EMRIA REPORT No. 16

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

RECLAIMABILITY ANALYSIS OF THE EMERY COAL FIELD, EMERY COUNTY UTAH

BUREAU OF LAND MANAGEMENT

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16. Abstract (Limit: 200 words)
As a multidisciplinary integration of field and archival data, to evaluate coal strip mining reclaimability in the Emery, Utah coal field, the initial effort consisted of collecting baseline data. These data covered the geology, overburden, hydrology, climate and vegetation of the area. Six new bore holes were drilled for overburden, ground water hydrology tests, and to obtain coal samples for analysis. Visual, cultural, and recreational resources appear modest when contrasted with the surrounding region. The land use potential is dominantly limited to range land which appears to be reclaimable after mining by the methods described. Site specific problems are a lack of available topsoil, coupled with a potential excess of boron, and general nutrient deficiency (Nitrogen, Potassium, Phosphorous) in the overburden. The top 40 to 60 feet of deeply weathered and leached overburden can generally be used with supplemental fertilization as a topsoil amendment. Rainfall is marginal for revegetation purposes. Use of fly ash (or bottom ash) from nearby power plants as both a geochemical soil supplement and mulch seems desirable. No significant groundwater connections with aquifers now in use is seen. A potential geochemical problem may arise by exposing the overburden to more rapid leaching. Sedimentation problems, as evaluated by a variety of techniques, do not appear significant.

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ENGLISH-METRIC CONVERSION FACTORS

To convert English unit	Multiply by	To obtain Metric unit
Inches (in)	2.54	Centimeters (cm).
Feet (ft)	3.048×10^{1}	Centimeters (cm).
	3.048×10^{-1}	Meters (m).
Miles (mi)	1.609	Kilometers (km).
Square feet (ft^2)	9.290×10^{-2}	Square meters (m^2).
Acres	4.047×10^{-1}	Hectares (ha).
	4.047×10^{-3}	Square kilometers (km^2).
Acre-feet (acre-ft)	1.233×10^{3}	Cubic meters (m^3).
	1.233×10^{-3}	Cubic hectometers (hm^3).
Cubic yards (yd^3)	7.646×10^{-1}	Cubic meters (m^3).
Pounds (lb)	4.536×10^{-1}	Kilograms (kg).
Short tons (tons)	9.072×10^{-1}	Metric tons (t).
Pounds per acre (lb/acre)	4.883	Kilograms per hectare (kg/ha).
Btu/lb	2.326	Kilojoules per kilogram (kJ/kg)
Gallons (gal)	3.785×10^{-3}	Cubic meters (m^3).
Gallons per minute (gal/min)	6.309×10^{-2}	Liters per second (L/s).
Degrees Fahrenheit (°F)	([1])	Degrees Celsius (°C).

[1] Temperature in °C =(temperature in °F - 32)/1.8.

Energy Minerals Rehabilitation Inventory and Analysis

EMRIA Report No. 16

Reclaimability Analysis of the Emery Coal Field Emery County, Utah

Prepared For

Bureau of Land Management

By

Geoscientific Systems
and Consulting

8405 Pershing Dr. #402
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This EMRIA study is a multidisciplinary integration of field and archival data, to meet the information needs of evaluating coal strip mining reclaimability in the Emery, Utah coal field. The initial effort consisted of collecting baseline data, on the geology, overburden, hydrology, climate and vegetation of the area. This effort was two-fold. First to compile a baseline set of data for the study area and its environ, and second to assess the site and region reclaimability with respect to a model mining plan. As part of the contracted effort, 6 new bore holes were drilled to evaluate overburden, serve as observation holes for ground water hydrology tests and to obtain coal samples for analysis. From the completed baseline study, the visual, cultural, and recreational resources of the Emery coal field are modest when contrasted with the surrounding region. The land use potential appears limited to range land and on a portion of the lands to the NW and North of the study site, limited agriculture. Evidently these values are reclaimable. Site specific problems identified in the study are a lack of available topsoil within the study area coupled with a potential excess of boron, and general nutrient deficiency (Nitrogen, Potassium, Phosphorous) in the overburden. This creates a need for special care in choice of overburden for amendment to insure revegetation success. The top 40 to 60 feet, deeply weathered and leached overburden can generally be used with supplemental fertilization as a topsoil amendment. Rainfall is marginal for revegetation purposes but may suffice if a 3 to 5 year window is chosen. However, sufficient surface water exists for modest irrigation of reclaimed lands, provided suitable arrangements are made. Use of fly ash (or bottom ash) from nearby power plants as both a geochemical soil supplement and mulch seems desirable. No significant groundwater connections with aquifers now in use is seen, but in view of the potential geochemical problem created by exposing the overburden to more rapid leaching, special concern to avoid deeper aquifer and runoff contamination is implied. Sedimentation problems, as evaluated by a variety of techniques, appear not to be a significant problem.

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This EMRIA study is a multidisciplinary integration of field and archival data, to meet the information needs of evaluating coal strip mining reclaimability in the Emery, Utah coal field. The initial effort consisted of collecting baseline data on the geology, overburden, hydrology, climate and vegetation of the area. In this, objective support was drawn from a series of companion studies set up by the BLM but conducted by other groups. These may be briefly enumerated as follows:

1) Geologic and stratigraphic studies by Dr. Thomas Ryer of the USGS, Denver.
2) Coal analyses by Dr. Joseph Hatch of the USGS, Denver.
3) Hydrologic, and water quality studies by Greg Lines of the USGS, Salt Lake.
4) Field revegetation experiments on the site with native species by Dr. Neil Frischknecht and Robert Ferguson of the Forest Services Shrub Sciences Lab, Provo.
5) Greenhouse and geochemical tests on ground core (overburden) performed by Dr. Robert Heil of Colorado State University, Ft. Collins.

Unfortunately, with the exception of Ryer's work, these studies could give only late or incomplete results at this writing. We have made the effort to incorporate the best currently available data from each of these studies by interviewing the investigators, but would advise the reader to seek out the publications which should result from these studies as they become available, and carefully compare their results to those presented here. These later studies may alter some of the conclusions listed here. If so, this report should be amended at that time to reflect those changes.

As part of the contracted effort, 6 new bore holes were drilled to evaluate overburden, serve as observation holes for groundwater hydrology tests and to obtain coal samples for analysis. Due to problems encountered in the drilling, the number of holes was expanded to nine, (holes 2A, 3A, 4A) and the original program considerably lengthened. As a result, the overburden and greenhouse analyses were largely based on data from bore holes 3 through 6, with only supplemental investigations conducted on the latter bore holes.

New color and color IR vertical and oblique aerial photography was taken to record the vegetative cover, and control ground vegetation transect lines. These images were also used to evaluate soils, geology and small drainage features. Some question was raised from these studies as to the accuracy of the recently completed SCS 3rd order soil survey of the site. As a result it was decided to resurvey a portion of the site which included the revegetation test plots. This was contracted to Dr. Rudolph Ulrich. Significant changes in mapped soil units were noted in this area, although the companion revegetation experiment was evidently unable to use this more accurate mapping in their data reduction. Dr. Archie Smith of Utah was provided with coal core for evolved gas and coal analyses. His coal analyses are included, the evolved gas analyses are unavailable at this writing.

The balance of the effort was completed by GSC and consultant staff. This effort was two-fold. First to compile a baseline set of data for the study area and its environ, and second to assess the site and region reclaimability with respect to a model mining plan. Review, guidance, and assistance in planning and implementation was received from; Dick Jewell, Hydrologist and BLM COAR, at Price, Utah, Benton Tibbetts, Geologist, EMRIA Staff, and David Lyons, Contracting Officer for BLM, Denver. Figure 1 presents the location of the study area with respect to major cultural, topographic and drainage features. Figure 2 portrays the test site related to regional land ownership and management patterns. Figure 3 shows the study area's relationship to prior EMARS and other coal leases or nominations. Finally Figure 4 shows the existing pattern of land use for the area. The historical development of the area is summarized in the Historical/Cultural Resources section. Although early agrarian settlements opened up the area, coal and now coal fired power plants are the mainstay of the economy.

Summary of the Situation on the Emery Study Site

From the completed baseline study, the visual, cultural, and recreational resources of the Emery coal field are modest when contrasted with the surrounding region. The land use potential appears limited to range land and on a portion of the lands to the NW and North of the study site, limited agriculture. Evidently these values are reclaimable. The local economy would benefit from a coal mining development in the Emery field. The coal resource, which could be recovered by strip mining, has been estimated as 140 million tons, of good quality.

The study area upon which detailed investigations were conducted is reasonably typical of the Emery coal field at large and hence problems and approaches identified may be more generally applied.

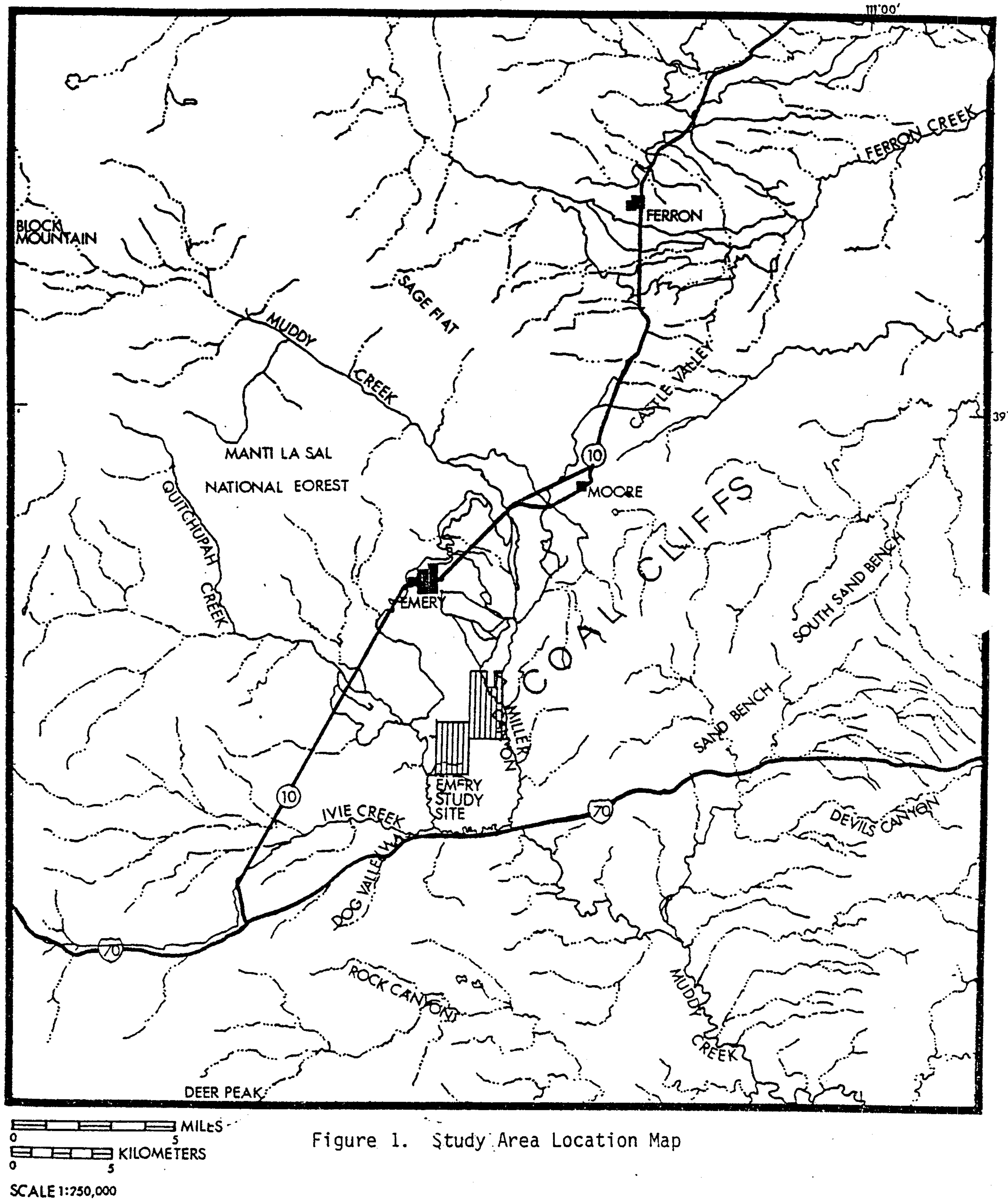
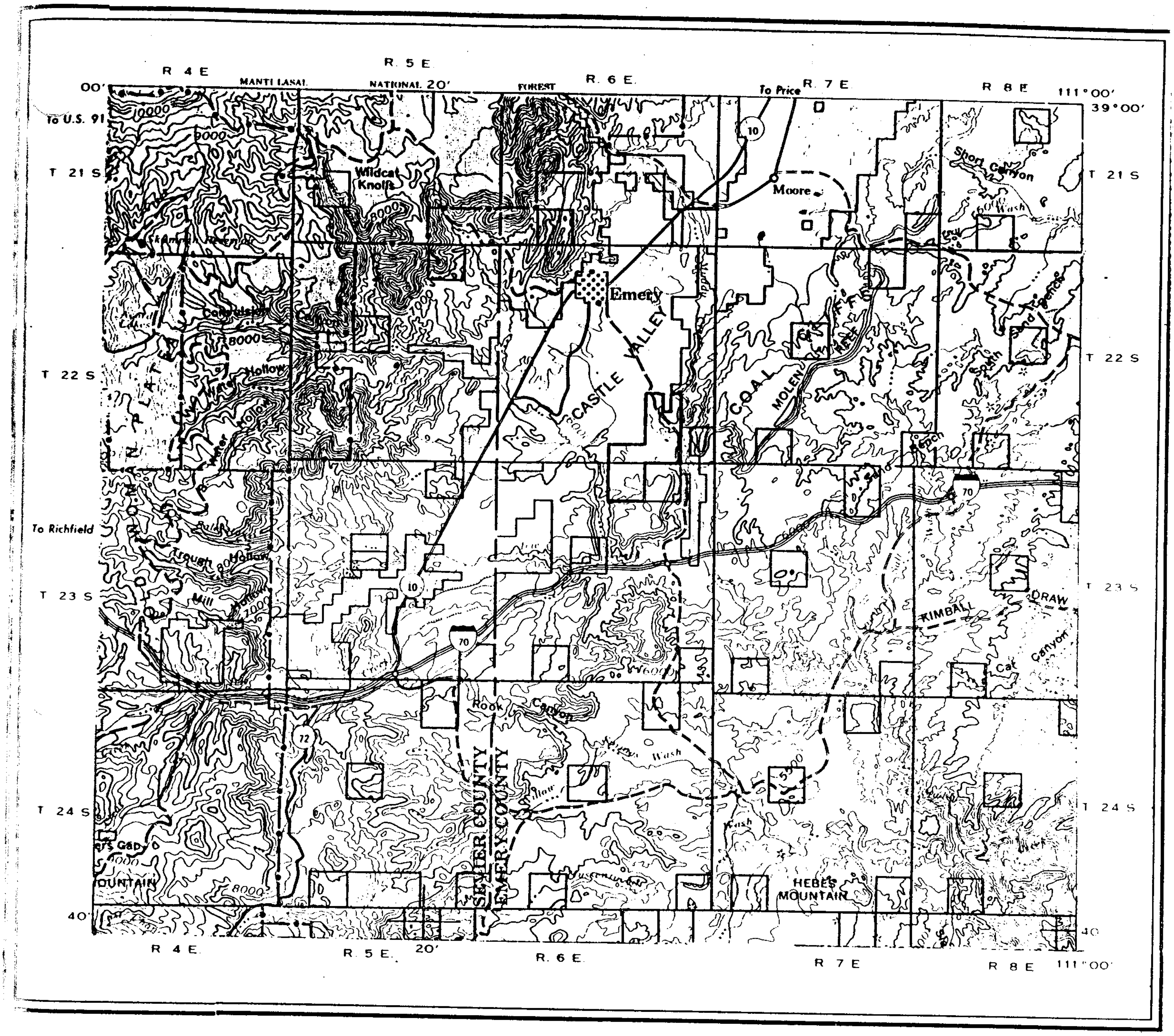


Figure 1. Study Area Location Map

LAND OWNERSHIP AND PUBLIC MANAGEMENT



LEGEND

NATIONAL RESOURCE LAND	STATE LAND
PRIVATE LAND	NATIONAL FOREST

Contour interval 200 feet with supplementary contours at 100 foot intervals. Polyconic projection.

4 3 2 1 0 4 8 12

SCALE IN MILES

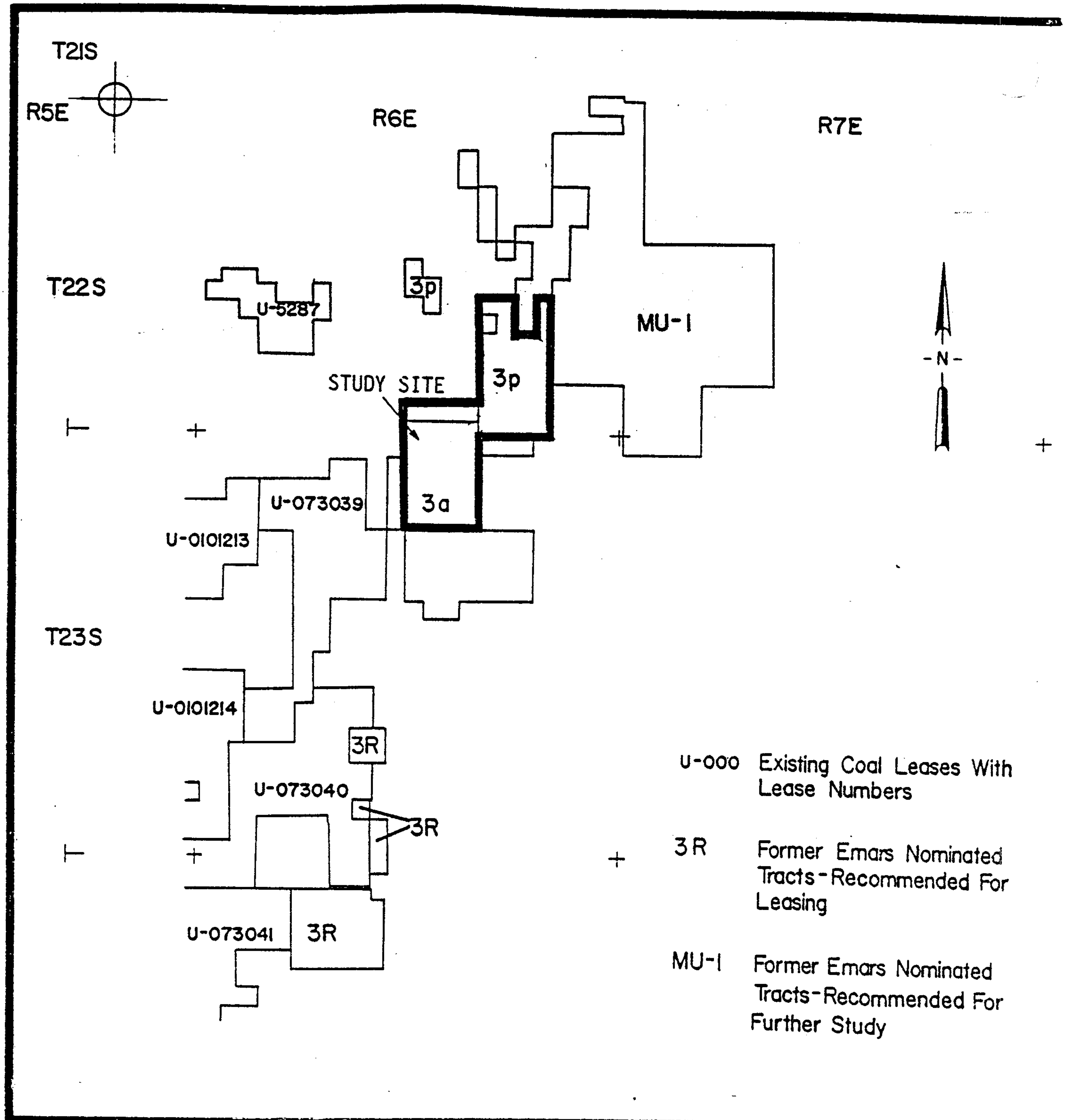


Figure 3. Coal Leasing in the Emery Field.

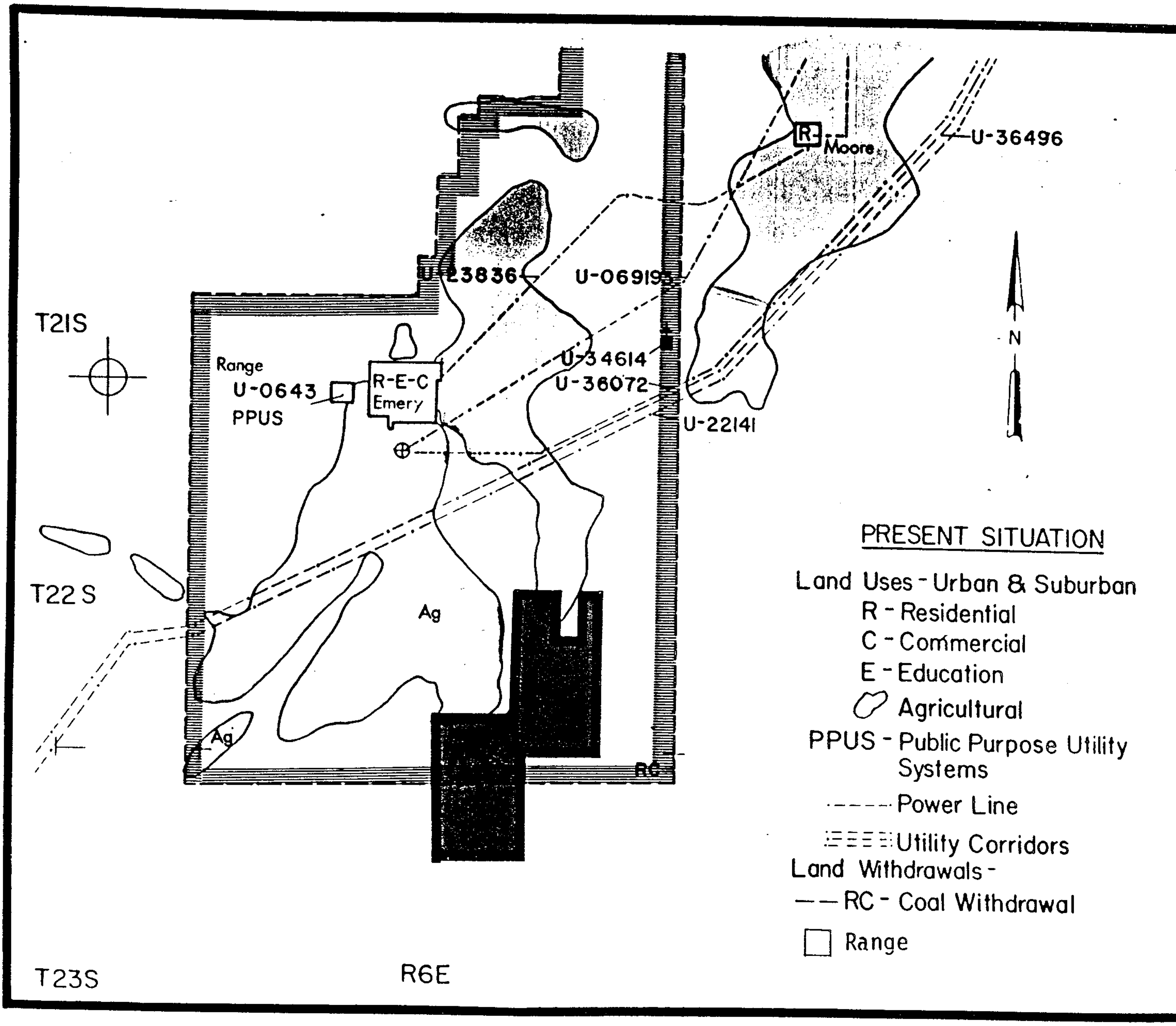


Figure 4. Present Land Use - Study Site

With respect to the Emery study site itself, the NW and SE portions of the site appear to meet criteria for stripping (100 to 200 depth to 20 foot coal seams). The northwestern area is the only part of the site containing the Blue Gate Shale (Persayo-Chipeta) soil derivatives. However, this appears to be the dominant soil type over the larger strippable resources which are more characteristic of the Emery coal field. But at least one of the defined strippable areas on the study site is representative of this "worst case" soil type. As a topsoil, the Blue Gate is nearly worthless, having the highest salinity and shrink swell potential, and lowest available moisture of all types represented. It may have some value in creating permeability barriers in site reconstruction if its salinity can be tolerated, but as a top soil it either requires amendment or disposal.

With regard to the drainage subbasin potentially disrupted by the stripping of the NW area, this would be the Miller Canyon drainage with an area within the study zone of 1195 acres. We note that continuation to the north of the presumed northern limit of recoverable coal would intercept Miller Creek, but mining in this area is unlikely. Miller Creek carries away irrigation water from the north and has been capturing small stream drainage as it erodes to the north and they change their channel geometry due to sediment filling. Diversion of these waters out of the coal pit by a bypass west to the town of Emery or a return to Miller Canyon further downstream, would be required. If the mine "makes" significant water this must be added to the diversion. If the first option is chosen, the Miller Canyon Creek would undoubtedly dry up in summer causing loss of the modest riparian habitat on the site. Perhaps mine water could be used to preserve this habitat if its quality were suitable.

This site would be most visible from the town of Emery. The average slopes are low to moderate here. However, here no significant streams are involved and prevention of wastes from entering Christiansen Wash by a series of sediment ponds is feasible. For the area the geochemical content of the sampled surface waters are not exceptional.

The second strippable area on the SE corner of the test site, involves the statistically more typical (for the study site) Castle Valley and Palisade soils. The revegetation tests conducted were essentially on these soils with minor areal exceptions. These experiments certified the soils as reclaimable even with admixture of shallow weathered overburden sandstone and some shales. In fact the bore hole geochemistry for bore holes 5 and 5A indicates the deeper overburden to be (unlike bore hole 3 to the north) a more acceptable soil supplement. But the extremely poor greenhouse results cast doubt on the use of the overburden as a supplement over all the site. In this region, conservation and storage of the topsoil is the obvious choice. The presence of a significant belt of Rock land over this site would require "stretching" this top soil over the Rock land area if mined and amending and blending with the nutrient poor, crushed shallow overburden; fly ash from the adjacent power plants or the less toxic deeper overburden suitable leached or crushed.

Evaluation of Toxic, Detrimental and Essential Elements in the Overburden

Several problems have yet to be resolved regarding the interpretation of the overburden geochemical data given by Heil and Deutsch (1979), Affolter et al., (1978) and the USGS (1979) water analyses. The latter did not include many of the elements reported by Heil and Deutsch and Affolter et al. The report by Affolter et al., (1978) did not analyze the siltstones and sandstones of the Ferron Formation. This probably does not constitute a serious problem in admixing sandstone in the formation of reconstituted subsoil or topsoil because trace element levels in siltstones and sandstones are generally lower than shales. Finally, the data reported by Heil and Deutsch represent those samples derived from crushed core bedrock samples. This material was not soil; fertilizer was added to the crushed rock for pot tests. Growth results indicate that salt tolerant native species perform less well than western wheatgrass, which seems unacceptable (Figure 5). GSC greenhouse tests on unfertilized overburden and the same seedstock were even more disappointing, as might be expected. But these backup tests do confirm Heil's results at least qualitatively. The problem of the cause of plant mortality is aggravated because similar pot tests by Heil from the Foidel Creek area did not produce as many deaths. GSC performed limited germination tests on the seed used and obtained 10 to 20% yields, hence poor germination does not account for the severity of these results. On review of the geochemical data, toxic concentrations do not appear either in the water, Ferron shale or crushed core samples. However, detrimental to toxic levels of boron (especially in the lower part of bore hole #6) and deficiencies of manganese, copper, and zinc may occur.

KEY:

1- Marine Sandstone

2- Alluvial and Delta Plain Rocks
Sandstone, Siltstone,, Claystone

3- Coal

4- Delta Front/ Marine Sequences
Sandstone, Siltstone, Claystone

5- Ash- Burned Coal

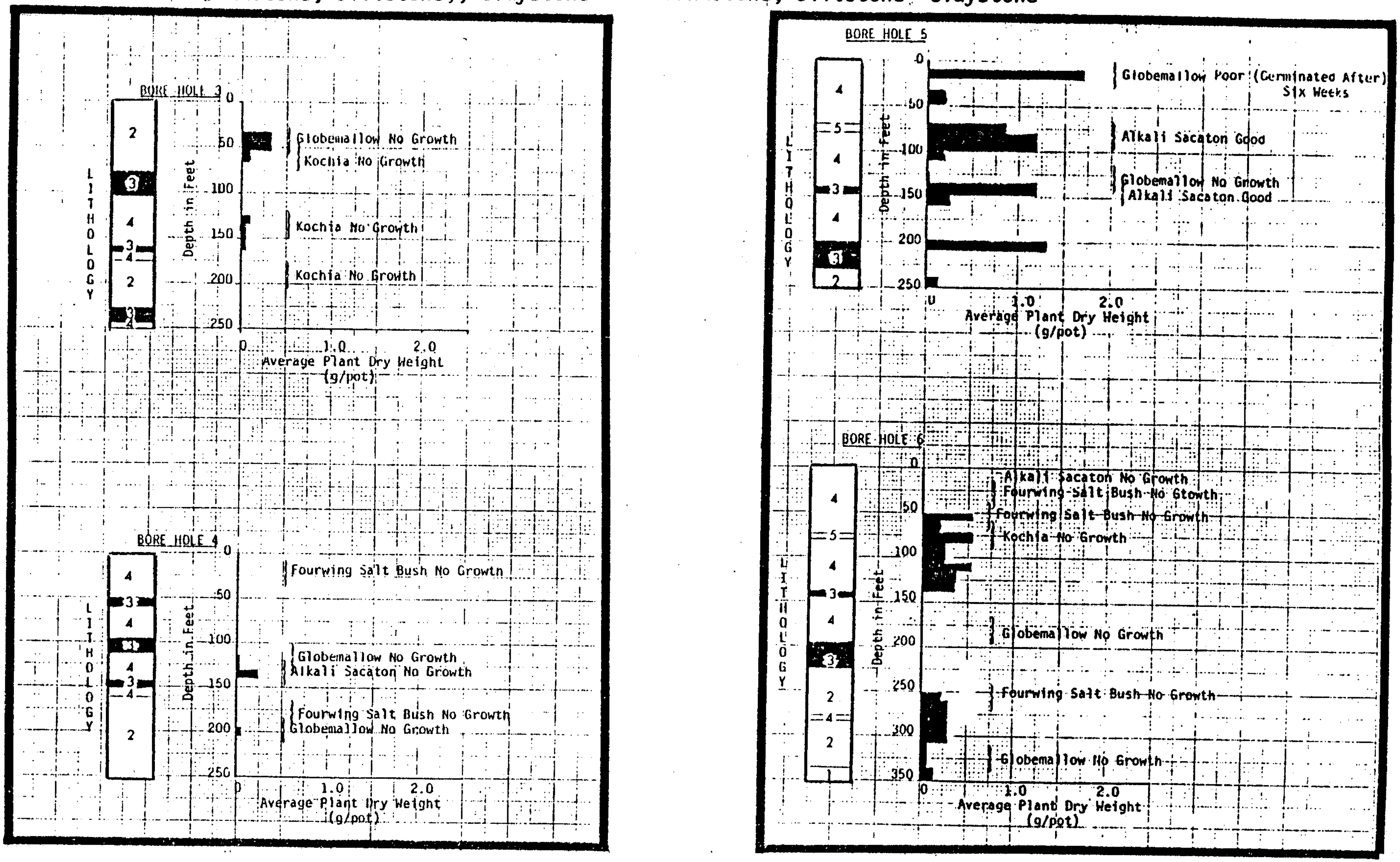


Figure 5. Greenhouse Comparison of Western Wheatgrass Growth Rates in Overburden.

Returning to the problems of admixed fertilizer added to crushed rock in pot tests, a possible concern is the lowering of pH by this fertilizer. Since Emery crushed rock (with the exception of pyritic and carbonaceous shale zones) are generally alkalic, a reduced pH would tend to mobilize whatever potentially toxic elements may be present. Under conditions of high pH, most toxic metals form insoluble carbonates and hydroxides. We recommend analysis of extractable toxic elements from leachates before and after addition of fertilizers.

Based on the evaluation of major, minor and trace elements, four possible overburden configurations might be considered. First, we recommend an adequate clay seal above the Ferron siltstones after the I coal seam is removed. A permeable coarse layer should be placed on top of this seal. Above this a reconstituted subsoil should be added. Finally, a thick-permeable topsoil layer is recommended if overburden must be used in the amendment. If boron is present, a slow growth rate would occur until sufficient leaching and removal of boron in the coarse rock substrate can take place. In the case of mobilized toxics, accelerated downward leaching may be achieved by addition of fertilizer to the topsoil

The second action does not involve a leach and lateral transport by a gravel substrate above the clay seal. Instead, dilution of the reconstituted overburden and topsoil by admixing either Ferron sandstone, Quaternary windblown sands, or fly ash from the nearby Emery Power Plant is suggested.

In addition to neutralizing power, fly ash, admixed with spoil, effects favorable physical changes of the mix, which improves plant growth (Doyle, 1976, p. 134). Since the density of the mix is reduced by admixture of the fly ash, the pore volume, moisture availability, and air capacity increase. These factors improve root penetration and depth.

If trucks hauling coal away from the strip mining area can return with fly ash loads from the power plant site, possibly low cost stockpiling of this product at the strip site would be achieved. The ashed samples of coal analyzed by the USGS (1979) suggest that nutrients are present which might enhance plant survival if fly ash is added.

The strippable coal resource to the west of the study site would potentially involve thicker alluvial soil sequences, which if a unitized development were involved, could be borrowed for the poor topsoil strippable regions on the plateau. Drainage from this site would be to the east into Quitchupah Creek. It is conceivable that the confined Ferron Sandstone aquifer, beneath this western part of the coal field, with artesian flow, could be impacted. For this area (off the study site) a more significant ground water disposal problem is implicit during mine dewatering. Also a potential hazard is possible to the municipal water supply of Emery by downward seepage into unsealed vertical joints. Extremely high iron contents were found in surface waters in the area. These may be taken to indicate the possible presence of other trace elements of greater concern which may be masked by the iron. The elimination of some small springs feeding into local creeks could result, but this is questionable considering the baseline data available. The removal of the necessary overburden should not effect the artesian pressure of the confined Ferron aquifer to the east.

As it now stands the study area has limited range/wildlife habitat/watershed value and possible recreational values. On the other hand, if the carrying capacity of the land could be increased as a result of an improved moisture retention capacity due to strip mining and shaping, then local long-term benefit may accrue in the process.

Secondly, for whatever reason, drought or loss of vegetative cover, springs and seeps from the plateau are now dried up. Thus a reasonable second objective would be to intercept a portion of the runoff in small basins after the mining by surface shaping and producing an increased infiltration surface zone.

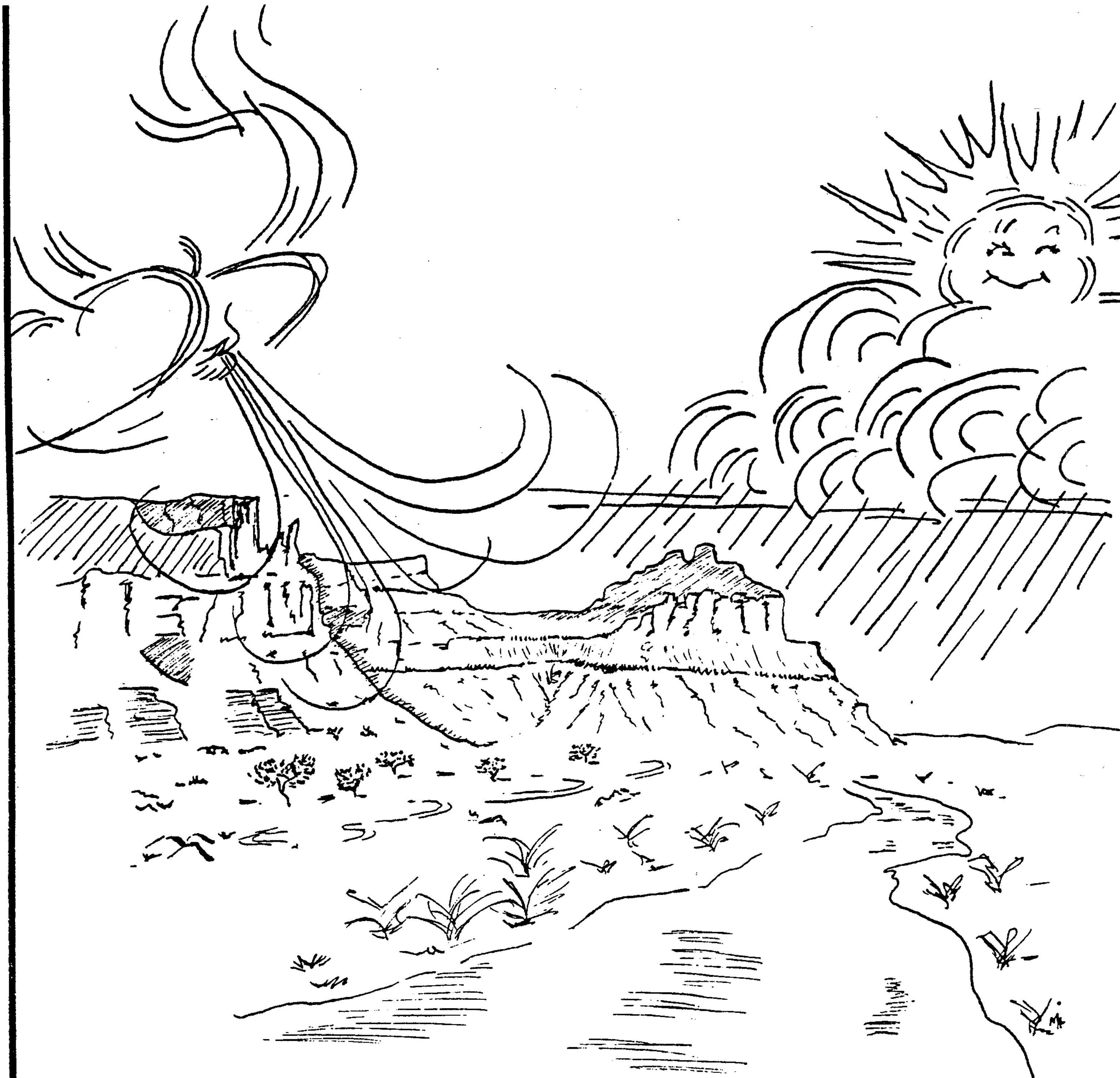
Thirdly, after the interruption of the existing stratigraphy by the mining process, a single ground water zone will develop above the floor of the coal mine. This increase in infiltration may serve to dilute near surface salinity and enhance vegetation and stock water supplies. On the other hand the altered chemical properties of the ground water may produce undesirable characteristics downslope. In the reclamation process a balance between these situations is needed.

Fourth, introduction of new grass, forbs and shrub species, native to the region but not how well represented on site could improve the ultimate range carrying capacity. The restored strip mined lands offer opportunity for such introduction free of competition.

Fifth, the existing wildlife in the area appears to be meager, evidently it would be possible to introduce a superior habitat for deer and elk, on the unmined sites by shaping small hills as cover with water nearby. Game could be introduced.

A sixth objective would be to provide superior flood control catchment basins as a by-product of the strip mining operation. As discussed in the strip mine model, a natural result of a mining operation is a final pit which may have inadequate fill. If this pit could be placed to catch excess runoff, it would protect the downslope surface construction, provide water for supplemental irrigation and avoid potential stream contamination by sediment or other runoff water geochemistry.

A seventh objective would be to isolate any toxic wastes from the ground and surface water supplies. Essentially we would wish to have a closed cycle system result in such areas with losses to evapotranspiration and input from precipitation. We would wish to avoid excess surface water entering such a zone, and infiltrating. Hence impoundments, barriers or surface coating with parafin or asphalt as is employed in water harvesting might be considered. Vertical fractures below the floor of such a disposal site must be sealed to avoid contaminating deeper aquifers.



CLIMATE

CLIMATE

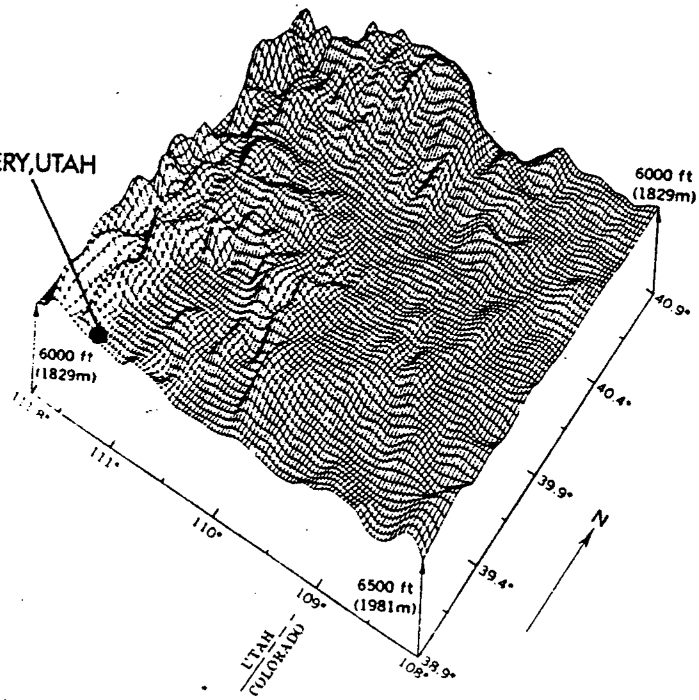
General

The Emery coal field lies at the eastern foot of the Wasatch Plateau, the northernmost of the high plateaus of Utah, as do several other of the Utah coal fields (Figure 6). At higher elevations of the Wasatch Plateau, over 11,000 feet, annual precipitation averages more than 30 inches, largely as winter snows which provide most of the streamflow and ground water. This precipitation depletes the moisture from the wintertime westerly flow, and the general downslope motion of this flow across Castle Valley, in which Emery lies, make winters rather dry there, with about 3 inches of winter precipitation.

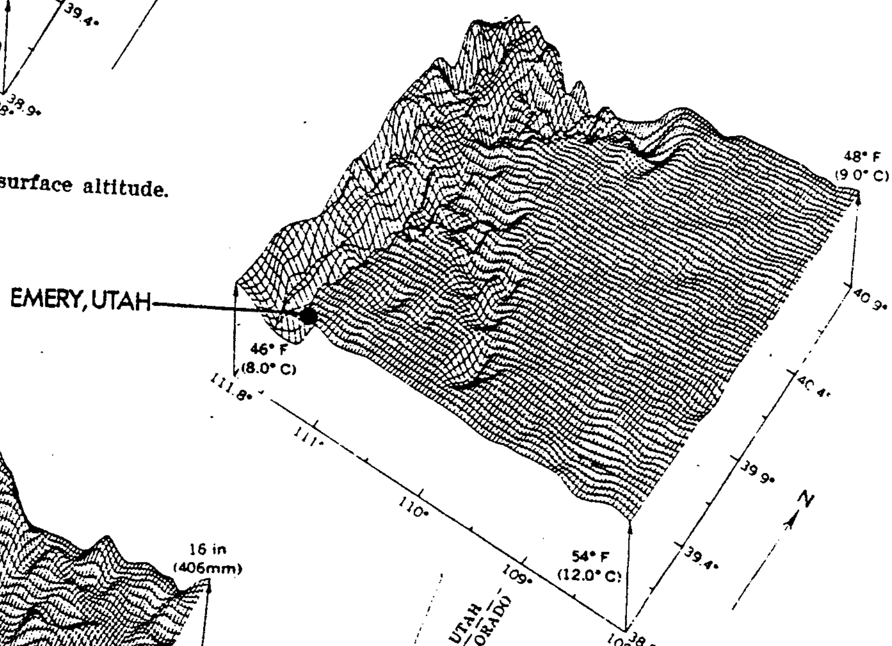
In contrast, in summer moist air occasionally penetrates northward from the Sea of Cortez and, sometimes, from the Gulf of Mexico. As this flow rises northwestward from the Colorado River, convective showers and rare thunderstorms are formed, bringing most of the region's precipitation. But the stronger sunshine and warmer temperatures, although only around 70°F, increase evaporation and transpiration, so that most of the summer rain evaporates quickly.

Average annual precipitation around Emery coal field is less than 10 inches, with extensive areas receiving less than 8 inches, some less than 6 (Figure 7). The town of Emery at 6,220 feet elevation receives 7.55 inches annually on the average. Studies in other parts of western United States have suggested that revegetation of reworked land is unlikely when precipitation is less than 12 inches. Hence in the Emery coal field and in portions of the adjacent coal fields shown in Figure successful revegetation may require extensive irrigation, except in those few years when precipitation is almost double the average.

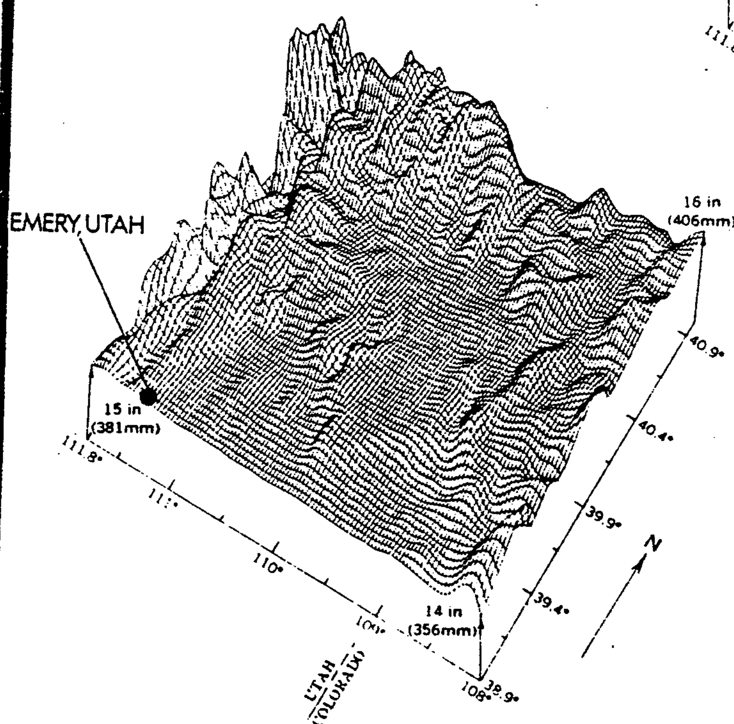
Weather conditions during the few years after mining and reclamation will determine whether topographic and vegetative restoration of surface mined lands in Emery county will succeed. Careful consideration should be given to eventual uses of the mined land, to avoid spending $5,000 an acre to restore land which then will be worth $55 an acre, as cited by Singer (1977). Newly reshaped terrain can be eroded by wind and rain before vegetation is established, if such is permitted by the sequence of weather conditions. While further weather cannot be predicted with sufficient precision to indicate the probable success of land reclamation and revegetation, probabilities can be extracted from records of the



Distribution of land-surface altitude.



Distribution of average annual temperature, 1941–70.



Distribution of average annual precipitation, 1941–70. Each vector base is equal to 9 in (229 mm).

Figure 6. Perspectives of Average Annual Precipitation and Temperature Related to Topography.

Figure 7. Normal Annual Precipitation (in inches)

past behavior of the weather.

Over the slightly rolling and partially dissected terrain of the Emery EMRIA study area, weather conditions vary naturally somewhat, from place to place, but perhaps less than the normal year-to-year variations at any one place. On the whole, Emery weather of past years, which constitutes climate, should be an adequate guide to conditions during the next decade or two in the Emery coal field. In fact, climate doesn't vary excessively throughout most of Castle Valley, in whose south end Emery lies, and indeed for tens of miles farther south, along the eastern foot of the high plateau. Conditions described here should be generally applicable to possible mining areas as far south as the Henry Mountains.

Fortunately, the Emery EMRIA site is only 3 to 6 miles SSE of the town of Emery, for which weather records obtained from 1901 to 1978 have been tabulated and summarized by the U.S. Weather Bureau and its successor, the Environmental Data Information Service. Other summaries have been compiled by various federal and state agencies. In addition, hourly records were obtained for ten months in 1972-1973 at a site two miles north of the EMRIA area. Detailed data from this site are given in Appendix 1 ; data from the town station are summarized here.

From 1901 until 1978, a series of five observers measured maximum and minimum temperatures, and rainfall amount, every day, with some interruptions. The station was moved only four times, to various residences a few blocks apart in the level townsite, and data from the four locations appear compatible.

Temperature

Temperatures experienced at Emery during 30 years, 1941-1970, are shown in Figure 8 (from Richardson, 1975). Mean temperatures by month for each recorded year are given in Table 1, arranged into two half-years, beginning with October ("winter") and April ("summer"). This division more clearly reflects the nature of Emery's climate, and is used in all tables.

One index frequently used to characterize the climate of an area, mean annual temperature, can be misleading because two areas reporting the same mean annual temperature may actually have quite different climates. Thus temperature extremes as given in Tables 2 and 3 must also be con-

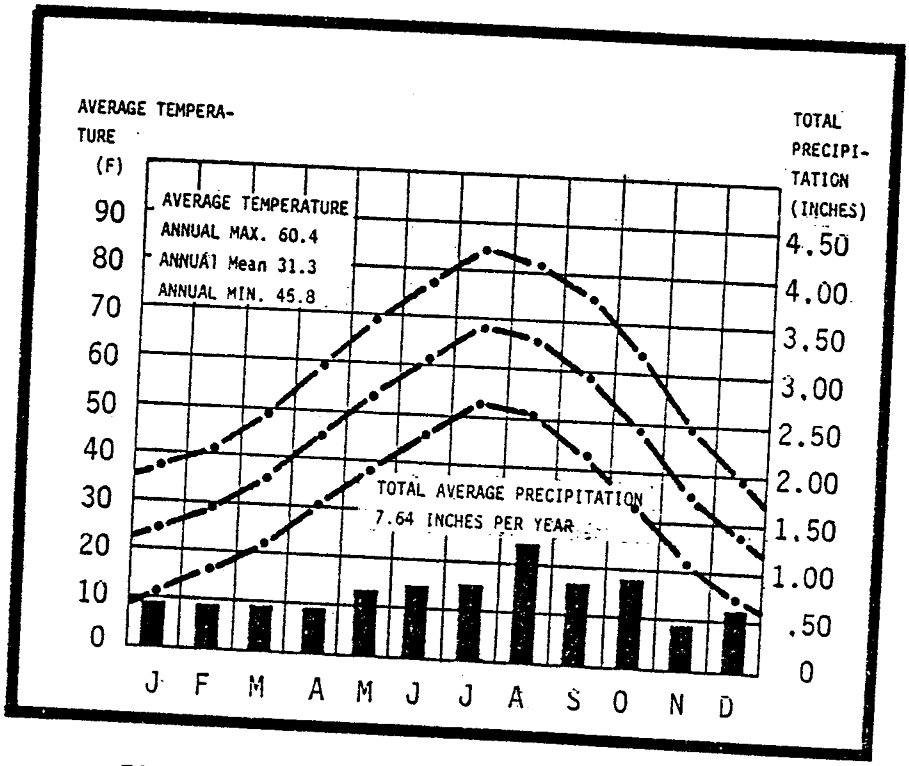


Figure 8. Emery Climatological Summary (Monthly Averages 1941-1970)

Table I.

Mean Temperature, by months, at EMERY UT (38°55 N, 111°15 W, 1893 m MSL)

	OCT	NOV	DEC	JAN	FEB	MAR	WINTR	APR	MAY	JUN	JUL	AUG	SEP	SUMMR	YEAR
1901-02	49.8	37.8	31.4	28.3	31.8	33.0	35.4	43.0	49.0	59.9	60.4	61.6	56.3	55.0	45.2
1902-03	44.8	34.8	24.6	26.2	19.2	35.1	30.8	40.8	47.4	58.7	62.8	65.0	52.6	54.6	42.7
1903-04	48.8	38.4	25.8	22.6	33.0	34.8	33.9	42/4	50.6	56.2	61.2	60.2	52.1	53.8	43.8
1904-05	39.0	33.6	22.4	24.2	25.6	36.4	30.2	41.0	45.3	57.4	59.4	62.3	—	—	—
1905-06	38.6	34.3	—	26.4	35.0	36.8	—	45.2	53.8	59.6	68.2	69.2	57.4	59.0	—
1906-07	49.0	34.1	31.6	25.5		43.6		49.0	51.9	56.5		67.0	56.6		
1907-08	53.4	41.4	30.3	27.9	30.5	43.5	37.8	51.1	54.2	59.0	69.8	65.2	56.4	59.3	48.6
1908-09	44.6	35.9	26.8	—	32.8	37.6	—	44.5	52.3	64.8	69.0	67.4	60.0	58.8	—
1909-10	53.1	44.3	17.8	21.8	26.3	45.4	34.8	50.6	54.0	62.6	67.8	60.3	50.8	59.7	47.2
1910-11	50.7	44.0	31.6	31.9	29.0	38.4	37.6	43.6	53.6	61.5	64.9	63.5	64.0	58.5	48.1
1911-12	39.4a	29.9		26.8	34.4	35.8		39.0	54.0	60.6	63.8	64.0	49.0	55.1	
1912-13	39.7	39.0		20.4	30.7	34.6		43.4	54.6	60.2	60.6	68.6	59.5	57.8	
1913-14	50.0	39.7	28.3	22.9	25.4	34.4	33.5	48.6	55.0	50.5	62.2	58.8	58.1	55.5	44.5
1914-15	49.0	36.6	26.0	22.7	22.2	31.7	31.4	45.8	46.5	54.3	63.4	62.2	50.4		
1915-16	50.6	42.0	27.8	20.4	28.4	39.8	34.8	48.0	53.0	61.8	65.7	62.8	58.0	58.2	46.5
1916-17	48.4	35.2	25.2	16.6	29.6	32.8	31.8	40.5	46.0	60.8	69.4	66.0	59.8	47.1	44.2
1917-18	47.1	45.2	34.6	26.8	29.2	38.0	36.8	44.8	52.8	66.2	65.8	64.0	57.8	58.6	47.7
1918-19	53.2	35.8	21.9	18.8	24.4	36.2	31.7	43.7	55.6	63.8	70.6	68.2	61.1	60.5	49.1
1919-20	45.0	37.2	24.9	26.6	33.8	34.6	33.7	38.2	56.1	63.0	67.8	66.4	62.0	58.9	46.3
1920-21	53.2	38.0	24.2	25.3	33.4	40.1	35.7	43.7	50.2	65.4	—	—	—	—	—
1921-22	—	—	31.0m	20.5	25.2	33.0	—	40.2	53.6	65.9	69.7	67.2	61.0	59.6	—
1922-23	48.4	34.6	30.8	31.4	25.6	34.5b	34.2	43.6	55.0	60.4	70.5	63.8	54.8	58.0	46.1
1923-24	43.2	36.2	25.1m	22.4a	34.2	31.0	32.0	44.6	56.4	65.9	69.5	66.8	55.7	59.8	47.0
1924-25	44.6	34.6	18.6	17.3	29.6	38.6	30.6	46.2	58.4	60.5	69.3	65.0	55.3	59.1	44.8
1925-26	46.4	32.4	30.0	55.4	32.0	38.8	34.2	48.8	54.4	65.4	68.0c	65.4	56.6	59.8	45.2
1926-27	48.8	37.0	23.6	27.4	31.4	35.6	34.0	44.2	52.5	63.0	68.6	63.4	56.4	58.0	44.3
1927-28	47.9	38.4	22.1	28.4a	30.5	39.8	34.5	41.7	55.6	60.4	68.6	65.3	59.0	58.4	46.4
1928-29	47.2	34.6	23.2	22.6	21.6	36.4	30.9	41.4	52.4	62.1	70.0a	67.2	56.0	58.2	44.6
1929-30	47.4	34.2	30.4	13.7	32.0	35.4	32.2	49.9	50.0	63.9	68.4	65.4	56.0	58.9	44.9
1930-31	44.4	33.8	24.7	25.2	33.3	34.8	32.7	47.3	53.8	65.0	73.0	67.9	59.9	61.1	45.9
1931-32	49.1	32.2	21.8	18.6	30.8	36.6	31.5	44.5	53.0	61.8	68.4	67.0	59.8	59.1	45.3
1932-33	47.3	37.4	18.8c	19.3	15.4	37.1	29.2	40.1	48.2	65.4	70.8	66.2	62.3	58.3	44.0
1933-34	53.0	39.6	30.6	29.8	37.4	45.0	39.2	49.7	60.0	60.9	71.8	68.9	59.4	61.8	45.5
1934-35	50.8	38.4	29.6	28.4a	32.2	34.4	35.6	43.0	49.4	64.6	68.6	66.6	59.9	58.7	47.2
1935-36	46.6	34.0	27.0	26.5	29.1	39.5	37.8	47.8	56.4	64.4	68.5	66.6	56.8	60.1	47.9
1936-37	45.3	35.8a	26.9	8.7	22.6	36.2	29.2	43.8	57.2	61.2	67.5	67.4	60.4	59.6	44.4
1937-38	49.7	38.6	30.8	29.1	30.6	35.5	35.7	45.6	51.9	62.6	66.1	67.1	59.4	58.8	47.2
1938-39	48.3	29.4	28.5a	24.0	15.8	36.4	30.4	48.5	55.4	60.4	68.6	67.1	58.8	59.8	45.1
1939-40	48.3	40.0	—	—	32.2	39.7	—	46.7	58.6	66.2	69.8	68.0	58.5	61.3	—
1940-41	49.1	32.5a	25.0	25.0	31.0	36.6	33.2	40.2	54.4	57.8	65.8	64.8	54.0	56.2	44.7

Table I (cont.)

Mean Temperature, by months, at EMERY UT (38°55 N, 111°15 W, 1893 m MSL)

	OCT	NOV	DEC	JAN	FEB	MAR	WINTR	APR	MAY	JUN	JUL	AUG	SEP	SUMMR	YEAR
1941-42	44.5	36.6	27.5	23.7	23.1	34.1	31.6	45.8	50.5	60.2	67.2	65.4	56.8	57.6	44.6
1942-43	49.0	36.8	31.8	28.6	32.9	36.9	36.0	50.2	52.0	58.7	66.9	65.2	59.8	58.8	47.4
1943-44	48.0	35.4	26.6	21.0b	24.0b	33.5	31.4	40.8d	51.8	57.2	65.4c	65.0	58.6	56.3	43.9
1944-45	49.0	33.4	29.4	28.5	31.3	33.2	34.1	38.0d	53.3i	55.6	60.1	64.8	55.6	55.6	44.9
1945-46	48.4	34.3	23.2	22.4	29.6	38.8	32.8	51.4	51.1	63.5	68.6	66.6	58.5	60.0	46.4
1946-47	42.8	31.6	31.2	25.1	33.9	40.0	34.1	44.0	56.8	57.0	67.0	64.1	61.2	58.9	46.5
1947-48	49.8	30.0	25.6	26.0	25.6	29.5	31.1	45.1	54.0	60.6	66.6	65.4	61.2	58.3	45.0
1948-49	47.7	31.1	25.3	15.8	18.4	36.5	29.1	48.3	52.6	60.0	67.5	65.3	60.3	59.1	44.1
1949-50	45.7	43.8	23.5	20.6	31.7	37.5	33.3	47.4	52.0	61.6	66.3	65.4	57.4	58.3	46.1
1950-51	54.5	40.1	34.4	27.2	29.8	36.2	37.0	47.3	53.6	59.3	70.3	64.7	59.4	59.1	48.1
1951-52	46.1	31.7	21.8	21.9	26.3	30.5	29.7	46.2	55.5	62.5	68.1	67.1	60.6	60.0	44.9
1952-53	54.0	32.1	24.8	30.5	30.9	39.2	35.2	43.7	48.9	63.2	70.2	64.4	61.4	58.6	46.9
1953-54	48.5	38.5	25.8	28.0	39.3	36.3	36.0	50.3	57.4	60.9	70.8	67.8	60.3	60.9	48.5
1954-55	51.0	40.7	24.3	20.9	18.9	34.4	31.7	42.9	53.7	60.7	68.9	67.3	61.3	59.2	45.5
1955-56	50.6	34.2	30.4	31.2	25.4	39.9	35.3	46.1	55.8	65.5	68.2	64.5	62.0	60.3	47.3
1956-57	49.1	31.6	44.7	20.9	32.6	38.7	36.8	43.4	50.0	62.1	67.8	65.2	57.8	57.7	47.2
1957-58	46.4	31.8	29.7	27.7	34.8	33.3	34.0	42.3	58.0	64.5	68.3	69.3	59.7	60.3	47.1
1958-59	50.0	37.1	35.3	27.6	30.8	37.5	36.4	46.5	52.2	66.6	70.4	67.0	—	—	—
1959-60	—	—	28.0	18.6	23.8	38.7	—	46.4	52.9	64.2	70.0	67.3	61.3	60.3	—
1960-61	47.7	35.4	27.4	26.1	32.0	36.0	34.1	44.4	53.6	66.6	69.8	67.7	52.8	59.1	46.0
1961-62	47.2	33.2	21.9	25.0	32.7	31.9	32.0	48.6	52.0	61.1	67.3	66.1	58.4	58.9	45.4
1962-63	49.1	38.9	28.4	17.6	—	32.9	—	40.5	56.4	59.0	68.3	65.2	59.4	58.2	—
1963-64	51.6	34.2	24.1	21.5	25.6	31.1	31.3	43.7	52.1E	60.1E	71.5E	66.2E	57.7E	58.5	44.9
1964-65	51.0	32.1	25.5	30.4	28.7	33.6	33.5	44.1m	50.3E	58.2E	67.7m	65.1m	53.5	56.5	45.0
1965-66	51.3m	39.6m	25.5	31.2	23.3	—	—	—	—	—	—	58.1	—	—	—
1966-67	—	—	24.4	24.5	—	—	—	—	51.9	58.0m	70.5	68.4	59.6	—	—
1967-68	52.0	38.7m	18.4	18.3	31.8	39.1	33.1	40.5m	50.5m	62.9	65.7	61.0	56.1	56.1	44.6
1968-69	49.1	35.0	21.0	27.8	24.0	30.4	41.2	45.9	58.5	59.6	69.4	70.2	61.4	60.3	47.0
1969-70	42.4	34.7	30.5	26.5	—	34.8	—	40.0	54.3	62.2	69.5	69.8	56.0	58.3	—
1970-71	42.8	34.3	25.6	26.0	28.1m	35.3m	32.0	44.1	51.5	—	—	68.8	56.0	—	—
1971-72	44.1	—	—	28.1	33.6	44.0	—	45.6	54.7	64.2	69.6	66.2	58.0	59.7	—
1972-73	43.9m	32.6m	—	16.9	—	—	—	—	—	—	—	70.0m	—	—	—
1973-74	—	—	27.1	17.1m	22.9	42.0	—	43.0	57.8	66.2	67.9	66.7	60.2	58.6	—
1974-75	49.6	35.1	25.6	24.2	28.5m	35.6	33.1	38.5	49.7	58.9	69.4m	65.5	58.9m	56.8	45.0
1975-76	46.9	33.8	27.9	24.6	34.4	34.2	33.6	43.6	55.4	61.3	70.9	65.2	59.4	59.3	46.5
1976-77	46.3	38.8	24.3	24.6	34.0	32.2	33.9	47.5	—	67.5	69.9	69.4	60.7	—	—
1977-78	49.7	37.3m	31.7m	25.7	27.1	—									

a, b, c, ... etc., indicate 1, 2, 3, ... 35c. days missing; m = unspecified number of days missing.
E = estimated value.

Table 2

Hottest Temperature of Each Month, 1960-1978, Emery Utah

	OCT	NOV	DEC	JAN	FEB	MAR	WINTR	APR	MAY	JUN	JUL	AUG	SEP	SUMM
1960-61				52	55	61		74	81	--	98	98	80	--
1961-62	75	57	48	57	56	67	75	79	82	90	94	88	76	94
1962-63	76	71	60	51	--	64	--	71	82	87	92	85	65	92
1963-64	85	65	53	50	53	64	85	72	--	--	--	--	--	--
1964-65	81	63	58	53	55	59	81	--	78	84	89	89	79	89
1965-66	81	64	50	45	45	--	--	--	--	--	--	93	--	--
1966-67	--	--	53	52	--	--	--	--	86	91	92	91	87	92
1967-68	78	70	52	43	57	69	78	71	85	92	92	84	85	92
1968-69	79	68	58	58	48	69	79	77	85	86	98	95	85	98
1969-70	75	61	56	59	--	62	--	70	87	98	92	95	83	98
1970-71	76	61	51	65	59	73	76	72	78	--	--	91	88	--
1971-72	79	--	--	56	62	--	--	73	84	91	93	93	85	93
1972-73	77	56	--	39	--	--	--	--	--	--	--	93	--	--
1973-74	--	--	48	42	45	67	--	72	83	93	91	90	89	93
1974-75	79	62	47	59	58	59	79	65	80	87	91	90	86	91
1975-76	79	67	53	55	61	60	79	69	82	92	95	88	87	95
1976-77	75	68	50	53	62	61	75	77	84	88	91	92	90	91
1977-78	77	64	60	50	49									

Table 3

Coldest Temperature of Each Month, 1960-1978, Emery Utah

1960-61				-2	6	9		19	28	--	47	47	24	--
1961-62	17	12	-8	-2	-1	5	-8	18	21	31	40	32	26	18
1962-63	25	10	-12	-20	--	4	--	11	27	33	44	39	43	11
1963-64	22	6	-2	-11	-2	5	-11	23	--	--	--	--	--	--
1964-65	20	2	0	3	1	4	0	23	22	34	45	40	23	22
1965-66	24	15	1	-2	-4	--	--	--	--	--	--	41	--	--
1966-67	--	--	1	-1	--	--	--	--	12	37	47	45	31	--
1967-68	19	5	-8	-10	2	13	-10	15	24	28	28	30	23	15
1968-69	18	3	-7	-6	-4	1	-7	24	31	37	41	46	34	24
1969-70	17	8	-2	-6	--	8	--	12	20	33	38	48	29	12
1970-71	13	10	3	-16	-7	3	-16	14	25	--	--	45	23	--
1971-72	7	--	--	-3	-2	12	--	19	19	41	44	41	28	19
1972-73	--	13	--	-9	--	--	--	--	--	--	--	42	--	--
1973-74	--	4	7	-13	-3	18	-13	19	23	31	43	28	26	19
1974-75	24	9	-4	-5	2	5	-5	13	23	32	45	41	32	13
1975-76	12	6	5	-3	7	4	-3	18	28	30	46	42	36	18
1976-77	16	-5	3	-4	10	6	-5	16	28	41	47	42	29	16
1977-78	23	3	-1	3	-4									

sidered. Note in Table 3 the common occurrence of freezing conditions during the nominal summer growing season, which is masked by considering only the mean data.

The diurnal range (difference between the daytime maximum and the night-time minimum) should be considered in assessing the climate of the region. In general, stations on mountain slopes, where air drainage is good, have a much smaller diurnal range than stations in valleys, including small mountain valleys, where air is more stagnant. Thus seasonal variation in mean daily (diurnal) range is greater for valley stations than for stations located on slopes.

"Growing degree days" (GDD) are an arithmetic accumulation of daily mean temperatures above a certain threshold temperature. They are a simple means of relating plant growth, development, and maturation to environmental air temperatures. Different species of plants have different base threshold temperatures below which theoretically they do not grow. At temperatures above this base or threshold value, the amount of plant growth is approximately proportional to the amount of heat or temperatures. Table 4 gives the number of degree days above 40° F and 50°F respectively, corresponding to the generally accepted values of the base temperature for important plants.

The growing degree day value for any day is easily obtained by subtracting the appropriate base or threshold temperature for the specific crop from the mean temperature. Thus, on a day with a maximum of 65° F and a minimum of 55° F, the mean temperature would be 60° F, which yields 10 degree days base 50, for a plant with 50° F threshold temperature. Actually the National Weather Service now uses a 50°- 86° F growing degree day, with all temperatures over 86° F counted as though they were 86° F, i.e. 36 GDD, base 50 would be calculated for an 86° F mean temperature day.

At Emery the frost-free or growing season is a little more than four months long (Richardson, 1975). On the average, temperatures have remained for:

132 days above 32° F, from May 21 to September 30;
166 days above 28° F, from April 30 to October 13;
187 days above 24° F, from April 21 to October 25;
212 days above 20° F, from April 6 to November 4;
236 days above 16° F, from March 22 to November 13.

Table 4. Growing Degree Days

Week Beginning	A. (40 F) Emery Mean	A. (40 F) Emery S.D.	B. (50 F) Emery Mean	B. (50 F) Emery S.D.
Mar 01	3	7	0	0
Mar 08	7	8	0	0
Mar 15	8	10	0	0
Mar 22	13	17	0	0
Mar 29	22	16	1	3
Apr 05	26	24	2	6
Apr 12	52	27	7	10
Apr 19	58	36	14	15
Apr 26	57	26	12	13
May 03	83	38	28	23
May 10	92	37	33	27
May 17	96	31	34	24
May 24	114	29	50	25
May 31	115	33	49	28
Jun 07	140	32	71	30
Jun 14	162	26	92	27
Jun 21	176	30	106	29
Jun 28	185	23	116	23
Jul 05	195	18	125	18
Jul 12	202	20	132	20
Jul 19	203	19	133	19
Jul 26	203	16	133	16
Aug 02	196	14	126	14
Aug 09	188	20	118	20
Aug 16	184	12	114	17
Aug 23	171	17	101	17
Aug 30	165	24	95	24
Sep 06	147	23	78	23
Sep 13	134	19	65	19
Sep 20	111	24	45	21
Sep 27	101	29	37	20
Oct 04	83	29	24	16
Oct 11	66	25	12	14
Oct 18	47	27	6	9
Oct 25	34	24	2	5
Nov 01	18	17	0	1
Nov 08	8	12	0	0
Nov 15	5	8	0	0
Nov 22	4	10	0	0
Nov 29	2	6	0	1
Dec 06	1	5	0	0
Dec 13	0	0	0	0
Dec 20	0	3	0	0
Dec 27	0	1	0	0
Jan 03	0	0	0	0
Jan 10	0	2	0	0
Jan 17	0	0	0	0
Jan 24	0	1	0	0
Jan 31	0	1	0	0
Feb 07	1	3	0	0
Feb 14	1	2	0	0
Feb 21	2	6	0	0
Totals =	3889	297	1961	214

The Emery coal field is slightly higher than the town, and therefore slightly colder. The various durations are one to two weeks shorter than those given for Emery.

Days of first and last occurrences of specified temperatures in spring and autumn are almost symmetrically distributed around their mean values, which are therefore also median values. That is, chances are even that the actual date in any given year will be earlier or later than the median. The probabilities that the differences between such last (or first) occurrences will differ by as much as the estimated number of days is indicated below (Jeppson et al., 1968):

Difference (Days):	1	3	5	7	9	11	13	16	21
Probability (%):	5	10	15	20	25	30	35	40	45

Thus the probability that a temperature of 38° F or colder will occur for the last time in spring no later than April 30-5 = April 25, is 50-15=35%; the probability that such last occurrence will be no later than May 5 is 65%. Likewise, the probability that 28° F or colder will occur in autumn 5 days or more before the median date of October 13 is 35%. The median length of the interval between last and first occurrences of 28° F or colder is 166 days, but the probability that it will be at least 10 days shorter, or 156 days, is 15 + 15 =30%, because actual dates in spring and autumn appear to be independent statistically. Thus the probabilities given above also apply to durations of various "frost-free" periods.

Precipitation

Mean annual precipitation for the region surrounding the Emery coal fields has been shown in Figure 2, emphasizing areas receiving less than 8 and less than 6 inches annually. This map is based on calendar year averages for the 30-year "normal" period, 1931-1960, when Emery received 7.27 inches. For various other periods, the Emery averages as tabulated and published by the Weather Bureau have been slightly greater (Table 5). But calendar year amounts have varied from 0.94 inches in 1902 to 13.56 in 1957, 13.78 in 1906, 14.83 in 1909, and 16.84 in 1941.

Seasonal precipitation is more significant than calendar year amounts. Most useful is division of the year into two halves, beginning with October ("winter") and April ("summer"). Monthly precipitation for the entire period of record at Emery is arranged in this way in Appendix 2.

The six-month "winter" receives only 39% of the year's precipitation, as shown by the following figures for the entire period, 1901-1978 (missing data in some years makes the annual total differ from the sum of the winter and summer averages):

	Winter	Summer	Year
Mean Precipitation	2.97	4.58	7.58
Standard Deviation	1.05	2.16	2.71
Coefficient of Variation	.35	.47	.36

The coefficient of variation (ratio of standard deviation to mean) is greatest in summer, indicating that precipitation is more variable then. Before 1930, winters were slightly wetter and summers slightly drier than in the following 38 years, as indicated in Figure 9, which shows the percentage frequency with which various seasonal totals have occurred.

No relation is apparent between the precipitation of one winter and that of the following summer season, as indicated by the scatter of the dots in Figure 10. A dry winter is just as likely to be followed by a wet summer as by a dry one. Nor is much relation shown between winter precipitation and snow accumulation at one of the two snow courses at the headwaters of Muddy Creek (Figure 11). Annual snow accumulations at both snow courses, as furnished by the Soil Conservation Service (Whaley and McWhirten, 1976) are given in Appendix 3. These water contents of the snowpack in late March indicate the water then will be available for irrigation during the "summer".

Extreme Probability Precipitation Events

Two tabulations of precipitation probability are presented in Appendices 4 and 5 . One gives the probability that various amounts of precipitation will not be exceeded during intervals of one week, two weeks, and three weeks of the standard Farmer's Year, beginning on March 1. The other indicates the probability of sequences of rainy days for three definitions of rainy day (.01, .05, and .10 inch) during one, two, and three-week periods of the same Farmer's Year. The one-week rainfall amount probabilities are shown in Figure 12.

Rainfall intensity is not great at Emery, the greatest daily catch in 78 years being only 2.60 inches in May of 1928. Greatest daily amounts in

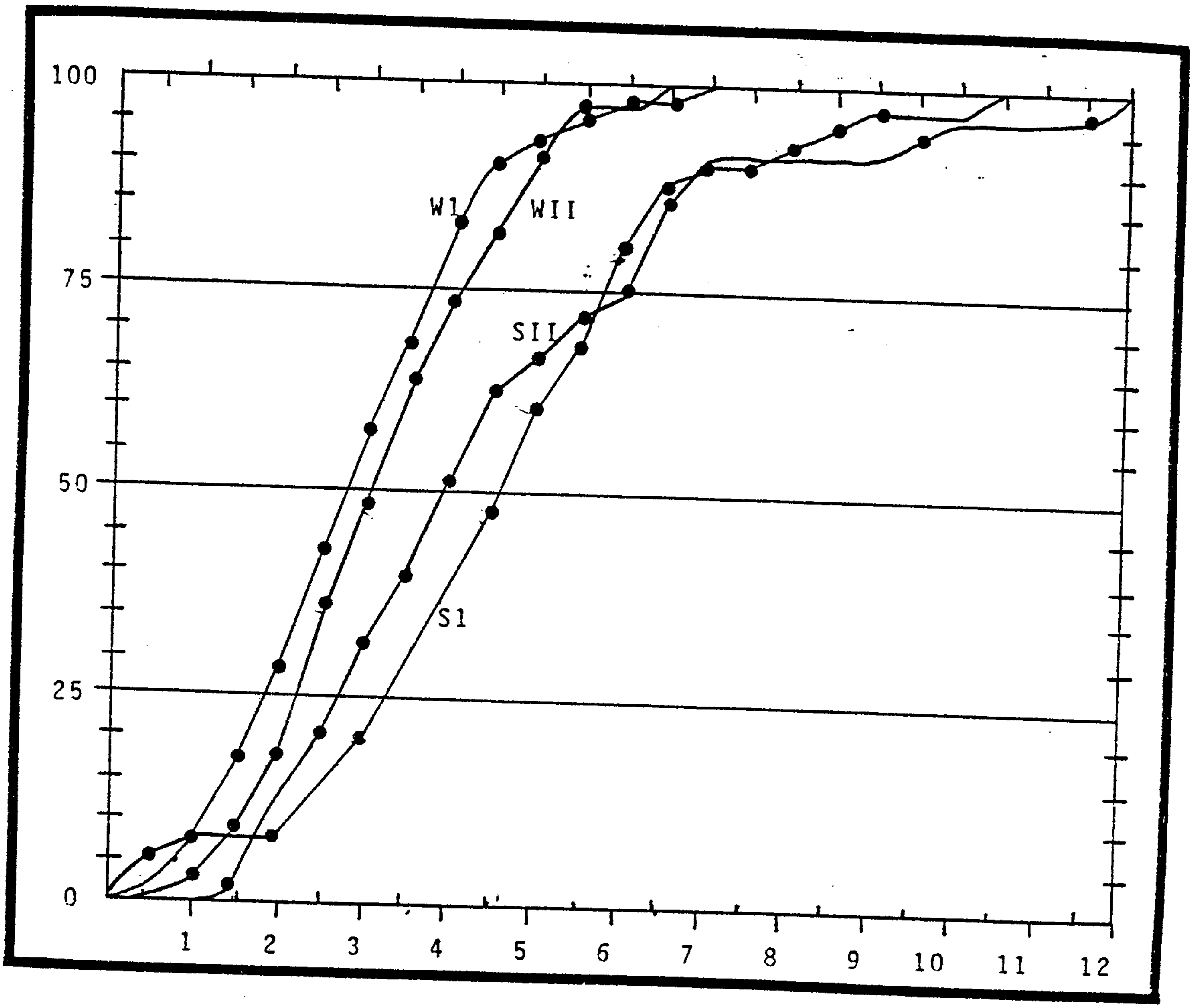


Figure 9. Cumulative Frequency of Seasonal Precipitation, Emery, Utah.

W= Winter (Oct. - Mar.)
S= Summer (Apr. - Sep.)
I= 1901 - 1941
II= 1941 - 1978

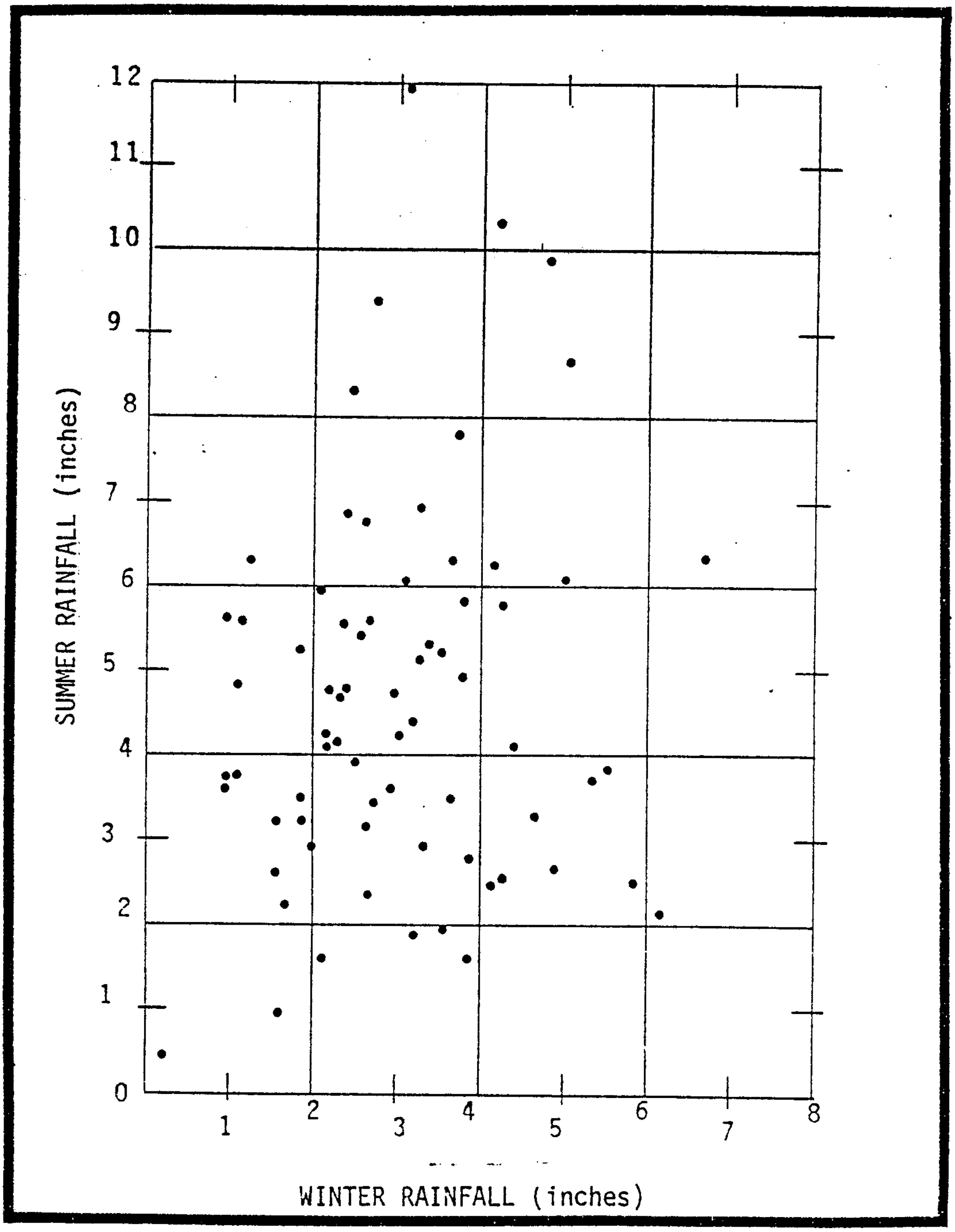


Figure 10 Distribution Plot of Winter and Summer Precipitation.
Precipitation in Winter (Oct. - Mar.), Abscissa, and in following Summer (Apr. - Sep.) at Emery, Utah, 1901 to 1978 (1922, 1966, 1967 and 1976 missing).

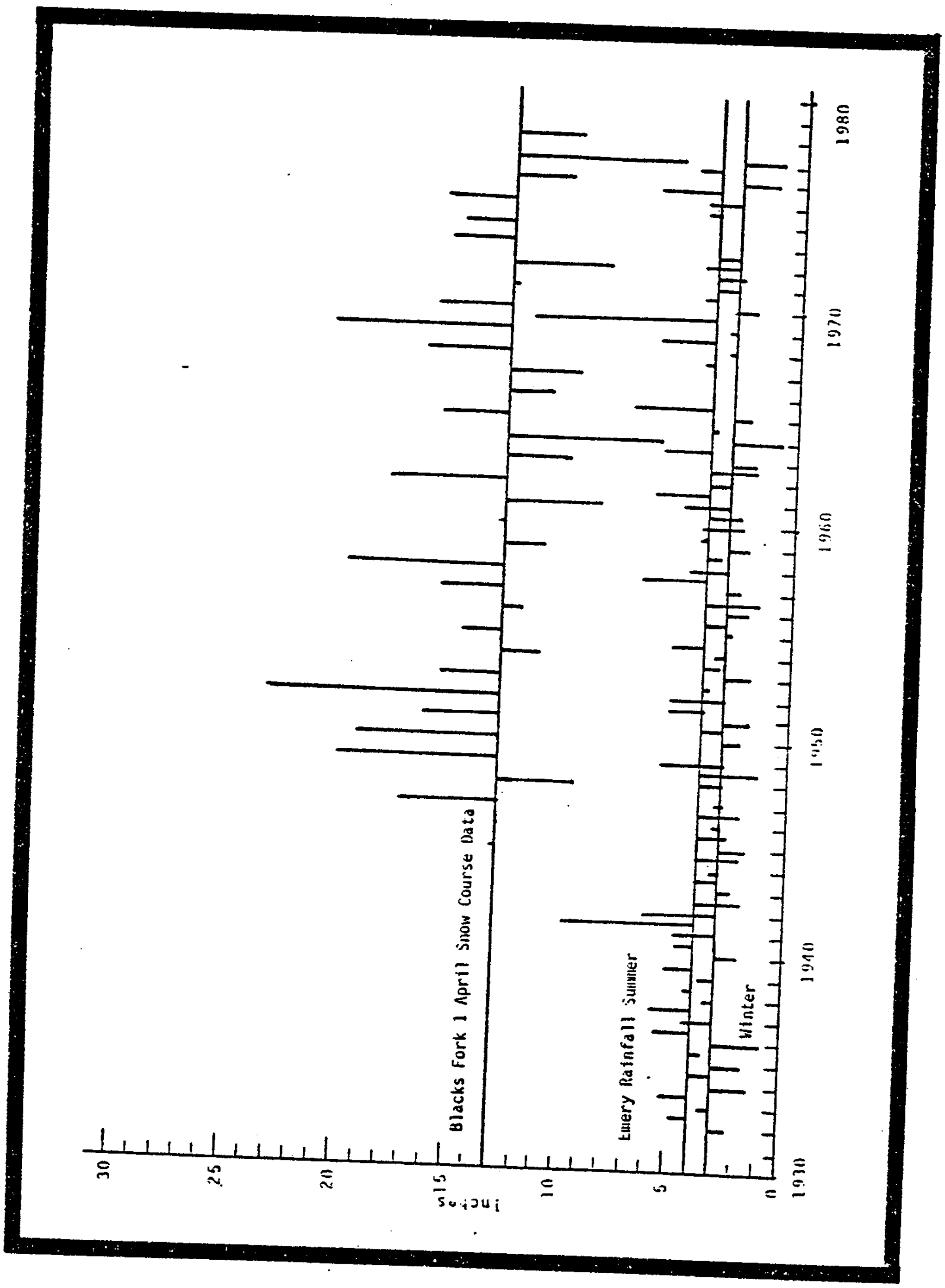


Figure 11 Emery Area Precipitation. (From 1930 to 1978)

Table 5

Mean Monthly Precipitation for Various Periods - Emery, Utah													
Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Cum. Year
1901 - 20	.73	.35	.48	.52	.68	.42	.43	.54	.42	.87	1.22	1.13	7.81
1901 - 3-	.69	.32	.46	.47	.64	.45	.42	.62	.44	.83	1.23	1.07	7.81
1931 - 52	.80	.32	.58	.52	.38	.49	.37	.50	.54	.83	1.24	.72	7.29
1931 - 60	.89	.59	.50	.59	.47	.40	.40	.71	.41	.41	1.07	.83	7.27
1941 - 70	.86	.41	.57	.47	.42	.46	.43	.62	.71	.73	1.17	.79	7.64

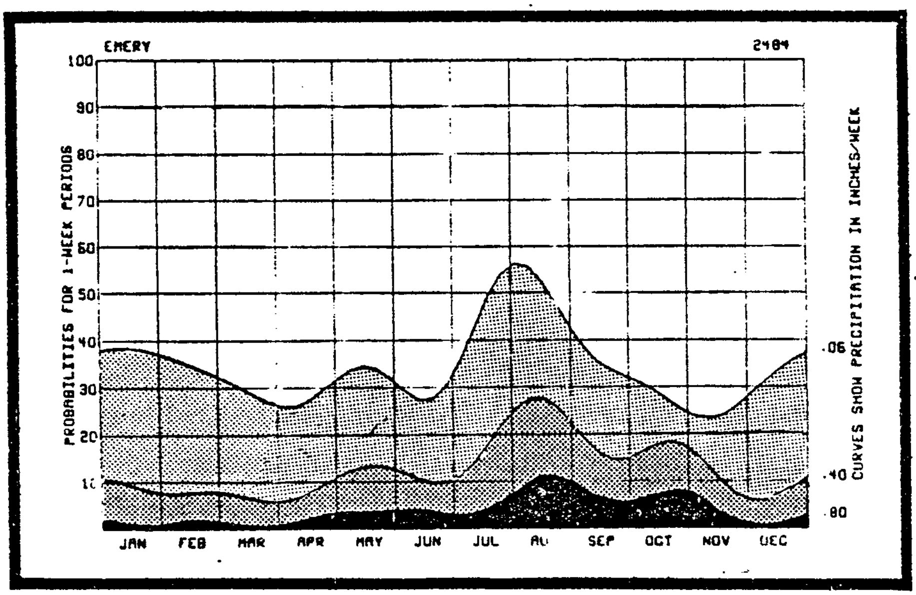


Figure 12. Precipitation Probability Graph (Jeppson et al., 1968). (1 week rainfall)

inches for each month have been estimated by Richardson, (1975):

OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
2.07	1.03	0.70	0.83	0.72	1.22	1.25	2.60	1.40	2.13	2.16	1.69

"Probable maximum precipitation (PMP) estimates," defined as the estimated "upper limits of rainfall ... for use in hydrologic design" have been compiled for the Colorado River and Great Basin drainages by Hansen et al., (1977). Their procedure, allowing for both convergence ("synoptic") and orographic influences, yields the following estimates of the maximum precipitation in August, normally the wettest month, averaged over drainage areas of 10 and 418 square miles:

Duration	6	12	18	24	48	72	hours
10 square miles	4.8	6.5	7.8	8.7	11.3	12.6	inches
418 square miles	3.1	4.6	5.7	6.5	8.8	9.8	inches

The smaller area approximates the total Emery coal field under study, the larger one is the entire drainage of Muddy Creek above Interstate 70, a few miles downstream. Structures and excavations in the coal mining area should be designed for the 10 square mile data, except for those features along the Muddy which may be affected by the drainage from storms over the larger area. The average flow of Muddy Creek is about 36.6 cubic feet per second, the maximum, on May 10, 1952 was 3,340 ft^3/sec, or 94.6 m^3/sec. More details are given under the "Hydrology and Water Supply" section.

The other type of storm to consider is the "cloudburst", which releases rainfall of the order of an inch within an extremely short period (i.e. one hour). A USGS compilation in the general area of the Book Cliffs shows such storms occurring within a 30 year period (USGS Open-File Rept.) Recall again that Emery data for 78 years gives the greatest daily (24 hr.) rainfall as only 2.60 inches. This is much less than the PMP estimates given before. One such storm was evidently experienced in November, 1978, with a corresponding sediment catch in our trough type sediment traps as discussed in the sedimentation section. In any case we have simulated a one inch rainfall within a one-hour period for our rainfall simulation experiments, evaluating sedimentation problems.

Comparison With 100 Year Return Period Rainfalls

Miller et al., (1973) compared PMP estimates and 100 year - 24 hour rainfall values in the western United States. The 100 year return 24 hour data are heavily weighted by thunderstorm rain. The 100 year data range from 20 to 35% of the PMP, but do not, of course, apply to the same area as was computed for the PMP. If elected, the 100 year return rainfall values would be a less stringent design criteria.

Evapotranspiration Demand

Need for water to support revegetation efforts will primarily depend on evapotranspiration demand during the summer months. Normally 75% of the precipitation enters the soil, two-thirds of which is lost to evapotranspiration. Dominant recharge of aquifers and wetting of topsoils will hence occur due to snow melt. Although intense short duration summer storms are common, they would have little effect in supplying usable water to support plant growth. By reference to Figure 13, we can see that high losses for the area average precipitation can normally be anticipated. Reservoir design must also take these factors into account, by designing excess storage capacity to account for evaporative losses.

For revegetation water needs and surface water impoundment losses for irrigation, we need the evapotranspiration for the freeze-free season. Evapotranspiration for the freeze-free period does not follow the same pattern as that for the entire year. The available heat units become greater as one progresses from the mountain peaks down the slopes to the valley. The length of growing season also increases as one moves from the mountains to the foothills. However, in moving from the foothills on into the valley bottom, the growing season again becomes shorter due to accumulation of cold air drainage. As a result of the shortened growing season, the actual evapotranspiration for the freeze-free season will often be greater in the foothill regions than in the valley bottoms.

Monthly and annual values of potential evapotranspiration computed by the Thornthwaite method are given in Table 6. Standard deviations (SD) were calculated using the Ashcroft (1968) method. Monthly and annual standard deviations are also shown.

Table 6

Potential Evapotranspiration in Inches
(Thornthwaite Method-Calculated Yearly)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Amount	0.5	0.5	0.9	2.0	3.3	4.5	5.5	4.9	3.5	2.1	0.8	0.5	23.2
Standard Deviation	0.5	0.6	0.8	0.9	0.9	0.9	0.7	0.7	0.7	0.8	0.8	0.6	1.4

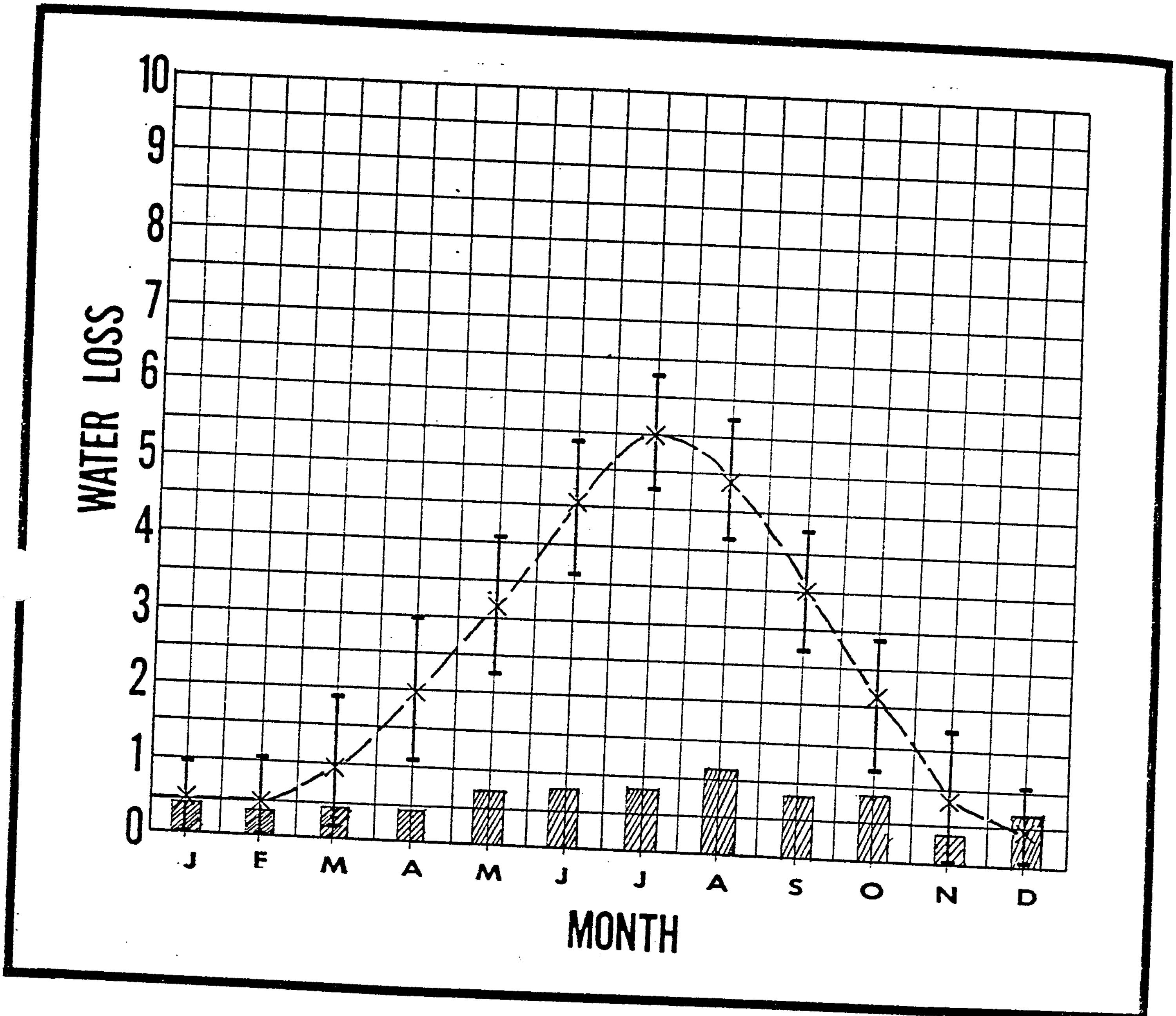


Figure 13. Evapotranspiration by Month - Emery, Utah

⊢X⊣ Standard Deviation

▨ Average Precipitation

Other weather-related factors may have adverse effects on revegetation of the Emery site. Low annual precipitation rates compounded with erratic distribution patterns and high summer storm intensities are not optimum conditions for seed germination and plant growth. On the Mancos Shale the effectiveness of the incoming precipitation is further reduced by the occurrence of shallow soils over much of the area and by relatively low soil moisture that could otherwise be utilized in seed germination, seedling establishment, and general plant growth. Dry, cold, windy winters may also result in relatively high percentages of winterkill among recently established vegetation (Figure 14, Figure 15).

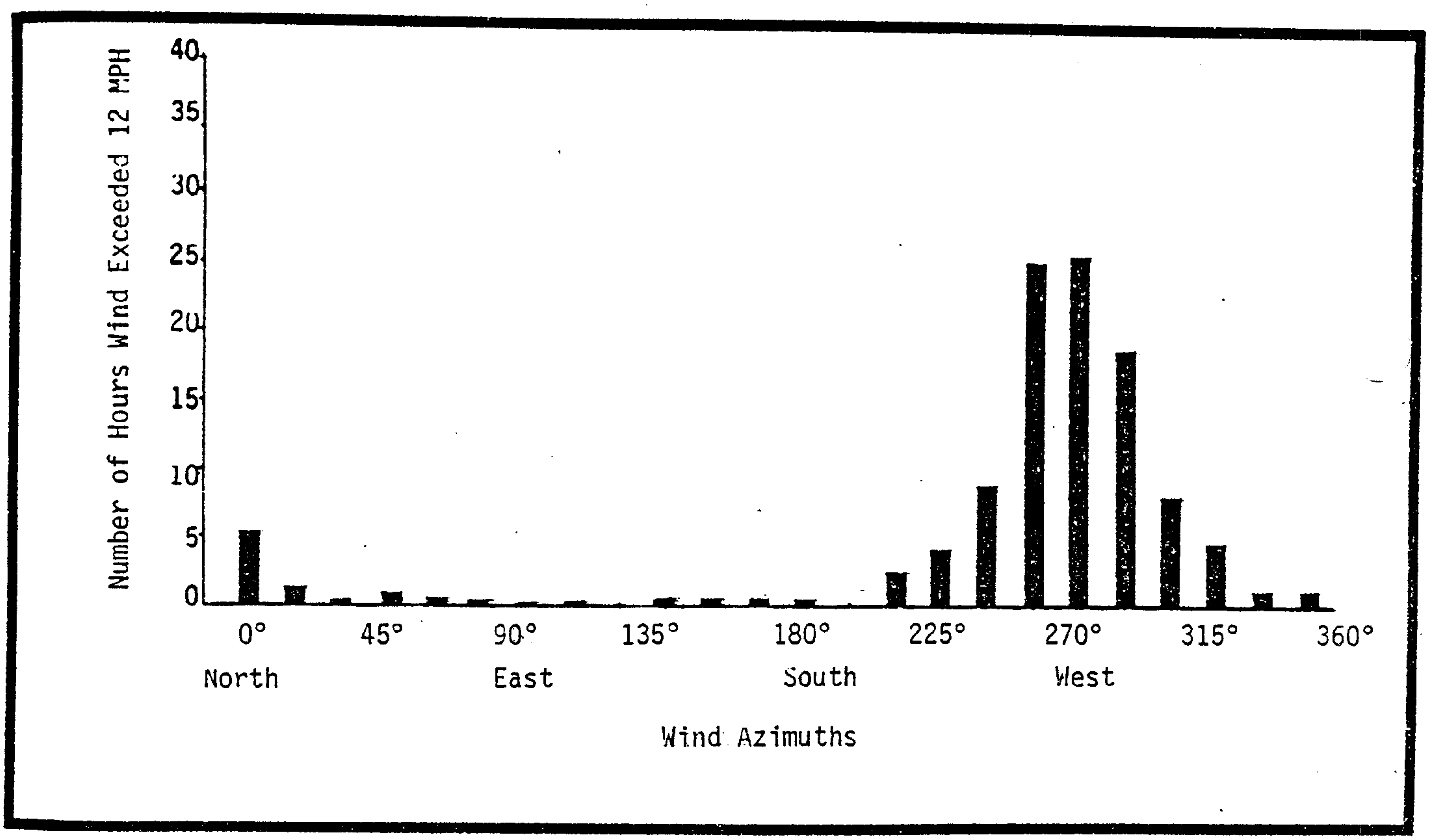


Figure 14 . Wind Erosion - Nine Month Average
(November, 1972 thru July 1973)

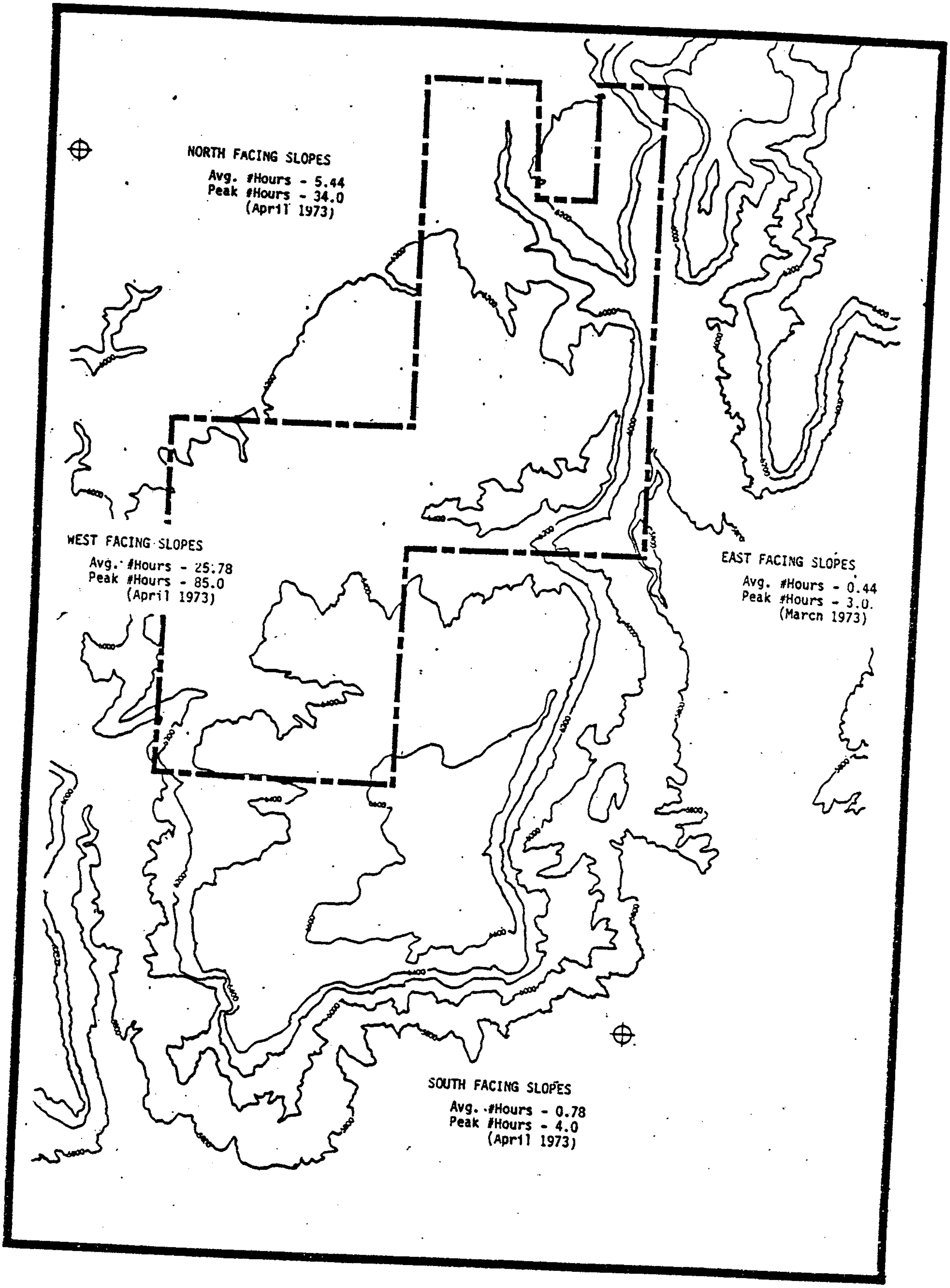


Figure 15. Relative Probability of Wind Erosion by Slope Exposure and Season. (Number Hours Wind Exceeded 12 MPH by Month)

South facing slopes at the study site will characteristically be subjected to more droughty conditions than slopes with northern aspects or exposures. These droughty conditions result primarily from the prevailing winds and from higher temperatures due to greater amounts of incoming solar radiation. Soil movement due to wind erosion may expose the tender roots of plant seedlings or bury the seedlings.

Emery on the east slope receives little winter precipitation. As the air comes in from the southeast, it rises over the Wasatch Plateau. Hence, summer storms account for a large share of the yearly precipitation in Emery.

The probability of receiving appreciable precipitation in a 7-day period is at or near its greatest in either May or October (during the closed low seasons) for all Utah stations. Precipitation probability graphs for Emery stations are shown in Figure 12. The precipitation levels plotted in Figure 12 are 0.06, 0.4 and 0.8 inches of weekley rainfall.

Peck and Williams (1961 and 1962) related precipitation to topography and atmospheric circulation. The normal annual precipitation (isohyetal) map for Emery is shown. The October through April precipitation is important in water storage as snowpack. The "growing season" precipitation is May through September. Precipitation-elevation relationships can be observed by comparing the isohyetal maps with the relief.

Summary

Climatic factors will normally have an adverse effect on revegetation of the study area and must be reckoned with. The most significant factors influencing reclamation techniques are the low precipitation, high wind velocities on some slope exposures, and the resulting high potential evapotranspiration rates over the growing season. Summer frosts with kill potential are not infrequent. The winter winds may also redistribute the snow leaving many areas bare which would permit winterkill of new vegetation. Soil movement caused by the wind damages vegetation by abrasive action and deflation around root systems. Because of greater amounts of incoming solar radiation, south facing slopes tend to be more droughty than north and east facing slopes. The result is an unfavorable environment for summer seed germination and plant growth. Late summer rainfall (August) may serve later grasses, but high evapotranspiration would require heavy summer rainfall (3/4 inches) to be useful.

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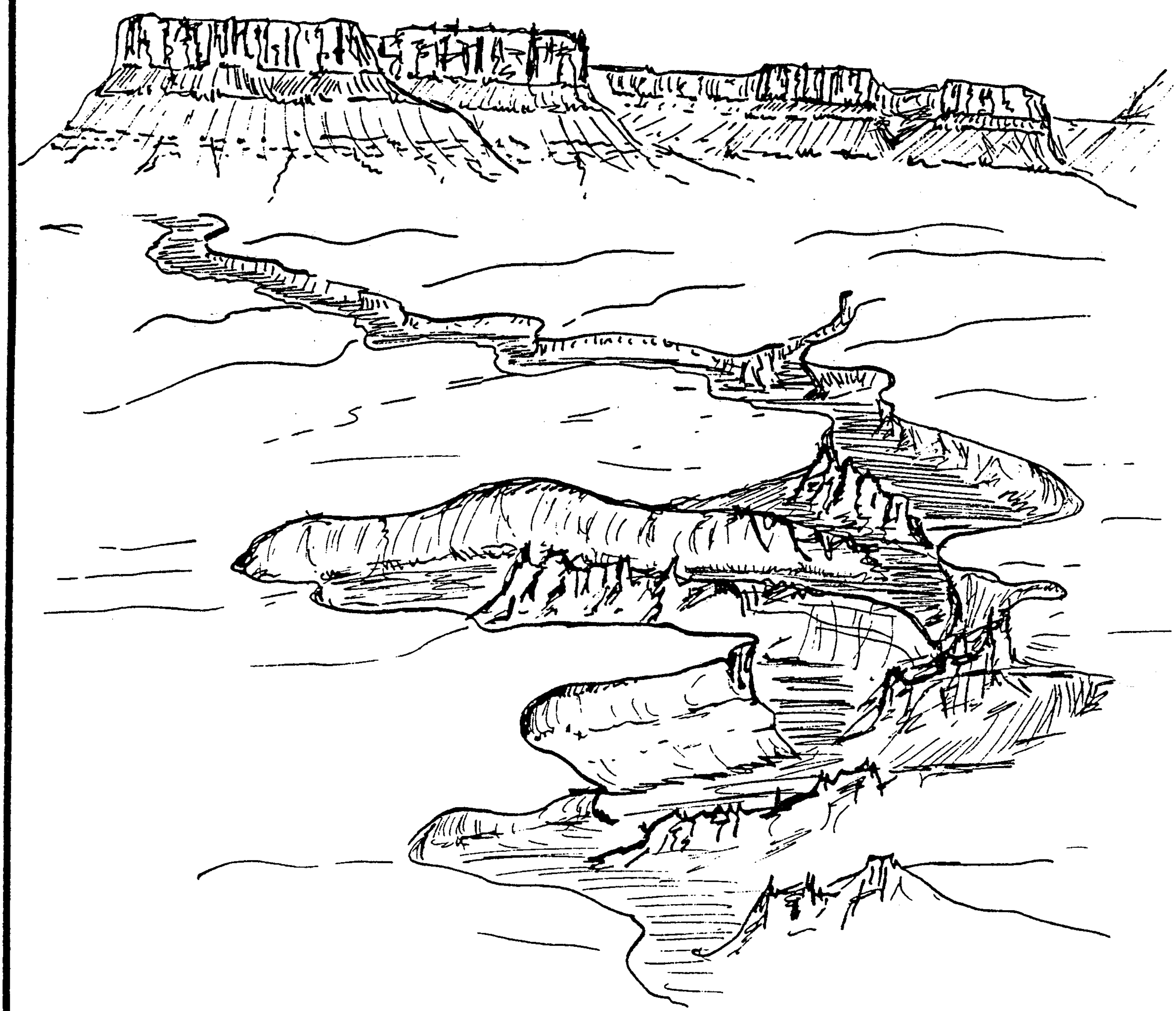


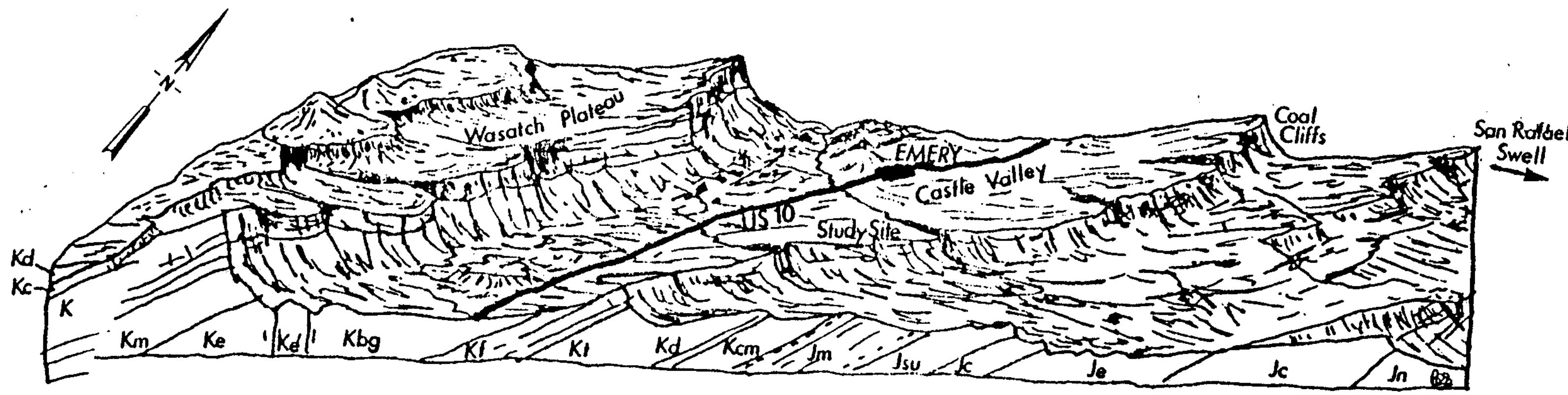
PHYSIOGRAPHY, RELIEF, & DRAINAGE

PHYSIOGRAPHY, RELIEF AND DRAINAGE

The Emery study area occupies the northwestern border of the canyon lands which are an extension of the Colorado Plateau and cover about half of the state of Utah (Gregory and Moore, 1931). This section borders the high plateaus of Utah. It lies within the Colorado Plateaus' physiographic province of the intermontane plateau (Dutton, 1880 and Fenneman, 1946). The western flank of the San Rafael Swell, where the strata dip generally 2° - 4° northwest, is eroded into a long line of southeast facing escarpments locally called the "Coal Cliffs" (see Figures 16 and 17

The study area generally occupies the gently sloping upland surface of a dissected questa on the southern margin of the Wasatch Plateau. The mesa, thus isolated, is a south facing extension of a main plateau underlying the entire Emery region. The elevations of the upland range from 6680 feet to about 6400 feet with a general northwesterly slope of 200 feet/mi. The valley bottoms, in the lowland, range from 5800 to 5600 feet in elevation. The mesa is underlain by gently dipping sedimentary beds, including the coal units, truncated by erosion along the main drainage streams (Austin and Skogerboe, 1970).

As shown in Figure 18, the main drainage in the area is the 3rd order Muddy Creek, flowing southward along the eastern escarpment of the mesa. Ivie Creek, a 2nd order tributary, flows eastward into Muddy Creek on the south, and 2nd order Quitchupah Creek flows southward into Ivie Creek on the west, isolating the mesa from the lowland. All the first-order tributaries are intermittent, draining the upland west and east into the Quitchupah and Muddy drainages. Nearly all of the 1st order basins on the upland surface drain westward into Quitchupah Creek. The main exception is Miller Canyon and its tributaries, eroding headward NW toward Emery, capturing the upland drainage, formerly tributary to Christiansen Wash and the Quitchupah drainage. The gradients of these streams are generally small, except locally where they cross the steep to vertical escarpments. On the upland, the tributaries are incised slightly and drop 200 to 360 feet per mile and range from 800 feet to 1100 feet per mile across the escarpment. The lowland Quitchupah and Muddy Creeks grade only 30 feet per mile. Tributaries to the main N-S drains merge



K - Cretaceous (undifferentiated

Kc - Castlegate Sandstone

Km - Masuk Shale (member of Mancos Shale)

Ke - Emery Sandstone (member of Mancos Shale)

Kbg - Blue Gate Shale (member of Mancos Shale)

Kf - Ferron Sandstone (member of Mancos Shale)

Kt - Tununk Shale (member of Mancos Shale)

Kd - Dakota Sandstone

Kcm - Cedar Mountain Formation

Jm - Morrison (?) Formation

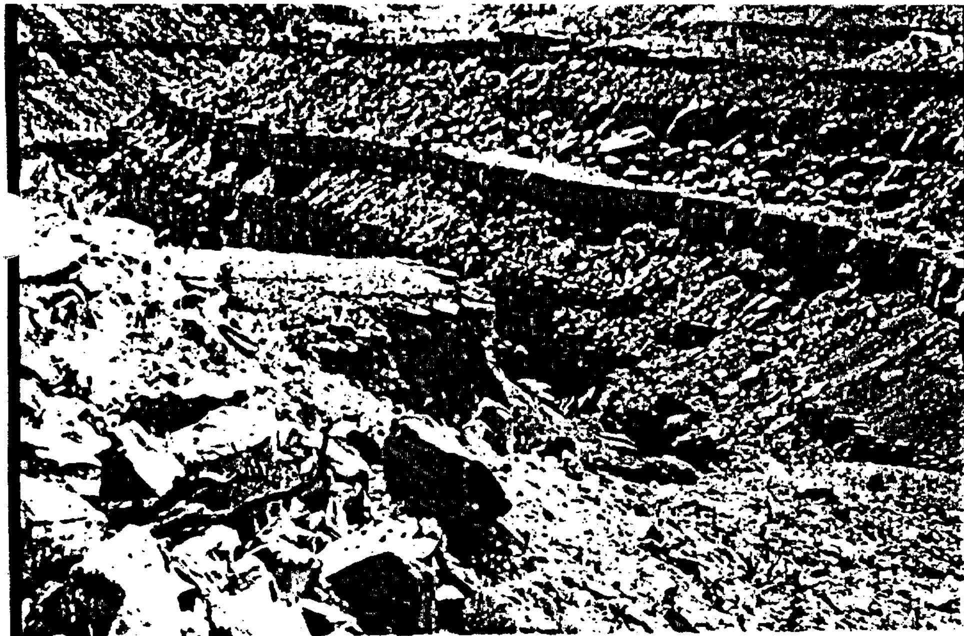
Jsu - Summerville Formation

Jc - Curtis Formation

Je - Entrada Formation

Jn - Navajo Sandstone

Figure 16. East-West Cross Section and Physiographic Diagram of Emery Coal Field and Surrounding Area.

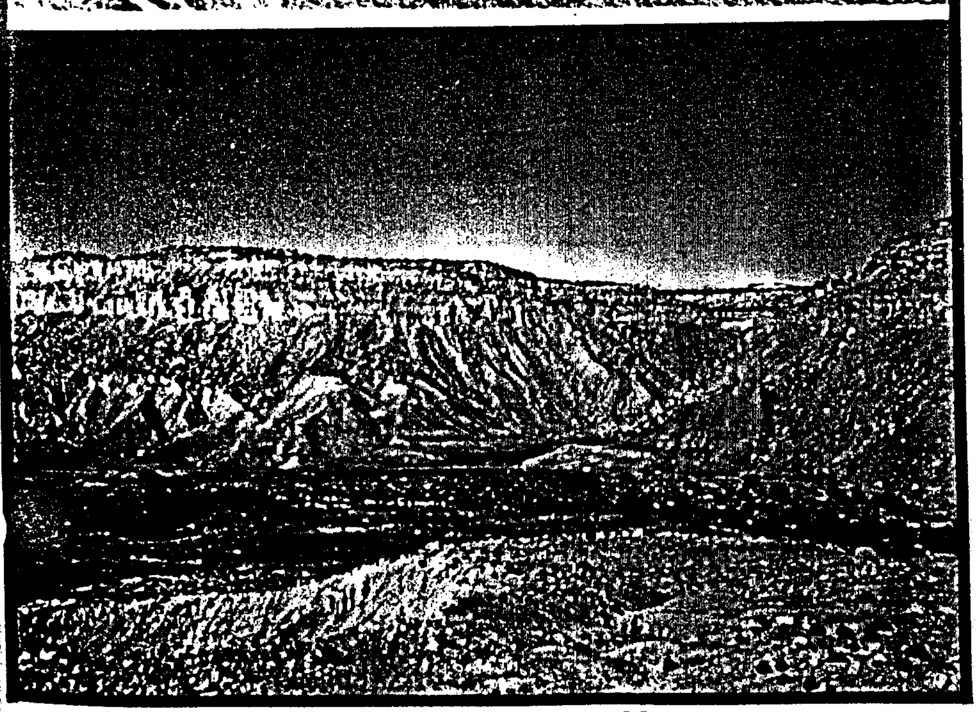


Canyons

View west from top of study site, Quitchupah drainage at upper left corner. Showing cliff forming sandstone units and canyons, lower coal present in creek bottom (not visible); I-J Coal seam is burned in this area.

Plateaus

View SW across Quitchupah drainage showing plateau facing study area in background. Quitchupah flow is from right to left. Ivie Creek is visible in upper left hand corner

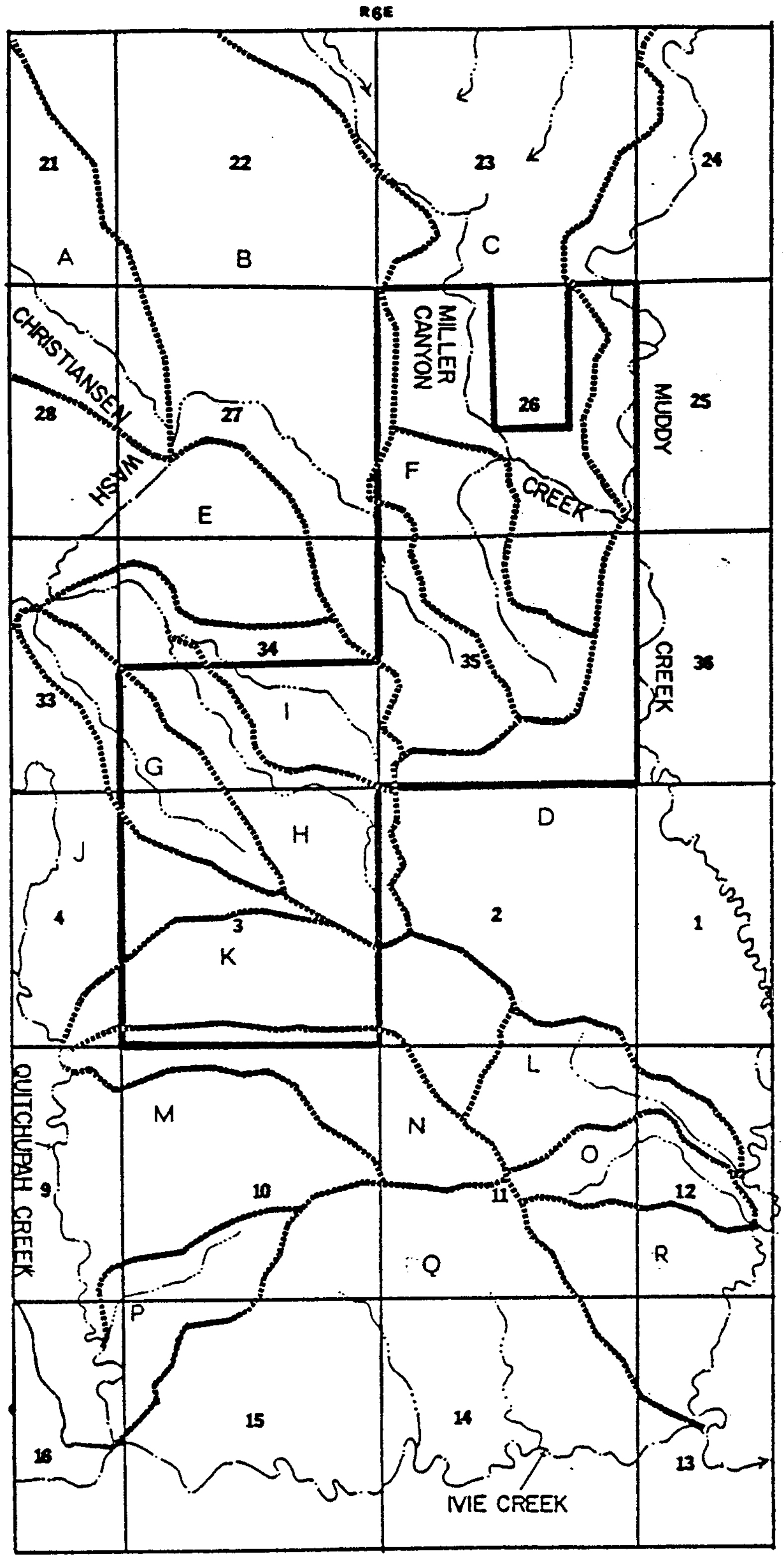


Muddy Creek

View west across the Muddy Creek drainage. Bear Gulch Mine at right.

Figure 17. Landscape Views

Basin	Acres	Avg. Slope (%)
A	372	2
B	1459	3
C	1195	8
D	2442	14
E	507	3
F	293	9
G	240	4
H	377	5
I	255	5
J	383	12
K	455	7
L	237	15
M	460	13
N	320	9
O	164	10
P	205	15
Q	1120	11
R	311	10



EMERY, UTAH

SMALL DRAINAGE BASINS

DRAINAGE DIVIDE
PERENNIAL STREAMS
INTERMITTENT STREAMS

0 8000 Feet

0 1 2 Miles

Figure 18

in the vicinity of Emery on the nearly horizontal upland surface. None of the perennial streams with their low gradient and mean dendritic channel pattern seems capable of carrying excessive sediment load. The intermittent upland channels are also meandering and of low gradient (see Figure 18).

Summary

Perennial streams are the Muddy, Quitchupah, and Ivie Creeks and Christiansen Wash. All have been known to go dry on occasion during summer. They are presently sustained at least in part by irrigation flows. The terrain consists of canyon lands and plateaus, which locally form the "Coal Cliffs". Locally, the area elevations range from 5600 feet on the valley bottoms to 6680 feet on the top of the plateaus.

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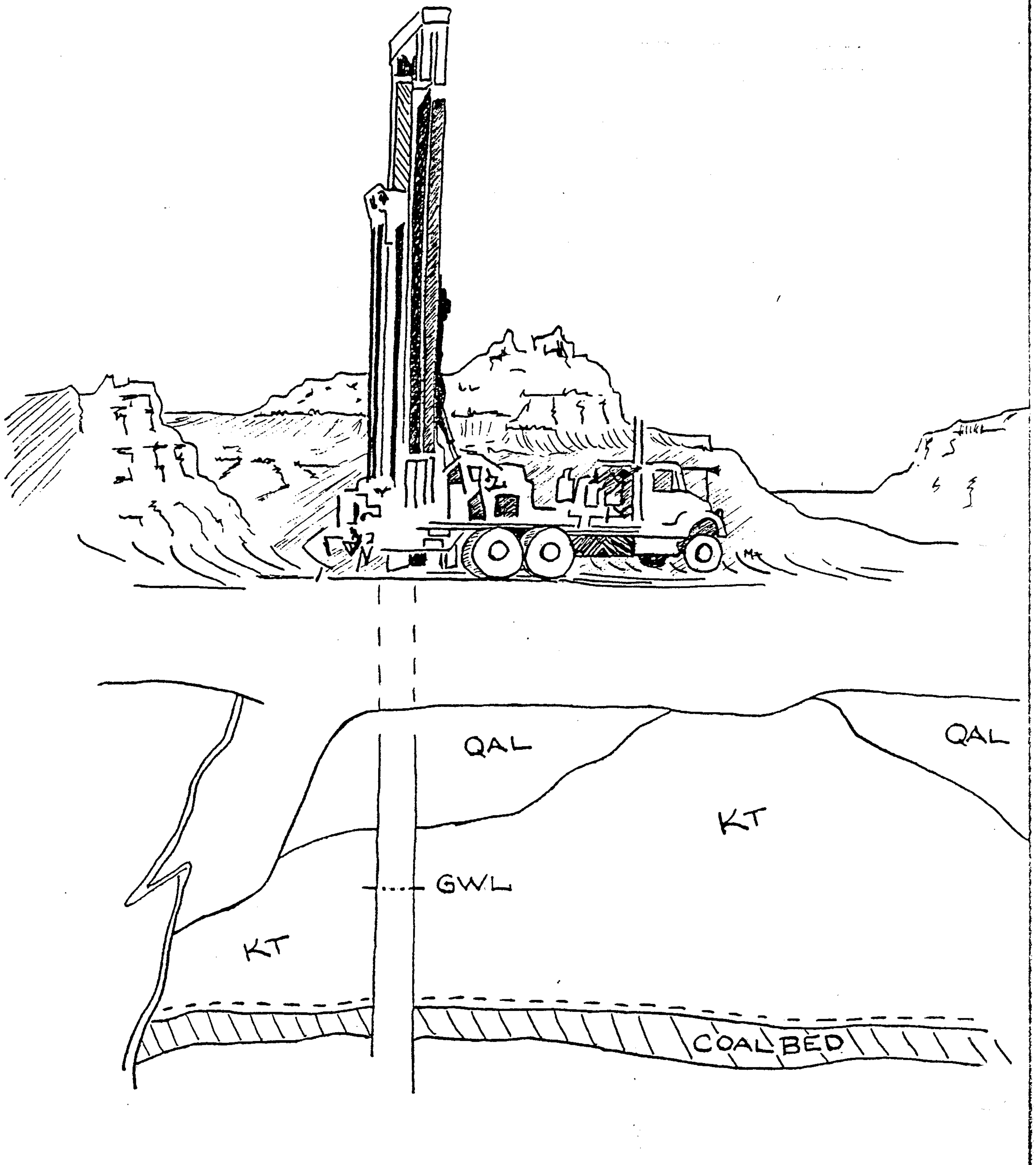
GEOLOGY



Regional Geologic Setting

The Emery coal field is located on an intermediate bench within the generally northwest dipping Upper Cretaceous marine strata. These units form an extension of the older rocks which make up the plateaus and canyon lands of central Utah (Figure 18). West of the Emery field, the steep eastward facing cliffs of the overlying westerly dipping Upper Cretaceous and Lower Tertiary sedimentary rocks mark the eastern edge of the Wasatch Plateau. East of the region the underlying Cretaceous and Jurasic sediments of the anticlinal San Rafael Swell dip westward beneath the study area, and form the lowlands and the lower benches to the east (Figure 19). The region has been described by Lupton (1916), Spieker (1925) and Doelling (1972).

Local Geologic Setting

The study area in the Emery coal field is entirely within the resistant cliff-forming Ferron Sandstone member of the Upper Cretaceous Mancos Shale (Figure 20). The Ferron crops out in a long line of northeast trending steep to nearly vertical cliffs, the Coal Cliffs, along the western edge of Muddy Creek, forming the middle bench between the Wasatch Plateau and the San Rafael Swell. Figures 21 and 22 (Ryer, 1979) give two fence diagram cross-sections of the area constructed from outcrop and bore hole data. The beds dip generally northwest 2-4 degrees and are locally exposed as a dip slope plateau by erosion of the overlying Blue Gate member. The Ferron Sandstone member averages 400 feet thick and is commonly divided into an upper and lower unit, but this simple division becomes unworkable northeast of the study area. The lower unit is characteristically continuous yellow-gray, fine to medium sandstone in tabular or sheet-like beds, commonly calcareous. The Ferron sandstone is marine, locally cross-bedded, and grades into the underlying Tununk Shale. It represents episodes of the retreat of the Cretaceous Sea to the northeast.

The upper unit is less continuous, commonly cross-bedded, with lenticular beds of fine to coarse sandstone, lenses and intercalated beds of shale, siltstone, and coal. The sands, shales and coals represent fluctuations of the non-marine coastal swamp environment at the edge of the Cretaceous Sea. All of the coal in the Emery area is in this unit. There is a minor

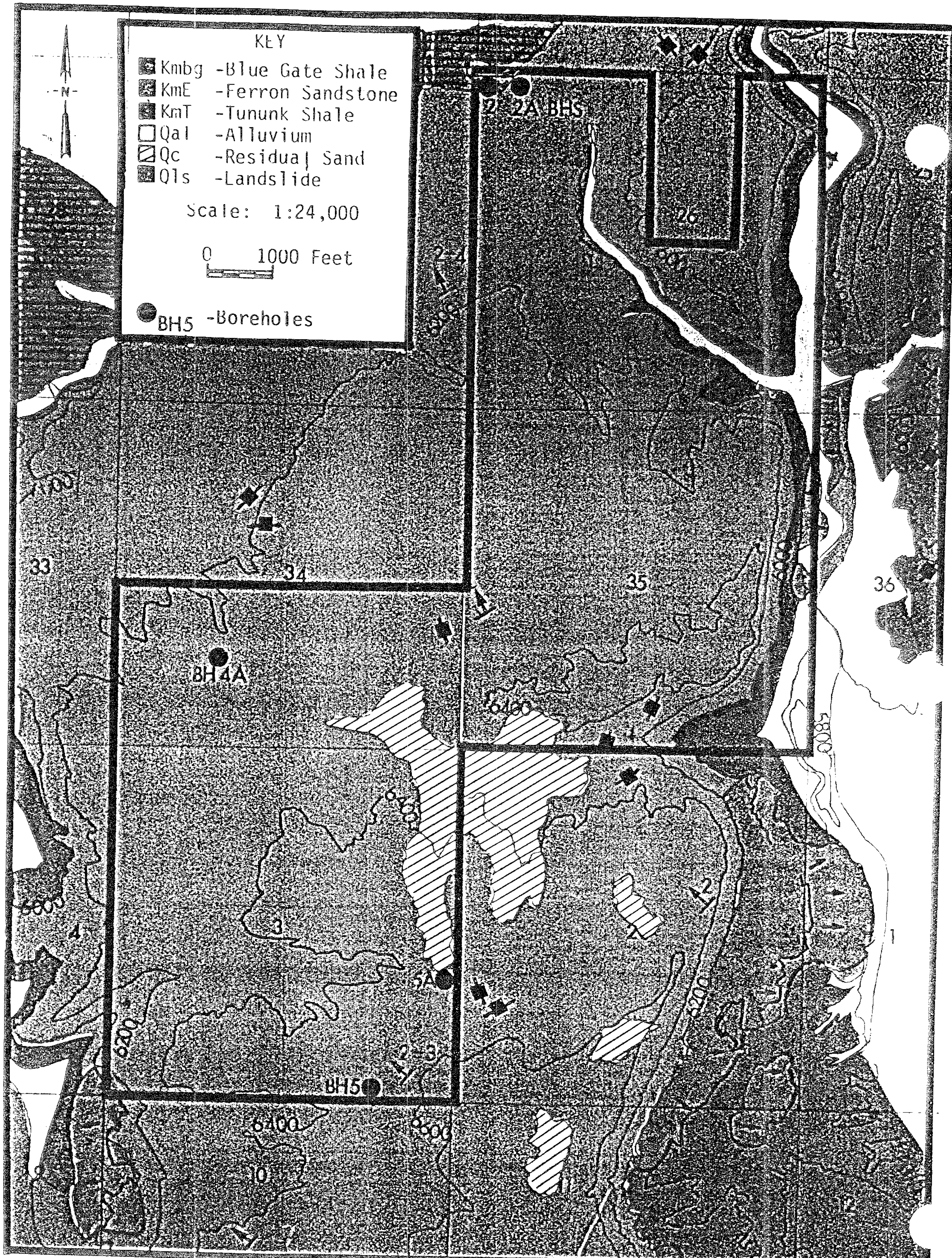


Figure 19. Geologic Map of Emery Test Site, Showing Bore Hole Locations.

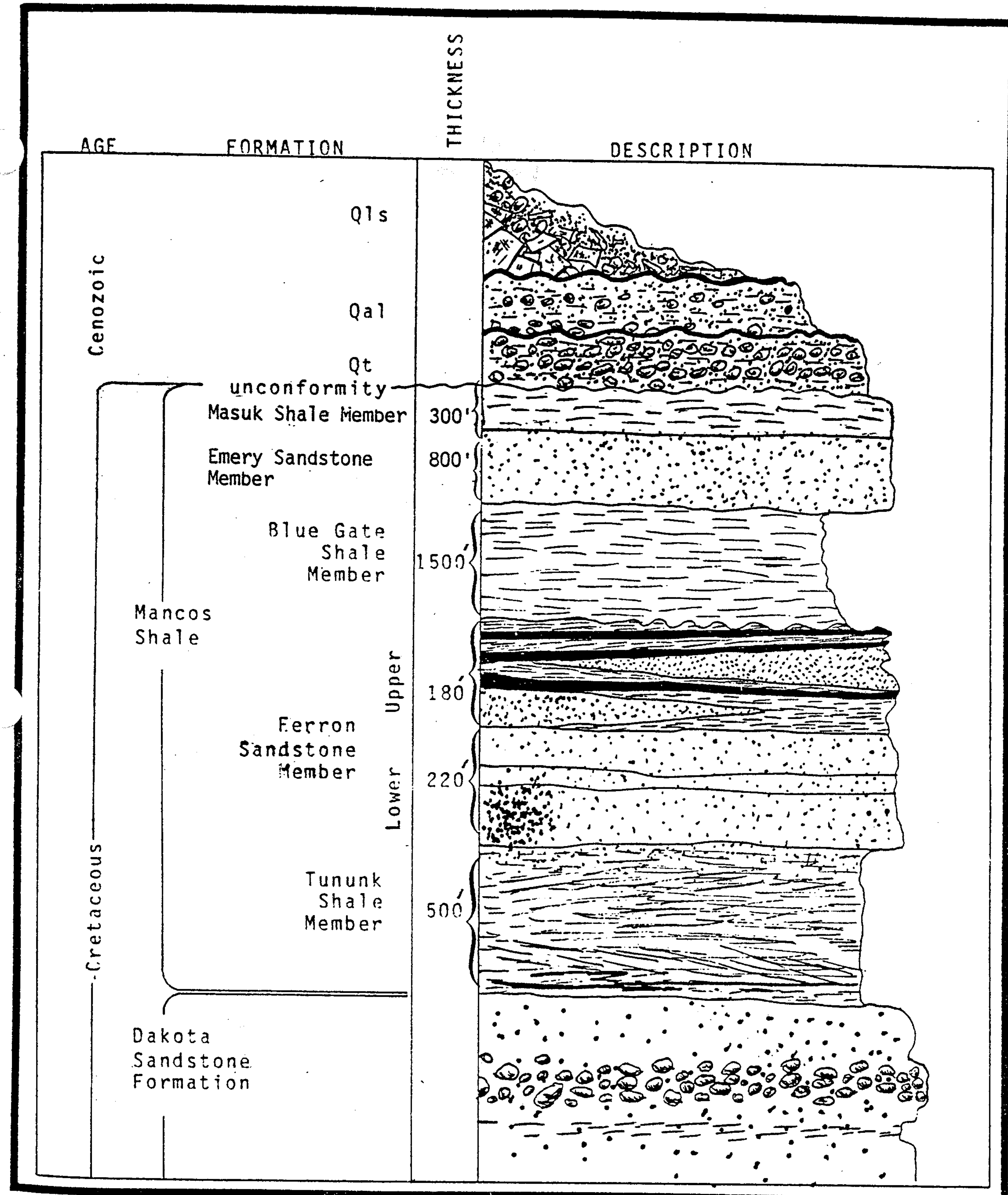
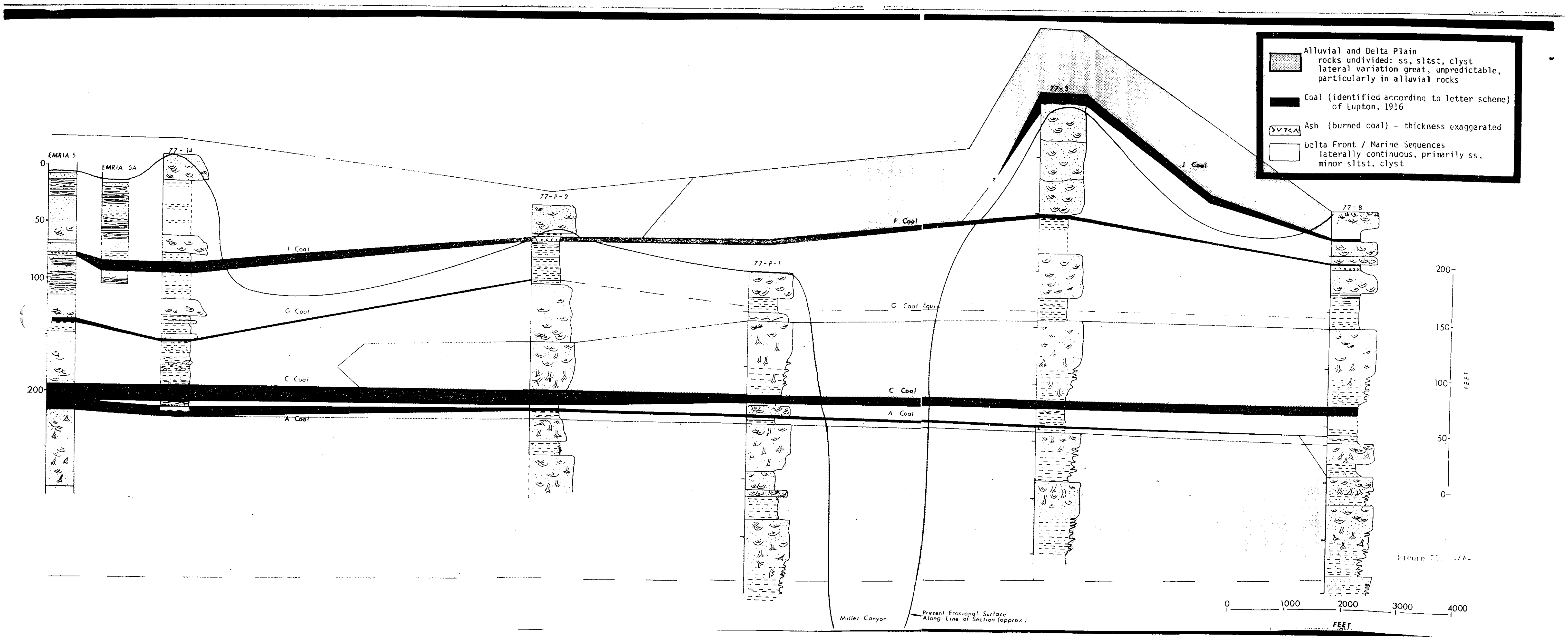
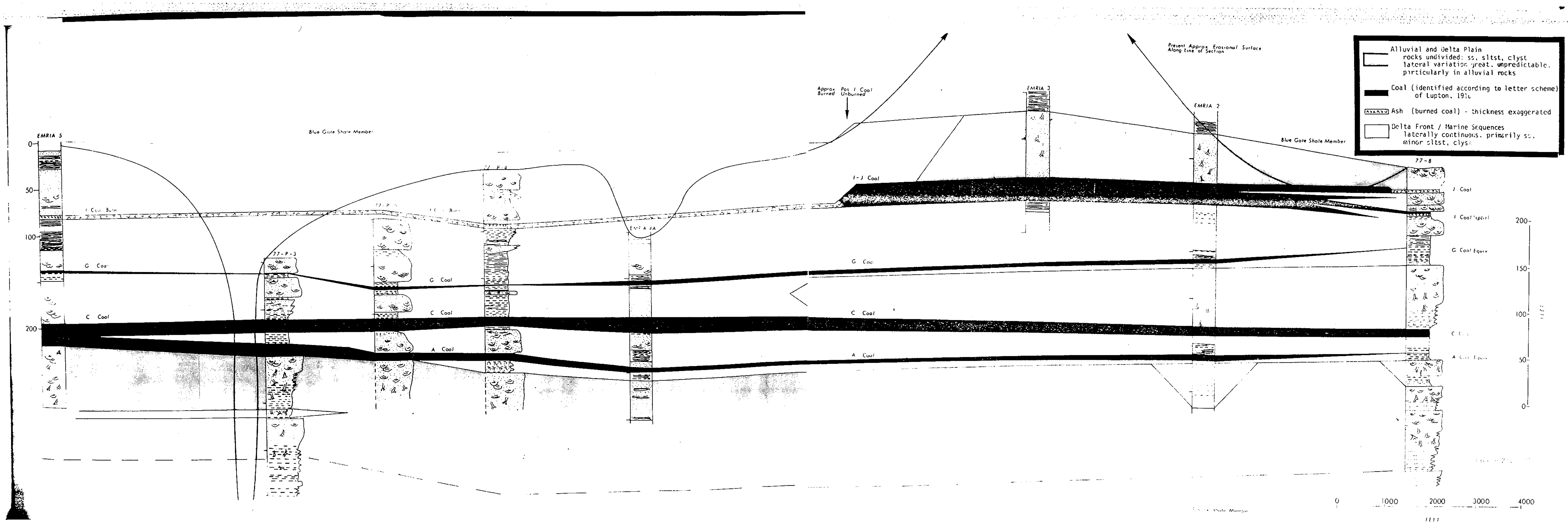


Figure 20 . Generalized Stratigraphic Column.


Alluvial and Delta Plain rocks undivided: ss, sltst, clyst lateral variation great, unpredictable, particularly in alluvial rocks
Coal (identified according to letter scheme) of Lupton, 1916
Ash (burned coal) - thickness exaggerated
Delta Front / Marine Sequences laterally continuous, primarily ss, minor sltst, clyst
EMRIA 5
EMRIA 5A
77-14
77-P-2
77-P-1
77-3
77-8
I Coal
G Coal
G Coal Equiv
C Coal
A Coal
J Coal
0
50
100
200
FEET
150
Miller Canyon
Present Erosional Surface Along Line of Section (approx.)
0
1000
2000
3000
4000



Alluvial and Delta Plain rocks undivided: ss, sltst, clyst lateral variation great, unpredictable, particularly in alluvial rocks
Coal (identified according to letter scheme) of Lupton, 1916
Ash (burned coal) - thickness exaggerated
Delta Front / Marine Sequences laterally continuous, primarily ss, minor sltst, clyst
EMRIA 5
EMRIA 3
EMRIA 2
77-8
77-P-3
Blue Gate Shale Member
Approx Pos. I Coal Burned Unburned
Present Approx. Erosional Surface Along Line of Section
I-J Coal
J Coal
G Coal
C Coal
A Coal
G Coal Equiv
0
1000
2000
3000
4000

amount of erosion of the contact, disconformable with the overlying Blue Gate Shale member. The underlying marine Tununk Shale member averages about 500 feet in thickness, is black or bluish-gray, and erodes easily, forming lowlands or slopes between more resistant units. The shale is locally silty and sandy in the upper and lower portions and grades into the overlying Ferron Sandstone. Near the lower boundary the shale is locally carbonaceous.

The overlying Blue Gate Shale member is a saline bluish-gray silty mudstone. This eroded to form the southern extension of Castle Valley. The unit exists as a veneer or as isolated outcrops throughout the study area, locally covering the underlying resistant Ferron Sandstone. The Blue Gate is distinguished in the field by its irregular "badland" erosion topography and the incompleteness of its vegetative cover.

Engineering Geology

The stripping of overburden to exploit the coal resources in the Emery study area is susceptable to one primary geologic hazard, the collapse of excavation benches in the vicinity of surface fractures. Based upon the large volumes of gas encountered in drilling near the burn zone, there are potential hazards in exposing trapped gas (methane) during stripping. Flooding by released groundwater apparently is a negligible hazard in the area.

Surface fractures are common and locally abundant in the area and derive from three sources: (a) the natural stress-fracturing of brittle surface rocks (Figure 23), (b) tension fields produced by subsidence of previously mined underground seams, which may be relieved along natural joint features as at the old Browning Mine (Figure 24), and (c) tension fields resulting from subsidence caused by subsurface burning of the coal (Figures 24 and 25). These collapse hazards are compounded by the regional physiography of steep cliffs and plateaus.

The engineering usefulness of the local lithologic materials is limited. Roads and level sites are easily graded into the soft or crumbly shale and sandstone, but there is no suitable aggregate source in the overburden. The sandstone readily weathers and decays to sand after only one season. During wet seasons the shale similarly weathers to a sticky mass. Figure 26 presents an analysis of the feasible angles of repose for various spoil slopes.

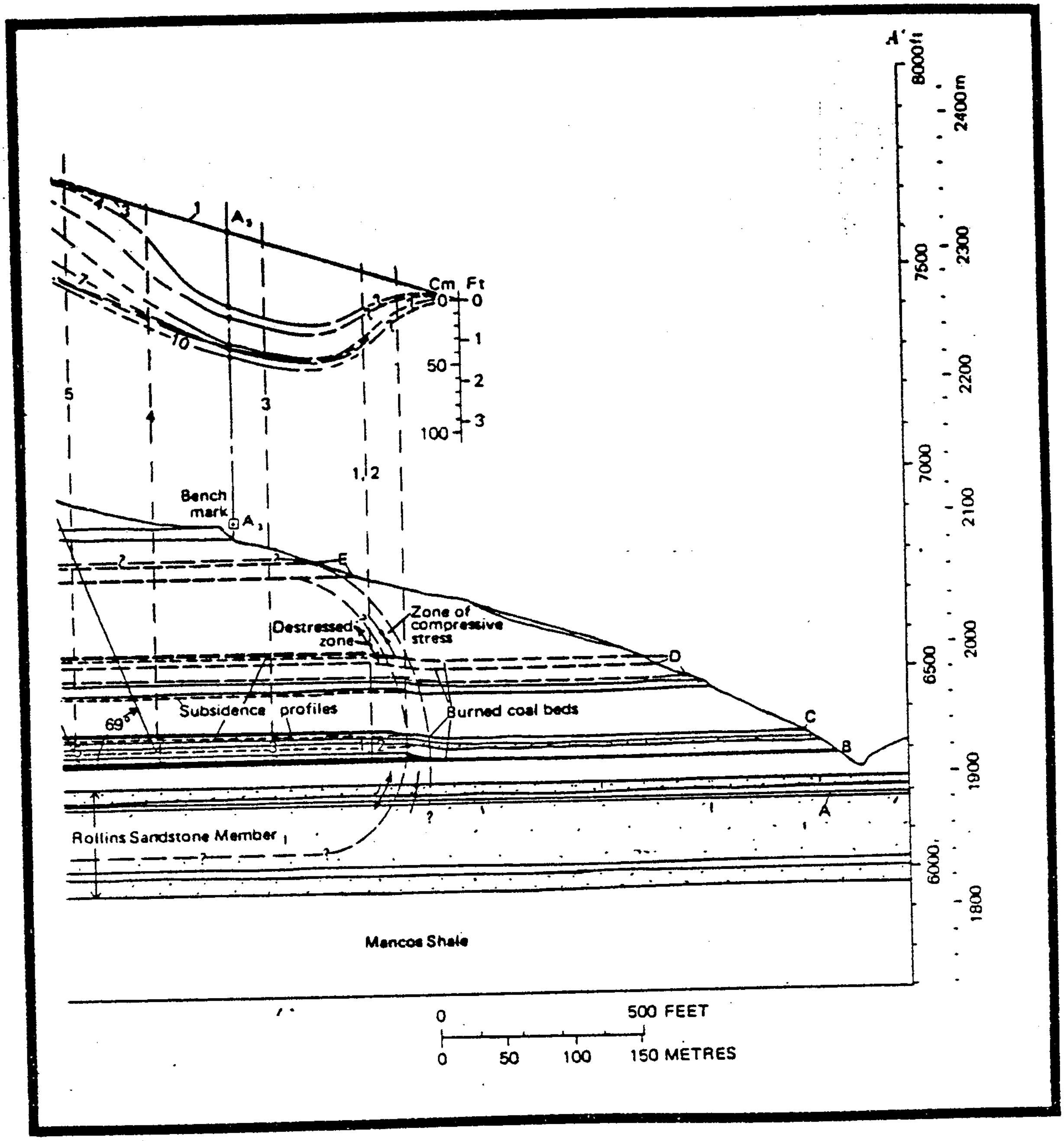


Figure 23. Stresses in Overburden Analogous to Emery Site Conditions. (Note Zone of Compressive Stress)

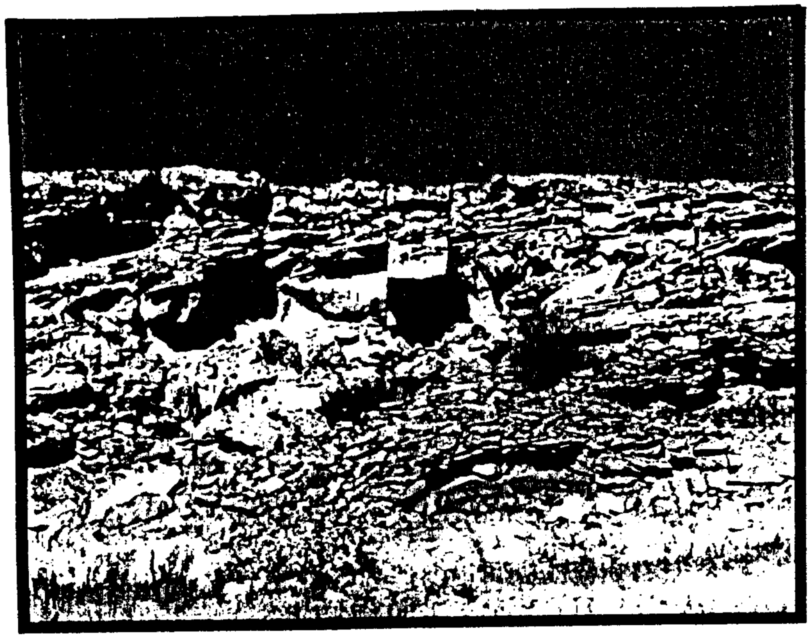


Figure 24 . Natural Fracturing of Ferron Sandstone Above Simulated Strip Mine Site on Christiansen Wash.

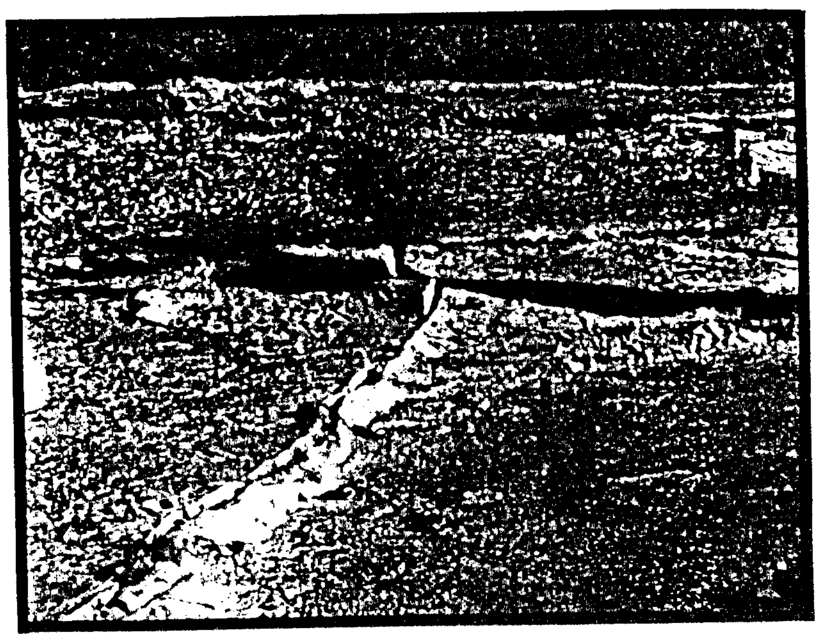


Figure 25 . Surface Jointing Cracks in Ferron Sandstone Over Subsidence Area.

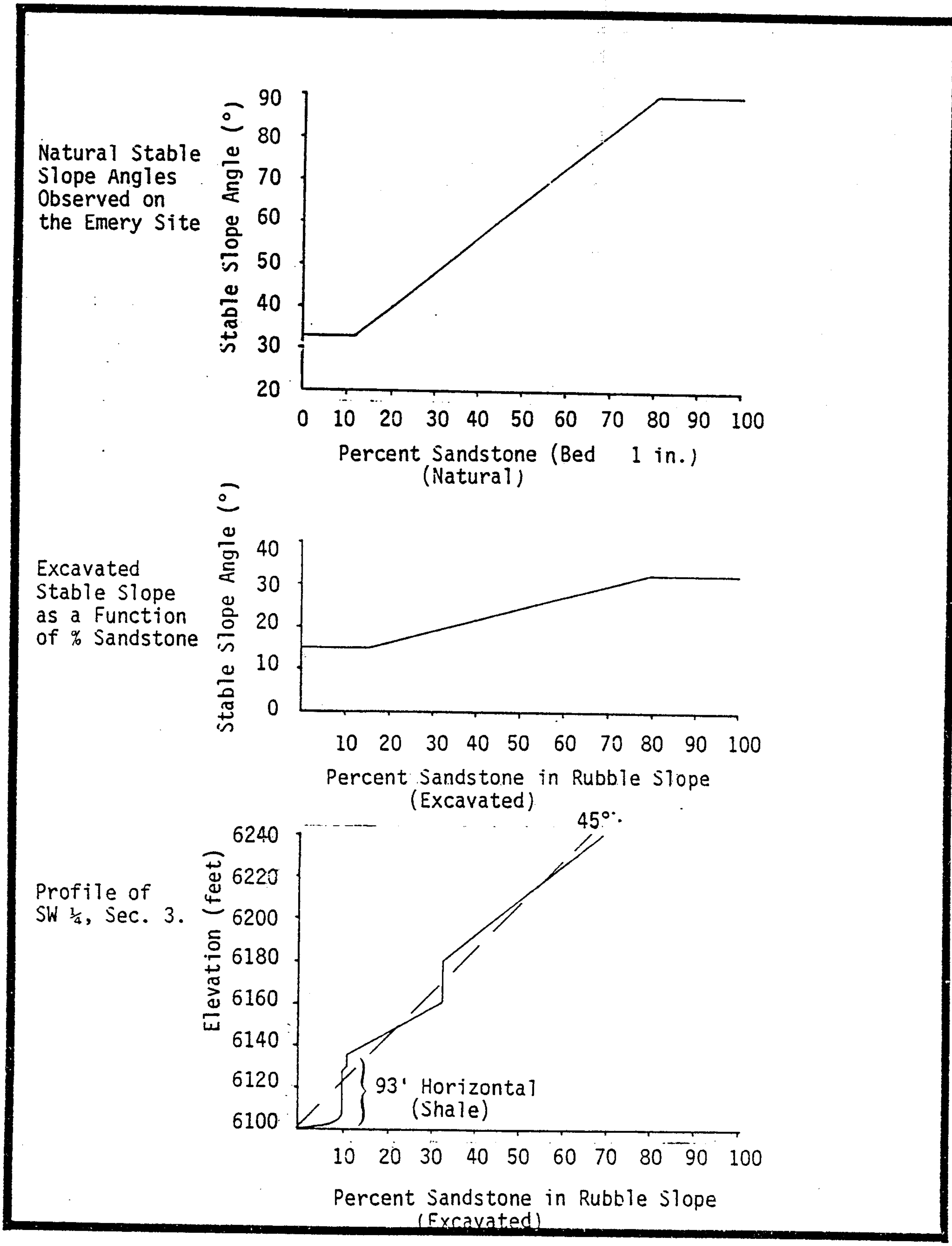


Figure 26. Slope Stability Consideration.

Landslides and Slope Failure Potential

A common practice in cut and fill operations is to divert water, such as in our case that derived from dewatering coal, to the spoil, so as to promote rapid infiltration. This avoids washing off of top soil, and formation of rills and gulleys, but might create a serious mass overloading problem (Figure 27). The result may vary from slow earth flows to rapid debris flows. In general, this practice should be avoided particularly where such a flow, if produced, would endanger right-of-way, block streams or canals and cause flooding. The production of undesirable geochemical leachates would also result, as discussed in the overburden section of this report. Seismic events could, of course, act as a trigger for such slides, or even rock falls of blocks already undermined or unstabilized by strip mine operations.

Summary

The Masuk Shale member is the uppermost member of the Mancos Formation. Together with the Emery Sandstone it forms the highest resistant benches on the west side of Castle Valley at the base of the Wasatch Plateau. The unit is 800 feet thick, light yellowish-gray and locally carbonaceous.

The Cenozoic deposits comprise Quaternary landslides, alluvium, and older remnant terraces. The alluvium and terrace deposits are crudely stratified, poorly sorted sands and gravels occupying the valley sides and bottoms, and in the lower valleys, serve as the perennial aquifer for the area. The landslide deposits are local accumulations of coarse to fine angular boulders and cobbles from the steep cliffs of the resistant strata.

The local structure consists of gentle tilting of all the strata 2-4 degrees toward the northwest conforming to the western flank of the San Rafael Swell on the east and the trend of the Wasatch Plateau on the west. A major fault system passes through the western margin of the area approximately corresponding to the eastern boundary of the Wasatch Plateau known as Joe's Valley fault zone, which is visible as a sharp vegetation break to the west in the cover satellite photo. It consists of an area 2 miles wide of north-south trending normal faults 75 miles long creating a line of narrow grabens downthrown approximately 2800 feet interrupting the regular attitude of the rocks. No faults directly affect the study site .

Figure 19 summarizes the existing landslide potential of the area.(Qls). Coupled to this must be the concept of distress due to built up compressive stress from the coal burning subsidence. These areas too must be recognized. Finally the methane gas evolution evidently from the coal burning, must also be considered.

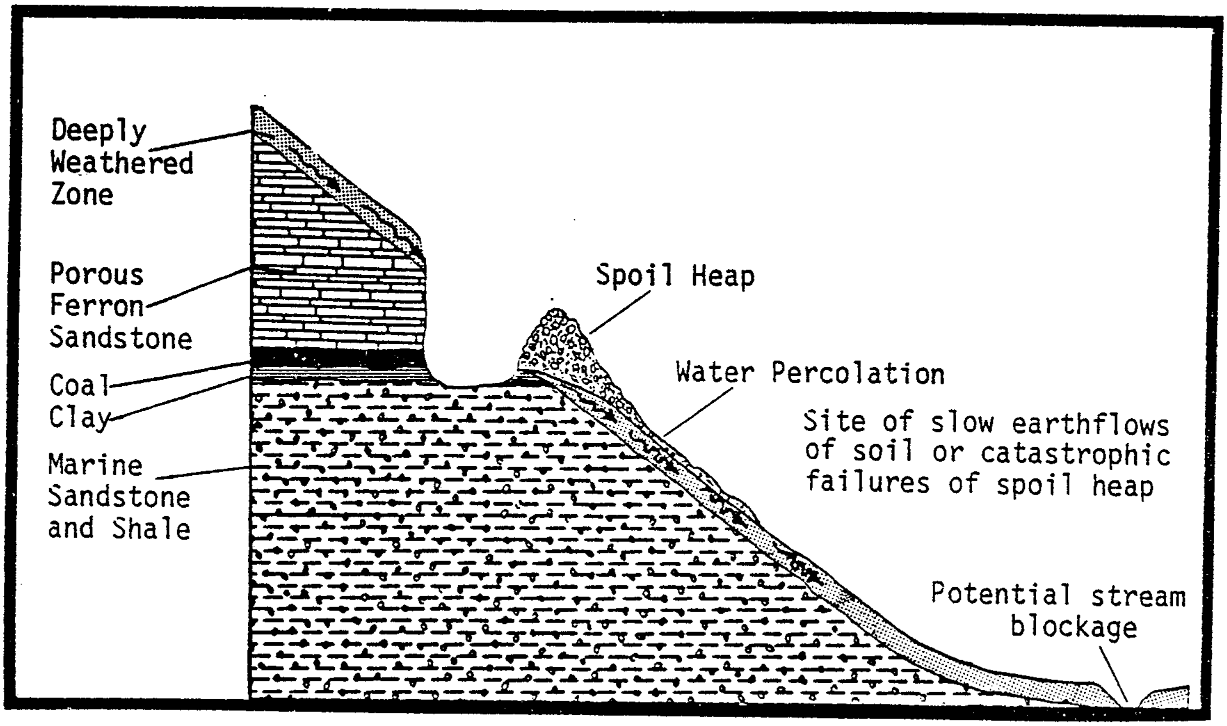


Figure 27. Potential Overloading and Water Percolation May Cause Slow Earthflows, Debris Slides, and Debris Flows.

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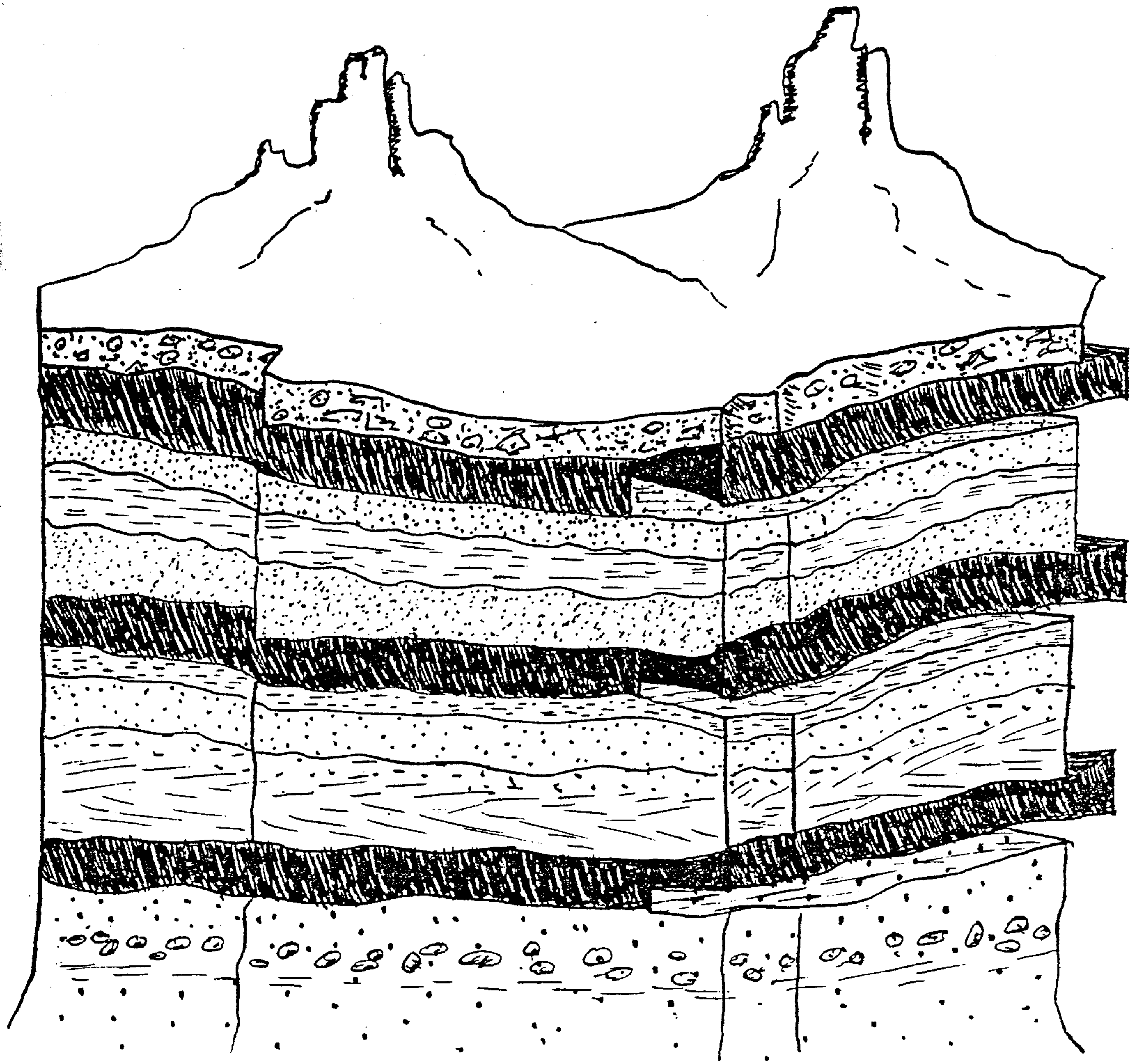


COAL RESOURCES

The Emery Coal Field

The Emery coal field has been estimated by Doelling (1977) to contain a minimum of 1.4 to 2 billion tons of coal (see Table 7). Of this, 45% is considered recoverable (630 to 900 million tons), and 140 million tons are considered strip-minable. As shown in Figure 28, the field lies east of the southern part of the Wasatch Plateau.

The field (Figure 28) is 25 miles long and 2 to 10 miles wide, tapering southward. The latitude of Emery township is the approximate northern limit of economic coal. The coal thins and disappears to the north, as shown in the fence diagram (Figure 22) the width of the field is limited by an erosional east escarpment and the Joe's Valley-Paradise fault zone to the west. Extreme dips on the coal beds are 2 to 12 degrees, but more generally dips range from 4 to 7 degrees. Jointing fractures are evidently the only impediment to mining.

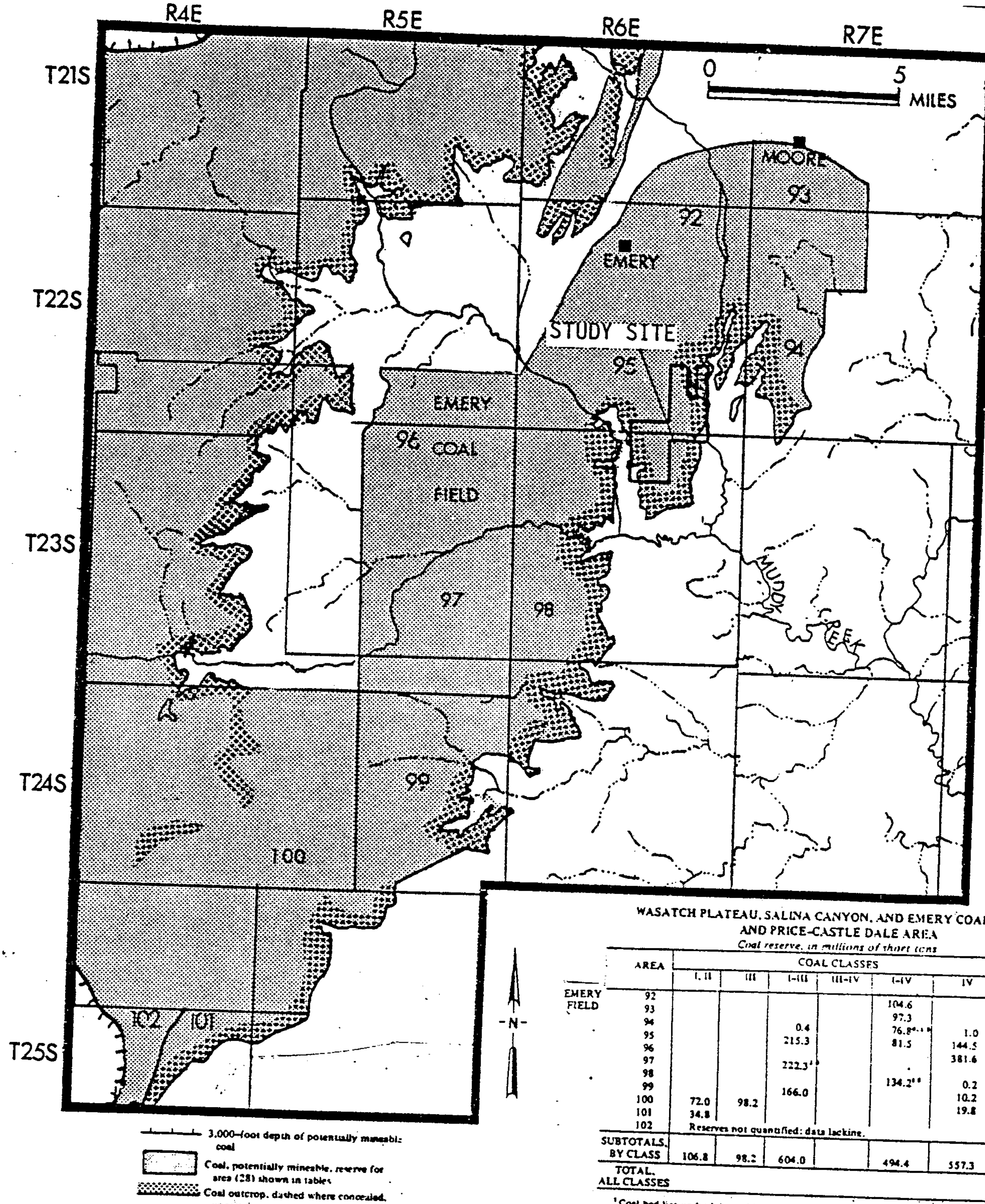
Table 7

Emery Field - Coal Seams

Emery Field Seams	Avg. Devel. Thickness	Max. Exposed Thickness
M bed (south)	4 to 6 feet	10. feet
K and L beds	thin	4.0
* J bed	4 to 10	12.0
I bed	5 to 10	13.0
H bed	thin	5.0
G bed	thin	2.0
F bed (east central)	5 to 7	7.5
D and E beds	thin	3.0
C bed (north)	5 to 8 feet	12.0
B bed	thin	2.0
A bed	4 to 12	13.0

*Locally, I and J beds are merged.

Coal not consumed at a local power plant, must be trucked 45 miles to Salina or northward 50 miles to Wellington to lines of the Denver & Rio Grande Western Railroad for out-of-state shipments. One producer has indicated plans for a 1,000,000 tons per year strip mine to serve midwest markets. Local power plants are projected to consume 9 to 10 million tons of coal annually from the Emery, southern Wasatch Plateau or Henry Mountains coal fields.



WASATCH PLATEAU, SALINA CANYON, AND EMERY COAL FIELDS, AND PRICE–CASTLE DALE AREA

Coal reserve, in millions of short tons

	AREA	COAL CLASSES						SUBTOTALS (BY AREA)
		I, II	III	I–III	III–IV	I–IV	IV	
EMERY FIELD	92							
	93					104.6		104.6
	94					97.3		97.3
	95			0.4		76.8[4,5,6]	1.0	78.2
	96			215.3		81.5	144.5	441.3
	97						381.6	381.6
	98			222.3[4,9]				222.3
	99					134.2[11]	0.2	134.4
	100			166.0			10.2	176.2
	101	72.0	98.2				19.8	190.0
	102	34.8	Reserves not quantified: data lacking.					34.8
SUBTOTALS, BY CLASS		106.8	98.2	604.0		494.4	557.3	
TOTAL, ALL CLASSES								1,860.7

[1] Coal bed lies under lake and is probably faulted.
[2] Coal occurs in a more complex geologic setting and is more deeply buried here than to the south, with coal of area generally north-dipping and faulted.
[3] Based on inference that coal is probably like that to the east in persistence, thickness, and tonnage.
[4] Includes some coal thinner than 4 feet.
[5] Some coal may not be minable.
[6] Probably more than 100,000,000 tons.
[7] May not be minable due to faults in area, and locally coal may be deeper than 3,000 feet.
[8] Average thickness is less than 4 feet over much of the area.
[9] Possibly should be classed as I–IV.
[10] Recent drill hole data indicates that this estimate may be too high.
[11] Chiefly classes II–IV.
[12] Plus noted unquantified amounts could possibly add 10–20 percent to the tabulated tonnage.
[13] This quantity may be slightly too low.
[14] Mainly class III.
[15] Includes some 3-foot thick coal.
[16] Coal nowhere exposed. Coal bed is at a much lower stratigraphic position than the minable coal farther west.
[17] Coal may or may not be present in minable quantities, but deep burial generally would preclude mining except perhaps between areas 103 and 106.

COAL CLASSES[1]

Class I — *Measured reserves* based on adequate exploration data; properly correlated; control no more than one-half mile apart.

Class II — *Indicated reserves* based on geologic measurement supplemented by limited drill-hole information and limited to 1½ miles from a control point.

Class III — *Inferred reserves* based on geologic inference and projection of the habit of the coal beyond 1½ miles from control points.

Class IV — *Potential reserves* based on geographic and geologic position with little surrounding data; includes coal covered by no more than 3,000 feet of overburden.

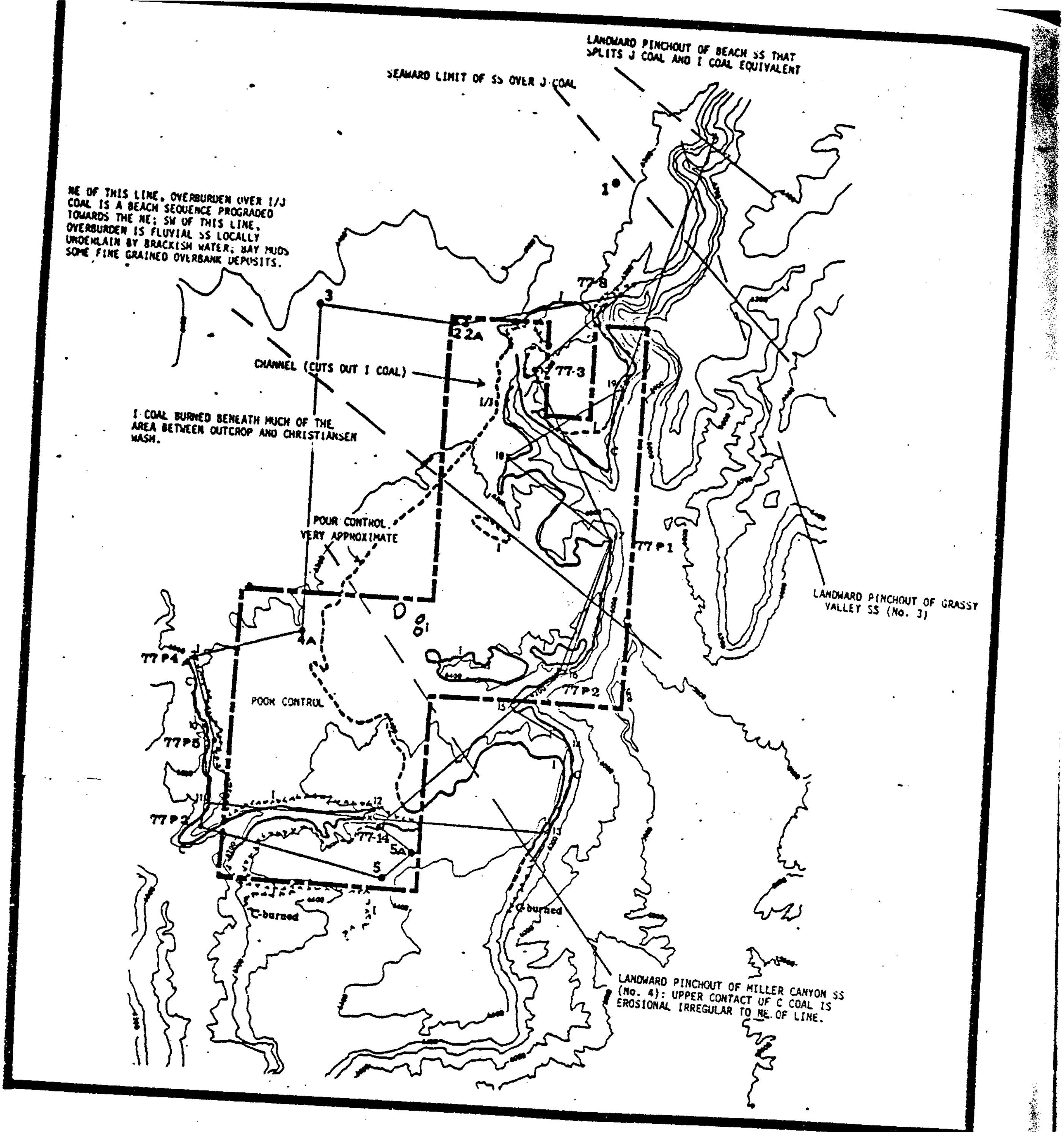
Most of the coal reserve is based on surface measurements which are not always as reliable as the drill. The reserve commonly is underestimated because surface measurements usually are smaller than thickness penetrated by drilling. Class I and II figures are combined in these reports; no attempt was made to separate the more reliable figure. The first three reserve classes constitute the principal reserve and more nearly reflect the current potential. The reserves include only coal beds that average 4 feet or greater thickness and are covered by less than 3,000 feet of overburden except where otherwise noted. Less than 50 percent of the total reserves are economically mineable.

[1] The division of coal into four classes generally follows that described by Doelling (1972c, p. 549).

Figure 28. Coal Resources Map (USGS 1979)

Study Site Resources

A recent update of the Emery coal field geographic distribution and reserve estimates are presented in Figure 28, adapted from the Central Utah EIS (USGS, 1978). From our own core data, the strippable coal resources on the study site are depicted in more detail in Figures 29 and 30 for 100 and 200 foot depth capabilities. They are considered a typical subset of a larger strippable resource lying to the NW in a belt oriented NE-SW. A three dimensional computer model of the coal resources is presented in Figures 31, 32, 33, and 34. This computer model was employed to depict the complexity of the coal resource, and treat the twin competing processes of erosion and underground coal fires which have removed a portion of the resources which would be inferred from a simple stratigraphic interpretation of the numerous outcrops. The figures present four aspect views of the coal resources on site with each of the significant coal layers depicted in relative correspondence to their actual thickness. The cells with residual coal are filled in colors corresponding to the coal layer they represent. Figure 35, is an isopach map of coal overburden. This gives the depth to strip, where coal is present. Both 100 and 200 foot overburden lines are presented on the coal distribution map based essentially on the I-J seam, but note that both the deeper C and A seams are recoverable as well under these ground rules. To the north, along the NW-SE line, indicated in Figure 29, along Miller Creek, the coal splits up and pinches out. This represents the practical limit of coal resources to the north from current data. Evidently these coals have a higher sulfur content as well (e.g. viz Table 8). The C coal pinches out to the north in the coal cliffs east of Muddy Canyon. To the south it thins markedly in the vicinity of Interstate 70, pinching out just north of the location of bore hole #6. Hence both A and C coals may be exploitable SE of the study area. In the region, maximum coal thickness occurs within a distance of about 6 miles landward of the pinchout of the delta front sandstone units (Ryer, 1979). First and second delta cycles are evident in outcrops along the N. Quitchupah, followed by a layer of channel sands. In the northern part of Quitchupah Canyon, the A and C coals are separated by 20 ft. of channel sandstone, but at bore hole #5 the two coals merge in a fashion similar to the merging of the I-J seams to the north. The total coal analyses presently available from the USGS (Affolter, Hatch, Ryer, 1979) are for bore holes 1, 5, 2, and 2A.



KEY

- • Outcrop Locations
- —x— Fence Diagram Track
- ● Bore Holes
- —— Strippable Coal
- (I) Coal Layer =(letter)
- ~~~~ Burned Coal
- ▬ ▬ ▬ EMRIA Site

Figure 29. Cross-Section and Bore Hole Location Map With Respect to Strippable Coal.

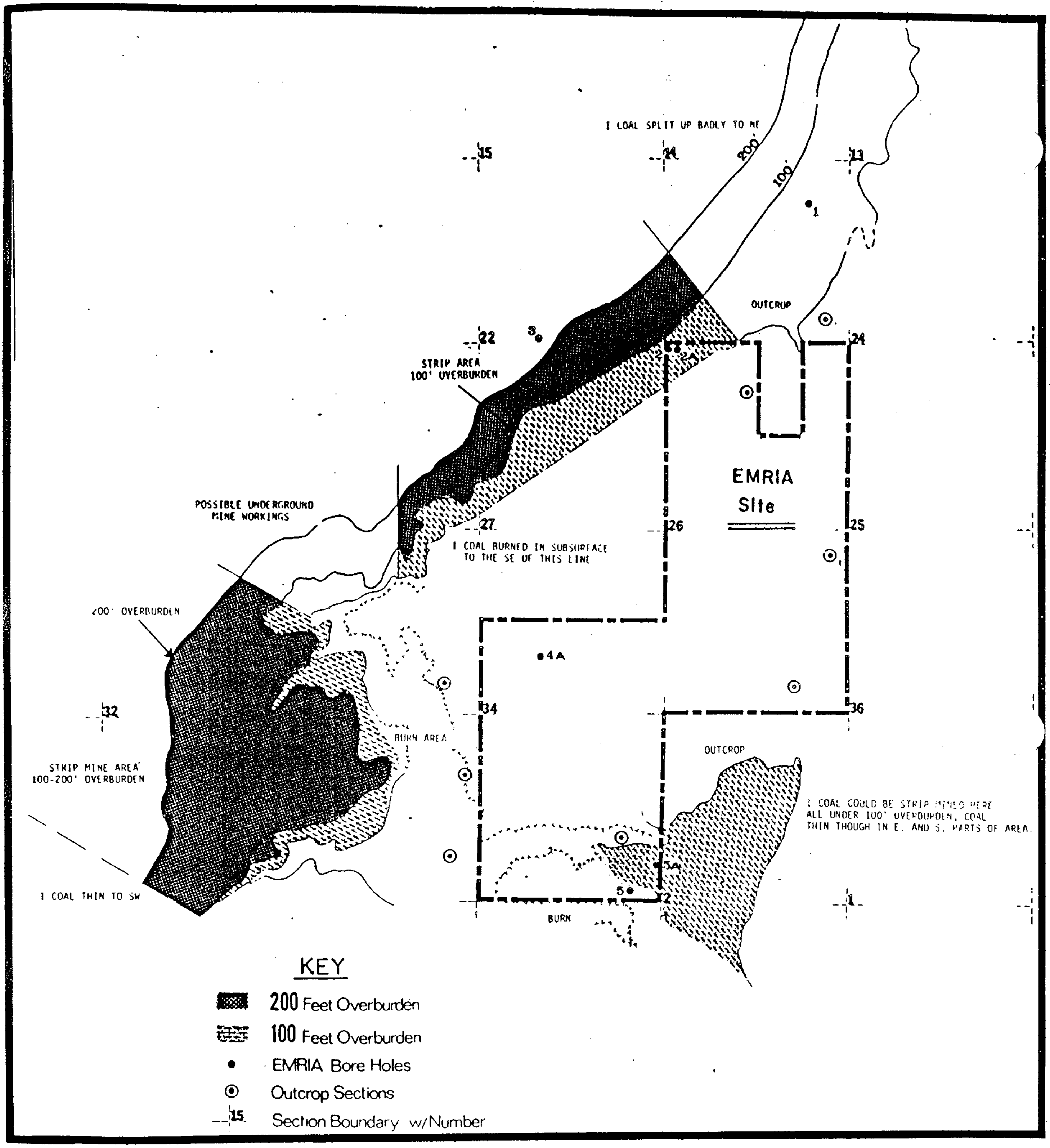


Figure 30. Strippable Coal and Burn Areas

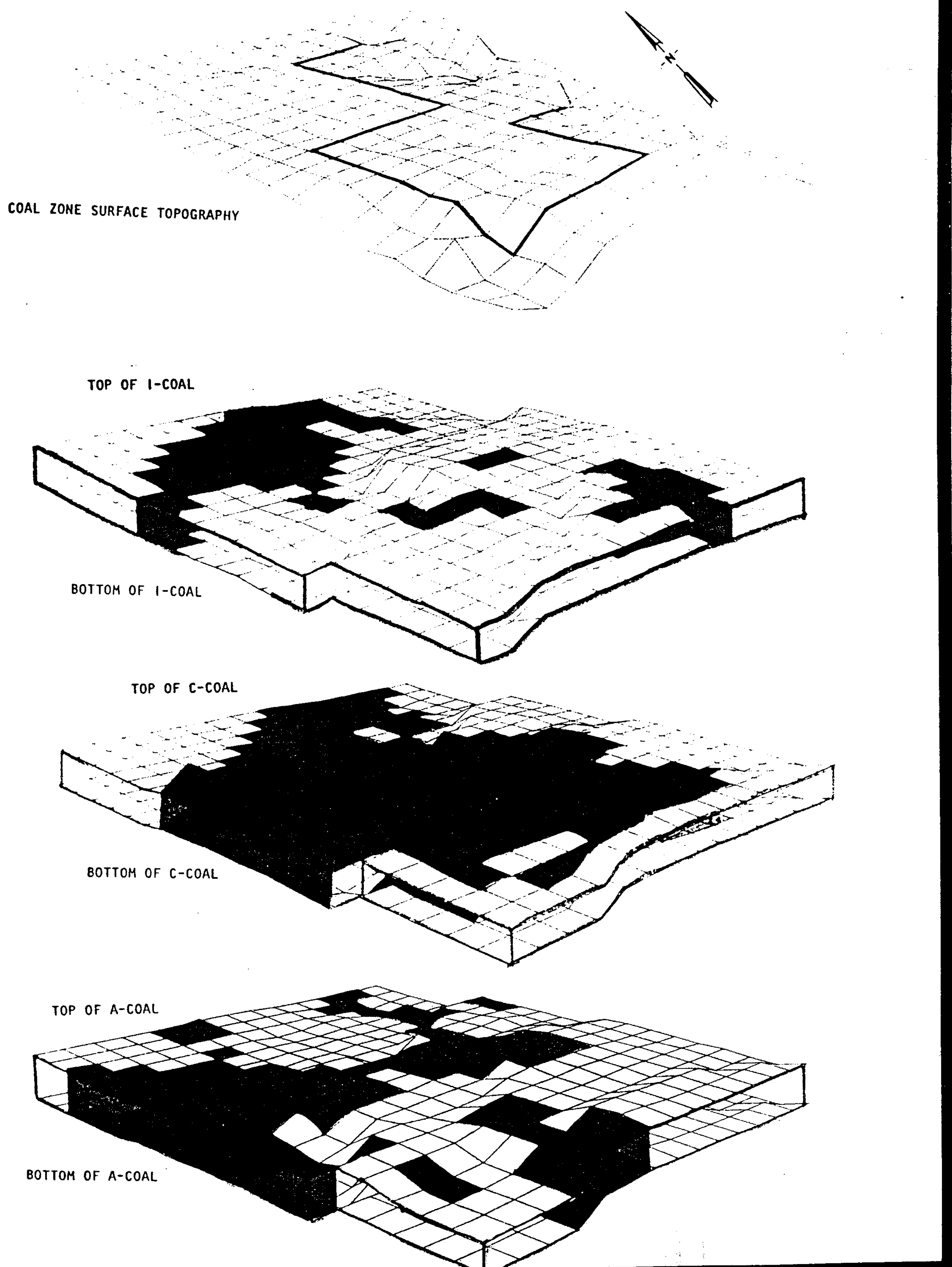


Figure 31. Perspective View Towards 45° Emery Study Site.

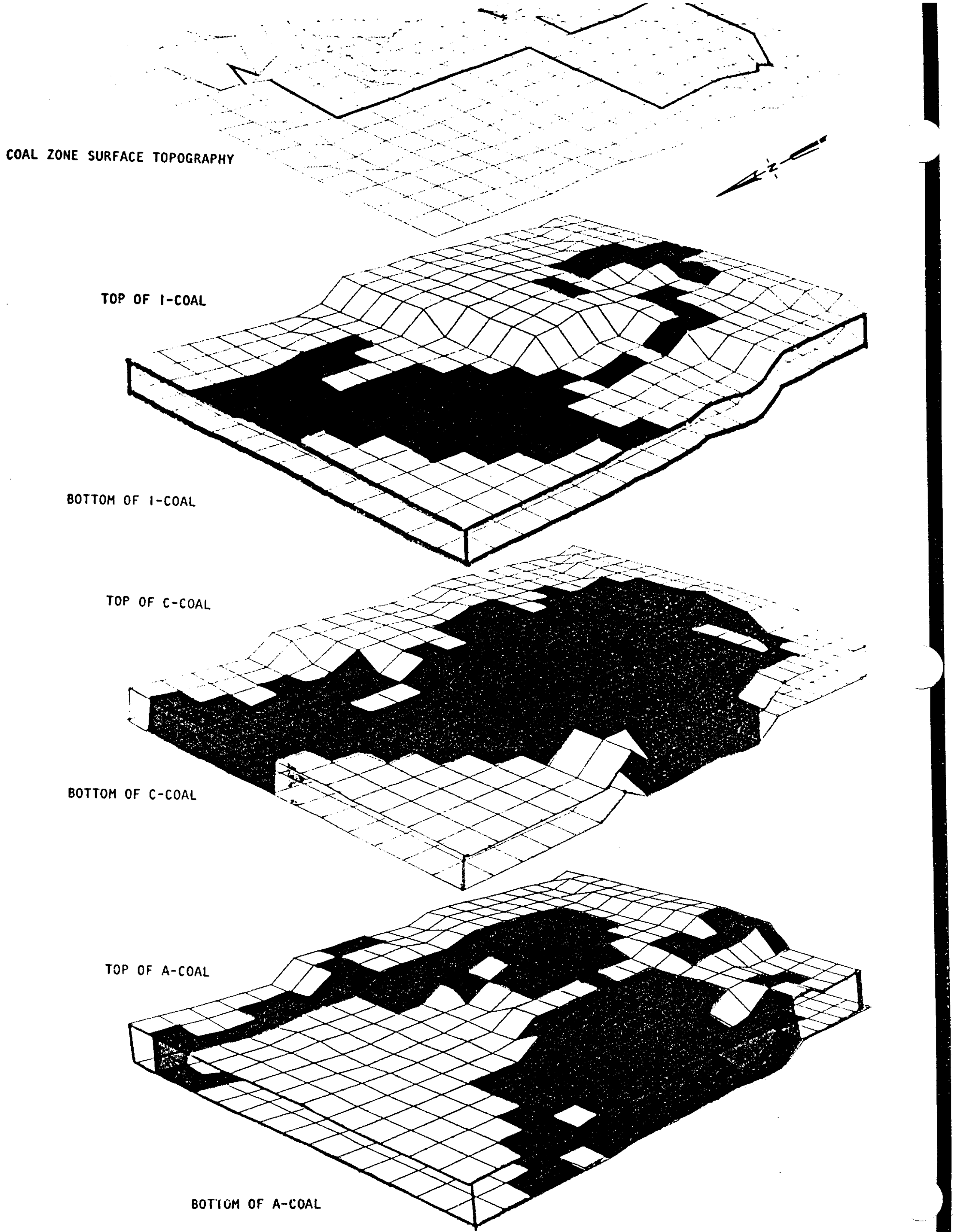


Figure 32. Perspective View Towards 135° Emery Study Site.

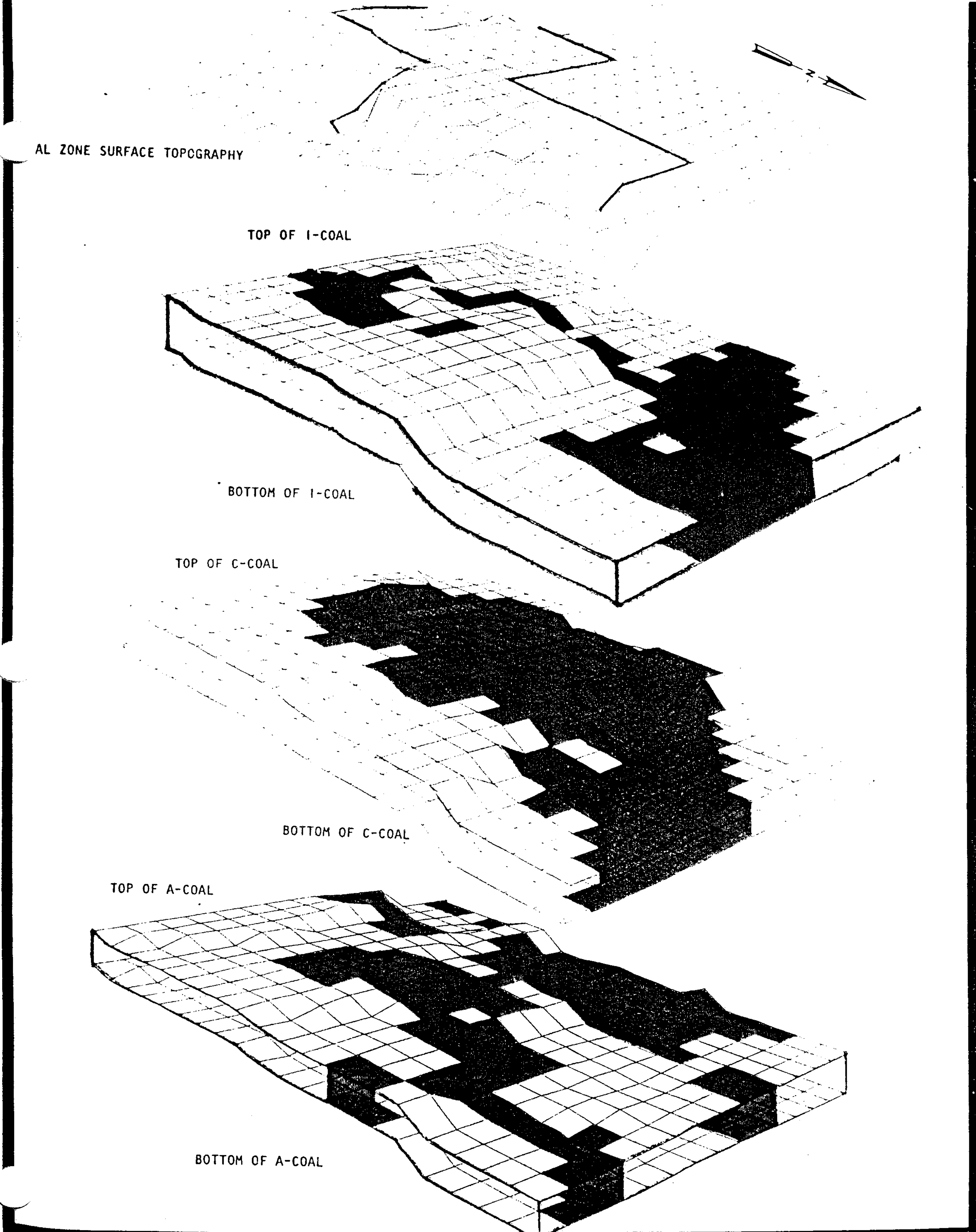


Figure 33. Perspective View Towards 225^{0} Emery Study Site.

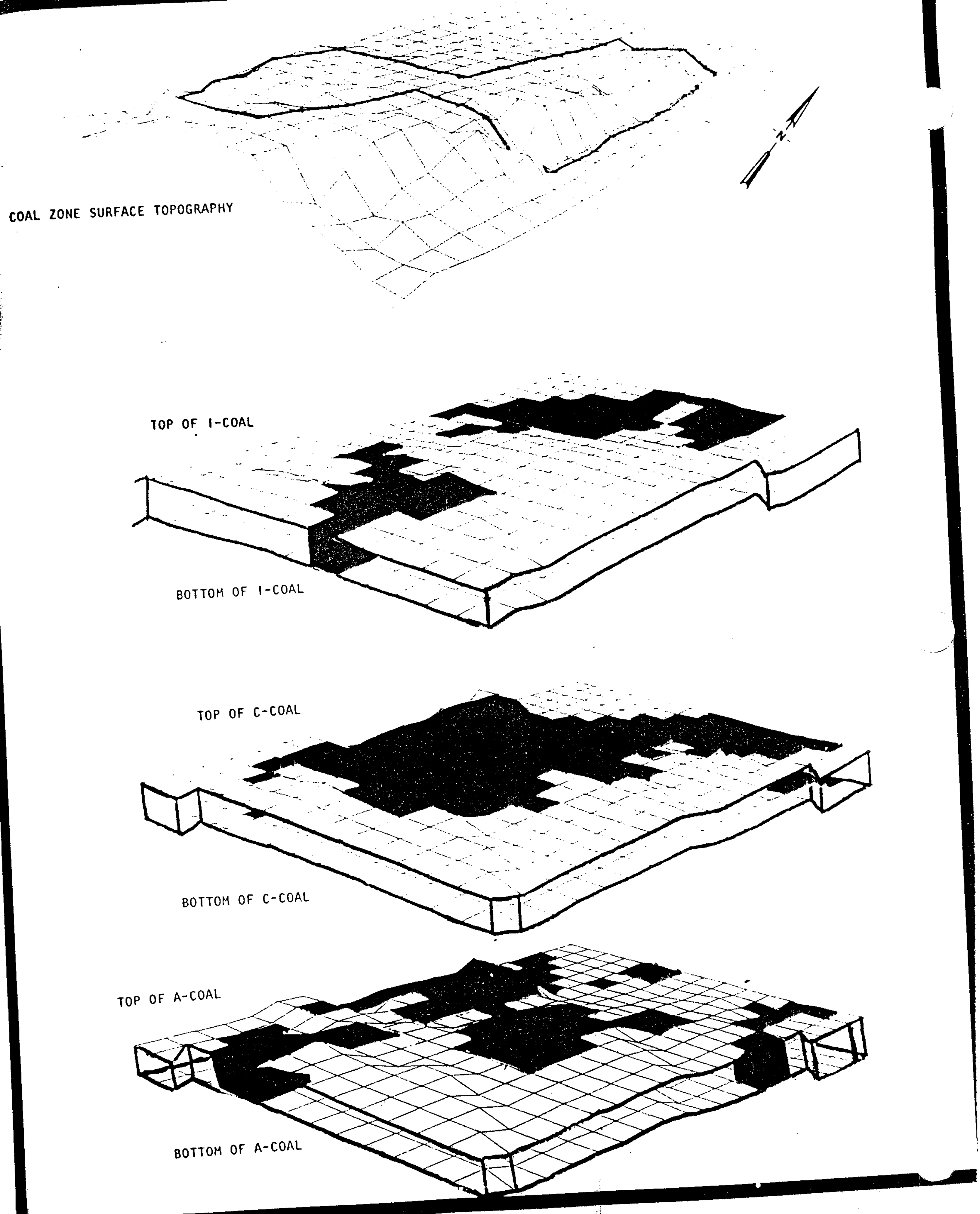


Figure 34. Perspective View Towards 315^{o} Emery Study Site.

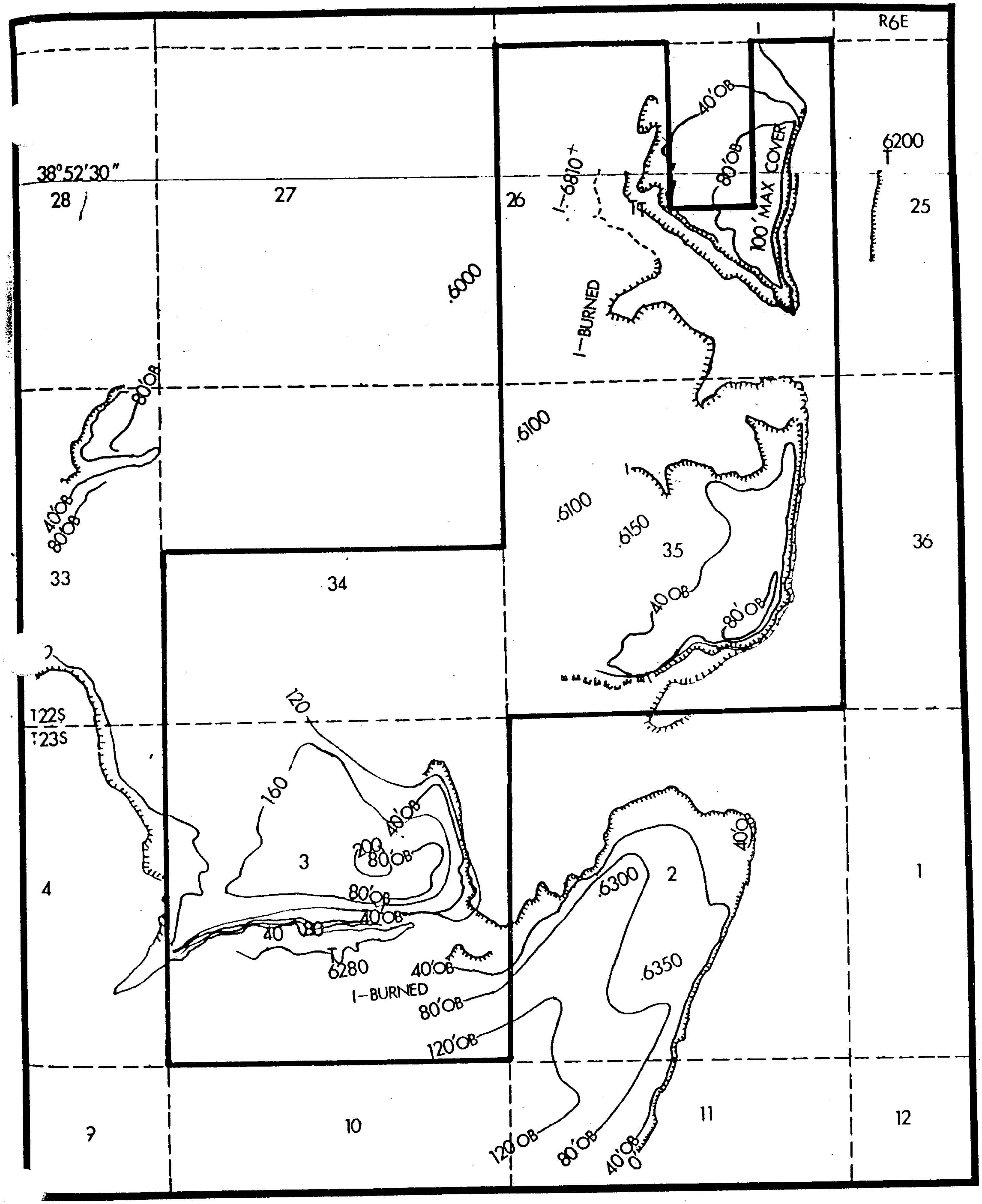


Figure 35. Strippable Coal Overburden Isopach Map (overburden depth in feet)

Table 8. COAL ANALYSIS	Proximate				Ultimate Analysis						Heat Value BTU/lb.	Free Swelling Index
	Moisture	Volatiles	Carbon	Ash	Hydrogen	Carbon	Nitrogen	Sulfur	Oxygen	Ash		
<u>Borehole 2A</u>												
83.8 to 85.0 ft.	3.5	41.4	49.8	5.3	5.7	73.8	1.3	1.8*	12.0	5.3	13139	-
98.1 to 99.0 ft.	2.8	36.4	44.4	16.4	5.0	64.1	1.2	2.2*	11.2	16.4	11508	-
239.0 to 240.0 ft.	2.6	35.0	44.2	18.2	4.6	63.7	1.2	.7	11.6	18.2	11125	-
<u>Borehole 4A</u>												
53.2 to 56.8 ft.	3.6	39.4	40.2	16.8	5.1	62.5	1.1	3.6*	10.8	16.8	11164	1.5
93.9 to 99.5 ft.	3.8	36.1	39.6	20.5	4.8	58.9	1.0	2.1*	12.7	20.5	10527	1.0
101.2 to 108.7 ft.	4.0	37.2	43.8	15.0	5.1	64.3	1.1	.7	13.7	15.0	11394	1.0
144.0 to 149.0 ft.	3.7	40.2	46.8	9.3	5.5	70.0	1.2	1.0	13.0	9.3	12503	1.0
<u>Borehole 5</u>												
137.5 to 139.5 ft.	8.8	36.6	39.2	15.4	5.1	57.2	1.1	2.3*	18.9	15.4	10084	.0
199.5 to 202.3 ft.	4.1	38.8	44.1	13.0	5.2	65.9	1.1	.9	13.8	13.0	11710	1.0
204.0 to 208.3 ft.	4.5	37.9	42.0	15.6	5.1	63.3	1.1	.5	14.3	15.6	11206	1.0
208.5 to 211.8 ft.	5.4	37.7	45.6	11.3	5.2	66.9	1.2	.6	14.8	11.3	11799	1.0
212.9 to 215.7 ft.	5.1	38.3	45.2	11.4	5.3	66.8	1.2	.9	14.4	11.4	11720	1.0
216.0 to 219.0 ft.	3.9	38.2	43.3	14.6	5.2	65.6	1.1	.7	12.7	14.6	11613	1.0

*excessive sulfur value

Table 8. (cont.)

	Proximate				Ultimate Analysis							
	Moisture	Volatiles	Carbon	Ash	Hydrogen	Carbon	Nitrogen	Sulfur	Oxygen	Ash	Heat Value BTU/lb.	Free Swelling Index
Borehole 6												
54.2 to 56.9 ft.	5.8	39.4	41.8	13.0	5.2	62.2	1.2	3.4*	15.1	13.0	11128	0.5
80.9 to 81.9 ft.	5.0	35.0	32.1	27.9	4.6	50.3	1.1	3.9*	12.3	27.9	9006	0.5
109.3 to 110.7 ft.	6.1	37.6	44.8	11.5	5.4	65.4	1.3	.8	15.6	11.5	11458	0.5
111.3 to 114.5 ft.	6.0	39.4	47.9	6.7	5.5	67.3	1.3	.4	18.8	6.7	12250	0.5
114.5 to 117.7 ft.	6.7	40.3	48.0	5.0	5.7	69.9	1.3	.5	17.7	5.0	12426	0.5
118.7 to 123.2 ft.	5.7	37.6	43.8	12.9	5.2	63.4	1.1	.9	16.5	12.9	11266	0.5
205.7 to 206.8 ft.	5.2	40.3	47.9	6.6	5.7	68.6	1.3	1.4*	16.4	6.6	12299	0.5
243.0 to 243.7 ft.	5.0	40.7	46.9	7.4	5.6	68.1	1.3	1.9*	15.8	7.4	12191	0.5
286.3 to 293.3 ft.	5.1	38.5	45.0	11.4	5.4	65.7	1.4	.6	15.5	11.4	11684	0.5

*excessive sulfur value

Proximate Analysis - involves the determination of four constituents: (1) water, called moisture; (2) mineral impurity, called ash, left when the coal is completely burned; (3) volatile matter, consisting of gases or vapors driven out when coal is heated to certain temperatures; and (4) fixed carbon, the solid or cakelike residue that burns at higher temperatures after volatile matter has been driven off.

Ultimate Analysis - involves the determination of carbon and hydrogen as found in the gaseous products of combustion, the determination of sulfur, nitrogen, and ash in the material as a whole, and the estimation of oxygen by difference.

The I coal may indicate a sulfur problem with peak values up to 6%, but more commonly 3-4% sulfur is found at the top of the I seam. To meet EPA standards (< 1% sulfur) coal rinsing and blending may be required.

Summary

As shown in Table 8, 6 of the 13 coal beds are over 4 ft. thick. Seventy-six percent of the reserve is estimated to be under less than 1000' of cover (Doelling, 1977). The seams were given letter designations by Lupton (1916) ascending from A to M. The host formation is the Ferron Sandstone member of the Mancos Shale, which ranges in thickness from 300 to 900 feet, generally thickening north to south. The base of the unit is a massive cliff-forming sandstone 80 to 140 feet thick above which are delta plain beds containing the first sequence of coal beds A to F (Lower Group or Zone of Doelling, 1972). Of these, the A bed is more important economically to the south and the C bed to the north. Overlap occurs in the central part of the field, essentially at the southern end of the study area. Above the Lower Zone is an 80 to 200 foot interval that is mostly sandy containing the normally uneconomical F and G coal seams. The Upper Zone of Doelling (1972) contains beds H to M. The merged I and J beds are of greatest importance to our study, but are extensively burned on the site. The separation is minimal in many areas making one very thick seam (up to 25 feet). Overburden in the study area is shallow over these beds, permitting strip-mining of the I-J seam as noted. In this context, the A-C beds could be taken in conjunction as well. The uppermost M bed develops to economic thickness locally and in many areas could be taken by surface mining methods, but is eroded out on the study site.

Coal quality data are presented in Table 8 (Hatch, 1979). Most analyses, published and elsewhere, have been based on samples taken from mines operating in the I bed thus presenting some bias (e.g. Lupton, 1916; Doelling, 1972, 1977; USGS, 1978). Samples collected at outcrop would present an unrealistically low Btu/lb. estimate. An operating mine average is 12,000 Btu/lb. on an as-received basis. The coal samples taken in this study were somewhat lower; about 11,000 Btu/lb. Sulfur content of coals varies considerably from area to area and from seam to seam with an as-received range from 0.31 to 4.6% and most falling between 0.5 and 2.5%, but in some cases, as noted, exceeds accepted levels (i.e. 1.8 to 3.9%).

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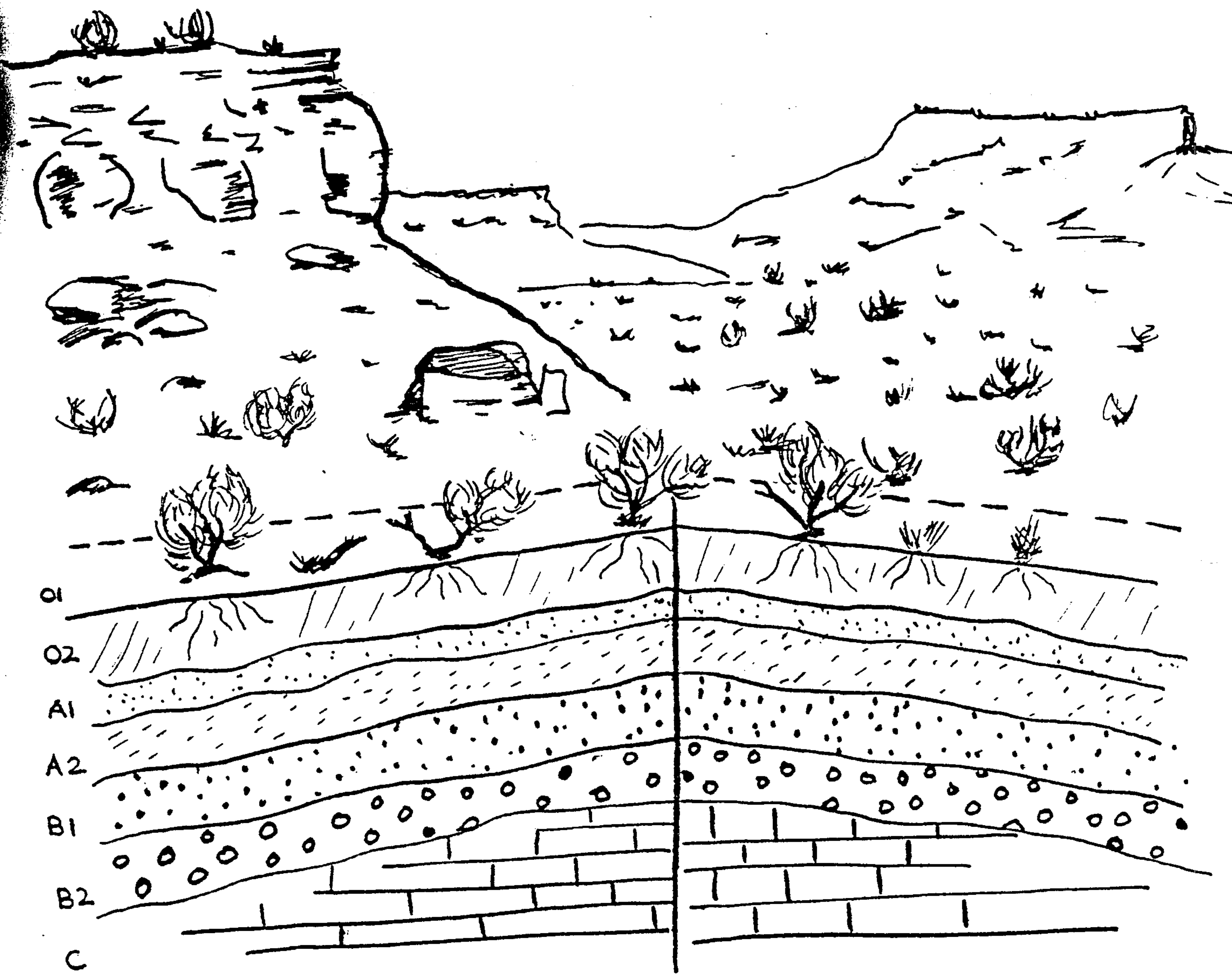


SOILS

Detailed mapping and descriptions of soils occurring on the study site have been provided by the Soil Conservation Service (SCS, 1954; 1978), and these data have been supplemented by field observations and analyses carried out during the current study. In general, soils of the area are shallow and subject to high salinity. Agricultural development is very limited and the most important type of land use is grazing, which takes place on most of the suitable terrain. Figure 36 shows soils as mapped by the SCS. Data from quantitative sampling of plant communities has been used to assess the relative fertility of the various units as indicated by percent vegetative cover. The floristic composition is discussed with each soil type. No extreme differences in floristic composition were noted between soil types, except for those soils which correspond to special landforms (e.g. Ry-Rock Land; Ml-Made Land). Species coverage values do vary with soil type, but the two basic vegetation types, Shadscale and Pinyon-Juniper, are found on most soils which have slopes less than 20%. Comparison of soil and vegetation maps reveals a close correspondence between units of the Castle Valley series and the Pinyon-Juniper vegetation type, which was used as an indicator of this substrate.

Mapping Unit Descriptions (Table 9 gives a summary of the physical attributes)

Castle Valley Series

The Castle Valley soils series consists of sloping to steep, shallow, calcareous, well-drained soils on upland benches and mesas. These soils have formed in material that weathered from sandstone and interbedded shale. Areas of these soils are generally surrounded by scarp faces of very steep Shaly Colluvial Land or Rock Land.

In a typical profile, the surface layer is brown loamy very fine sand. The subsoil is brown, very fine sandy loam that has lime at its base. Sandstone bedrock is at a depth of about 10-20 inches. Flat, angular fragments of sandstone make up 15 to 50 percent of the volume, with the highest percentage near bedrock.

Castle Valley (CeE2), extremely rocky, very fine sandy loam, is found on 0-20% eroded slopes. From 60-75% of this mapping unit is Castle Valley soil and the rest is rock outcrop. The Castle Valley soil is the model profile for the series. The texture of the surface layer is variable, because of deposition and removal of material by wind action. In places, as much as half of the original surface layer is gone.

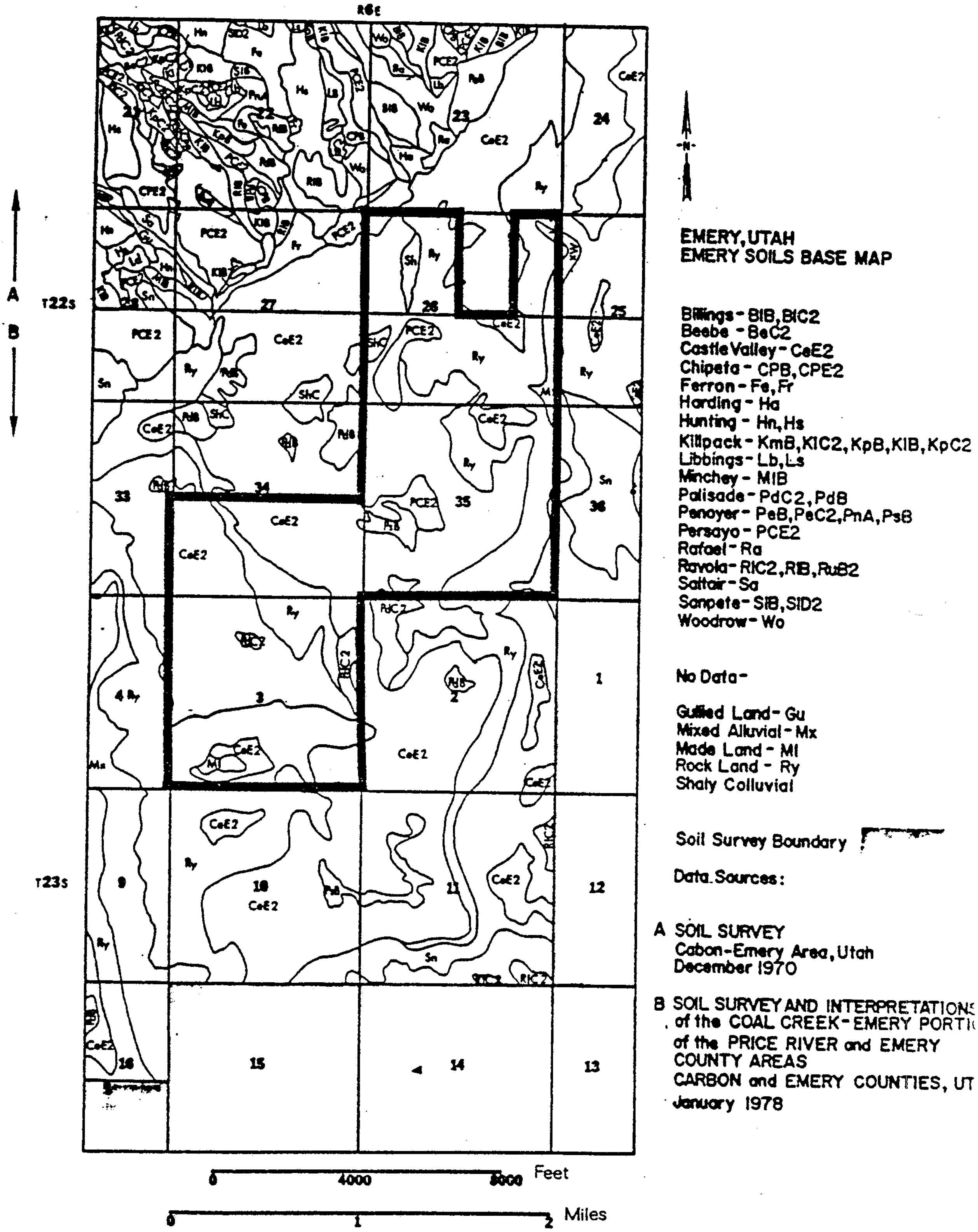


Figure 36. Emery, Utah - Emery Soils Base Map.

Table 9. Physical Soil Characteristics

Soil Legend	Texture	Permeability	Available Water Capacity	Soil Reaction	Salinity	Erosion Factors	Wind Erod. Group	Slope	Area on Site (acres)	Aver. Depth (in.)	Volume (acre ft.)
Penoyer (PsB)	L, VSFL SICL L, VSFL	0.6-2.0 0.2-0.6 0.6-2.0	0.17-0.19 0.17-0.19 0.17-0.19	7.4-8.4 7.4-8.4 7.4-8.4	4 4 4	.43 5 .43 5 .43	4L 4L	1-3%	25.53	48	102
Persayo (PCE2)	L, SICL WB	0.6-2.0 0.0-0.0	0.17-0.19 0.0 -0.0	7.4-8.4	2-16	.49 1	4L	1-20%	74.67	8	50
Chipeta (CBF2, CBF)	SICL, SIC	0.06-0.2	0.11-0.15	7.4-8.4	8-16	.43 1	4L	3-30%	(not on site)		
Shaly Colluvial (ShC)	CB-VFSL CL CB-CL	2.0-6.0 0.6-2.0 0.6-2.0	0.11-0.13 0.12-0.14 0.12-0.14	7.4-8.4 7.4-8.4 7.9-9.0	4 4 4	.37 2 .43 .37	8	3-6%	9.99	24	20
Palisade (PdC2, PdB)	VFSL VFSL VFSL	0.6-2.0 0.6-2.0 2.0-6.0	0.15-0.17 0.15-0.17 0.14-0.16	7.9-8.4 7.9-9.0 8.5-9.0	2 2 2	.43 5 .43 .43	3	3-6% 1-3%	31.73	60	158
Castle Valley (CeE2)	GR-VFSL	2.0-6.0	0.8 -0.13	7.4-8.4	4	.37 1	8	0-20%	1217.24	8	815
Rock Land (Ry)	Coarse Fragments	Var	Var						779.60	2	130
Mixed Alluvial (Mx)	SI-CL	Var	Var		No Data Available				60.52	48	240
Man-Made Land (ML)	Var	Var	Var						11.64	0	0

Included in mapping were areas of soils having depths less than 10 inches over sandstone and other areas in which the soils are more than 20 inches thick.

Drainage is good, and permeability is moderately rapid. Roots penetrate to the sandstone and then spread horizontally. From 2 to 3 inches of available water is retained by this soil; depending on the depth to bedrock. Runoff is slow to medium except in areas of bare rock where the amount of runoff is high. The susceptibility to further erosion from wind and water is slight to high. Many areas of this unit contain deep ravines.

The Castle Valley soils are almost exclusively covered by Pinyon-Juniper woodland with a very sparse understory of shadscale, black sage, and indian ricegrass. Vegetative cover averages 25-30%.

Penoyer Series

The Penoyer soils series consists of well-drained, calcareous soils that are medium textured. These soils occupy medium to small areas of alluvial fans, flood plains, and alluvial plains on the bottoms of canyons. They have formed in alluvium, derived from sandstone, limestone, and basic igneous rocks.

In a typical profile, a surface layer of light brownish-gray, strongly calcareous loam about 9 inches thick is underlain by a layer of light brownish-gray loam and very fine sandy loam.

Penoyer soils are generally dry, unless snow covered or irrigated. The content of calcium carbonate ranges from 5 to 25%. Reaction ranges from mildly to moderately alkaline. Salinity ranges from slight to moderate. Clay mineralogy is mixed, but the clay fraction is dominantly montmorillonite. The texture of the A horizon ranges from very fine sandy loam to silty clay loam. The profile between 10 and 40 inches consists of light loam, silt loam, or very fine sandy loam with less than 18% clay and less than 15% coarser sand. All of the upper 40 inches is about the same color. Below a depth of 40 inches, the texture ranges from clay loam to sandy loam.

Penoyer (PsB), very fine sandy loam, is found on 1 to 3% slopes. This soil is similar to the model profile for the series, except for the surface layer texture. Penoyer is found in the southern portion of the survey area, near Ivie and Quitchupah Creeks.

Included in mapping were areas of shallow, fine sand over shale and sandstone.

Runoff is slow, and the susceptibility to wind erosion is moderate. Hummocks 6 to 12 inches high have formed in some areas. In places, head cutting is active and deep gulleys have formed.

This soil type is of limited extent on the site. It supports fairly diverse stands of grasses and shrubs, often with no single dominant species. Line transect data showed that black sage, shadscale, rabbitbrush and ephedra were the most important shrubs, while galleta and indian ricegrass formed most of the understory. Prickly pear cactus (*Opuntia polycanthus*) was found to have invaded certain areas of this soil type.

Persayo Series

Persayo series soils are calcareous, well-drained soils found on moderately fine textured, gently sloping to steep slopes. They form in residium weathered from shale hills. The associated vegetation is mainly galleta grass and shadscale.

In a typical profile, the surface layer is light brownish-gray loam about 1 inch thick. The underlying material is light brownish-gray loam and silty clay loam that contains a weak to moderate gypsum horizon. Shale bedrock is at a depth of about 12 inches.

As a rule, Persayo soils are dry. The part of the profile below 10 inches is silty clay loam that contains less than 35% clay. Weathered fragments of shale make up 5 to 70% of the material in this part of the profile. The shale fragment content increases with depth. All of the upper 20 inches has about the same color. In the C3cs horizon, the content of gypsum ranges from 0.5 to 10%. Gypsum crystals range from few to common.

Persayo soils occur with the Chipeta soils. The Persayo-Chipeta association (PCE2) is found on 1 to 20% eroded slopes. About 60% of this mapping unit is Persayo loam on 1 to 20% eroded slopes, and 40% is Chipeta silty clay loam occurring on 3 to 20% eroded slopes. These soils are intermingled and occur in no identifiable pattern. The Chipeta soil generally is on ridges.

The Persayo soil is the model profile for the series. This soil is well drained and has moderate permeability. Roots penetrate down to the shale, and then spread horizontally. This soil may take up 1 to 3 inches of available water, the amount depending on the depth to bedrock. Runoff is medium, and the susceptibility to erosion is moderate.

The soils in this mapping unit are used mainly for spring and fall range. Sheet erosion is active, and in many places shallow gulleys have cut down as far as the shale bedrock.

The Shadscale vegetation type is well developed on this soil type. Highest coverage values for Atriplex confertifolia and Hilaria jamesii, the two main species in the type, were found on Persayo soils. A variety of other shrubs occur as sub-dominants including four-wing saltbush, kochia and cuneate saltbush.

Palisade Series

The Palisade series consists of deep, medium-textured, well-drained, nearly level soils deposited on mesas and benches. As a rule, the soil occurs on the lower parts of benches in medium to large areas. The Palisades series forms in alluvium and glacial outwash derived from calcareous sandstone mixed with shale and limestone. Palisade soils have strongly calcareous horizons throughout.

In a typical profile, the surface layer is pale-brown, limey, soft loamy fine sand about 3 inches thick. The underlying material is very pale brown and yellowish-brown very fine sandy loam, and it is strongly calcareous to moderately calcareous. Gravel and cobblestones may occur at depths between 2 and 5 feet.

The Palisade soils generally are dry. They have a mixed clay mineralogy. The part of the profile between 10 and 40 inches is very fine sandy loam or light loam that contains less than 18% and more than 15% sand coarses than very fine sand. In places gravel and cobblestones make up as much as 50%, by volume, of the lower one-third of this 30-inch section. The content of calcium carbonate in the limey horizons ranges from 15 to 40%. Below a depth of 40 inches, the texture ranges from very fine sandy loam to gravelly loamy sand.

Palisade (PdB), very fine sandy loam, is found on 1 to 3% slopes. The profile of this soil is the one described as typical of the series. Gravel and cobblestones are between depths of 2 and 5 feet in places.

Drainage is good and permeability is moderate. Root penetration is deep. About nine inches of water is retained by this soil, but only 4.5 to 5.5 inches is readily available to plants. Runoff is medium, and the susceptibility to erosion is moderate.

The Shadscale vegetation type is well developed on Palisade soils. The coverage of perennial plants averages 15-18% for samples taken from this substrate, with 12-15% of the cover accounted for by shadscale and galleta.

Palisade (PdC2), very fine sandy loam, is found on 3 to 6% eroded slopes. This soil is similar to the model profile for the series, except that it is steeper and more eroded. It occurs in small areas on benches.

Runoff is medium and the susceptibility to erosion is high. Although not observed on the Emery study site, some areas having this soil type are reported to develop gulleys 2 to 3 feet deep with a whitish calcareous subsoil exposed through erosion to 3-4 inches below the surface.

Ravola Series

The Ravola soils series are deep, medium textured, moderately permeable, and well drained. These soils occupy moderate to large areas on alluvial fans, on flood plains, and in narrow alluvial valleys, and formed in alluvium that washed from shale and sandstone.

In a typical profile, the surface layer is light brownish-gray, slightly hard, moderately calcareous loam about 9 inches thick. The underlying material is light brownish-gray, moderately to strongly calcareous loam that in places is weakly stratified with layers of sandy loam or clay loam.

Ravola loam (R1C2) is found on 1 to 3% eroded slopes. This soil is similar to Ravola loam found on 1 to 3% slopes, except for the steeper slope ranges and erosion. It occupies alluvial fans.

Runoff is rapid, and the susceptibility to erosion is high. Sheet erosion is active. In many areas, especially near the steep, nearly bare shale hills, gulleys are 4 to 8 feet deep and 100 to 400 feet apart.

Plants associated with this soil type are those adapted to extremely dry conditions, and are often the same species observed in rocky and craggy places, such as rabbitbrush, ephedra and occasionally species of yucca.

Sh Series

Shaly very fine sandy loam (ShC) is found on 3 to 6% slopes. This soil is similar to Castle Valley (CeE2) except that it is less rocky and the depth to bedrock is 20 to 40 inches. Slopes are 3 to 6%.

This is a moderately deep, well drained, moderately fine textured soil and is found on gently sloping upland benches. Sh soil has strongly calcareous horizons throughout.

In a typical profile, the surface layer is light brown, soft, cobbly very fine sandy loam about 6 inches thick. The subsoil is light yellowish-brown, hard clay loam about 14 inches thick. The substratum is limey, very hard, cobbly clay loam. Sandstone bedrock is at depths of 20 to 40 inches.

Drainage is good, and permeability is moderate. Roots penetrate to the sandstone and then spread horizontally. Estimated available water holding capacity is 4 to 6 inches depending on the depth to bedrock. The lowest elevation stands of juniper in the study area were observed on this soil type.

Shaly Colluvial Land (Sn), is a mixture of soil material, cobblestones, and fragments of rock which accumulated on moderately steep and steep slopes and at the bases of slopes, primarily as the result of gravity sliding. This colluvium is variable in thickness, and in some places it is as much as 3 feet thick over shale. As the shale on the slopes of the mesa and benches erodes away, this capping falls and rolls down the slope. From 20 to 40 percent of the surface is shale outcrops. Because of the steep slopes, the lack of precipitation to establish plants, and the unconsolidated nature of the colluvium, moderate to severe erosion is present.

Vegetative coverage is very low, with an average of less than 5%. Species found in these areas tend to be extremely xeric, such as ephedra, rabbitbrush, shadscale and occasionally pickleweed.

Rock Land (Ry)

Rock Land is a miscellaneous soil type having a surface 50 to 70% covered by stones, boulders and outcrops of shale and sandstone. Most of this land type is moderately to severely eroded. Any soil characteristics are almost obscured by the stones and boulders. The slopes are very steep to perpendicular, but typically they lie between 50 and 80%.

Included in mapping were gently sloping, deep fine sandy loam. Intermingled with the sandstone outcrops were inclusions of shallow fine sandy loams. Also included on some of the north-facing slopes were small areas of an unidentified soil.

This land type has almost no value for farming, although some areas have a sparse cover of grass, hardy shrubs, and juniper. This vegetation grows on all exposures, but it is dominant on north and west exposures. Small areas are accessible to livestock and wildlife, but most of the land type is too steep and rocky for grazing.

Made Land (Ml)

Made Land is a miscellaneous land type that consists of areas where the soil has been artificially moved. On the soil map the material was used to fill and cover crevices in the rock formation to extinguish fire in the underlying coal beds. These soils were shallow to sandstone or shale bedrock. The texture of the soil is very fine sandy loam or silty clay loam.

Most of the area has little or no vegetation and is presently of little value for grazing. Where the soil material is very fine sandy loam, the land can be revegetated. The places occurring on shale have silty clay loam texture, high salt content and are very difficult to revegetate. Below are soil attributes used in Figures 37 through 44 :

Figure 37 - Soil Salinity (mmohs/cm)= Measure of salt content
Figure 38 - Soil Reaction (pH)= Acid-Alkali nature of soil
Figure 39 - Permeability (in/hr)= Ability to absorb water
Figure 40 - Available Water Capacity (in)= Measure of water available to plants.
Figure 41 - Erosion (K) Factor = Susceptibility to erosion
Figure 42 - Erosion (T) Factor = Susceptibility to erosion
Figure 43 - Wind Erosion Group = Susceptibility to wind erosion
Figure 44 - Shrink Swell Potential = Factor determining bulk expansion or contraction on wetting

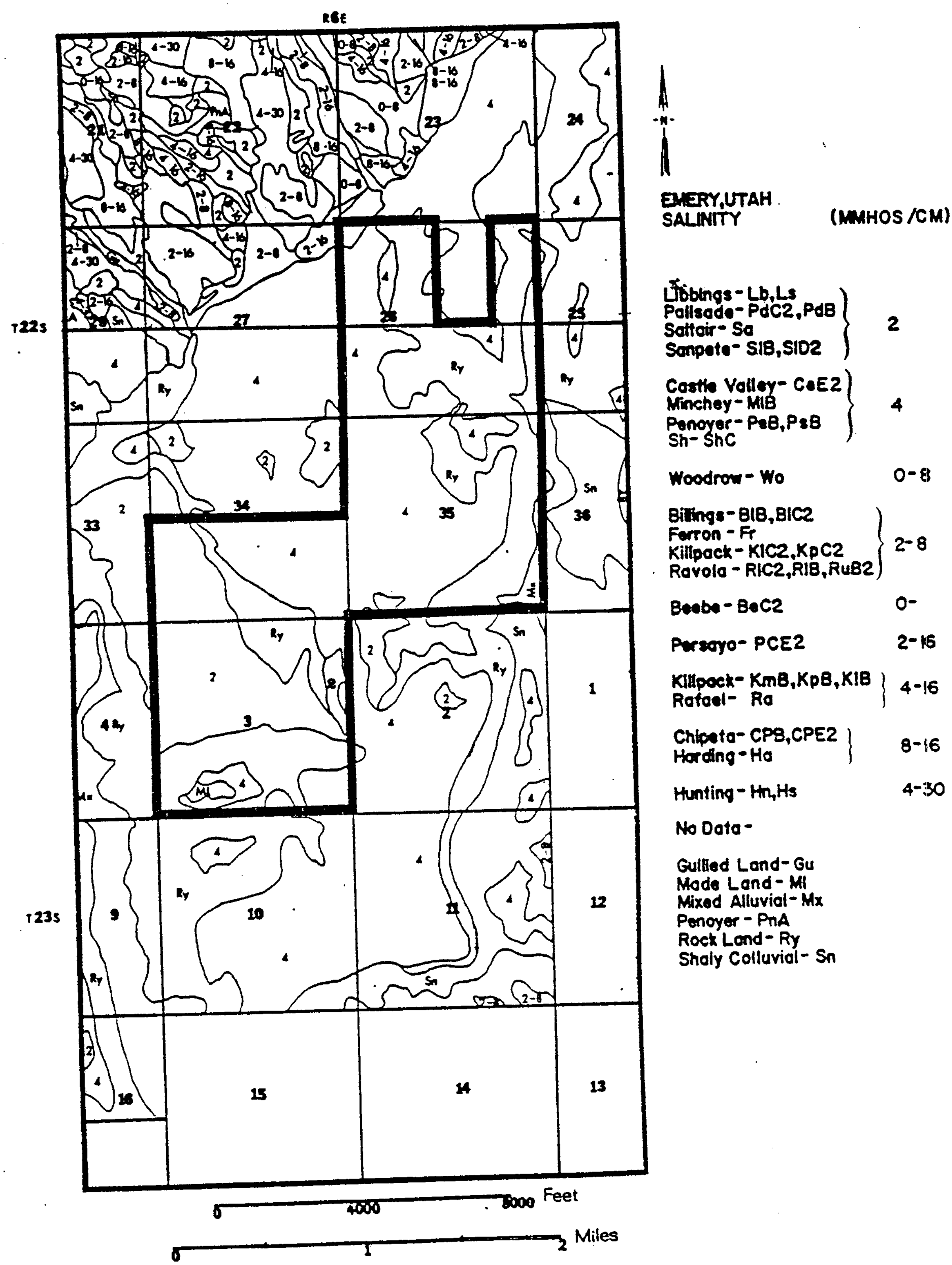


Figure 37. Emery, Utah - Salinity.

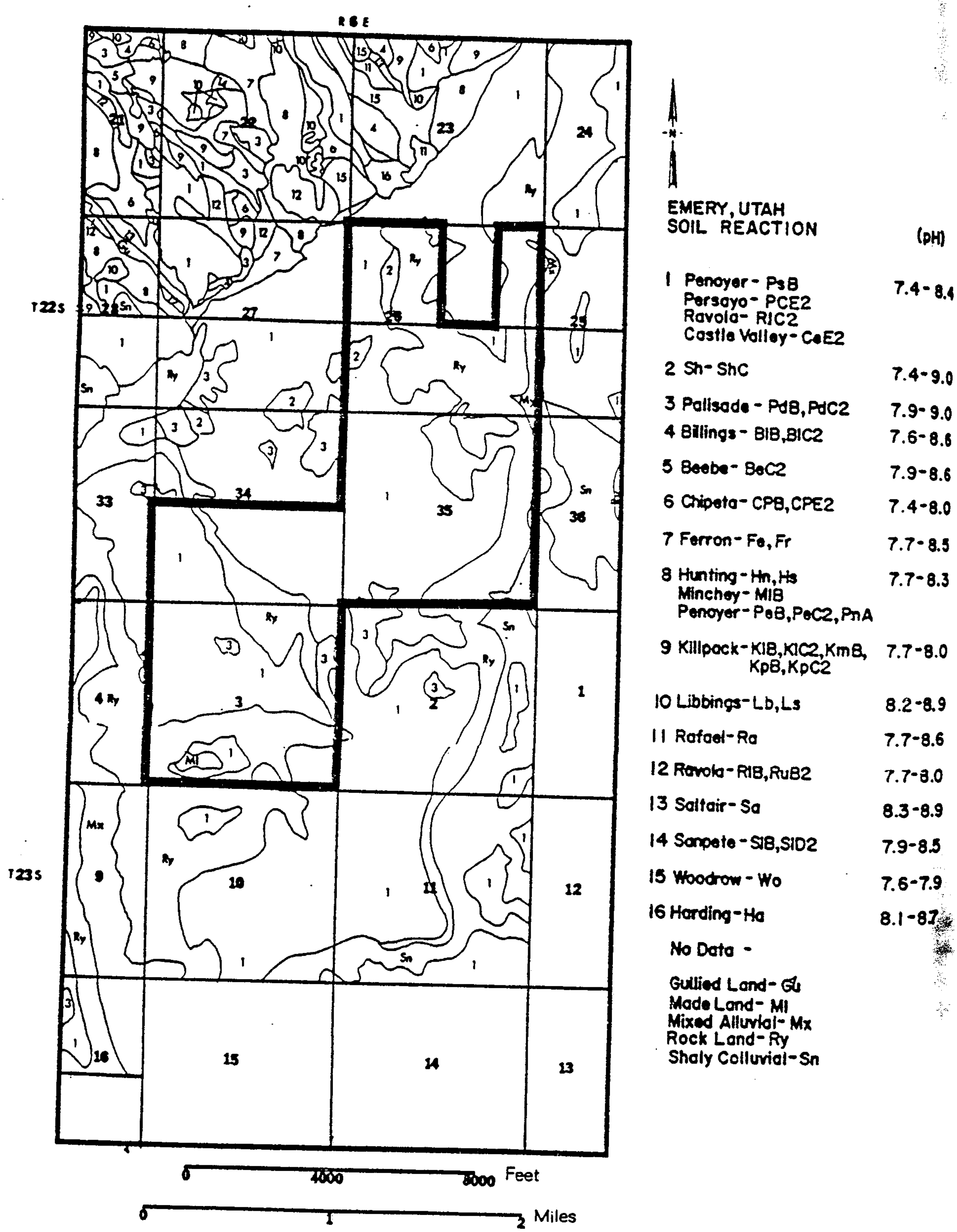


Figure 38. Emery, Utah Soil Reaction

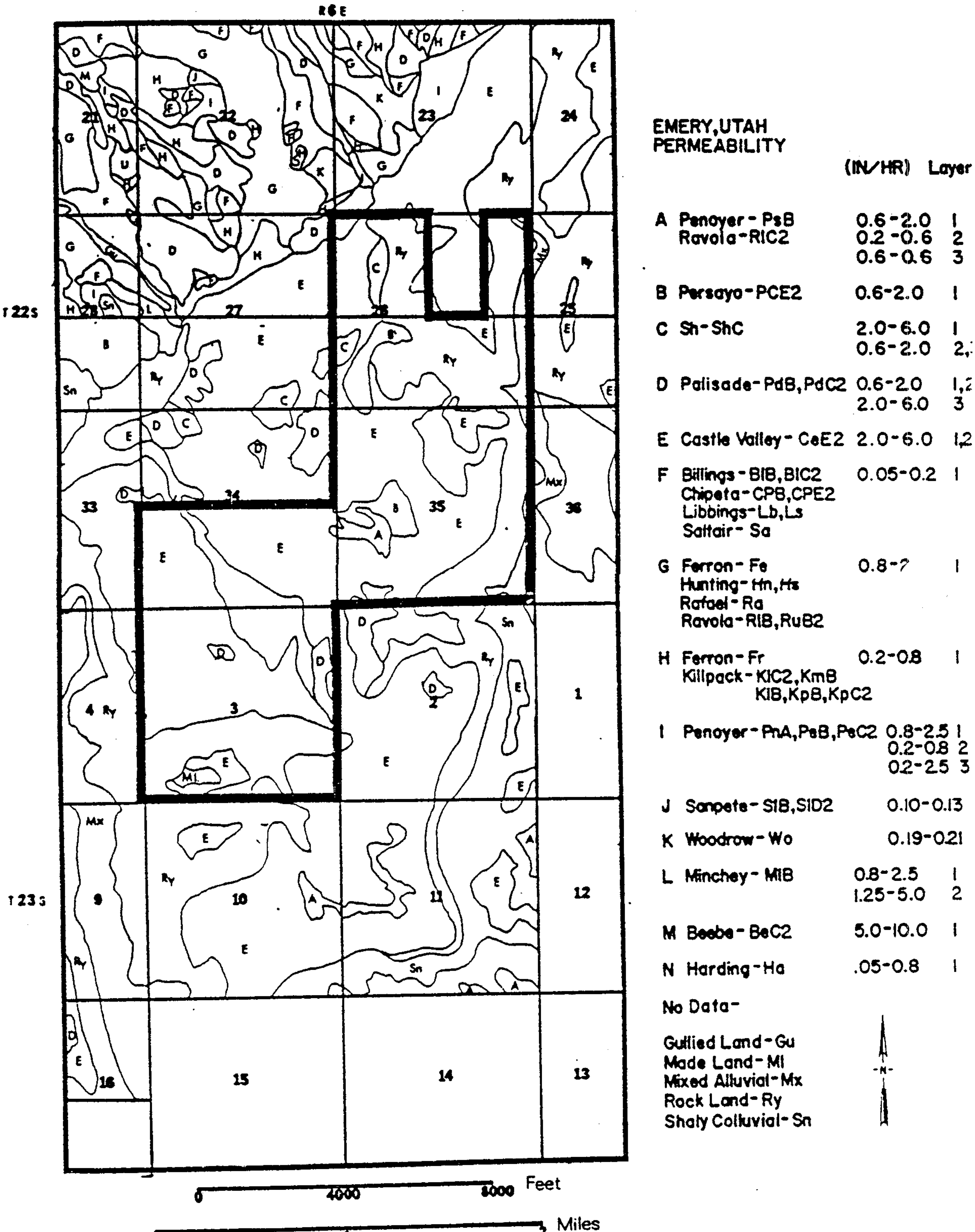


Figure 39. Emery, Utah - Permeability.

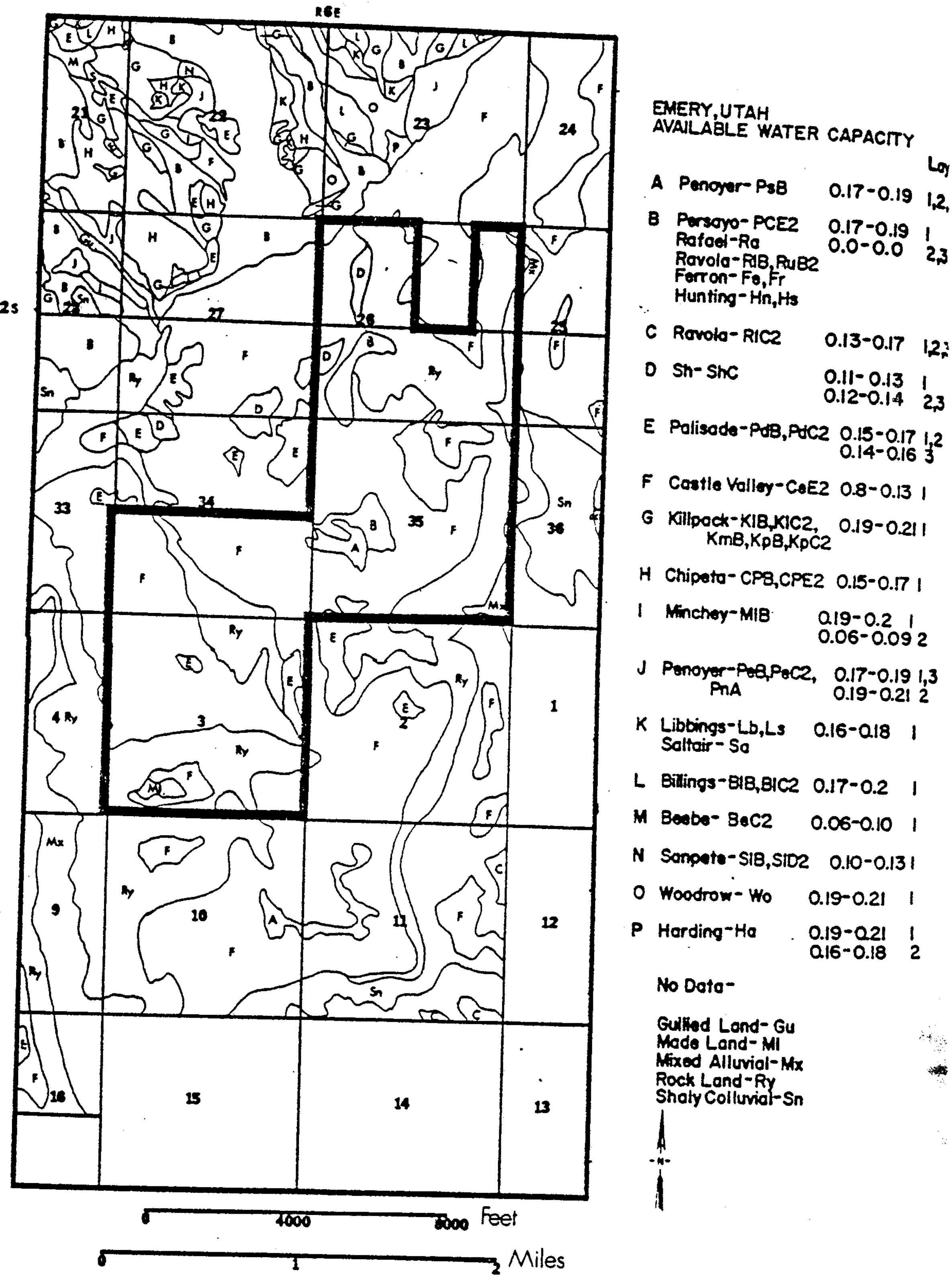


Figure 40. Emery, Utah Available Water Capacity.

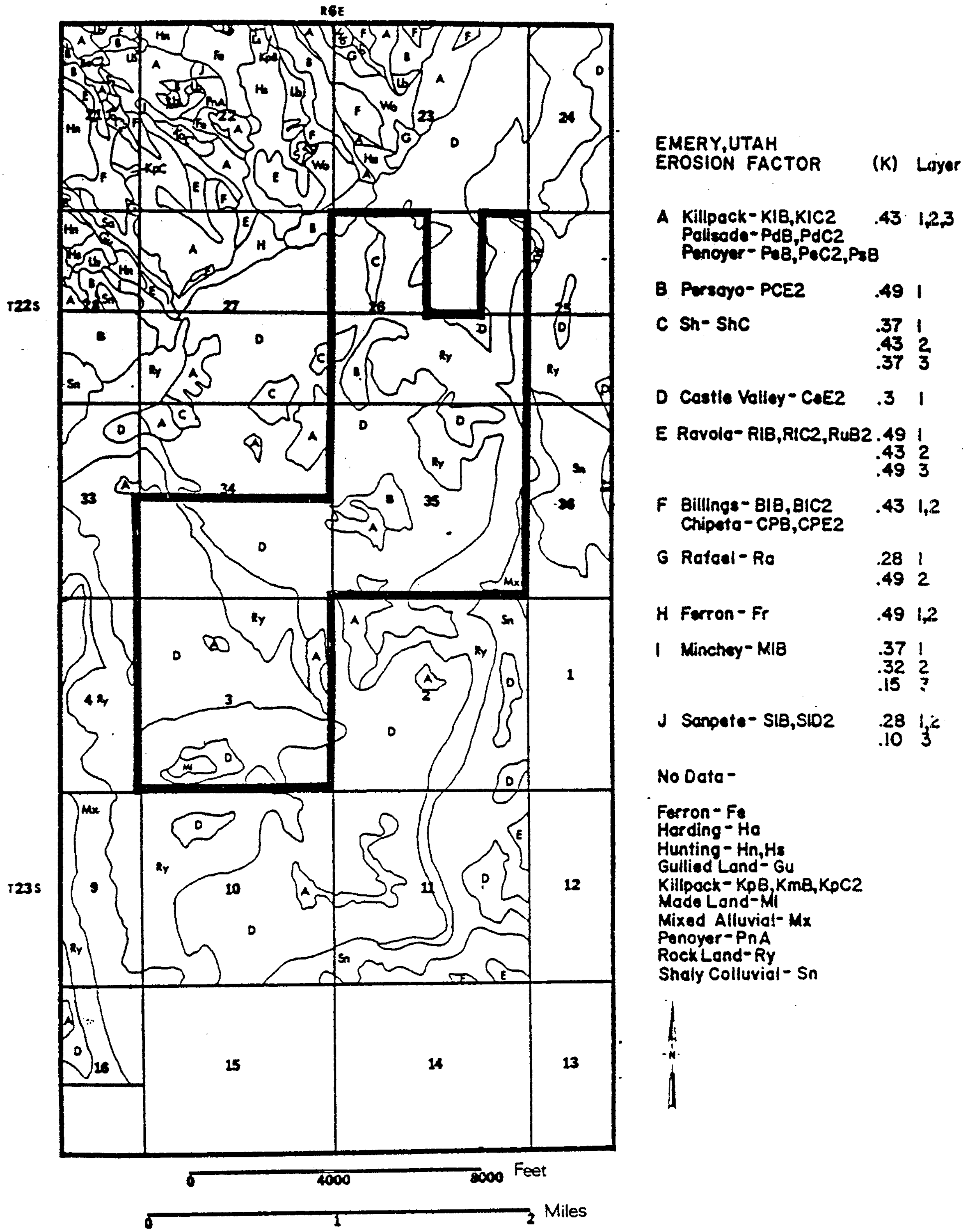


Figure 41. Emery, Utah Erosion Factor (K).

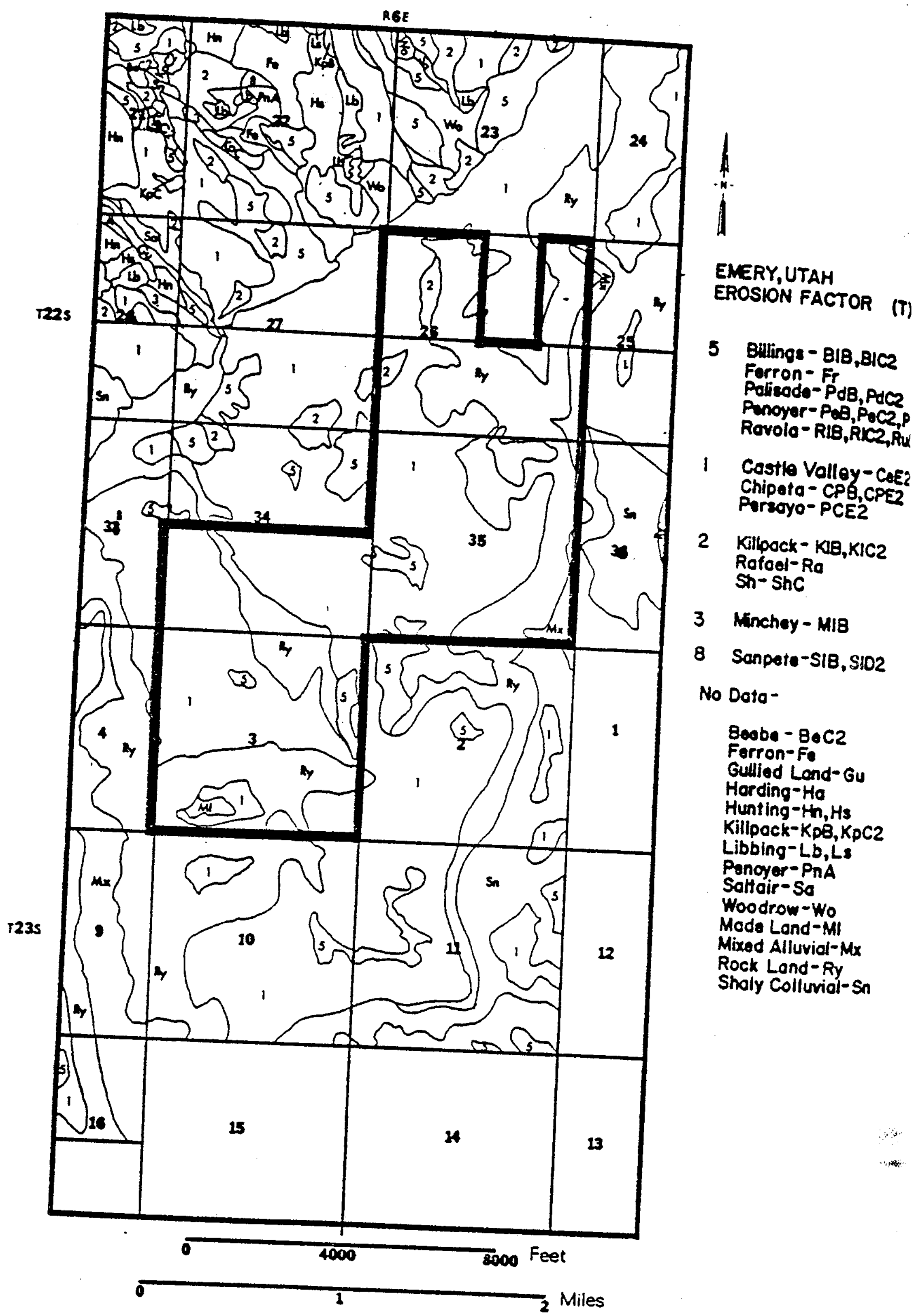


Figure 42. Emery, Utah Erosion Factor (T).

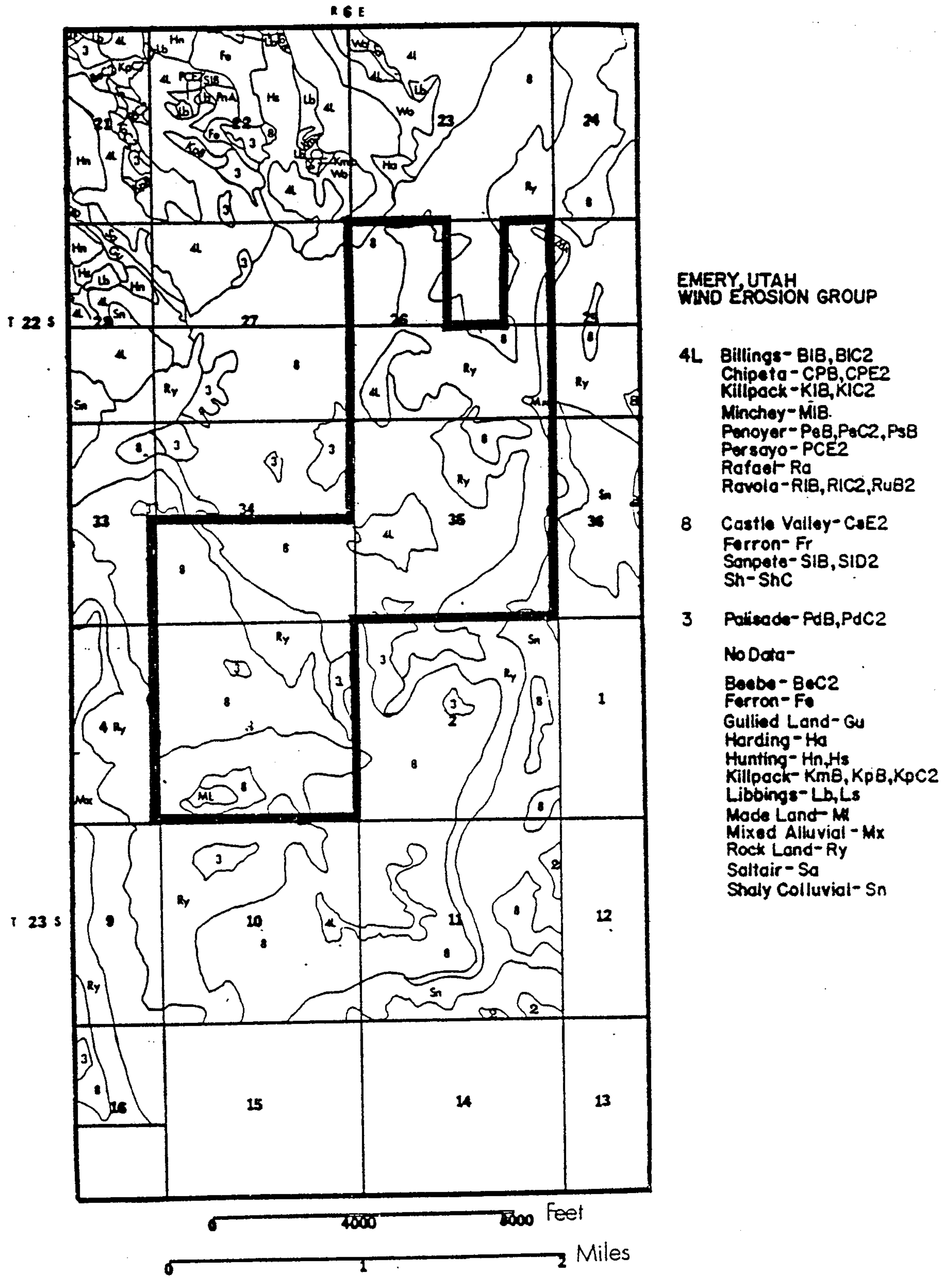


Figure 43. Emery, Utah - Wind Erosion Group.

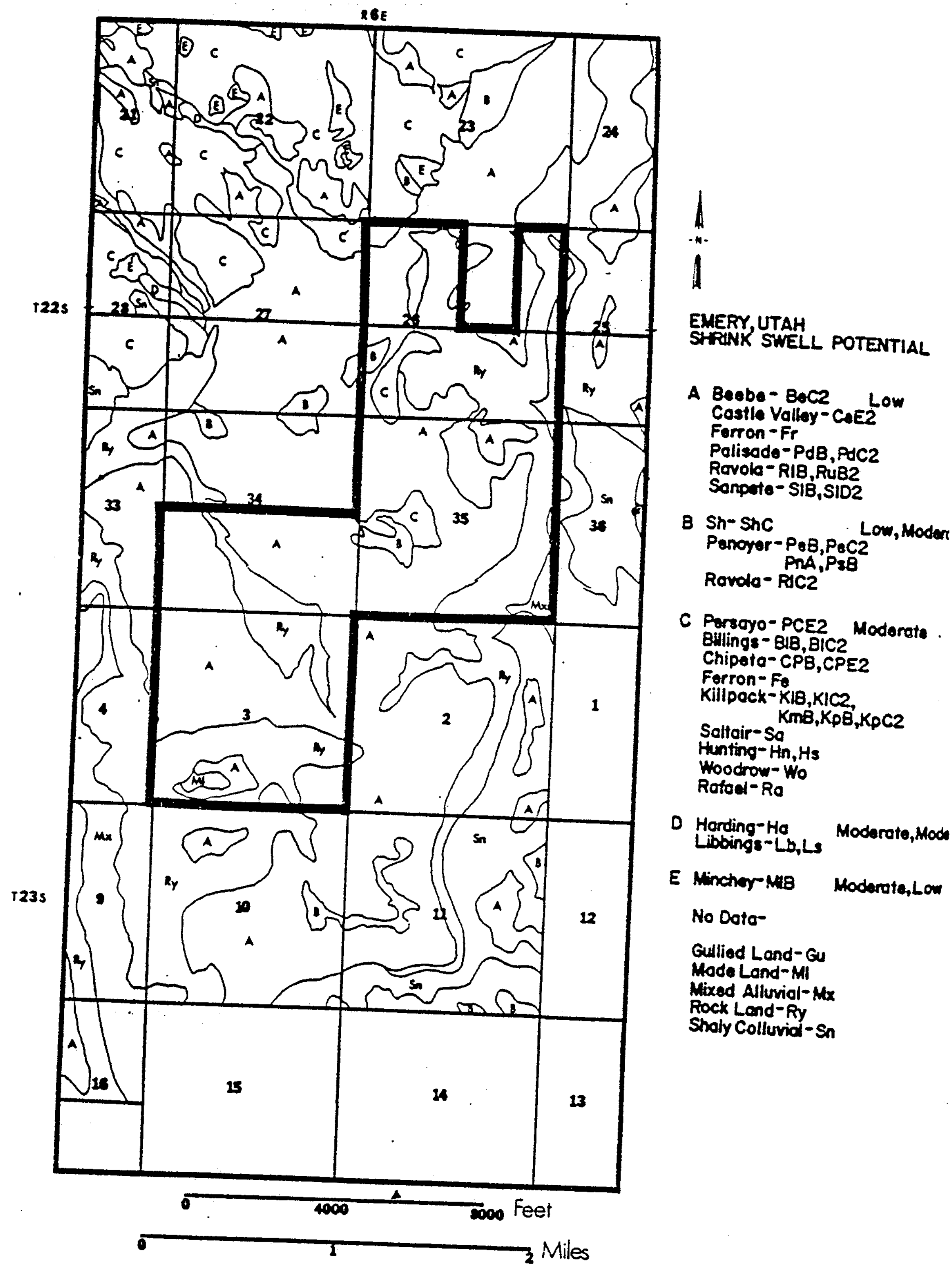


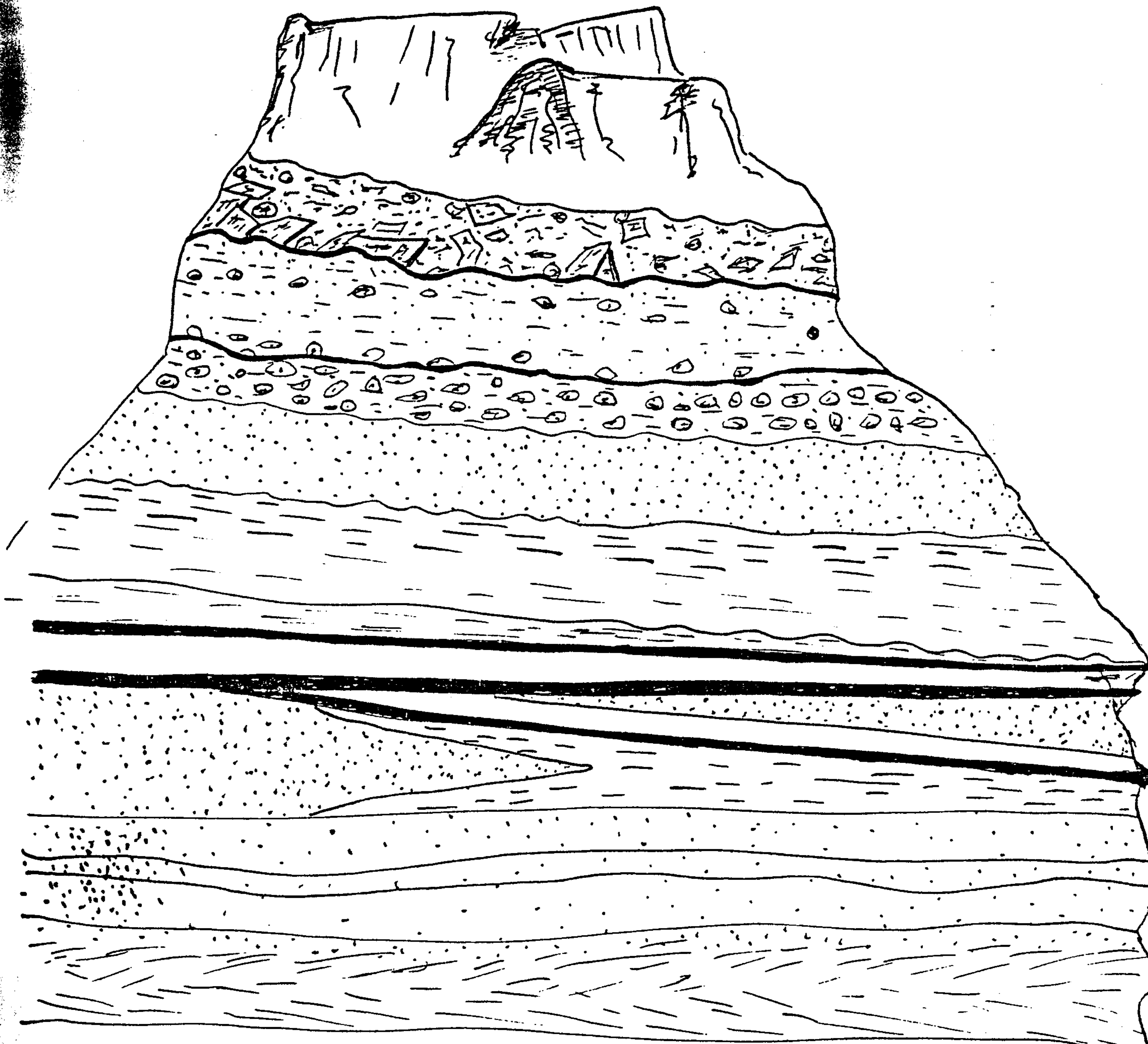
Figure 44. Emery, Utah Shrink Swell Potential

REFERENCES

Swenson, J.L., D.T. Erickson, K.M. Donaldson, J.J. Shiozaki, 1970; "Soil survey of Carbon-Emery area Utah, U.S. Soil Conservation Service, 77p.

Soil Conservation Service, 1978; "Soil survey and interpretation of the Coal Creek-Emery portion of the Price River and Emery County area- Carbon and Emery Counties, Utah, 129 p.

Ulrich, Dr. Rudolph, 1978; "Personal Communication"



OVERBURDEN

This section reviews the physical and chemical properties of the overburden in the test site area relative to their suitability as planting media (topsoil) and subsoil. Analytical techniques and procedures are given in Heil, 1979. The format of this section is a synthesis of the final report by Heil and Deutsch (1979) with data provided by the United States Geological Survey (1977) with emphasis on interpretations by Gough and Shacklette (1976).

Relative to extractable essential elements from crushed overburden materials from boreholes 2, 3, 4, 5, and 6, pH and textural data, (Heil and Deutsch, 1979) identify 77 problem identification categories (Figures 45 & 46) which fell into 42 problem area groups. Conclusions drawn from this study based on over 120 samples submitted from greenhouse tests are as follows:

Much of the overburden (55%) appears to be too saline for use as soil in an arid climate due to the potential for salt accumulation in the root zone. Materials with salinity above 4 mmho's were dismissed from initial greenhouse tests on these grounds. Another common characteristic was found to be high sodium absorbtion ratio. Samples with excess sodium were deemed unsuitable. In addition, many samples (40%) were found to have potentially limiting characteristics for one or more of the following reasons:

1. Nitrogen deficiency is common to nearly all materials.
2. Phosphorous deficiency is common to nearly all materials.
3. Potassium deficiency is common to a large percentage of materials.
4. Micronutrient deficiencies are common. Copper and zinc are most common and manganese to a lesser degree. It is important to note that the criteria used for evaluating micronutrient deficiencies are based on deficiencies associated with agronomic crops sensitive to these elements. Thus, the micronutrient interpretations must be considered somewhat arbitrary. Our main concern would be the effect of low copper in materials where Mo levels may be high. Data provided later in this report indicates that the Mo level is quite low in most materials. Overall, we suspect that micronutrients would not be a major fertility problem.
5. Texture has been identified as being a potential concern with a large number of materials. Low available water holding capacity and fertility would be the major problems associated with

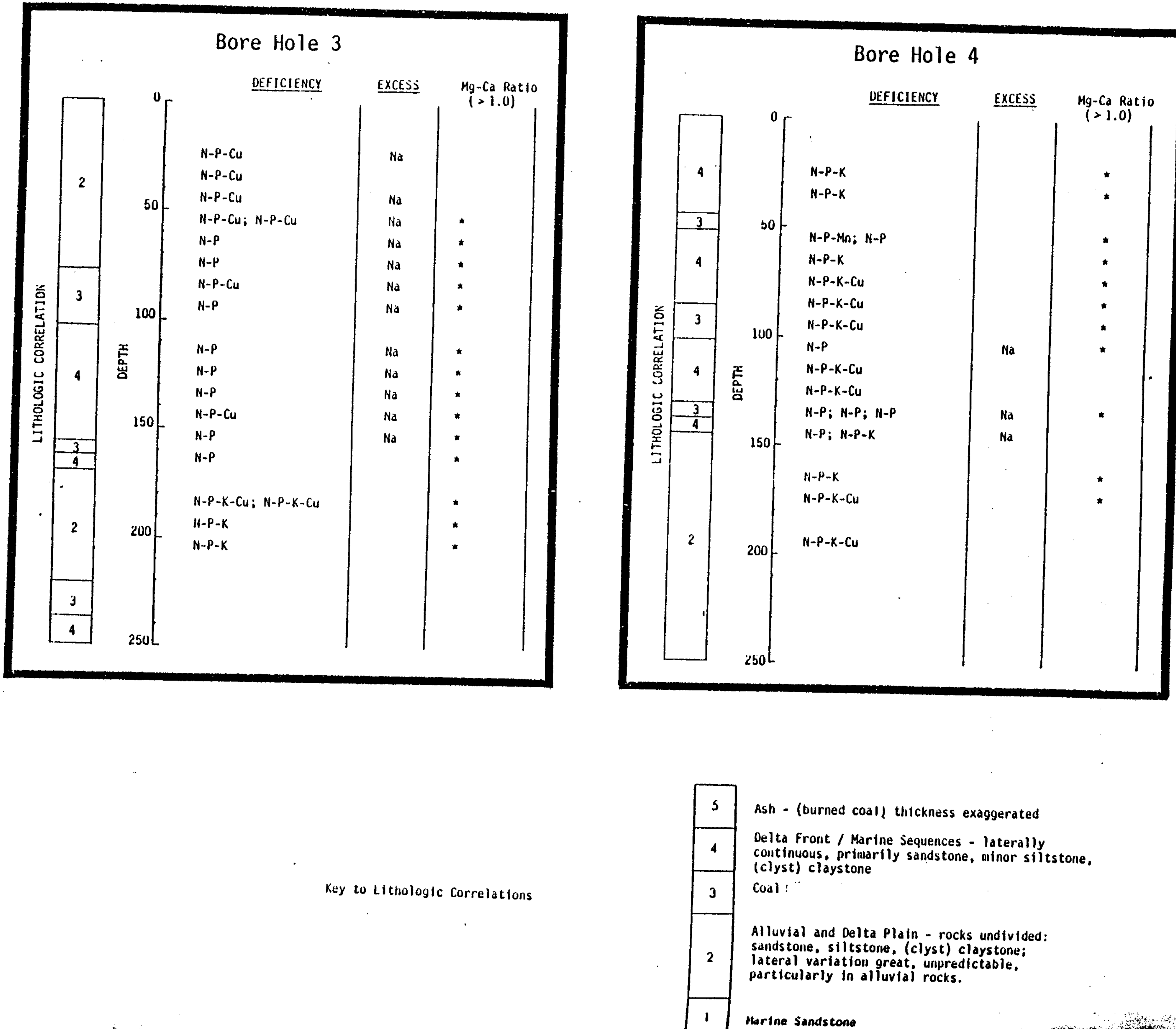


Figure 45. Overburden Growth Suitability in Bore Holes 3 and 4.

Depth	Deficiency	Excess	Mg-Ca Ratio (> 1.0)
0	N-P-K		*
	N-P; N-P-K-Cu-Zn		*
	N-P-K-Cu-Zn		*
	N-K		
50	N-P-Cu; N-P-K; N-P		*
	N-P		*
	N-P; N-P; N-P		*
	N-P; N-P		*
	N-P-K-Mn		*
100	N-P-K; N-P; N-P		*
	N-P-K-Mn	Na	
	N-P-Mn; N-P-Mn; N-P-Mn	Na	
	N-P-Zn-Mn	Na	
150	N-P-K-Cu; N-P; N-P	Na	
	N-P-Zn	Na	
	N-P	Na	
	N-P-K-Cu		
200	N-P	Na	
	N-P-Mn	Na	
	N-P; N-P	Na	
	N-P	Na	
	N-P; N-P	Na	
250	N-P	Na	
	N-P; N-P	Na	
	N-P	Na	
300	N-P-K-Cu		*
	N-P-K		*
	N-P		*
350	N-P-K-Cu		

Bore Hole 6

Depth	Deficiency	Excess	Mg-Ca Ratio (> 1.0)
0			
	N-P-K-Mn; N-P-K-Mn		*
	N-P-K		*
50	N-P-K		*
	N-P; N-P-Cu-Mn; N-P-Mn		*
	N-P-K-Mn		*
	N-P-Mn		*
100	N-P		*
	N; N-P; N-P		*
	N-P-K; N-P-K-Cu		*
	N-P-K		
	N-P; N-P-K		*
150	N-P-K-Cu		*
	N-P-K-Cu		*
	N-P-K-Zn-Cu		*
200	N-P		*
	N-P-K-Zn-Fe-Mn-Cu	Na	
	N-P-K-Fe	Na	*
250	N-P-K		

Bore Hole 5

Key to Lithologic Correlations

5	Ash - (burned coal) thickness exaggerated
4	Delta Front / Marine Sequences - laterally continuous, primarily sandstone, minor siltstone, (clyst) claystone
3	Coal
2	Alluvial and Delta Plain - rocks undivided: sandstone, siltstone, (clyst) claystone; lateral variation great, unpredictable, particularly in alluvial rocks.
1	Marine Sandstone

Figure 46. Overburden Growth Suitability in Bore Holes 5 and 6.

the coarse textured materials. High runoff potential and erosion would be major problems associated with the coarse textured materials. The high runoff potential is a concern both as it affects environmental quality as well as plant growth.

6. Salinity is a serious problem associated with many materials.
7. High sodium concentrations are common to many materials.
8. Excessive boron and selenium levels are common in many samples.
9. High arsenic and nickel concentrations in some samples.
10. Low pH must be considered as potentially limiting because of its relationship to heavy metal solubility. This is a concern both from an environmental and plant growth point of view.
11. Magnesium to calcium ratios. There is evidence that the productivity of some plants is decreased due to a high Mg to Ca ratio in the soil. As shown in the descriptions of the "Problem Identification Categories" in Figure 45, the Mg to Ca ratio in the saturation extract exceeds 1.0 in many materials. The effect of high Mg to Ca on plant growth appears to be a function of the interrelationship of several factors; namely total concentration of Mg and Ca in soil solution, pH of the soil, bicarbonate concentration, salinity and crop species. There is insufficient data available to evaluate this factor at this time, particularly as it relates to the study area.
12. Low cation exchange capacity (less than 5 meq/100gm) suggests low productivity potential.

In summary, deficiencies in nitrogen, phosphorous, potassium and possibly zinc, copper and manganese; sodium; salinity; low pH and texture appear to be the kinds of specific problems associated with the materials studied, in terms of plant growth suitability. The particular problem or combination of problems are defined for each of the "Problem Identification Categories" in Heil and Deutsch, 1979.

The discussion of the chemical and physical characteristics of the Emery core samples is based on the following three tables taken from Heil and Deutsch (1979):

Table A. DTPA-NH_4HCO_3 Extractable B, Pb, As, Se, Al, Ni, Mo, Cd, Sr, Zn, Fe, Mn, and Cu Materials from Bore Holes 3, 4, 5, and 6.

Table B. Geochemical Data for Total and Extractable As, Se, Cd, Cu, Ni, Zn, Mo, Mn, and Fe on Selected Materials.

Table C. Laboratory Characterization Data to Determine Plant Growth Suitability.

Extractable Zn, Cu, Mn, and Fe were determined using a DTPA* extract. All other elements shown were determined from an ammonium bicarbonate-DTPA extract. Data for the materials analyzed are shown on the basis of the "Problem Area Groups". We grouped the materials in this manner in an attempt to determine the relationship between the amounts of the elements considered in this portion of the study vs. the chemical and physical characteristics which were used in determining plant growth suitability. Mean concentration, range and standard deviations of the concentration of each element on the basis of "Problem Area Groups" are also given.

A summary of the extractable geochemical data shown in Appendix 8 gives the following important relationships:

1. The evaluation of materials with respect to effect of moderate to high acidity on the mobility of heavy metals in the environment is well supported by the extractable geochemical data. This factor was identified as a potential problem for materials in Groups 5, 12, 17, 18, 20, 21, 27, 28, 29, and 42. An examination of the data in Heil, 1979, indicates that the extractable Al, Zn, Ni Fe, Mn, and Cu are consistently higher in these groups as compared to materials with an alkaline environment.
2. In general, extractable Se, As and B were higher in the groups identified as having salinity problems. This only confirms our existing knowledge that these elements which usually accumulate as evaporites are often associated with deposits which contain relatively high levels of soluble salts.
3. Potential high Mo availability to plants or mobility in the environment normally is associated with highly alkaline environments. The extractable data indicate that Mo levels are relatively low and do not indicate any potential problem.
4. Standard deviations indicate that for most elements other than those already discussed, there appears to be no consistent relationship between the "Problem Area Groups" and the elements studied.

* DTPA = diethylenetriamine pentaacetic acid

5. In general, extractable Pb levels appear to be higher in materials with low pH. However, this relationship is not consistent. Pb levels appear to be as high or higher in some alkaline materials as compared to the low pH materials. The extractable Pb levels in some materials are higher than what have been reported as the mean total concentration for most soils (10.0 ppm) or geologic materials (5 to 20 ppm). Because of the apparent randomness in Pb concentration as a function of pH and other chemical characteristics, as well as the abnormally high levels in some materials, we must consider that either contamination or error in the analyses have affected the results. We are not sure that the Pb data reflect the real situation that exists. Further evaluations are required to resolve this problem. We suspect that with the method used, that high Al and high Fe may influence the determination of Pb. However, there is no direct evidence from the data that high Pb contents were always associated with high Al and Fe.

In summary, it is important to note that even though extractable chemical analyses data more closely approximate the actual soil solution condition than do total analyses, we must recognize the limitations of the former in terms of predictive capability. Several factors must be kept in mind are:

1. Very little data is available that correlates plant uptake with extractable levels of elements, particularly with regard to native species.
2. The extracant used in this study has a pH of 7.6, thus this effect on the extractability of elements from soil or overburden materials which are acid is not well documented.
3. Most methods, such as the method used in this part of the study, are still being investigated relative to the effects in interferences of various elements on one another and the resulting data.
4. Based on the above considerations, Heil and Deutsch (1979, p. 36) feel that the interpretations are valid. However, to interpret the data further would be risky and may lead to faulty conclusions.

Major Elements of Significance

Nitrogen (N)

Virtually all of the overburden tested were found to be low in nitrogen, as the range was from 5 - 50 lbs/acre (normally referenced to the upper 6 to 8 meters of topsoil). An overall nitrogen content of 40 lbs/acre would be the minimum recommended for reclamation (Goodman, 1973), and since part of the nitrogen in tested samples was not in a form directly used by plants, supplemental N will be needed. Although excessive nitrogen fertilization may not improve the growth of salt desert species, and may encourage noxious weeds which respond quickly to fertilizer (Goodman, 1973) passive soils levels of nitrogen must be raised to at least 40 lbs/acre.

Potassium (K) and Sodium (Na)

Potassium values are variable, with a range from 100 to 400 lbs/acre. Most materials with greater than 200 lbs/acre will have adequate K, unless the soils are excessively acidic or basic. Generally, plants have sufficient K where the pH is in the range of 5.0 - 7.0, but outside this range, plants may suffer from K deficiency (especially poor root development) regardless of the K content because of the preferential assimilation of calcium, which is often plentiful in the soils of arid areas (Heil, 1979). The problem of high alkali content as indicated by sodium is indicated by the number of rejected samples in the greenhouse tests due to salinity (including alkali salts) and SAR values (Table 10). The alkaline nature of local soils is one of the most adverse problems in the soil reconstitution/revegetation phase of this area.

In bore hole #3 the upper 171 feet are in shale where the saturated pH is 8 - 8.5. This excessive alkali content (shown in Figure 47) reaches about 4000 ppm. However, bore holes 4, 5, and 6 are not drilled in Blue Gate Shale. In the upper Ferron Sandstone of bore hole 3 at about 175 feet the delta plain facies are relatively high in alkalies in their upper members but show a decrease to less than 250 ppm. In all other bore holes, the low alkali content is shown in Figure 47. Bore hole #5 for all footage above the I coal seam is in alluvial and deltaic plain siltstones and sandstones. Here, the low alkali siltstones, which range from about 50 to about 500 ppm Na and K, would make an excellent soil dilutant to reduce

Sample Number	Electrical Cond.	SAR	Sample Number	Electrical Cond.	SAR
BH-3-18	11.6	32.2	BH-3-12	5.8	36.4
3-19	4.3	15.9	3-13	9.0	36.2
3-20	10.4	11.4	3-14	6.7	44.0
4-7	2.1	27.3	3-15	6.7	49.5
4-9	6.0	21.1	3-16	9.3	53.2
4-9B	8.9	18.3	3-17B	17.9	39.2
6-25	1.7	15.7	6-22	2.9	17.0
6-37	1.6	16.6	6-24	3.3	19.2
6-4	4.1	40.0	6-27	1.5	17.4
6-30	1.3	16.1	6-29	1.5	18.4
6-31	3.6	39.6	6-35	2.2	18.9
4-16	5.5	2.2	6-36	1.7	16.9
4-8	4.7	2.8	6-41	6.2	49.2
6-28	1.7	13.0	6 46	1.9	20.6
4-12	17.8	0.2	6-47	2.2	23.2
3-8	5.2	28.8	4-17	4.6	2.7
6-49	8.1	13.7	5-3	4.6	4.7
6-56	4.5	0.9	5-13	4.8	1.4
5-14A	4.2	0.9	5-14B	4.4	1.1
5-19	16.2	3.6	6-16	6.4	6.6
6 9	15.2	1.2	6-14	7.0	4.3
4-1	5.5	3.1	6-15	8.6	5.1
4-6	4.8	13.3	6-12	6.5	5.9
4-5	6.0	7.6	6 13	6.4	4.0
4-11	3.2	15.5	6-23	2.5	15.6
5-15	4.4	0.8	3-7	6.4	16.8
6-8	15.2	1.1	3-17	15.5	34.7
3-9	7.8	45.1	6-39	1.8	16.8
3-10	7.2	43.3	6-40	1.8	17.8
3-11	6.9	38.7	6-43	1.2	17.8
			6-45	2.0	27.4

Note: Criteria used for Evaluation:

Salinity

Electrical Conductivity - 0-4 mmho's - Suitable
Electrical Conductivity - 4-8 mmho's - Marginal
Electrical Conductivity - 8 or greater - Unsuitable

Sodium

SAR-0-12 - Suitable
12 or greater - Unsuitable

Table 10. Samples Eliminated from Greenhouse Study doe to Salinity and/or Sodium.

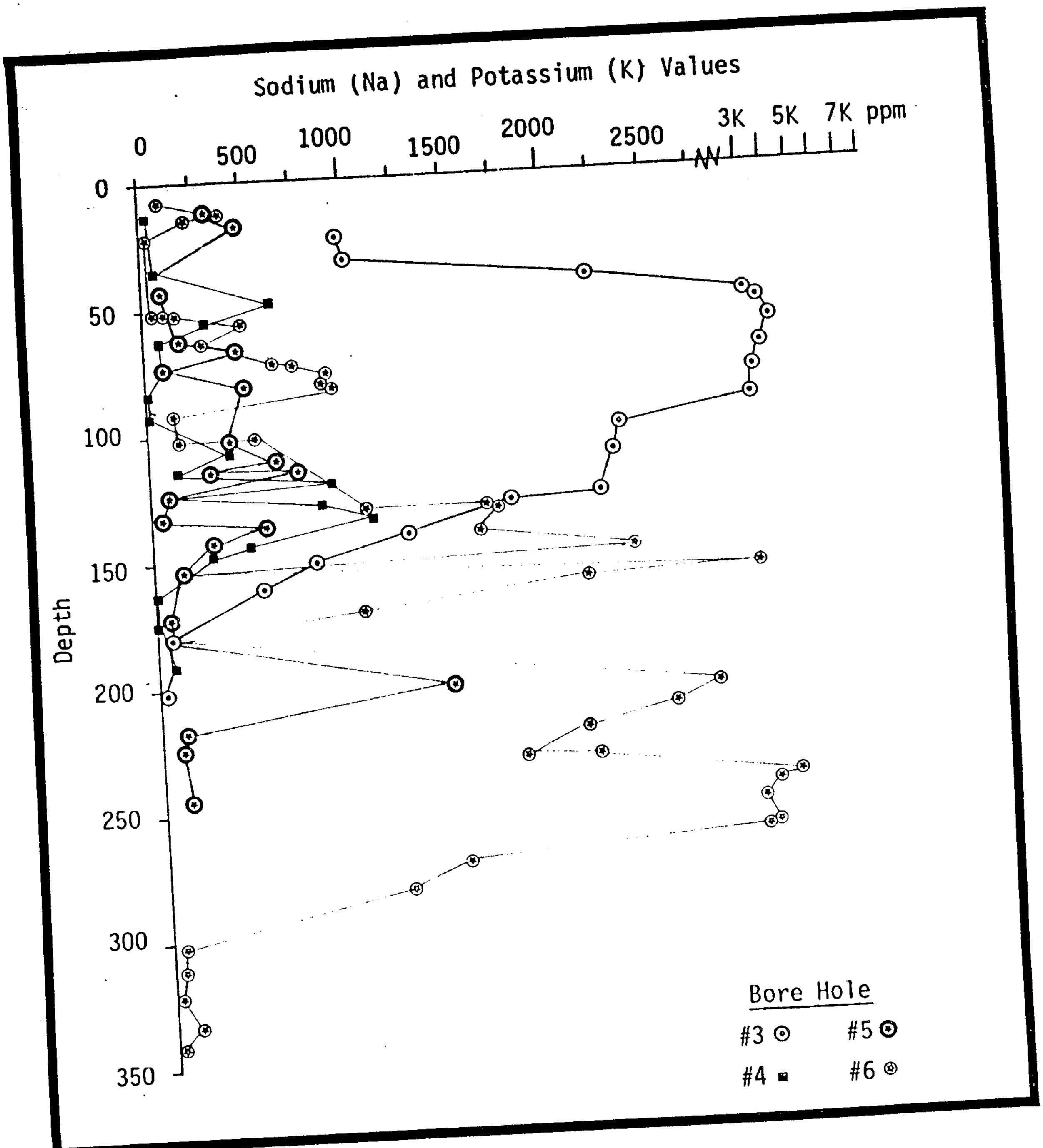


Figure 47. Total Alkalis in EMRIA Bore Hole Samples

alkali values. Bore hole #6 in its lower half (below 150 feet) shows sharp spikes in the total alkali content to levels approaching the Blue Gate Formation of bore hole #3. However, the depth at which these high alkali bore hole #6 levels exist precludes their incorporation into the reconstituted soil and subsoil. In all cases the thickest and purest sand units of the Ferron Sandstone show minimal potassium and sodium concentrations.

Calcium (Ca)

With the exception of a thin anomalous zone at 40 feet in bore hole #3, saturated extractable Ca is below 600 ppm which can be considered a deficiency. The average of Ca in Ferron shales also reflects this deficiency; the average is 2400 ppm, far below that of the average shale which is 22000 ppm. Bore #4A exhibits more variability with some saturated extractable Ca spikes at 125 feet and 195 feet due primarily to a high dolomite content reflected by corresponding magnesium spikes

Magnesium (Mg)

Mg is a major essential element for plants and animals. True toxicity is unknown. Ferron shales are relatively low compared to "average" shale (3600 ppm vs. 16000 ppm). The range of total Mg in 12 Ferron shales is from 1400 to 60000 ppm (Affolter et al., 1978). The range in NH_4 OAC extractable Mg in Emery core samples ranges from 32 ppm to 3630 ppm (sample 27 bore hole #5) with an average well below 1000 ppm. Heil's anomalous sample 27 (Figure 48), which is probably a volcanic ash horizon, is also unusual in its very high Ca, Zn and Cu concentrations and the highest CEC value (of 32.3).

Aluminum (Al)

Because overburden leachates (geologic formations and soil) in the Emery area have a high pH (with the exception of pyritic coal or coal associated shale), aluminum toxicity in plants, livestock and man is considered minimal since its solubility is less than 2 ppm at reasonable soil pH values over 4.9. (Aluminum solubility rises at very high pH values.)

Minor and Trace Elements

A review of the data provided by Heil and Deutsch (1979) indicates that of the minor and trace elements there is some concern with certain deficiencies of Cu, Mn and Zn and possible near toxic levels of B and Se in some samples. We detail the geochemistry of these elements below and provide data on other minor and trace elements of interest (As, Br, Cd, Cl,

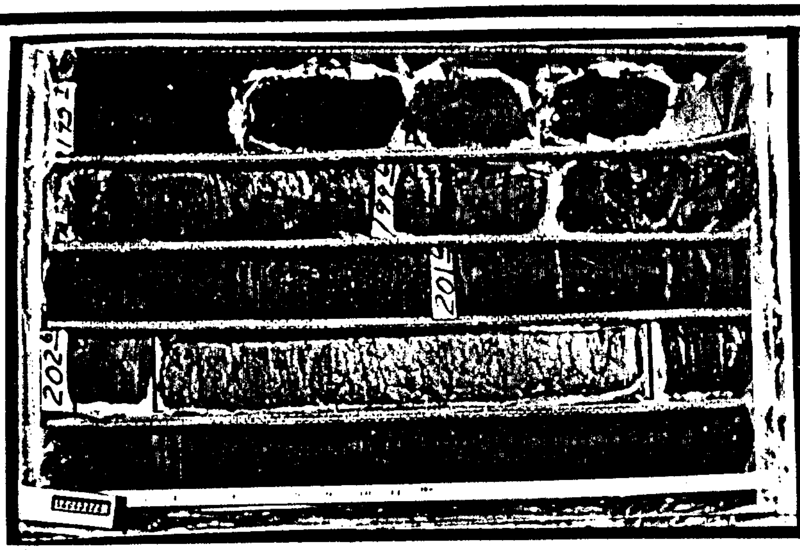


Figure 48. Borehole 5 - Geochemical Anomalous Zone [in brackets], Sample 27 (Heil, 1979)

Footage:

195	7	COAL, blk, competent, tr marcasite on cleat surf, non-calc, brittle
196	6	SS, gry, non-calc, tite
196	10	COAL, as abv
197	7	COAL, shaley, dk gry, w/ COAL stringer @ 199' 7"
199	11	COAL, blk, pure, massive, tr marcasite on cleats, non-calc
201	6	COAL, dk gry, shaley, competent, non-calc trans to
202	8	MUDSTN, lgt cream-brn, incoh, non-calc, crumbly
204	2	Sharp contact, COAL, sft, slickensides, massive
206	4	End Box 20

			ppm				
	7. SAT	CEC	Ca	Mg	Na	Zn	Cu
Sample 27 Mudstone	67.6	32.3	5160	3630	1190	14.50	3.00

Cr, Co, F, I, Pb, Li, Hg, Ni, Tl, Sn, and V) in Appendix 8, bearing in mind that As and Ni are present in sufficiently high concentrations in some samples to warrant concern (Heil and Deutsch, 1979, p. 53).

Boron (B)

Although boron is essential in higher plants, the difference between ideal concentrations of boron in soils and toxic concentrations is only 1 or 2 ppm. Affolter's data for boron are for ashed coal samples and are therefore much higher than whole rock values. Water soluble extractions are best indicated in the water quality analyses (USGS, 1979). Most boron concentrations in the Emery area streams are below 0.5 ppm. For values above 0.75 ppm, in irrigation water, some sensitive crops may begin to show toxicity symptoms (Bradford, 1966). These high (>0.75 ppm) values of boron occur as follows:

Table 11.
Boron Content in USGS Water Samples

Sample	ppm Boron (B)
SRU 5-373 (D-20-8)	.890
(D-22-6) 29-DAC Consol. Mine Ceiling Sample #1	.850
(D-22-6) 30-BDA-1 Blue Gate Well #3	.870
(D-21-7) 4 AAC-1 Blue Gate Well #1	.780
(D-20-8) 22 CAA SRU 5, 413 Seismic Test	1.100
SRU 8-1061 Seismic Test Hole Miller Canyon	2.600
SRU 8-1037 Seismic Test Hole Miller Canyon	1.100

From multivariant cluster analysis of plant growth characteristics, Heil and Deutsch (1979) indicate that boron, salinity, and high alkalinity either alone or in combination caused death of plants in pot tests in cluster 4 and samples 5-19 in cluster 8. The depth interval represented in the sample 4-12 cluster 5 is 93' 6" to 94' 2" and in sample 5-19 is 143' 3" to 143' 9", both below the I coal seam. High (>0.75 ppm) extractable boron values are given in Table 10 and graphed in Figure 49. The toxic level of boron for man is 5300 ppm.

Copper (Cu)

The element is mobile as copper chlorides, nitrates and sulfates. Toxicity to plants apparently occurs only near copper ore deposits.

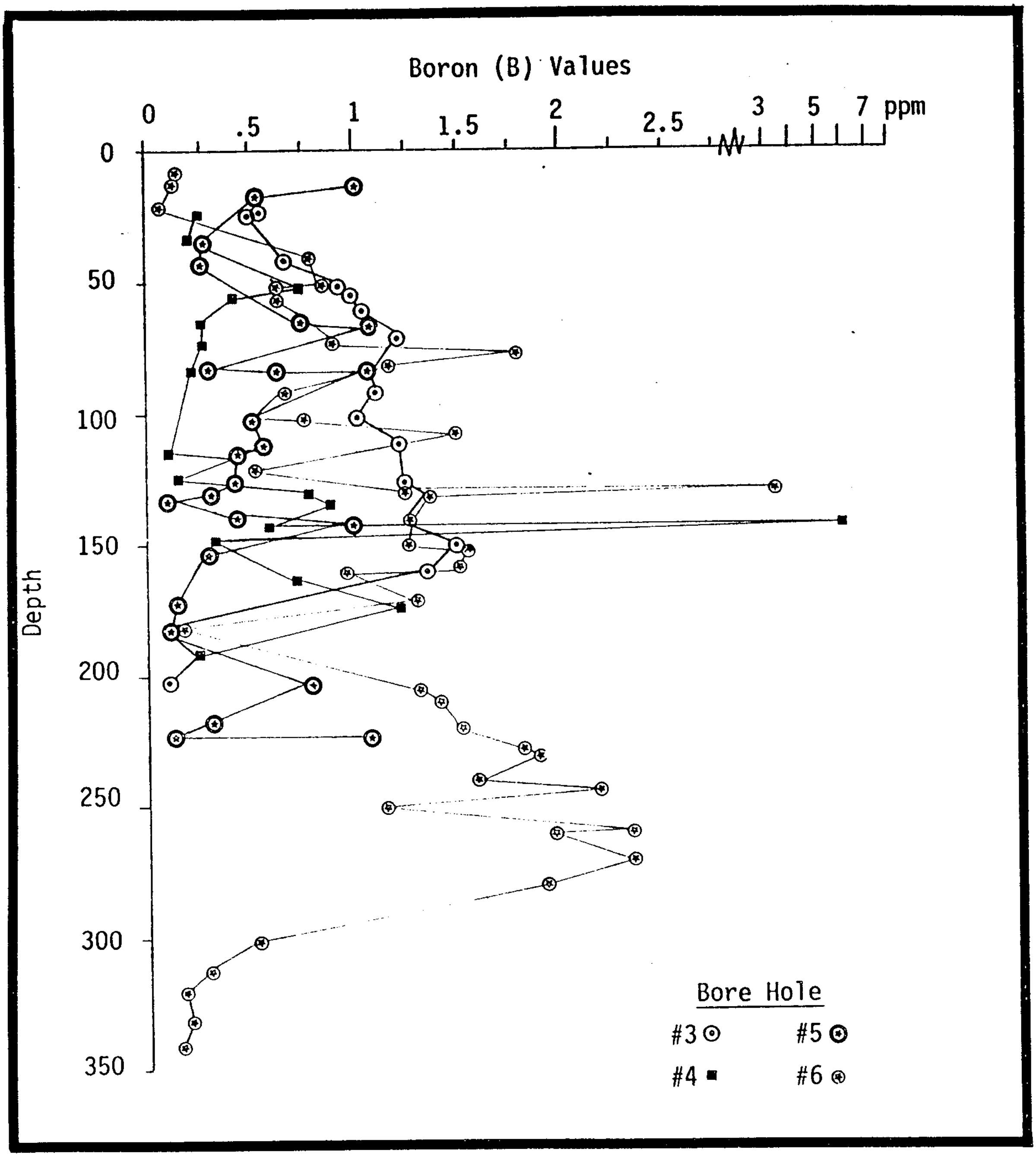


Figure 49. Boron (B) Values in EMRIA Bore Hole Samples

Copper present in herbicides and fungicides can cause adverse effects the concentration exceeds about 150 ppm in acid soil. An outstanding Cu anomaly exists in the upper part of a coal seam at a depth of 130' 11" to 131' 5" in bore hole #6 where a DTPA extract shows a Cu value of 15.7 ppm along with a major anomaly in Zn (21.8 ppm). Most extractable Cu values in cores are below 4 ppm. Heil and Deutsch (1979) cite a general extractable copper deficiency in the samples analyzed. Ashed Emery coal values (Affolter et al., 1978) range from 34 to 140 ppm Cu with an average above that of Wasatch Plateau coal samples.

Manganese (Mn)

As with Mg, Mn is also an essential element for plants and animals but in trace amounts. Only amounts of Mn in excess of about 450 ppm Mn (dry weight basis) in their tissues show toxicity. Extractable DTPA Mn in Emery bore hole samples are all below 21 ppm and most are under 5 ppm. Extractable Mn is therefore generally deficient in most of the crushed core samples analyzed by Heil and Deutsch (1979). Total Mn in Ferron pyritic shales (Affolter et al., 1978) ranges from 16 to 45 ppm with an average of 25, well below that of the "average" shale (66 ppm). A reciprocal relationship exists in the ashed coal from the Ferron Formation versus ashed coal from the Wasatch Plateau (18 versus 7, respectively).

Molybdenum (Mo)

Mo is not a toxic element to plants although above 5-6 ppm in dry forage for cattle and 10-12 ppm in dry forage for sheep, molybdenosis may occur. The problem could be a matter of concern in the Emery area since Mo is more available to plants at high pH. Extractable Mo (by the ammonium bicarbonate DTPA method) is well under 0.1 ppm for most bore hole samples; the maximum recorded by Heil being 0.82 ppm in bore hole #6 (51' 4" to 51' 7") in the upper level of a coal seam. The Emery area soils may be deficient in Mo since the minimum level in plants should be at least 0.1 ppm (Johnson, 1966). Mo is not reported in the USGS (1979) water analyses. Affolter et al., (1978) shows an average for 12 Ferron shales of 5 ppm (Table 12). Even the ashed coal averages from the Ferron Formation are equal to or less than 2 ppm Mo.

Table 12

Arithmetic Mean, Observed Range, Geometric Mean, and Geometric Deviation of Contents of 35 Elements in 12 Shale Samples from the Ferron Sandstone Member of the Mancos Shale, Emery Coal Field, Emery County, Utah.

Element	Arithmetic Mean	Observed Range		Geometric Mean	Geometric Deviation	Average Shale
		Minimum	Maximum			
			Percent			
Si	19	14	22	19	1.1	27
Al	11	6.2	16	10	1.4	8.0
Ca	.24	.09	.56	.22	1.6	2.2
Mg	.36	.14	.60	.32	1.6	1.6
Na	.13	.06	.46	.11	1.8	.96
K	.56	.27	1.5	.50	1.6	2.7
Fe	2.0	.56	4.2	1.5	2.0	4.7
Ti	.40	.22	.59	.38	1.3	.46
			Parts per Million			
As	8.5	0.4	54	2.9	4.6	13
B	70	50	100	70	1.3	100
Ba	150	50	500	150	1.9	580
Be	2	1.5 L	5	1.5	2.6	3
Co	3.8	.5	9.2	2.7	2.6	19
Cr	31	4.7	75	22	2.7	[illegible]
Cu	26	16 L	57	22	1.9	[illegible]
F	430	240	850	400	1.5	740
Ga	30	10	50	20	1.7	19
Hg	.32	.02	1.7	.13	3.9	.4
Li	88	47	170	80	1.6	92
Mn	27	16	45	25	1.5	66
Mo	5	5 L	10	5	1.6	850*
Nb	15	10 L	15	15	1.3	11
Ni	10	7 L	30	7	2.1	68
Pb	30	15 L	59	26	1.7	20
Sb	1.2	.2	2.3	.9	1.9	1.5
Sc	7	5 L	10	5	1.7	13
Se	3.1	2.0 L	4.6	2.9	1.4	.6
Sr	100	20	150	70	1.7	300
Th	23	10	47	20	1.7	12
U	11	2.2	31	8.8	2.0	3.7
V	50	15	100	50	1.8	130
Y	10	10 L	15	10	1.4	26
Yb	1	1 L	1.5	1	1.4	2.6
Zn	56	18	120	47	1.8	95
Zr	150	50	200	100	1.6	160

* This value appears to be in error

(For comparison, average shale contents are included (Turekian and Wedepahl, 1961). All values except geometric deviation are in percent or parts per million and are reported on a whole-shale basis. As, Co, Cr, F, Hg, Sb, Th and U values used to calculate the statistics were determined directly on whole shale. All other values used were calculated from determinations made on shale ash. L, less than value shown.)

Selenium (Se)

The element causes health problems in animals both at low and high concentrations. At optimum concentration levels, Se is an essential element. In soil Se is made available to plants mostly as calcium selenate and organic selenium. Elemental Se and selenite, especially basic ferric selenite, are only slightly available to most plants. Concentrations in Se from shale bedrock to soil plants growing on this soil occur in the following concentration ranges in a known seleniferous area in Canada (Byers and Lakin, 1939):

Bedrock	0.3 to 3 ppm
Soil	0.1 to 6 ppm
Plants	3.0 to 4200 ppm

Selenium values in crushed core samples analyzed by Heil range from 0.06 to 4.7 ppm; values in Ferron shale range from 2 to 4.6 ppm with a comparable range in ashed coal (Affolter et al., 1978). Dissolved Se in stream water (USGS, 1979) is very low (0.004 to 0.06 ppm). <u>Atriplex canescens</u> (fourwing saltbush), used in experiments by Heil and Deutsch, is known to concentrate selenium and can accumulate to levels lethal to livestock (Kingsbury, 1964; Davis, 1972).

Zinc (Zn)

Zinc-rich soils, those with concentrations exceeding 1000 ppm, are distinguished by also having high Pb levels (of over 1000 pp,) but not Cd (Ernst, 1974 p. 3). In the Emery area, the Zn values are generally much lower and for many samples constitute a possible deficiency. However, in some pot tests, zinc levels are high (Heil and Deutsch, 1979) with a positive correlation with Cu. A maximum value (30 ppm) of extractable Zn occurs in the base of a carbonaceous shale (with calcite stringers) overlying a clean siltstone in bore hole #6 at a depth of 81' 6" to 81' 10". Paralelling Heil's observation that extractable soil Zn in most samples is relatively low, the total Zn content of 12 Ferron shales on the average (Table 11) is about half of that of the "average" shale (56 versus 95 ppm, respectively). This relationship is reversed in the coal samples of the Ferron Formation with respect to average Wasatch coal (15 versus 6.9 ppm, respectively). Only three determinations were made of dissolved Zn in stream waters by the USGS and these range from 0 to 0.01 ppm Zn (samples F, I and M of Figure 50).

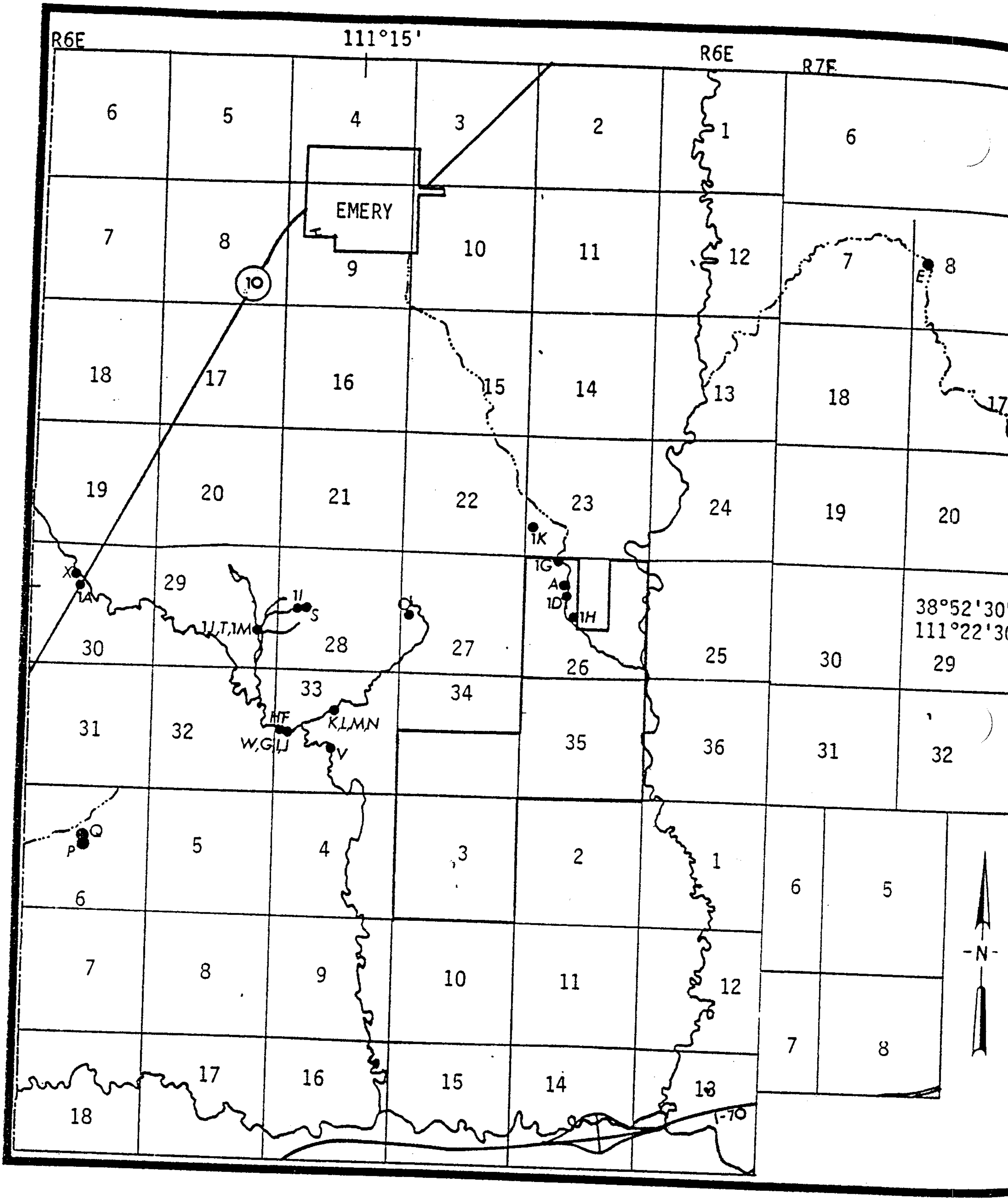


Figure 50. USGS Water Quality Sample Analysis Sites. See Appendix 8 for reference to Sample Stations.

Summary of Toxic, Detrimental and Essential Elements in the Project Area

Several problems have yet to be resolved regarding the interpretation of the geochemical data based on the report by Heil and Deutsch (1979), Affolter et al., (1978) and the USGS (1979) water analyses. The latter did not include many of the elements reported by Heil and Deutsch (1979) and Affolter et al., (1978). The report by Affolter et al., (1978) did not analyze the siltstones and sandstones of the Ferron Formation. This probably does not constitute a serious problem in admixing sandstone in the formation of re-constituted subsoil or topsoil because trace element levels in siltstones and sandstones are generally lower than shales. Finally, the data reported by Heil and Deutsch represent those samples derived from crushed core bedrock samples. This material was not soil and fertilizer was added to the crushed rock for pot tests. Growth results for native species other than western wheatgrass were disappointing (Table 13). The problem of the cause of plant mortality is aggravated because similar pot tests by Heil from the Foidel Creek area did not produce as many deaths. On review of the geochemical data, we note from Table 14 that toxic concentrations either in the water, Ferron shale and crushed core samples are not present. However, detrimental to toxic levels of boron (especially in the lower part of bore hole #6) and deficiencies of manganese, copper, and zinc may occur.

Returning to the problems of admixed fertilizer added to crushed rock in pot tests, we are concerned with a lowering of pH by this fertilizer. Since Emery crushed rock (with the exception of pyritic and carbonaceous shale zones) are generally alkalic, a reduced pH would tend to mobilize whatever potentially toxic elements may be present. Under conditions of high pH, most toxic metals from insoluble carbonates and hydroxides. We recommend analysis of extractable toxic elements from leachates before and after addition of fertilizers.

Based on the evaluation of major, minor and trace elements, four possible overburden configurations might be considered. First (Figure 51), we recommend an adequate clay seal above the Ferron siltstones after the I coal seam is removed. A permeable coarse rock layer should be placed on top of this seal. Above this a reconstituted subsoil should be added.

Table 13

Growth Results Obtained in Greenhouse from Kochia, Fourwing Saltbush, Scarlet Globemallow and Alkali Sacaton. (after Heil and Deutsch, 1979 p. 67)

Greenhouse Pot No.	Species Grown	Western Wheatgrass Performance	Other Native Species Performance
8	Alkali sacaton	Good	Good
5	Globemallow	Good	Poor-germinated after 6 weeks
7	Fourwing salt brush	Good	No germination or growth
23	Kochia	Good	No germination or growth
25	Alkali sacaton	Poor	Poor germination and growth
26	Globemallow	Poor	No germination or growth
27	Fourwing salt brush	Poor	No germination or growth
28	Kochia	Poor	No germination or growth
29	Fourwing salt brush	No growth	No germination or growth
13	Globemallow	No growth	No germination or growth
17	Kochia	No growth	No germination or growth
15	Alkali sacaton	No growth	No germination or growth

Table 14

General Characteristics of Overburden
Major and Trace Element Content

Element	Essential: Acceptable Level	Essential: Possibly Too Low	Essential: Possibly Too High (detrimental to toxic)	Non-Essential: Acceptable for Plants	Non-Essential: Possibly Too High (detrimental to toxic)
Al				X	
As				X	
B			X		
Br	X				
Cd				X	
Cl	X				
Cr				X	
Co					
Cu		X			
F					
I					
Pb				X	
Li				X	
Mg		X			
Mn		X			
Hg					
Mo	X				
N		X			
Na			X		
Ni					X (?)
P		X			
K		--- Variable ---			
Se					X (?)
Tl				X	
Sn				X	
V				X	
Zn		X			

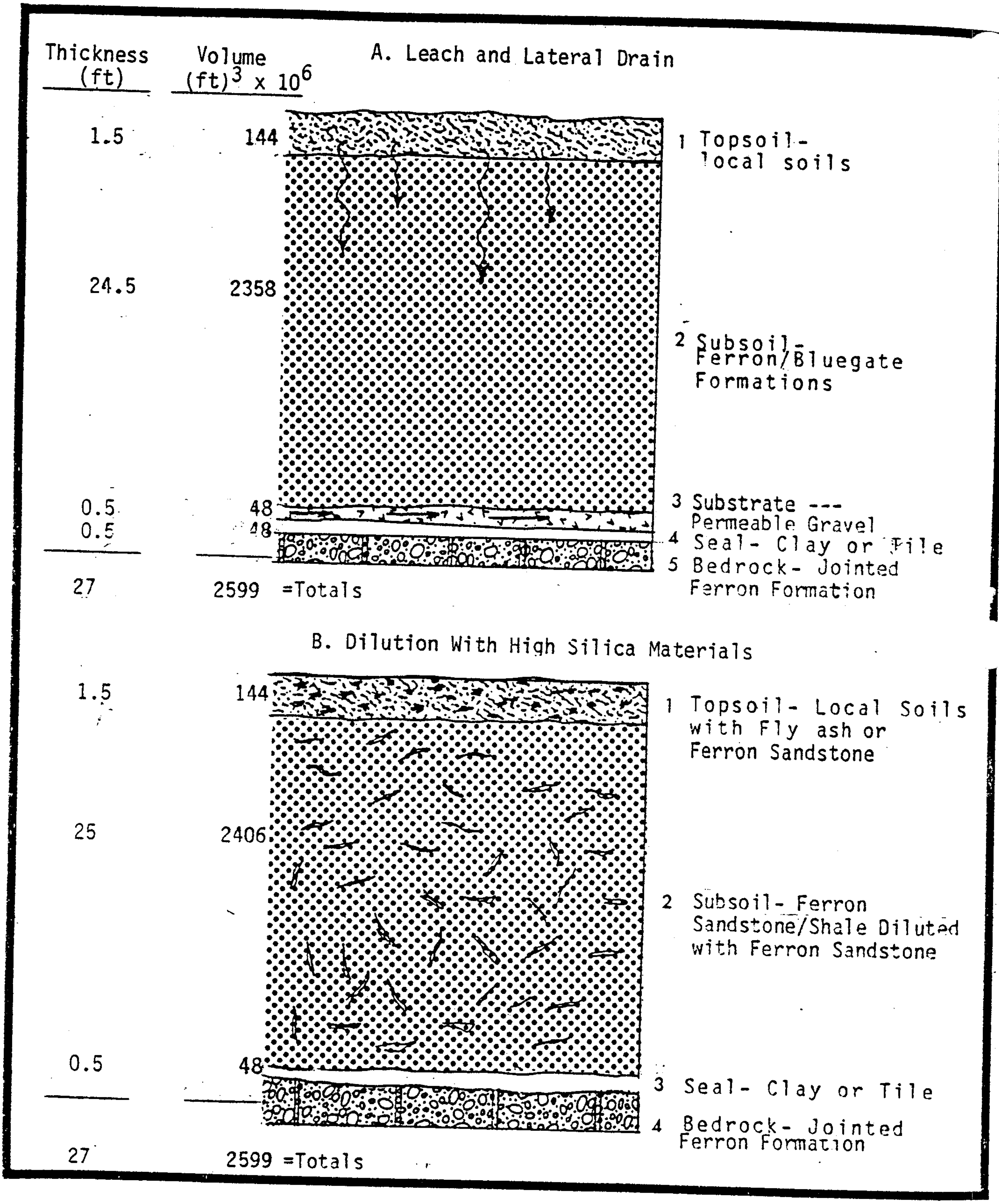


Figure 51. Alternate Overburden Configurations for Optimum Revegetation. Present Thickness of Weathered Zone (Based on Drilling Water Loss Logs) is 45-48 Feet.

Finally, a three foot topsoil layer is recommended. If boron is present, we will assume a slow growth rate until sufficient leaching and removal of boron in the coarse rock substrate can take place (Figure 51). In the case of mobilized toxics, accelerated downward leaching may be achieved by addition of fertilizer to the topsoil.

The second action does not involve a leach and lateral transport by a gravel substrate above the clay seal. Instead, we suggest dilution of the reconstituted overburden and topsoil by admixing either Ferron sandstone, Quaternary windblown sands (Qca of Figure 18), or fly ash (Figure 51). Fly ash admixture which must be quantitatively evaluated, would qualitatively provide the benefits shown in Table 15.

Table 15

Advantages of Fly Ash Soil Dilution

1. Dilute (lower) the alkali content
2. Increase the sulfur content and therefore
3. Lower the soil pH
4. Increase the calcium content
5. Possibly raise the zinc and copper contents
6. Dilute the boron content
7. Increase the soil moisture retentivity and soil/plant root moisture accessibility

The amount of fly ash generated by the Emery coal fired power plant is 780 tons/day. Most fly ash is mildly to moderately alkaline so that this waste product can substitute for limestone in strip mine spoils neutralization. The neutralizing capacity of fly ash derived from bituminous coal ranges from 15 to 200 tons of fly ash per ton of $CaCO_3$.

In addition to neutralizing power, fly ash, admixed with spoil, effects favorable physical changes of the mix, which improves plant growth (Doyle, 1976, p. 134) Since the density of the mix is reduced by admixture of the fly ash, the pore volume, moisture availability, and air capacity increase. These factors improve root penetration and depth.

If trucks hauling coal away from the strip mining area can return with fly ash loads from the power plant site, possibly low cost stockpiling of this product at the strip site would be achieved. The ashed samples of coal analyzed by the USGS (1979) suggest that nutrients are present which might enhance plant survival if fly ash is added to the spoil (Table 16). We suggest pot test on soil mixes with fly ash to quantify optimum mixtures.

Table 16

Chemical and Screen Analysis of Fly Ashes (after Doyle, 1976, p. 133)

	Fly Ash 1	Fly Ash 2	Fly Ash 3
pH	11.40*	9.1 - 10.6	11.90
Bulk density, g/cc	1.12	0.93	1.15
Chemical analysis, wt pct			
Aluminum (Al_2O_3)	23.90	23.90	23.60
Silicon (SiO_2)	46.30	42.20	47.70
Iron (Fe_2O_3)	22.90	24.00	15.60
Phosphorous (P_2O_5)	.30	.20	.60
Titanium (TiO_2)	.90	.80	2.70
Calcium (CaO)	1.90	4.00	3.50
Magnesium (MgO)	.80	1.20	1.50
Potassium (K_2O)	2.20	2.20	2.20
Sodium (Na_2O)	.60	.60	1.90
Cobalt	.02	.02	ND**
Boron	.008	.02	ND
Manganese	.03	.05	ND
Copper	.02	.02	ND
Molybdenum	.007	NT***	ND
Carbon	5-7	12.4	1.54
Sulfur (total)	.24	.51	.34
Screen analysis, wt pct			
+60 mesh	2	2	1
-60+100 mesh	5	3	2
-100+150 mesh	4	4	2
-150+200 mesh	8	7	4
-200 mesh	81	84	91

*pH of fly ash used at site 1 was 11.4; when used the next year at site 2 the pH had dropped to the range of 4.4 to 9.5

**Not determined.

***Not detected.

Chemical and Physical Characteristics of Soil and Fly Ash

Sample	Organic Matter (percent)	pH	Effective $CaCo_3$ (pounds/acre)	Available P (pounds/acre)	Exchange K (pounds/acre)	CEC (meq/100 g)	Bulk Density (g/cc)	Field Capacity (percent)	Texture Sand (percent)	Texture Silt (percent)	Texture Clay (percent)
Soil A	1.7	4.8	7,500	50	257	12.7	1.18	20.6	28	72	0
Soil B	1.5	3.1	20,000+	190	93	14.1	1.19	27.5	22	74	4
Soil C	2.2	6.3	3,000	34	252	14.1	1.18	24.1	22	74	4
Fly ash	–	7.7	–	42	1,000+	–	1.48	17.0	46	52	2

A final advantage to the use of fly ash in soil dilution is to reduce permeability caused by overburden swelling.

When large volumes of rock are dug up and subsequently replaced as fill, the new ground surface may be higher than the original surface depending on the thickness of coal removed. This phenomenon is called overburden swelling and may provide as much as a 20% increase in apparent volume of the fragmented rock. Thus if stripping occurs to 100 ft. depth, we might expect a 20 ft. overburden swell. This should be distinguished from ground swell due to the expansion of wetted clays (i.e. the soil shrink-swell potential in Figure 44). Overburden swelling is due to the fact that broken rock fragments cannot be packed as tightly as the original rock. As a result the replaced rock has a significant amount of void space filled with either air or water. Its permeability, or ability to transmit fluids, is likewise increased. The increased access of these weathering elements, coupled with the increased surface area of the rock exposed to them, allows leaching to occur at an advanced rate. Since harmful materials may be present in the Emery overburden rock, contamination of local streams, or shallow aquifers may result unless the formation is sealed.

In addition to leaching problems, the raised ground level and/or changed contour may pose revegetation problems, aesthetic conflicts, and instabilities. Differential settling may occur over some extended time. Drainage patterns can also be changed due to the presence of the overburden swell. Surface water runoff will decrease due to increased infiltration and ground water recharge. Fly ash dilution can minimize these problems.

The third overburden configuration (Figure 52) is that conceived by the Department of Energy's Pacific Northwest Laboratory, which uses water runoff for irrigation. The method eliminates the need for major recontouring of mining debris and the need for irrigation to maintain plant cover.

In research sponsored by DOE's Biomedical and Environmental Research Division, Dr. Ronald J. Sauer is studying the possibility of using the steep slopes of spoil piles to collect rainfall for growing marketable

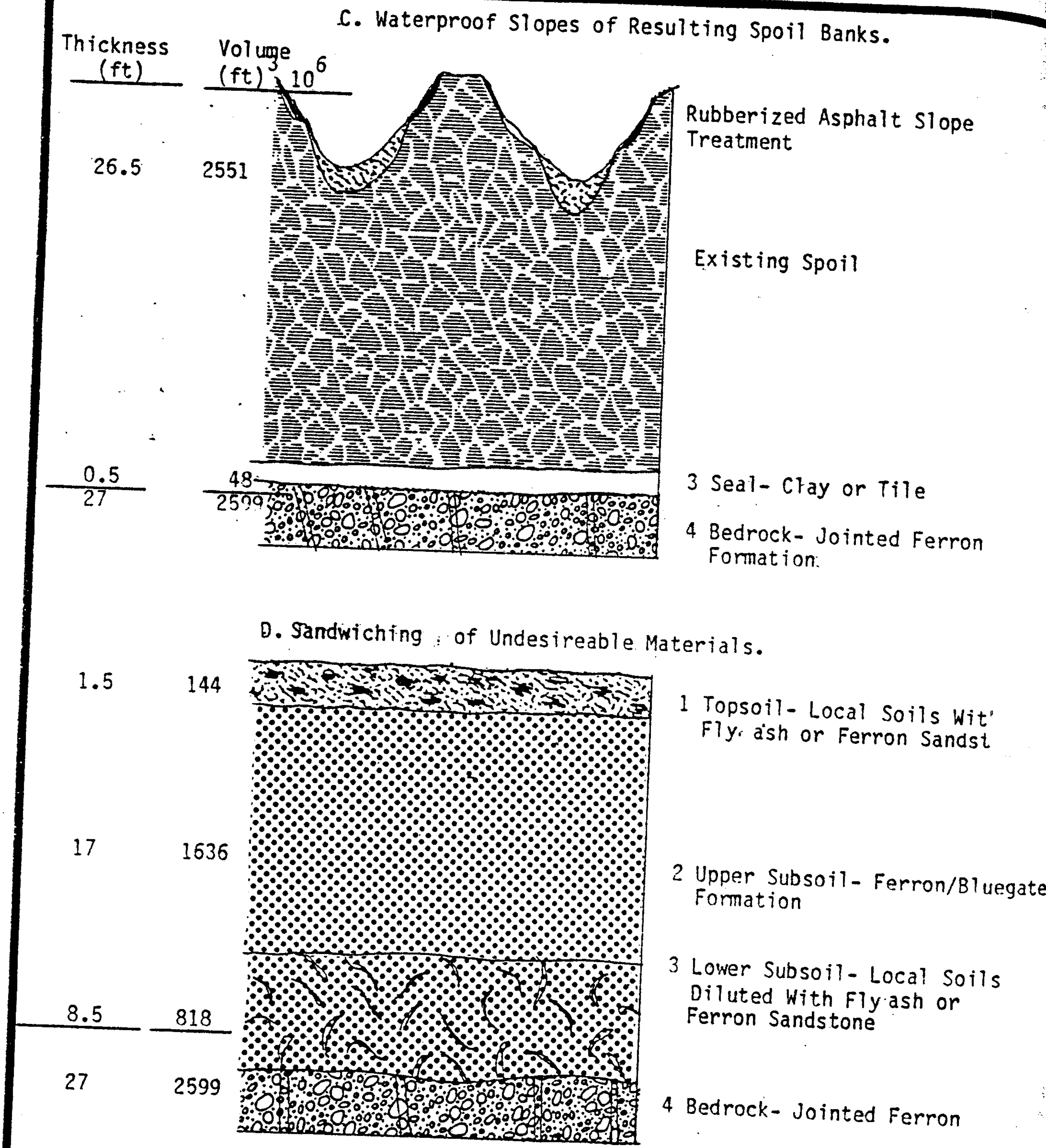


Figure 52. Alternate Overburden Configurations for Optimum Revegetation. Present Thickness of Weathered Zone (Based on Drilling Water Loss Logs) is 45-48 Feet. Concept C. after Sauer (1979), Concept D. after Hinkley (1979).

crops in arid regions.

The method requires minimal recontouring of the spoil banks, with only the tops and sides smothered. Soil spread in the narrow valleys between the banks is seeded with marketable crops, such as winter wheat or grapes. Irrigation is supplied by rainfall, which runs off the waterproofed slopes of the spoil and concentrates in the valleys.

In this way, three-fourths of the land collects moisture for cultivating the other fourth - an important step in arid areas where precipitation is scarce. One inch (25mm) of rainfall becomes 4 in. (100mm) of moisture in the cultivated valleys, offsetting the need for expensive irrigation systems.

A current research objective is to develop an effective, long-lasting, and economical slope treatment. Rubberized asphalt, a combination of ground-up tires and asphalt, is the best treatment tested so far, he notes. A paraffin wax treatment, sprayed on the hillside in a molten state, is also being studied.

Dr. Sauer is also considering treating slopes with salt. A demonstration site, located in Washington's arid Columbia Basin region, is composed mainly of sand and rock. However, in most strip-mining areas of the West, typical spoil has a high clay content. Salt cements clay particles together to produce a virtually waterproof surface. Dr. Sauer hopes to try this method in a new demonstration site being planned for the Black Mesa area of the Southwest.

The fourth alternative (Figure 52) is simply to sandwich the undesirable spoil in between a modified topsoil and a "clean" lower subsoil above accessable aquifers. In this case if the lower subsoil is admixed with fly ash (to reduce permeability and boron/alkali content) the requirement for a clay seal above the permeable Ferron sandstone units might not be neccessary (personal conversation, T. Hinkley, May 11, 1979).

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VEGETATION

VEGETATION

Throughout the Central Utah Region, precipitation is the principal factor controlling the distribution of major vegetation types. Although the Emery study site lies at more than 6000' elevation, it lies in the rainshadow of the Fish Lake Mountains and receives only 7-8" annual precipitation. The severity of the arid climate is accentuated by the seasonal rainfall distribution, which peaks in July-August when air temperatures and evapotranspiration potential is at a maximum. Consequently, the precipitation is less available for use by plants. Another result of the arid conditions is high soil salinity which is produced by the upward migration of ground water towards the land surface where it evaporates, leaving salts in the upper soil horizons. Much of the area consists of tablelands with steep talus slopes and unweathered rock debris around the perimeter of the benches. Soils derived from such materials are juvenile and consist of very coarse, thin veneers where present, with little or no organic component. Thus, naturally occurring environmental conditions are very harsh. At the same time, it is these conditions which create the habitats to which the natural vegetation has become adapted. During the course of evolution, local plants and those which have migrated into the area have been constantly improving their survival potential by a variety of adaptations which allow them to survive here, where more mesic species cannot. Were conditions to change toward a more moist environment for several years, the present vegetation would be eliminated by the other species more suited to the new environment. The plant assemblage which appears to have the highest potential for rehabilitation of mined lands in the Emery area consists mainly of the same species occurring there naturally because of their preadaptation to local conditions. For example, Bleak et al., (1965) found that seeds from native grasses and shrubs collected on one site in the shadscale zone would perish when planted in another area of the shadscale zone, while endemic ecotypes reproduced successfully. Physinomic, physiologic and morphological characteristics have been found to vary greatly among several important shrubs, as is often the case with widespread species. Assessment of the present resource is prerequisite to outline of mining and rehabilitation objectives, and essential for development of a reclamation plan. Given the extent and sensitivity of the present vegetation and the severity of the climate, it is not probable that the post-mining environment would be suitable for plant growth without significant long-term support for transplanted and seeded shrubs and grasses.

Assessment of the present vegetation cover was accomplished by a combination of aerial photo interpretation and field data collection, supplemented by a review of past and present research on the characteristics of the regional flora. Aerial photos were obtained as part of this study in August, 1977 and July, 1978 at scales of 1:6,000 and 1:12,000. Additional 1:24,000 coverage was obtained on the second aerial survey. False color LANDSAT imagery was also utilized in the analysis of regional vegetation patterns over a large area.

Field data was collected throughout the project with major efforts in October, 1977 and June, 1978. Line transects (Figure 53) were used in 54 locations to obtain values for species coverage in each vegetation type, as well as estimates of the surface extent of bare rock, litter, and bare soil. For each transect, the numbers and intercept lengths of each species were recorded along the transect. Location and transect orientation were recorded, and slope and soil characteristics were noted. In addition to the transects, species lists were compiled for an additional 28 sites. This was useful for assessment of special habitat types, such as cliffs, talus slopes, and washes, where line intercept measurements are not feasible.

The bulk of the soils data was supplied by the Soil Conservation Service and this material is discussed in a subsequent section. Supplemental soils data has been collected in the areas where revegetation experiments are being carried out on the site.

VEGETATION OF THE CENTRAL UTAH REGION

The Emery, Utah study site lies in Castle Valley between the San Rafael Desert on the east, and the Fish Lake Mountains on the west. A transect along this elevation gradient crosses several vegetation zones. Beginning at the upper elevations of the mountains, Western Spruce and Fir dominate (Figure 54). Below this zone, an association of Spruce, Fir and Douglas Fir is prevalent, especially on south and west facing slopes, while many north and east facing slopes support large Aspen groves. A Scrub Oak association is found below this zone, and forms a dense cover of small evergreen trees and tall shrubs. Pinyon-Juniper woodland is found further downslope, extending from the lower foothills of the mountain range out into the desert on the upper benches (above 6,000'). Below this, desert shrub communities dominate, as shadscale becomes the most common type

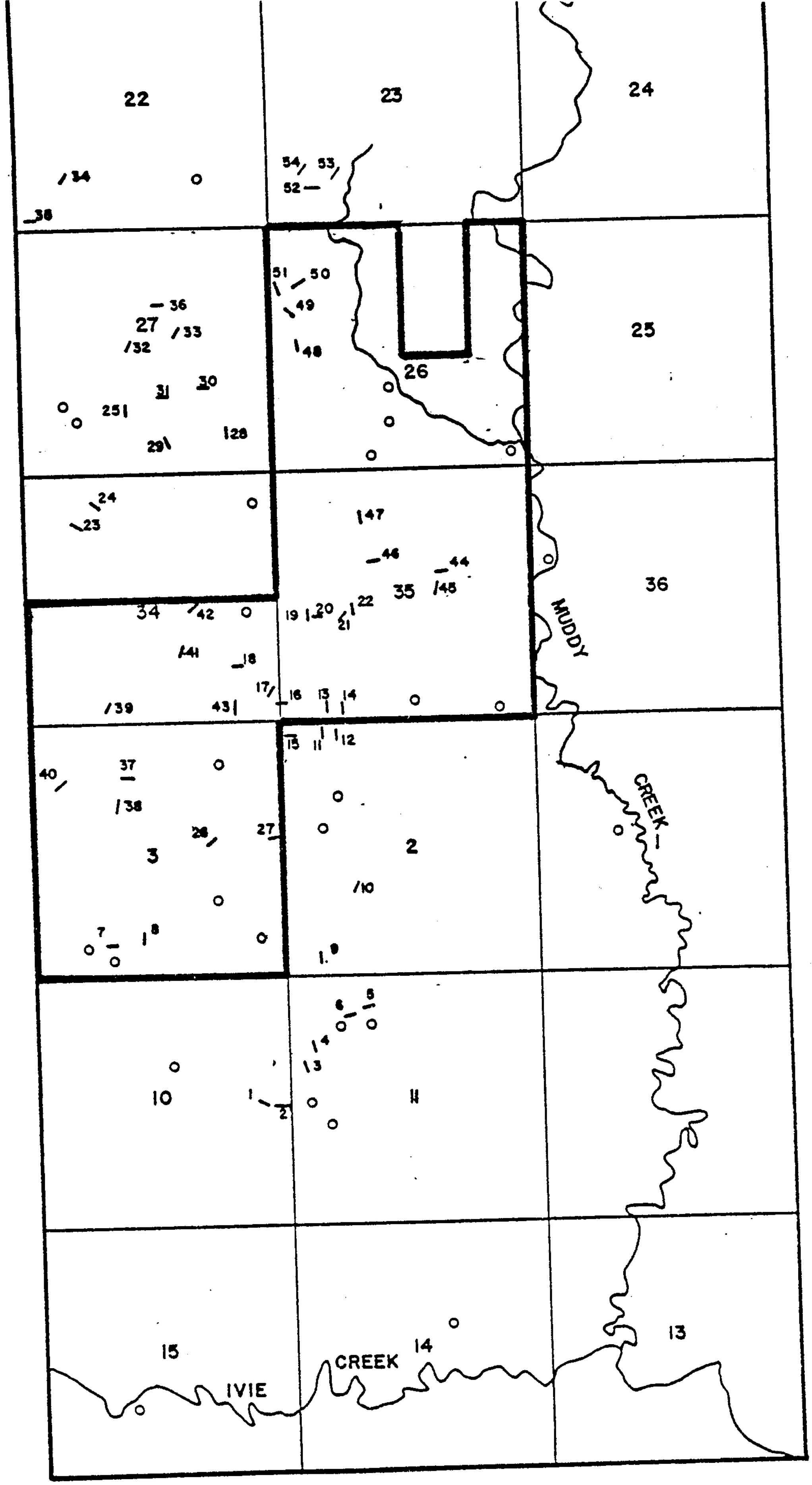


Figure 53

TRANSECT AND SAMPLE LOCATIONS

O Species collection — 100 Ft. Transect

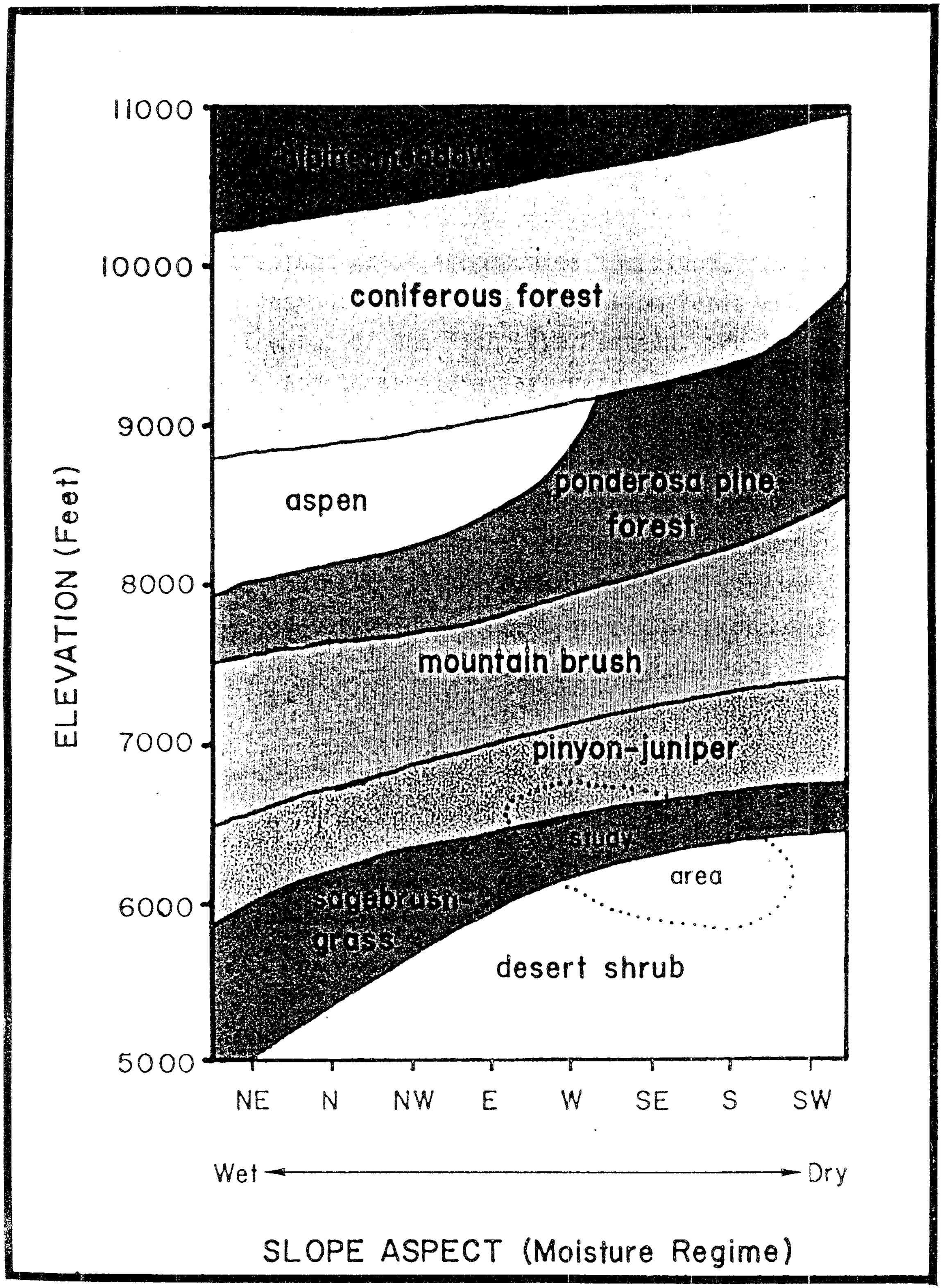

ELEVATION (Feet)
11000
10000
9000
8000
7000
6000
5000
coniferous forest
aspen
ponderosa pine forest
mountain brush
pinyon-juniper
study area
sagebrush-grass
desert shrub
NE
N
NW
E
W
SE
S
SW
Wet
Dry
SLOPE ASPECT (Moisture Regime)

Figure 54

on mature soils. Figure 55 illustrates a hypothetical transect from the mountain range to the west edge of the San Rafael Swell. While each one is clearly recognizable, the transitions between these major types are broad and contain species from several types. Representation of this complex gradient greatly simplifies the complexity of the transition in floristic composition between the high mountains and dry deserts.

The climatic gradient which accompanies the slope from mountain to desert is largely responsible for the vegetation zones and their spatial arrangement. At the top of the Fish Lake Plateau, precipitation exceeds 36 inches annually, and temperatures are generally 15° to 25° F cooler. Downslope, precipitation is much less, since the rainshadow of the Fish Lake Mountains limits the Emery area to less than 8 inches in an average year. The transition from one vegetation zone to another is as gradual as the precipitation gradient. There are few sharp linear contacts between one zone and the next as the formations are gradational. The Salt Desert shrub type vegetation characteristic of the Utah deserts is widespread throughout the west where annual rainfall is less than 8-12 inches.

VEGETATION TYPES, EMERY AREA

The Emery, Utah study area straddles two major vegetation types prevalent in Central Utah and elsewhere in the intermountain West: Pinyon-Juniper Woodland and Shadscale Scrub. The study area includes typical stands of both types, as well as an ecotone, or zone of transition between the two. In general, Pinyon-Juniper occupies the upper poritons of Molen Reef, above the Coal Cliffs at the Emery site, and extends for several miles on the benches to the northeast. The lower part of the bench and most of Castle Valley supports the Shadscale type or other associates of Salt Desert shrubs. Special habitat types including cliffs and talus slopes, washes, perennial streams, coves and canyons, and other disturbed sites also have special, recognizable plant associations, but the Pinyon-Juniper and Shadscale types appear to be dominant on areas of mature soil. Figure 56 maps the site.

The Pinyon-Juniper Woodland type consists of an open forest of Pinyon Pine (*Pinus edulis*) and Utah Juniper (*Juniperus osteosperma*). Because of

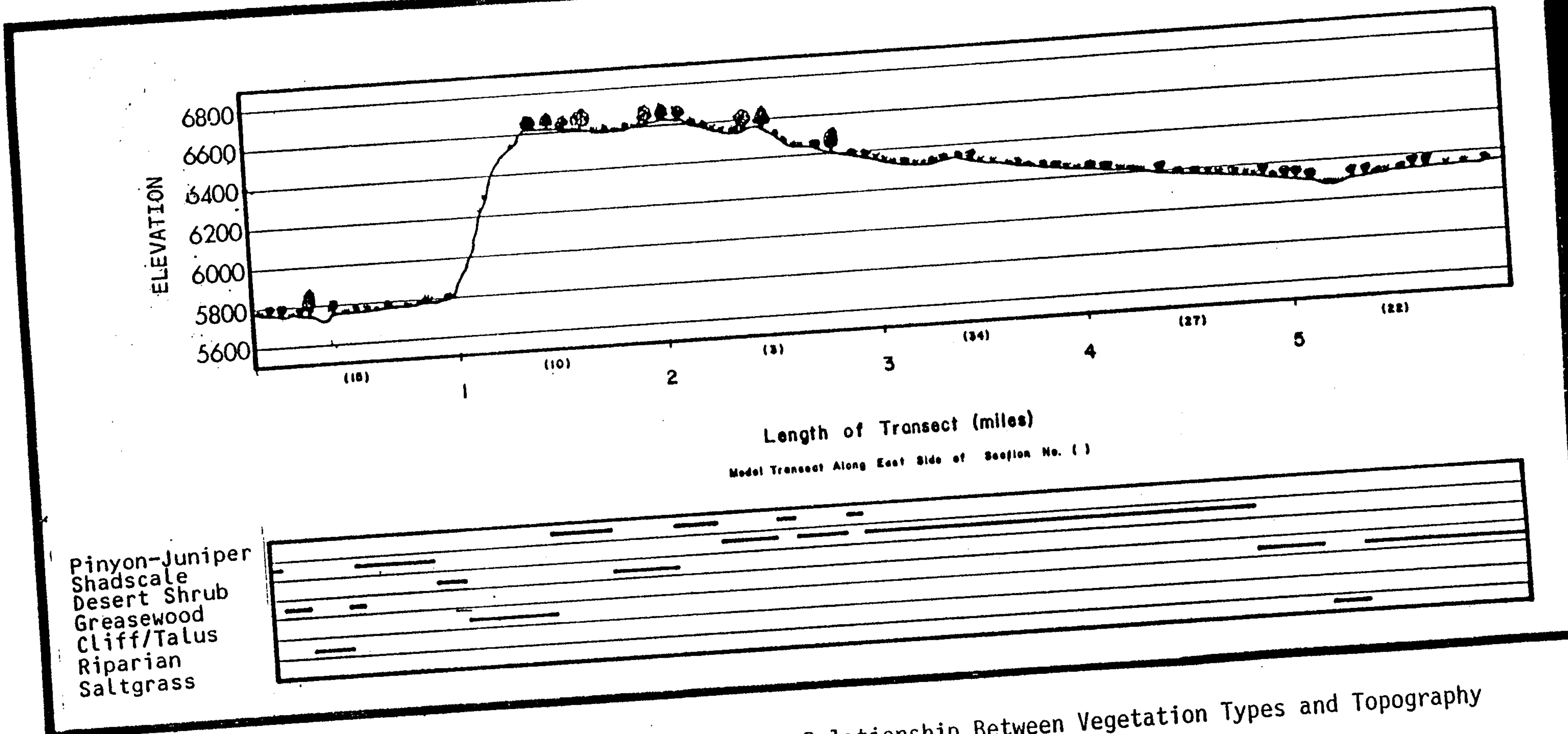


Figure 55. N-S Cross Section Showing Relationship Between Vegetation Types and Topography

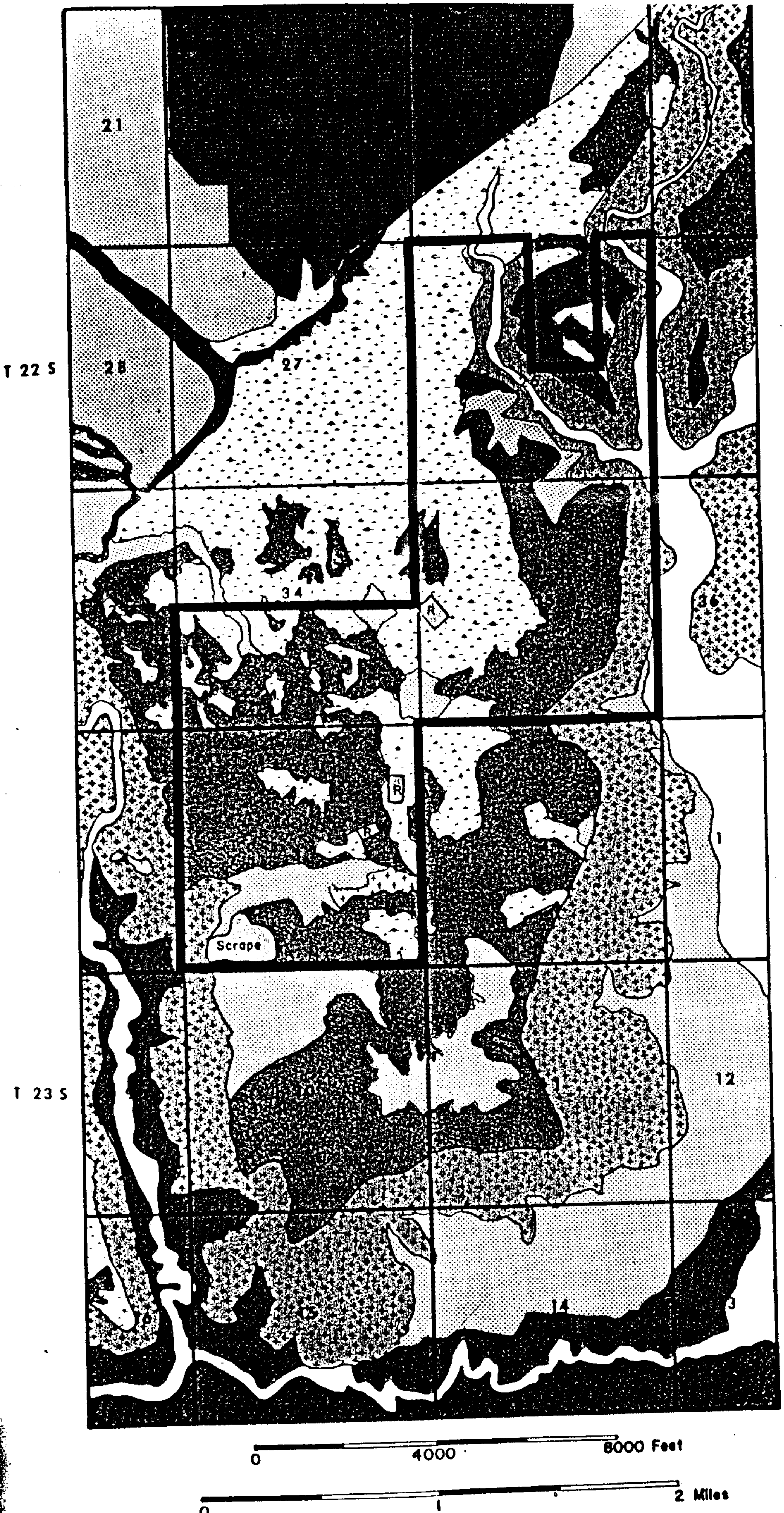
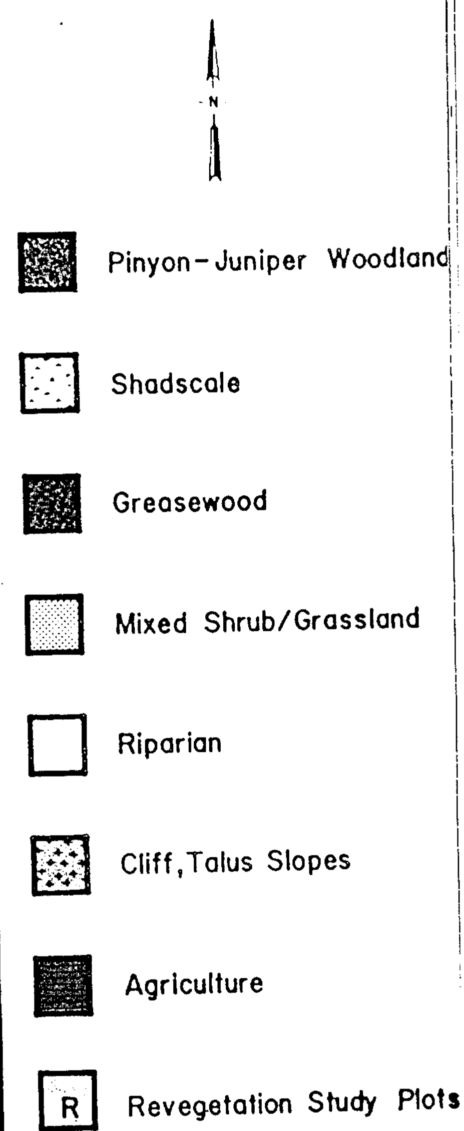


Figure 56
EMERY, UTAH AREA VEGETATION



their limited size and low density, Pinyon-Juniper Woodland has been referred to as a pygmy forest type (Cottam, 1929; Tanner and Hayward, 1934; ,mussen, 1941; Woodbury, 1947). It is the most extensive type in this part of the state. Both trees are evergreen and are widely spaced so that branches of adjacent plants do not usually touch. Maximum size may be 25 feet, but most trees are 15-20 feet in height and are nearly as wide. The highest elevation woodland (6400') consists of about 50% Pinyon Pine, with the remainder in Juniper. There is not a large cover of understory vegetation. At lower elevations the proportion of Juniper increases, as Pinyon gradually drops out. Total vegetation coverage for the type averages about 45%, leaving 55% bare soil and rock. Associated shrubs include:

Amelanchier alnifolia
Atriplex confertifolia
Artemisia sp.
Cercocarpus intricatus
Chrysothamnus sp.
Cowania mexicana
Ephedra sp.
Opuntia polycantha
Rhus trilobata
Yucca harrimaniae

Grasses include:

Agropyron inerme
istida fenleriana
outeloua gracilis
Hilaria jamesii
Oryzopsis hymenoides
Stipa comata

In certain topographic lows on the upper benches, deeper soils (and presumably soil moisture) accumulate and support a mixed shrub/grass formation. This type occupies fine grained soils and is among the most productive lands in the vicinity of the study area when moisture is available. This is shown by the heavy cover of annuals following the wet winter of 1977-1978. None of this type is found on the study site proper. Vegetal coverage of 30% is found in the spring when up to 24% of the surface supports annuals. Lappula occidentalis, Erigonum inflatum and Chenopodium album accounted for most of the annual growth. Perennial shrubs in this type are Atriplex confertifolia, Chrysothamnus viscidiflorus, and Artemisia nova. Grasses include Hilaria jamesii and Bouteloua gracilis. There is some evidence that Juniper are invading the site, as young trees are found along the perimeter. This problem is discussed below.

Downslope from the pure Pinyon-Juniper Woodland, shrubs and grasses appear in increasing numbers as a second canopy layer in clearings between the trees. This type is transitional between the Woodland and Shrub formations, and includes the strong elements of both. Juniper accounts for up to 18% of the 25-30% total coverage in this type, while Pinyon Pine drops out almost entirely. While there are a few Juniper found as far downslope as the Ferron Sandstone-Blue Gate Shale contact at 6200', this vegetation type is not extensive.

Shadscale Scrub is the most prevalent formation on the lower portion of the bench, and is common throughout the intermountain region. It is usually considered to be an edaphic climax on Saline Valley Soils (Holgrem, et al., 1973), but may also persist where salt concentration is relatively low. It is composed of low, widely spaced shrubs, with a generally whitish-gray appearance, and perennial bunch grasses. Total vegetal coverage is 8-20%. The composition of this type is variable, perhaps due to spatial variations in soil salinity, however, its appearance is white uniform. Shadscale (Atriplex confertifolia) and Galleta grass (Hilaria jamesii) have the highest coverage values in the Shadscale zone. There are a number of other important shrubs:

Artemisia nova
Artemisia tridentata
Atriplex cuneata
Ceratoides lanata
Kochia americana
Opuntia polycantha
Sarcobatus vermiculatus
Yucca harrimaniae

and grasses:

Agropyron cristatum
Boutelouca gracilis
Oryzopsis hymenoides
Stipa comata

These two major vegetation types, Pinyon-Juniper and Shadscale, account for almost 70% of the area in the Emery study site. Other communities are generally restricted to disturbed or otherwise special habitat types.

Almost pure stands of Greasewood (Sarcobatus vermiculatus) are found on the margins of most perennial streams in the area. It is found on heavy clay-rich, highly saline soils, and is the principal phreatophyte of the Shadscale zone (Holgrem et al., 1973). The most extensive stand parallels Christiansen Wash where it flows along the Ferron-Blue Gate contact. Associated species are Halogeton glomeratus, Salsola kali, and Atriplex species. Iodine bush (Allenrolfea occidentalis) is found where the surface has become encrusted with alkali accumulation, while saltgrass (Distichlis stricta) occurs in the channel of Christiansen Wash and several places where there is perennial runoff of irrigation water.

Table 17. Percent Cover of Vegetation Mulch, Soil, and Rocks - Estimated Yield.

	PINYON-JUNIPER WOODLAND		SHADSC		GREASEWOOD		MIXED SHRUB/GRASSLAND		RIPARIAN		CLIFF/TALUS SL	
	%Cover[1]	Yield[2]	%Cover	Yield	%Cover	Yield	%Cover	Yield	%Cover	Yield	%Cover	Yi
TREES												
Juniperus osteosperma	19	(580)	.9	(50)	---	---	.4	(30)	---	---	P	(20)
Pinus edulis	12	(350)	---	---	---	---	---	---	---	---	P	---
Populus fremontii	---		---	---	---	---	---	---	3.0	(400)	---	---
Salix sp.	---		---	---	---	---	---	---	7.0	(700)	---	---
Tamarix pentandra	---		---	---	---	---	---	---	9.0	(500)	---	---
SHRUBS												
Allenrolfea occidentalis	---	---	P	---	1.9	(18)	---	---	.7	(20)	.2	---
Amalanchier alnifolia	P	---	P	---	---	---	---	---	---	---	.2	(10)
Artimesia nova	P	---	.4	---	.2	---	.3	---	---	---	P	---
Atriplex canescens	P	---	.4	---	1.1	(44)	.6	(8)	---	---	.7	(12)
A. confertifolia	1.0	(20)	8.6	(390)	2.2	(45)	3.2	(75)	---	---	.5	(4)
A. cuneata	---	---	1.0	(25)	2.0	(55)	P	---	.4	(8)	.4	(6)
Ceratoides lanata	---	---	.3	---	---	---	P	---	---	---	---	---
Cercocarpus intricatus	.5	---	P	---	---	---	---	---	---	---	.4	---
Chrysothemnus nevadensis	.5	---	P	---	P	---	P	---	.3	---	1.0	(8)
C. viscidiflorus	.2	---	P	---	P	---	1.0	(.12)	.4	---	1.2	(12)
Ephedra nevadensis	.3	---	.1	---	---	---	.6	---	.3	---	.4	---
E. viridis	---	---	P	---	---	---	.3	---	---	---	.6	---
Grayia spinosa	---	---	.2	---	P	---	P	---	---	---	---	---
Gutierrezia sarothrae	P	---	.1	---	---	---	P	---	---	---	---	---
Kochia americana	---	---	1.3	(26)	P	---	.6	(16)	.4	---	---	---
Opuntia polyacantha	.8	---	1.0		---	---	1.0	---	---	---	---	---
Sarcobatus vermiculatus	---	---	P	---	23.1	(575)	P	---	8.9	(120)	---	---
FORBS												
Chenopodium sp.	---	---	P	---	.4	---	.4	---	---	---	---	---
Eriogonum inflatum	---	---	1.1	(18)	---	---	1.3	(28)	---	---	---	---
Eriogonum sp.	.5	---	P	---	.4	---	.8	---	---	---	P	---
Halogeton glomeratus	---	---	P	---	2.4	(32)	P	---	.9	---	---	---
Lappula occidentalis	.7	---	1.2	---	---	---	2.2	(12)	---	---	P	---
Salsola kali	.4	---	P	---	1.1	---	P	---	.4	---	.6	(3)
Sphaeralcea grossulariaefolia	---	---	P	---	---	---	P	---	---	---	---	---
GRASSES AND GRASS-LIKE PLANTS												
Agropyron inerme	---	---	P	---	---	---	P	---	---	---	---	---
Aristida fendleriana	---	---	P	---	---	---	P	---	---	---	---	---
Boutelona gracilis	.3	---	.4	---	---	---	.4	---	---	---	P	---
Distichlis stricta	---	---	---	---	2.9	(60)	---	---	4.3	(6)	---	---
Hilaria jamesii	1.0	---	8.1	(12)	P	---	3.1	(6)	---	---	.3	---
Juncus balticus	---	---	---	---	---	---	---	---	1.2	---	---	---
Oryzopsis hymenoides	P	---	.3	---	.4	---	P	---	---	---	.5	---
Phragmites communis	---	---	---	---	---	---	---	---	.8	---	---	---
Scirpus sp.	---	---	---	---	---	---	---	---	.6	---	---	---
Stipa sp.	---	---	P	---	---	---	P	---	---	---	---	---
Typha	---	---	---	---	---	---	---	---	.4	---	---	---
OTHER MISCELLANEOUS	.5	---	1.1	---	3.7	---	2.1	---	1.9	---	.5	---
Mulch	21.6		18.2		25.6		9.9		3.4		1.0	
Bare soil	29.3		40.8		30.6		54.9		42.5		36.3	
Rock	11.4		15.0		3.0		16.9		13.2		55.5	
TOTAL VEGETATION COVER	27.7		26.2		40.8		18.3		40.9		7.5	
Estimated Yield		(1000)		(525)		(695)		(245)		(2000)		(80)
Area (acres)	947		597		*		198		130		243	

1) P indicates presence
2) Yield units are lb./acre

* Not found on study site proper

Large areas of the study site consist of talus slopes on the margins of the benches and steep sided canyons and washes. These support a very low density association of shrubs and grasses which develop in small soil pockets between rocks and boulders. Certain rock strata exhibit a tendency to fracture into large blocks and create a deep crevice habitat which supports such species as the shrubs Ephedra nevadensis, Rhus trilobata Atriplex canescens and Yucca harrimaniae, and the grasses Aristida sp. and Oryzopsis hymenoides.

Agricultural land uses are restricted to the area underlain by Blue Gate Shale, generally to the north of the study site. Most of the area is planted to alfalfa (Medicago sativa) which is supported by irrigation and there are some fields of improved pasture land.

SUCCESSIONAL STAGES AND THEIR RELATIONSHIP TO REHABILITATION

Disturbance of the land surface which destroy or modify the plant cover begin a process called succession, in which certain types of plants invade the new territory, and are gradually replaced by other species as the soil matures and new microhabitats are created. This is usually a lengthy process. Following fires in Pinyon-Juniper Woodland, Barney and Frischknecht (1974) found that 85-90 years may be required for a full return to the original conditions. As the transition is made from bare rock or soil to the mature climax vegetation, the plant cover goes through a number of changes in a somewhat predictable order. For example, Barney and Frischknecht (1974) observed the following stages following Pinyon-Juniper burns: Skeleton Forest and bare soil; annual stage; perennial grass-forb stage; perennial grass-forb-shrub-young Juniper stage; shrub-Juniper stage; Pinyon-Juniper Woodland. The floristic composition of each stage consists of specific plants with preadaptations to the precise environmental conditions present at that time. For example the first plants to invade following fire are weedy annual species, whose physiological adaptations allow them to colonize an open, dry and somewhat sterile habitat. Gradually, the organic and moisture content of the soil builds up and perennial grasses and forbs outcompete the annuals by consuming available resources and filling open space. This stage is in turn replaced by plants better adapted to the changing conditions, until the self-perpetuating Pinyon-Juniper Woodland returns.

Rehabilitation of mined lands is, in one sense, an attempt to speed the process of succession, in order to avoid the long time period which would ordinarily be required for the existing Pinyon-Juniper and Shadscale vegetation types to return. It is even possible that they might never return if toxic materials were left at the surface. It is useful, then, to evaluate the study area to see what types of plants are doing well at sites which have been disturbed. Within the vicinity of the Emery site, there are a number of sites which can be evaluated to infer possible post mining conditions. Of particular interest is an area on the bench above the east side of Quitchupah Creek, which was scraped clear of soil and vegetation in 1966 to smother a burning coal bed. The burning coal bed is known to have been ignited at least 70 years prior, according to local residents. The Bureau of Mines reported large cracks in the sandstone overburden, which they inferred to have developed as a result of the fire. The vegetation, a moderate stand of Pinyon-Juniper (based on 1952 aerial photos) with little understory vegetation, was removed with earth moving equipment and the surface was drilled and blasted. Three to five feet of soil were removed from a nearby borrow pit and used to attempt to cut off the air supply to the fire by depositing it in the cracks. Once the new surface was graded, the entire area was seeded with "grass" (Bureau of Mines, 1966).

It has been 12 years since the surface soil was removed and the process of secondary succession has failed to produce a perennial vegetation cover. The as-
At present, much of the area is barren rock and windblown sand.
sertion in 1966 that grass seeding "should retard erosion and return the area to its original or better grazing potential" (Bureau of Mines, 1966) has failed to materialize. If the surface was graded and covered by 3 to 5 feet of soil after the fire was smothered, most of it has been removed by the wind, and the present flora is of little use to livestock because of the scarcity of palatable materials.

A detailed survey of the entire disturbed area found 20 plant species. Many of these are annuals, and are probably not present in any numbers following dry winters. The most conspicuous plant is the Russian Thistle (Salsola kali), which is almost useless for erosion control or grazing. Fourwing saltbush (Atriplex canescens) has done well in small protected sites and grows to relatively large size compared to its stature on the rest of the study site. Rabbitbrush (Chrysothamnus sp.) is also present at low density. The total vegetal coverage on the scraped area is less than 3% which included the contribution of this year's annuals. Perennial species account for less than 1% cover. Fourwing saltbush (Atriplex canescens) is the most promising of the plants found on this site. Currently, it is not dominant or even frequent in any vegetation type in this locale. A. canescens is widespread in the west, occurring from the Great Plains to the Pacific Coast Mountains, and from Canada to Mexico at elevations from sea level to 8000' (Blauer et al., 1976). In any species with such a wide geographic distribution, it is common to find great variation in the forms and tolerances of the plant within different parts of its range. Although there has been some research concerning methods of propagation and potential for rehabilitation, extensive tests should be conducted with local plants to determine if the ecotype found on the scrape area has exceptional ability to colonize primitive soils. Although fourwing saltbush is a valuable forage shrub, it also can concentrate selenium from soils where it occurs (Kingsbury, 1964; Davis, 1972). Livestock losses have been reported where there was little forage (Hitchcock et al., 1964). Table 18 gives a list of species encountered for all habitats in the area.

Summary

Cattle grazing takes place during the winter and spring months over most of the Emery study site. Except for a few inaccessible benches, cattle have been observed in all areas with a high concentration of use around those stock ponds located along ephemeral washes. Grazing intensity has been sufficient to induce some striking changes in the character of several plant communities.

The expansion of the Pinyon-Juniper Woodland has been noted at the Emery site and may possibly be attributed to chronic heavy grazing. Research throughout the intermountain region has shown the expansion of woodland into heavily grazed sagebrush or shadscale communities (Arnold et al., 1964; Cottam and Stewart, 1940; Pickford, 1932).

In many locations there are Juniper seedlings on the margins of established woodland stands where shrub vegetation is adjacent. In addition, the understory in the mature Pinyon-Juniper areas is usually extremely

TABLE 18

THREATENED AND ENDANGERED PLANT SPECIES, EMERY COUNTY*

Species	Status[1]	Critical Habitat
Threatened:		
Asclepias ruthias	T - C	Sandy Soil
Astragalus rafaelensis	T - C	Morrison, Chinle, Moenkopi
Castilleja scabrida	T - NC	Dakota
Erigonum smithii	T - C	Estrada, Blown Sand
Parthenium ligulatum[2]	T - C	Carmel, Green River Shale
Phacelia constancei	T - NC	Mud-Slitstone
Phacelia rafaelensis	T -NC	Moenkopi
Scelrocactus wrightii	T - C	Mancos Shale
Endangered:		
Astragalus pardalinius[3]	E - NC	Entrada Sandstone, Sand
Cryptantha jonesiana	E - C	Moenkopi
Cryptantha johnstonii	E - C	Carmel
Cycladenia humulis[4] (var. jonesii)	E - C	Moenkopi
Erigonum intermontanum	E - C?	Green River Shale
Physaria grahamii	E - C?	Green River Shale

1. C - Critical; NC - Not Critical; ? - Uncertain
2. Published as Parthenium alpinum var. ligulatum
3. Published as Phaca pardalina
4. Published as Cyclanderia jonesii

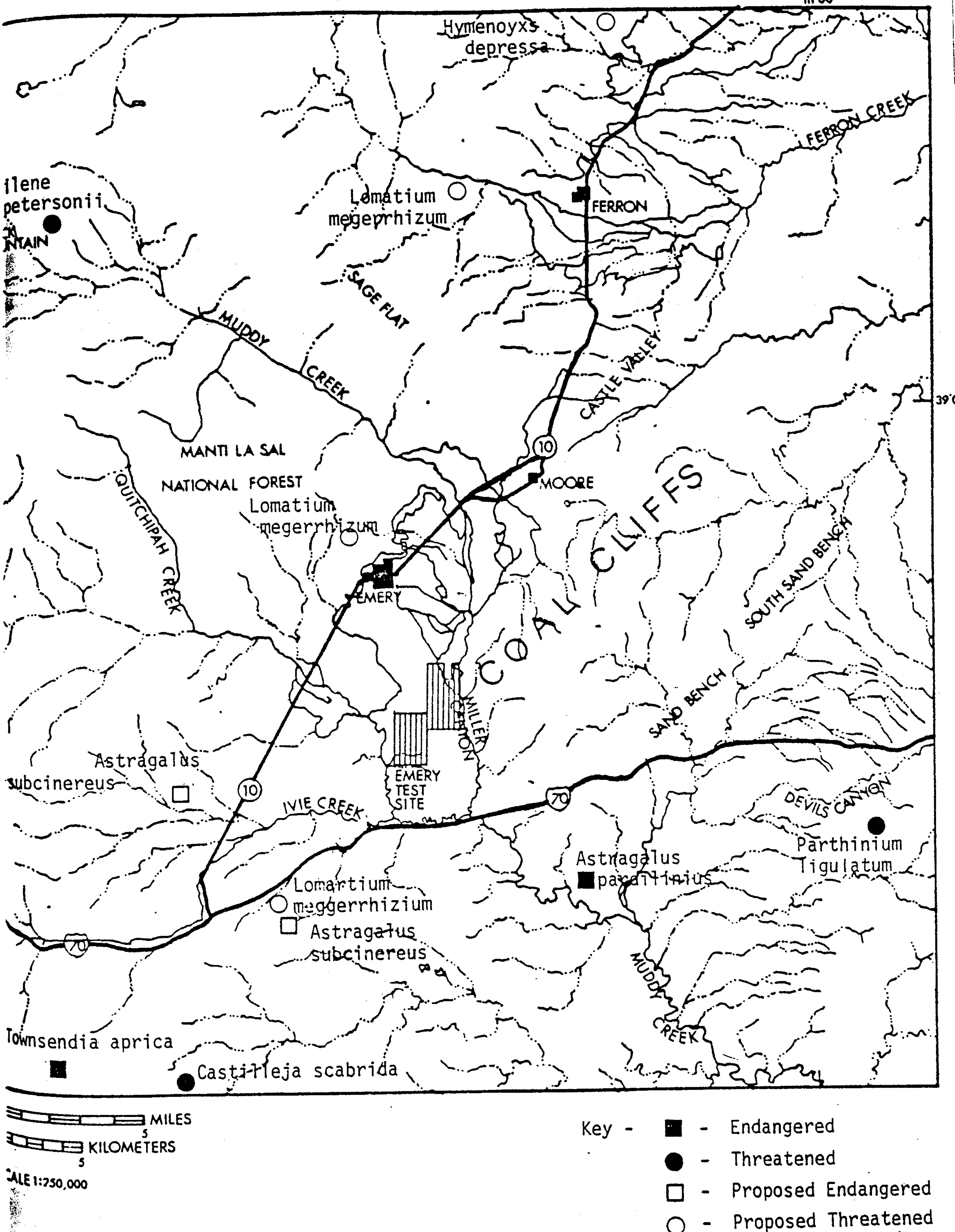
* From Welsh, 1977

sparse or entirely absent. Historical aerial photos from 1952-1962, 1969 and 1977 have been examined to evaluate the expansion of the Pinyon-Juniper type and it was found to have occurred in several areas.

In addition to outright conversion of shrubland, other areas show evidence of alteration in floristic composition and forage value, and possibly gross productivity, which may be due to grazing. Unpalatable shrubs, forbs, and grasses have become established where the competition from desirable browse plants has been reduced. Halogeton glomeratus, which was introduced from Central Asia, is common in the lower Shadscale zone and contains oxalic acid which may be toxic to cattle in large amounts. A Prickly Pear Cactus (Opuntia polycantha) has become frequent in the upper Shadscale zone. The production value of the present vegetation is probably lower because of the past grazing history.

A survey of the region for threatened and endangered species shows that 14 species or subspecies have been noted in Emery County (Welsh, 1977). Of these, 8 are listed as threatened, and 5 are endangered (Table 18). None of these species were observed on the study site, but several species have been collected within 25 miles (Figure 57). However, since the impact of mining is expected to be limited to the site and immediate vicinity neither threatened nor endangered species are expected to be affected.

Figure 57. Threatened and Endangered Plants
(Welsh, 1977)



PLANTS OF THE EMERY STUDY AREA AND VICINITY

The following is a listing of plant species encountered in the vicinity of the Emery, Utah study site between August, 1977 and July, 1978. Listings are arranged alphabetically by family, genus and species. Common names are given where they apply. Nomenclature follows that of Welsh and Moore (1973), or in a few cases, Tidestrom (1925).

In all, there are 25 families represented by 65 genera and 83 species. These include most of the common plants from the major vegetation types in the Castle Valley.

A[illegible]RDIACEAE - Cashew family

Rhus trilobata	Squawbush

ASTERACEAE - Sunflower family

Artemisia cana	
A. dracunculus	
A. filifolia	Old Man Sagebrush
A. frigida	
A. nova	Black Sagebrush
A. tridentata	Big Sagebrush
Aster spp.	Aster
Chrysothamnus nauseosus	Rubber rabbitbrush
C. viscidiflorus	Green rabbitbrush
Encelia frutescens	
Erigeron spp.	Fleabane
Gutierrezia sarothrae	Snakeweed
Heterotheca villosa	Golden Aster
Iva axilaris	Marsh Elder
Tetradymia spinosa	Spiny horsebrush
Thelesperma subnudum	
Xanthium strumarium	Cocklebur

ASCLEPIADACEAE - Milkweed family

Asclepias spp.	Milkweed

BORAGINACEAE - Borage family

Lappula occidentalis	Stickseed
Lithospermum multiflorum	Stoneseed

CACTACEAE - Cactus family

Echinocereus triglochiatus	Hedgehog cactus
Opuntia polyacantha	Prickly pear

CAPPARIDACEAE - Caper family

Cleome spp.	Beeplant

CHENOPODIACEAE - Goosefoot family

Allenrolfea occidentalis	Pickleweed
Atriplex canescens	Four-wing saltbush
A. corrugata	Mat saltbush
A. confertifolia	Shadscale
A. cuneata	Castle Valley clover
Ceratoides lanata	Winterfat
Chenopodium spp.	Goosefoot
Grayia spinosa	Spiny hopsage
Halogeton glomeratus	Halogeton
Kochia americana	Summer cypress
Salsola kali	Russian thistle
Sarcobatus vermiculatus	Greasewood

CRUCIFERAE - Mustard family

Brassica spp.	Mustard
Stanleya pinnata	Princes plume

CYPRESSACEAE - Cypress family

Juniperus osteosperma	Utah juniper

CYPERACEAE - Sedge family

Scirpus acutus	Bulrush
S. americanus	

ELAEAGNACEAE - Oleaster family

Elaeagnus angustifolia	Russian olive

EPHEDRACEAE - Ephedra family

Ephedra nevadensis	Mormon tea
E. viridis	

HYDROPHYLLACEAE - Waterleaf family

Phacelia corrugata	Scorpion weed
P. demissa	

JUNCACEAE - Rush family

Juncus balticus	Baltic Rush

LEGUMINOSAE - Pea family

Astragalus sp.	Milkvetch

LILIACEAE - Lily family

Yucca harrimaniae	Native yucca

MALVACEAE - Mallow family

Sphaeralcea grossulariaefolia	Globe mallow

P[illegible]EAE - Pine family

Pinus edulis	Pinyon pine

POACEAE - Grass family

Agropyron inerme	Beardless wheatgrass
A. cristatum	Crested wheatgrass
Agrostis alba	Redtop
Aristida fendleriana	Threeawn
A. longiseta	
Bouteloua gracilis	Blue grama
Distichlis stricta	Saltgrass
Hilaria jamesii	Galleta
Hordeum jubatum	Foxtail barley
Oryzopsis hymenoides	Indian ricegrass
Phalaris arundinaceae	Canary reed grass
Phragmites communis	Common reed
Pluchea sericea	Arroweed
Puccinellia distens	Alkali grass
Poa pratensis	Kentucky bluegrass
Sitanion hystrix	Squirreltail
Sporobolus airoides	Alkali sacaton
S. cryptandrus	Sand dropseed
Stipa comata	Needle and thread grass
S. columbiana	

POLYGONACEAE - Buckwheat family	
Eriogonum inflatum	Desert trumpet
E. spp.	
RANUNCULACEAE - Buttercup family	
Clematis spp.	Virgin's bower
ROSACEAE - Rose family	
Amalanchier alnifolia	Serviceberry
Cercocarpus intricatus	Mountain mahogany
Cowania mexicana	Cliffrose
Rosa woodsii	Wood's rose
SALICACEAE - Willow family	
Populus fremontii	Cottonwood
Salix spp.	Willow
TAMARICACEAE - Tamarix family	
Tamarix pentandra	Saltcedar
TYPHACEAE - Cattail family	
Typha latifolia	Cattail

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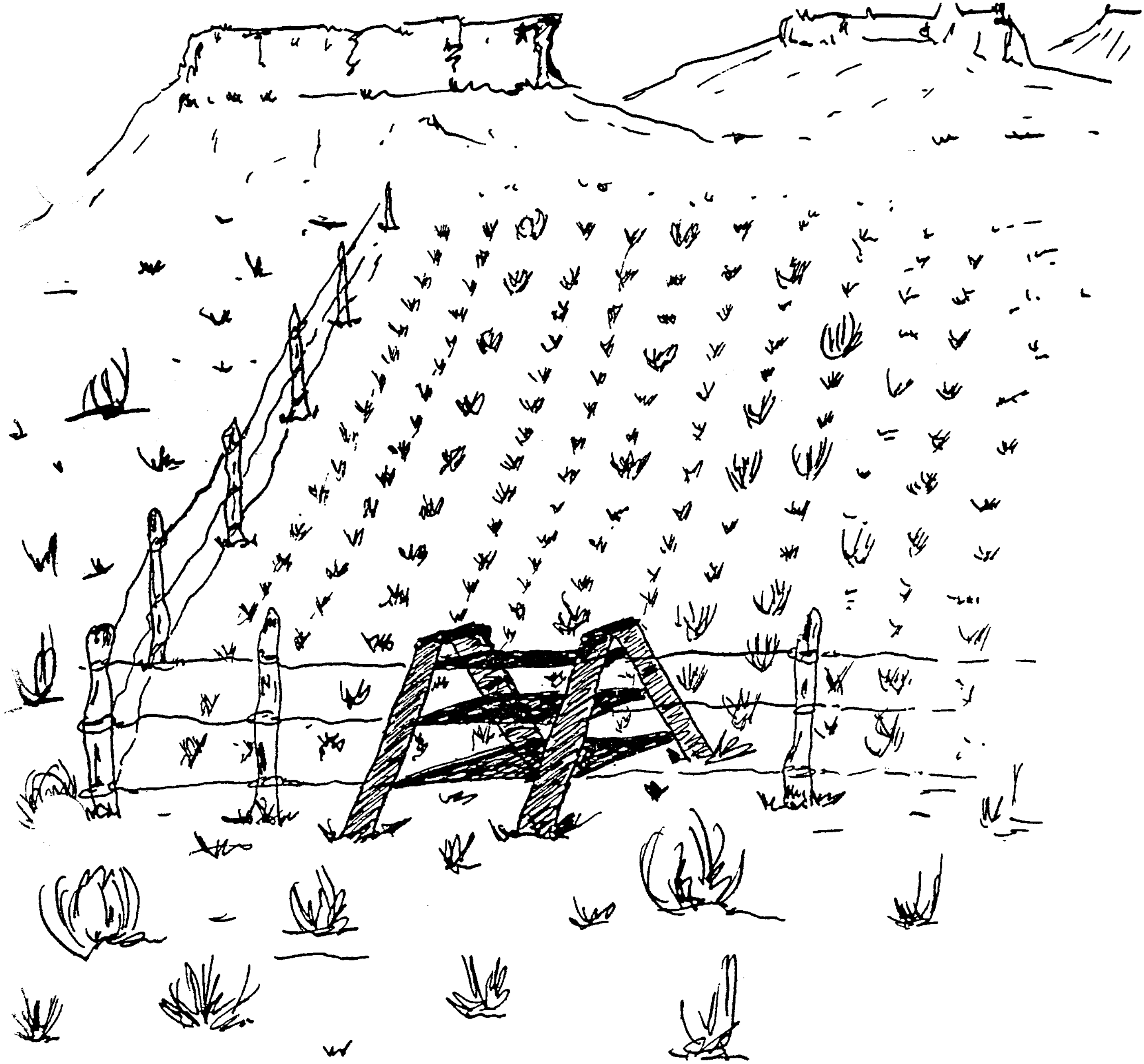


REVEGETATION

The primary consideration for revegetation appears to be drought. It inhibits seed germination, causes mortality in plants which do emerge and forces heavy use of plants by small mammals even in the absence of livestock grazing. Field trials of various species and practices for establishment of plants under post-mining conditions are still being carried out on the Emery study site by the U.S. Forest Service Intermountain Forest and Range Experiment Station for the BLM. Additional reports should be available from this work in the near future. Two basic types of experiments were attempted on each of the main soil types present at the site. Test of the performance of individual species of grasses and shrubs were carried out using small plots, while larger plots were seeded with a mixture of grasses and shrubs treated with a variety of soil amendments and surface preparation techniques. Because of the arid climate, successful germination and establishment of plants is difficult in some years without supplemental water. Positive results will be achieved in years with above normal precipitation if proper seed mixtures and cultural treatments are applied, while the success of revegetation efforts for dry years will depend on supplemental irrigation (See for example, Bleak et al., 1965).

Three main soil series were involved in these studies. The Persayo series consists of 0-12 inches of loam and silty clay over shale bedrock. Penoyer soils are 0-14 inches of silty clay loam over loam which extends to at least 60 inches depth. The Castle Valley series has less than 20 inches of fine sand over sandstone bedrock which tends to decompose readily when exposed at the surface. Penoyer and Persayo soils are Entisoils of the Typic Torrifluent and Typic Torriorthent subgroups, respectively. Castle Valley series soils are Aridisols of the Lithic Xerollic subgroup. In addition, a blue shale subsoil typical of much of the area was used for a limited number of trials (Further details of soil characteristics are included in another section).

Sites were selected on the basis of the soil maps prepared by the SCS. Each site is level to gently sloping. Preparation of the sites prior to seeding consisted of simulation of a post-mining environment by removal of the top 15 inches of soil, ripping of subsoil (and bedrock) to a depth of 30 inches with a D-9 Caterpillar, and smoothing and replacement of the stockpiled topsoil. The "reclaimed" soils were amended by addition of alfalfa hay at the rate of 2.5 tons/acre or a one inch layer of bark-wood fiber compost, or no treatment. These soil additives were rotovated into the soil to a depth of six inches. Following this preparation for sites on each soil type, the areas were subdivided into smaller plots for 3 types of trials: 1) growth from seed of a mixture of 9 species (5 grasses, 4 shrubs); 2) trials of individual grass species on small plots treated by various means; and 3) trials of container grown shrubs on soils treated by various means. The experimental design is summarized in Table 19.

Results of Revegetation Trials

Grass and Shrub Seedings - Nine species were seeded on Persayo and Penoyer soils by 3 different methods: 1) treatment with a gouger/seeder which left a pitted surface; 2) treatment with a spring tooth-type harrow following seed broadcast with a cyclone hand seeder; and 3) treatment with a cultipacker to firm the loose soil following seeding by a cyclone hand seeder. Seed was applied to all plots at the rate of 20 lbs./acre mixed in the proportions shown in Table 20.

Data was collected on July 12, 1978 using a 2 x 5 foot wire frame marked off in 1 square foot segments. Results of analysis of variance showed that the frequency (presence per quadrat) of grasses was lower on the gouged treatment than on the cultipacked or harrowed areas. There was no statistically significant difference in frequency of grasses between cultipacked and harrowed treatments on the Persayo soils, while the harrow treatment produced higher frequency than cultipacked on Penoyer soil (Figure 58(A,B,)).

The harrow treatment showed the highest frequency of shrubs on both soil types. Of the four species seed, white sage comprised 55% of the shrubs counted on sample plots, followed by shadscale (35%), fourwing saltbush (6%) and Nevada ephedra (4%).

Breakdown of frequency counts by soil amendments and growth form is shown in Figure 58 (C,D,). On both basic soil types, the alfalfa hay amendment produced the highest frequency of grasses. While the bark-wood fiber treatment produced higher frequency than the control area on Persayo soils, the results were slightly lower for bark-wood fiber than the control on Penoyer soils. Among the shrubs, bark-wood fiber was superior to alfalfa hay on both soils, but the control area produced the

Table 19

Summary of Revegetation Experiments

Layout	Soil Treatment	Soil Type: Persayo	Soil Type: Penoyer	Soil Type: Castle Valley	Soil Type: Blue Gate
10 grasses seeded separately on 10' x 15' plots of topsoil and subsoil	Alfalfa hay Kaibab mulch no amendment	x- x- x- } broadcast seed	x- x- x- } broadcast seed		
9 species (5 grasses, 4 shrubs) in seed mixture	Alfalfa hay Grass hay Kaibab mulch	Each treatment seeded by three methods: 1) Gouger-seeded 2) Hand Seeder/harrow 3) Hand Seeder/cultipacker			
9 species (5 grasses, 4 shrubs) in seed mixture	'above'			a) Ripped w/topsoil b) Ripped w/o topsoil c) Stockpiled topsoil only	
21 container grown shrubs	Supplemental water given to ½ the samples	Planted 4/20/77	Planted 4/13/77	Planted 4/21/77	Planted 4/13/77

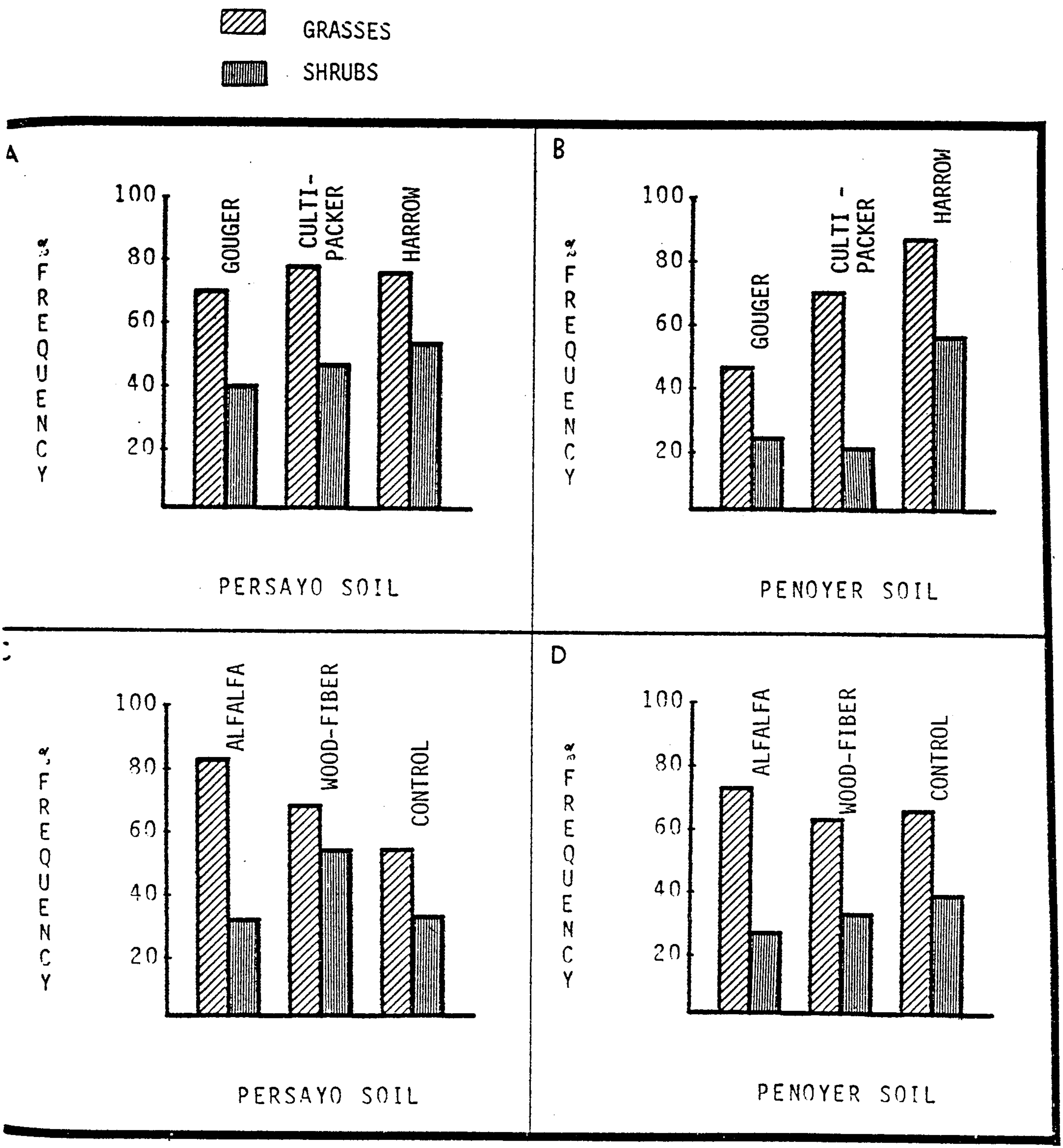
Table 20

Seed Mixture Used at Emery Site

Common Name	Scientific Name	% of Mixture by Weight
Crested wheatgrass	Agropyron cristatum	15
Streambank wheatgrass	Agropyron riparium	15
Russian wildrye	Elymus junceus	15
Indian ricegrass	Oryzopsis hymenoides	10
Alkali sacaton	Sporobolus airoides	5
Fourwing saltbush	Atriplex canescens	10
Nevada ephedra	Ephedra nevadensis	10
Whitesage	Ceratoides lanata	10
Shadscale	Atriplex confertifolia	10

In addition to the 3 seeding methods, 3 soil treatments were used (alfalfa hay, grass hay, bark-wood mulch) for a total of 9 plots.

Figure 58. Performance of Shrubs and Grasses by Soil and Treatment



highest frequency on Penoyer soils (Figure 59).

Competition from an annual weed (Kochia scoparia) apparently restriced the height of growth of grass seedlings on all treatments where alfalfa hay was used, while its effect on young shrubs is not know. The seed of Kochia was an adulturant in the alfalfa hay applications, and the extent to which these plots produced seed will be evident in subsequent growing seasons, by the presence of additional plants.

Small Area Grass Plots - Trials of three soil types were carried out following simulated mining (as described previously) on Persayo and Penoyer soils. On one half of each area, topsoil was replaced following ripping of the subsoil, while the remainder was left without topsoil. Seeds of 10 species were sown separately on plots 10 x 15 feet in each of three treatment areas: 1) alfalfa hay; 2) bark-wood fiber; and 3) control. Each plot was duplicated twice on both topsoil and subsoil areas, for a total of 12 plots for each species, and 120 plots in all. Seeding of species listed in Table 21, took place on December 6. 1977 (except the last three species - seeded in March) on Persayo soils. Penoyer soils were seeded in March 1978.

Table 21
Grass Species Seeded in Small Plots

	Grams/Plot
"Nordan" crested wheatgrass (Agropyron desertorum)	16
Induced Tetraploid x Natural crested wheatgrass	16
"Fairway" crested wheatgrass (A. cristatum)	32
Russian wildrye (Elymus junceus)	32
Indian ricegrass (Oryzopsis hymenoides)	32
Squirreltail grass (Sitanion hystrix)	32
Alkali sacaton (Sporobolus airoides)	16
Blue grama (Bouteloua gracilis)	16
Sand dropseed (Sporobolous cryptandrus)	16
Palmer penstemon (Penstemon palmeri)	16

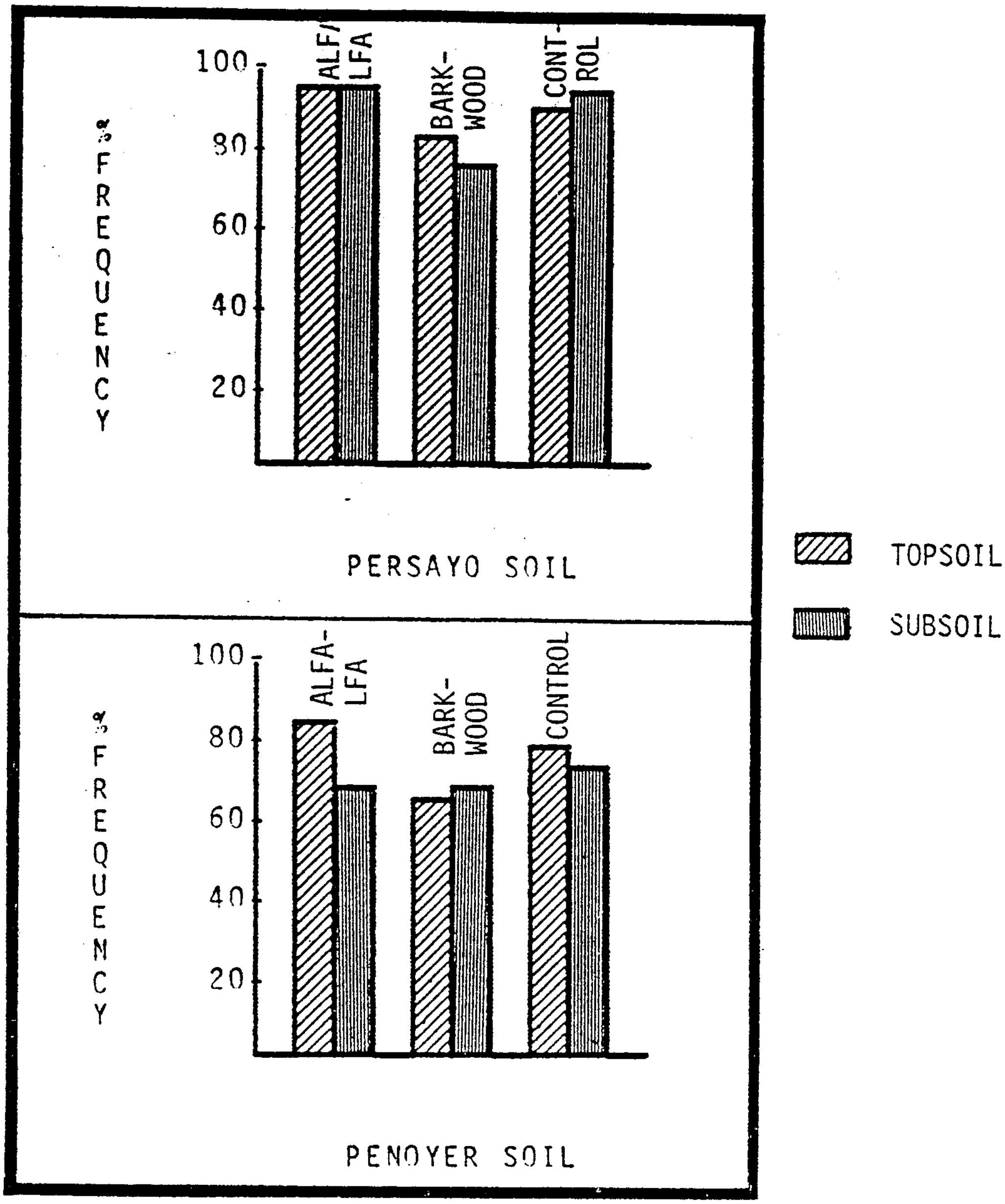


Figure 59. Performance of Grasses on Topsoil and Subsoil

Data collected using the same methodology as in the preceeding discussion showed both frequency and numbers (density) of grass seedlings were highest on the alfalfa hay plots, followed by the control area and bark-wood fiber treatments (Figure 58). There was little statistical difference between the performance of grasses on topsoil vs. subsoil in terms of frequency or density, however seedlings on topsoil were generally taller. All three wheatgrass species and Russian wildrye had the highest overall ratings, while Sporobolus, Bouteloua and Penstemon species were the lowest. Very few seeds of these last three species germinated and emerged.

Container Grown Shrub Plantings

Container grown shrubs were transplanted to plots of 5 x 10 feet in size, using four replications for each of 21 shrub taxa (Table 22). Plantings were carried out on Persayo, Penoyer and Castle Valley soils, as well as a Blue Shale subsoil typical of much of the area. Plants were arranged in two rows of four plants each, spaced 30 inches apart. One liter of water was added to each plant at the time of transplanting and subsequently on 3 dates at roughly 4 week intervals. Thereafter, only 2 of the 4 replications for each variety received supplemental water, amounting to 2 liters each on August 24 and September 12, 1978.

Transplants survived well on all soil types, except those on Blue Shale which did not receive extra water, where some mortality occurred. Little mortality was observed on any of the other substrates regardless of the amount of supplementary water. At the end of the 1978 growing season, average height of plants was greatest on the Castle Valley soil, followed by Persayo, Penoyer and Blue Shale respectively (Figure 60).

Species Useful for Reclamation in the Emery Area (Table 23)

A number of plant species appear to have specific characteristics which make them suitable for reclamation of the Emery area, and in some cases, to the arid south-central region of Utah. However, several of the species discussed below are wide-ranging which indicates the possibility of significant ecotypic variations in tolerance for various environmental conditions. Large intraspecific variations in ecological adaptations are common, so that seed taken from a promising species in

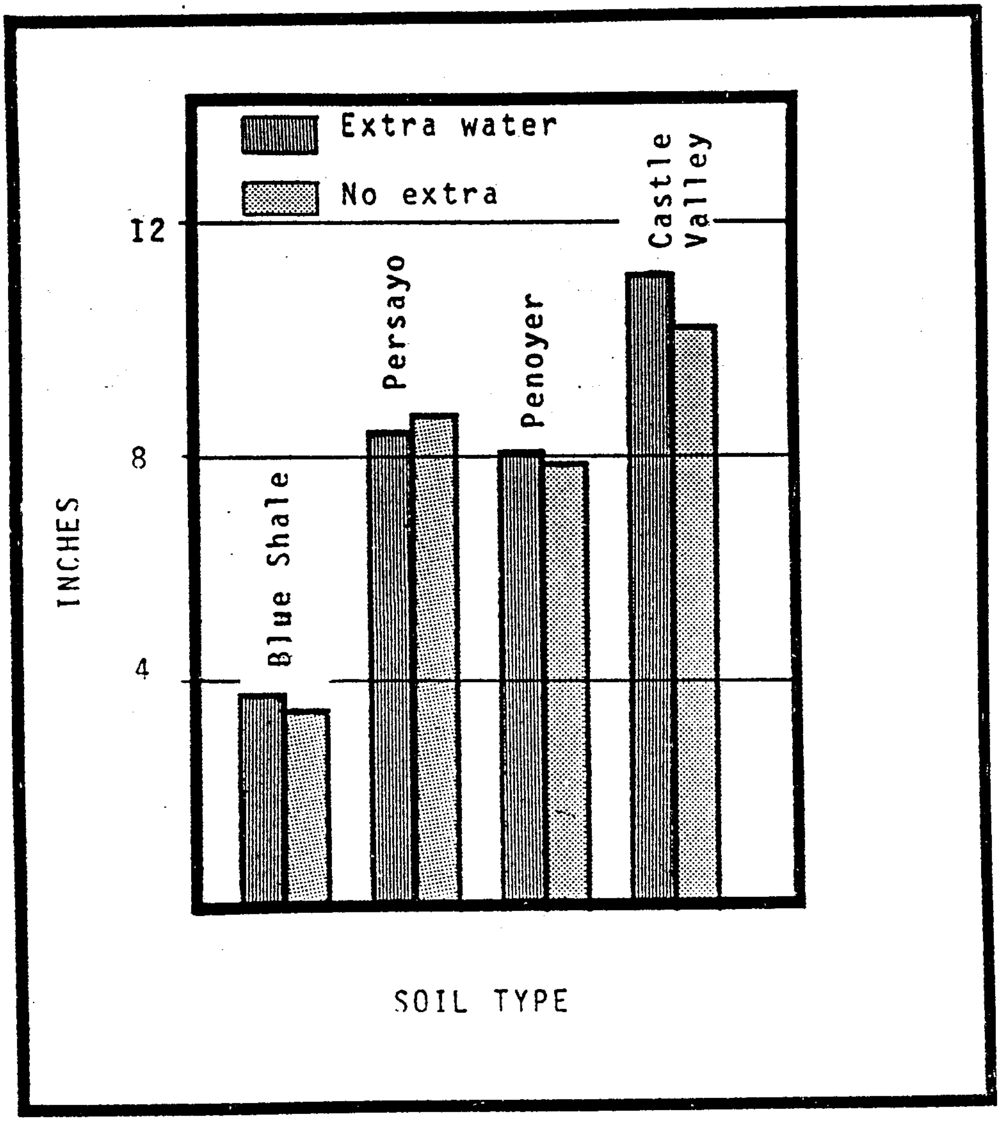


Figure 60. Performance of Container Grown Shrubs by Soil Type.

Table 22

Container Grown Shrub Species Planted on Emery Sites (1978)

Species
Artemisia nova
Atriplex aptera
Atriplex canescens
Atriplex canescens x A. cuneata
Atriplex canescens x A. idahoensis
Atriplex canescens x A. tridentata
Atriplex gardneri
Atriplex navajoensis
Atriplex obovata
Atriplex robusta
Atriplex tridentata
Atriplex tooelensis
Ceratoides lanata
Ceratoides papposa
Ephedra nevadensis
Erigonum corymbosum
Grayia spinosa
Kochia prostrata #7, #11, #14 (clay sources)
Kochia prostrata #2, #9, #12 (sandy sources)
Kochia prostrata var. villosissima
Camphorosma monspeliaca

Table 23

PLANTS WITH HIGH REHABILITATION POTENTIAL

BOTANICAL NAME	COMMON NAME	[1]PRESENT STATUS	PALAT-ABILITY	EROSION CONTROL
Shrubs				
* Atriplex canescens	Four wing saltbush	3(4)	High	High
* A. confertifolia	Shadscale saltbush	1	Medium	High
A. cuneata	Cuneata saltbush	3	High	High
Artemisia nova	Black sage	3	?	Medium
* Ceratoides lanata	Winterfat, White sage	3	High	Medium
* Chrysothamnus nauseosus	Rubber rabbitbrush	3(4)	High	High
C. viscidiflorus	Yellow rabbitbrush	3(4)	High	High
* Ephedra nevadensis	Mormon Tea	4	Medium	Medium
Kochia prostrata		not present	?	?
Kochia americana	Summer cypress	2	?	Medium
Sarcobatus vermiculatus	Greasewood	2(4)	Low	Medium
Grasses				
Bouteloua gracilis	Blue grama	2	Medium	Medium
Aristida fendleriana	Threeawn	3	Medium	Low
A. longiseta		3	Medium	Low
Hilaria jamesii	Gallenta	1	High	Medium
* Oryzopsis hymenoides	Indian Ricegrass	3	High	Medium
Sitanion hystrix	Squirreltail	2	Low	Low
Stipa comata	Needle and Thread	2	Low	Low

1: Relates to distribution. 1 = widespread, common; 2 = frequent; 3 = infrequent; 4 = frequent in special habitat.

* denotes plants which do well on disturbed sites.

one area may perform poorly, or lack the desirable traits when planted in a different part of its range. This will become especially important when seed or wild stock is collected for reclamation of any site. As a general rule, it will be desirable to collect plant materials from the area where they are to be used due to the potential for preadaptations which may be genetically encoded. However, Bleak et al., (1965) found that native shrubs were better able to survive severe drought than grasses.

Shrubs

Fourwing saltbush (Atriplex canescens) was found to do well on disturbed areas of the study site, although it is not a major component of the native undisturbed vegetation. Local plants observed on disturbances were of unusual height (< 1 meter) compared to plants growing in the shadscale vegetation type (>.5 meters). In the revegetation trials, fourwing formed 6% of the established shrubs. In trials of container grown stock, it performed well with little mortality at the Emery site, although in studies at Henry Mountains, it did not do well. There is a relatively extensive literature concerning methods and results of revegetation trials with fourwing saltbush (e.g. Cable, 1971; Aldon 1971; Bleak et al, 1965; MacArthur et al, 1974). This plot hybridizes freely with several other saltbush species as well as other members of the Chenopod family (Blauer, et al, 1976). Artificially induced crosses may yield hybrids with new characteristics desirable for reclamation and the wide range of ecotypes provides a large gene pool from which to select. Fourwing saltbush has been reported as a facultative selenium (Se) absorber and may be "mildly poisonous" in areas where the soil contains this element (Kingsbury, 1964; Davis, 1972). Livestock losses have occurred where animals had no other food (Hitchcock, et al, 1964).

Shadscale saltbush (Atriplex confertifolia) is the dominant shrub on large areas of western range, and was found in most habitat types in and around the Emery study site. Different ecotypes are tolerant of a wide range of soil conditions, where soluable salts range from 160-3000 ppm and pH from 7.4 to 10.3 (Hanson, 1962). Because of the rigidity and spininess of mature plants, shadscale is not heavily grazed and tends to increase under grazing pressure (Blauer et al, 1975). Although establishment from direct seeding is reported to be difficult (Blauer et al, Op. Cit.), shadscale accounted for 35% of the shrubs established in the Emery trials and stock survived well at both Emery and Henry Mountains.

Grasses

Several native and introduced grasses show promise for use in central Utah reclamation projects. Success or failure of germination and establishment is in part a function of the seasonality of rainfall or supplemental irrigation. This is more generally true for grasses, since many of the native shrubs can make quick use of available water, while certain grasses concentrate growth during certain seasons and become dormant the rest of the year. Frischknecht and Ferguson (1978) have noted the similarity of the rainfall pattern between Emery, and the Great Plains, as both have a late summer maximum. Galleta and blue grama grass are prominent in both areas. With respect to the revegetation trials, it was noted that cool-season grasses, such as crested wheatgrass and Russian wildrye performed well, while warm-season species (sand dropseed, alkali sacaton, blue grama) faired poorly due to summer drought.

Indian ricegrass shows particular promise for the Emery area because of its drought tolerance and ability of the local population to colonize disturbed areas. Although subject to mortality in a prolonged drought the population may be expected to survive if an adequate seed stock is present in the soil.

White sage (*Ceratoides lanata*) is perhaps the most promising shrub for reclamation of the central Utah region. This shrub has a wide distribution in North America, and occurs from salt deserts with annual precipitation of less than 7 inches to the subalpine zone with as much as 40 inches. Temperature, elevation and latitudinal ranges are likewise variable. A recent monograph (Stevens, et al, 1977) summarizes existing knowledge of the ecology, methods of establishment, and uses for reclamation of white sage. These authors note the plants outstanding drought tolerance, response to grazing and relative ease of establishment. Trials carried out on the Emery site were extremely encouraging, as white sage comprised 55% of shrubs established in the seed mixture.

Little rabbitbrush (*Chrysothamnus viscidiflorus*) may be established from seed, and is a common pioneer on disturbed sites in central Utah. Rubber rabbitbrush (*C. nauseousus*) is also a good pioneer and may be useful for soil surface stabilization. Both species tend to enhance the growth of other herbs and grasses (MacArthur et al, 1974).

A number of other shrubs should be considered for use in reclamation of this region, including mat saltbush, experimental saltbush hybrids and subspecies, Nevada ephedra, spiny hopsage, and prostrate kochia. It must be emphasized that species performance may vary greatly according to the source area from which wildlings or seeds are collected.