Information Series 26

Reconnaissance Study of Coal Fires in Inactive Colorado Coal Mines

By
Peter Rushworth
Bruce D. Haefner
Jeffrey L. Hynes
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Colorado Geological Survey
Department of Natural Resources
Denver, Colorado / 1989

Cover drawing: Vulcan Mine Coal Fire,
approximately one and one-half miles southeast of New Castle, Colorado.

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EXECUTIVE SUMMARY

Between 1984 and 1988 the Colorado Geological Survey and Colorado Mined Land Reclamation Division inspected over 50 locations reported as possible coal mine fire sites. Of these, at least 29 were found to be active with most involving abandoned coal mine workings. Several coal-outcrop and refuse-dump fires were inspected and at least some of these sites are burning or smoldering. Other coal fires, both mine and non-mine, may exist. The uncertainty is due to the variation in intensity over time of many fires and the ambient conditions at the time of inspection.

Mine and coal crop fires and coal waste fires can all present serious safety hazards to the public. Coal fires are dangerous due to the instability of the ground surface and the possibility of toxic exhaust gases being trapped in hollows under certain atmospheric conditions. Coal fires may be examined and evaluated with a reasonable degree of safety by persons aware of the risks—the general public should never approach coal fires.

Many fires have burned for decades or more with the coal fire changing in intensity and character from time to time. Most coal fires in Colorado are inefficient and relatively slow burning. A few fires are quite hot. The passage of time may hinder abatement or control measures, or may act to extinguish the fire naturally. One of the most significant problems associated with the passage of time is the human element since coal fires are long-term problems. Many different persons and governmental agencies have been involved in reclamation efforts, and as a result, insight and expertise in the reclamation of coal fires can be lost through budget cuts, retirements and other changes.

This report is intended to compile pertinent information concerning coal fires active in 1988. This information will assist future efforts to study, control or make use of existing coal mine fires. Much data is abstracted from U. S. Bureau of Mines and Office of Surface Mining records.

With respect to characterizing active coal fires, one of the more important features to determine is the location and direction of the fire front. The factors involved in controlling the movement and velocity of the fire front are numerous and complex. So many assumptions have to be made that no reliable prediction of the direction of movement of the fire front can be made. Therefore, no estimates of potential coal losses are presented. Most of the Colorado coal fires are currently in areas already mined out, therefore, the coal resource involved has little or no economic value. Continued monitoring of active and suspected coal fire sites will aid in mapping the progress of potentially wasteful coal fires and in identifying possible public safety hazards.

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INTRODUCTION

This investigation was initiated by the Colorado Mined Land Reclamation Division, Inactive Mine Reclamation Program (CIMRP) to evaluate and summarize mine fire activity, existing or potential resource losses and public safety hazards from active fires. In the course of the investigation, the Colorado Geological Survey reviewed literature pertaining to mine fires and consulted with personnel of the following agencies:

- Colorado Geological Survey (CGS)
- Colorado Division of Mines
- Colorado Mined Land Reclamation Division (CMLRD)
- Office of Surface Mining (OSM)
- U.S. Geological Survey (USGS)
- U.S. Bureau of Mines (USBM)
- Mine Safety Health Administration (MSHA)

In addition, information was sought from the private sector, mining firms, geological, geophysical and remote sensing companies and consultants. Data obtained were incorporated with findings of coal mine fire field observations by CGS and CIMRP staff.

Historically, about 86 coal fires have been reported in Colorado as shown in Table 1. This investigation did not include those coal fires which were successfully extinguished by mine operators allowing mining to resume. In addition, only those mine fires in which the owner has no continuing reclamation responsibility under the Surface Mining Control and Reclamation Act (SMCRA) were evaluated. About 50 suspected coal fire sites were visited, and at least 25 coal mine fires and two coal crop fires are active. Currently, over 100 acres in Colorado are directly affected by active coal fires, showing heating and venting. A larger area, perhaps over 700 acres, is either actively burning, heating, or has at one point in time.

The investigation of coal fires by CIMRP is in its fourth year and is ongoing. This study of coal fires highlighted the changing and episodic nature of coal fire activity. Fires listed as inactive at the outset of the project were later observed to be heating and venting. Conversely, some mines thought to be active showed no current evidence of burning. Some fires abated by any number of techniques still retain a significant mass of sensible heat. Should erosion cut through a seal, or subsidence induce fracturing, allowing air contact with coal, then an "inactive fire" may again become active.

The terms "active" and "inactive" are relative to the point in time and the observations that can be made given the ambient conditions when the coal fire site is inspected. Emphasis was given to fires thought to be active at the start of the CGS project in September 1984. It is possible that some fires listed as inactive in the tables may now be burning or possibly may re-ignite in the future. Continued monitoring of active and inactive coal fires sites is essential to address the abatement potential and public safety effectively.

The original objective of this study was to limit investigations to coal fires initiating in mines. However, it is sometimes difficult to distinguish between mine fires and outcrop fires. For example, historic mines can be correlated with the Burning Mountain No. 2 and No. 3 Mine Coal Fires, but some sources refer to them as outcrop fires (Donner, 1962–1976); and despite the presence of a mine at the Minnesota Creek Mine Coal Fire, the burning coal beds are above and laterally distant from the area of mining activity.

Another type of coal fire considered in the latter part of the study were those originating in mine waste dumps. Although it may be part of a coal mine operation, a burning dump poses less of a threat of spreading unchecked and of threatening vast reserves of coal than a fire involving the mine itself, simply because of its limited areal extent at the surface. But if the dump is in contact with a coal outcrop or an older mine access, it could become an outcrop or mine fire quite easily, as happened at the Farmer's Mutual Mine. In addition, spontaneous combustion may occur in a waste pile generating the noxious odors of sulfur compounds, but without evident fire and significant heat at the surface.

Table 1. Known coal mine, crop and dump fire locations by county.

COUNTY	NAME .	REGION*	LOCATION	TYPE	STATUS
Boulder	Eldorado	DN	NESW, Sec. 21, T1S, R70W	Mine	Inactive
Boulder	Hi-Way	DN	SWSWSW, Sec. 14, T1S, R69W	Mine	Inactive
Boulder	Kitchen Slope	DN	NWNE, Sec. 21, T1S., R.70W.	Mine	Inactive
Boulder	Lewis Nos. 1 and 2	DN	NENENE, Sec. 21, T1S, R70W	Mine	Active
Boulder	Marshall Nos. 3 and 4	DN	NESENW, Sec. 21, T1S, R70W	Mine	Inactive
Delta	Blackburn	UI	SWSE, Sec. 11, T13S, R91W	Mine	Inactive
Delta	Blossom	UI	NWNW, Sec. 13, T13S, R95W	Mine	Inactive
Delta	Burnt Timber	UI	E1/2SW, Sec. 25, T13S, R96W	Mine	Inactive
Delta	Currant Creek	UI	NWSE, Sec. 12, T13S, R94W	Mine	Inactive
Delta	Dry Creek	UI	?, Sec. 6, T13S, R93W	Mine	Inactive
Delta	Dugger-Rollins	UI	SWNW, Sec. 35, T13S, R96W	Mine	Inactive
Delta	Fairview	UI	SWNWNE, Sec. 19, T13S, R96W	Mine	Inactive
Delta	Green Valley	UI	SENWSE, Sec. 12, T13S, R95W	Mine	Inactive
Delta	Independent No. 2	UI	NWNENW, Sec. 13, T13S, R95W	Mine	Inactive
Delta	Minnesota Creek	UI	SWNWNE, Sec. 35, T13S, R91W	Mine	Active
Delta	Red Canyon	UI	S1/2NWSW, Sec. 12, T13S, R95W	Mine	Inactive
Delta	Rowland	UI	?, Sec. 26, T13S, R96W	Mine	Inactive
Delta	States	UI	NWNW, Sec. 18, T13S, R94W	Mine	Active
Elbert	Barker Pit	DN	SWSENW, Sec. 21, T10S, R58W	Mine	Inactive
Fremont	Beacon	CC	SESENE, Sec. 27, T19S,	Mine	Inactive
Fremont	Brookside	CC	SESWNE, Sec. 10, T19S, R70W	Mine	Inactive
Fremont	Double Dick	CC	NWSESE, Sec. 24, T20S, R70W	Mine	Active
Garfield	Black Raven	UI	S1/2NWNW, Sec. 16, T5S, R92W	Mine	Inactive
Garfield	Burning Mtn. No. 1	UI	SWSWNW, Sec. 31, T5S, R90W	Mine	Active
Garfield	Burning Mtn. No. 2	UI	NWNE, Sec. 27, T5S, R91W	Mine	Active
Garfield	Burning Mtn. No. 3	UI	SESE, Sec. 21, T5S, R91W	Mine	Active
Garfield	Coryell	UI	SESWSW, Sec. 32, T5S, R90W	Mine	Active
Garfield	D & H Coal Mine	UI	NENENE, Sec. 17, T5S, R92W	Mine	Active
Garfield	Haas	UI	NWNW, Sec. 16, T5S, R92W	Mine	Inactive
Garfield	Harvey Gap	UI	NWSWNE, Sec. 24, T5S, R92W	Mine	Active
Garfield	Hot Point	UI	W1/2Sec. 10, T8S, R102W	Crop	Inactive
Garfield	IHI No. 1	UI	NWNW, Sec. 16, T5S, R92W	Mine	Inactive
Garfield	IHI No. 2	UI	NWNW, Sec. 16, T5S, R92W	Mine	Inactive
Garfield	Loma & Mack Area	UI	SWSW, Sec. 11, T7S, R104W	Mine	Inactive
Garfield	Mack S. Canyon No. 1	UI	SWSW, Sec. 5, T7S, R103W	Mine	Inactive
Garfield	McDonald	UI	SESE, Sec. 31, T5S, R90W	Mine	Active
Garfield	Pocahontas No. 2	UI	NESE, Sec. 28, T7S, R89W	Mine	Active
Garfield	South Canyon No. 1	UI	NWNW, Sec. 14, T6S, R90W	Mine	Active
Garfield	South Canyon No. 2	UI	NENWSW, Sec. 10, T6S, R90W	Mine	Active
Garfield	Stove Canyon	UI	NWNE, Sec. 13, T8S, R102W	Mine	Inactive
Garfield	Sunlight	UI	SWSWNW, Sec. 16, T7S, R89W	Mine	Inactive
Garfield	Vulcan	UI	SENWNW, Sec. 1, T6S, R91W	Mine	Active
Garfield	W. H. Canyon	UI	NENE, Sec. 17, T5S, R92W	Mine	Inactive
Gunnison	Oliver No. 2	UI	SWSE, Sec. 10, T13S, R90W	Mine	Inactive
Gunnison	Owens Gulch	SJ	Not known	Mine	Inactive
Jackson	Birney	NP	NWSW, Sec. 24, T7N, R81W	Mine	Inactive
Jackson	Moore No. 2	NP	NWSWNW, Sec. 25, T7N, R81W	Mine	Inactive

Table 1. Continued

COUNTY	NAME	REGION*	LOCATION	TYPE	STATUS
Jackson	Moore No. 4	NP	N1/2Sec. 26, T7N, R81W	Mine	Inactive
Jackson	Riach/North Park No. 2	NP	NWSW, Sec. 24, T7N, R81W	Mine	Active
Jackson	Rosebud No. 1	NP	NENE, Sec. 26, T7N, R81W	Mine	Inactive
Jackson	Rosebud No. 3	NP	SENE, Sec. 26, T7N, R81W	Mine	Inactive
La Plata	Hesperus No. 2	SJ	SWSW, Sec. 14, T35N, R11W	Mine	Inactive
La Plata	Mountain	SJ	NWSE, Sec. 5, T34N, R9W	Mine	Inactive
Las Animas	Brodhead	RM	NENWSW, Sec. 16, T30S, R65W	Mine	Inactive
Las Animas	Engleville	RM	SWNWNE, Sec. 29, T33S, R63W	Mine	Inactive
Las Animas	Morley	RM	S1/2SESE, Sec. 36, T34S, R64W	Dump	Active
Las Animas	Royal	RM	SESESW, Sec. 21, T30S, R21W	Mine	Inactive
Las Animas	Stevens	RM	NWSESW, Sec. 25, T33S, R64W	Mine	Inactive
Mesa	Coal Gulch	UI	NWSE, Sec. 18, T8S, R101W	Mine	Inactive
Mesa	Corcoran Point	UI	W/2, SW, Sec. 26, T9S, R100W	Mine	Inactive
Mesa	Farmers Mutual	UI	SESW, Sec. 36, T9S, R100W	Mine	Active
Mesa	Fruita No. 1	UI	?, Sec. 29, T8S, R100W	Mine	Inactive
Mesa	Garfield	UI	SESE Sec. 6, T11S, R98W	Mine	Active
Mesa	Go Boy	UI	SESWNE, Sec. 2, T11S, R98W	Mine	Active
Mesa	Palisade	UI	N1/2SE, Sec. 4, T11S, R98W	Mine	Inactive
Mesa	Smoky Mountain	UI	E1/2NW, Sec. 19, T8S, R101W	Crop	Active
Moffat	Axial	UI	SWNWNE, Sec. 2, T3N, R93W	Mine	Active
Moffat	Wisconsin Mine	UI	NWSE, Sec. 31, T7N, R93W	Mine	Inactive
Moffat	Wise Hill No. 3	GR	W1/2W1/2, Sec. 31, T6N, R91W	Mine	Active
Montezuma	McElmo	SJ	SWNWNE, Sec. 35, T36N, R16W	Mine	Active
Montezuma	Ute Pasture	SJ	Unsurveyed, Sec. 1, T32N, R16W	Crop	Active
Montrose	Onion Lake	SJ	NWSW, Sec. 3, T47N, R7W	Crop	Unknown
Ouray	Lou Creek	SJ	SENENE, Sec. 22, T46N, R7W	Mine	Unknown
Ouray	Slagle	SJ	E1/2NW, Sec. 5, T46N, R7W	Mine	Inactive
Rio Blanco	Black Diamond	UI	SENW, Sec. 15, T1N, R94W	Mine	Active
Rio Blanco	Colthart	UI	S1/2NW, Sec. 13, T1N, R102W	Mine	Inactive
Rio Blanco	Rienau	UI	NWNWSE, Sec. 29, T2N, R93W	Mine	Active
Rio Blanco	Riley & Wesson	UI	SWSE, Sec. 19, T2N, R92W	Mine	Inactive
Rio Blanco	Skull Creek	UI	E1/2E1/2, Sec. 35, T3N, R102W	Crop	Active
Rio Blanco	White River No. 1	UI	NESW, Sec. 11, T2N, R101W	Mine	Inactive
Rio Blanco	White River No. 2	UI	NESW, Sec. 11, T2N, R101W	Mine	Inactive
Routt	Arrowhead	GR	SENW, Sec. 8, T4N, R85W	Mine	Inactive
Routt	Kaspar	GR	N1/2N1/2, Sec. 11, T4N, R87W	Mine	Active
Routt	Ramsey	GR	SWNE, Sec. 4, T5N, R88W	Mine	Inactive
Routt	Slater	GR	S1/2SW, Sec. 17, T12N, R88W	Mine	Inactive

***Colorado Coal Regions and Fields:** **CC—Canon City Field**
DN—Denver Region
GR—Green River Region
NP—North Park Field
RM—Raton Mesa Region
SJ—San Juan River Region
UI—Uinta Region

COAL FIRES: Characteristics, Dynamics and Investigation

IGNITION

The ignition temperature of coal ranges from about 790° F to 900° F. A fire may start at lower ambient temperatures if the conditions allowing spontaneous combustion are present. According to Kim (1977), the rate of air flow, change in moisture content and rank of coal are the main controlling factors in spontaneous combustion. Colorado coals of subbituminous and high-volatile bituminous rank are prone to self-ignition when broken.

Spontaneous combustion may initiate at 176° F to 200° F. Dryden (1963) lists the activation energy of this first of three stages of spontaneous combustion at three to four kcal/mole. Several mechanisms may induce this reaction at low temperature including thermophilic bacteria contained in the coal. The second stage of spontaneous combustion is in the range of 176° F to 320° F where the activation energy ranges from six to eight kcal/mole. Between 250° F to 285° F occluded oxygen combines with coal hydrocarbons to form carbon and water which escalates temperature. The final stage of spontaneous combustion brings the temperature of the coal to the range of 355° F to 555° F with an activation energy of 12 to 17 kcal/mole.

The rapid and highly exothermic nature of spontaneous combustion may bring the temperature of the coal up to ignition. Broken or friable coal exposing greater surface area, and entrained sulfur both contribute to the spontaneous combustion reaction.

PROPAGATION

The propagation of coal fires is determined by the complex relationship of, at minimum, the following factors:

- Coal thickness
- Competence of overburden
- Structural geology/fracture system
- Weathering
- Hydrogeology
- Mine geometry
- Diffusivity and conductivity of overburden

Coal fires propagate toward any source of oxygen. A low pressure zone generated at an advancing fire front draws air from available sources. In a mine this could be existing or partially collapsed entries, or through gob.As the fire progresses, self-induced fracturing of the overburden also contributes to the flow of oxygen.

Coal fires are contained in working mines with the installation of stoppings and seals to deprive the fire of oxygen. The mine workings usually allow access around the fire and its intensity may be judged firsthand.

Fires spreading beyond mine workings and proceeding out-of-control into virgin coal operate under more complex conditions. Colorado coal fires propagate in the following manner (modified from Shellenberger and Donner, 1979):

Stage 1. Fire rapidly developing vents and/or moving air with obvious rushing sound.

Stage 2. Coal fire creates an extensive fissure system. Fire may be working under deep cover or may be straining to draw air through distant cracks.

Stage 3. Fire may appear dormant. Venting is limited to small, discrete locations. Fire obtains oxygen with difficulty or fire has nearly spent available fuel.

Stage 4. Fire out and unlikely to re-ignite. Ground is cooled below ignition temperature or coal is spent.

Coal fires move in virgin coal to the extent that oxygen is available. Fissures form and allow ventilation relative to the strength and competence of the overburden. In general, fissures are located behind the working fire, and active vents are usually within 50 feet of the fire front (Herring, personal communication, 1984). Venting may be related to geology such as localized vents along a sandstone bed or chimneys forming at the intersection of a joint set. The characteristics of several fire stages might be displayed at different places within the same coal fire area.

The high temperature of coal fires and accompanying alteration of minerals was used by Coates (1980) to measure the velocity of the fire front. Through radiometric dating of altered zircons in clinker in the Powder River Basin the rate of movement was found to be about three feet per century. Fire cells define the fire front, and younger clinker showed a lower density of cells than older clinker.

MINING AND COAL FIRES

The historical development of coal in the United States, and in Colorado, promoted coal mine fires and their spread. In Colorado, for example, historic coal output was almost equally divided between a relative few large mines and a great number of small mines (Rushworth, 1984). The small mines met local demand for residential and commercial purposes. In most such mines production was intermittent, at best, with significant time intervals between production cycles. Questionable operating practices and poor handling of coal contributed to starting of coal fires and to an inability to extinguish them promptly. Some factors commonly involved in ignition and propagation of coal mine fires are as follows:

- Warming fires underground
- Storage of coal underground
- Extended periods of inactivity allowing spontaneous combustion
- Undermining old workings
- Improper sealing of shafts, raises and tunnels
- Working in a burning coal seam

Ventilation

Most early coal extraction was punch mining. In punch mining the development proceeds a relatively short distance in from the crop to win coal with minimal capital investment. One major constraint on early coal mining was ventilation. The unaided flow of air generally did not provide sufficient ventilation more than a few hundred feet from the portal.

Before the widespread application of fans improved ventilation was obtained usually by ventilation shafts. Openings to air at different levels allowed natural draft to circulate air in workings. Extensive mines using fans may also require ventilation shafts or raises for improved air flow. The necessity of numerous openings for ventilation of active workings bears directly on the difficulty of controlling coal fires in old, inactive coal mines in Colorado.

Raises and Rock Tunnels

Raises in coal represent an opportunity to mine coal with little additional effort. Raises were employed extensively in the steeply dipping coals along the Grand Hogback. Usually raises were driven up to 100 feet on 40 to 60 foot centers. As in the case of shafts, raises weaken the continuity of the rock structure and may be sites of subsidence before and after a coal fire. Raises in coal probably tend to act as chimneys lined with coal and contribute to propagation along the outcrop and feed oxygen to the main coal body.

Rock tunnels were frequently driven from one seam to another. This technique was especially favorable in the steeply-dipping coals of the Grand Hogback Coal Field. When the practical limit of a main drivage and raises was reached a short rock tunnel to a stratigraphically higher or lower seam could continue operations without adverse ground control problems. In addition, the expense of opening a new portal was eliminated. However, a fire in either seam could communicate to the other. Interseam access provides new fuel to a coal fire and gives a fire the opportunity to propagate along a coal seam other than the seam in which the fire originates.

COAL FIRE MINERALOGY AND ROCK ALTERATION

Coal fires generate sufficient heat to alter the preexisting suite of minerals in a manner analogous to metamorphism. Craig and others (1982) use the term pyrometamorphism to describe the effects of an underground coal gasification experiment on post-burn overburden. The term paralava refers to clinker and rocks exhibiting partial mobility and melting. Pseudolava refers to scoria and slag, and buchites are rocks exhibiting a mineralogic suite most often associated with high-temperature metamorphism. In most cases, however, buchites retain the original sedimentary structures.

The absence of oxidized minerals such as hematite and the presence of magnetite, for example, indicates a reducing environment. According to Craig and others (1982), the gas mixture formed through coal gasification, or intense coal fires, contains several reducing species requiring low partial pressures of oxygen. The red to brick red colors of clinker are not found in underground coal gasification experiments. Gray to greenish gray colored buchites found at coal fires may indicate that their condition of formation was highly reducing and high temperature, low pressure.

FIELD INVESTIGATION PROCEDURE

In the field investigation of sites safety was given highest priority as two-man teams operating under the "buddy system" would inspect a site before traversing a coal fire. If the fire appeared to compromise ground support or a slope was observed to be prone to slides, no traverse was made. Traverses across abandoned mine properties first investigated any active vents, altered rocks, changes in rock color, areas of vegetation kill and unusual or different vegetation growth. Cracks, pits, shafts and adits were also approached and examined for signs of heating or venting.

Temperature readings were taken of vents to characterize the latent heat of the coal fire and assist in correlating fire activity with the water content and odors associated with various temperature regimes. Drilling for the purpose of installing thermocouple wires to monitor the progress of the coal fire was undertaken at the Wise Hill No. 3 and Go Boy Mine Coal Fires. The drillholes were drilled with a four inch bit to depths ranging between 25 and 91 feet, and calculated to bottom at ten feet above the top of the coal. ChromAl thermocouple wire with Teflon coating that can sustain temperatures of up to 700°F was used to monitor coal fire activity. The direct-reading device used was a Doric 450A-ET digital thermometer costing about $300.

Coal fire investigations originate with research into historical accounts of coal mine fires, maps of inactive coal mines and investigation of personal and historical accounts of coal fires. In cold weather the most striking indication of coal fire activity is ground heating, snow melt, steaming or venting. In addition, many coal fires reveal their existence by supporting lush moss growth which contrasts with native vegetation, especially in winter.

On cold days vents are quite obvious when the background color of the soil or vegetation is dark, or when the plume is seen against a blue sky. The angle of the sun relative to vent and observer can greatly affect the prominence of a plume of steam condensate or smoke. Also, on cold days, steam may condense on nearby vegetation forming a distinctive rim of ice-encrusted grass or weeds downwind of vents. In warmer weather rock discoloration, vegetative kill or the noxious odors of incomplete coal combustion are the primary indicators of fire activity.

Rock discoloration was noted at almost every site. The discoloration due to fire ranges from a bleached white to a muted orange-red depending upon the mineralogy of the rock in a pre-burn state. Within the Cretaceous coal sequence in which all fires, except the Riach Mine Coal Fire in the North Park Coal Field, are located, efflorescence and color change was observed associated with venting at both efficient and inefficient coal fires. Most mineralization occurs as an efflorescence around the mouth of a vent. Zonation of the efflorescent minerals is not typical, but was observed at the Riach Mine Coal Fire and at new, high temperature vents, such as at the D & H Mine Coal Fire near Rifle.

In areas where neither rock discoloration nor ground heating are useful signals of coal fire activity then the characteristic odor of coal fires may be useful. The gaseous emanations of most coal fires are distinctive, repugnant and unforgettable. In general, the lowest temperature fires, 110° F to 140° F produce the most bothersome odors. Coal fires with higher temperatures produce less noxious odors, but may produce higher volumes of toxic gases, such as carbon monoxide.

Nearly all fires carry the pervasive, unpleasant odor of coal distillates. By-products such as creosote and mercaptan may contribute to the noxious smell (Herring, 1980). Since hollows and depressions protected from the wind could trap and concentrate effluent gases, which may include carbon monoxide and hydrogen sulfide, these areas were avoided during the inspection of suspected coal fires.

Venting is an obvious indicator of fire activity. At least two types of plumes are recognized—smoky plumes and steam condensate plumes. Smoky plumes emanate from fires burning inefficiently and releasing particulates from incomplete combustion. Low temperature vents, those less than 140°F, were observed to exhibit three main traits. Most venting less than 90°F consists of low velocity air absent of odor. However, venting is more complex above approximately 90°F. Some vents yield an odor high in petroleum distillates. Smoky vents contain significant particles and often are accompanied by sulfur compounds deposited along vent orifices.

Smoky plumes tend to waft and wane and not project a significant distance out of the crevice or vent opening. The orifice surrounding a smoky plume is often stained black, probably with soot or carbon black, and the vent appears moist and is usually warm to hot. The black staining is apparently an ephemeral feature, since it may erode away from the vent or be scraped off with an instrument. It is possible that old smoky plumes could be located by the field inspection. Most smoky plumes showed a temperature of 90°F to 140°F.

Steam condensate plumes emanate from efficient and hot-burning coal fires. Under the high temperature regime of an efficient fire, rapidly moving plumes jet from vents. In the visible light spectrum these plumes are nearly invisible unless the ambient temperature is below the dew point, or the optical relationship allows detection of heat refraction patterns. Often steam plumes are found by observing locations of rocks altered by pyrometamorphism. Temperatures at these vents can range from 140°F to above 1200°F.

Other visual clues are associated with both types of plumes. For example, both types of plumes may emit intense heat capable of scorching grass or roots of trees in the area at one time or another. The observed plume is diagnostic of the fire cell feeding the vent and may not indicate the true nature of the fire. For example, a smoky plume emanating from a localized inefficient fire cell is not representative of an adjacent fire cell burning hot and generating steam plumes at another location. Areas around steam plumes seem more likely to have vegetation kill than similar are associated with smoky plumes.

Certain forms of vegetation may selectively be present in the environment immediately surrounding either type of vent. Moss, especially, is found in the throat of vents with an exhaust temperature of less than 160° F and for a small distance around the vent. Lush, green moss is located near active vents in some fires and faded to dying moss is an indicator of old or presently dormant vents. Some forms of ground cover are common on the heated ground and not usually found on lands unaffected by the coal fire.

In certain fires, a ring of native grass may thrive year round at the periphery of the burn area. The healthy green grass is a striking indicator of heating in areas typically consisting only of straw-colored brush and sage. In general, a Colorado coal fire is more likely to be marked with selected pioneering species not found native to the habitat surrounding the fire area than to be marked by vegetation kill.

REMOTE SENSING AND GEOPHYSICAL INVESTIGATIONS

Various methods of remote sensing were considered for their usefulness in the monitoring of active coal fires. These include conventional remote sensing methods that target certain portions of the electromagnetic spectrum from a distance, such as visible and false-color-infrared aerial photography and thermal-infrared imagery. Also investigated were geophysical methods, such as magnetic, electromagnetic and self-potential surveys, which measure the fields generated at depth.

Aerial Photography and Remote Sensing

Black-and-white aerial photography is readily available from the Colorado Geological Survey (CGS)and the U.S. Geological Survey's National Cartographic Information Center (NCIC), as well as other local, private sources. The CGS's files contain three different photo sets with varying coverage. The most complete coverage is the Army Map Service's 1953 to 1956 set, at a scale of 1:60,000. A more recent Mark Hurd photo set is less complete and at a smaller scale of 1:80,000. Some Front Range counties also have recent coverage at a larger scale. The USGS has participated in the NHAP (National High Altitude Photography) Program, and coverage from flights since 1980 is available through the NCIC, at a scales of 1:80,000 and larger.

Black-and-white photography offers only limited information concerning coal fires. Although subsidence features can be discerned from low sun-angle photography (Myers and others, 1975), available photography generally has a higher sun-angle. Further, subsidence can result from delayed settling of mine workings, especially where room-and-pillar methods were used, thus not necessarily denoting fire at all. Critical effects on vegetation and soil moisture will not be as noticeable on black-and-white photography from the visible spectrum as on other parts of the spectrum, such as false-color infrared. The most valuable aspect of black-and-white aerial photography appears to be from a general, photogeologic point of view. So, the 1953–1956 AMS photos were used for each mine fire area only for that general approach.

False-color, or near-infrared imagery should be a very useful tool for monitoring coal fire sites. Site inspections confirm that effects on vegetation can be pronounced in active mine fire areas. In some cases, the fire benefits the vegetation, supplying moisture from combustion gases that otherwise would not be available. Grass, moss, and other groundcover thrive and should be detectable in the near infrared band of the spectrum. In other cases, the heat of the fire evaporates soil moisture before tree and shrub roots can obtain it, ultimately causing death of the vegetation. While dead vegetation can be noted on photography in the visible spectrum, vegetation still alive but under stress from the fire would be visible on false-color infrared imagery.

It is not known whether the vegetation and soil moisture effects will outline a fire front and show its movement with time. It may be that they are far enough removed from the active fire to indicate only presence of fire activity. However, even if they are only an indicator of fire activity, these can provide a valuable tool for locating previously unknown or questionably active coal mine fires.

Thermal infrared imagery would probably be the most informative of all the remote sensing tools. With its ability to measure heat radiation from the surface being scanned, the thermal infrared sensor would record temperature variations around and within the fire area. The points of highest temperature would correspond to vents rather than active fire cells. However the temperature differences between neighboring vents might isolate local hot spots. Vents can emit heat ranging from

100° F to 1200° F higher than surrounding surfaces, so the temperature variations are large enough to be recorded with good results. Imagery obtained at night or during the winter with a moderate snow cover would probably give maximum thermal gradients. Repeat flights under similar conditions could show migration of hot spots and define a fire front.

There are disadvantages to this type of imagery, however. One is the relative scarcity of reliable equipment and operators familiar with its use. Another is that flights must be closer to the ground than conventional aerial photography for the degree of resolution required, and that overflights must be repeated over a period of time in order to show movement of the fire front. The elevation and terrain of the sites to be monitored may make it difficult for helicopters or fixed-wing aircraft to obtain the imagery safely. And finally, the cost of collecting and processing the data to make it applicable for monitoring coal fires is prohibitive. One estimate obtained in 1984 for a single scan of a broad area containing two to three sites was roughly $4,500. However, infrared video technology studied in 1988 indicates that larger, and more widely scattered, areas could be studied also for about $4,500. In both cases, however, the need for repeat flights at later dates would increase the total costs greatly.

Geophysical Investigations

A geophysical approach to the remote sensing of coal fires immediately brings to mind magnetic methods. The heat of the coal fire is enough to elevate temperature in the coal and the surrounding rock to a sufficient degree to cause a change in remnant magnetization upon cooling. Magnetic effects between burned and unburned coal should be distinctly different. The use of magnetic methods to delineate areas of clinker is well illustrated by Hasbrouck and Hadsell (1978). A magnetic survey of an active coal fire poses a problem in that the fire front and margins on either side are too hot to have acquired remnant magnetism. Thus, the survey would probably show a broad transition zone between burned and unburned coal.

Electrical geophysical methods appear to have greater utility in detecting coal fires. Rodriguez (1983) made a self-potential survey of the Lewis No. 1 and No. 2 Mine Coal Fires and successfully located two areas of active burning. The theory behind this method is that coked coal is a good electrical conductor (Bartel, 1982), and that a temperature gradient across a rock sample also generates a voltage gradient across the sample (Corwin and Hoover, 1979). Therefore, a self-potential anomaly at the surface should be directly over the source of elevated temperature. Other methods were employed by Rodriguez. An electromagnetic survey measured conductivity contrasts, which correlated well with the self-potential resistivity variations, but found little more than decreasing resistivity with depth. In addition, a magnetic survey measured anomalies offset from the self-potential anomalies, suggesting the direction of migration (Rodriguez, 1983).

Shallow seismic instruments were employed at the Wise Hill No. 3 Mine Coal Fire to ascertain the depth to bedrock for construction needs. Poor results were obtained due to extensive cracking and fissuring of both bedrock and near-surface unconsolidated materials. Near-surface, high resolution seismic may be able to provide stratigraphic information relating to the position of the coal mine roof, but not the location of the fire front.

CONTROL OF COAL FIRES AND COLORADO CONTROL PROJECTS

CONTROL OF COAL FIRES

The control of coal fires can provide several positive public benefits:

- Reduction of noxious fumes and gases
- Increased public safety
- Conservation of the coal resource
- Reduction of brush and forest fire threat
- Conservation of surface land use

There are three main techniques of quenching coal fires in the western United States according to Shellenberger and Donner (1979):

- Starvation
- Asphyxiation
- Cooling

Starvation of a fire removes fuel or prevents a fire from reaching additional fuel. The methods are removal and barrier, respectively. Removal is effected by the bulldozing of burning material away from the coal face, where physically possible. The barrier method involves trenching through unburned coal and backfilling with incombustible material.

Asphyxiation of a fire may involve sealing, inundation or flushing. Surface sealing, most common of the western United States control projects, places a mantle of soil several feet thick over the fire area to reduce intake vents and block exhaust vents. Inundation of a fire with water is rarely practiced since removal of water afterward leaves physico-chemical conditions ripe for spontaneous combustion of coal. Flushing of a fire with inert material or gases has met with partial success in the eastern United States, but is apparently not often economic. Cooling of a fire is accomplished by inundation. This method is not practical unless the water level is maintained and water is readily available. These conditions are typically not feasible in Colorado.

Factors affecting the control of fires include, but are not limited to the following:

- Ground slope
- Geology of rock sequence overlying the coal
- Dip (inclination of coal seam)
- Coal thickness
- Geometry and condition of mine workings
- Number of seams
- Depth, quantity and character of soil
- Intensity of fire

Surface seals comprise over 85 percent of abatement attempts in the western United States due to the relatively low cost (Shellenberger and Donner, 1979). Surface seals use soil and rocks cut or blasted from non-coal bearing intervals located nearby or topographically above the coal fire. Most of the coal fires observed during the study by the CGS had received some form of abatement work in the past.

Breached seals are the most commonly observed factor causing reactivation of abated coal fires. With an effective seal cutting out the air supply, the coal and host rocks still contain a great deal of residual heat. Chaiken (1980) reports that a ton of material with an average temperature of 900° F has a sensible heat content of one–half million Btu's. A breached seal may result from a new vent not covered by the seal, sub-sidence or erosion and drainage incising channels in the seal. In addition, some seals were breached due to slope failure, or coal fire migration to a new area without a thick surface seal cover.

Seasonal and climatic cycles contribute to stress placed on a seal and may eventually compromise its integrity. Changes in barometric pressure place strain on any seal. With perfect seals a change in pressure yields no change in the volume of the underlying cavity. However, leaks permit changes in volume and allow air exchange with renewed supply of oxygen.

The freeze/thaw cycle induces movement of unsorted or poorly sorted clasts within the seal. Zones of weakness are created and, most certainly, the transmission of air is increased through reworked seal material. Rocks mobilized by freeze/thaw were observed at most seals. In some cases, such as at D & H Mine Coal Fire, vents were emanating from paths apparently created by migration of rocks induced by the freeze/-thaw cycle.

The economic selection of material used in a seal is limited to that near the coal fire. Improved crushing on-site may reduce the possibility of rock migration due to freeze/thaw. Other materials may contain desirable qualities for a seal at first glance. A clay seal might seem advantageous due to its small grain-size. However, Chaiken (1983) notes that the volume of a clay seal decreases with drying, and desiccation would induce cracking. A clay seal must be kept moist to be effective. Although mud cracks were observed at some seals, no desiccation cracks were deep enough to compromise the integrity of a seal over a coal fire. A seal of sufficient thickness over a large enough surface area will asphyxiate a coal fire. In most control projects a fire may be considered likely to re-ignite, unless the temperature is brought to below 200° F.

One danger in monitoring the progress of a control project is that drill holes may reventilate a fire, or permit trapped noxious gases to escape uncontrolled. Improper sealing of a monitoring drill hole could permit spontaneous combustion in a new or different area. Similarly, the abatement activities of flushing and trenching might alter the circulation of air and fumes to the extent that the fire spreads or starts in an unexpected location.

COLORADO COAL FIRE CONTROL PROJECTS

Table 2 is a listing of control projects undertaken by the USBM, USGS, OSM and CIMRP. More than 40 control projects were undertaken between 1949 and 1988. The success rate is about 60 percent, and the cash value of monies expended in controlling coal fires is over one million dollars. It is most likely that a lapse in funding following 1978 Federal budget cuts prevented several control projects from continued maintenance essential to successful abatement. The surface seal method was applied in about 85 percent of control projects.

The success rate of seals is, in general, quite good if continued maintenance and monitoring are carried out. The success of a surface seal is determined largely by prompt action after discovery of the coal fire and, thereafter, continuing inspections and maintenance. The tremendous energy within a coal fire will usually induce a breach in the seal. Typically, the first breach in a surface seal will be a thin sutured fissure. With time, the fissure will widen and expand, causing an increase in available oxygen to the fire. As the fire regenerates, other vents will develop. This will eventually render the surface seal ineffective in controlling fire spread. From a review of USBM coal fire reports it is apparent that many coal fires were ultimately extinguished by timely repair of surface seals, usually hand shoveling or nominal dozer time being all that was required.

The costs of frequent, minor repair work will be substantially less than the cost of one major construction project. The low costs of many early coal fire control projects reflects a general, long-term stability in the cost of construction work from the 1940s through the early 1970s. Through the 1970s due to increased costs in labor, fuel, insurance and bonding and increased reclamation requirements the cost of similar work today may show a fivefold cost increase from the earlier efforts. Surface seal construction is undertaken on either an emergency basis by OSM or following a cost-benefit study by CIMRP. Funding for a coal fire maintenance program exists for CIMRP project work, but is slated to end in 1992.

The most comprehensive chronology of coal mine fire activity from USBM records is for the Axial Mine Coal Fire (Shellenberger, 1972). Most coal fires are in remote areas, however, the Axial Mine Coal Fire was under nearly constant observation by a nearby coal mine operator. Recorded contacts between the operator and USBM personnel provide a basis for examining the time span between events on a stressed surface seal. The average time between significant events affecting the surface seal was 316 days with the longest interval of relative quiescence being 947 days.

The average time span between inspections of other USBM project work averaged 580 days. This interval between inspections corresponds roughly with the time interval between CGS and CIMRP coal fire inspections. Since each coal fire is unique there is no basis for extrapolating these time intervals between surface seal failures to other coal fires. However, it is apparent that, in most cases, this rate of inspection would not be frequent enough to locate and repair minor breaches in surface seals.

Table 2. Known coal fire control projects in Colorado by year.

PROJECT NAME	COUNTY	YEAR	METHOD	COST $	CURRENT STATUS
IHI No. 1	Garfield	1949	Fire barrier	39,900	Inactive
North Park	Jackson	1949	Fire barrier	57,800	Inactive
Skull Creek	Rio Blanco	1951	Fire barrier	18,600	Active
Dugger/Rollins	Delta	1952	Surface seal	19,200	Inactive
Coal Gulch	Mesa	1953	Surface seal	26,800	Inactive
IHI No. 2	Garfield	1953	Removal	10,600	Inactive
Slagle	Ouray	1954	Surface seal	15,200	Inactive
Yellow Jacket	Rio Blanco	1954	Surface seal	16,000	Inactive
Onion Lake	Montrose	1955	Surface seal	21,300	Inactive
White River No. 1	Rio Blanco	1959	Surface seal	3,600	Inactive
White River No. 2	Rio Blanco	1959	Surface seal	6,800	Inactive
Haas	Garfield	1961	Removal	7,200	Inactive
Minnesota Creek	Delta	1961	Surface seal	9,700	Active
Smoky Mtn. Phase 1	Mesa	1961	Surface seal	11,700	Active
Axial Phase 1	Moffat	1962	Surface seal	5,500	Active
Smoky Mtn. Phase 2	Mesa	1962	Surface seal	46,700	Active
Smoky Mtn Phase 3	Mesa	1963	Surface seal	38,000	Active
Rosebud No. 1	Jackson	1963	Surface seal	1,000	Inactive
Smoky Mtn Phase 4	Mesa	1964	Surface seal	24,700	Active
Hot Point	Garfield	1965	Surface seal	3,700	Inactive
Coalmont	Jackson	1966	Surface seal	500	Inactive
Stove Canyon	Garfield	1966	Surface seal	7,200	Inactive
Ute Pasture Phase 1	Montezuma	1968	Surface seal	22,600	Inactive
Garfield	Mesa	1969	Surface seal	15,400	Active
Farmer's Mutual	Mesa	1969	Surface seal	1,800	Active
Rosebud No. 3	Jackson	1969	Surface seal	500	Inactive
Ute Pasture	Montezuma	1971	Surface seal	12,800	Inactive
Axial Phase 2	Moffat	1972	Seal/barrier	37,300	Active
Black Raven	Garfield	1972	Surface seal	24,000	Inactive
Kaspar	Routt	1972	Surface seal	4,400	Active
Riach	Jackson	1974	Surface seal	12,200	Active
D & H Phase 1	Garfield	1975	Surface seal	23,400	Active
Wise Hill No. 3	Moffat	1976	Surface seal	5,000	Active
Ute Pasture Phase 3	Montezuma	1977	Surface seal	50,000	Inactive
D & H Phase 2	Garfield	1977	Surface seal	56,000	Active
W. H. Canyon	Garfield	1981	Surface seal	2,500	Inactive
Double Dick	Fremont	1983	Barrier	300,000	Active
Minnesota Creek	Delta	1983	Surface seal	1,900	Active
Marshall No. 3	Boulder	1984	Surface seal	40,000	Inactive
Smoky Mtn	Mesa	1985	Surface seal	12,800	Active
D & H	Garfield	1985	Surface seal	40,000	Active
Double Dick	Fremont	1985	Trench refill	150,000	Active
D & H	Garfield	1987	Surface seal	20,000	Active
States	Delta	1988	Surface seal	5,600	Active
Wise Hill No. 3	Moffat	1988	Surface seal	57,000	Active
TOTAL				**1,286,900**	

COAL FIRES IN COLORADO

The list of Colorado coal fires in Table 1 is a compilation of historic records. Not included are those coal fires which were successfully extinguished by mine operators allowing mining to resume. Twenty-nine coal mine, crop, and dump fires were considered to be active in 1988. In these areas several portals may be present, but, in general, after burning for some time the influence of separate portals on a fire may be indistinguishable in the surface expression of a fire. In other words, working areas that were once separate may now be involved in a single coal fire.

The Colorado coal fires active in 1988, as shown in Table 3, are grouped according to coal region. This allows a brief discussion of regional geologic setting before the more detailed treatment of the fire sites. Figure 1 shows the coal regions and fields in the State of Colorado and the general locations of active coal fires.

Estimates of the direct surface area affected by the coal fires are also presented in Table 3. The value of 116 acres understates the true extent of the problem since the surface expression of a coal fire is significantly less than the area actually involved in fire. For example, a large mine of 50 or more acres may be totally involved in fire, however, due to topography or geologic conditions may have a relatively small surface expression of one or two acres. Only the surface expression of the coal fire can be estimated with reliability, estimates of total acreages involved in fire are subject to many variables, many of which are unknown. Coal mines which have burned, but are now extinguished are not included in this estimate.

ANALYSIS OF COLORADO COAL FIRES

Colorado coals are mined from rocks of Upper Cretaceous to Eocene age. The Upper Cretaceous coals formed in deltas along a shallow continental sea bordered by highlands. Sedimentary processes dominated in controlling the geometry of coal bodies. Upper Cretaceous delta-plain and back-barrier coals tend to have an elongate geometry parallel with depositional features such as shorelines, and are occasionally disrupted by crevasse splays, wants or distributary channels. In contrast, Paleocene and Eocene coals were influenced by a fresh-water regime in tectonically controlled intermontane basins. In general, even with the limited lateral extent of individual coal deposits, Colorado still has a very significant coal resource.

CANON CITY COAL FIELD

The Canon City Coal Field is in the Laramide age Canon City Structural Basin, an embayment at the southwest extremity of the Denver Basin. It is bounded on the north by the Front Range Uplift, on the west and southwest by the Wet Mountains Uplift, and on the south by the Apishapa Uplift. This southern boundary separates it from the Raton Basin. The Canon City Coal Field contains more stratigraphic similarities to the Raton Basin than to the Denver Coal Region. The Apishapa Uplift caused removal of the coal-bearing sequences that were once continuous between the Canon City and Raton Basins (Murray, 1982).

The Vermejo Formation of late Cretaceous age contains the only coal-bearing sequence in the Canon City Field. It is composed of coals, claystones, siltstones, and sandstones deposited in a delta plain setting. The coal beds formed parallel to major fluvial channels, with intermittent splay splits (Billingsley, 1978). The Double Dick Mine Coal Fire is at the New Double Dick Mine, which extracted coal from the six foot thick Brookside coal bed of the Brookside coal zone. This is the uppermost coal zone in the Vermejo Formation.

DOUBLE DICK MINE COAL FIRE

The Double Dick Mine Coal Fire is in Fremont County 7.5 miles south-southwest of Florence in the NWSESE of Sec. 24, T20S, R70W, Sixth Principal Meridian. It is on a low, dissected divide between Newlin Creek and an unnamed intermittent tributary to the northwest. The site is reached by taking Colorado 67 for 4.25 miles south of Florence, then turning right on a secondary highway and following it four miles southwest. An unimproved road to the right leads 0.25 mile to the mine workings and the fire area. Figure 2 is a map showing the general location of the coal fire.

The New Double Dick Mine operated on this site from 1929 to 1968. The mine is credited with the production of 540,686 tons of bituminous coal from the six foot thick Brookside seam. There are two theories about the cause of the fire. One suggests spontaneous combustion within the abandoned mine workings.
The other suggests that the gob used by the company operating a nearby surface mine to backfill an adjacent strip pit in 1982, caught fire and burned downward into the mine. Whatever the origin, the remaining pillars and partially collapsed rooms allowed the fire to spread.

Table 3. Location of active coal mines in Colorado by map number.

MAP NO.*	MINE NAME	COUNTY	TYPE	LOCATION	REGION+	AREA (ACRES)	7 1/2' QUAD-RANGLE	COAL FIELD
1	Axial	Moffat	Mine	SWNWNE, Sec. 2, T3N, R93W	UI	0.5	Axial	Danforth Hills
2	Wise Hill No. 3	Moffat	Mine	W1/2W1/2, Sec. 31, T6N, R91W	GR	14.5	Round Bottom	Yampa
3	Kaspar	Routt	Mine	N1/2N1/2, Sec. 11, T4N, R87W	GR	2.5	Dunckley	Yampa
4	Riach/North Park No. 2	Jackson	Mine	NWSW, Sec. 24, T7N, R81W	NP	12.5	Coalmont	North Park
5	Skull Creek	Rio Blanco	Crop	E1/2E1/2, Sec. 35, T3N, R102W	UI	2.0	Rangely NE	L. White River
6	Black Diamond	Rio Blanco	Mine	SENW, Sec. 15, T1N, R94W	UI	1.0	Meeker	Danforth Hills
7	Rienau	Rio Blanco	Mine	NWNWSE, Sec. 29, T2N, R93W	UI	1.0	Rattlesnake Mesa	Danforth Hills
8	D & H Coal Mine	Garfield	Mine	NENENE, Sec. 17, T5S, R92W	UI	10.5	Silt	Grand Hogback
9	Harvey Gap	Garfield	Mine	NWSWNE, Sec. 24, T5S, R92W	UI	5.5	Silt	Grand Hogback
10	Burning Mtn. No. 2	Garfield	Mine	NWNE, Sec. 27, T5S, R91W	UI	4.5	New Castle	Grand Hogback
10	Burning Mtn. No. 3	Garfield	Mine	SESE, Sec. 21, T5S, R91W	UI	4.5	New Castle	Grand Hogback
11	Burning Mtn. No. 1	Garfield	Mine	SWSWNW, Sec. 31, T5S, R90W	UI	6.0	New Castle	Grand Hogback
11	Coryell	Garfield	Mine	SESWSW, Sec. 32, T5S, R90W	UI	3.0	New Castle	Grand Hogback
11	McDonald	Garfield	Mine	SESE, Sec. 31, T5S, R90W	UI	4.0	New Castle	Grand Hogback
11	Vulcan	Garfield	Mine	SENWNW, Sec. 1, T6S, R91W	UI	3.0	New Castle	Grand Hogback
12	South Canyon No. 1	Garfield	Mine	NWNW, Sec. 14, T6S, R90W	UI	9.5	Storm King Mtn.	Grand Hogback
12	South Canyon No. 2	Garfield	Mine	NENWSW, Sec. 10, T6S, R90W	UI	5.0	Storm King Mtn.	Grand Hogback
13	Pocahontas No. 2	Garfield	Mine	NESE, Sec. 28, T7S, R89W	UI	1.0	Cattle Creek	Grand Hogback
14	Lewis Nos. 1 and 2	Boulder	Mine	NENENE, Sec. 21, T1S, R70W	DN	1.4	Louisville	Boulder/Weld
15	Smoky Mountain	Mesa	Crop	E1/2NW, Sec. 19, T8S, R101W	UI	4.0	Ruby Lee Res.	Book Cliffs
16	Farmers Mutual	Mesa	Mine	SESW, Sec. 36, T9S, R100W	UI	0.8	Corcoran Point	Book Cliffs
17	Garfield	Mesa	Mine	E1/2E1/2, S, Sec. 6, T11S, R98W	UI	2.0	Round Mtn.	Book Cliffs
18	Go Boy	Mesa	Mine	SESE, Sec. 2, T11S, R98W	UI	1.0	Palisade	Grand Mesa
19	States	Delta	Mine	NWNW, Sec. 18, T13S, R94W	UI	5.5	Cedaredge	Grand Mesa
20	Minnesota Creek	Delta	Mine	SWNWNE, Sec. 35, T13S, R91W	UI	2.0	Bowie	Somerset
21	Double Dick	Fremont	Mine	NWSESE, Sec. 24, T20S, R70W	CC	8.0	Rockvale	Canon City
22	McElmo	Montezuma	Mine	SWNWNE, Sec. 35, T36N, R16W	SJ	1.0	Cortez	Durango
23	Morley	Las Animas	Dump	S1/2, SESE, Sec. 36, T34S, R64W	RM	0.5	Starkville	Trinidad
Total						**116.7**		

***See Figure 1.**

+Coal Regions and Fields: **CC—Canon City Field**
DN—Denver Region
GR—Green River Region
NP—North Park Field
RM—Raton Mesa Region
SJ— San Juan River Region
UI—Uinta Region

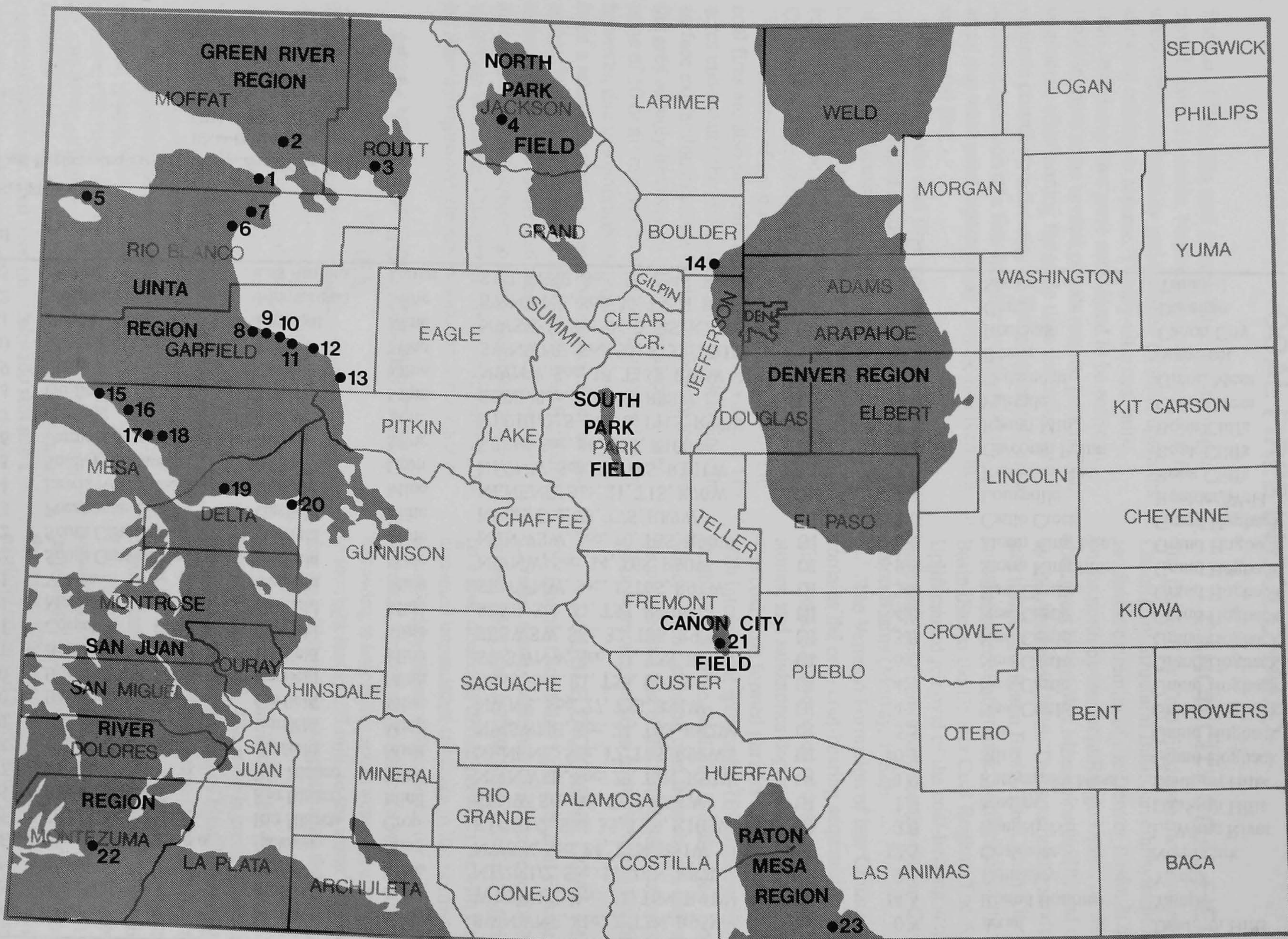


Figure 1. Colorado coal regions and fields and active coal fire sites. (See Table 3.)

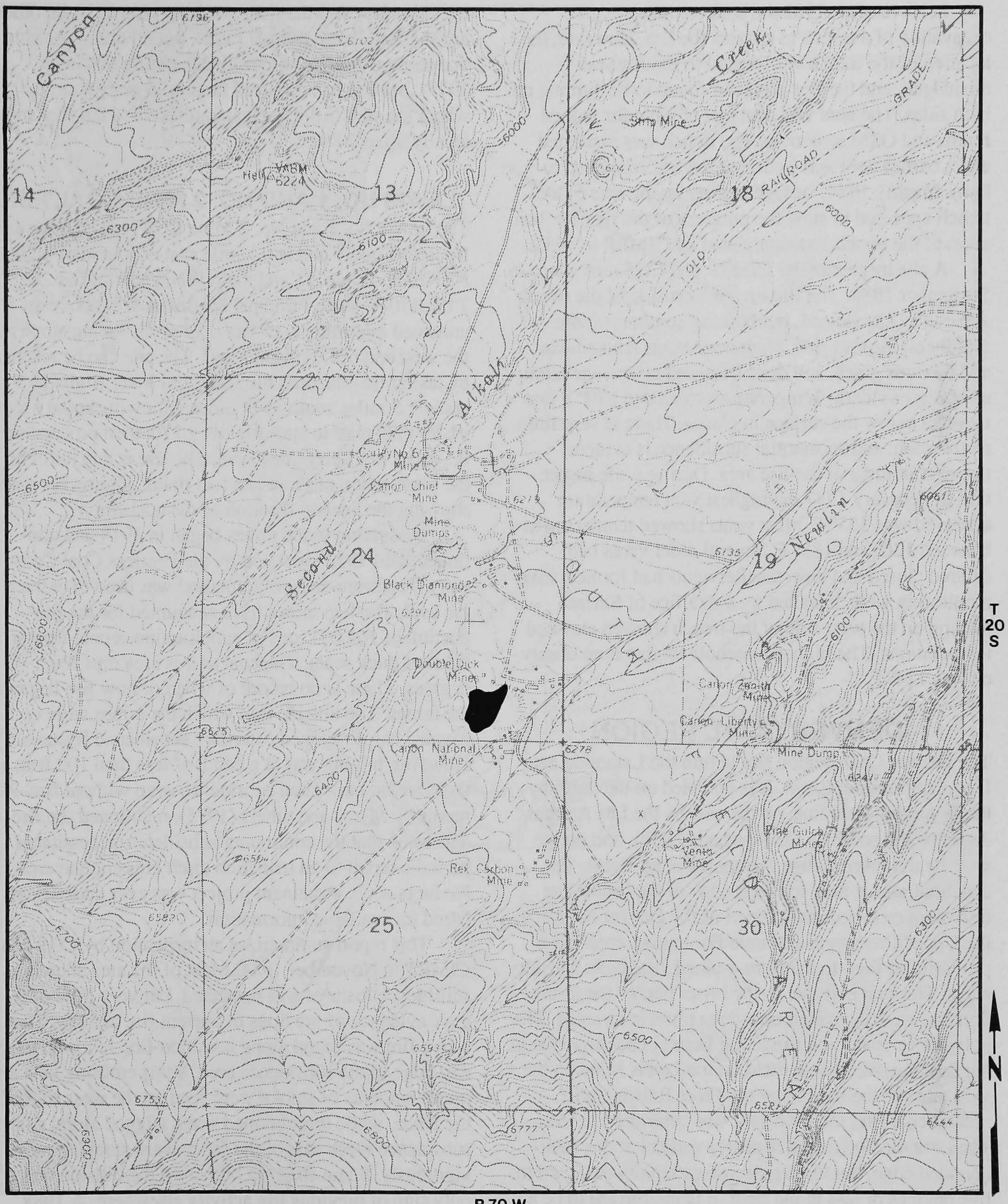


Figure 2. Location of the Double Dick Mine Coal Fire site (base from Rockvale 7.5-minute Quadrangle, scale 1:24,000.)

In November, 1982 the coal company began excavation of a trench to contain the fire. However, the location of the trench with regard to the fire was misjudged, and the fire was later found to be burning on both sides. The area was declared eligible for federal funds, and OSM took over. The trench was expanded and a barrier wall was built, but the fire continued to burn. In early 1984, surface sealing on the face of the trench appeared to slow the progress of the fire. Reclamation of the trench was completed by CIMRP in 1985.

A site inspection by CIMRP and CGS took place in September 1984. The fire on the west side of the trench apparently has slowed, but burning continues more rapidly on the east side. Numerous vents emit smoke and noxious gases, and dead trees and other vegetation effects are evident. Temperatures exceeded 570° F just two feet below the surface in places. There is very little overburden, and substantial subsidence is evident throughout most of the fire area. During a site inspection in February 1987 the highest vent temperature observed was 355° F. Most vents showed temperatures between 120° and 185° F. Several older vents had sutured closed and new, smaller vents had formed. Five monitoring wells installed by the Office of Surface Mining on the west side of the trench showed elevated temperatures. The highest borehole temperature observed was 124° F.

DENVER COAL REGION

The Denver Coal Region lies within the Laramide age Denver Structural Basin. It is bounded on the north by the Wyoming state line, on the east by the Las Animas Arch, on the south by the Apishapa Uplift, and on the west by the Front Range-Rampart Range Uplift. The synclinal axis is near the west edge of the basin. The important coal-bearing interval of the Denver Region is the Upper Cretaceous Laramie Formation, consisting primarily of fine- to medium-grained sandstone and silty clays. The coal beds are in the lower part of the formation and were deposited on a delta plain in swamps. The only active coal mine fire in the Denver coal region is in the Boulder-Weld Coal Field, at the Lewis Mine on the west edge of the basin near the Front Range Uplift. A second coal fire, the Marshall, was controlled in 1986. The Laramie Formation is nearly vertical at this fault-bounded edge, but the dip decreases rapidly eastward to five degrees or less in the field. It is interpreted to be a back levee deposit on the northern margin of a basement-fault-controlled depocenter. Some northeast-trending faults through the field are deep-seated, while others are shallow, listric normal faults, but all are apparently due to growth-faulting during deposition (Weimer, 1977). Mining has occurred largely in graben areas where the coal is thicker, generally five to ten feet and locally up to 20 feet.

LEWIS NO. 1 AND NO. 2 MINE COAL FIRE

The Lewis No. 1 and No. 2 Mine Coal Fire is located in Boulder County and is 0.5 mile east of Marshall in the NENENE of Sec. 21 and the NWNWNW of Sec. 22, T1S, R70W, Sixth Principal Meridian. It is above an unnamed intermittent stream on a south-facing slope at the west end of Davidson Mesa. The site can be reached by taking the Marshall turn-off from State Highway 93 about 1.5 miles south of Boulder, following county road 91 for 0.25 mile to state highway 170, then proceeding 0.5 miles to Cherryvale Drive. The fire is due north of the intersection of these last two roads. Figure 3 is a map showing the general location of the coal fire.

Production in the mines began in 1914 and continued until 1942, operated by the Peerless Coal Company. The room-and-pillar method was used to extract the coal. The two mines have accounted for the production of 164,057 tons of subbituminous coal from a 5.5 foot thick seam. The coal in this area dips four degrees. There is no record of when or how fire began in the mines. The hillside into which the mines were excavated has developed extensive subsidence features. However, mining was at a depth of less than 100 feet, so there would have been subsidence even without fire. A report by Myers and others (1975), mentioned the fire and noted that the continuing subsidence necessitated periodic repair to an irrigation ditch crossing the area. No large-scale abatement project was ever undertaken, based on available information.

This report summarizes an inspection by CGS and CIMRP in November 1984. Most of the area showing subsidence features was inspected, but very little of it gave evidence of previous or current fire activity. The active fire was found along a section-line fence on the east edge of the subsidence area. Vents emitting heat and minor amounts of smoke were seen on the west side of the fence, while three stained vents aligned along a large subsidence crack east of the fence were smoking more vigorously. Some charring higher on the hillside was the only sign of previous fire activity elsewhere. A 1988 inspection by CGS showed little change in aforementioned fire activity.

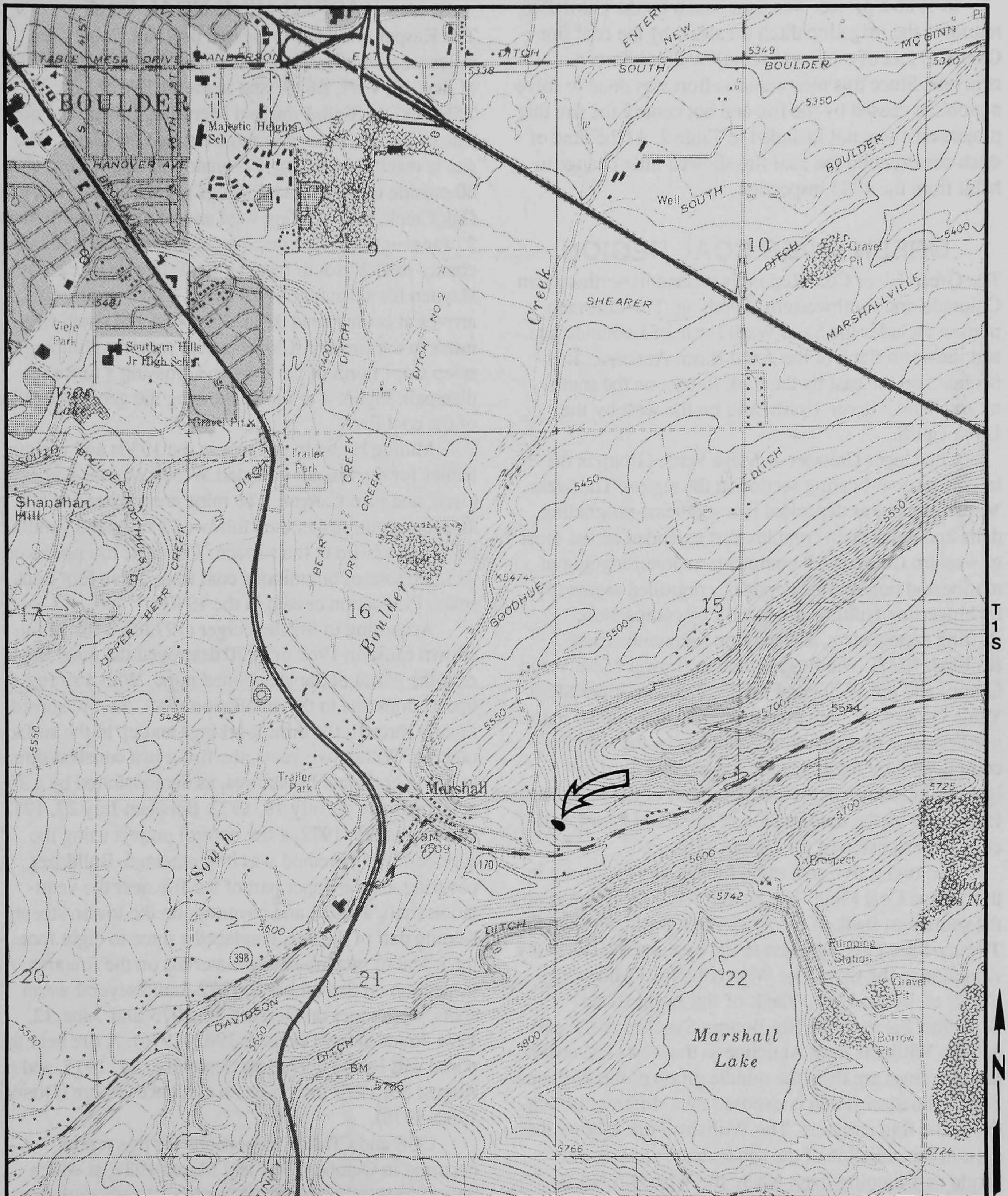


Figure 3. Location of the Lewis No. 1 and No. 2 Mine Coal Fire sites (base from Louisville 7.5-minute Quadrangle, scale 1:24,000.).

In 1986 a project was undertaken by the CIMRP to reinforce the irrigation ditch breached by the coal fire. Over 800 feet of ditch was rebuilt with reinforced concrete. Since this reclamation effort was done to solve a problem caused by the fire and not control the fire this project cost was not included in Table 2. At the time of ditch construction the coal fire showed little change in habit from the 1984 inspection.

GREEN RIVER COAL REGION

The Green River Coal Region is located in northwestern Colorado and southwestern Wyoming. The Colorado portion includes the Sand Wash Basin of Laramide age and the north flank of the Axial Basin Anticline. It is bounded on the east by the Park Range, on the south by the White River Uplift, and on the west by the Uinta Uplift.

The Upper Cretaceous Mesa Verde Group is the important coal-bearing section in the region. The Mesa Verde Group was deposited in a southeast-prograding delta and delta-plain complex that extended across most of western Colorado. It comprises an intertonguing of marine and non-marine deposits, controlled regionally by hinge-line faulting and locally by compaction, shifting depocenters, and varying sediment supply (Collins, 1977). The Iles Formation (Lower Mesa Verde Group) and the Williams Fork Formation (Upper Mesa Verde Group) are both predominantly non-marine in this northern area of deposition. Structurally, the region is complicated by folding, faulting and late Tertiary igneous intrusives in the southeast part of the Sand Wash Basin, and by the deformation of the Axial Basin Anticline, an extension of the Uinta Uplift.

The two active coal mine fires in this region are in the Yampa Coal Field. The Kaspar Mine Coal Fire is on the southwest flank of the Sand Wash Basin between the Twenty-Mile Park Syncline to the east and the Dunckley Anticline to the west. The Wise Hill No. 3 Mine Coal Fire is on the northeast flank of the Axial Basin Anticline, between the Big Bottom Syncline to the east and the Williams Fork Anticline to the west. The coals in both mines are from the middle group of the Williams Fork Formation. Each is exposed by a different breaching of the fold structure. The Williams Fork follows the crest of the anticline of the same name, eroding the gentle east-dipping flank where the Wise Hill No. 3 Mine is located; whereas, Fish Creek has cut a water gap through the steep east-dipping ridge at the Kaspar Mine.

KASPAR MINE COAL FIRE

The Kaspar mine fire is located in Routt County ten miles west-northwest of Oak Creek in the N1/2N1/2NW of Sec. 11, T4N, R87W and in the SESW of Sec. 34, T5N, R87W, Sixth Principal Meridian. It is on the north side of a steep water gap ridge cut by Fish Creek. The site is reached by taking Colorado 131 south from U.S. 40 outside of Steamboat Springs for about 16 miles to Oak Creek, then heading west and north on county road 27 for roughly 12.5 miles. An alternate route is to take county road 27 south from U. S. 40 five miles east of Hayden for a distance of 10 miles. Either approach arrives at county road 37 leading west and south two miles to the fire site. Closer access requires climbing the steep slope north of the road and crossing a fence in disrepair. Figure 4 is a map showing the general location of the coal fire.

Mining began in the area in the 1930s and various names for the Kaspar included Weber Wagon, Webers-kirch, and Fish Canyon. The mine entry extended 500 to 700 feet along strike, then followed a raise and ventilation shaft up-dip to the surface. The mine has produced 215,000 tons of bituminous coal from a five foot thick seam. Production ceased in the 1940s.

According to Shellenberger (1973b), a fire of unknown cause in 1969 or 1970 destroyed the mine tipple near the portal of the abandoned mine. With a strong upcast draft due to the ventilation shaft, the fire spread rapidly through the mine workings and up to the surface outcrop. Within two years, the fire was a constant threat to ignite grass and brush fires, as demonstrated by a 30 acre grass fire on July 18, 1972. Between July 27, 1972 and August 25, 1972, a fire control project using the surface sealing method was implemented. Bulldozer covering, on the upper part of the fire near the ventilation shaft, and cut and covering, on the lower, steeply sloping part of the fire, emplaced a three to eight foot thick seal of incombustible materials on the fire area. An inspection on September 2, 1972 found several warm spots, while ones on October 31, 1973 and June 12, 1974 found none (Donner, 1962–1976). A fire near the portal was hand-covered on September 21, 1975, and on August 30, 1978 there was no evidence of fire (Donner, 1962–1976).

CGS and CIMRP inspections for this report occurred in October 1984 and March 1987, at which times it was evident that the fire is still active with little character change. Several vents some 100 to 150 feet slope distance above the portal were observed to emit smoke and steam. Those emitting smoke were character-

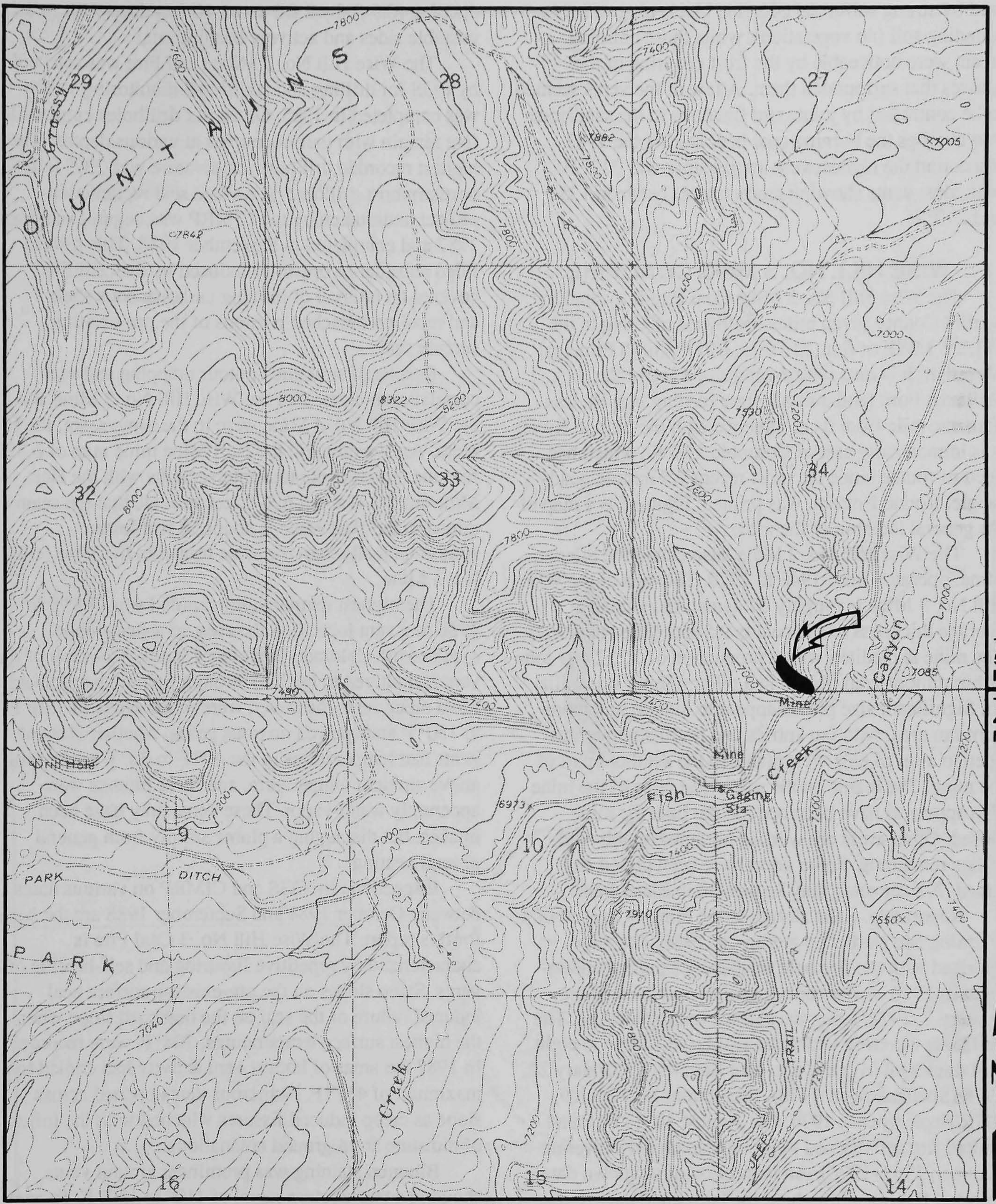


Figure 4. Location of the Kaspar Mine Coal Fire site (base from Dunckley 7.5-minute Quadrangle, scale 1:24,000.)

ized by strong sulfurous oder and blackening of surrounding soil (no vegetation), while those emitting steam were noticeable by the frost covering of the grasses that surrounded them. A few of the vents seemed to be controlled by joints and fractures in the sandstone that overlies the burning coal bed. During the 1987 inspection the highest vent temperature was 312° F, with most vents showing temperatures between 135° and 240° F.

WISE HILL NO. 3 MINE COAL FIRE

The Wise Hill No. 3 Mine Coal Fire is located in Moffat County seven miles southwest of Craig in the W1/2W1/2SE of Sec. 31, T6N, R91W, Sixth Principal Meridian. It is on a west-facing slope above the Williams Fork (and a small draw feeding into it), less than one mile from its confluence with the Yampa River. It is immediately east of Colorado 13/789, which has been re-routed since the most recent 7.5 minute quadrangle, Round Bottom, was printed. Figure 5 is a map of the general location of the mine.

The Wise Hill No. 3 Mine, also called the Silengo Mine, operated from 1940 to 1970. The area of the Wise Hill No. 3 Mine is roughly 87 acres. An estimated average thickness of the coal is 9.5 feet (Silengo, 1967). The mine is credited with a production of 1,232,699 tons of bituminous coal. Room and pillar mining was utilized. Significant size pillars appear to remain in the preburn fan area, with fan entries and north-south mains open to a set of east-west mains in the southern part of the mine. The mains on the southwest edge of the mine also appear to have been open at the time the mine closed. Other areas are worked out, presumably with pillars remaining. Some areas have been pulled and caved. A rider seam may be present in some areas.

Reportedly, a fire started at the mine as a result of a warming fire started by a drunk in 1945. The mine operated with the fire held in abeyance until abandonment in 1970. A fire control project commenced on January 7, 1976, using the surface sealing method. The bulldozer covering technique emplaced a three to eight foot thick seal over the one-acre fire area by January 22, 1976 (Shellenberger, 1976). Inspections on March 9, 1976, September 4, 1976, and August 30, 1978 found limited fire activity and required some hand shoveling (Donner, 1962–1976). An inspection of unknown date reported fissures throughout the burn area, most extensive in two areas where temperatures two feet below the ground surface exceeded 500° F . It also reported a small opening (0.5 ft. by 2 ft.) about 10 feet deep with unstable sides and actively burning coal.

The Wise Hill No. 3 Mine Coal Fire was selected by CGS for drilling and additional monitoring which was completed in 1985. Of the six drillholes emplaced five remain with thermocouples at various depths. The highest recorded drillhole temperature was 237° F in the northernmost drillhole. A surface seal reclamation project undertaken by the CIMRP was begun December 1987 and completed in September 1988. This project filled subsidence openings induced by the coal fire, covered an interval of burning carbonaceous shale and repaired breached portions of the pre-existing surface seal.

Results of structure contour mapping and seam correlation indicate that the Wise Hill No. 3 Mine and the Wise Hill No. 4 Mine were in the same seam, the H seam. An elevation on the Hart Mine mine map of 6,320 feet and structure contour intersections with the Hart Mine entries at about 6,370 feet indicate that the seam mined in the Hart Mine is about 50 feet lower stratigraphically than the seam mined in the Wise Hill No. 3 Mine.

The highest temperature recorded was 708° F in 1986 in a vent located at the crest of a steep slope overlooking Colorado Highway 13/789. A portion of the vent had altered to buchite through pyrometamorphism. Most other vents, however, were in the range of 120° F to 150° F and spewed noxious gases. Another class of vents had temperatures in the 40° F to 50° F range, still above ambient temperature, and these plumes were apparently water vapor. These vents may have been intakes, but displaying a plume simply from general ground heating

Inspections by CGS and CIMRP on various dates between October 1984 and September 1988 are the basis for this report. The Wise Hill No. 3 Coal Fire is characterized by repetitive fissuring and self-healing of vents. Steep slopes on the pre-existing surface seal induced failure of the seal on the outboard slope where the highest surface temperatures, 708°F, were recorded. In 1987 the areas of hottest vent activity had cooled to a maximum of 417° F. Numerous vents opened across slope as creep induced fissures widened with the influx of moisture from ground emanations.

Bitumen staining was prominent around vents showing a temperature range of 110° to 130° F. Toward the northern extreme of coal fire activity a carbonaceous shale sequence was alternately smoldering and flaming up as material slumped or tore away from the outcrop.

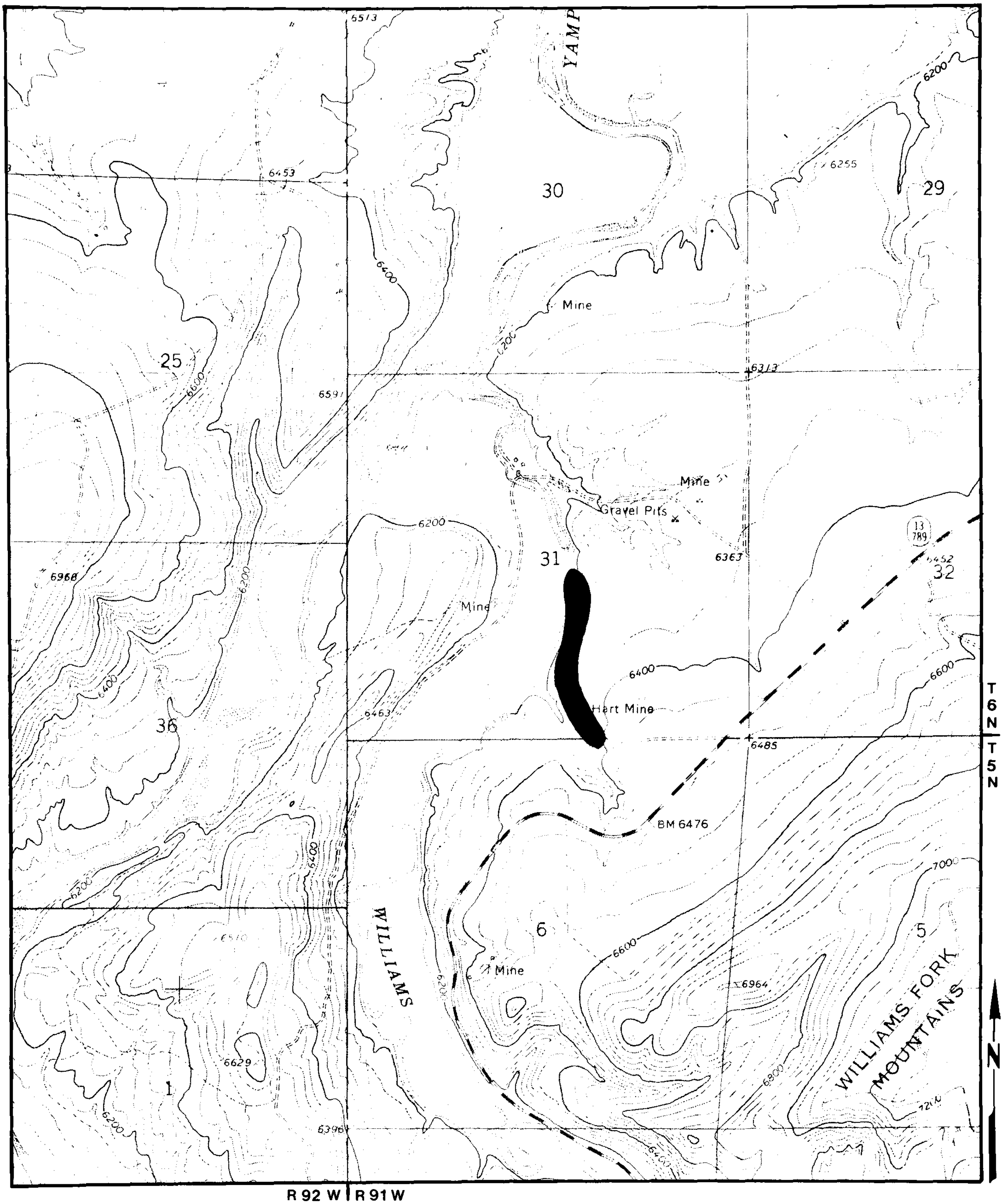


Figure 5. Location of the Wise Hill No. 3 Mine Coal Fire site (base from Round Bottom 7.5-minute Quadrangle, scale 1:24,000.)

This carbonaceous shale unit was independent of the main coal fire although its ignition was probably triggered by venting from the underlying coal fire by communications with active vents.

More fissuring was observed where the slope faces southwest above a draw feeding into the Williams Fork. A few vents in this area were smoking and giving off the characteristic sulfurous odor, and there was one large cavernous depression on this slope. Vegetation was limited to grasses throughout most of the burn area, while it was entirely lacking near the fissures and smoking vents. All subsidence openings induced by the coal fire, vents and fissures as well as the smoldering carbonaceous shale unit were blanketed with surface seal material and revegetated in a construction project between December 1987 and September 1988.

NORTH PARK COAL FIELD

The North Park Coal Field includes the North Park Basin, a high, intermontane structural basin of Laramide age. It is bounded by the Medicine Bow/Front Range Uplift on the east, the Rabbit Ears Volcanic Field on the south and southwest, and the Park Range Uplift on the west.

The coals in the North Park Coal Field occur in the Coalmont Formation of late Paleocene to early Eocene age. The formation consists of terrigenous clastics, carbonaceous shales, and coals. The middle Coalmont member is a coarser deposit from braided streams in a rapidly subsiding alluvial basin of moderate relief. The Upper Coalmont Member was deposited in meandering channels and splays as topographic relief in the basin decreased (Hendricks, 1978).

The one active coal mine fire in the North Park Coal Field is in the Coalmont district. A second, relatively small coal fire at the Moore No. 2 Mine was extinguished incidental to reclamation of the Coalmont Mine in 1986 by CIMRP. These mines are near the west edge of the basin, close to the Park Range and the Rabbit Ears Volcanics. The Coalmont Formation strikes west of north and dips 10° to 25° to the northeast. A series of northwest-trending normal faults associated with the down-warping of the basin, cut the area, with displacements generally much less than 500 feet.

RIACH MINE COAL FIRE

The Riach Mine Coal Fire is located in Jackson County, 0.25 mile southeast of Coalmont in the NWSW of Sec. 24, T7N, R81W, Sixth Principal Meridian. It is on the west slope near the crest of a low divide separating Little Grizzly Creek (one mile west) from Grizzly Creek (three miles east). It is reached by travelling on Colorado 14 approximately 24 miles north of the junction with U.S. 40 on Muddy Pass. A light duty road leads west two miles to the town of Coalmont. The fire site is on the north side of the road and is easily approached. Figure 6 is a map showing the general location of the coal fire.

The mine has had several different names—Riach, Birney, North Park No. 1 and Coalmont No. 1. Operations began there as a small wagon mine in 1890. The completion of a railroad to the site in 1911 allowed greatly increased production in the extensive room-and-pillar mine. The fire apparently started by a coffee/warming fire built underground in the mine during the winter of 1915–1916. Several studies were conducted between 1929 and 1966, but no action resulted because of lack of funds or the recommendation that the fire burn itself out. During the interim, the fire spread throughout the mine, slowly collapsing the mine roof and overlying strata, until a large pit of about 12.5 acres formed.

The U-shape of the pit followed the converging limbs of the plunging anticline from which the coal was extracted (Donner and Johnson, 1966). The fire control project was initiated on April 16, 1971, although work was not started until June 4, 1974 and was completed July 13, 1974. The surface sealing method was implemented by 340 hours of bulldozer cut and covering work to emplace a three to eight foot thick seal over the fire area, according to Shellenberger (1974). Inspections on August 14, 1975 and July 19, 1978 noted slight evidence of heating and minimal erosion (Donner, 1962–1976). On November 6, 1980, three surface cracks on the northwestern bench area were recorded, but the condition was termed "otherwise excellent" (Donner, 1962–1976). An inspection at an unknown, later date revealed several hot spots, with collapse features on the north and east sides of the pit.

The inspection for this investigation was made in October 1984 by CGS and CIMRP. At that time, the fire was determined to be active. The main evidence was a line of vents emitting steam along the east wall of the pit, extending from near the bottom of the pit at the north end to high on the pit wall at the south end. The warmth and moisture at the vents supported a growth of lush, green moss and pale green, leafy groundcover, neither of which was growing anywhere else in the area. Further evidence of an active fire was a faint sulfurous odor detected on the flat area southwest of the pit and on the

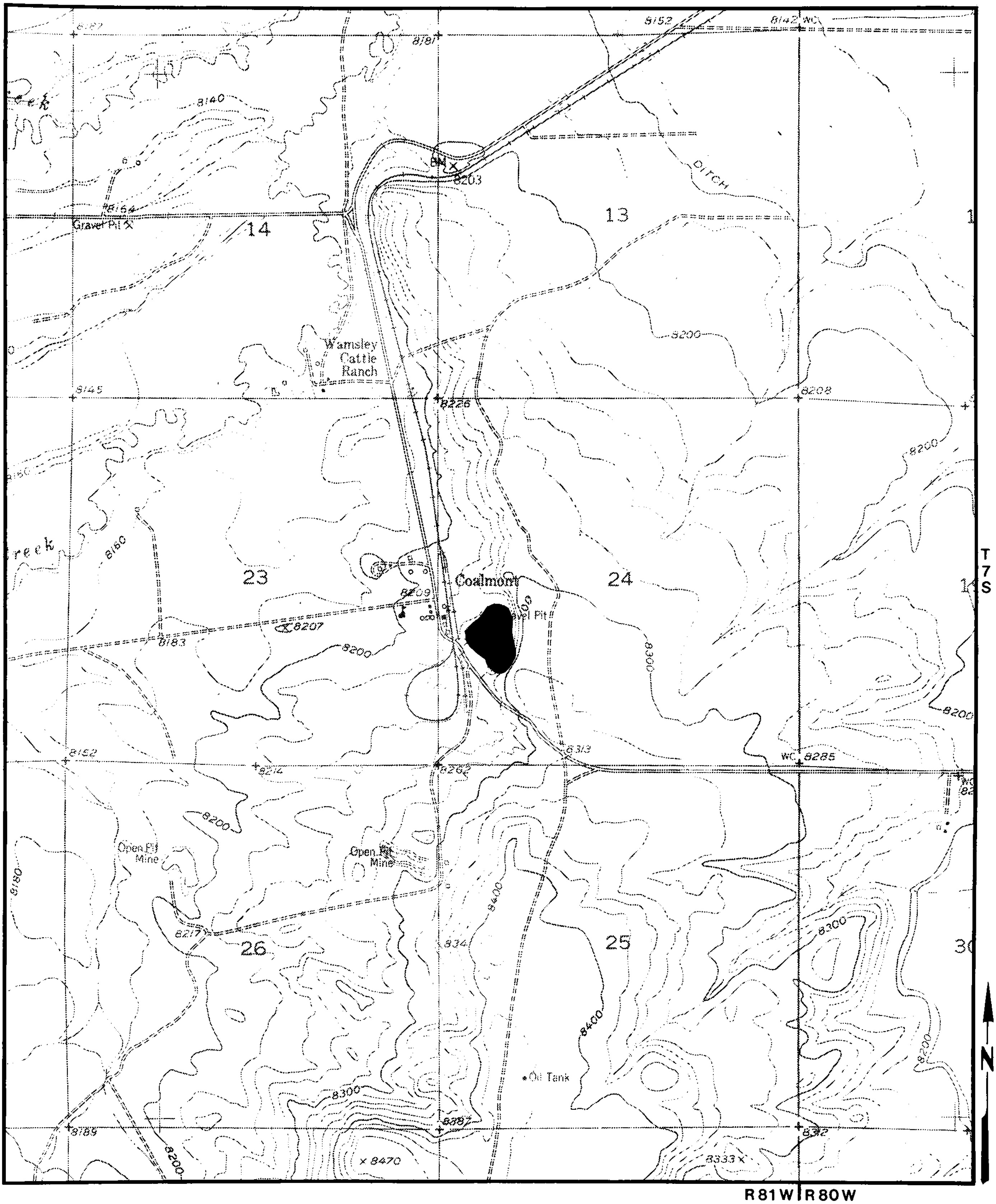


Figure 6. Location of the Riach Mine Coal Fire site (base from Coalmont 7.5-minute Quadrangle, scale 1:24,000.)

southern slope of the west extension of the pit. Although no vents were found in these areas, a snowmelt pattern was observed on that southern slope which may be an indication of internal heating. An inspection in September 1988 showed little change from the previous inspection. The highest recorded temperature was 128°F, in venting at the east and south portions of the pit.

RATON MESA COAL REGION

The Raton Mesa Coal Region occupies the Raton Structural Basin of Laramide age in portions of south-central Colorado and north-central New Mexico. The Colorado portion is bounded on the west by the Sangre de Cristo Uplift, on the north by the Wet Mountains Uplift and the Apishapa Uplift, and on the east by the Las Animas Arch. The basin is asymmetrical, with gentle dips on the east flank and sharply upturned to overturned dips on the west flank. The middle of the Colorado portion of the basin is penetrated by the Spanish Peaks, Tertiary igneous intrusions with many associated dikes, sills, and laccoliths.

There are two coal-bearing formations in the region, the Upper Cretaceous Vermejo Formation and the Upper Cretaceous to Paleocene Raton Formation. As discussed in the Canon City Coal Field section, the Vermejo Formation was deposited in a delta plain setting. The upper part of the formation seems to correspond to an upper delta plain environment (Flores, 1980). The Raton Formation contains a basal conglomerate, suggesting an orogenic source to the west, and the overlying sandstones, siltstones, silty shales and coals represent swamp and floodplain facies (Johnson and Wood, 1956). Thus, both formations represent a progradational sequence from lower delta plain to alluvial plain.

Presently, the only fire in the region is on the refuse dump at the abandoned Morley Mine. The four to eleven foot thick Morley coal bed of one of the lower Vermejo coal zones crops out at the mine. Other Vermejo coal outcrops occur along the margins of the basin. A second smoldering refuse dump, the Sopris, was reclaimed in 1988 incidental to construction work undertaken by CIMRP.

MORLEY MINE WASTE DUMP FIRE

The Morley Mine Waste Dump Fire is located in Las Animas County and is nine miles south of Trinidad approximately in the S1/2SESE of Sec. 36 (unsurveyed Maxwell Grant), T34S, R69W, Sixth Principal Meridian. The dump is on the west slope above Raton Creek and can be reached by taking I-25 south of Trinidad, exiting after 11 miles and heading north on an unimproved road for 1.5 miles to the site of the abandoned town of Morley, the abandoned mine, and the dump. Figure 7 is a map showing the general location of the coal fire.

The Morley mine opened in 1906 and had a peak production of 500,000 tons per year in the late 1920s. It was never mechanized because of the large amounts of methane gas underground. Production slowed in the 1950s, and the mine was closed in 1956 when all workable deposits were exhausted. The date of the fire in the refuse dump is unknown.

Inspections by CGS and CIMRP in September 1984 and again in February 1987 found the evidence of burning, or warming, to be high on the northwest part of the dump. The refuse material was warm to the touch at or within 0.5 feet of the surface in areas of subsidence cracks and small vents. Most temperatures were elevated only 20 to 30 degrees above nominal ground temperature. Venting was not visible but there was an odor. The burning portion of the dump was a lighter red color and coarser-grained than the rest. While grass and small pines grow elsewhere on the dump, there is no vegetation on the burning, or warming, portion. Due to the relatively low temperature of the warming area, and low coal content of the waste pile no abatement action is recommended at this time.

SAN JUAN RIVER COAL REGION

The San Juan River Coal Region occupies portions of southwestern Colorado, southeastern Utah and northwestern New Mexico. The Colorado portion includes the northern edge of the San Juan Structural Basin of Laramide age, the San Juan Uplift on the east, the Gunnison Uplift on the northeast, and the Uncompahgre Uplift on the north.

Although the type locality of the Mesa Verde Group is within this region, it is not time-equivalent with the Mesa Verde Group that is the important coal-bearing section of the Green River and Uinta Coal Regions. Coals in the San Juan River Coal Region occur in the Dakota, Menefee, and the Fruitland Formations, all in the Upper Cretaceous sequence. The Fruitland rocks are time equivalent with the Mesa Verde Group of the Green River and Uinta Coal Regions, and it occupies a similar depositional setting, except that the delta complex was prograding to the northeast here (Manfrino, 1984).

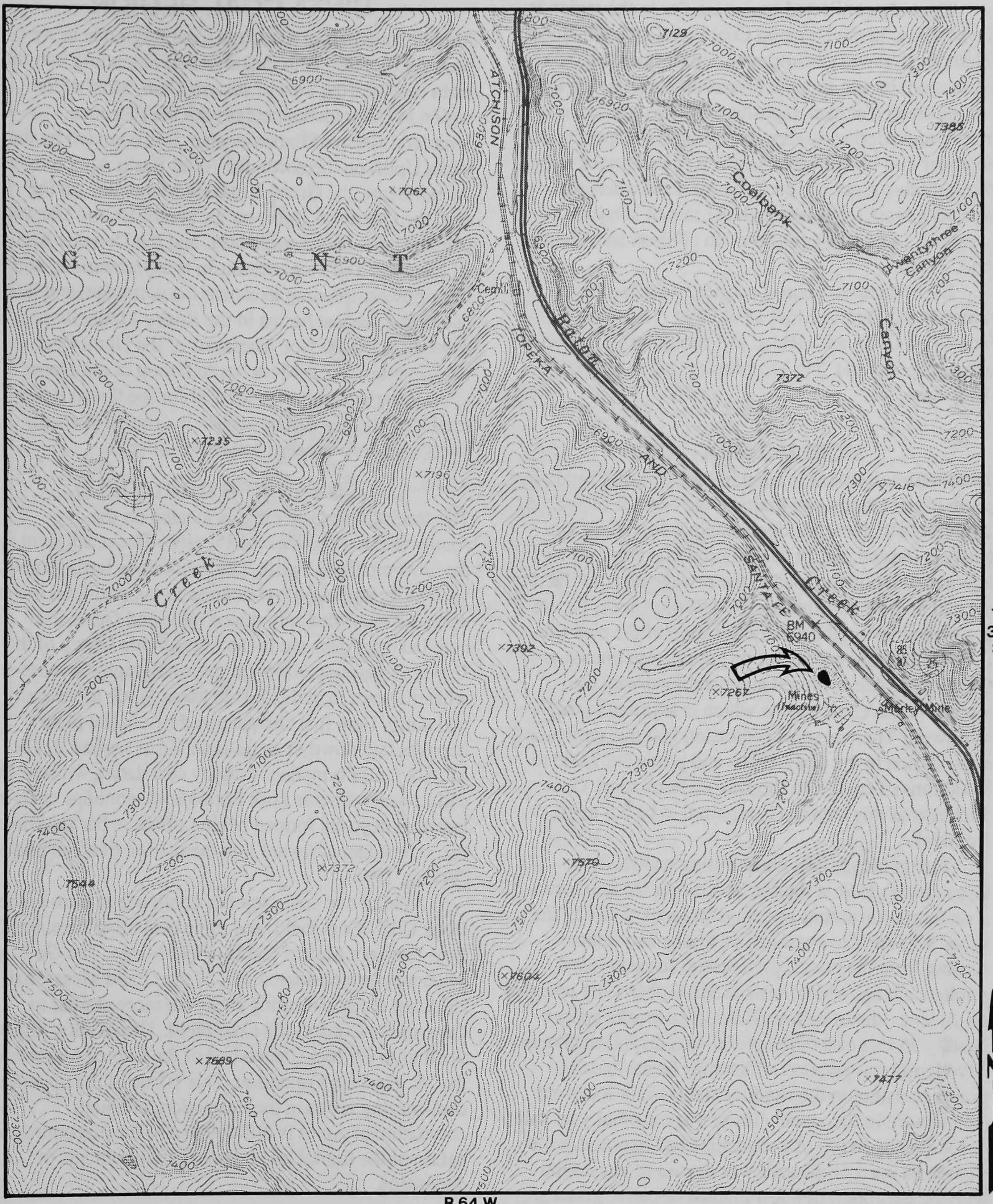


Figure 7. Location of the Morley Mine Waste Dump Fire site (base from Starkville 7.5-minute Quadrangle, scale 1:24,000.)

The only confirmed coal mine fire in the region is the McElmo in the Durango Coal Field, which includes relatively thin and discontinuous coals from the Dakota Formation. In this area the formation consists of a lower unit of braided stream deposits, a middle coal-bearing unit of meandering-stream and floodplain deposits, and an upper unit of shoreface sands. It is interpreted to be a transgressive sequence on a coastal plain where the sediment supply was less than the rate of subsidence, with little or no delta construction (Wilson and Livingston, 1980).

Several earlier control projects were located at mines in the Tongue Mesa Coal Field. The coal field is located on Cimmaron Ridge and could not be inspected due to fencing and "No Trespassing" signs posted by the owner.

MCELMO MINE FIRE

The McElmo Mine is located in Montezuma County just south of the Cortez city limits in the NWNE of Sec. 35, T36N, R16W, New Mexico Principal Meridian. The partly collapsed, partly backfilled portal faces westward into a roadcut on the road to the sewage disposal facility located on a small tributary to McElmo Creek. Figure 8 is a map showing the general location of the coal fire.

Production records for this mine, also known as Old Hopper, are confused and combined with the records of the Cortez Mine which is adjacent to the southwest. There is some indication that this particular mine started in the early 1920s and produced 7,000 to 8,000 tons of coal from the Dakota Formation. Coal thickness at this location is reported to be 3.5 to 10 feet thick.

Fire evidence was noted during a CGS field inspection to look at the site as a candidate for closure of abandoned, hazardous openings in January 1983. The visual signs of fire consisted of smoke and steam venting from the portal, preferential snowmelt and smoke staining. A field visit in September 1984 revealed no direct evidence of fire. Subsidence cracks approximately 75 feet east of the portal area displayed abnormally vigorous vegetation which may be attributed to excess moisture in the summer and warmer localized temperature in the winter. There was essentially no soil development on top of a sandstone bed exposed at the surface so most of the area was devoid of vegetation with the exception of a few clumps of native grasses.

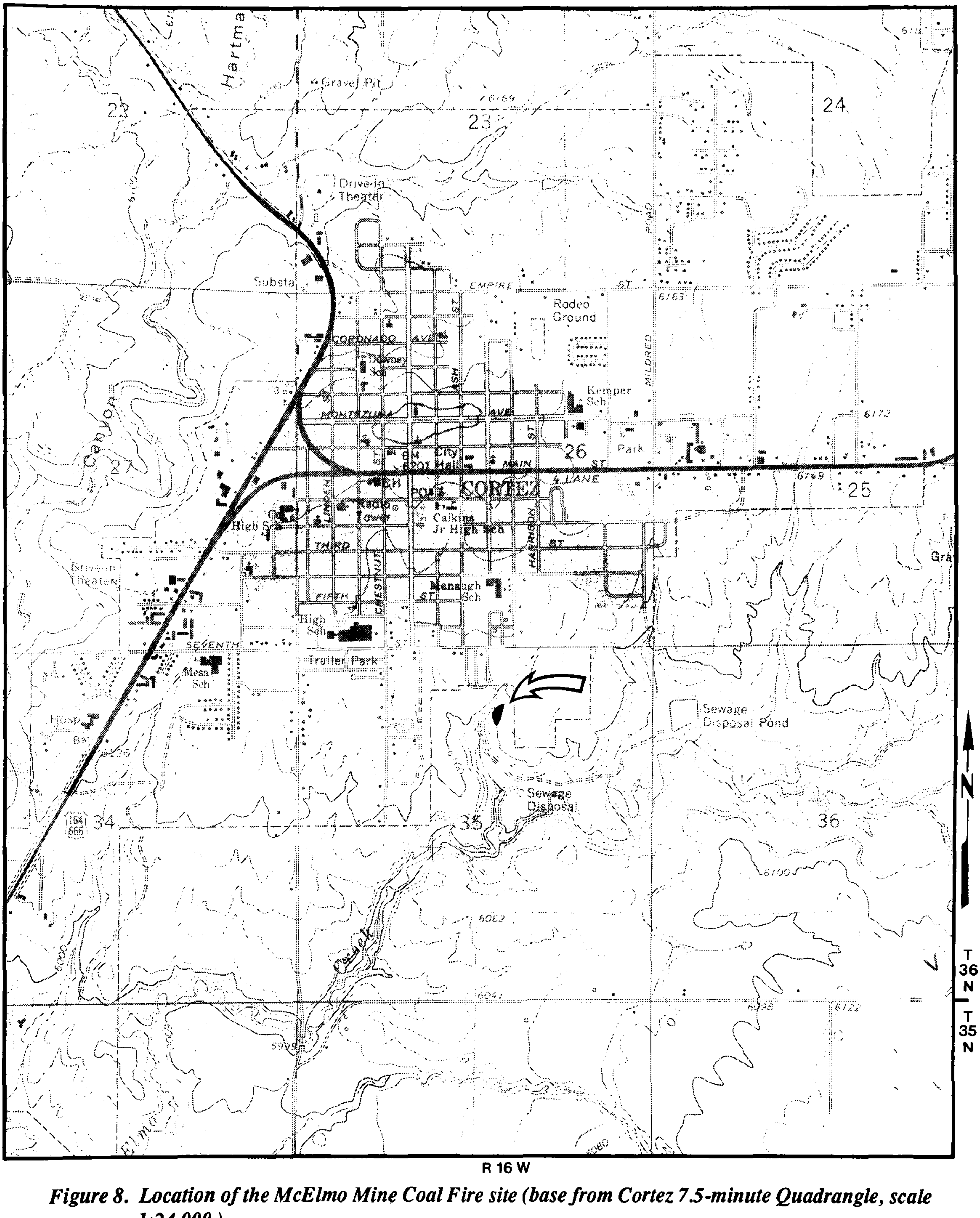
UINTA COAL REGION

Roughly one-half of the Uinta Coal Region is in west-central Colorado, with the other half extending into the main coal-bearing area of eastern Utah. Most of the region in Colorado coincides with the Piceance Structural Basin of Laramide age. It is bounded by the Uinta Uplift on the north, the Axial Basin Anticline on the northeast, the Grand Hogback Monocline on the east, the Gunnison Uplift on the southeast, the Uncompahgre Uplift on the southwest, and the Douglas Arch on the west. The Piceance Basin is asymmetrical, with its northwest-trending axis near the east edge, and it is one of the deepest basins in the Rocky Mountain region, exceeding 25,000 feet. The coals of the Uinta Coal Region occur in the Mesa Verde Group of the Upper Cretaceous system. As discussed for the Green River Coal Region, this deltaic sequence prograded southeastward across most of western Colorado.

BOOK CLIFFS COAL FIELD

The Book Cliffs Coal Field is located on the southwestern margin of the Piceance Basin, adjacent to the Uncompahgre Uplift. The structure is fairly simple, with rocks dipping a few degrees to the northeast toward the basin axis with only minor folds and faults. The coal-bearing rocks are in the Mesa Verde Group of the Upper Cretaceous, although the stratigraphy is somewhat different than the deltaic Mesa Verde to the east and north. Here it is characterized by coastal plain deposits laid down in an on-lap/off-lap sequence. The Mt. Garfield Formation, roughly correlative with the Iles and Lower Williams Fork Formations, contains coals in lagoonal deposits formed behind offshore bar sandstones that interfinger eastward into the marine Mancos Shale (Young, 1955).

At least one coal crop fire continues to burn in the Book Cliffs Coal Field, and three coal mine fires, the Go Boy, Farmer's Mutual and Garfield Mines. The Go Boy Mine may be considered part of the Grand Mesa Coal Feld, but the coal-bearing rocks are more similar to those of the Book Cliffs Coal Field. The Go Boy mined the four to six foot Cameo bed of the Cameo Member of the Mt. Garfield Formation. This is one of the uppermost coal-bearing zones in the Formation, although correlation of zones is difficult due to the discontinuous nature of the littoral and lagoonal environments of deposition.



R 16 W

Figure 8. Location of the McElmo Mine Coal Fire site (base from Cortez 7.5-minute Quadrangle, scale 1:24,000.)

Farmer's Mutual Mine Coal Fire

The Farmer's Mutual Mine is located in Mesa County about eight miles north and east of the intersection of 25 road with the Highline Canal, north of Grand Junction in the SESW of Sec. 36, T9S, R100W and NENW Sec. 1, T10S, R100W; both of the Sixth Principal Meridian. Figure 9 is a map showing the general location of the coal fire.

The Farmer's Mutual Mine is credited with the production of 46,783 tons of bituminous coal from the Lower Mt. Garfield Formation which is Upper Cretaceous in age. The production years for the mine are 1908–1912 and 1916–1951. The mine was opened by a slope driven southeast from an elevation of 5800 feet. A coal seam of average three foot thickness, known locally as the Book Cliffs coal bed, was developed by a combination of room and pillar and, reportedly, longwall mining techniques.

A control project was undertaken between April 1969 and May 1969. The surface sealing method was employed to quench a fire apparently started by a slack dump fire. The fire propagated rapidly down dip (Shellenberger, 1978). Inspection of the coal fire in November 1984 by CGS personnel showed minimal activity in a confined area. An inspection in September 1986 showed no activity and the fire was mapped as inactive. An inspection by CGS and CIMRP in March 1988 indicated resumption of fire activity with minor venting with the highest recorded vent temperature being 125° F.

Garfield Mine Coal Fire

The Garfield Mine is located in Mesa County at the top of the Book Cliffs nearly 1,000 feet above I-70 near Clifton. Vehicle access is gained by taking an unimproved road behind the Cameo Power Plant which winds over eight miles. The coal fire is located in the SESE of Sec. 6, T11S, R98W of the Sixth Principal Meridian. Figure 10 is a map showing the general location of the coal fire.

The mine was operated from 1907–1948 and has posted production of 288,097 tons of bituminous coal from the Lower Mesa Verde Group of Upper Cretaceous age. The mine was opened by the drift method. The coal bed, known locally as the Palisade coal bed, strikes N70W and dips 11NE. The Garfield Mine was developed by room and pillar technique on a three to six foot thick coal zone.

A control project was initiated in May 1969 and completed in June 1969 at the coal fire site. A surface seal was emplaced by drilling and blasting a section of cliff located above the fire site, dropping a large quantity of broken rock onto the fire zone. The surface seal was difficult to work due to its proximity to nearby residences and highways. Some of the mine openings were covered by the surface seal (Shellenberger and Donner, 1969). A CIMRP inspection in October 1987 showed a resumption of coal fire activity.

Go Boy Mine Coal Fire

The Go Boy Mine Coal Fire is located in Mesa County 2.5 miles northeast of Palisade in the NWSE of Sec. 2, T11S, R98W, Sixth Principal Meridian. It is at the head of an unnamed box-canyon that drains west into the Colorado River. Access to the site is gained by travelling east of Palisade on G Road for 2.5 miles and turning right on a light-duty road just before the junction with U.S. 6/24. After 0.25 mile, the road forks. The right hand fork reaches the mine from below by making a left turn after 0.25 mile onto a rough road. Following this road another 0.25 miles, and scrambling on foot over the steep rimrock is necessary to reach the mine portal and fire areas. The left hand fork also approaches the mine from above by turning right after 0.5 miles, heading up the mesa for about one mile, switching back up the rimrock and past the Palisade water treatment plant, then turning right at a locked gate onto an unimproved road and continuing 0.5 miles to the site. Figure 11 is a map showing the general location of the coal fire.

Go Boy is the most recent in a series of mine names for this property including New Grand Mesa, Winger, and Hilltop. The earliest production reported was in 1911, although it has been suggested the mine began operation in 1890. The date and origin of the fire are unknown, although spontaneous combustion is a likely candidate. It appears the fire had started before production ceased in 1968 and that the operation in the final years simply worked around it. Powderhorn Coal Company acquired the mine after its closure and flooded it in an attempt to extinguish the fire, but it was drained too soon and the fire re-kindled. Other reclamation work was done on the site by Powderhorn, including flushing of the fire area by inserting hoses into the vents. This was unsuccessful since the fluids would drain down-dip rather than accumulate in the fire area.

An inspection of the Go Boy Mine Coal Fire was conducted by CGS and CIMRP on December 27, 1984 The cold, rainy conditions were better for observing fire evidence than the warm and dry weather of an earlier, unsuccessful inspection in October. Several vents were noticed on the slope west of the portal. Two vents which

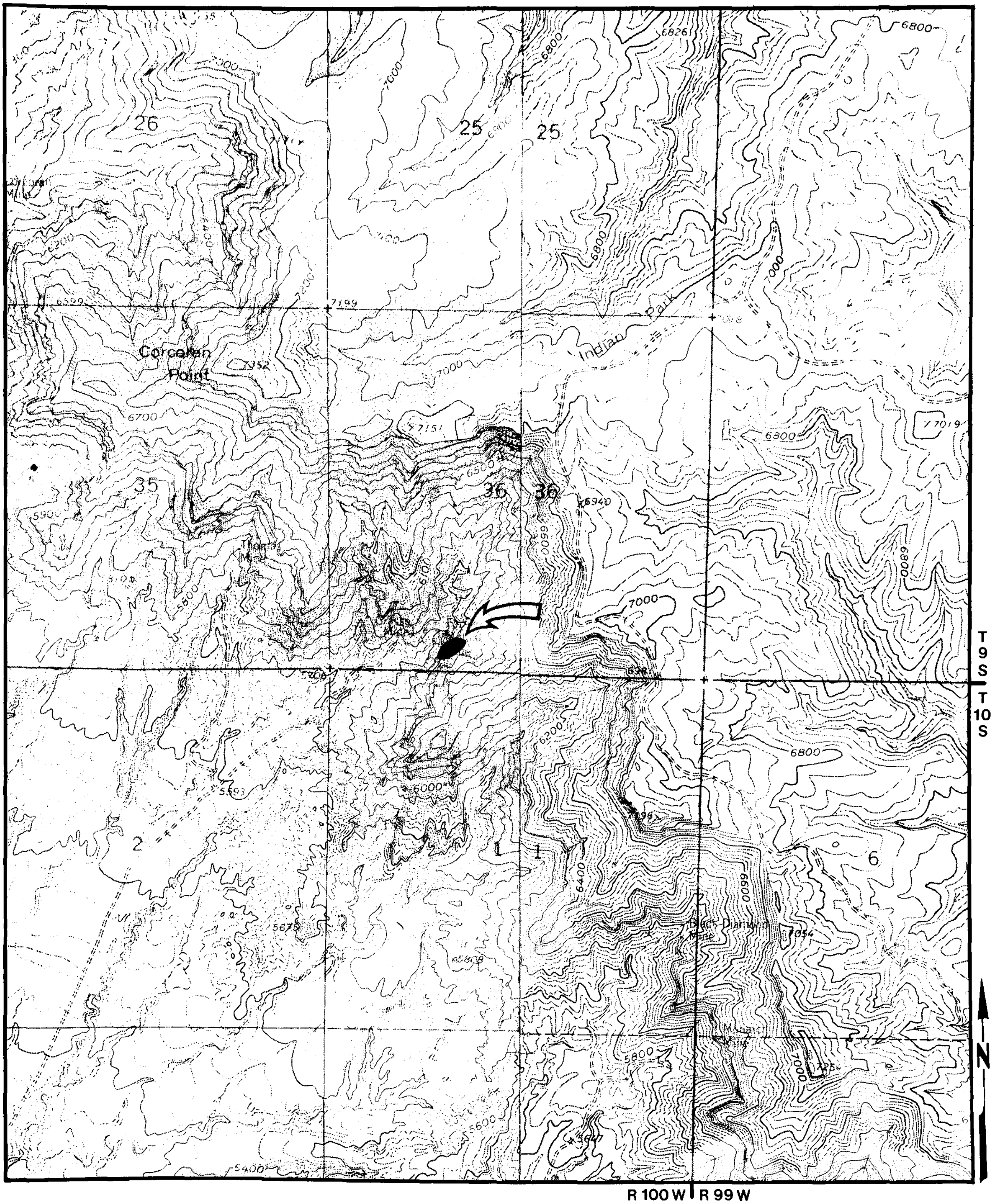


Figure 9. Location of the Farmer's Mutual Mine Coal Fire site (base from Corcoran Point and Round Mountain 7.5-minute Quadrangles, scale 1:24,000.)

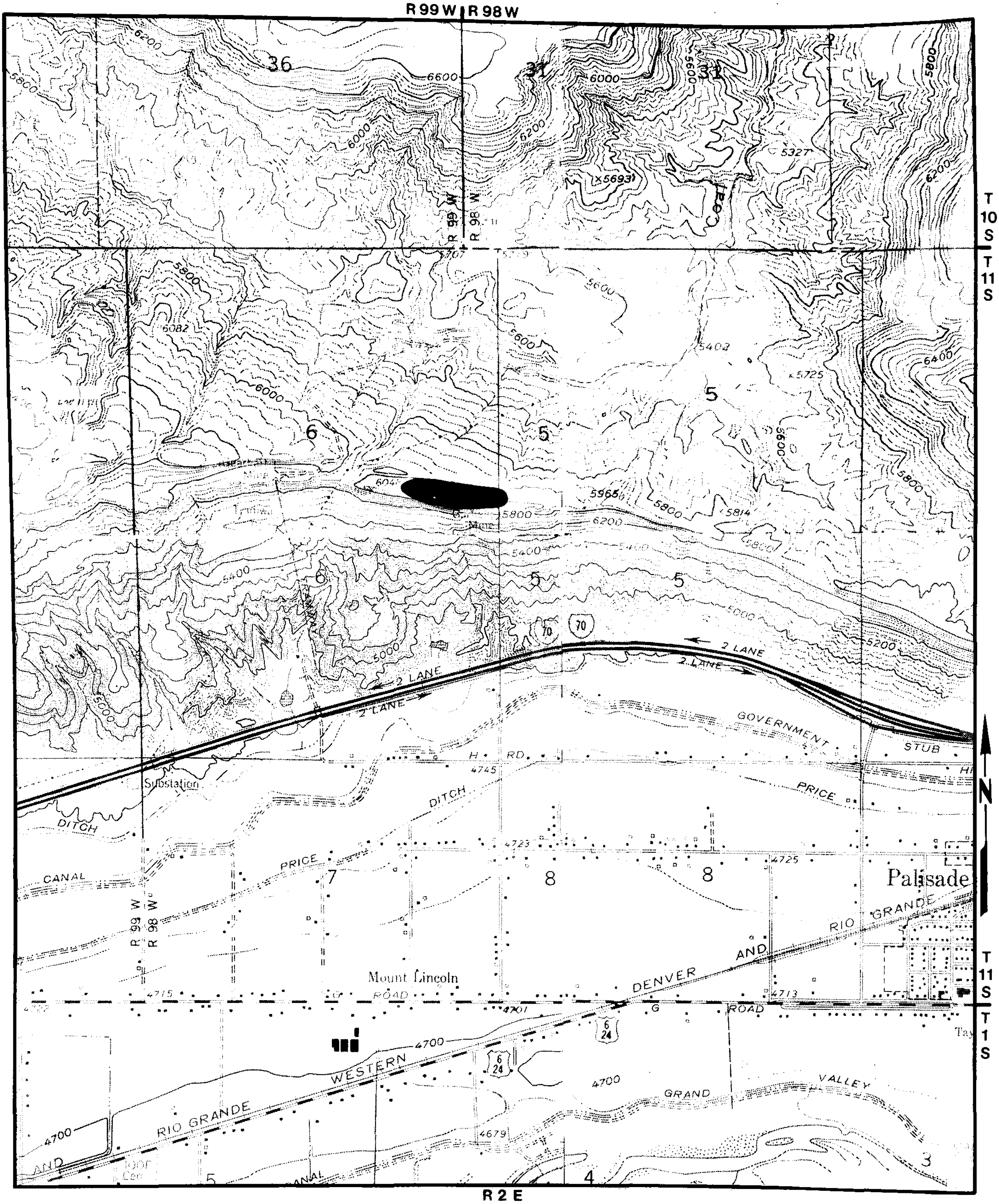


Figure 10. Location of the Garfield Mine Coal Fire site (base from Clifton and Palisade 7.5-minute Quadrangles, scale 1:24,000.)

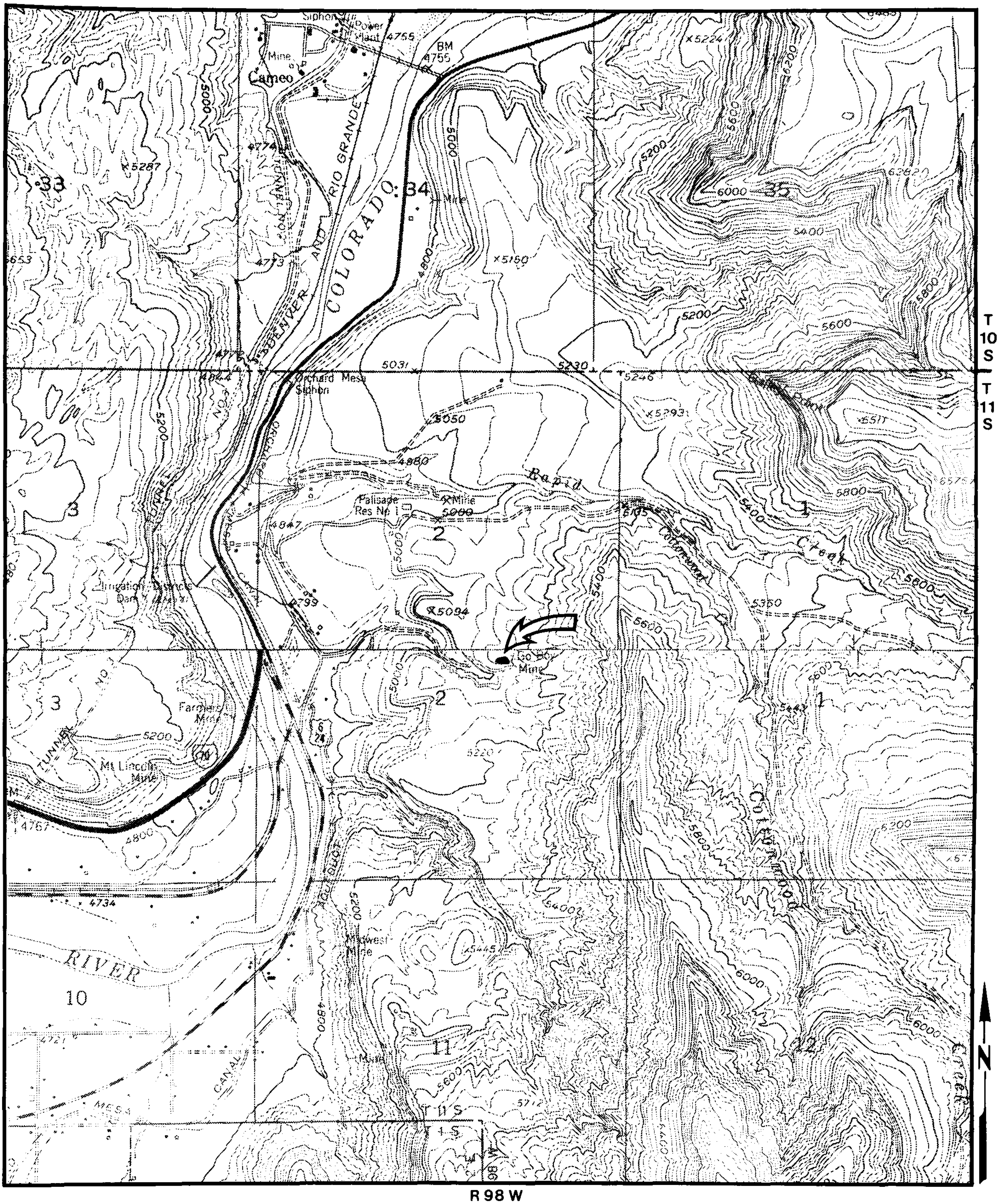


Figure 11. Location of the Go Boy Mine Coal Fire site (base from Cameo and Palisade 7.5-minute Quadrangles, scale 1:24,000.)

lacked active emanations appeared to have been enlarged, perhaps by the flushing activity or erosion. Another was stained and actively smoking, and a hose was still present in it, leading from the base of the slope to the vent. Vegetation was sparse in the immediate area of the vents but was otherwise unaffected on the slope.

Drilling of the Go Boy Mine Coal Fire was done by CGS in February 1985. Two of the eight drillholes were lost between 1985 and 1986 due to flushing, other thermocouples in the drillholes indicated persistence of relatively low fire-induced temperatures through inspections into 1987. Inspection of the Go Boy in December 1987 showed emanation from the ventilation shaft of low, 125° F, temperature, sooty smoke. The ventilation shaft of the Go Boy Mine was capped by CIMRP in 1988.

Smoky Mountain Coal Crop Fire

The Smoky Mountain Coal Crop Fire is located in Mesa County 14 miles north of Fruita approximately in the CSENW of Sec. 19, (unsurveyed) T8S, R101W, Sixth Principal Meridian. It is high on a west-facing slope above a canyon on the south side of Coal Gulch Creek. The site is reached by following U.S. 6/50 one mile west of Fruita, turning right on county road 16 and travelling 6.25 miles north. There, a light duty road continues north, and after about 6 miles, an unimproved road bears east. Within 3.5 miles, the mine at the base of the canyon containing the fire site is seen, and 0.25 mile farther, the bulldozed road leading to the fire site turns south. This grade climbs the steep canyon slopes in a distance of two miles, arriving immediately above the fire area. The site is on and surrounded by land administered by the Bureau of Land Management, and all minerals are federally owned. Figure 12 is a map showing the general location of the coal fire.

There never was an active mine or prospect of record in the fire area, although there is an abandoned mine at the base of the canyon where it meets Coal Gulch, and one on the other side of Coal Gulch. The origin of the fire is unknown, but is believed to have been caused by spontaneous combustion or lightning. The fire was known by ranchers to be burning for many years, and residents claim the fire was burning when the region was settled in the 1860's. A fire control project was deemed necessary because of the millions of tons of coal threatened on this federally-owned land.

Initial studies for the project began in 1958, and work started on July 11, 1961. The surface sealing method was implemented, using bulldozer cut and covering. However, the steep nature of the terrain, the large area to be covered, and the numerous sandstone ledges on the slope forced the project to be carried out over a three-year period. Three different access roads had to be built, and the bulldozer work was supplemented by jackhammer and wagon-drill drilling and blasting. By September 21, 1964, a four to eight foot thick seal had been emplaced over the fire area (Donner and Johnson, 1965). Additional bulldozer work was required in 1965 and 1966, while inspections on September 14, 1967, September 26, 1968, April 30, 1973, and October 11, 1975 needed only hand shoveling to cover hot spots (Donner, 1962–1976).

The inspection on October 27, 1984 by CGS found the fire to be active still. Much of the sealed area near the top of the slope was lacking vegetation as well as snow cover from a light, overnight snowfall. Also, vents near the sandstone ledge topping the ridge above the disturbed area were actively smoking, and the strong sulfurous odor was detected before the area was in sight.

DANFORTH HILLS COAL FIELD

The Danforth Hills Coal Field is at the northern limit of the Uinta Coal Region, on the south flank of the Axial Basin Anticline. Here, the Iles and the Williams Fork Formations are still predominantly non-marine, but shale members have become more important. For example, the Mancos Shale Tongue of the Iles Formation at Meeker thickens to the south as basal sandstones pass through facies changes into the Mancos Shale (Collins, 1977). Likewise, tongues of marginal marine sediments equivalent to the Lewis Shale occur in the middle of the Williams Fork Formation at Meeker (Newman, 1965).

The Danforth Hills Coal Field has two structural elements—the Axial Basin Anticline with its accompanying folds, and the Grand Hogback Monocline. There is a coal mine fire occurrence in each of these. The Axial Mine Coal Fire is near the axis of the Collom Syncline, where the rocks dip almost imperceptibly to the southwest. Coal from two beds nearly 45 feet thick (Collom A and B) in the middle group of the Williams Fork Formation was mined there. The Black Diamond Mine Coal Fire is on the north-trending Grand Hogback but is very near a pair of faults that mark its termination at the Sulphur Creek Syncline. Here, coal mined from the 18 foot thick A bed of the Black Diamond Group (Upper Iles Formation) gives the mine its name. A third mine fire, the Rienau, is situated between the other two fires on the south flank of the Sulphur Creek Syncline. The 11 to 20 foot thick Rienau coal bed was

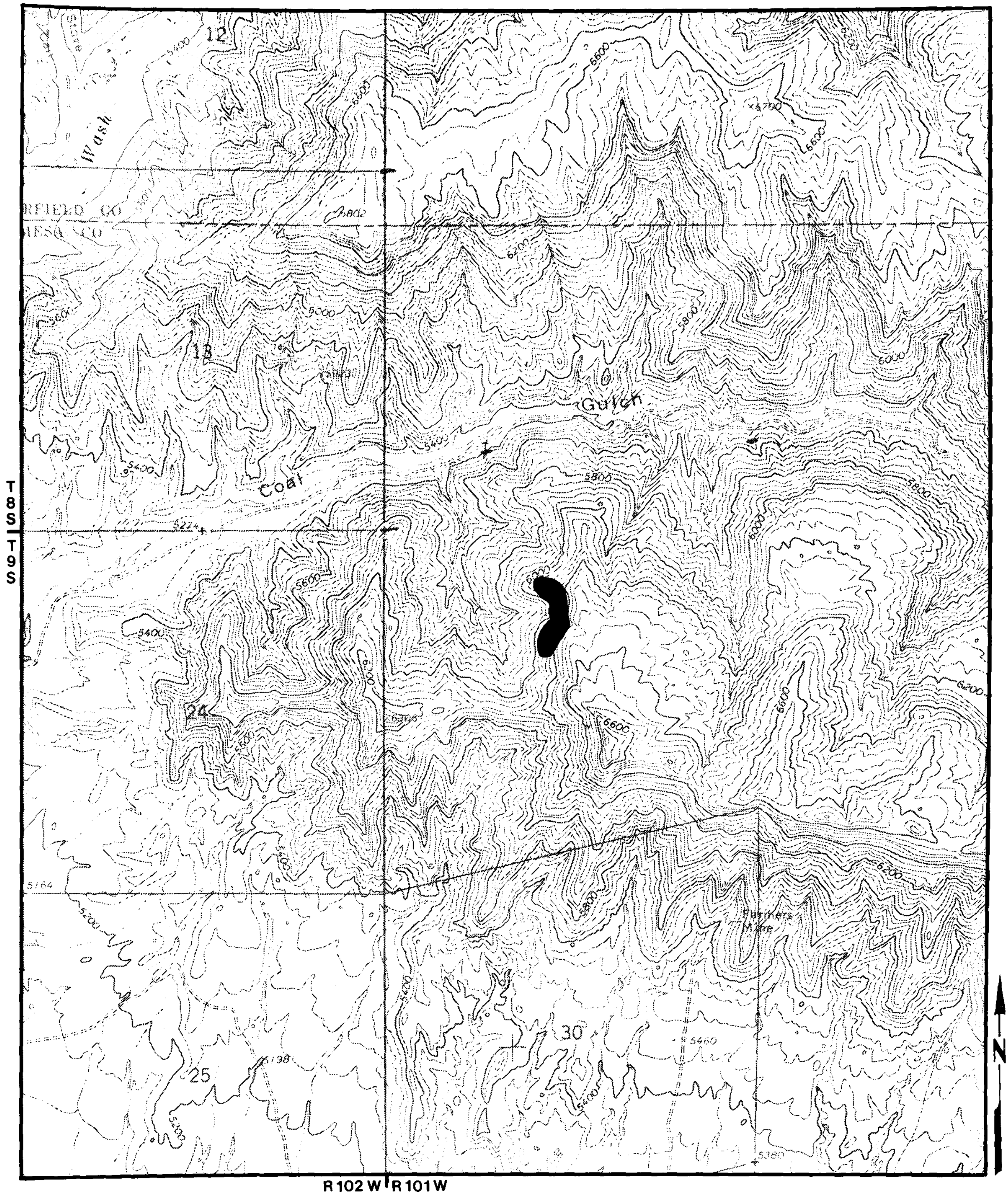


Figure 12. Location of the Smoky Mountain Coal Crop Fire site (base from Ruby Lee Reservoir 7.5-minute Quadrangle, scale 1:24,000.)

mined there from an uncorrelated zone in the Williams Fork Formation.

Axial Mine Coal Fire

The Axial Mine Coal Fire is located in Moffat County 28 miles southwest of Craig and 18 miles north-northeast of Meeker, at the SWNWNE of Sec. 2, T3N, R93W, Sixth Principal Meridian. It is on the east-facing slope above Good Spring Creek and on the south-facing slope above Streeter Gulch at the junction of the two, immediately west of Colorado 13/789. Although it is only a short distance up the slope above the road, access is blocked by a Colowyo Coal Company property fence. The Colowyo Coal Company office is about 2.5 miles north of the fire site, 0.25 miles west of the highway, and permission for access must be obtained. Figure 13 is a map showing the general location of the coal fire.

The mine was first known as the Collom Mine, when opened by Joseph Collom in 1906–07. It became the Streeter Mine when ownership changed hands in 1937. Production increased tenfold at this time from an average of 750 tons of coal per year to over 7,500 tons, due to the use of mobile mechanized equipment. Prior to 1944, all production was from the upper coal bed, accessed by two drifts. The upper bed was closed in the spring of 1949. Production from the lower coal bed with access by three drifts, began in 1944, but was halted by the collapse of the mine on October 19, 1951. Incompetent pillars in the upper mine and insufficient superjacent pillars within the two mines probably could not support the overlying massive sandstone (McConnell, 1953).

It is believed that a fire started in the mine from spontaneous combustion of pulverized and broken coal from the collapsed pillars. Smoke was first observed on January 4, 1953 rising from the upper mine portals, which were closed three months later. Then in the spring of 1957, smoke was seen venting from the lower mine portals, and they were closed with dirt and rock by mine employees. By 1961, the fire was still burning in both beds, and a control project was recommended.

According to Ratkovich and Dimitroff (1961b), the surface sealing method was performed by bulldozer cut and covering between October 2 and October 25, 1962. Sixteen inspections between 1963 and 1970 required additional work, often the removal of rocks which had created voids in the cover. By 1971, it was apparent the fire had progressed to an area where one of the lower portals intersected a portal to a neighboring active mine, the Red Wing (also called the Shaver). So from July 1, 1972 to November 22, 1972, a second phase of the control project was undertaken, involving surface sealing and limited fire barrier work in the area of the intersecting portals (Shellenberger, 1972a).

Field inspections by Donner on October 31, 1973 and February 28, 1974 found general cooling of the fire area, with snow remaining in shady spots where the barrier work had been done. But a March 9, 1976 inspection reported venting on the point of the ridge, an unworked section between the south and east facing slopes. And by August 30, 1978, the valley fill from the adjacent Colowyo Surface Mine had obscured the barrier work, and there was renewed fire activity on the mid-slope cut area. It was reported that the mine fire would be completely reactivated if left unattended.

The inspection for this investigation was conducted by CGS and CIMRP on October 25, 1984, and though access to the fire area was restricted by Colowyo Coal Company property fences, steam or smoke was seen venting occasionally from the mid-slope cut near the point of the ridge. The character of the fire had not changed during a site inspection of March 1987.

Black Diamond Mine Coal Fire

The Black Diamond Mine is located in Rio Blanco County one mile north of Meeker in the SENW of Sec. 15, T1N, R94W, Sixth Principal Meridian. The mine portal faces south into a steep-sided valley at the confluence of an unnamed tributary and Anderson Gulch. The roof is composed of massive, well-jointed sandstone. Original access to the mine was via wagon road in the bottom of Anderson Gulch. Large sections of this roadway have been destroyed by ongoing erosion since the mine was closed. In the mid 1950s a fire road was cut into the area from the east and it climbs out of the drainage about 0.25 miles south of the portal. The mine and old, fallen surface structures are clearly visible from the footpath in the bottom of Anderson Gulch which is littered with coal debris all the way to the mine. Figure 14 is a map showing the general location of the coal fire.

The Black Diamond produced just over 30,000 tons of subbituminous coal from the Sulfur Creek unit of the Cretaceous Iles Formation between 1916 and 1930. The mine was closed due to the fire in 1930 and the portal was sealed until 1938 when it was reopened. The fire was still going so the adit was closed again.

A field inspection conducted by CGS and CIMRP in September 1984 revealed the fire to be active. The total affected area is approximately three acres. The active fire is adversely affecting 0.2 acres. Noxious

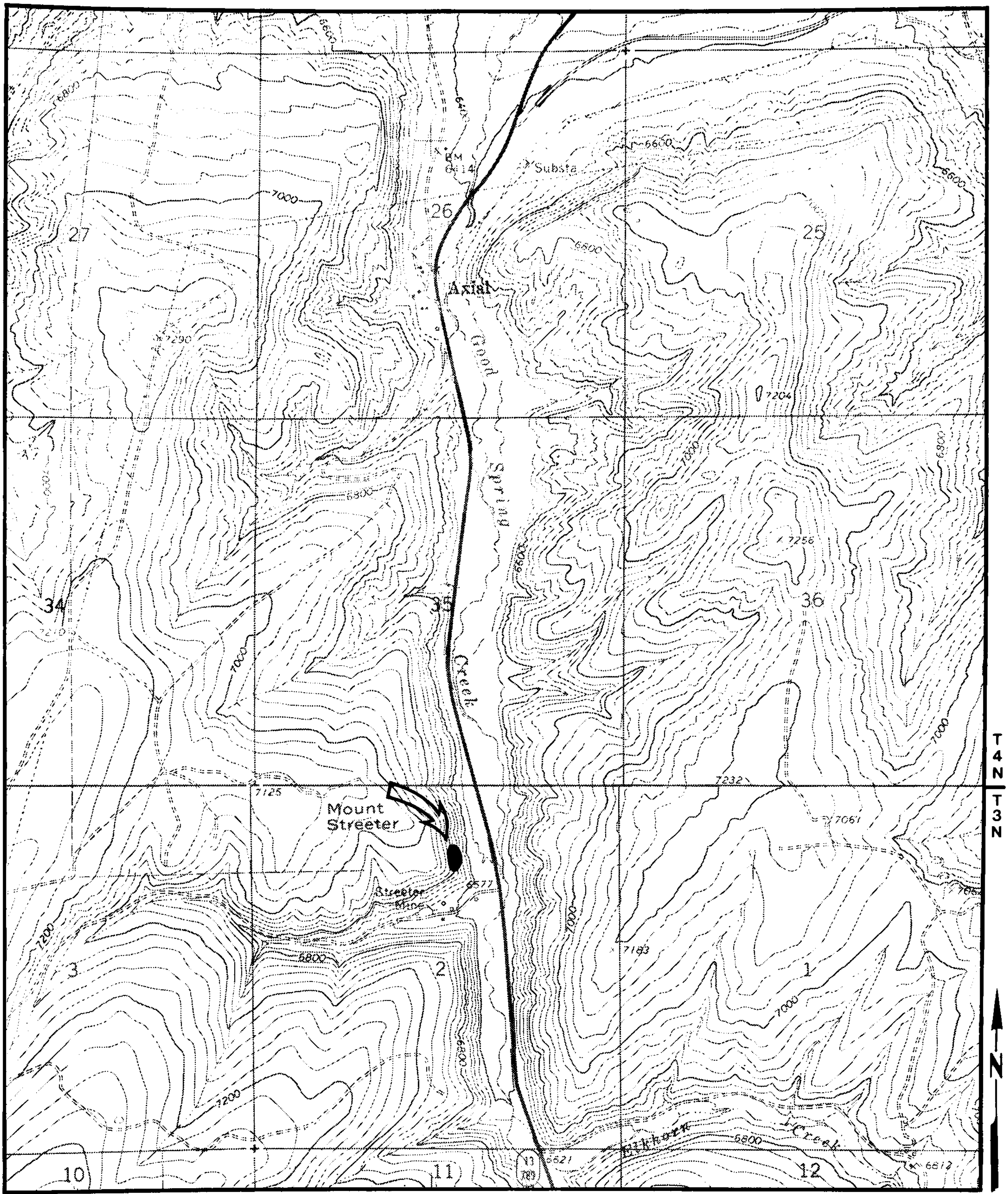


Figure 13. Location of the Axial Mine Coal Fire site (base from Axial 7.5-minute Quadrangle, scale 1:24,000.)

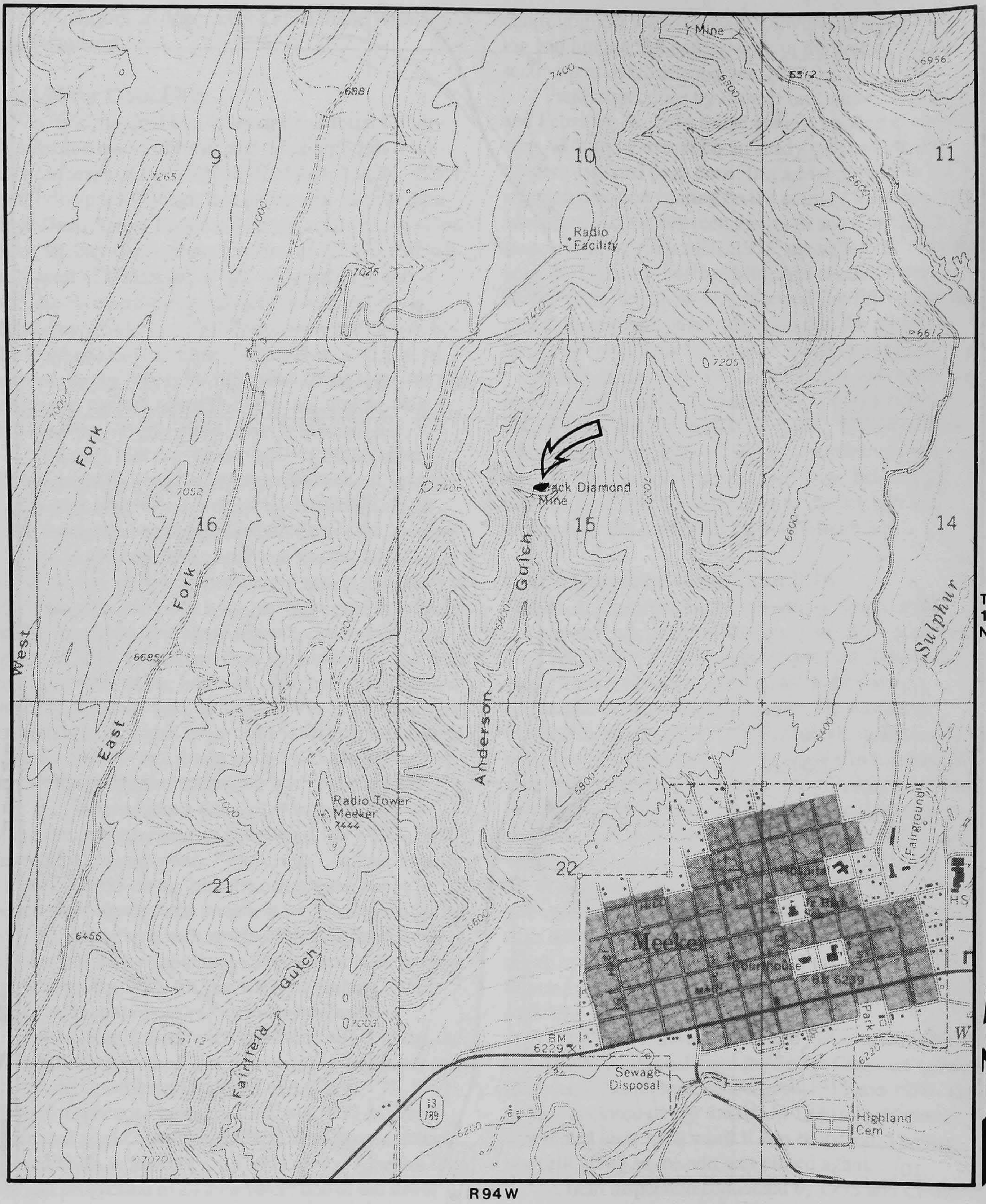


Figure 14. Location of the Black Diamond Mine Coal Fire site (base from Meeker 7.5-minute Quadrangle, scale 2:24,000.)

fumes of sulfur and venting steam and smoke are issuing from several small vents. The orientation and location of the vents is controlled by subsidence along the well-developed joint pattern in the overlying sandstone. The fire is of very low activity and restricted area but the opportunity for it to spread under the sandstone ridge to the north is real albeit small. Localized vegetation distress was observed in close proximity to the active vents and a line of dead conifers clearly marks the historic path of the fire front across the area.

Rienau Mine Coal Fire

The Rienau Mine Coal Fire is located in Rio Blanco County seven miles north-northeast of Meeker in the W1/2NWSE of Sec. 29, T2N, R93W, Sixth Principal Meridian. It is on the east slope above Curtis Creek across from the Rienau No. 2 Mine. It can be seen from Colorado Highway 13/789 which follows the creek through this narrow valley. Figure 15 is a map showing the general location of the coal fire.

The mine operated between 1928 and 1965, and the current operations on the west side began in 1965. The origin of the fire is unknown, and it is said to have started before 1970, according to personnel of Inter-North Company. Small-scale control efforts are thought to have taken place. There is very little documentation on the fire.

The site was inspected by CGS on December 28, 1984. The snowmelt pattern was very striking, noticeable from the highway from a distance of several hundred feet. The northern end of the snowmelt area was low on the slope and near the mine portal. Several slump features were apparent there and vegetation was sparse. To the south, the snowmelt area paralleled the slopes, and no venting was observed. A few horizontal, linear vegetation patterns suggested isolated subsidence, but the dominant evidence of disturbance was the lack of snow cover. An inspection May 1987 showed acceleration of the fire upslope and temperatures at the surface near 350° F.

GRAND HOGBACK COAL FIELD

The Grand Hogback Coal Field is located on the eastern margin of the Piceance Basin. It follows a north-south trend from Meeker to about 10 miles northwest of Rifle, then runs east-southeast to near Glenwood Springs, then south again to a point about 20 miles west of Aspen. En echelon faults exist at the flexures in the monocline, and minor folding occurs at the southern end near the Tertiary intrusives of the Gunnison Uplift. The stratigraphic character of both formations in the Mesa Verde Group becomes more shaly to the south. At its southern end, the Williams Fork Formation is subdivided to include the Bowie Shale and the Paonia Shale. Though still largely non-marine, these lower deltaic plain sediments (lagoonal, paludal, and lacustrine) do contain significant marine intervals as far north as New Castle (Collins, 1977).

Coal mine fires of the Grand Hogback Coal Field are all located on the hogback itself. Because of the steep dips, from 40° to nearly vertical, they represent the greatest challenge in terms of abatement. All burning mines in the field are on the east-southeast-trending portion of the hogback and all have mined coal from the Wheeler and/or Allen coal groups of the Williams Fork Formation. Bed thicknesses vary from six to sixty feet, with up to 1,000 feet of overburden.

Burning Mountain No. 1, No. 2 and No. 3 Mine Coal Fires

These three separate coal fires in Garfield County are located along a 3.5 mile stretch of outcrop along the Grand Hogback. The outcrop is exposed at the west edge of the New Castle town limit and continues 3.5 miles to the west-northwest, from the SWSWNW, of Sec. 31, T5S, R90W, to the N1/2SESE of Sec. 21, T5S, R91W, Sixth Principal Meridian. The fires are on the steep north-facing slope above Elk Creek. Two of the fires have been considered outcrop fires rather than mine fires, but all three are adjacent to abandoned mines. All three fire areas are readily observed from the Elk Creek Road northwest of New Castle, but do not have a common access. The Burning Mountain No. 1 Mine Coal Fire may be best approached by climbing the slope above the I-70 frontage road (U. S. 6 and U. S. 24) on the west side of New Castle west of Elk Creek. A trail to the Burning Mountain No. 2 fire starts at an unimproved road just south of Elk Creek Road about three miles from New Castle, and the Burning Mountain No. 3 Mine Coal Fire may be reached above a similar unimproved road one mile farther from New Castle. Figure 16 is a map showing the general location of the Burning Mountain No. 1 Mine Coal Fire. Figure 17 shows the general location of the Burning Mountain No. 2 and 3 Mine Coal Fires.

Unfortunately, the information on these mines is sparse. The Burning Mountain No. 1 fire is associated with a New Castle Mine shown on a map of inactive coal mine data (Turney and Murray-Williams, 1984) but none of the information sheets for mines with that name

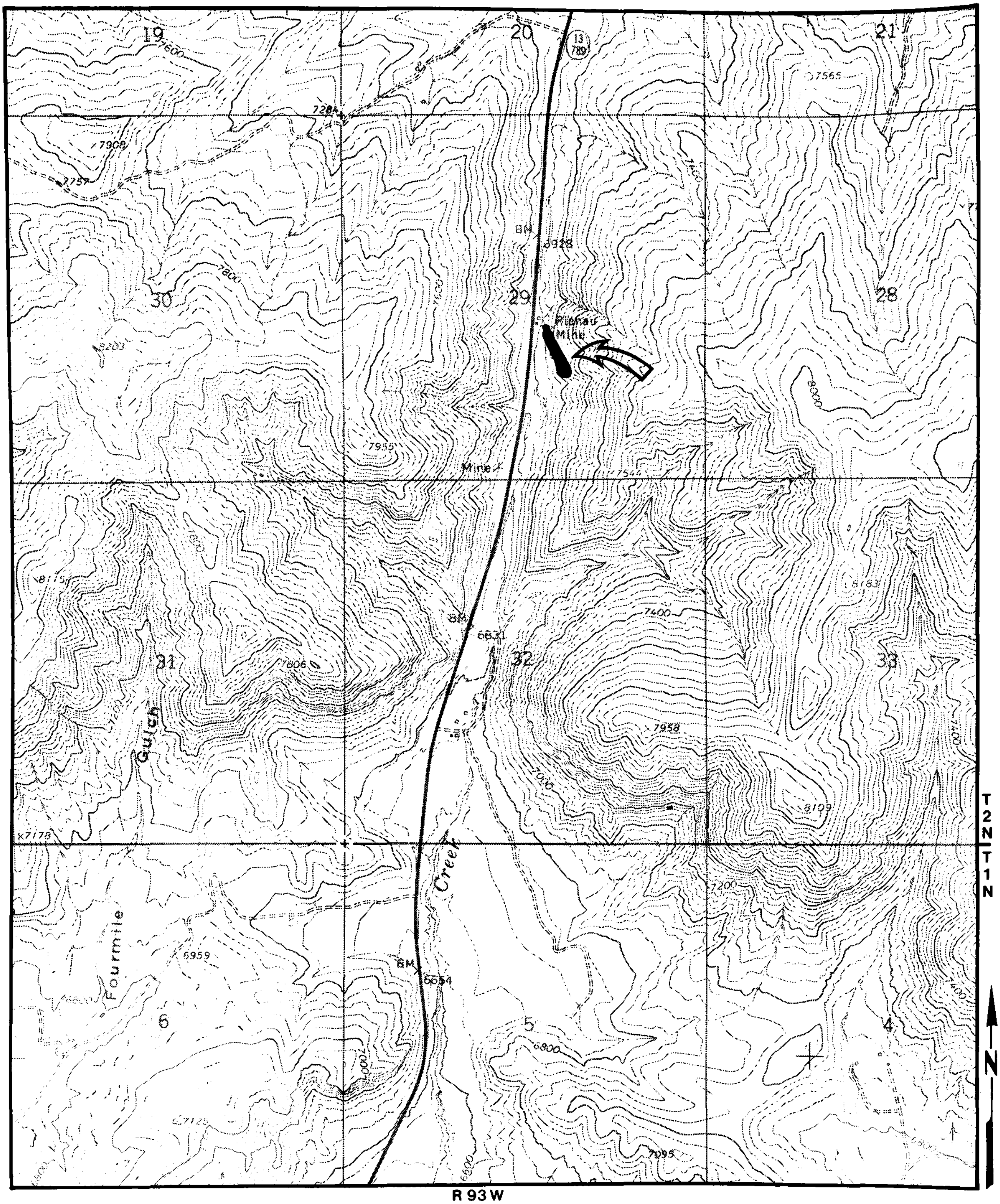


Figure 15. Location of the Rienau Mine Coal Fire site (base from Rattlesnake Mesa 7.5-minute Quadrangle, scale 1:24,000.)

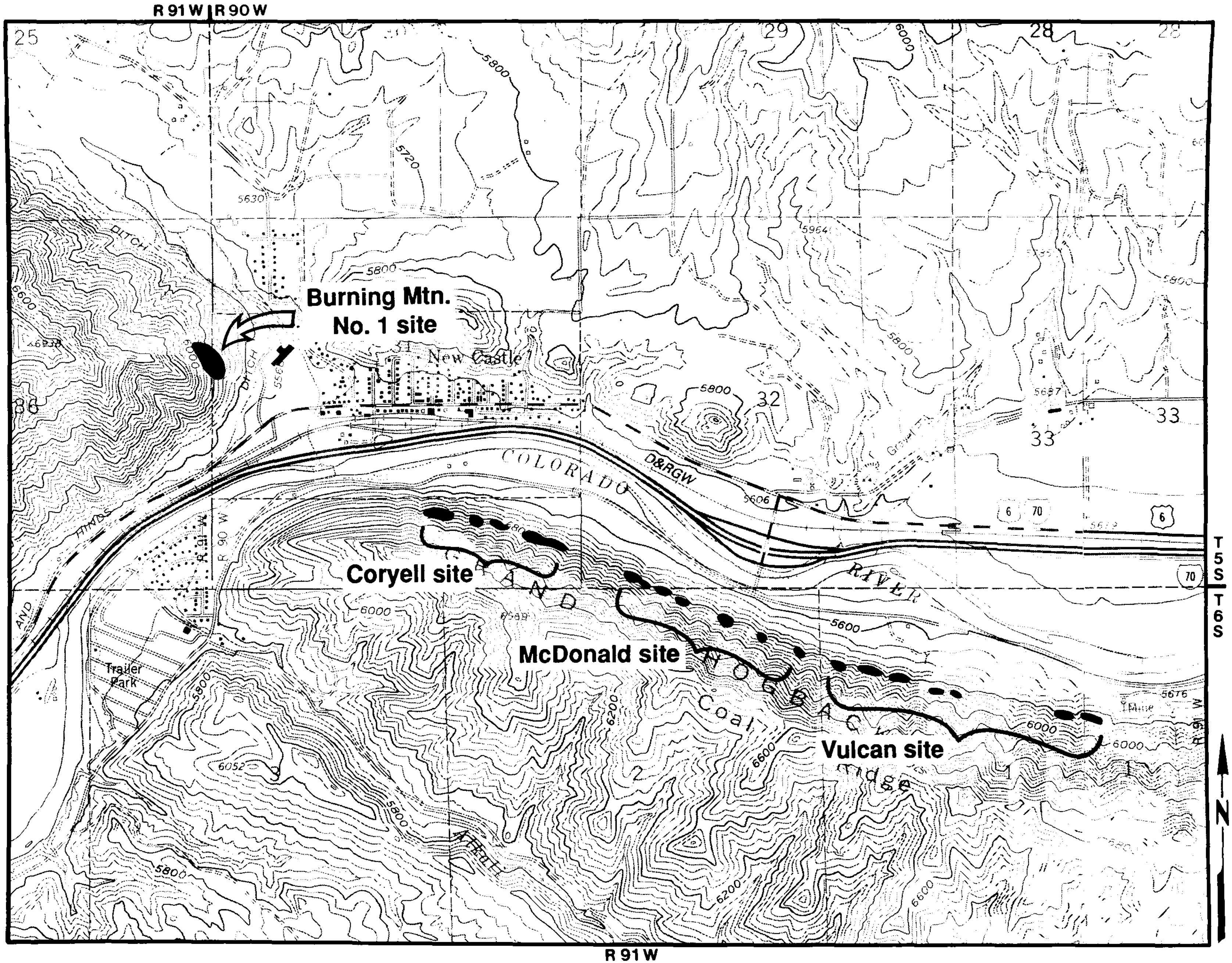


Figure 16. Location of the Burning Mountain No. 1 and McDonald-Coryell-Vulcan Mine Coal Fire sites (base from New Castle and Storm King Mountain 7.5-minute Quadrangles.)

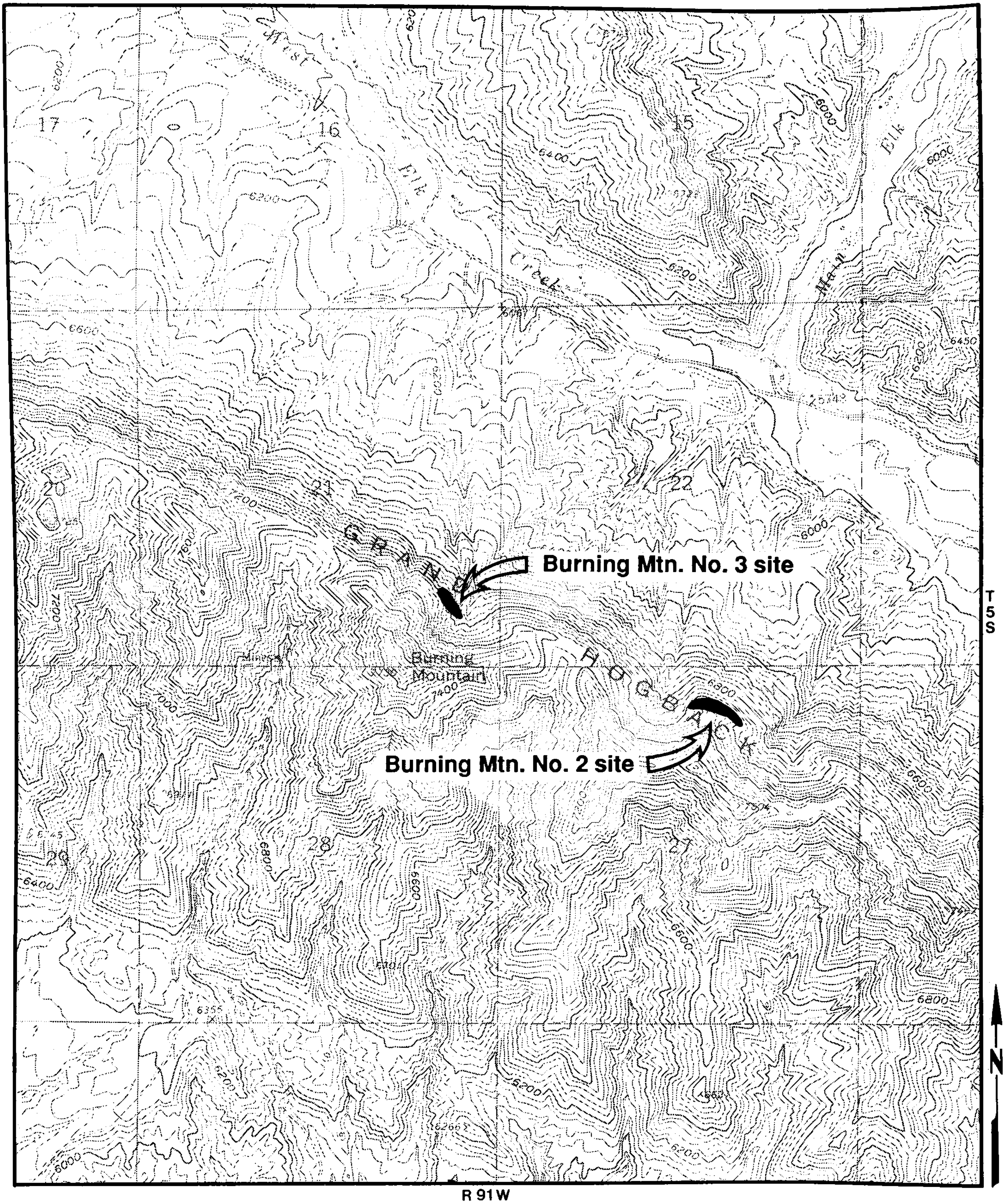


Figure 17. Location of the Burning Mountain No. 2 and 3 Mine Coal Fire sites (base from New Castle 7.5-minute Quadrangle, scale 1:24,000.)

give a location there. So the years of operation and the data and cause of the fire are unknown. The Burning Mountain No. 2 Mine Coal Fire appears to be related to the Elk Creek/Peacock Mine. It operated between 1896 and 1936, but there is no mention of fire. The Burning Mountain No. 3 Mine Coal Fire has the same location as the Morgan Mine, also called the Silt Mine and the Llewellyn Mine. These operated between 1929 and 1941; and again, there is no report of fire. OSM records show that Burning Mountain No. 2 and No. 3 Fires were visited on June 15, 1971 and September 13, 1975. The Burning Mountain No. 2 Fire was moderately active during the first inspection with three large vents exhausting hot gases, alteration of surrounding rocks, and coal impregnated with crystalline sulfur. The second inspection found numerous small vents emitting steam only. The Burning Mountain No. 3 Fire was characterized by small vents and an older fire area overgrown with scrub oak on the first visit. The second visit recorded only steam issuing from vents, one described as a small grotto-like opening. Both fires had some hand-shoveling cover work done on the later inspection. Other than that, no fire control work has been reported for any of these three fires.

This report summarizes an inspection made by CGS and CIMRP in October 1984. A light snowfall greatly enhanced the visibility of fire activity. All three fires lacked snow cover, and characteristic red and green colors were revealed. The red color was due to barren, weathered, and possibly altered, bedrock in the disturbed area, while the green color was grass growing near steam-emitting vents. All three also appeared to have a few vents emitting smoke or steam condensate as whitish clouds were visible from up to a mile distant. The character of the coal fires had not changed as observed in a subsequent visual inspection made in October 1988.

D & H Coal Mine Fire

The D & H Mine Coal Fire is located in Garfield County about seven miles northeast of Rifle in the NENENE of Sec. 17, T5S, R92W, Sixth Principal Meridian. It is on an east-facing slope at the head of a canyon draining into Rifle Creek on the south side of the Grand Hogback. The mine is accessed by a right turn from Highway 325 1.25 miles north of its intersection with Highway 13/389. A gravel road crosses the Rifle Creek Valley and winds up to Cactus Mesa. A mine road winds two miles up Haas Canyon to the coal fire area. Figure 18 is a map showing the general location of the coal fire.

The Dutton & Halsey, or D & H, mine was portalled in the period between 1898 to 1900. U.S. Bureau of Mine records report that the coal fire started in 1915 or 1916 within the mine workings on fee land. It is most likely that the fire in the D & H Mine ignited the nearby, and younger, I.H.I. Nos. 1 and 2 Mine Coal Fires. As with most mined coals in the Grand Hogback field the rank is high volatile B bituminous. The presumed cause of the fire is spontaneous combustion of broken coal in an underground room.

The mine worked the 10 to 12 foot thick Wheeler coal seam about 300 feet up from the canyon floor. According to Gale (1910) the D & H Mine had driven about 400 feet along the N75W striking coal. Raises in coal were driven up 80 feet on 40 foot centers. A second portal was driven about 225 feet downslope also in the Wheeler seam at an elevation of about 7,000 feet. The second portal also accessed the stratigraphically lower D seam through 20 to 30 foot drifts across the 55° to 75° dipping sequence.

According to U.S. Bureau of Mines records the three acre D & H Mine Coal Fire project was one of the most costly per acre due to severe access restrictions. Over 2,100 feet of road was constructed for access to the fire. Dozer work totaled almost 600 hours, and over 140,000 pounds of ANFO was used for blasting material to form a seal (Shellenberger, 1975). Field observers surmised that the coal fire could endanger federal coal in the adjacent Sec. 4 of T5S, R92W. The first work at D & H Mine was carried out between October 24, 1973 and December 20, 1973 at a cost of about $23,000 (Shellenberger, 1973c). The second part of this work cost just over $56,000 and was carried out between August 22, 1975 and November 25, 1925 (Shellenberger, 1975).

The general area of the D & H Mine Coal Fire was inspected by CGS in October 1984. The seal was breached by a fire-induced subsidence crack at the southeasternmost extent of the middle bench. Other vents may have formed from movement of poorly sorted clasts during freeze/thaw migration. The odor of sulfur was pronounced along the intersection of the seal and the in-place hanging wall. The effect of extensive surface disturbance to create the seal obliterated any evidence of rock color alteration. A surface seal repair project was initiated in 1985 by OSM. The intense heat of the fire has now caused cracking and venting in the

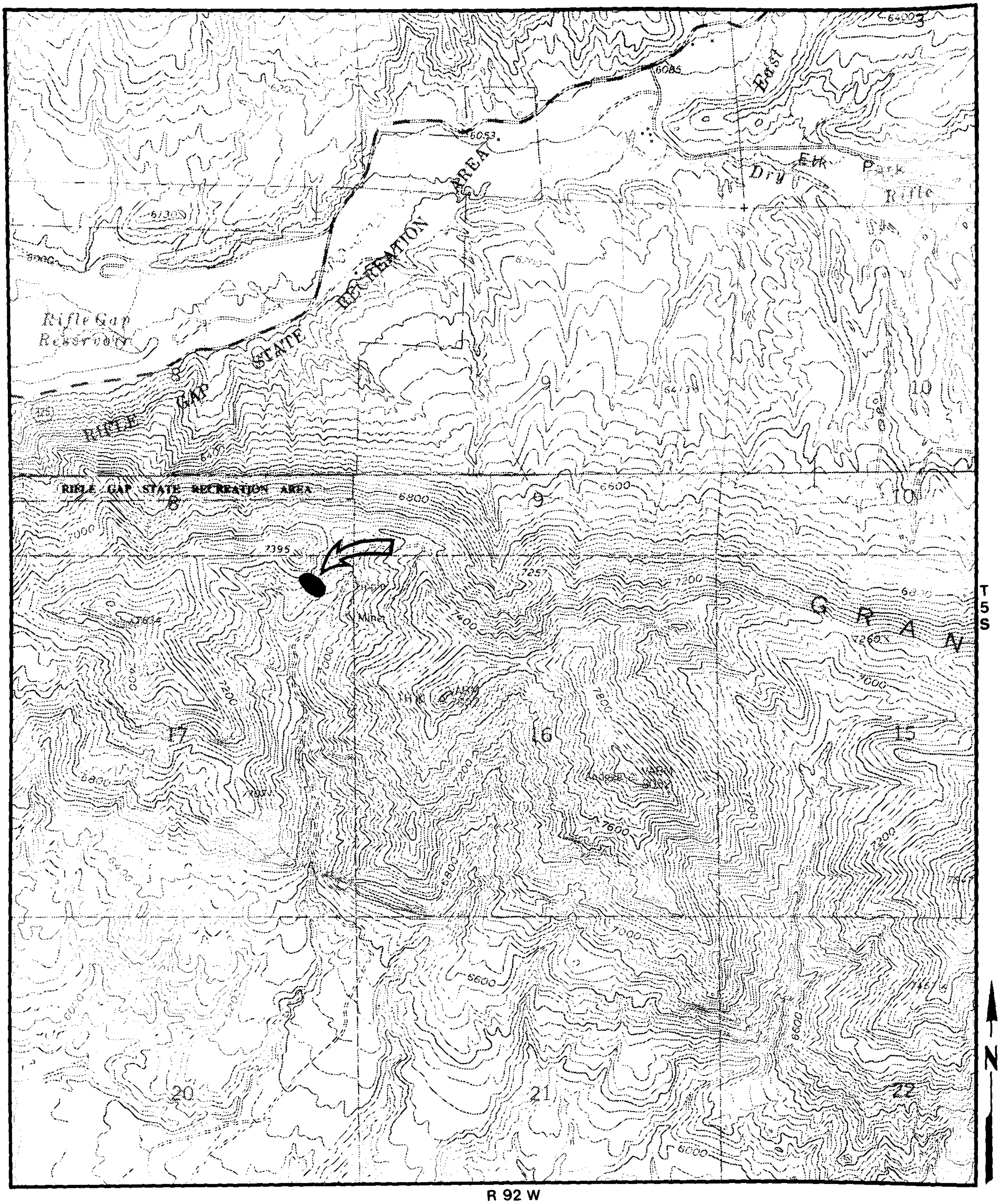


Figure 18. Location of the D & H Mine Coal Fire site (base from Rifle Falls and Silt 7.5-minute Quadrangles, scale 1:24,000.)

repaired surface seal. The highest vent temperature recorded in 1987 registered 1177° F before the thermocouple melted. Persistent venting below the surface seal and at the junction of the seal and bedrock may be areas of oxygen intake as indicated by strong, loud inrushing air at these locations.

There was evidence of a small, one acre, brush fire near the base of the seal, however, it is uncertain as to whether the coal fire was responsible. The ground surface on and around the seal is rugged, strewn with boulders making missteps potentially hazardous. The entire seal was searched for venting and possible air intakes along the coal crop, and while odors were ubiquitous, venting was observed only on the middle bench.

Harvey Gap Mine Coal Fire

The Harvey Gap Mine Coal Fire is located in Garfield County about four miles north of Silt in the NWSWNE of Sec. 24, T5S, R92W, Sixth Principal Meridian. It is on the west side of Harvey Gap in the Grand Hogback, above the light duty county road that leads to Grass Valley Reservoir. Figure 19 is a map showing the general location of the coal fire.

The mine utilized three portals between 1913 and 1955. According to Boreck and Murray (1979) production records are recorded as follows.

Portal	Production (t)
Harvey Gap No. 1	17,500
Harvey Gap No. 2	48,000
Harvey Gap No. 3	17,700

Available information indicates that the Harvey Gap Nos. 2 and 3 Mines worked at least two seams. The date of origin of the fire is not certain although the Harvey Gap No. 3 closed in 1955.

The coal fire was first visited by CGS and CIMRP on October 4, 1984, and again on November 29, 1984. The first visit was conducted with an ambient temperature of 68° F. Since vents were not visible by binocular scanning from the road, it was necessary to climb about 380 feet up the 25 percent slope to view active vents. Vents are irregularly distributed about the defoliated scarp above the road. High temperature vents have altered many rocks to buchites. There was no soot surrounding vents, and in many cases vents had deeply charred tree roots remnant from the pre-burn vegetation.

The ambient temperature during the second visit to the Harvey Gap Mine Coal Fire was about 20° F. Steam condensate plumes up to 50 feet high were visible from nearly half a mile. A visual binocular scan revealed a much higher density of vents than originally thought from the first visit during warmer ambient conditions.

The Harvey Gap Mine Coal Fire is an efficient, hot-burning fire. Access to the fire for control purposes is forbidding, despite its short map distance from the road. Surface seal emplacement would require extensive and difficult road construction in steep terrain. Availability of seal material is limited and would require extensive blasting of local material or many haul truck runs to bring material in from off site.

McDonald-Coryell-Vulcan Mine Coal Fire

These mines are located along an outcrop in Garfield County that exhibits signs of active burning in at least two seams for a distance of two miles. The names and locations of the various mines are somewhat confused, but there is no doubt that the fire started in one or two mines now affects all of them. The outcrop is exposed from 0.5 miles south to 2.5 miles east-southeast of the town of New Castle from the NWSWSE of Sec. 31, T5S, R90W, to the NESWNW of Sec. 1, T6S, R90W, Sixth Principal Meridian. They are on the steep north-facing slope of the Grand Hogback above the Colorado River. The fire area is reached by crossing to the south side of the Colorado River at the New Castle exit from I-70, and following the dirt road east or west along the base of the hogback. Access to individual mines or fire cell hot spots may be gained by climbing up the slope from the road. Figure 16 is a map showing the general location of the coal fires.

Three mines began operating in the late 1800's (New Castle No. 1, 1888; Vulcan, 1892; Coryell, 1898), and all three had an early history of gas and dust explosions. The Coryell and Vulcan stopped production in 1909 and 1918, respectively. The first fire reported in the area was in 1954 at the New Castle No. 1, and two years later the mine ceased operation. The New Castle-Vulcan Mine was opened in 1956, but a mine fire broke out in 1962, at which time the mine was closed. One more mine operated in the area, the McDonald, also called the New Castle No. 2, but its dates of production are not available. Neither of the two fire reports gives any information as to the origin.

The inspection for this report was conducted by CGS on October 28, 1984. A light snowfall overnight provided an ideal situation for observing evidence of fire from a distance. The entire two mile length of the coal seam outcrop was visible as a series of patches bare of snow, all in line at about the same elevation on the slope, except the easternmost two or three, apparently in a

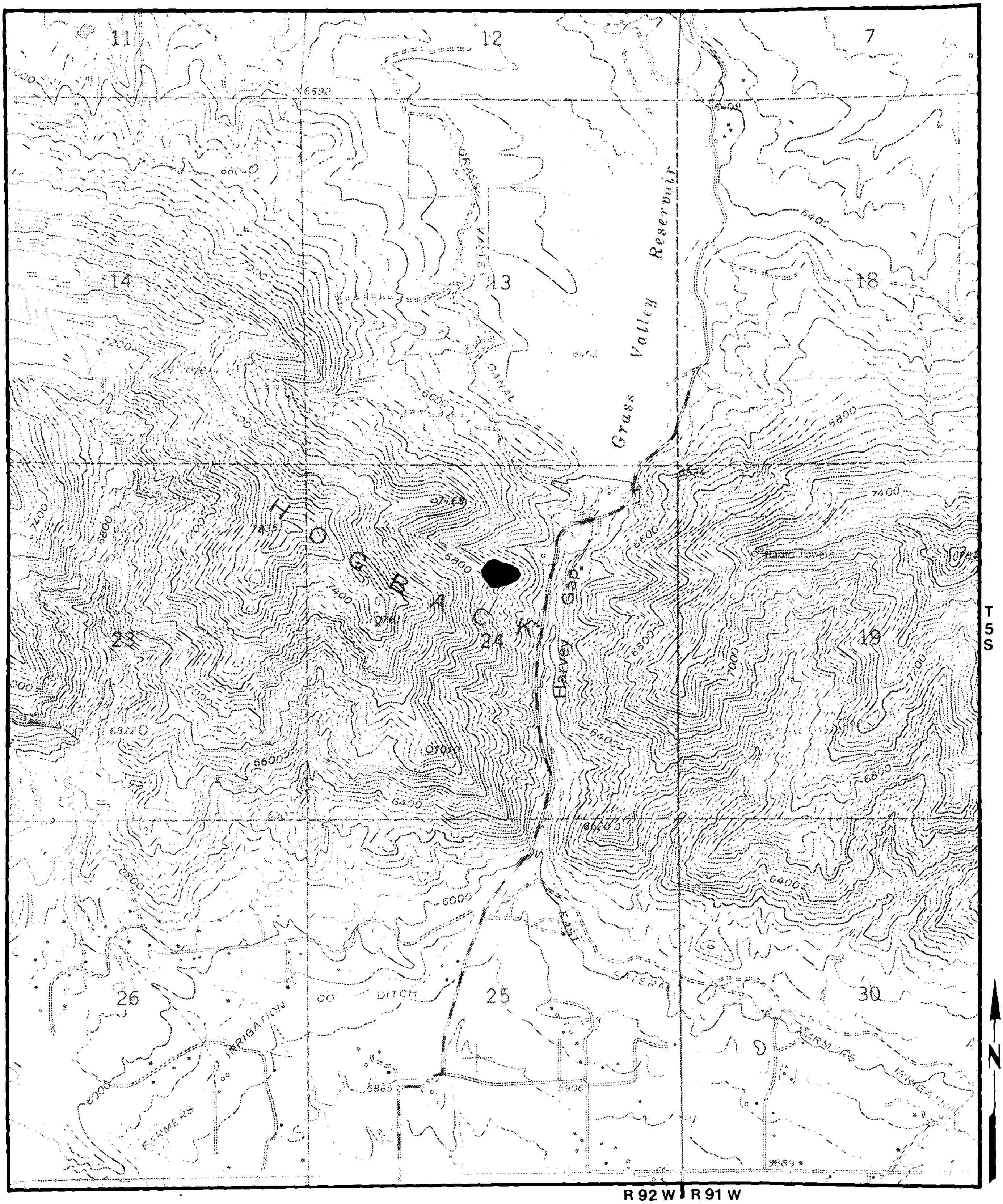


Figure 19. Location of the Harvey Gap Mine Coal Fire site (base from Silt 7.5-minute Quadrangle, scale 1:24,000.)

lower seam. Some of these patches supported a good growth of green grass, evidence of steam-emitting vents providing warmth and moisture. Other patches contained vents giving off smoke, visible to the naked eye from the opposite side of the river. Though the patches were separated by areas with snow cover, they probably represent hot spots on a substantial, widespread fire-front.

Pocahontas No. 2 Mine Coal Fire

The Pocahontas No. 2 Mine is located in Garfield County about 6.5 miles south of Glenwood Springs on the west side of Four Mile Road. A private ranch road leads to the coal fire area located in the SWNESE, Sec. 28, T7S, R89W of the Sixth Principal Meridian. Figure 20 is a map showing the general location of the coal fire.

The Pocahontas Nos. 1 and 2 Mines were operated from 1899–1951 and have been credited with 176,132 tons of bituminous coal produced from three coal seams. The coal bearing rock unit in this area is the Lower Mesa Verde Group which is Upper Cretaceous in age. The greatest production has come from the lowermost coal seam (A bed) amounting to 110,083 tons. The middle seam (C bed) produced 22,106 tons and the top coal (D bed) produced 44,033 tons. The mine was opened by underground drift from a number of portals at various elevations. The coal seams, which strike N17W and dip 42SW, were developed by room and pillar mining technique. An inspection by CIMRP in February 1988 showed a relatively small area exhibiting snow melt. The highest temperature recorded at the surface was 135° F.

South Canyon No. 1 (Old South Canyon) Mine Coal Fire

The South Canyon No. 1 Mine, located in Garfield County, is situated five miles southwest of Glenwood Springs and extends along the Grand Hogback from the SENWSE of Sec. 10 to the CNWNW of Sec. 14, T6S, R90W, Sixth Principal Meridian. Coal has been extracted from both the east and west sides of South Canyon Creek about two miles south of its confluence with the Colorado River. The South Canyon No. 1 Mine Coal Fire is reached by taking the South Canyon exit from I-70 about five miles west of Glenwood Springs, crossing the Colorado River and continuing south 2.5 miles on a light duty road. The hot spots can be approached for closer inspection by climbing the slopes on either side of the canyon. Figure 21 is a map showing the general location of the coal fire.

In this area, a portion of the Grand Hogback known as Coal Ridge has been incised by South Canyon Creek, exposing dipping coal beds. The Old South Canyon Mine was developed by two separate drift openings, one on either side of South Canyon Creek. Coal extraction on the east side of the creek was from a seam which has been correlated with the Wheeler seam at Newcastle. On the west side of the creek development was in this same seam as well as from a stratigraphically higher seam which correlates with the D seam, also at Newcastle (Gale, 1910). The mine is credited with the production of 10,000 tons between 1887 and 1903. From 1903 to 1951 the mine was operated as the South Canyon No. 1 and posted a production of 915,000 tons, most of which was shipped to Denver and Cripple Creek. During this time, the mine was worked from the adit on the east side of South Canyon Creek and both the east and west workings of the old mine were joined under the creek. From 1958 to 1968 the mine was again operated, under the name New South Canyon.

A 1910 inspection of the mine by the U.S. Geological Survey revealed a fire in the west Wheeler coal seam and a report of the inspection states that controlling efforts had been unsuccessful at that time (Gale, 1910). There is also mention of fire activity on the west side in 1951, the same year operations ceased at the mine. The portion of the mine on the east side of the creek has no documented history of fire. It seems unlikely that the fire now observed on the east side of South Canyon Creek was caused by a spreading of the west fire because of the water table barrier at creek level.

The first inspection of this fire by CGS and CIMRP took place on October 28, 1984. A light snowfall overnight enhanced the evidence of the existing fires and allowed observation from the road in the canyon. A very large area on the east side was obviously disturbed, lacking snowcover and vegetation, and was emitting smoke from numerous vents. Smoke was also seen from a different vantage point in the ravine to the north on this same, east side, suggesting the fire front has advanced through the intervening spur.

On the west side of the valley, three hot spots were seen as areas of snowmelt, one near the valley bottom, another midway up the slope, and the other high on the slope. The highest was visible from other points along the road. The upper two had vents emitting smoke. The entire outcrop on the west side was discernible by vegetation changes. The unit stratigraphically higher (to the south) had a grass cover, while that below (to the north) had a shrub-like growth; between was either a

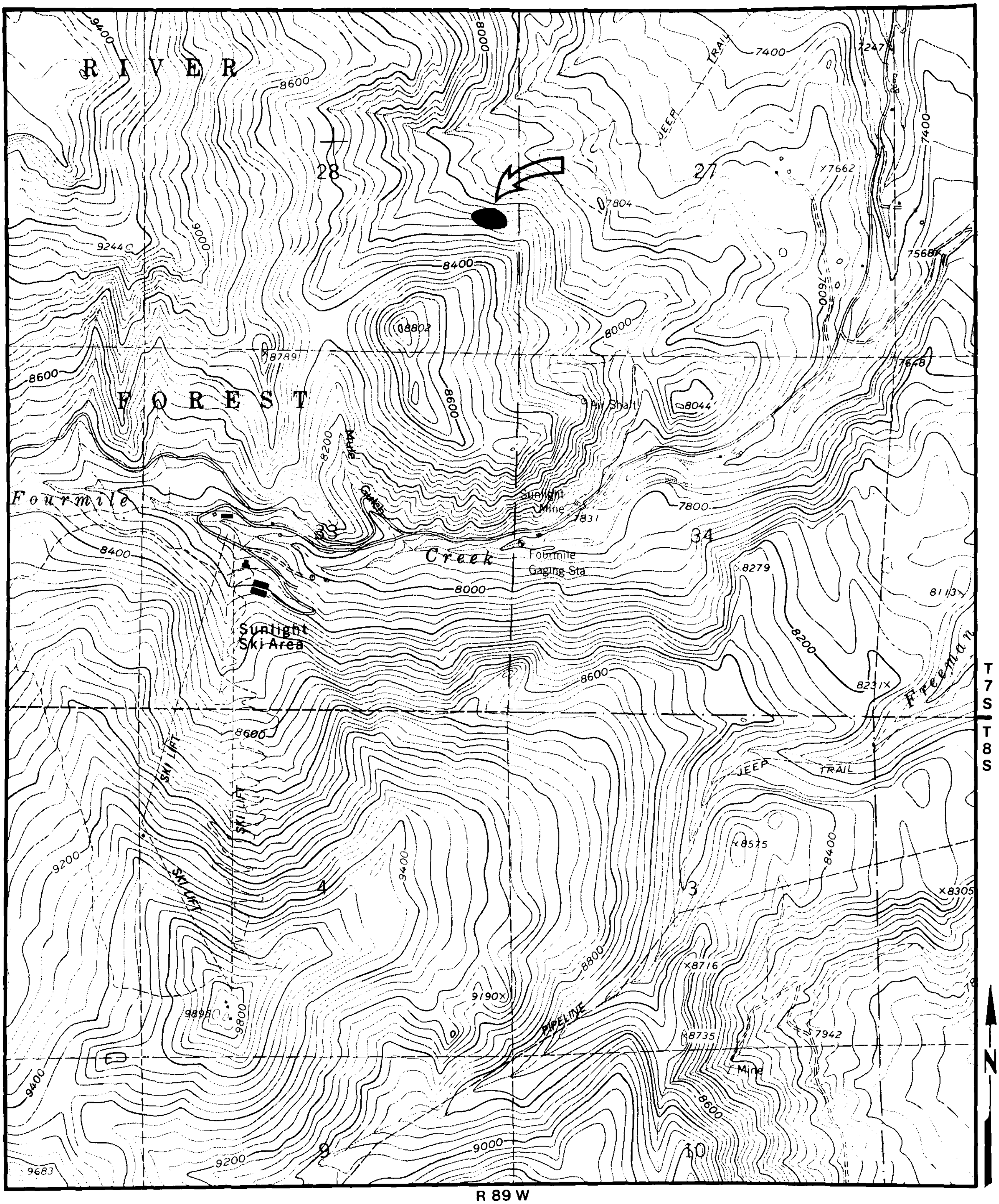


Figure 20. Location of the Pocahontas No. 2 Mine Coal Fire site (base from Cattle Creek 7.5-minute Quadrangle, scale 1:24,000.)

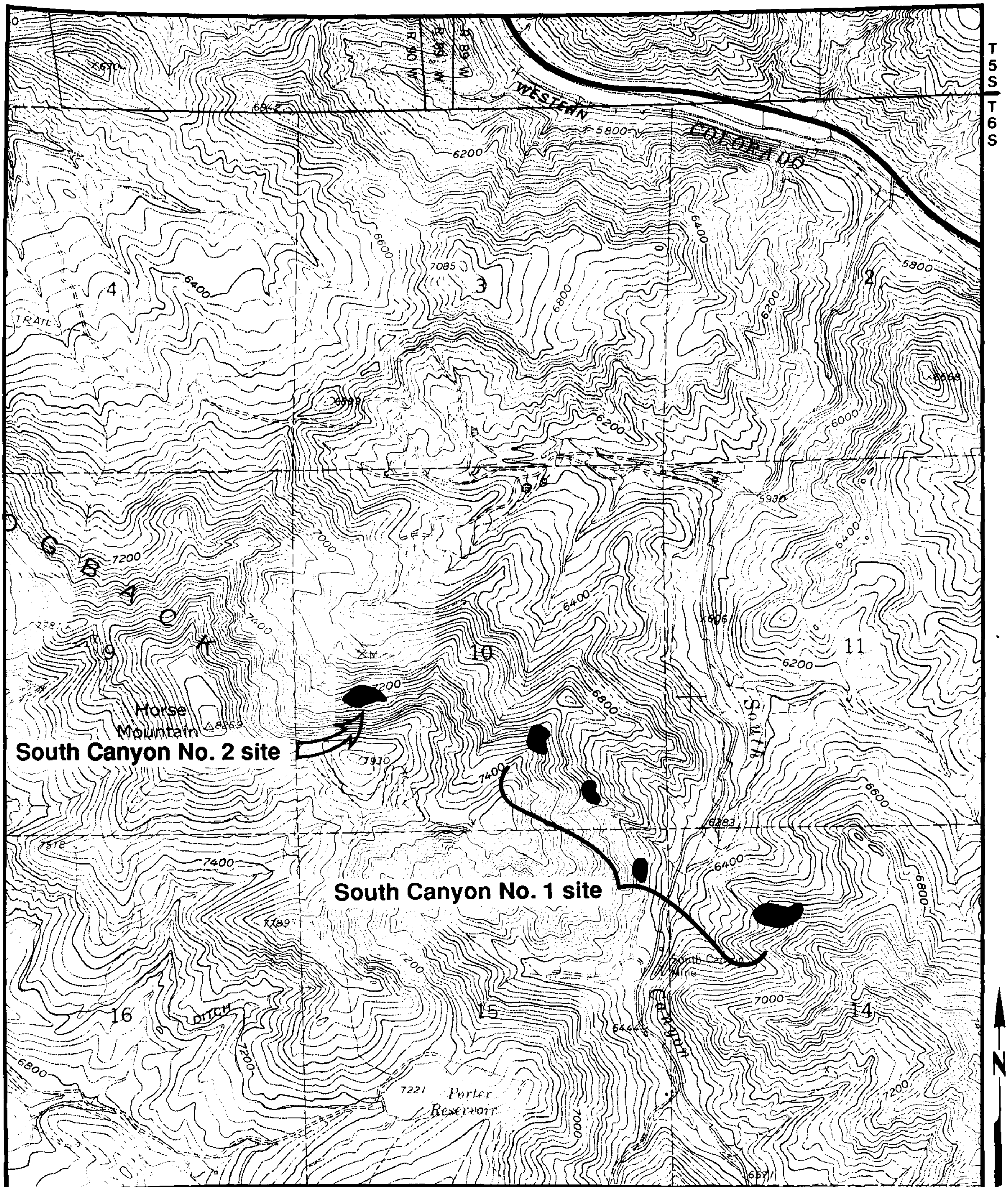


Figure 21. Location of the South Canyon No. 1 and No. 2 Mine Coal Fire sites (base from Storm King Mountain 7.5-minute Quadrangle, scale 1:24,000.)

white snow cover or barren soil on the hot spots. An inspection in March 1987 showed irregularly spaced hummocks along the coal subcrop line on the west side of the canyon to be white hot buchites. The vent temperatures were in excess of 1115° F before insulation melted off the thermocouple wire. An inspection in July 1988 showed that these hot spots had cooled to a maximum of 425° F.

South Canyon No. 2 Mine Coal Fire

The South Canyon No. 2 Mine Coal Fire is located in Garfield County 5.5 miles west of Glenwood Springs in the NENWSW of Sec. 10, T6S, R90W, Sixth Principal Meridian. It is on the north-facing slope of an easterly peak of Horse Mountain, above an intermittent tributary of South Canyon Creek and the city dump for Glenwood Springs. Access to the South Canyon No. 2 Fire is gained by exiting I-70 at South Canyon, five miles west of Glenwood Springs, crossing the Colorado River and continuing south about one mile on a light duty road. A right turn on an unimproved road leads to the Glenwood Springs city dump after 0.5 mile, and a four-wheel drive road leads to the southwest about one mile to the mine. The fire site is on the slope directly above the mine, although switchbacks to the west give a gentler approach. Figure 21 is a map showing the general location of the coal fire.

The mine was operated from 1938 through 1941 under the name of Gem Mine and again from 1942 to 1946 under the current name, South Canyon No. 2. The mine has produced coal from three distinct coal seams and is credited with the production of 32,482 tons. There is no documented history of fire at the mine. There is no connection in the mine workings with those of the South Canyon No. 1, to the southeast.

The inspection for this report was conducted by CGS and CIMRP on November 7, 1984. Though snow had not fallen recently, most of the north-facing slope retained a snow cover, and the fire area was easily seen from a distance, bare of snow and with a growth of green grass. An old mine grade allowed access to the fire area for closer inspection. At least one large vent was emitting smoke, but subsidence cracks in the grass cover surrounding it and rocks visible within the cracks suggested active slope instability, so the vent was not closely approached. A local resident reported that the vent looked like a funnel or a crater up close. Though most of the grassy area covered a circular bulge on the slope, there was a thin, linear strip of grass extending to the east, following the outcrop. Another area of interest was to the west of the grassy bulge. What appeared to be a recent slump had exposed much bare soil and a few overturned trees. Soil within the slump area was seen to be adjusting its angle of repose, even as the inspection took place. No vents were seen anywhere in this slumped area.

GRAND MESA AND SOMERSET COAL FIELDS

The Grand Mesa and Somerset Coal Fields are on the southern edge of the Piceance Basin. Most of these fields are structurally simple, with rocks dipping gently north toward the axis of the basin. However, in the Somerset Field, Tertiary intrusions have disturbed the rocks, locally inclining them in various directions. Coal mined in the fields occurs in the Bowie and Paonia Shale Members of the Williams Fork Formation. Here, these units are interpreted to be mid-deltaic to swamp-barrier beach deposits; the high sulfur content of the lowest portion of each coal bed suggests an initial brackish-water environment of deposition (Matthias and Reitz, 1979).

There are two active coal mine fires in the Grand Mesa and Somerset Coal Fields. The States Mine Coal Fire is located at the base of the south slope of Grand Mesa, where the strata are nearly flat-lying. A 10 to 14 foot thick "basal" bed in the Bowie(?) Shale Member was mined there. The Minnesota Creek Mine Coal Fire is five miles due north of a Tertiary intrusion, and there is slightly greater dip to the rocks there. This mine worked the A coal bed of the Bowie(?) Shale, but the fire appears to have started in beds D and E of the same member, with a total thickness of six to ten feet.

Minnesota Creek Mine Coal Fire

The Minnesota Creek Mine Coal Fire is located in Delta County 3.5 miles east-northeast of Paonia in the SWNWNE of Sec. 35, T13S, R91W, Sixth Principal Meridian. It is on the south-facing slope of Jumbo Mountain, between intermittent drainages of Minnesota Creek. The Minnesota Creek Coal Fire is reached by taking the Minnesota Creek Road from the southeast corner of Paonia for a distance of about four miles. A rough road turns left up a gully between a storage yard for farm machinery and a house, leading to the mine after about a mile. The fire area is somewhat higher on the slope to the west. This description is taken from previous access notes and was not independently verified during either 1984 inspection. Figure 22 is a map showing the general location of the coal fire.

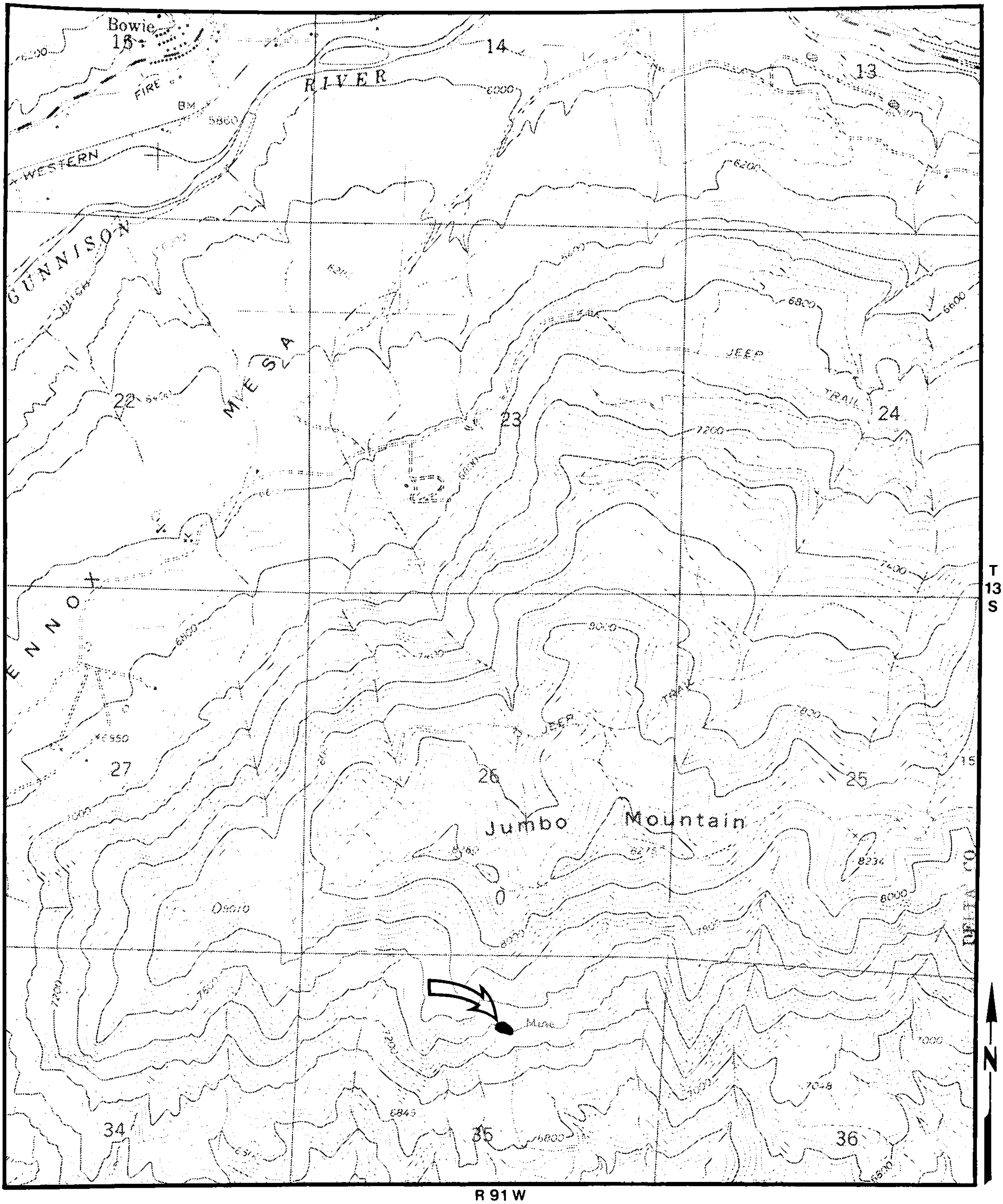


Figure 22. Location of the Minnesota Creek Mine Coal Fire site (base from Bowie 7.5-minute Quadrangle, scale 1:24,000.).

A lease for coal mining in the subsequent fire area was obtained in 1934, and one entry was driven 120 feet into the coal bed from the outcrop. The lease expired in 1936 and the mine was abandoned in the same year. The fire was first noticed in 1937 by the landowner of some adjacent property. His search of the mine entry failed to locate the fire, but on a second trip, he found fire activity to be higher than and west of the entry. The origin of the fire has not been determined, though its location away from the entry cannot rule out lightning strikes or spontaneous combustion at the outcrop. The control project began on June 20, 1961 and was completed on July 28, 1961. The surface sealing method was used by bulldozer covering and complementary jackhammer drilling and blasting work (Jolley and Dimitroff, 1961). Inspections in the spring of 1963, October 1964, September, 1966, November 1967, May 20, 1970, November 14, 1973, and September 1975 all required hand-shoveling maintenance, but each found the fire activity decreasing, and the last reported it to be nearly extinguished.

This report summarizes an inspection by CGS and CIMRP on November 8, 1984. An earlier attempt on October 26, 1984 failed to locate the fire because high ambient temperatures prevailed and hindered the discovery of subtle vents and areas of heat emanation. The successful inspection took place immediately after a light snowfall, just as the clouds were lifting. At first, the suspected fire area retained its snow cover, but within 10 to 15 minutes, two horizontal patches of bare ground appeared through snowmelt. The lower of the two grew larger, and five to ten minutes later, smoke was observed venting. The lower area may have extended its snowmelt pattern to the east, but the overcast and growing darkness made it difficult to ascertain.

States Mine Coal Fire

The States Mine Coal Fire is located in Delta County 2.5 miles northwest of Cedaredge in the NWNWNW of Sec. 18, T13S, R94W, and in the NENENE of Sec. 13, T13S, R95W, Sixth Principal Meridian. It is on both the north and south slopes of a draw which flows west into Kiser Creek. Access to the States Mine Fire is gained by turning west at the main intersection on Colorado 65 in Cedaredge, continuing 1.25 miles, turning north and travelling 0.75 miles, then turning west. This road descends from the mesa into the valley after 0.5 miles, and is followed for one mile before a right turn is made. Within 0.25 miles, the mine workings are visible on both sides of the road, and the fire area is also on both sides, reached by switchbacks in the road. Figure 23 is a map showing the general location of the coal fire.

The mine is reported to have operated from 1914 until 1951. There is no record of where or how the fire started in the mine, nor have any major attempts been made to control the fire. An inspection for an inactive mine inventory on July 30, 1980 found no surface evidence of smoke, steam, heat, odor or staining, though cracks were noted in a roadbed above the portal to the mine and on the slope above the road. The cracks on the road had been repaired by the county and the landowner, but had reopened. Pits had also opened on the slope inside the lower switchback a few months before the inspection, and the landowner hired a bulldozer to fill them in.

This report summarizes several inspections by CGS and CIMRP, the first on October 26, 1984. At that time, the effect on vegetation was the most obvious evidence of the fire. A number of dead trees along a bench just below the roadbed at the first switchback were noted, and heat was venting through cracks that had developed within their root systems. Otherwise, vegetation was lacking in this area, and exposed bedrock appeared reddened. The road itself did not appear to have been recently disturbed but a local resident spoke of complete subsidence of the road in past years. A later inspection on December 27, 1984 found the fire area to be much larger in extent. The snow cover on the south side of the road had melted over a portion of the slope near the coal spoil pile in the gully. The owner of the property mentioned a steaming or smoking vent on the flat area above the snowmelt patch. Though this was not observed, other vents were found. They retained a snow cover, however, so they were either not exhaust vents or were not active. A control project in August 1988 by OSM placed material on vents emitting noxious odors bothering residents.

LOWER WHITE RIVER COAL FIELD

The Lower White River Coal Field is at the northwestern end of the Piceance Basin, where it abuts the Douglas Arch and the Uinta Uplift. The northwest-trending Rangely Anticline and Red Wash Syncline are the most prominent structural features in the area. Northeast-trending faults associated with the Douglas Arch also extend into the area. Here the Mesa Verde Group consists primarily of sandstones, interlayered with carbonaceous mudstone and coal. The depositional setting appears to be closer to the highland source area

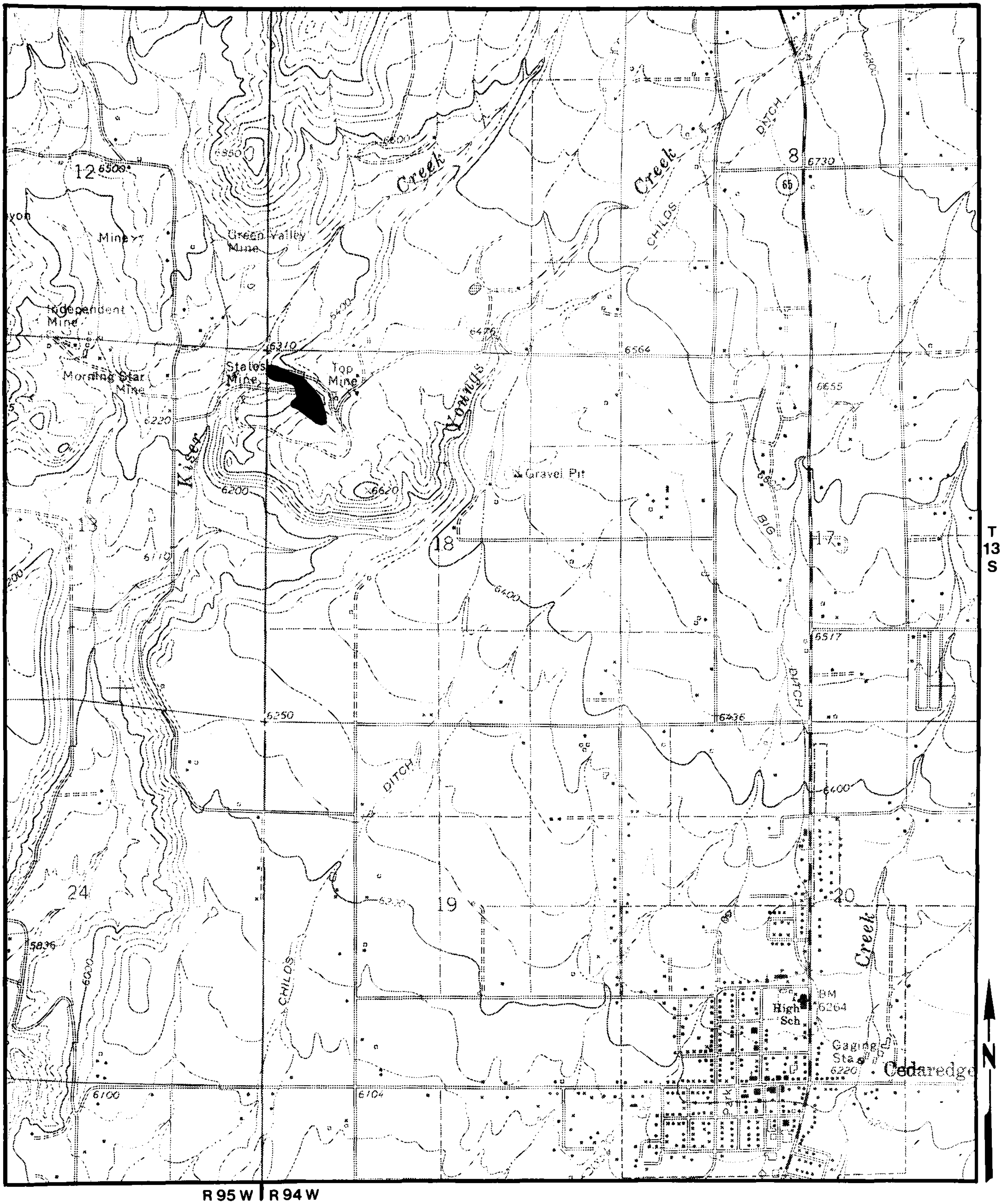


Figure 23. Location of the States Mine Coal Fire site (base from Cedaredge 7.5-minute Quadrangle, scale 1:24,000.)

than other parts of the basin (Hansley and Johnson, 1980), with fluvial and coastal plain sediments more important than deltaic ones (Matthias and Reitz, 1979).

Most of the mining in the field has occurred on the breached north flank of the Rangely Anticline, where coal beds crop out in the rimrock above the White River dipping less than 10° to the northeast. The Skull Creek Coal Crop Fire ignited in an unnamed coal bed of the Williams Fork Formation on a small mesa near the rim. Thickness of the coal at that location is 16 feet, and the overburden on the mesa is no more than 12 feet.

Skull Creek Coal Crop Fire

The Skull Creek Coal Crop Fire is located in Rio Blanco County 6.5 miles north of Rangely at the CE1/2E1/2 E1/2 of Sec. 35 and the CW1/2W1/2W1/2 of Sec. 36, T3N, R102W, Sixth Principal Meridian. It is on a mesa along the divide between low relief Scullion Gulch to the east and Nate Spring Draw and the White River breaks to the west. The fire site is reached by taking Colorado 64 about nine miles east and north of Rangely, then turning left on a county road and following it for 5.5 miles. From there, an unimproved road leads west and south 3.5 miles to the fire site. After three miles, the road passes through the trench that isolates the fire, and the remaining 0.5 miles is rough and requires four-wheel drive. The road very closely approaches the low, narrow mesa where the fire is burning. Figure 24 is a map showing the general location of the coal fire.

It is uncertain whether this fire began in a mine or at an outcrop. The only mine of record in the general area is the Gordon Mine at the SESESE of Sec. 36, but its start-up date of 1963 is well after the fire began. The topographic map of the area shows an intermittent pond nearby called Burning Mine Reservoir. However, the report for the control project on the fire suggests the fire started by spontaneous combustion in exposed coal at the western tip of the mesa. The fire had advanced 800 feet down dip by the time the control project was initiated in 1950. Work actually began on September 13, 1951 and was completed by December 2, 1951. The fire barrier method was performed by bulldozer blading, jackhammer drilling and blasting, and scraper hauling to excavate a 900 foot long trench. The trench was 110 feet wide at the surface and 20 feet wide at the bottom. The maximum vertical depth was 60 feet near the center. The trench was backfilled with incombustible material to a height of 10 feet above the exposed coal bed (Russell and Smith, 1951).

During an inspection by CGS on November 7, 1984, evidence of fire was found near the mid-point of the mesa. This evidence consisted mainly of subsidence cracks in the overlying sandstone across the top of the mesa and all along the edges. These cracks emitted heat and in some cases supported a growth of grass or moss. Although a sulfurous odor could be detected from time to time, no actively smoking vents were seen. The fire has not advanced across a small gap separating the mesa from a topographic high adjacent to the trench, as there has been some recent surface mining of coal near this gap. So, even though it has been isolated, there is still coal remaining to be burned before the fire is out.

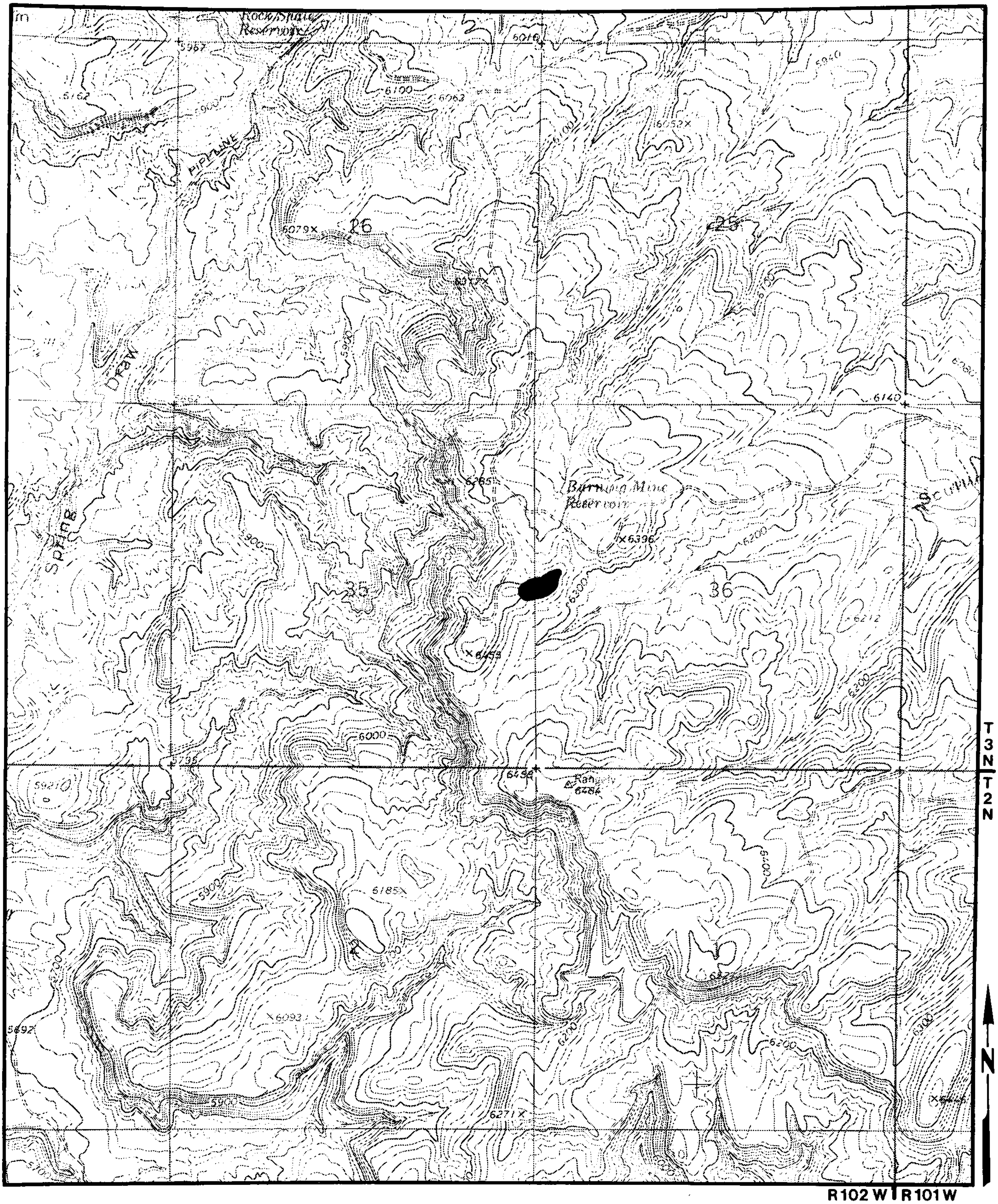


Figure 24. Location of the Skull Creek Coal Crop Fire site (base from Rangely NE 7.5-minute Quadrangle, scale 1:24,000.)

RECOMMENDATIONS AND CONCLUSIONS

The ground over currently burning and inactive coal mine fires is significantly weakened by fire activity, and should be considered potentially very hazardous. Coal mine fire sites, both active and inactive, and especially surface seals of active coal fires are extremely dangerous due to the potential for subsidence and off-gassing, in the case of active coal fires. The element of danger is not restricted to the area exhibiting venting, but over portions of the mine with thin overburden, chimney subsidence, pillar robbing and in those areas near access or ventilation openings. During the many field inspections made by CGS and CIMRP, suspicious subsidence features distant from active venting were noted and avoided. The unwary may not recognize the genetic cause of a subsidence pit nor be aware of the consequences of accidentally encountering the superheated or toxic gases present in active coal fires. The prospect of rescue from a caving coal mine fire is very remote.

The investigations of coal fire activity in inactive Colorado coal mines should continue. In general, on-the-ground inspections will reveal features related to coal fire or coal fire-induced subsidence activity which may be unattainable by aerial overflights or remote sensing imagery. Field investigations will spot air intakes for coal fires, slope failure of existing surface seals, and drainage patterns affecting surface seals whereas an overflight may not.

Largely because of the success of the Rodriguez (1983) study, it is recommended that geophysical methods of monitoring coal fires be explored as an alternative to drilling. A combination self-potential and magnetic surveys may outline the extent of current fire cells and define areas of origin and migration. There are limitations to these surveys which might be encountered at some of the fire sites. Sources of both self-potential and magnetic noise may exist, either due to man-made surface structures, subsurface geologic conditions or equipment left in the mine. However, with proper error analysis, worthwhile data may result even under the most adverse circumstances.

Statewide, the loss of coal resources due to coal fire is, at this time, believed to be minimal relative to the total Colorado coal resource. The depletion of coal resources at mines with coal fires was calculated from production figures doubled to account for a 50 percent loss due to room and pillar extraction techniques (Boreck and Murray, 1979). Of the 29 known active coal fires, most are localized in previous extraction zones. This fact indicates that these coal fires are not increasing statewide depletion figures to any appreciable degree as coal being consumed has already been taken into account as lost due to low recovery percentages.

Undoubtedly there has been some local spreading of fires into unmined coal zones at some locations. Coal fire advance rates in virgin coal are greatly hampered by decreased oxygen to the fire front. A reliable quantitative evaluation of lost coal resources requires more detailed measurement and orientation of fire zones and a better understanding of fire advance dynamics at site specific areas in Colorado.

The surface seal approach to abatement should be investigated for possible innovative engineering applications. Technologies and materials such as geotextiles and reinforced earth may be appropriate within layers of a surface seal permitting steeper slopes, or reduced material quantities, for higher success without maintenance. An engineering study of surface seals in Colorado should analyze effects of particle size, slope stability and drainage requirements. In addition, it may be feasible to employ vegetative ground covers which would essentially self-repair small breaches in the surface seal. Small breaches in surface seals become failed seals within a short period of time. Any methods permitting a longer seal life or reduction in breaches will greatly improve the chances of extinguishing the coal fire.

Innovative methods of harnessing the power of coal fires should be examined. Chaiken (1980) has several technologies under license which may permit wasteful coal fires to provide electricity to the power grid. Such a process would provide an element of control to a coal fire which otherwise would have none. Accelerating a coal fire through a control process would improve combustion and therefore reduce noxious and toxic emissions.

Many coal fires were started by spontaneous combustion of the coal in storage. Research into the factors abetting spontaneous combustion in Colorado coals would benefit current coal producers. In areas of abundant coal outcrop or coal crop "robbing" such information may indicate whether exposures should be covered or monitored for development of coal fires. It is unlikely that currently active coal mines will generate uncontrollable coal fires such as those reported in this volume. However, it is likely that should new coal fires develop that they would be outside and distant from current active coal mines or in coal outcrop, and start either by spontaneous combustion or lightning strikes. New coal fires may also develop within existing inactive coal mines if water is introduced and spontaneous combustion occurs. Therefore, the practice of applying water to coal fires should halt either through education, regulation or legislation.

In most cases coal fires are remote, burning in mined-out, low value or unrecoverable coal. One coal fire, the States, has impacted nearby residences through noxious fumes. Other coal fires, such as the D & H, are visited frequently by hunters, off-road vehicles and hikers. Still other coal fires are quite prominent, such as the McDonald-Coryell-Vulcan, along I-70 near New Castle yet are rarely visited, and are probably unnoticed by thousands of passing motorists.

Burning mines, crop fires, or spoil pile fires near populated areas or other favored recreational sites should receive special attention as they are potentially deadly sites for the unsuspecting. Future reclamation activity should be limited to carefully selected fires which may impact humans, such as the States and D & H Mine Coal Fires. Taking no action in controlling coal mine fires will continue wasting a natural resource, but more importantly may limit the options of future mining ventures adjacent to the coal fire. The success rate of surface sealing is high if maintained, however, it is unlikely that funding for current reclamation programs will continue indefinitely.

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