located further uphill of the subsidence feature. The smell of coal combustion was apparent near the northeast portion of the zone, coinciding with the location of the higher temperature venting. Smoke, steam, sulfur deposition, creosote deposition or thermal alteration of rock were not observed anywhere in the fire zone. Vegetative characteristics above and adjacent to the fire zone were not observed, as a result of the surface fires having removed these materials.



Sand Springs Outcrop Fire. View toward South.



Sand Springs Outcrop Fire Location. North at top.

A two to three foot thick coal outcrop occurs on the south westerly facing portion of the ridge. The coal appears to be of poor quality, is well oxidized, and exhibits low strength. It is assumed that this seam is that which is observed to be on fire, approximately three hundred feet to the north / north west of the outcrop. The outcrop is covered by colluvial debris in all other locations.

There is no indication of past mining activity in the vicinity of the outcrop, within the coal fire zone or on the hidden crop line. No coal or reject pile remnants, structures, open or collapsed entries or old roads or trails were observed in the area. These field observations lead to the conclusion that this is a coal crop fire that is unrelated to mining activities.

The original cause of the crop fire may have been a lightning strike or a surface fire passing over a then-exposed outcrop. It is somewhat difficult to explain how the underground fire may have ignited a vegetative fire, mainly because of the low

surface temperatures observed. It may be possible that the fire sporadically exhibits more active behavior than that which was observed at the time of the field visit. A plausible scenario is that a surface fracture developed, allowing the fire to violently reactivate as a result of oxygen introduction. The reactivation may have produced sufficient heat to cause combustion of overlying vegetation, tumble weeds or other wind blown materials. Because the coal appears to be thin, near surface and of poor quality, the recurrence interval of such an event would probably be infrequent, and the duration of the event would likely be short.

General Observations:

The fire may be characterized as a small, likely near surface event, exhibiting low surface temperatures.

The lack of sulfur minerals and surface rock alteration, as well as the low observed surface temperatures, may be more indicative of coal properties than of fire efficiency.

The fire may periodically become very active, exhibiting surface temperatures capable of igniting nearby vegetation. If this occurs, it is likely a relatively rare event.

Human health and safety risk is low, as the site is very remote, surface temperatures are low and fractures are relatively small.

Wildfire hazard is low, because little vegetation is left on site. When or if the vegetation re-grows, the hazard may be elevated due to periodic increases in fire activity.

CONCLUSIONS

A systematic field investigation of known active and dormant fires at abandoned underground coal mines indicates that a greater number of coal mines are burning in Colorado than had been previously thought. This increase in numbers is a function of the cyclic nature of coal fires, and as a result of the systematic nature of this evaluation. Because fires at abandoned underground coal mines are dependent on available oxygen, and because the volume of available oxygen is variable over time as a result of subsidence activity and other factors, it is likely that in the future fires will develop at other abandoned mines, and that some currently burning mines will become dormant. Given the observations made in 2002 and 2003, it is possible that the Go Boy, Garfield, Farmers Mutual and McElmo fires will be dormant soon. Unfortunately, prediction of which mines will be host to new fire events is not possible. Therefore, continued periodic monitoring of known dormant and active fires is necessary.

It is not unlikely that other active fires exist in Colorado. As additional fires are documented, they will be included in the state inventory, and will be evaluated and monitored.

Comparison of earlier characterizations of individual fires to current conditions illustrates the cyclic nature of mine fire events. Some of the fires evaluated during this project exhibited increased activity compared to the level of activity documented in the mid-1980's. In contrast, others that were moderately active in the mid-1980's were clearly less active when evaluated in 2002 and 2003. The ability of a fire to draw an adequate and substantial supply of oxygen, all external influences aside, appears to be the determining factor in the level of activity experienced at an underground coal mine fire. Proximity of heated coal to an outcrop, the presence of water, and the nature and extent of subsidence phenomenon are likely key components in the ability of a fire to draw oxygen.

Garfield County is host to 13 of the 32 known active fires in Colorado. This striking percentage of coal fires is likely a direct result of the nature of the coal and, more strongly, the method of extraction employed in the Grand Hogback coal seams. Although records indicate that six of the 13 mines involved in Garfield County fires were mined by stope methods, it is thought that the actual number of mines employing this mining technique is greater than reported. This mining method is used exclusively in steeply dipping coal seams, which are generally found in the Grand Hogback coal mining district, which occurs roughly between Rifle and Glenwood Springs. This unique mining method results in a room and pillar-like mine arrangement; however, the rooms extend upwards at angles approaching 55 degrees or greater, as opposed to the typical situation of a nearly

horizontal room. Record keepers who may have depended solely on maps when recording mining methods would be easily confused by the similarities of room and pillar and stope mining maps. The technique employed is an important distinction, as the stope mine creates chimney-like rooms of extracted coal that rise up-dip, toward the ground surface, from the main haulage way. These chimney-like stopes, or rooms, create conditions that are extremely conducive to fire propagation, and probably result in a more active and hotter fire situation. Understanding the mining method and ventilation system are important aspects of developing an abatement technique. Ultimately, the stope mine fires will probably require an abatement technique that is uniquely suited to this environment.

The qualitative evaluation of surface characteristics of an underground coal fire can provide an initial evaluation as to the hazards presented to the public and the environment. These factors are readily apparent as subsidence fractures or pits develop, and as smoke or steam escapes into the atmosphere. However, this qualitative assessment is not a comprehensive evaluation of the level of activity, or more importantly, the actual location of the subsurface fire. An evaluation of the surface expression of the fire is useful in making land use decisions based on actual and perceived threats to the population. These threats include health and safety issues resulting from recreation or other activities occurring over or near a fire, and the potential threat of a wildfire as a result of fire venting. The level of threat as a result of the underlying fire may also drive abatement decisions and techniques.

The qualitative assessment of fire activity at the ground surface at fires where previous abatement work has been accomplished is a good indicator of the success or failure of the abatement technology employed. It is important to note that each fire is unique. Very few fires share similar characteristics; mining methods, oxygen availability, overburden characteristics and topographic differences all play critical roles in the development and intensity of a fire. Therefore, no one technique is transferable to all fires. Because the fires are complex, and are probably more often than not discontinuous as a result of roof fall or subsidence collapse, a comprehensive understanding of the subsurface fire environment is a necessary component when devising an abatement technique.

Sealing of the ground surface over a fire was a favored abatement technology used extensively from the 1950's through the 1970's. This technique is generally the most economic; however, it is highly dependent upon maintenance of the seal, and upon the complete coverage of the ground surface overlying all fire related features to succeed. Failure of the surface seal as a result of a lack of long term maintenance is thought to be the most common reason why many of the surface sealed fires continue to burn.

Of the remainder that are still burning, it appears that the seal did not extend far enough away from the perimeter of the fire body, allowing an oxygen supply to reach the fire. Where the seal was placed extensively enough, and where it was not breached by erosion, the seal served to smother the fire. Fires at eight sites where the Bureau of Mines employed surface seals are now classified as dormant, and two others are nearly dormant.

Other abatement techniques, usually injection of grout or grout impregnated with foaming agents, have succeeded in accomplishing limited abatement in specific areas. Surface evaluation of the Wise Hill and IHI Number 3 fires indicates that the grout injection was successful in either bifurcating the fire, or perhaps to confining the fire to certain areas. It is evident that where these fires continue to burn, they are generally intense, very active and generally fairly efficient. This may indicate that the amount of material injected into the fire was not sufficient, that the placement location was less than optimal, or that the material did not effectively reach all of the intended targets.

RECOMMENDATIONS

As the population of Colorado continues to grow, and as the pressure the public puts on previously little used lands escalates, the likelihood of human interaction with a fire at an abandoned underground coal mine increases. This interaction may well be hazardous to those involved, regardless of whether it is a result of hot, open subsidence features, wildfire or noxious fumes. To help minimize the impacts of abandoned underground coal mine fires to Colorado, the following steps are recommended to take place:

- (1) **Develop quantitative method(s) of evaluating fire activity via surface methods.** A quantitative evaluation of the mine fires would be based on data that can be duplicated and evaluated on a regular basis. This data would likely include obtaining and recording vent gas composition, heat values, photographic documentation and location information at significant vents and other surface features. The evaluation methodology could be developed over an approximately eight to 12 month period by Minerals and Geology, Inactive Mines Program staff.
- (2) **Develop a quantitative method of assessing fire hazards as a mechanism to trigger abatement activities.** Measurable indicators of hazards presented by individual fires could be developed. These indicators would likely include an assessment of subsidence features, vent temperatures and locations, relationship of the fire to adjacent land uses, and proximity of the fire features to vegetation. If indicator values at a particular fire present a hazard rated as moderate or more severe, subsurface evaluation and abatement at an appropriate level would be proposed. Division of Minerals

and Geology Inactive Mines Program staff would develop the assessment methodology over an approximately eight to 12 month period.

- (3) **Evaluate fires on regular basis.** The status of all known active underground coal mine fires should be evaluated on a regular basis. An aerial assessment by Division of Minerals and Geology Inactive Mines Program staff using a hand held infrared imaging tool is a quick, economic and reliable method of evaluating surficial fire conditions. This, coupled with an annual comparison of previous year's data, would be a key mechanism to trigger an-on-the-ground follow up should anomalous data be recorded. Division of Minerals and Geology Inactive Mines Program staff could conduct a field evaluation of actively burning fires once every two years, unless the aerial investigation dictates that a more immediate site visit is warranted. This bi-annual evaluation would encompass use of the fire activity and fire hazard assessment tools developed in recommendations 1 and 2, above.

- (4) **Develop or research methods of mapping subsurface burning areas via remote sensing.** If a reasonably reliable method of mapping subsurface burn fronts based on surface geophysical methods can be developed or adapted, the rate of burn front migration could be used as a tool to make land use and abatement project decisions. Division of Minerals and Geology Inactive Mines Program staff began initial work with this technology in the late spring of 2004. Additional investigations will be proposed for 2006. This work may be followed by drilling to confirm subsurface conditions. If the confirmation drilling indicates that surface geophysical methods are successful in delineating subsurface features of interest, additional investigative work at an active fire would be proposed for the 2007 construction season.

- (5) **Data distribution system to land use planners, land owners and land management agencies.** The distribution of data and information to land owners, land management agencies and city and county officials is a critical step in minimizing the impact of underground coal mine fires to the citizens of the state. A GIS containing pertinent information relevant to active and dormant fires could be created and periodically updated. The development and distribution of a GIS containing pertinent information, updated as new data becomes available, is an effective and graphic method of information distribution. The GIS could be updated annually as a result of the aerial evaluation, or every other year as a result of the field evaluation discussed in recommendation 3, above.

(6) Research and implement cost effective methods of minimizing impacts to the public and environment from underground coal mine fires. The Division of Minerals and Geology should continue to attempt abatement of active underground coal mine fires, as funding is available, and as state and site priorities dictate. Other agencies, organizations, landowners and interested parties should be approached as cost – share partners to offset the tremendous costs of implementing an abatement program. The use of data sets generated as part of site-specific investigations, and the implementation of innovative techniques should be encouraged through abatement and investigation projects. Education, including interaction with specialists throughout the nation, should be encouraged so that new techniques are developed and implemented. These should be on-going activities appropriately funded by the Inactive Mines Program annual grant, and should be incorporated by Division of Minerals and Geology Inactive Mines Program staff into the annual work plan.

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