ABANDONED COAL MINE LANDS RESEARCH PROGRAM

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STRATEGIES FOR ESTABLISHMENT OF BIG SAGEBRUSH
(*Artemisia tridentata* spp. *wyomingensis*)
ON WYOMING MINED LANDS

G.E. SCHUMAN, D.T. BOOTH, AND J.R. COCKRELL, and J. GORES

Strategies for Establishment of Big Sagebrush (Artemisia tridentata spp. wyomingensis) on Wyoming Mined Lands.

G.E. Schuman, D.T. Booth, J.R. Cockrell, and J. Gores

Introduction

Wyoming big sagebrush is one of the most widely distributed and adapted shrub species in Wyoming and the region. Although considerable debate has surrounded its value, and the need for re-establishment during mined land reclamation, the fact remains that reclamationists are often advised and sometimes required to restore sagebrush to mined lands at densities that approximate predisturbance conditions. In light of this, methods for establishment of big sagebrush are an important area of revegetation research and technology development. Sagebrush is well adapted and persistent when mature, but establishment from seed has proven difficult. Problems include low seedling vigor, seedling inability to compete with herbaceous species, poor seed quality and/or ecotypic adaptation, inability of agronomic seeding methods to meet seed microsite requirements, and effects of altered soil conditions on establishment of the effective vesicular-arbuscular mycorrhizal (VAM) associations that are important to sagebrush seedling survival.

A research study was initiated in January 1991, to test several cultural approaches so as to define effective strategies for obtaining stands of big sagebrush on mined lands. Specific objectives include:

1. Efficacy of direct-applied topsoil for enhanced sagebrush stand establishment through effects of VAM and the topsoil as a seed source.
2. The value of stubble mulch crop of annual grain for sagebrush establishment through effects on snow catchment and microsite modification.
3. The usefulness of surficially applied hay/straw mulch in improving sagebrush establishment through seed/seedling protection and microsite modification.
4. The effect of competition from concurrently seeded herbaceous species on establishment of sagebrush, and
5. The value of seeding fourwing saltbush as a pioneer species for enhancing soil biological properties leading to the natural recruitment of sagebrush.

The research will allow evaluation of the primary questions and interactive effects among treatments in a manner to suggest an optimal combination of methods to enhance sagebrush revegetation. It is anticipated that application of technology developed from this project will directly benefit entities involved in western mined land reclamation.

Project Description

This project is composed of two compatible studies that are being conducted at North Antelope Coal, the "Establishment Study" and "Pioneer Plant Study" (Figure 1), and a survey of several revegetated mine sites to assess shrub revegetation success for seedings made in 1984 or before. The Establishment Study is testing techniques for sagebrush establishment and the Pioneer Plant Study is a longer-term investigation of plant succession manipulation intended to enhance sagebrush establishment.

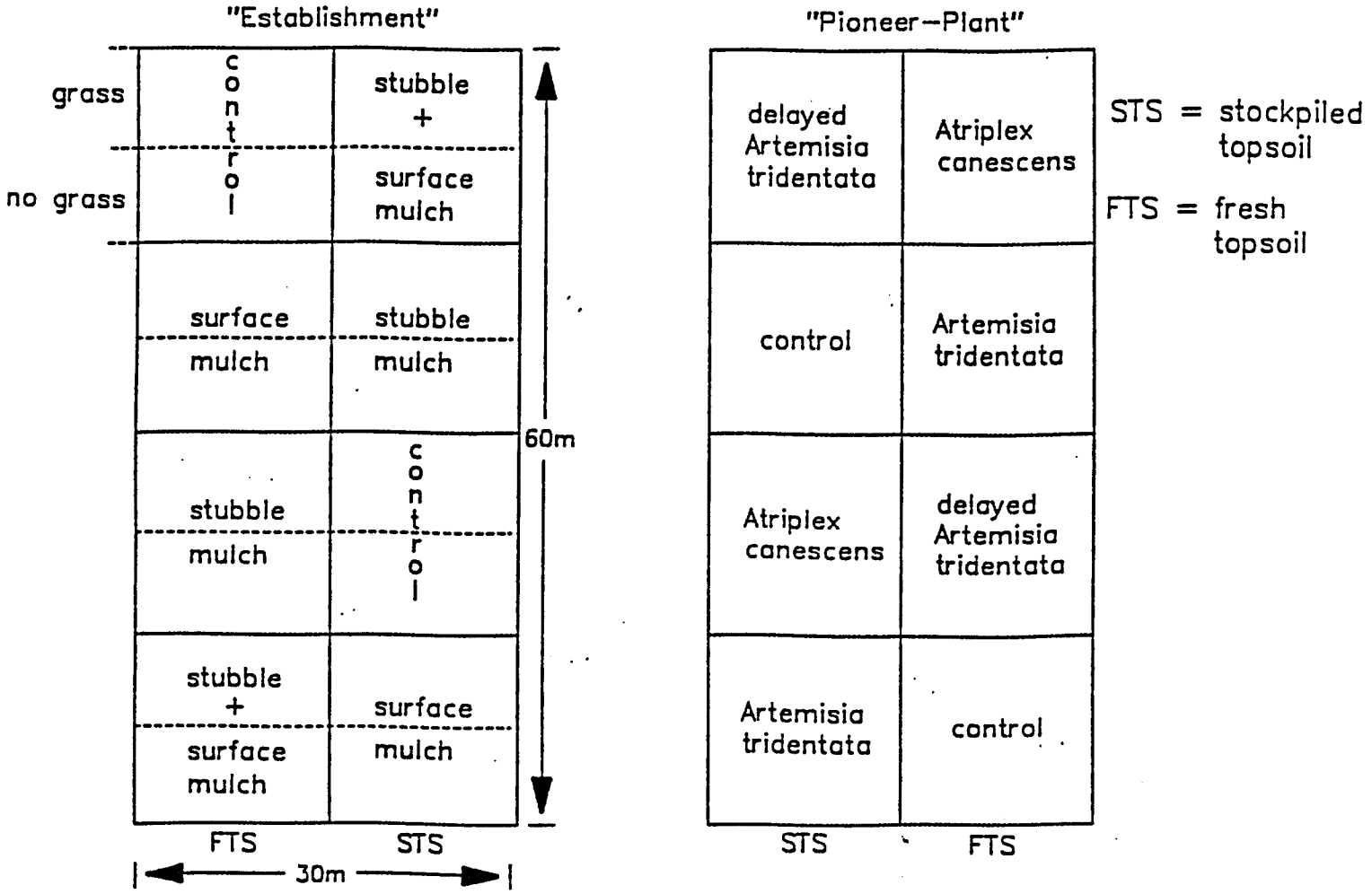

Figure 1. Field plot diagram of a representative block of the "Establishment" and fourwing saltbush "Pioneer Plant" studies; each block will be replicated three times with main treatments (Table 1) randomly assigned within the split-plot experimental design.

Establishment Study

This study is evaluating three sets of main treatment variables (Table 1): topsoil salvage procedures (fresh vs. stored), mulch method (stubble, surface, stubble + surface, and non-mulched), and level of herbaceous species competition (concurrently seeded grasses vs. no seeded grasses). Sagebrush was seeded similarly within all combinations of the above main treatments using broadcast methods. Figure 1 portrays the field plot design. Each block is divided into two topsoil treatment plots, each of which is split into four stubble treatments plots; each stubble treatment plot is further divided into three grass seedling-rate treatment plots.

The two topsoil treatments are included to evaluate the hypothesis that sagebrush establishment will be enhanced by use of fresh-stripped topsoil instead of stored topsoil (i.e., topsoil that had been stockpiled at least 5 years prior to respreading on mine spoils). It is postulated that freshly stripped topsoil will have a minimum loss of fertility, VAM and, possibly viability of seed bank sagebrush seeds, and therefore, a higher potential for natural establishment of sagebrush than stored soil.

The mulch treatments are to test the hypothesis that modifications seedbed conditions will improve establishment of surficially seeded sagebrush. Mulches are known to modify the seedbed microclimate with regard to temperature and moisture. Two mulches are being tested, alone and in combination: a grain stubble and a surface application of hay/straw mulch. Grain stubble has been found effective in trapping snow, modifying diurnal temperature fluctuation, and increasing water infiltration and storage in the soil. Because of these benefits, researchers found stubble mulching to result in greater grass seedling establishment than that with other mulching to result in greater grass seedling establishment than that with other mulching practices; the same results would be expected for sagebrush, particularly when surface seeded. The surficially applied hay/straw mulch will likely have little effect on snow accumulation, but may beneficially modify seedbed microclimate through water conservation and temperature moderation; it also may protect sagebrush seeds and seedlings from physical and desiccative effects of wind and/or insolation.

The grass seeding treatments are to evaluate the hypothesis that sagebrush will be more effectively established in absence of competition from concurrently seeded herbaceous species. The three treatments are absence and two seeding rates of a mixture of vigorous cool-season, native perennial grasses.

Pioneer Plant Study

This study involves two sets of main treatment variables (Table 1): topsoiling procedures (fresh vs. stored, for the same purposes described in the Establishment Study), and shrub seeding procedures. Mulch method (grain stubble) and level of seeded herbaceous species competition (no seeded grasses) is held constant under all main treatment combinations. The shrub seeding treatments imposed on each topsoil treatments are: a) seeded to sagebrush, b) seeded to fourwing saltbush, c) one year delayed seeding of sagebrush, and d) an unseeded control. After the first growing season for seeded shrubs, treatments a), b) and c) will be over-seeded annually with sagebrush to assure that viable seed is present each spring. The experimental design (Figure 1) divides each block into two topsoil treatment plots, each of which are further split into four shrub seeding treatment plots.

The topsoil and shrub seeding treatments allow testing for two contrasting hypotheses. The first,

hereafter referred to as the "exclusion" hypothesis, is that fourwing saltbush seeding rates greater than 2.2 kg/ha (26 seeds/m^2) result in monotypic stands that exclude invasion of other species, particularly

Table 1. Treatments applied in "Establishment" and fourwing saltbush "Pioneer Plant" studies. All combinations of main treatments will be implemented within each study.

Treatments	Establishment Study	Fourwing Saltbush Pioneer Plant Study
TOPSOIL	1. Fresh Topsoil 2. Stored Topsoil	1. Fresh Topsoil 2. Stored Topsoil
MULCH	1. Stubble Mulch 2. Surface Mulch combinations) 3. Stubble + Surface Mulch 4. Control (no mulch)	Not Varied (Stubble mulching will be practiced on all treatment
COMPETITION	1. Seeded Cool-Season Grass Mixture 2. Control (no seeded grasses)	Not Varied (No grasses will be seeded)
SHRUB SEEDING	Not Varied (sagebrush will be seeded on all treatment combinations)	1. Fourwing Saltbush seeded Year 1 and overseeded with sagebrush Years 2 & 3. 2. Sagebrush seeded Year 1 and overseeded with sagebrush in Years 2 & 3. 3. Delayed seeding: no shrubs seeded Year 1, sagebrush initially seeded in Year 2 and overseeded in Year 3. 4. Control (no shrubs seeded)

climax shrubs such as sagebrush. It has been suggested that if seed mixtures contained more sagebrush and less fourwing saltbush, more sagebrush would establish on reseeded mined land.

The contrasting view, hereafter referred to as the "pioneer plant" hypothesis, is that planting sagebrush and other climax plants before sufficient soil improvement (biological and physical) has occurred predestines poor survival of climax plant seedlings. It is postulated that fourwing saltbush is a pioneer species that can be used to prepare the site for the later-seral species big sagebrush. Saltbush densities of one plant/m^2 may not exclude sagebrush, but instead may promote the soil improvement necessary for sagebrush to establish and survive. If this hypothetical relationship is valid, the most successful and economical method of obtaining healthy stands of sagebrush may be to initially plant a suitable pioneer species such as fourwing saltbush. The rationale for this view is: a) the perceived need for disturbed soils to regain, through effects of the pioneer species, predisturbance levels of VAM and other developmental attributes required to support sagebrush populations, and b) the beneficial modification of seedbed microclimate that may occur with the establishment of a pioneer shrub species. Fourwing saltbush has been previously proposed and justified as an effective pioneer species that will promote the desired soil and microclimate changes.

Comparisons of vegetation responses among the various treatment combinations will allow us to evaluate sagebrush establishment, survival and plant succession with and without fourwing saltbush as a pioneer species. If the exclusion hypothesis is true, there will be little interaction between topsoil and shrub seeding treatments. Plots seeded to sagebrush only will have the greatest, and plots seeded to fourwing saltbush will have the least sagebrush development. Conversely, there will be significant topsoil and shrub seeding treatment interactions if the pioneer plant hypothesis is true. In that case, sagebrush development on stored topsoil should be greater where fourwing saltbush was established than where it was not. Sagebrush should also have greater development on the fresh topsoil than where it was not. Sagebrush should also have greater development on the fresh topsoil than on stored topsoil. In all treatments, survival of sagebrush seedlings should increase as soils and plant communities develop. Proper evaluation of the pioneer plant theory will require additional years beyond the period covered by this proposal.

Survey Study

A Survey Study was initiated to compliment the Establishment and Pioneer Studies. The general objective of the study was to evaluate reclaimed mine sites within Wyoming that had been revegetated at least 10 years to determine if direct seeding of big sagebrush had resulted in sagebrush establishment and to determine if natural invasion of big sagebrush is occurring where it was not included in the revegetation seed mixture. Revegetated mine sites were selected at 4 coal mines in the Powder River Basin, 3 coal mine sites in southern/southwestern Wyoming and a uranium mine in central Wyoming. Two revegetation sites reseeded at different times were sampled at 3 of the coal mines. Twenty 50 m belt transects were sampled at all sites except two, where either 5 or 10 transects were sampled because of the small size of the revegetated area. Each belt transect was 4 m wide which resulted in a transect of 200 m^2. All shrubs within the belt transect were identified and counted. The shrubs were listed as alive or dead and shrub height and stem diameter determined. Shrub and grass cover was determined using point frame and line-intercept methods.

PROGRESS REPORT

The project was initiated January 1, 1991, and is being carried out in cooperation with North Antelope Coal Company, north of Douglas. Mr. Scott Belden, Environmental Supervisor with North Antelope Coal Company, is our site coordinator and cooperator.

Establishment Study

Topsoil source had a significant effect on sagebrush emergence, first year survival, and second year seedling establishment (Table 2). Seedling emergence and establishment the second year after seeding was unexpected. Young and Evans (1989) found no detectable seed reserve within 6 months after seed dispersal, and concluded that viability was short-lived. Our data indicates that sagebrush seed broadcast in February 1992 also produced seedings in 1993. In fact, the number of sagebrush seedlings observed in 1993 was generally several fold greater than those counted during the first year after seeding.

The effect of mulch type on sagebrush seedling establishment has become less important (Table 2). During the first year after seeding the stubble and surface mulch were superior to the combination of the two; however, after two years of seedling establishment there is little difference between the mulch types except for the control (no mulch). However, after 3 full growing season little difference exist between the mulch treatments. The data continues to indicate that microsite environment may play a significant role in sagebrush germination and early establishment.

Grass competition continues to play a significant role in establishment and survival of big sagebrush (Table 2). The number of sagebrush seedlings established when no grass competition was imposed is over 4 times that when a typical grass seeding rate was used or when a rate two times the normal rate was used. This data suggests that grass competition significantly affects sagebrush establishment from seed and probably will continue to limit recruitment of shrubs.

Sagebrush seedlings were collected from the various treatment plots and evaluated for VAM infection. The plants collected were considered to be those that emerged in 1992 and were outside of the permanent 1 m^2 quadrats used to monitor seedling emergence and development. VAM infection percentage was very consistent and varied little between topsoil source, mulch type and grass competition (Table 3). The lack of a difference in VAM infection percentage was very consistent and varied little between topsoil source, mulch type and grass competition (Table 3). The lack of VAM infection percentage differences may reflect: (1) that the VAM inoculum was inadequate in both the stockpiled and fresh stripped topsoil, (2) that only those sagebrush seedlings that were infected had survived early seedling stages, and/or (3) that VAM inoculum had built up to levels necessary for infection in the stockpiled topsoil through reintroduction via soil movement and biological development (Loree and Williams, 1984).

The large increase in sagebrush seedlings in 1993 and 1994 was surprising, especially the large increase observed between the June and October 1993 counts. This increase can be attributed to two things: (1) the small sagebrush seedlings were difficult to observe during the June count because of small dense annual weeds and (2) the precipitation during the months of June, July, and August was significantly above normal and the temperatures for that period were below normal which allowed germination and establishment of sagebrush after the June observations were made. Mr. Scott Belden, Environmental Supervisor at North Antelope Coal Company, observed delays of over a month in grass emergence on areas reseeded that spring due to the below normal temperatures.

The sagebrush establishment data suggest that if sagebrush is to be successfully established on mined lands then it should be broadcast seeded on fresh stripped topsoil, a mulch used, and herbaceous plan

Table 2. Sagebrush seedling numbers (seedling/m^2) as affected by topsoil source, mulch type, grass competition and time.

Treatment	Spring 92	Fall 92	Spring 93	Fall 93	Fall 94
	Seedlings/m^2				
Topsoil Source					
Fresh	1.52	1.24	2.52	4.506	6.82
Stockpiled	0.03	0.03	0.48	2.26	3.23
Mulch Type					
Stubble	1.17	0.96	1.99	4.33	5.76
Surface	1.25	1.04	1.89	4.18	5.51
Stubble + Surface	0.66	0.54	1.68	3.12	4.45
Control	0.01	0	0.43	1.99	4.07
Grass Competition (kg PLS/ha)					
0	1.88	1.60	3.05	6.66	6.26
16	0.34	0.21	0.74	1.98	4.58
32	0.09	0.37	0.71	1.56	4.18

Table 3. VAM Infection Percentage of Sagebrush Seedlings

Treatment Variable	% Infection	Number of Seedlings
Topsoil Source		
Fresh	66	66
Stockpiled	76	66
Mulch Type		
Stubble	73	36
Surface	71	36
Stubble + Surface	72	36
Control	67	24
Grass Competition		
(kg PLS/ha)		
0	73	69
16	68	63

competition be limited. This may require a technology that reduces herbaceous species seeding rates or that sagebrush be seeded alone in strips that are bounded on all sides by a standard reclamation seeding mixture. These strips would be limited in size to ensure that erosion was not a problem, but would be adequate in size to achieve shrub establishment density standards. A strip planting technique would be the best alternative to ensure stability of the soil resource and the strip sagebrush planting can also act as a seed source for natural recruitment of sagebrush into surrounding revegetated areas. The data also suggest that the sagebrush seed viability is much longer than previously thought. We are confident that the seedlings observed are coming from sown seed because control plots of the adjoining Pioneer study do not have any sagebrush seedlings present. These plots would represent any seed dispersal from native sagebrush communities.

Pioneer Study

Sagebrush seedling numbers on the sagebrush plots were much greater in the spring of 1993, fall of 1993 and spring of 1994 than the fall 1992 counts (Table 4). Counts of fourwing saltbush indicates little mortality during the second growing season. Sagebrush establishment on the fourwing saltbush plots is roughly half of that on the delayed sagebrush plots. By an examination of the pattern of plant occurrence in sample quadrats, we may be able to determine if this pattern is due to the influence of the saltbush seedlings or a random occurrence. The number of sagebrush seedlings on the saltbush plots is comparable to that counted on the fresh topsoil-delayed sagebrush treatment. Overall the fresh topsoil plots have more sagebrush seedlings present than observed on the stockpiled topsoil.

Survey Study

Survey studies were initiated this past summer to evaluate the effectiveness of past attempts to establish sagebrush by direct seeding and to evaluate to what degree natural invasion of sagebrush is occurring on revegetated mined lands in Wyoming. Belt transects were used to evaluate sagebrush seedling establishment on mined lands that had been revegetated in 1977-1984. Two types of reclamation/reseeding types were evaluated: (1)Areas seeded with a mixture of grass, *Artemisia tridentata spp. wyomingensis*, and *Atriplex canescens*, and (2) Areas seeded with a mixture of grass and Atriplex canescens. No stands of fourwing saltbush seed alone are available for sampling. Six mine sites seeded to type 1 and three sites seeded to the type 2 mixtures were sampled. The data in Table 5 show that an average of 0.4 sagebrush/m^2were present in the sites where sagebrush was seeded, this density would meet previously proposed standards.. Where sagebrush was not seeded with the grass-shrub mixture it represents a very small component (0.003 seedlings/m^2) of the community, indicating that natural seed dispersal and invasion are occurring very slowly. These data indicate that if sagebrush is intended to be a significant component of the plant community it will be necessary to include it in the seed mixture.

Table 4. Sagebrush and fourwing saltbush seedling numbers as influenced by seeding treatment.

Treatment	Topsoil Source	Spr 1992	Fall 1992	Spr 1993	Fall 1993	Spr 1994
		seedlings/m^2				
Sagebrush seeded 1st and 2nd year	Stockpiled	1.3	0.4	7.4	10.3	12.3
	Fresh	0.2	0.1	3.5	3.8	7.0
Sagebrush seeded 2nd year only	Stockpiled	0	0	3.4	6.2	5.6
	Fresh	0	0	3.9	6.3	11.9
Saltbush seeded 1st and Sagebrush 2nd year	Stockpiled	(3.9)	(3.5)	(3.9)0.9	(3.3)0.9	(3.1)3.2
	Fresh	(4.7)	(4.2)	(4.5)2.0	(4.7)3.7	(3.8)7.5
Control (not seeded)	Stockpiled	0	0	0	0	0
	Fresh	0	0	0	0	0

Numbers in ( ) are saltbush seedlings/m^2

Future Plans

We are continuing both the Establishment and Pioneer Study phases of this research to further evaluate the sagebrush survival and growth and to further evaluate the role of VAM in sagebrush establishment and survival. We are also presently using photographic methods to evaluate both the fourwing saltbush and sagebrush seedlings, in the Pioneer Study, to better understand the pioneer plant relationship.

Table 5. *Artemisia tridentata spp. wyomingensis* and *Atriplex canescens* density on reclamation seeded 1977-1984 in Wyoming.

Artemisia tridentata, Atriplex canescens and grass seeded, 1980-1984, six mines.

	Artr		Atca	
	Range	Mean	Range	Mean
#seedlings/m^2	0.024-1.712	0.419	0-0.268	0.065

Atriplex canescens and grass seeded, 1977-1981, three mines.

#seedlings/m^2	0-0.010	0.003	0.062-0.694	0.215

Literature Cited

Loree, M.A.J. and S.E. Williams. 1984. Vesicular-arbuscular mycorrhizae and severe land disturbance. P. 1-14. In: S.E. Williams and M.F. Allen (eds). VA Mycorrhizae and Reclamation of Arid and Semiarid Lands. Univ. Wyo. Agr. Stn. Rep. SA1261.

Young, J.A. and R.A. Evans. 1989. Dispersal and germination of big sagebrush (Artemisia tridentata) seeds. Weed Science 37:201-206.

TOXICOLOGIC EVALUATION OF CHRONIC SELENOSIS IN WYOMING HERBIVORES

M.F. RAISBECK, E.L. BELDEN, D. O'TOOLE,
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Toxicologic Evaluation of Chronic Selenosis in Wyoming Herbivores

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The objective of this project is improved understanding of chronic selenosis in economically important herbivore species in Wyoming. As reported previously (AMLRP report Fall '93) we devoted March through October of 1993 to an intensive experimental examination of chronic selenosis in yearling steers. Efforts since that report have been devoted to detailed histopathologic, chemical and immunological analysis of tissues from these animals. A second species, pronghorn antelope, was examined in a chronic experiment structured to validate the results of the steer study in the other major economic species at risk on reclaimed mine lands. This report summarizes results of AMLRP-funded or partially funded research since the Fall '93 report.

Immunology, Steers

As outlined in previous reports, yearling steer calves were exposed to measured daily doses of Na_2SeO_3 or selenomethionine which approximated 5, 10 and 30 ppm dietary selenium exposure. Immunologic evaluation of these calves was completed in the Spring of '94. Basically, there were no statistically significant differences between treatment groups in any of a number of *in vitro* parameters (eg. lymphocyte blastogenesis with PHA, LPS, Con-A, total lymphocyte counts, IL2 and IL4-like cytokine production, and total immunoglobulin production) of immune competence measured. Significantly, however, there was a dose-related decrease in primary antibody production to foreign protein immunization. The threshold of this effect is approximately 10 ppm dietary Se.

The latter result is interesting for several reasons. This is the first report of selenium-induced immunotoxicity in cattle, and one of only a very, very few in any species. Repeated attempts to impact antibody production *in vitro* were successful only with chemical forms and concentrations of Se which were directly cytotoxic. We demonstrated a similar effect in another species (mice) given selenocystine, Na_2SeO_3 or selenomethionine, and antelope on seleniferous hay and have evidence of similar effects in cattle grazing a moderately seleniferous mine site in northeastern Wyoming. Thus, we believe this effect is more than just a single species laboratory curiosity.

Our interpretation of the results of these experiments is that Se somehow interferes with antigen processing and presentation to lymphocytes and or interferes with other

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cellular responses required for antibody production. Inability to duplicate the Se composition of the *in vivo* cellular milieu has so far prevented elucidating the nature of the cellular impairment.

Decreased primary antibody response had no effect on the overall well-being of the steers of the Summer, '93 experiment. However, under range conditions, with stress, sub-optimal sanitation and nutrition, it could increase susceptibility to infectious diseases. Decreased disease resistance, in turn, might result in clinical illness and death, or, more likely, in decreased productivity. Selenium-decreased immune competence is of potentially even greater significance in wildlife populations, which lack the protection of vaccines, supplemental feedstuffs and medical care which domestic herbivores receive.

Pathology, Steers

Histologic examination of 1600 tissue specimens from the steer experiment was completed. The most striking finding was in the hooves of an animal (#14) which was force fed selenomethionine by gelatin capsule and which subsequently developed visible clinical signs of alkali disease. Lesions consisted of disorderly formation of tubular horn (the principal structural component of hooves), secondary to hyperplasia, acanthosis and dyskeratosis in epithelium of the hoof. Similar but less severe lesions were discovered in one mid-dose (10 ppm) selenomethionine, all of the high-dose selenomethionine (30 ppm) and one high dose (30 ppm) Na_2SeO_3 steers, and from a heifer which died of Se-induced heart failure after 1 mg/kg BW Na_2SeO_3 for 80 days in a separate experiment (AMLRP Fall '92). One high dose selenomethionine steer and #14 also had follicular atrophy in the skin of the distal tail, accounting for hair loss. With the exception of #14, none of these animals evidenced any grossly visible hoof abnormalities, nor any lameness. This is the first report of the pathologic basis of the hoof and hair lesions of alkali disease.

Antelope Study

To validate the steer results in a second, non-domestic species, and to evaluate the effect of "natural" selenium an experiment was undertaken in antelope from November through May. Captive-raised antelope (4 adults, 5 yearlings) were maintained on a diet of 40% alfalfa, 60% high selenium grass hay (15 ppm total dietary Se as fed) for 6 months after an acclimation period. Low Se native grass hay was similarly ground with alfalfa and fed as a control diet. Although the antelope initially ate the ground grass/alfalfa diet readily, feed refusal of both the control and experimental diet was a recurring problem from day 30 until the end of the study.

Due to the small number of animals available and the loss of a control animal to an iatrogenic infection, we have de-emphasized statistical analysis of this study. Feed consumption and weight gain were less in antelope on the high Se ration, especially the fawns. Clinical pathology and biochemistry did not reveal any obvious differences between the groups, nor deviations from historical normals. Blood Se

concentrations, while elevated in the experimental group, were more similar to the bovine $SeO_3^=$ group than to the bovine selenomethionine group.

Gross *post mortem* examination of the antelope revealed only incidental lesions. Histopathologic evaluation of tissues, including a detailed examination of hooves, from the antelope did not reveal any evidence of Se-induced effects; hooves and skin were normal. A range of mild lesions were present in some of the animals, both controls and experimentals, such as degeneration of white matter in the spinal cord, goiter and mineralization in the posterior brain stem; these are incidental findings. Likewise, repeated clinical pathology and biochemistry did not indicate any adverse health effects attributable to the diet.

There were no consistent trends in the *in vitro* immunocompetency assays associated with the high Se diet. It should be noted that the flighty nature of the species, plus physical sampling difficulties resulted in a great deal of inter-sample variability which may have compromised our ability to detect significant trends. Nevertheless, the primary antibody response to hen egg albumin was less in animals on the high Se hay diet than in controls. This result parallels and lends credence to those in studies in other species.

Publications/technology transfer

To date, experiments funded in part by the AMLRP have resulted in one Master's thesis, three refereed publications accepted or in print with another three in preparation and eleven presentations at regional, national or international meetings exclusive of the AMLRP.

Peer-reviewed publications

O'Toole D, Raisbeck MF: Pathology of experimentally induced chronic selenosis ("alkali disease") in yearling cattle. *J Vet Diagn Invest*, accepted Oct, 1994.

O'Toole D, Castle LE, Raisbeck MF: Comparison of histochemical autometallography (Danscher's stain) to chemical analysis for detection of selenium in tissues. *J Vet Diagn Invest*, accepted Sept, 1994.

O'Toole D, Raisbeck MF, Case JC, Whitson TD: Irradicable canard: an exegesis of selenium-induced "blind staggers" and the extent of historical livestock losses attributed to selenosis on western U. S. rangelands. *J Vet Diagn Invest*, submitted Oct, 1994.

Belden EL, Schamber R, Raisbeck, MF: Chronic selenium immunotoxicity in cattle. in preparation for *Infect Immun*.

Schamber R, Belden EL, Raisbeck MF: *In vitro* selenium immunotoxicity. in

preparation for *Infect Immun.*

Raisbeck MF, O'Toole D, Belden EL: Experimental chronic selenosis in cattle. in preparation for *Tox Appl Pharm.*

Thesis, other UW research publications

Schamber R: *Selenium immunotoxicity.* MS thesis, UW Dept Vet Sci, 1994.

Castle LE, Raisbeck MF, O'Toole D: Comparative analysis of rat tissue selenium concentration by chemistry and histochemistry. *McNair Scholar's Journal,* July, 1994.

Invited presentations

Raisbeck MF, O'Toole D, Belden EL, Sanchez DA, Siemion RA: Progress in selenium research. *Planning, Rehabilitation and Treatment of Disturbed Lands, 6th Billings Symposium,* Billings, MT 3/24/93.

Raisbeck MF, O'Toole D, Belden EL, Sanchez DA, Siemion RA: Selenium vs. sulfur: A comparison of effects in range mammals. *Planning, Rehabilitation and Treatment of Disturbed Lands, 6th Billings Symposium,* Billings, MT 3/25/93.

Raisbeck MF: Selenium toxicity. 3 hr presentation on *"Advances in Science and Medicine"*, Am Vet Med Assn, San Francisco, CA 7/12/94.

Raisbeck MF, O'Toole D, Sanchez DA, Siemion RL: Re-evaluation of Selenium Toxicity in Grazing Mammals. planned for ASSMR, Gillette, WY June, 1995.

Schamber RA, Belden EL, Raisbeck MF: Selenium immunotoxicity. planned for ASSMR, Gillette, WY June, 1995.

Raisbeck MF, O'Toole D, Belden EL, Waggoner JW, Thorne ET: Toxicologic evaluation of chronic selenosis in Wyoming herbivores. planned for ASSMR, Gillette, WY June, 1995.

Presentations

Castle LE, Raisbeck MF, O'Toole D: Comparative analysis of rat tissue selenium concentration by chemistry and histochemistry. UW McNair Scholar's Program, Laramie, WY, 7/28/93.

O'Toole D, Raisbeck MF: Danscher staining in tissue from rats exposed to oral selenium: *Caveat tinctor!* Am Assn Vet Lab Diagn, Las Vegas, NV 10/26/93.

Schamber R, Belden EL, Raisbeck MF: Selenium immunotoxicity. Rocky Mountain ASM Spring 1994 meeting, Boulder, CO. (Awarded best student presentation).

Raisbeck MF, O'Toole D, and Belden EL: Comparative toxicology of selenite and selenomethionine in herbivores. Am Assn Vet Lab Diagn, Las Vegas, NV 10/26/93.

O'Toole D, Raisbeck MF: Comparative pathology of selenite and selenomethionine. Am Assn Vet Lab Diagn, Las Vegas, NV 10/26/93.

METHODOLOGY FOR THE GEOMORPHIC CLASSIFICATION AND DESIGN OF DRAINAGE BASINS AND STREAM CHANNELS IN THE POWDER RIVER COAL FIELD OF WYOMING

T.A. WESCHE, H.W. LOWHAM, R.L. DADDOW, M.E. SMITH

SEMI-ANNUAL REPORT FOR THE ABANDONED COAL MINE LAND RESEARCH PROGRAM

METHODOLOGY FOR THE GEOMORPHIC CLASSIFICATION AND DESIGN OF DRAINAGE BASINS AND STREAM CHANNELS IN THE POWDER RIVER COAL FIELD OF WYOMING

PRINCIPAL INVESTIGATORS

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Richard L. Daddow	-	U.S. Geological Survey / Water Resources Division

GRADUATE RESEARCH

A CLASSIFICATION OF DRAINAGE BASINS IN THE EASTERN POWDER RIVER BASIN COAL FIELD OF WYOMING.

Anthony J. Anderson - University of Wyoming

CHARACTERIZATION OF DRAINAGE NETWORKS FOR MINE LAND RECLAMATION IN THE EASTERN POWDER RIVER BASIN, WYOMING

Lee E. Jensen - University of Wyoming

OVERVIEW OF DESIGN PROCEDURES USED FOR RECLAMATION OF DRAINAGE BASINS AND STREAM CHANNELS IN THE POWDER RIVER BASIN

Suzy L. Noecker - University of Wyoming

October 31, 1994

Introduction

Three graduate research studies have been completed under this project. Each study addressed one of the primary objectives outlined in the project proposal: 1) inventory, review, and summarize design procedures being used for reconstruction and reclamation of drainage basins and stream channels in the Powder River coal field of Wyoming; 2) develop a classification system for drainage basins and stream channels in the Powder River coal field of Wyoming based on the natural, physical characteristics of selected groups of small drainage basins; and 3) analyze and summarize the geomorphic characteristics of different classes or types of drainage basins and stream channels, thereby developing geomorphic methodology and criteria for the design of reconstructed drainage basins and stream channels.

Progress During Reporting Period

The two primary graduate research projects were completed during the reporting period. Master's of Science Theses in Range Management/ Water Resources were finalized by Lee E. Jensen and Anthony J. Anderson and approved by the Graduate School of the University of Wyoming (See below). These theses address the second and third objectives of the overall project respectively. A third graduate research project, by Suzy Noecker, addresses the first objective of the overall project and is now in press. The first two theses compiled and analyzed an extensive database regarding drainage basin and stream channel morphology in the Eastern Powder River Basin coal field. The three graduate research projects are currently being compiled into the final technical report for submission to the Abandoned Coal Mined Land Research Program. A draft of the final report is expected to be submitted to AML for review on or about August 31, 1994.

Status of Project Reports

Jensen, Lee E. Characterization of Drainage Networks for Mine Land Reclamation in the Eastern Powder River Basin, Wyoming. M.S. thesis, Universiy of Wyoming, Department of Range Management / Wyoming Water Resources Center, July 1994.

Anderson, Anthony J. A Classification of Drainage Basins in the Eastern Powder River Basin Coal Field of Wyoming. M.S. thesis, University of Wyoming, Department of Range Management / Wyoming Water Resources Center, July 1994.

Noecker, Suzy L. (In Press) Overview of Design Procedures Used for Reclamation of Drainage Basins and Stream Channels in the Powder River Basin. M.S. thesis, University of Wyoming, Department of Range Management / Wyoming Water Resources Center.

Final Technical Report to AML

Jensen, Lee E., A. J. Anderson, S. L. Noecker, and T. A. Wesche, (In Press). Methodology for the Geomorphic Classification and Design of Drainage Basins and Stream Channels in the Eastern Powder River Basin coal field of Wyoming. Final technical report to the Abandoned Coal Mine Land Research Program. University of Wyoming Office of Research. Laramie, Wyoming.

Summary of Results

Three hundred eighty-four low order drainage basins (64 third order, 128 second order, and 192 first order) were selected from USGS, 1:24000, 7.5 minute, topographic quadrangles. The drainage basins were delineated, digitized, and analyzed. A database containing 31 variables was compiled using Lotus 1-2-3. Fifteen quantitative and six categorical variables were used in multivariate statistical analysis to characterize and describe each basin. The multivariate statistics, including principal components analysis, cluster analysis, and discriminant function analysis were used to categorize the drainage basins in each order. The resulting categories were adjusted as necessary, based on ground-truthing, professional judgment, and correlation of key parameters.

The resulting classification has three categories, or strata, defined by geology, basin area, and gross basin slope of the third order drainage basin. Second and first order basins were classified by the third order stream to which they are tributary.

Field investigations were conducted to quantify cross-sectional and longitudinal profile characteristics of 58 drainage networks selected from the 384 drainage basins. Data collected during this investigation included: 1) surveyed cross sections at several locations along each study reach; 2) surveyed longitudinal profiles of first and second order networks; 3) estimates of Manning's "n" for the study reaches with stream channels; 4) type and composition of the vegetative community; 5) observations regarding the geology, and geomorphology of each cross section and stream reach; and 6) photographic documentation of each cross section and stream reach.

The geomorphic characteristics of the basins in each strata were then used to develop design equations for the reconstruction of drainage basins and networks within each strata by order. The stream channel morphology was related to geomorphic characteristics of the drainage basin at this time. Approximately 200 statistically significant design equations were developed for reclamation in the Eastern Powder River Basin coal field.

Future Work

The final report will be submitted to AML for their review on or about October 31, 1994. Any further editing necessary will be performed and all required project completion documents will be submitted.

SPECIFICATION AND RECOMMENDATIONS FOR REPAIR OF RESIDENTIAL STRUCTURES DAMAGED BY GROUND MOVEMENTS RELATED TO MINE SUBSIDENCE

K.D. BASHAM, T.R. CARTER, and W.L. JOHNSON

SPECIFICATIONS AND RECOMMENDATIONS FOR REPAIR OF RESIDENTIAL STRUCTURES DAMAGED BY GROUND MOVEMENTS RELATED TO MINE SUBSIDENCE

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Amount: $59,000

Project Duration: April 10, 1993 to December 31, 1994

Abstract:

Abandoned mines underlay many areas of Wyoming. As mine cavities collapse they can cause settlement (subsidence) and ground distortions on the surface which may damage or even destroy buildings and affixed utilities. To increase the ability of building officials, contractors, architects, engineers, and homeowners of Wyoming to mitigate subsidence related building damage, the authors are reviewing and updating the Specifications and Recommendations For Residential Construction Subjected To Ground Movements Related To Mine Subsidence and developing a document entitled Specifications and Recommendations For Repair Of Residential Structures Damaged By Ground Movements Related To Mine Subsidence. The purpose of the first document, developed by the University of Wyoming in 1988 and funded by the WY DEQ/LQD, is to provide construction specifications and recommendations for new structures built in areas with a potential for mine subsidence. The intent of the construction specifications and recommendations document is to provide guidelines for residential construction that minimize subsidence related building damage. The document also serves as an essential part of the qualifying process to insure new structures through the Wyoming Mine Subsidence Insurance Program. The second document of repair manual will consist of guidelines, recommendations, and repair schemes for repair of residential structures damaged by mine subsidence type ground movements. The repair manual will help architects, engineers, construction professionals, and homeowners of Wyoming to efficiently devise and execute suitable repair schemes. The repair manual will also set a standard for optimizing subsidence related building repair which will help minimize future repeat subsidence damage and insurance reclaims. To help introduce both documents, the investigators plan to develop information pamphlets on mine subsidence, related building damage and repair schemes. Information pamphlets will provide initial guidance with regards to subsidence to homeowners and the building community. In summary, the results of this project will enhance the ability of Wyoming communities to minimize the potential residential building damage caused by mine subsidence and to optimize subsidence repair schemes.

Project Goals:

1) To review and update the DEQ - Land Quality Division's document entitled Specifications and Recommendations For Residential Construction Subjected To Ground Movements Related To Mine Subsidence.

2. To develop and publish a document entitled Specifications and Recommendations For Repair Of Residential Structures Damaged By Ground Movements Related To Mine Subsidence.

3. To develop information pamphlets to introduce both documents as well as an overview of subsidence related problems in Wyoming to homeowners and the building community.

Progress:

Phase I Develop and publish 2nd edition of
Specifications and Recommendations For Residential Construction Subjected To Ground Movements Related To Mine Subsidence

95 Percent Complete (out for review)

Phase II Develop and publish

Specifications and Recommendations For Repair Of Residential Structures Damaged By Ground Movements Related To Mine Subsidence

60 Percent Complete

Funding 17 Percent Remaining

THE INFLUENCE OF POST-HARVEST AND PREPLANTING SEED TREATMENT ON SAGEBRUSH SEEDLING VIGOR

D.T. BOOTH, E.E. ROOS, and Y. BAI

THE INFLUENCE OF POST-HARVEST AND PRE-PLANTING SEED TREATMENT ON SAGEBRUSH SEEDLING VIGOR

D.T. Booth, E.E. Roos, and Y. Bai

INTRODUCTION

Returning native shrubs to the post-mining plant community in a cost-efficient manner has remained a challenge for western reclamationists. Stand failure after direct seeding sagebrush may be due to inherently low seedling vigor, or to a need for better seed handling and sowing techniques. Harvesting and processing sagebrush seed for market is a relatively new enterprise and we have much that we do not know. As to improving seedling vigor, we know that controlled imbibition has benefited many agronomic species and is being used for crops where improved seedling vigor and synchronous seedling emergence are desired. Since Wyoming big sagebrush is commonly recommended for revegetation of mined lands, and since there is a need to improve seeding success, a study was initiated in the fall of 1993 to measure the effect of post-harvest seed handling on seed quality and the effectiveness of pre-sowing seed moisture manipulation to improve seedling vigor. The research objectives were to:

1. determine the effects on seed quality of processing sagebrush seed with an industrial debearder.

2. develop seed moisture curves to show the influence of initial seed moisture, time and treatment temperature on seed humidification;

3. evaluate the interaction of seed humidification, imbibition, and temperature on seed germination and seedling vigor;

4. establish an optimal seed handling technique for this species and evaluate the technique in its practical application on a mine reclamation site.

Project Description

The research is a cooperative effort by scientists of

the High Plains Grasslands Research Station, Cheyenne, WY (ARS), the National Seed Storage Laboratory, Fort Collins, CO (ARS), the University of Wyoming, Laramie, WY, and Wind River Seed Co. (Manderson, WY). The seed for the studies has been obtained from commercial suppliers and represents sources being used by mining companies in this region. Post-harvest handling, including seed processing, has also followed common commercial practice. The following studies have been completed, or are ongoing:

1. Pre-dispersal seed moisture. Seeds from several locations were collected in late winter. The initial seed moisture content was determined and seed germination and seedling vigor were tested.

2. Post-harvest seed handling. A 48" commercial debearder was be used for seed processing. A debearder is a machine developed to remove the grain from the seed head of bearded (awned) plants such as barley or wheat. It consists of rotating and fixed tines enclosed in a cylinder and set at an angle so that materials fed into one end of the cylinder are moved through the machine to the opposite end. Debearders are used for many types of seed cleaning, including processing sagebrush. Questions by industry representatives on the use and misuse of debearders for sagebrush seed prompted us to investigate the effect of debearder processing on seed quality.

3. Seed humidification. Seed humidification refers to holding seed over free water in a high humidity environment. The effect of this treatment was tested at 3 temperatures (5, 10 and 15°C) over 10 time periods (through 15 days) and for 2 seed collections. Seed moisture curves were developed to describe the influences of seed collections, initial seed moisture, and humidification temperature and duration on seed germination and seedling vigor.

Progress Report

Pre-dispersal seed moisture study.

Seeds collected from 5 locations in Wyoming in February 1994 exhibited different initial seed moisture at the time of harvest, ranging from 2.3 to 9.0%. Seed weight was also different among collections, averaging 0.022 to 0.032 g/100 seeds. After 4 days of imbibition at 5°C and 14 days of incubation at 20°C, total germination, germination rate and seedling vigor were different among the 5 collections. Seeds with moderate moisture content supported the highest and fastest germination. However, seeds with low moisture

content had the best vigor. Higher seed weight was correlated with higher germination and germination rate, but not related to seedling vigor.

Some researchers have implied that sagebrush seed is generally shed rapidly in the fall. However, there is large variations in the dispersal phenology among individuals within a population of fringed sagebrush (Artemisia frigida Willd.) and similar variation was evident when we collected big sagebrush seeds in February.

Post-harvest seed handling study.

Seeds were collected from 2 Wyoming locations in late October 1993, put in large woven polypropylene bags, then stored in an un-heated warehouse for approximately 4.5 months before being processed with a 48" Simon-Day debearder. Seed materials were processed for 2, 4, 6, 8 or 10 minutes. Temperature and (RH) inside the debearder were monitored (Fig. 1) and the moisture content of seed material, number of undamaged seeds per gram of material, the percent of seeds which had the pericarp removed, and average length of stems in the material were determined for each interval. Seed germination and seedling vigor were tested at 2 month intervals up to 6.5 months after processing by imbibing treated seeds at 5°C for 4 days, incuabating them at 20°C under light for another 14 days, then measuring seedling axial length. Temperature and RH inside the debearder increased linearly from 14.0 to 22.4°C and from 59.0 to 81.2% with processing time (Fig. 2). The moisture content of seed materials did not change with the processing time, indicating that the water status of seeds did not change. The number of undamaged seeds per gram of material did not change and was similar between collections (Fig. 3). This unexpected finding may result from the small seed size of this species. Stem length, which is used to measure the severity of treatment, decreased with processing duration while percent of seed with pericarp removed increased (Fig. 3). Total germination, germination rate and seedling vigor were similar among treatments in both collections, but different between collections. Total germiantion and germination rate increased with storage time (Fig. 4).

Seed humidification

Seed moisture change during humidification did not differ between the two seed collections. However, interactions among humidification, temperature and treatment interval were significant.

Seed moisture increased with humidification intervals at all temperatures (Fig. 5). The moisture content of seed was higher than the initial moisture after 16-h of humidification at 2°C and continued to increase until 5 days. At 5°C seed moisture was higher than the initial after 4-h of humidification and continued to increase after 5 days. Seed moisture increased significantly after 2-h of humidification at 10 and 15°C. There was no difference in seed moisture change for non-humidified seeds at any temperature except after 15-day intervals.

Germination was higher at 2, 5, and 10°C than 15°C, with an average of 64.9, 66.7, 64.8 and 62.6% for collection 1 and 78.9, 76.4, 78.3 and 72.9 for collection 2. There was no difference between humidified and untreated seed in germination, germination rate, or seedling vigor. There was an interaction between humidification and treatment interval. Germination was similar among intervals except at 8-h interval, which was lower than all others for all treatments. Germination was higher at the 15-day intervals than 8- and 16-h intervals. The influence of humidification treatments, temperature, interval and seed collections on germination rate was similar to that of total germination, including an interaction of treatment and interval.

Discussion and Future Plans

Data collected to date indicate that operating time in a debearder does subject sagebrush seed to increasingly sever treatment; but, that the commercial procedure which we followed did not have a negative influence on germination or seedling vigor. Whether processing influences seed quality when seed is held in storage or whether there is any influence of removing the pericarp is still being studied.

Results from the pre-dispersal seed moisture study suggested that the initial seed moisture may contribute to the differences in seed germination and germination rate. This was not supported by results of seed humidification studies. We found that while seed moisture is influenced significantly by the time seed is humidified, humidification treatments did not show a consistent difference from the check for germination, germination rate, or seedling vigor. These results suggest we should shift our focus to better understand the inter-relationship of seed moisture and temperature with germination rate and seedling vigor as related to wet/dry cycles a seed may experience in the seedbed. We also plan to conduct tests with rabbitbrush to determine if humidification may benefit a somewhat larger seed.

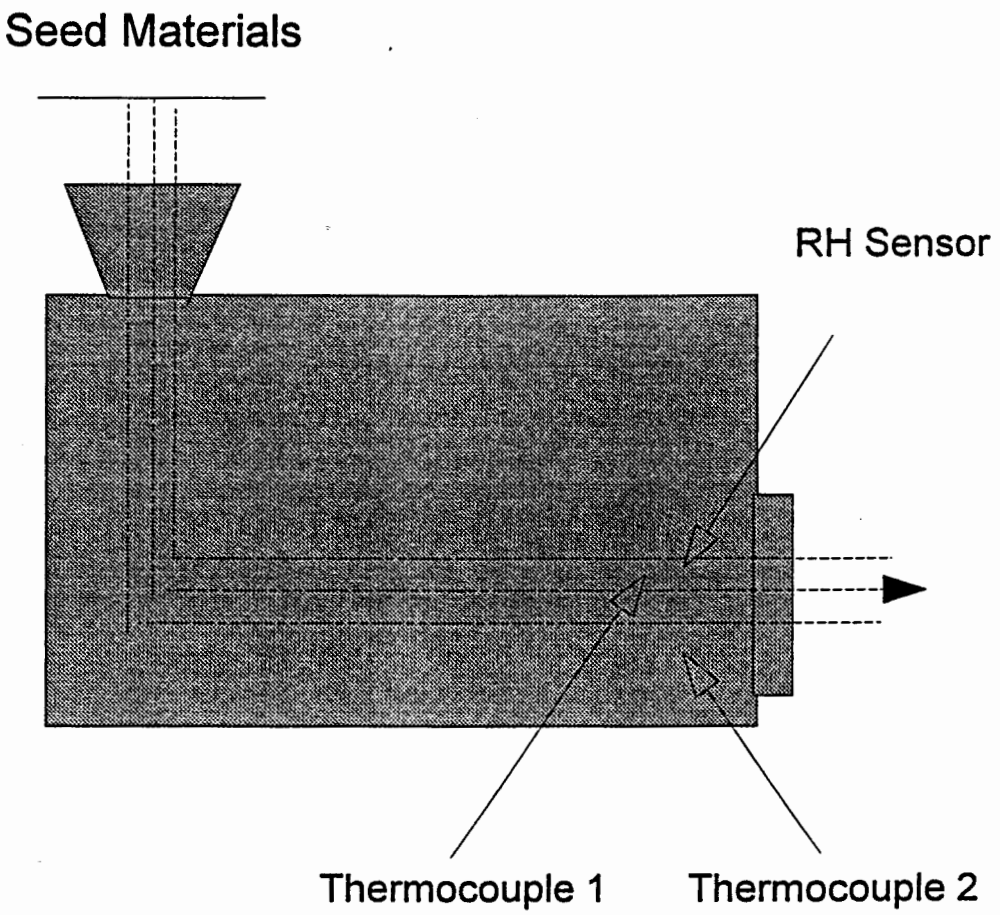

Fig. 1. Debearder schematic showing location of sensors during sagebrush seed processing.

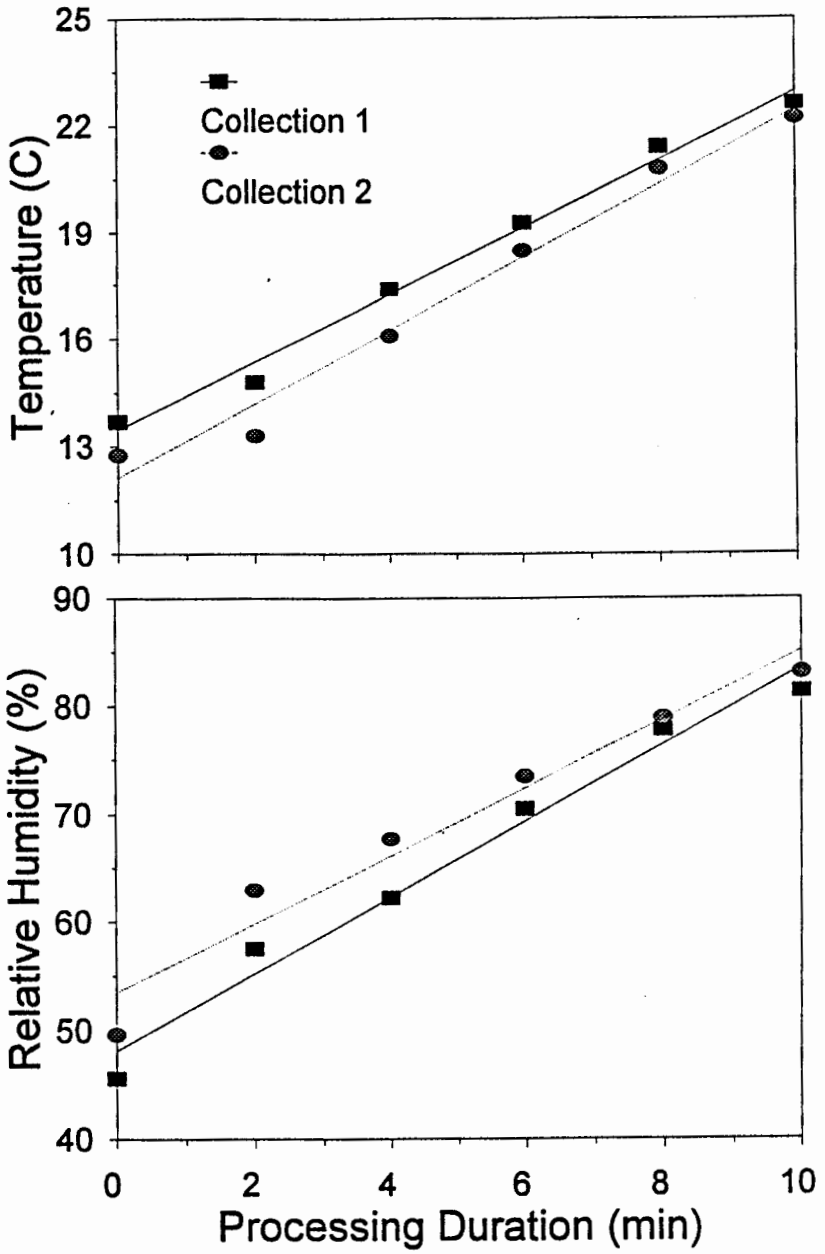

Fig. 2. Changes in temperature and relative humidity inside the debearder while processing Wyoming big sagebrush seed;
For collection 1, Temperature=13.47+0.95*Time, R^2=0.99,P=0.0001;
RH=48.12+3.54*Time, R^2=0.97, P=0.0002;
For collection 2, Temperature=12.13+1.03*Time, R^2=0.98, P=0.0001;
RH=53.50+3.16*Time, R^2=0.94,P=0.0008.

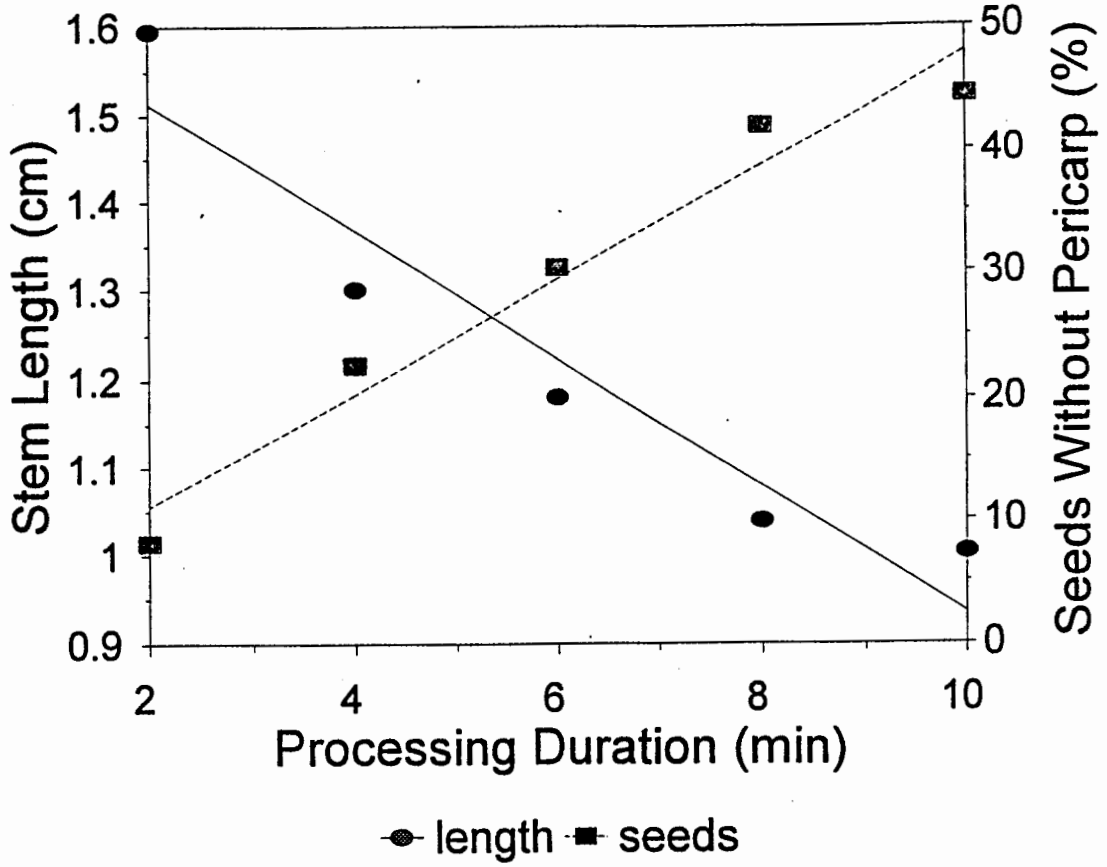

Fig. 3. Stem length and percent of Wyoming big sagebrush seeds without pericarp after processing with a debearder. Length=1.66-0.07*Time, R^2=0.89, P=0.0108; Seeds without pericarp=1.91+4.61*Time, R^2=0.94, P=0.0038.

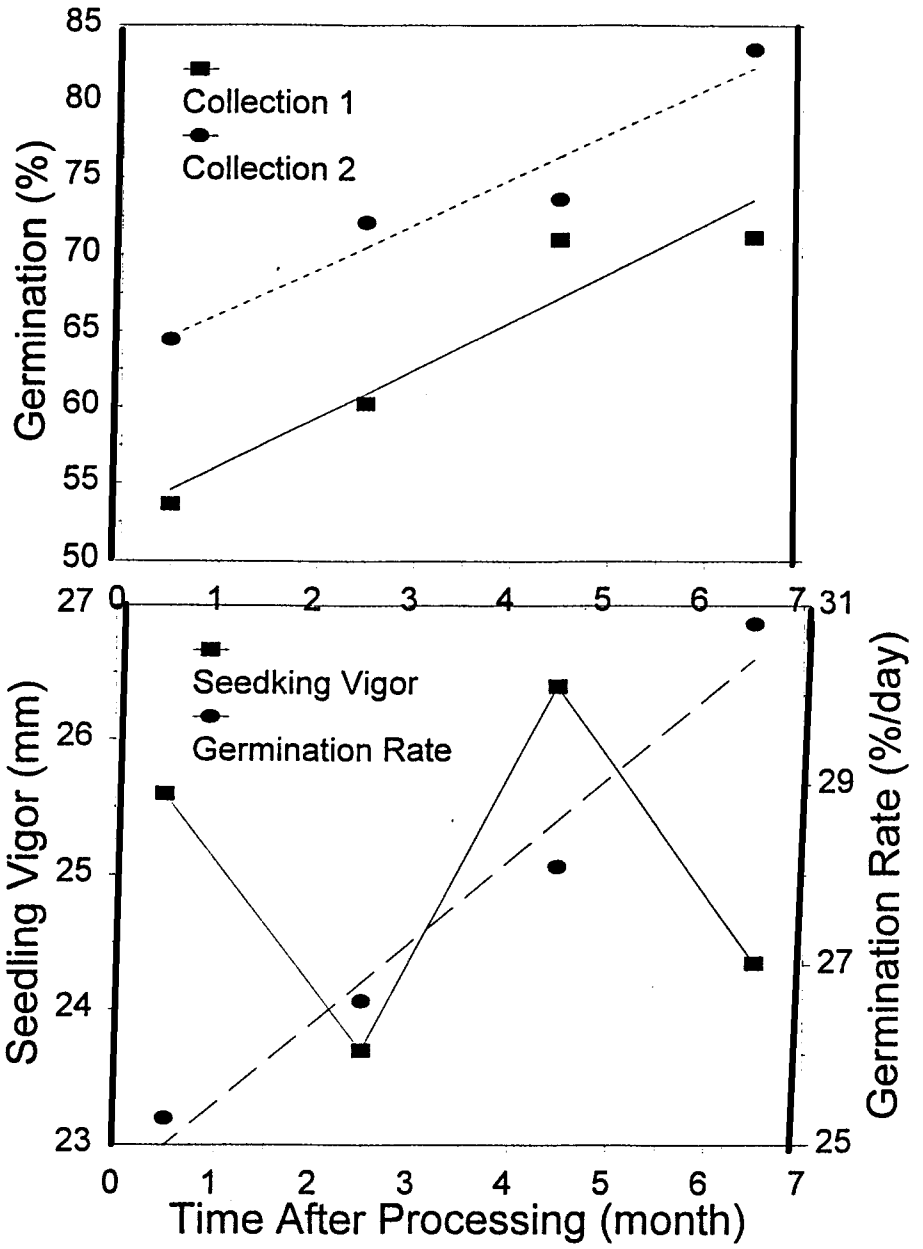

Fig. 4. Changes in seed germination and seedling vigor of Wyoming big sagebrush after processing with a debearder.

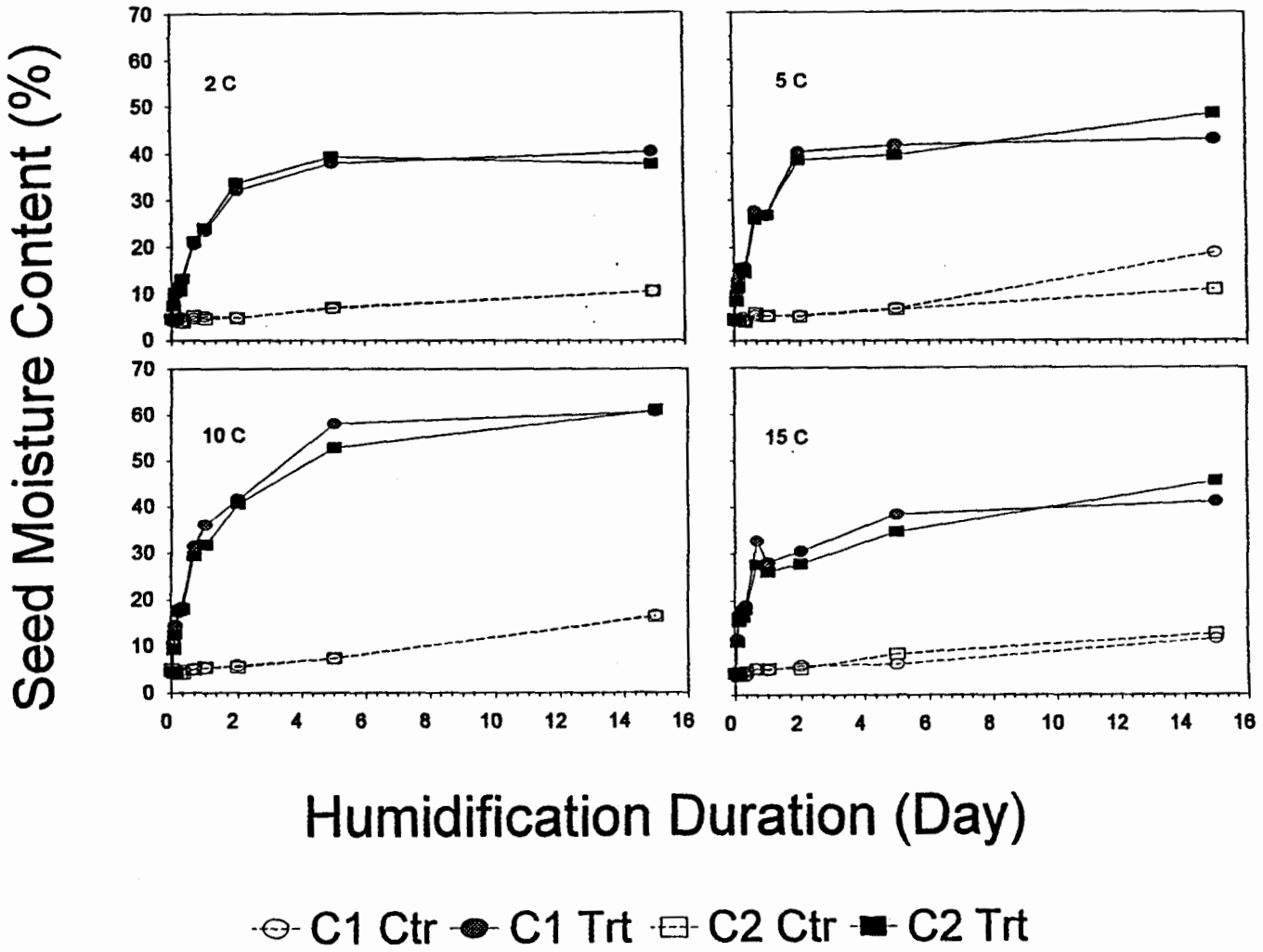

Fig. 5. Seed moisture content of humidified (Trt) and non-humidified (Ctr) seeds of collection 1 (C1) and collection 2 (2) at different temperatures and treated durations. LSD=4.9%.

THE ROLE OF NATURAL ORGANIC SOLUTES IN THE MOBILITY OF SELENIUM IN COAL MINE BACKFILL-GROUND-WATER SYSTEMS

R.B. SEE, K.J. REDDY, G.F. VANCE, A.A. FADLEMAWLA

FINAL SEMI-ANNUAL REPORT #7
THE ROLE OF NATURAL ORGANIC SOLUTES IN THE SOLUBILITY OF SELENIUM IN COAL-MINE BACKFILL GROUND-WATER SYSTEMS

Randolph B. See, U.S. Geological Survey
Katta J. Reddy, Wyoming Water Resource Center
George F. Vance, University of Wyoming
Amr A. Fadlemawla, University of Wyoming

SUBMITTED TO
THE ABANDONED COAL MINE LANDS RESEARCH PROGRAM
October 31, 1994
Office of Research
University of Wyoming
P.O. Box 3355
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Laramie, WY 82071-3355

INTRODUCTION

Natural organic solutes can play an important role in the solubility of selenium in coal-mine backfill aquifers. The information obtained from this research will increase our understanding of processes that influence the solubility of selenium in coal-mine backfill ground-water systems. The specific objectives of this research are:

1. To characterize the chemical and physical properties of surface coal-mine backfill and associated ground waters at three sites with large selenium concentrations in ground water;
2. To determine the role of natural organic solutes on selenium sorption/desorption and precipitation/dissolution processes; and
3. To quantify the effects of oxidation-reduction (redox) processes on the solubility of selenium in a redox controlling apparatus.

SITE SELECTION AND SAMPLE COLLECTION

Three sites with existing wells in backfill material were selected in reclaimed areas at two surface coal mines in the Powder River Basin. The mines are referred to by letter designation (A and B) throughout this project because of agreements with the companies not to identify the mines by name. Two sites were investigated at mine A (A-1 and A-2) and one site was investigated at mine B (B-1).

Six backfill cores were obtained during September 1991. Two backfill cores were collected from within approximately a 5 meter radius of the well at each of the three sites. Core holes ranged from 7.5 to 8.4 meters deep and were at least as deep as the associated well. Ground-water samples were collected from each well in September, 1991 and July or August 1992.

LABORATORY ANALYSES

Backfill Cores

X-ray diffraction analyses indicated that the backfill-core samples have similar types of mineralogy. Quartz, kaolinite, potassium feldspar, illite, and muscovite were identified in all samples. Additional minerals that were detected in some samples include: gypsum, calcite, dolomite, apatite, and geothite. Total elemental analyses indicated that all backfill-core samples had large iron contents. X-ray diffraction analysis, however, indicated that crystalline iron oxides were not present in the core samples at concentrations large enough to be detected.

The elemental contents of 18 selected backfill-core samples were analyzed. Results indicate total selenium concentrations in backfill-core samples ranged from 0.1 to 15.2 mg/kg.

Saturated-paste extracts were prepared for 68 backfill-core samples. The pH, specific conductance, and redox potential (Eh) were determined on the saturated pastes. Selenium, sulfate, and dissolved organic carbon (DOC) were determined on saturated-paste extracts. Saturated paste pH values for backfill-core samples ranged from 3.7 to 8.1. The larger pH values (7.2 to 8.2) are probably due to the buffering effect of carbonates, which were present in all samples. The saturated paste pH and Eh measurements for backfill-core samples collected near the ground-water table were very similar to those obtained for the ground-water samples. Specific

conductance values of all saturated-paste extracts exceeded 2 dS m^{-1}, indicating a large soluble salt content in the backfill-core samples. Selenium concentrations in the saturated paste extracts ranged from 1 to 156 µg/kg.

Sequential partial dissolution techniques were used to partition backfill selenium into functionally definable associations of selenium with solid phases of backfill-core samples. The organic phase accounted for 10 to 58 percent of the total selenium in backfill-core samples analyzed for this study.

Ground Water

Ground-water samples were analyzed for DOC, total selenium, major and trace elements. Total selenium concentrations from ground-water samples collected in 1991 were found to parallel the DOC concentrations (79 to 88 mg/L). Ground-water samples A-1 and B-1, which had high DOC concentrations, had selenium concentrations of 125 µg/L (A-1) and 88 µg/L (B-1). Ground-water sample A-2, which had a low DOC concentration (11 to 14 mg/L), had a selenium concentration of 3 µg/L.

Dissolved Organic Carbon

Dissolved organic carbon was fractionated into 6 fractions: hydrophobic acids, bases, and neutrals, and hydrophilic acids, bases, and neutrals. The results of the DOC fractionation analysis indicate DOC in the ground-water samples was dominated by organic acids (38 to 84 percent), with organic neutrals ranging from 10 to 45 percent, and organic bases ranging from <1 to 10 percent. Initial studies indicate that hydrophobic bases were a small percentage (0 to 2 percent) of the total DOC, therefore, hydrophobic bases were omitted from further analyses.

The hydrophobic and hydrophilic acids in the ground-water samples were isolated and concentrated. Ground-water samples from A-1 and B-1 wells were used in the isolation procedure. Ground-water samples from well A-2 were not used for isolation due to low DOC concentration. The isolated hydrophobic and hydrophilic acids were used in the sorption/desorption studies to determine their effect on Se sorption.

Sorption/Desorption Studies

Sorption/desorption experiments were conducted on six backfill-core samples. Results show that backfill-core samples have a very large selenite sorption capacity. All samples sorbed more than 90 percent of the selenium added as selenite (except one with a pH of 6.7 that sorbed 75 percent). The pH of the samples examined ranged from 3.7 to 6.7. Although pH is a major factor in controlling sorption, the sorption capacity generally remained constant within the observed pH range. Addition of hydrophilic acids decreased selenite sorption capacity more than the addition of hydrophobic acids. Total selenium desorbed subsequently by phosphate extraction was only about 50% of the sorbed selenium. This decrease may have been caused when precipitation processes occurred.

Precipitation/Dissolution Experiments

Precipitation/dissolution experiments were conducted to predict potential solid phases controlling the dissolved selenium concentration in solutions of backfill-core samples and to

evaluate the effects of DOC on selenium solubility in backfill environments. Analytical results from the precipitation/dissolution experiments were used in a geochemical speciation model (GEOCHEM) to calculate ion activities. The DOC had little effect on Se speciation or activity of selenite. Ion activity products indicated that dissolved selenium concentrations in some core samples were probably controlled by Cu_2Se solid phase. The chemical speciation results indicated that selenium formed neutral ion pairs in backfill-core samples. Because neutral ion pairs may not be sorbed onto oxides and clays as a charged species, this lack of sorption may present a potential for leaching of selenium.

Redox Controlling Apparatus

A redox controlling apparatus was constructed to control redox potential (Eh) and pH in water and backfill-core samples. The redox controlling apparatus was successful in controlling the redox status of the samples. The response of selenite and selenate to the imposed redox conditions did not completely follow thermodynamic predictions, possibly because of a lack of equilibrium conditions within the chamber. Selenate reduction in backfill-core samples followed thermodynamic predictions more closely than ground-water samples. The results indicated that in ground water, selenate and sulfate will remain stable and available under reduced conditions when thermodynamic conditions would predict otherwise.

SUMMARY

Three field sites were selected and sampled in reclaimed areas at two surface coal mines. Two backfill cores and two sets of ground-water samples were collected from each field site. Analyses of ground-water samples indicate that total selenium concentrations ranged from 3 to 125 μg/L and DOC concentrations ranged from 11 to 88 mg/L. Fractionation of DOC in ground-water samples indicated a predominance of organic acids (61 to 82 percent).

Results from sorption/desorption experiments showed that most backfill-core samples sorbed more than 90 percent of the added selenium and approximately 50% of the sorbed selenium could be removed by a subsequent phosphate extraction. The addition of hydrophilic acids decreased selenite sorption to a greater degree than did the addition of hydrophobic acids.

Precipitation/dissolution experiments indicated that dissolved selenium concentrations in some core samples were controlled by Cu_2Se solid phase. Calculated chemical speciation results indicate that selenium may form neutral ion pairs which may present a potential for leaching of selenium.

A redox controlling apparatus has been developed in which the affects of oxidation/ reduction conditions on selenium reactions were studied. The results indicated that in ground water, selenate and sulfate will remain stable and available under reduced conditions when thermodynamic conditions would predict otherwise.

THE IMPORTANCE OF SOLID AND SOLUTION SELENIUM SPECIATION IN MOBILITY AND PLANT UPTAKE OF SELENIUM FROM WYOMING COAL MINE LAND RECLAMATION

G.F. VANCE, K.J. REDDY, L.K. SPACKMAN, S. SHARMASARKAR

Abandoned Coal Mine Land Research Program

Semi-Annual Report

THE IMPORTANCE OF SOLID AND SOLUTION SELENIUM SPECIATION IN MOBILITY AND PLANT UPTAKE OF SELENIUM FROM WYOMING COAL MINE LAND RECLAMATION

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Wyoming Department of Environmental Quality
Land Quality Division

October 30, 1994

THE IMPORTANCE OF SOLID AND SOLUTION SELENIUM SPECIATION IN MOBILITY AND PLANT UPTAKE OF SELENIUM FROM WYOMING COAL MINE LAND RECLAMATION

George F. Vance, Shankar Sharmasarkar, Katta J. Reddy, and Lowell K. Spackman

Introduction

Selenium (Se), an element of interest and concern, has the potential of becoming increasingly mobile with time in oxidizing environments. During surface mining activities, materials previously in reducing environments become exposed to atmospheric conditions, thus increasing the potential of elevated levels of mobile and plant-available Se. Furthermore, solubility and mobility of Se in areas disturbed by mining may result in higher levels of Se in surface waters, ground waters, and in resaturated backfill environments. The post-mining land use of a majority of the abandoned and reclaimed coal mine lands is grazing land, pastureland and/or wildlife habitats. If Se mobilization is not attenuated, affected abandoned and reclaimed areas may not be suitable for post-mining land use or may require special resource management considerations.

Objectives

The objective of this research project is to examine the geochemistry of Se in abandoned and reclaimed coal mine sites, and native rangelands. The project was divided into the following four research tasks:

- development of a rapid and cost effective method for determining Se species in backfill and soil materials of abandoned and active coal mine sites,
- examination of solid-phase and solution speciation of Se in the rooting-zone of mine soils for correlation to plant uptake,
- characterization of Se adsorption/desorption and precipitation/dissolution processes controlling Se mobility in backfill and soil environments,
- determination of plant uptake of Se at coal mine lands and other affected sites that can be correlated to Se solid-phase and solution-phase speciation.

Selenium occurs naturally in several chemical forms; therefore, the analysis of the factors that control Se speciation and the direct analysis of Se species can be used to characterize and predict the processes that control Se solubility, mobility, availability, and plant uptake. This information will assist in designing preventative and/or remediation schemes for abandoned, reclaimed, and active coal mine lands.

Survey of Abandoned Coal Mine Lands in Wyoming

Several sources of information, which were described in the third semi-annual ACML research progress report, were used for locating research sites on abandoned and active coal mine lands. A comprehensive description of our survey of potential abandoned coal mine sites is available in an interim report submitted to the Office of Research, University of Wyoming on October 18, 1991.

Site Selection and Sample Collection

Five surface coal mines located in north, central and southern Powder River Basin were selected and sampled during the summer, 1991. During the summer 1992, the same five mines and two additional mines were sampled; a reclaimed abandoned coal mine located near Rock Springs and a reclaimed uranium mine located in the southern part of the Powder River Basin.

In both 1991 and 1992, plant, soil, and backfill samples were collected from abandoned, reclaimed and native sites. Forty three sites have been established within thirteen transects located on seven different mines. In both 1991 and 1992, the five dominant plant species at each site were sampled.

Sample Preparation

All soil, backfill, and plant samples were logged in and prepared for chemical analysis. The plant samples were oven-dried at 50-60°C for 24 hours and then ground to 0.4 mm using a Wiley Mill. The soil and backfill samples were divided in two, using a Riffle Splitter. One part was crushed with a hammer covered with cheese cloth and sieved to 10 mesh and the other air dried, sealed, and stored. The 2 mm size soil fraction was used in all analyses, except in the sequential fractionation study where 0.25 mm sized samples were used. Samples collected from AML (Abandoned Mine Lands) research sites were given the highest priority.

Soil Taxonomic and Chemical Characterization

The samples, collected from contrasting range and mine environments of Wyoming, varied with respect to location, depth of sampling, taxonomy, and physicochemical properties. The taxonomy of the soils at different sites were: Ustic Torrifluvents, Ustic Haplargids, Ustic Torriorthents, Ustic Calciargids, Mesic Haplargids, Ustic Torripsamments, Ustic Paleargids, Ustic Haplocambids, Typic Haplocambids, and Typic Torriorthent. In general, the soils have sandy or loamy textures, with a few exceptions of clayey soils. Most of the soils were alkaline; however, some reclaimed backfill materials were highly acidic, which could be due to pyrite oxidation during mining. The redox potentials of soil solutions indicated moderate to fairly high oxidative conditions. Electrical conductivity of saturated paste extracts varied widely, and in most of the soils electrical conductivities were high, thereby suggesting the potential for salt solubilization. Most of the soils also had extremely high level of soluble sulfate, with a few exceptions having moderately low sulfate levels.

Methods of Se Quantification

Ion chromatography (IC) was effective in directly speciating Se in aqueous phases into selenite-selenate at concentrations as low as 20 ppb. However, there were two limiting factors that affected Se quantification: type of Se extractant and nature of the soil-solution anionic composition. Higher concentrations of chloride, phosphate, sulfate and organic anions were found to interfere with selenite and selenate speciation. Thus, we were unable to analyze Se in chloride, phosphate, and AB-DTPA extracts by IC. Additionally, soils containing high soluble sulfates were not amenable to Se determination by IC. However, for aqueous extracts of low sulfate soils IC worked well.

Atomic absorption spectrophotometry with hydride generation (AAS-HG) was useful in detecting very low Se concentrations (1 ppb) and was especially useful for samples that could not be analyzed by IC. However, this method also had limitations: AAS-HG was capable of measuring total Se in the form of selenite, and so could not speciate selenite and selenate directly. Therefore, an indirect approach was used for Se speciation with AAS-HG. Each sample solution was analyzed for total Se after digestion with 30% H_2O_2 + 12 *M* HCl. Also, solution selenite was measured before the pre-treatment step. Selenate was calculated from the difference between total Se and selenite. The organic Se fraction was also determined by skipping the peroxide step in the digestion procedure in the procedures described above.

Thus, both chromatographic and spectroscopic techniques could be applied to quantify solution Se, although, each method of analysis had its own analytical limitations. Studies involving both instruments have shown comparative results, indicating the precision of both methods. However, certain samples showed discrepancies which were due to the fact that IC is capable of detecting Se as species, whereas, AAS-HG quantifies Se as components. A good correlation between chromatographic and spectroscopic findings, indicated negligible amounts of various Se species other than selenite and selenate.

Another method of Se quantification used in our study was high performance liquid chromatography (HPLC). Using fluorescence detection we were able to measure selenomethionine and several other amino acids in aqueous extracts of soils and plants. The results indicated the presence of greater amounts of amino acids derived from plants than soils, suggesting the logical conclusion that plants are a major source of organoselenium, whereas soils act as a sink for organoselenium compounds.

Solution and Solid Phase Se Speciation

Solution-phase Se speciation was conducted in water and phosphate extracts separately. In aqueous phases, selenate (Se^{+6}) was found to be the potential specie, while in the exchange phase, selenite (Se^{+4}) predominated, thereby indicating both Se species were available for leaching and/or plant uptake.

Solid-phase Se was partitioned sequentially into aqueous, exchangeable, acid extractable, sulfide and humic bound, and siliceous fractions. Again Se^{+6} was found to be the potential aqueous specie, while in the exchange phase Se^{+4} predominated. This result supports the findings of solution-phase speciation. Both Se^{+4} and Se^{+6} were found to be distributed almost evenly in acid extractable fraction. Speciation data for the last two fractions, however, was not conclusive.

With increasing exchangeable Se there was a corresponding increase in Se in the aqueous fraction. A similar increasing trend was found in plots of exchangeable Se fraction versus acid extractable Se fraction. This relationship suggests a probable interconvertibility between these three fractions. The results also indicated that soils with more resistant Se would have less Se in available forms; however, weathering of the resistant fractions would result in a gradual increase in Se availability. During pedochemical changes, the weatherable fraction would be first transformed to the conditionally available fraction, which, subsequently would be transformed to the available fractions; however, there could also be some interconversion between the available and conditionally available forms of Se.

Total soil Se increased with increasing clay content, with a reverse trend observed for sand content, thus suggesting Se was associated with the clay sized soil fraction. Siliceous Se was linearly related to total soil Se suggesting the presence of Se in silicate minerals. This fraction was again found to increase with increasing soil clay content, thereby supporting the above findings. Thus, we recommend further mineralogical studies for identifying siliceous Se.

Sorption and Precipitation Processes

Both column and batch techniques were used for studying sorption and precipitation processes. For different soils, sorption isotherms were found to follow either linear or curvilinear models, which indicated sorption could be either a continuous or discontinuous function of solution Se, depending on soil parameters, i.e., pH, clay content, mineralogy. Selenite sorption was greater than 90 percent within the suitability limit of 0.1 mg/kg; however, the amount adsorbed decreased with increasing Se treatment levels. A kinetic study indicated selenite had a faster rate of immobilization as well as solubilization, in comparison to selenate. Moreover, selenate had a shorter breakthrough time and lower K_d than selenite. Thus, selenite was found to be the potential specie that would be rendered immobile in comparison to selenate. Both Se species were desorbed over time by phosphate, although the desorption kinetics of selenite were very slow. The adsorption and desorption processes were found to be path-functions, which suggested the occurrence of hysteresis.

Presence of Ca, Fe, Mn in solution enhanced Se retention which could be due to metal-selenium precipitation; another reason could be the lowering of the negative charge density at the sorption sites caused by the presence of the metal ions, and hence a subsequent increase in adsorption. Thus, the degree of Se immobilization increased with decreasing pH. Geochemical modeling (GEOCHEM and MINTEQA2) of the soil-solutions indicated that presence of dissolved organic carbon (DOC) reduces the activities of Se species, which could be due to organo-Se complex formation. This would suggest that dissolved organic matter could possibly reduce Se bioavailability. However, overall results indicated that sorption and precipitation could occur simultaneously. Results also indicated a possible equilibrium between the adsorbed and soluble Se, which suggested exchangeable Se as well as non-specifically adsorbed Se can be released into the solution-phase during any continuous mechanical disturbances like water run off or percolation of precipitation. A similar findings was also recognized in the sequential partitioning study.

The studies with selenomethionine, a toxic Se-containing amino acid released by plants, indicated there are various fates of this compound. Selenomethionine was retained by soils in a nonlinear fashion, with clayey soils having

greater retentivity. Results also suggested mineralization of the organic compound to simple inorganic selenite, a possible transformation to other organo derivatives, and microbial degradation to volatile Se products.

From a management stand point, the findings of our studies suggest application of inorganic amendments (having more electropositive cations), organic manures and biosolids during reclamation would reduce Se release into soil solution; however, before adding these materials should be tested for potential contaminants.

Soil-Plant Se Correlations

The order of extractable soil Se from range and mine lands was: phosphate > AB-DTPA > hot water > saturated paste. In general there was a significant correlation between phosphate and AB-DTPA extractable Se irrespective of land type. In the abandoned soils, correlations between phosphate and AB-DTPA extractable Se with water extractable Se were noted, which was not observed in native and reclaimed sites. Saturated paste extractable Se levels were typically very low, and were not correlated with other extracts. In a number of sites, AB-DTPA as well as phosphate extractable Se was found to be greater than the WDEQ-LQD Guideline No. 1 (1984) suitability limit of 0.1 mg/kg.

The general plant Se distribution in various range and mine soils was: shrub>forb>grass. In native and abandoned lands the distribution pattern was: shrub>forb>grass, whereas in reclaimed land the trend changed to: forb>shrub>grass.

Soil-plant Se correlations were found to be specific to sampling site as well as vegetation type. In native range lands, Se in shrub vegetation was found to be related to both AB-DTPA and phosphate extracts, whereas forb Se corresponded to only AB-DTPA extractable Se; grass however, was not correlated with any of the extracts. In reclaimed mine sites, both shrub and grass Se contents were correlated to AB-DTPA extractable Se, whereas phosphate extractable Se and forb Se contents were not correlated. In abandoned sites, forb Se was related to AB-DTPA, water and phosphate extractable Se, whereas, grass was dependent on AB-DTPA and phosphate extractable Se only; shrub, however, did not show any correlations. In general, under comparable circumstances, AB-DTPA Se had stronger correlation to plant Se than phosphate Se. In native range samples, 0.1 mg/kg AB-DTPA extractable Se corresponded to 2 mg/kg Se in both shrub and forb vegetation, whereas 0.1 mg/kg phosphate extractable Se corresponded to 0.8 mg/kg plant Se. In reclaimed environments, 0.1 mg/kg AB-DTPA extractable Se corresponded to 0.9 and 1.3 mg/kg shrub and grass vegetation, respectively. On abandoned mine lands, calculated forb Se concentrations at the 0.1 mg/kg AB-DTPA, hot water and phosphate extractable Se level would corresponded to 0.6, 1.2 and 0.4 mg/kg plant Se, respectively, whereas for grass vegetation 0.1 mg/kg AB-DTPA and phosphate extractable Se corresponded to 0.8 and 0.6 mg/kg plant Se levels, respectively. In our soil-plant Se statistics we used a boundary condition of plant Se levels that were less than 5 mg/kg. This concentration limitation was done in order to avoid skewing or statistical bias in the analysis by any large number. From this correlation study we recommend site and vegetation specific characterization, rather than a general approach, and we also suggest the use of different class-intervals (i.e., low, medium, high) for the plant data.

Recommendations for Future Research

From our analytical studies we recommend simultaneous use of both chromatographic and spectroscopic techniques for Se quantification. However, further research is needed to develop more precise methodologies for Se analysis in order to correct the problems we encountered in some of the soil and water systems, and also to minimize quantification errors. From the management stand point, we recommend application of inorganic amendments (having more electropositive cations) and organic manures or biosolids during reclamation, which would potentially reduce Se released. However, research should be done to test for toxicity effects of other contaminants before adding the amendments, and to determine their interaction with respect to Se mobility. We also suggest a combined investigation that deals with the mobility of Se from soils to surface waters and aquifers. For the soil-plant correlation study we recommend site and vegetation specific characterization, rather than a general approach. We also suggest the use of different class-intervals (i.e., low, medium, high) for the plant data. Our sequential fractionation study also indicates the necessity of further mineralogical investigations for identifying siliceous Se.

RELATIONSHIP BETWEEN SOIL SELENIUM CONCENTRATIONS AND SELENIUM UPTAKE BY VEGETATION ON SURFACE COAL MINE LANDS IN WYOMING

G.F. VANCE, R.N. PASCH, P.K. CARROLL, M.S. PAGE,
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Semi-Annual Project Report

for the

Abandoned Coal Mine Land Research Program

RELATIONSHIP BETWEEN SOIL SELENIUM CONCENTRATIONS AND SELENIUM UPTAKE BY VEGETATION ON SURFACE COAL MINE LANDS IN WYOMING

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October 30, 1994

Relationship Between Soil Selenium Concentrations and Selenium Uptake by Vegetation on Surface Coal Mine Lands in Wyoming

George F. Vance, Roger N. Pasch, Brenda K. Schladweiler, Margaret Stacy Page and P. Kim Carroll

Introduction

Selenium is an important issue to abandoned as well as active surface coal mine land reclamation. Overburden material that is brought to the surface during surface coal mining operations may have extractable Se levels greater than 0.1 mg/kg, a level that has been identified as "unsuitable" for reclamation purposes in Wyoming. Surface mining may also affect soil/backfill Se chemistry, which may influence soil-plant Se relationships as well. This project examined the relationship between soil/backfill and plant Se concentrations at two surface coal mines in the Powder River Basin, Wyoming.

Objectives

The main objective of this project was to evaluate soil/backfill and plant Se relationships. The specific objectives of this study were to determine:

1) What extraction procedures might be a better indicator of "soluble" (plant available) soil Se?
2) What forms of Se are present in seleniferous soil and backfill materials, and how are these related to plant uptake of Se?
3) What impacts do chemical, physical and biological soil characteristics have on plant uptake of Se?
4) How does Se content of native and reclaimed plant species vary during a growing season?
5) What effect does soil depth have on plant uptake of Se?
6) What Se suitability limits should be recommended for backfill materials to be topsoiled and revegetated?

Site Selection

Sites selected for this project included two active coal mines (Black Thunder (BT) and Coal Creek (CC)) located south of Gillette. There are many advantages in involving active coal mines, one of which is the extensive soil and backfill Se data base that already exists.

The relationship between soil/backfill Se levels (determined by four different extraction methods and total Se) and plant Se levels (three different life forms - grass, forb, and shrub, as well as a composite grass sample, which was a random collection of a mixture of grasses) was examined. The information obtained from this study will be used to better understand conditions that influence Se uptake by plants. This is an important issue to abandoned and active coal mine lands because it may indicate how overburden materials should be handled in the backfilling and reclamation process.

Methods of Analysis

Four Se extraction methods (hot water Se (HWSe), AB-DTPA Se (ABCSe), KH_2PO_4 Se (HPSe), and saturated paste Se (SPSe)) and the analysis of total soil Se (TSe) were evaluated to determine which method(s) is the most reproducible and accurate for determining the effects of Se uptake by plants (grass (G), forb (F), shrub(S), and composite grass (CG)). Plant Se was determined after plant digestion using nitric acid. A quality control/quality assurance program (see original proposal for details) was developed by the two laboratories, Inter-Mountain Laboratory, Sheridan, Wyoming and the Soil and Environmental Chemistry Laboratory at the University of Wyoming, that conducted the soil and plant Se analyses. Selenium analysis of 1991, 1992, and 1993 vegetation and soil/backfill samples has been completed and a database created that contains 1809 rows (soil/backfill samples) and 24 columns (site, soil/backfill, and vegetation parameters).

Vegetation and Soil/Backfill Sampling

During the summer of 1991, 1992, and 1993, both vegetation and soil/backfill materials were sampled. Plant species inventories and percent plant cover at each site were tabulated during the summer sampling periods. A document containing site, soil/backfill, and vegetation characteristics is currently being finalized and should be available January, 1995.

Results

Objective #1 - *What extraction procedures might be a better indicator of "soluble" (plant available) soil Se?*

Although this project evaluated several Se extraction methods to determine the relationship between soil/backfill and plant Se concentrations, we did not analyze the various Se species present in the extracted solutions. We took the approach that if a particular extractant correlated to plant Se concentrations, then we could hypothesize which extractant would be a better predictor of plant-available Se. One consistent pattern noted in this study was that native site vegetation is more highly correlated to extractable Se concentrations than was reclaimed site vegetation; correlations at reclaimed sites were somewhat inconstant, which may be due to such variables as time of reclamation or site conditions. Because of the variation in native versus reclaimed site correlations, the above approach was inadequate for determining which extractant measures soluble or plant available Se.

Differences ($p=0.05$) between year 1991 and 1993 (full soil/backfill sampling years) were tested to determine if Se varied with time in the soil/backfill material that was averaged over holes by depth at each site. All Se analyses for depth 1 (e.g., topsoil) on reclaimed sites were significantly different between the two years. This was expected since reclaimed topsoil material is in direct contact with the atmosphere and has not reached equilibrium. For reclaimed site depth 2 and 3, SPSe was significantly different ($p=0.001$) between 1991 and 1993, whereas ABCSe was only slightly different ($p=0.05$) at depth 2. Only native site depth 1 was found to have significant differences between years for SPSe ($p=0.05$) and HPSe ($p=0.007$). Total and extractable Se in native site depths 2 through 6 were nonsignificant. Not averaging over the three holes at each site resulted in several significant differences with time as a variable, especially within reclaimed depth 2 and 3 (backfill material).

Based on this information, any relationship between Se in depth 1 of reclaimed sites and plant Se levels would possibly be in error. In fact, only a few correlations were determined for this combination. Another inconsistency in the data was noted for depth 1 of native sites which had soil Se levels that were generally very low, often close to the detection limit. This limited our ability to use Se in native depth 1 as a predictor of plant Se levels. As a result of these findings, total and extractable Se can be used in statistical investigations, but depth 1 of both native (0-30 cm) and reclaimed (topsoil depth) sites should be omitted from these evaluations.

Objective #2 - *What forms of Se are present in seleniferous soil and backfill materials, and how are these related to plant uptake of Se?*

For purposes of this study, it was assumed that the two plant available forms of Se are selenate and selenite, and that HW and SP would extract primarily water soluble Se, whereas ABC and HP would extract both water soluble and complexed forms of Se. Typically, the level of Se extracted from different soil/backfill materials was of the order HPSe>ABCSe>HWSe>SPSe. This was expected since phosphate is capable of displacing Se on exchange sites, DTPA in ABC can compete with Se complexes, hot water dissolves some Se complexes, and saturated paste is an inert form of extraction (e.g., only soluble Se forms are detected).

Using a significance level of p=0.05 and a correlation coefficient of 0.9 or greater, several trends were found when comparing soil/backfill extractable and total Se concentrations for the 1991 and 1993 data. When separating by mine and type, a consistent relationship was found, which indicated HWSe, ABCSe, and HPSe were all statistically correlated. Including depth as a variable in these examples resulted in several significant correlations; however, the only logical combinations are between type, and mine and type because mine, type, and depth combinations are meaningless since depths for native sites are by 30 cm increments and depths for reclaimed are by approximately 60 cm increments. With native sites, significant correlations were found for HWSe, ABCSe, and HPSe for all depths except depth 1 (top 30 cm of soil). Overall, depth 3 of native sites was the most consistent with respect to correlations among soil Se extract results; soil-plant Se correlations were also more significant in depth 3 of the native sites. All reclaimed depths 2 and 3 had HWSe, ABCSe, and HPSe that were significantly correlated. Separations by mine, type, and depth were also used to develop linear regression models defining the relationship among Se extraction methods.

Objective #3 - *What impacts do chemical, physical and biological soil characteristics have on plant uptake of Se?*

Initially, the 1991 data were used to develop simple linear regression models for soil/backfill Se versus plant Se relationships. A majority of these simple regression models were nonsignificant. Nine measured independent variables were also used for regression analysis and modeling. These nine variables were anticipated to be driving variables in the project, but, in actuality, age of the reclaimed areas, which was not considered initially, was determined to be a major factor. Multiple regression analysis including cofactors indicated pH was an important parameter for native sites only. Finally, polynomial models were developed that sufficiently described the relationship between soil Se and plant uptake on native areas; however, the polynomial models for reclaimed areas were still poorly correlated.

From our studies, it was evident that backfill Se alone was not sufficient to describe backfill-plant Se relationships. Because of the younger age of reclaimed sites, e.g., the earliest revegetation data was 1979, backfill Se concentrations were probably influenced by changing chemical and physical conditions that are accompaning backfill as it equilibrates in its new environment. Therefore, one might predict that age of reclamation may be an important variable that should be included in correlation and regression analyses. In fact, we found that separating the reclaimed sites into two groups (1979-1985 and 1986-1991) increased the correlations between backfill-plant Se. As expected, extractable Se levels in the older reclaimed sites were more highly correlated than were the relationships between younger aged reclaimed sites and the associated plants.

Objective #4 - *How does Se content of native and reclaimed plant species vary during a growing season?*

Based on the original data, it was difficult to pull out individual plant species and include them in the overall regression analysis and modeling effort; however, it was noted that reclaimed plant Se values were generally higher at both mines than the corresponding native plant Se values. With the exception of individual accumulator species, most plant values did not reach the anticipated toxic level of 5 ppm level. Within the modeling process, type (i.e., native vs. reclaimed) was significant, indicating data from the two vegetation types could not be combined.

Instead of evaluating Se concentrations in individual plant species, plants were grouped into composite grass, grass, forb and shrub lifeforms in order to maximize our statistical evaluations. Due to a postponement in the awarding of project funds, during 1991 only one vegetation cutting (five different plant clippings) was completed on approximately 100 sites. In 1992 and 1993, two cuttings were completed. Statistical evaluation of lifeform Se levels in cuttings one and two of 1992 and 1993 indicated there were no significant differences in time of plant collection. This suggests the vegetation Se levels can be averaged over cuttings for each year.

Note that this finding is specific to the conditions of this study and should not be used as a general statement for plant Se levels throughout the Powder River Basin.

Objective #5 - *What effect does soil depth have on plant uptake of Se?*

Depth was an important independent variable in both reclaimed and native areas. Depth was found to be significant in the modeling process, which indicates native site data could not be combined over depth. Data for depths 2 and 3 of reclaimed sites (i.e., backfill material) were nonsignificant, thus suggesting the data could be combined. As indicated above, depth 3 of native sites and depths 2 and 3 of reclaimed sites provided the most significant relationships, which were used to evaluate soil/backfill and plant Se correlations.

Objective #6 - *What Se suitability limits should be recommended for backfill materials to be topsoiled and revegetated?*

Both type and depth were found to be significant, which implies that data can only be combined by mines. Therefore, relationships between type, depth, soil/backfill extractable Se, lifeform Se, and in some cases cofactors (pH, SO_4, and EC) variables were considered in developing simple and complex models for soil/backfill-plant Se correlations. From the averaged cutting and hole data, several significant correlations were found for lifeforms versus extractable Se (HWSe, ABCSe, and HPSe) determined by depth. For native sites, the correlation between extractable Se and CG, G, F were greater than 0.75. For the reclaimed sites, extractable Se vs S (>0.75) and forbs (>0.5) were the only significant relationships that were detected

Summary and Conclusion

Soil and vegetation samples were collected in 1991, 1992, and 1993 from two active mine sites located in the Powder River Basin, Wyoming. Soil/backfill selenium (Se) levels were determined by five methods: total Se and hot water, AB-DTPA, saturated paste, and dihydrogen phosphate extractable Se. Selenium concentrations in four lifeforms were also examined in this study and included: composite grass, grass, forb, and shrub. Statistical analyses were conducted by regressing Se levels determined in the four dependent vegetation lifeforms against eleven independent soil variables to construct appropriate models for assessing potential Se problem areas within the Powder River Basin. These regression analyses were conducted with soil depth, vegetation type (native versus reclaimed), and mine (Black Thunder and Coal Creek) as important subcategories. Several significant correlations were detemined from the soil/backfill Se versus vegetation lifeforms.

Since Se oxidation and the resulting increase in plant available may be an ongoing process in mined areas within the Powder River Basin, it would be important to maintain longterm records of the current project. It may be that there is an initial flush of Se into the soil environment with a substantial drop after a certain period of time. In conjunction with this idea, other independent variables may need to be included in overall regression analysis. One of these factors includes age of the reclaimed area. Any discussion of reclaimed areas should be based on the relative age of the area.

In the last three years, considerable progress has been made in making Se laboratory analysis consistent between government agencies, mining companies, and other related individuals or organizations. Maintenance of this consistency is important if trends within a particular region are to be identified.

HANDBOOK OF RECLAMATION TECHNIQUES FOR THE WESTERN UNITED STATES WITH FIELD GUIDE

F. FERRIS, M. STEWARD, R. STOWE, L. VICKLUND
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University of Wyoming
Vice President for Research
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November 1, 1994

Re: AML Project Report, Handbook of Western Reclamation Techniques

The 19 authors have met five times in the past 6 months to detail the Handbook format. Through this process, and the resulting written communication, the section and subject authors were determined. The form for a technique and the level of detail have been determined.

These sections are in composition.

	Section	Section Author	Percent Complete
1.	Topsoil	Laurel Vicklund	25
2.	Hydrology	Frank Ferris	15
3.	Topography	Bob Stowe	10
4.	Wildlife Mit & Pro	Bonnie & Howard Postovit	5
5.	Vegetation	Larry Kleinman	5
6.	Postmining Land Use	Mickey Steward	5

We anticipate completion in the first quarter of 1995. Please call me if you have any questions.

Sincerely,

Frank Ferris

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ESSENTIAL HYDROLOGIC FUNCTIONS OF PLAYAS IN THE POWDER RIVER BASIN OF NORTHEASTERN WYOMING

V.R. HASFURTHER, K.A. CURTIS, and L.I. WILLIAMS

Abandoned Coal Mine Land Research Program
Semi-Annual Report

Essential Hydrologic Functions of Playas in the Powder River Basin of Northeastern Wyoming

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October 31, 1994

INTRODUCTION

This research has as its primary purpose to characterize the unique hydrologic functions of playas within the Powder River Basin of northeastern Wyoming by defining the interrelationships which exist between soils, vegetation and water and how these interrelationships will be important in the restoration of playa areas once they are drastically disturbed by mining activities.

PROGRESS DURING THE REPORT PERIOD OF APRIL 15, 1994 - OCTOBER 31, 1994

The members of the playa project conducted an informational meeting for mining industry personnel on June 2, 1994, at the Campbell County Public Library. The principal goals of this meeting were to review the study plan for the playa project; to solicit comments on the plan from the mining industry; and to enlist their cooperation in order to make this project a success. Representatives from Amax Coal West, Inc., Caballo Rojo Mine, Kennecott Energy, Powder River Coal Company and Thunder Basin Coal Company, were present at the meeting.

The mining company representatives participating in this meeting agreed to allow members of the playa project access to playas located within mine permit boundaries on an as-needed basis with prior notification. No financial commitments were made at this time.

Field investigations began in June 1994 and are projected to be completed in by September 1995. The field investigations have been separated into two phases. The first phase consists of a reconnaissance level survey and the second phase involves a detailed survey.

Soils

Reconnaissance level soils work for the fifty-nine playas was begun by conducting literature reviews. This work is ongoing.

Vegetation

During the summer of 1994, field work and data collection for the reconnaissance level survey was initiated. Literature reviews were conducted to collect previously published information on playas.

Fifty-nine playas located in the Powder River Basin were surveyed for the reconnaissance level study. The playas surveyed were selected randomly from an initial population of approximately 450 playas and screened to determine geologic and hydrogeologic setting, accessibility, the existence of modifications, and the overall condition of the playas. Playas selected for the study were functioning in

an unmodified hydrogeologic setting and appeared to be as close to a natural condition as possible.

The reconnaissance level survey was begun by identifying the transition zones between different vegetation communities that occurred on each playa and identifying the boundary between upland areas and the playa basin. The transition zones and playa/upland boundaries were staked, and the vegetation communities defined by the three (or four in some instances) most dominant species that occurred within that zone. Each staked location within the transition zone was then surveyed to determine its elevation and triangular coordinates.

Spreadsheets were generated in Lotus Works on a Compaq portable computer to transfer written field data into a form that will be useable in a database configuration. The spreadsheets include the coordinate locations, vertical angles, distances between coordinates, and horizontal angles (if applicable) for each playa. Preliminary analysis of the areas within each vegetation zone, the area of the playa as a whole, and the length, depth, and width of each playa are currently ongoing.

Water

As stated above, the playa's length, width, and depth were measured in conjunction with the vegetation surveys. This information will be consolidated with available topographic data and will be used to develop a relationship between the playa size and configuration and the water quantity which could potentially be stored within the playa throughout the year.

Meetings were held with representatives from Thunder Basin Coal Company on August 31, 1994 and with Kerr-McGee Coal Corporation and Powder River Coal Company on September 22, 1994. These meetings were to review the detailed portions of the study and to enlist industry support in the completion of this phase of the project. Of primary concern was the need for additional financing to conduct the drilling program, water quality analyses, and site instrumentation. We expect to have responses from Kerr-McGee Coal Corporation and Powder River Coal Company by Monday, October 31, 1994.

Amax Coal West, Inc. Belle Ayr Mine

The University of Wyoming entered into a contract with the Belle Ayr Mine on August 3, 1994. Under this contract, the University of Wyoming is to complete water-related studies similar to those proposed in the ACMLRP playa project. The following progress has been made to date on the Belle Ayr Mine playa study:

<u>Equipment</u>

Neutron probe access tubes and four- and six-foot soil moisture samplers were purchased. (The University of Wyoming is supplying two- and three-foot soil moisture tubes). Stevens 420 Level Loggers and Submersible Depth Transmitter II's were selected for the continuous monitoring of surface water elevations.

Water Quality Sampling

We began a review of sample collection methods (e.g., sample volume required, bottle types, preservation methods, etc.) for use with the soil water samplers. We contacted the Wyoming Department of Environmental Quality/Land Quality Division (WDEQ/LQD) for guidance on the critical constituents for which to sample. It is very likely that the soil moisture samplers will not collect a volume of sample sufficient to analyze for all the parameters listed in WDEQ/LQD's Guideline 8 - Hydrology, Appendix 1 - Water Quality Sampling. Lowell Spackman, Soil Scientist with WDEQ/LQD in Cheyenne, recommended that we sample for the major anions and cations (bicarbonate, carbonate, chloride, sulfide, iron, magnesium, potassium and sodium). If enough sample is available, testing for selenium and boron should also be conducted.

Site Preparation

Monitoring wells and piezometers were drilled during the period of August 26 - September 1, 1994. Weather and field conditions have delayed the installation of neutron probe access tubes and soil moisture samplers. It is expected that installation of this equipment will be completed by mid-November.

PRELIMINARY DATA INTERPRETATION

Preliminary data analyses and field observations indicate that different "types" of playas may occur within the Powder River Basin. These "types" may be based upon geographic location, the vegetation characteristics of the species present, soil types, and/or vegetation/soil correlations. However, specific playa "types" or classifications that may occur have not yet been identified, or supported, by the field data collected or statistical analyses.

FUTURE WORK

Reconnaissance Level Study

Soils

Soil sampling will also be conducted during Summer 1995. A minimum of 1 surface soil sample will be collected from the upland area and each vegetation community zone that occurs within the playa. Field analyses will be conducted to determine soil type, soil color, and clay, silt and sand contents. Sampling locations will be identified in the field.

Upon completion of the reconnaissance level field work, the survey data, vegetation maps, soil sampling data, and vegetation community information will be analyzed to determine if correlations and classifications can be made between the playas.

Vegetation
Due to unforeseen circumstances, several playas selected for the Reconnaissance Level Survey were not surveyed. Completion of the surveying is scheduled for the summer of 1995. During Fall 1994 and Spring 1995, vegetation maps for each playa will be prepared, and literature reviews and preliminary data analysis will continue. In addition, the database for the survey data will be constructed using Microsoft Access.

Detailed Survey

Detailed studies are projected to be performed on six individual playas during the summer of 1995. Field work will be conducted for both vegetation and soil.

Soils
Soil sampling will also be performed on each of the six playas. Soil samples will be collected at 30 cm intervals to a maximum depth of 180 cm at each of the ten vegetation quadrate sampling locations. Field analysis of the soil samples will consist of: determination of horizons present, thickness, color, electrical conductivity, pH, depth to water table, reduced iron concentration, surface horizon textural class, and dominant subsoil textural class. Laboratory analyses will be performed on one soil profile per playa and will include determination of organic matter content, soluble salts, particle size distribution, and mineralogy.

Vegetation
Detailed vegetation sampling will be performed on each of the six playas. The sampling will determine the types and amounts of vegetation present in approximately ten 1 meter x 1 meter quadrates in each visibly distinct upland and playa vegetation zone on each of the six playas. Data that may be collected includes (but is not limited to) count and identification of species present, estimates of percent cover, production and community composition, and determination of slope and exposure of the quadrate.

SCHEDULING

Unanticipated delays resulted for beginning the field investigations. State and Federal regulations and private landowner permission required to begin the performance of the field measurements took from April

until August of 1994. The project investigators expected this to only take one or two months maximum. As a result, the graduate students and field personnel were unable to get into the field to do actual field evaluations until the second week of August. These delays were a result of getting Department of Environmental Quality, Forest Service and private landowner permission for evaluating playas on federal and private lands, as well as, permission for drilling of wells, drillings for soil moisture lysimeters and soil classification, etc.

The time required to survey the 60 playas once permission was obtained was also underestimated. As a result, the project has not proceeded as proposed in the original schedule for the project. The principal investigators are therefore requesting the following revisions in the timing of the investigations.

May 1, 1995
: Have all climatological instrumentation installed in the field and begin water quality sampling of playas for all wells and lysimeters that have been installed.

June 30, 1995
: Completion of all instrumentation and well drilling for the detailed investigation of the 6 playa areas. As soon as items are completed, the sampling will be initiated.

July 31, 1995
: Completion of all surveying to define geomorphic parameters of all playa areas and verification of plant communities in each zone of all playa areas surveyed.

September 15, 1994
: Vegetation sampling and soil sampling in the field completed for all playa areas.

August 15, 1996
: Discontinue field sampling.

September 30, 1996
: Final report submitted.

This revised schedule will allow the project to continue collection of samples into the summer of 1996 and allow for any further field investigations found necessary from analysis of the data collected during 1994 and 1995. This would be a no increased cost extension of the contract from May 30, 1996 to September 30, 1996. Please consider granting of this request at this time.

STABILITY EVALUATION FOR DESIGNED EPHEMERAL CHANNELS IN WYOMING

S.L. RATHBURN, T. HANLIN, P.A. RECHARD, D.R. JENSEN

STABILITY EVALUATION FOR DESIGNED EPHEMERAL CHANNELS IN WYOMING

Sara L. Rathburn, Todd Hanlin, Paul A. Rechard, Daryl R. Jensen
Western Water Consultants, Inc.

Abandoned Coal Mine Land Research Program
Semi-Annual Project Review Seminar

November 8, 1994, Laramie, WY

INTRODUCTION

Channel reclamation at abandoned and active coal mines continues to be a central issue in mine land restoration throughout Wyoming. Most challenging to design engineers and regulatory personnel is evaluating the performance of designed channels under infrequent extreme events, capable of modifying a restored drainage. The research described herein extends initial work by Western Water Consultants, Inc. (WWC, 1993) on a statistical evaluation of designed channel success, by including the main coal-bearing regions of the state of Wyoming. The premise of the original work, and adhered to again, is that natural channels represent systems after which channel designs should be emulated. Thus, premining, or unmined characteristics of channels serve at the basis of our data set. The primary objectives of this research are to:

- collect and compile existing sources of data on premined channel and drainage basin characteristics
- test the applicability of regression relationships developed for southern WY to other geographic regions
- further investigate controls on channel slope using available channel sediment data
- develop a regional map of channel design criteria.

METHODOLOGY

Five areas of Wyoming have been identified as the main coal-bearing sites of interest to regulatory and mine personnel, which contain accessible information on native channel design characteristics. The study sites include: 1) Powder River Basin, 2) north of Glenrock, using information from the Dave Johnston Mine, 3) Rosebud Mine, near Hanna and Elmo, 4) Rock Springs, represented by abandoned Rainbow and Colony mines, and the active Jim Bridger mine, and 5) Kemmerer, using information from P&M mine. Information on premining channel characteristics has been collected for these five areas from the following sources:

1. Mine permit applications, specifically Appendix D-6 and Reclamation Plans.
2. Wesche et al. (1994), final report to ACMLRP, and Jensen (1994) and Andersen (1994), unpublished Master's theses.
3. Western Water Consultants (1993), final report to ACMLRP.
4. Rechard and Hasfurther (1980), WWRC report.
5. Apley (1976), unpublished Master's thesis.
6. Lowham (1988), and Lowham and Smith (1993), U.S.G.S. publications.

Current work involves compiling, and deriving the necessary data form the six sources. Although abundant data exist in these publications, the data are collected and reported in many different ways, which leads to inconsistencies. As a result, many of the parameters of interest are taken from topographic maps, or are estimated using hydrologic models (e.g. PREFRE, Trihydro, HEC-2) to ensure a consistent data set, and to increase the overlap between the six sources (Figure 1). The primary channel parameters of interest for our analysis include channel cross-sectional flow area, channel slope, hydraulic properties (top width, depth, velocity, shear stress, stream power) for various discharges, and bed and bank sediment characteristics (Figure 2). Drainage basin properties used include drainage area, main channel slope, and Area Gradient Index (AGI; drainage area main channel slope). A total of ~90 native ephemeral channels will be included into the data set.

Regression analysis will be conducted once the data set is finalized. Relationships that showed good correlation during our 1992-1993 research will be investigated to see if large areas can be delineated with common predictive equations. Additional work will be completed on the role of channel slope in influencing channel stability by incorporating grain size distribution information from channel bed and banks. Sediment samples are available for channels in the Powder River Basin (T. Wesche and L. Jensen, personal communication, 1994), and will be sieved by WWC. Once the regression analysis is complete, a regional map will be developed with design criteria for various areas of the state, and the data set will be made available as a data base computer file. Data files will be constructed in consultation with the Water Research Center to make our information consistent with WRC's Technical Information Processing System (TIPS).

Data Set Derivation

Model: PREFRE

estimates rainfall for storms of various durations and return periods

Results:

ppt for 2-yr, 10-yr, 100-yr, 1, 6, and 24-hr storm

↓

Model: TRIHYDRO

estimates discharge from rainfall amounts for a particular basin size

Results:

discharge for 2-yr, 10-yr, 100-yr, 1, 6, and 24-hr storm

↓

Model: HEC-2

water surface profiles model
calculates hydraulic properties at a cross section for multiple discharges

Results:

top width, depth, area, wetted perimeter, hydraulic radius, shear stress, stream power

Figure 1. Hydrologic models used in deriving consistent premined ephemeral channel parameters.

	Channel Xsec	Drainage Area	MBS	Hydraulics	Bed Material	Bankfull w, d	Bankfull Q
Mine Permit Applications							
Dave Johnston	●	●	●	●		●	●
Rosebud	●	●	●	●		●	●
Bridger	●	●	●	●		●	●
P&M	●	●	●	●		●	●
Wesche et. al.	●	●	●	●	●	●	●
WWC	●	●	●	●		●	●
Rechard & Hasfurther		●	●		●	●	●
Apley		●				●	●
Lowham; Lowham & Smith		●	●			●	●

Figure 2. Data sources with channel parameters either available or derived from topographic maps and hydrologic models.

GEOPHYSICAL DETECTION OF ABANDONED MINE TUNNELS

S.B. SMITHSON, M.C. HUMPHREYS, N.K. BOYD

Geophysical Detection of Abandoned Mine Tunnels

Progress Report
October, 1994

from
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Department of Geology and Geophysics
University of Wyoming
Laramie, Wyoming

GEOPHYSICAL DETECTION OF ABANDONED MINE TUNNELS

January 1994

From Scott B. Smithson
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UNIVERSITY OF WYOMING
Laramie, Wyoming 82071

Introduction:

This report presents results of "Geophysical Detection of Abandoned Mine Tunnels," a project to develop geophysical methods for resolving voids, faulting and collapse associated with abandoned mining operations in order to assist with remediation. This project proposes to develop equipment and methodology for locating voids and faulting in Rock Springs, the area in Wyoming that has experienced the greatest problems. This involves testing and calibrating high-resolution seismics (HRS) and ground-penetrating radar (GPR) over air-filled, rubble-filled, grout-filled, water-filled cavities, and as yet unmined coal beds. Calibration is furnished by coordinating with drilling results of engineering companies that are carrying out the remediation efforts in Rock Springs. As we develop these geophysical imaging techniques, we also take economic and environmental acceptability of operation into consideration.

Results:

High Resolution Seismics. High-resolution seismics (HRS) is based on seismic reflection methods at relatively high frequencies (greater than 100 Hz). These techniques are highly dependent on field data acquisition which is site-specific, depending on the nature of the surface weathered zone. For this reason, a number of tests using different sources and field techniques in different areas were performed. Techniques involved varying sources, source-receiver offsets and filter setting. Optimum source-receiver offset varied from 60 to 160 feet, depending on the target depth, and low-cut filter settings of 128 Hz worked best. Sources tested included a weight drop, a .308 caliber rifle, a .22 caliber rifle, and a sledgehammer. A sledgehammer was selected as the best source because it gave comparable results to the .308 rifle with minimal environmental disturbance; for example, it was cheap and effective. The .22 rifle was too weak and the .308 rifle (cheap surplus ammunition

was used) was good but noisy, and made people nervous in built-up areas. The weight drop produced too much seismic noise.

In terms of surface conditions, HRS gave useful results where soil, clay, or sandstone were at the surface. Working along sidewalks has proved difficult because the sidewalk propagates high-velocity seismic noise that interferes with seismic reflections.

Two new field computers have been obtained. One is a laptop with seismic processing software for real time display of data during acquisition and low-level processing; the other is a portable PC for complete processing and display of data in a motel room in the field. The computers, particularly the laptop, are critical for developing one of our main goals, real-time processing and display of data as it is acquired. In other words, we are seeking relatively simple techniques with real-time display after minimal processing so that potential subsidence areas and related features of interest can be identified on the spot. If we can do this and thus avoid the elaborate and highly technical processing that typically follows data acquisition to produce a final result in reflection techniques, these techniques will be a much more useful aid to remediation engineering.

Calibration of HRS and GPR has been achieved by coordinating our work with drilling operations conducted by Johnson Fermella Co. Inc. and by Morgan Mining and Environmental Consultants. In some cases, we have conducted a survey before (most desirable) and/or during grouting, and in other cases after grouting (less desirable). Drilling provides calibration that is useful for recognizing the signature of features associated with mined coal beds. In addition, we were able to lower seismic detectors into drill holes to determine a seismic travel time. This allows a travel time to the mined zone to be established so that a particular reflection and zone of interest can be identified on the seismic section (since basic HRS or even GPR measurements are in time which may be converted to depth). This is a first step in calibration. A second is to relate the seismic signature (the character of seismic pulses) to voids, rubble, pillars, or continuous coal beds as determined by drilling.

HRS profiles are presented for McKinley Street, Lincoln Street, Cody Street, and the water tank. Ground truth is provided by drilling at Lincoln and McKinley streets. Mined areas are at depths around 100 to 120 feet on these profiles. This depth is found in the upper part of the sections presented. An HRS profile over shallow (50-60 feet) mined areas at Alder Street is not presented

because the data was degraded by high-velocity noise along sidewalks. Here useful information was, however, obtained from GPR and follows in this report.

The Lincoln Street HRS profile runs along the alley next to the cemetery and was drilled after we recorded the profile. Coal was found along most of the profile and appears in the seismic profile (Figure 1) as a dark line. A void shown by drilling appears as a thick dark area. The HRS profile along McKinley Street (Figure 2) is calibrated by projecting from drilling about 50 feet off the profile. The coal horizon, at 120 feet, is indicated by the line on the right side of the section. A void with roof collapse encountered at 97 feet is marked by two shallower heavy lines a the left center of the section. Possibly a grouted void appears to the left. The shallow roof-collapse zone (Figure 2) indicates the kind of complication in seismic signature that must be further calibrated by drilling.

The Cody HRS profile (Figure 3) is located in a vacant lot southeast of Cody Street but has not been drilled. Based on amplitudes, we interpreted a mined zone (blue line in upper part of the section at about 110 feet depth. We will use further processing analysis and comparison with known voids to provide more support for the interpretation. An HRS profile was run at the new water tank located off the Southwest Beltway. The mined coal horizon is imaged (Figure 9) and two voids are interpreted. No drilling information is available.

Ground Penetrating Radar. Ground penetrating radar (GPR) has been tested with a number of problem areas at Rock Springs including a sink hole, faulted coal beds, grouted cavities, air shaft, and tunnel. The application of GPR is affected by nearby metal objects and the nature of the soil zone so that, in several cases, results were degraded by reflections from metal at the surface, and apparently by some conductive soil zones. The GPR system, however, works well on bedrock and provides depth coverage from the surface down to about 60 feet, the depth range where HRS is slower and less satisfactory.

The GPR is extremely fast, simple, and environmentally compatible (Figure 5), providing a real-time image of the subsurface. Faulted coal beds were imaged from down to a depth of about 20 feet and the faults themselves were directly imaged by the GPR (Figure 5). Along the Beltway, we were directed to a sinkhole that had been backfilled. The GPR image (Figure 7) of this area shows the sinkhole, a buried topographic ridge, and interference from three overhead wires. The sinkhole and buried ridge are imaged nicely; the cavity underlying the sinkhole may be revealed by

the thick dark area in the plot (Figure 7), but its presence is complicated by the arcuate interference, caused by overhead wires. Such interference effects were noted by the operator in the field. At Alder Street, we profiled over voids that had already been grouted at depths of about 50 feet Here two grouted areas were detected at slightly different depths (Figure 8) together with a water-filled cavity (Figure 9). The arcuate bands are reflections and diffractions at the top of both grout-filled and water-filled cavities. The grouted cavities were interpreted in the GPR image based on their occurrence at grout-filled drill holes and likewise with the water-filled cavity. Because the GPR signatures may appear similar, more work (like looking at true amplitude) needs to be done to improve interpretation. GPR profiles were recorded over two mine adits at depths of 30-35 ft and the position of the adit is successfully shown (Figure 10). A GPR profile over a fault at Pioneer Street in SE Rock Springs is shown but needs further processing for clarity (Figure 11). In summary, the GPR method has produced useful subsurface images in seven cases and unsatisfactory results in two cases. Future study involves developing a better understanding of subsurface signatures and solving the problem of surface interference and attenuation.

Please note that original figures were in color and could only be mass-produced in black and white. For color detail, please see originals on file at the Research Office.

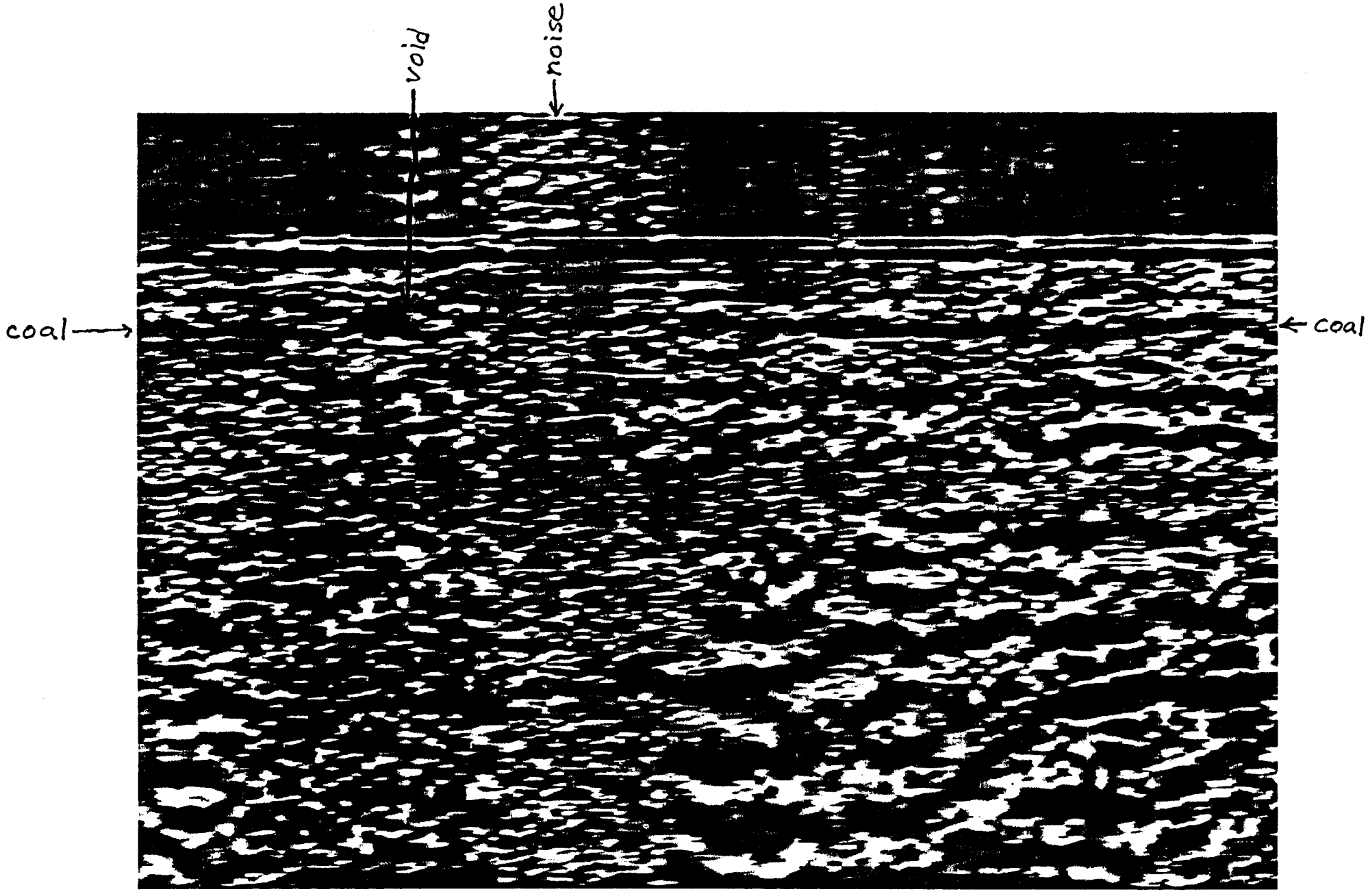

Figure 1. HRS profile along Lincoln Street alley next to cemetery. Coal horizon is indicated by dark line and void by the thick area.

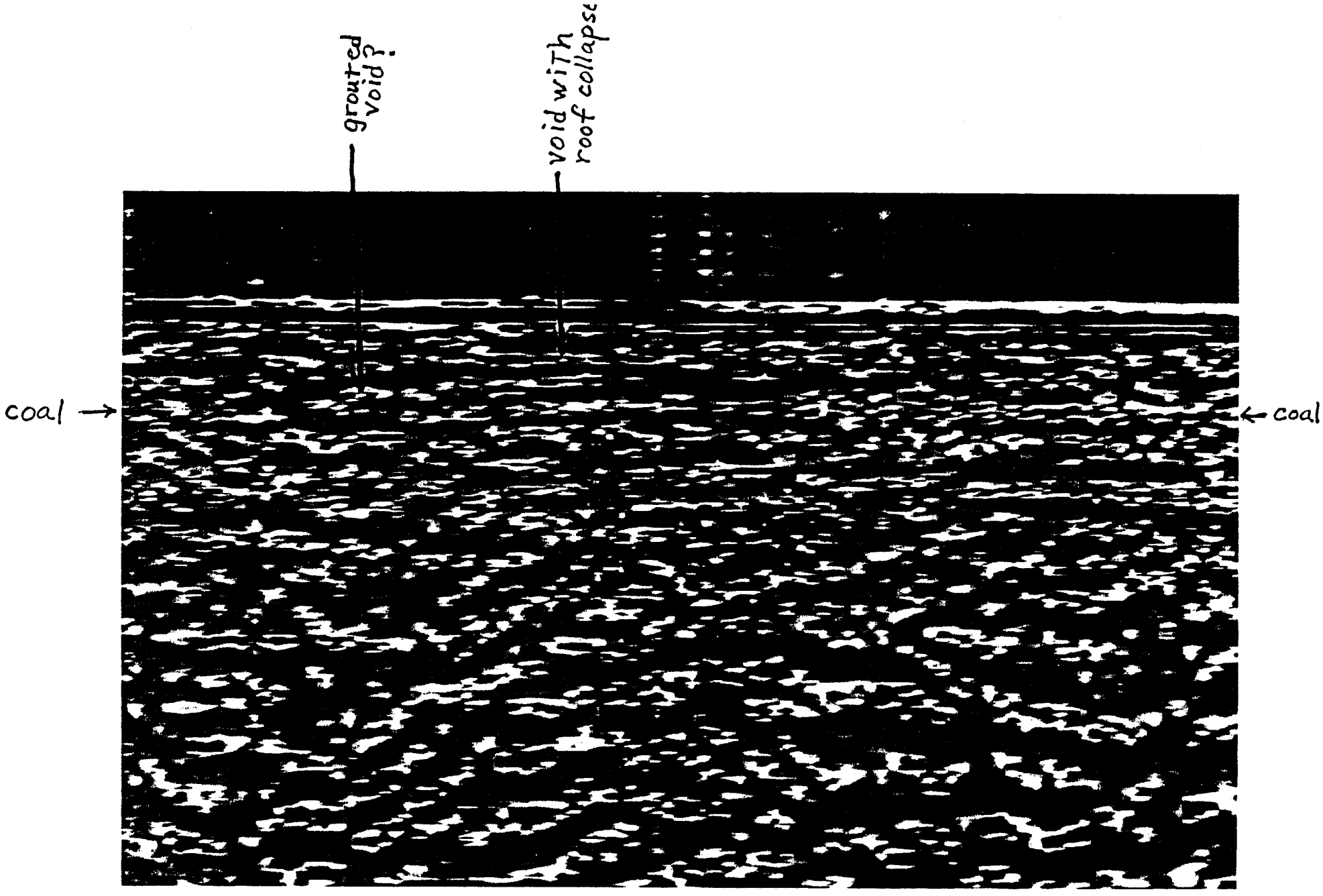

Figure 2. HRS profile along McKinley Street alley. Coal horizon, roof collapse, and grouted void (?) are indicated.

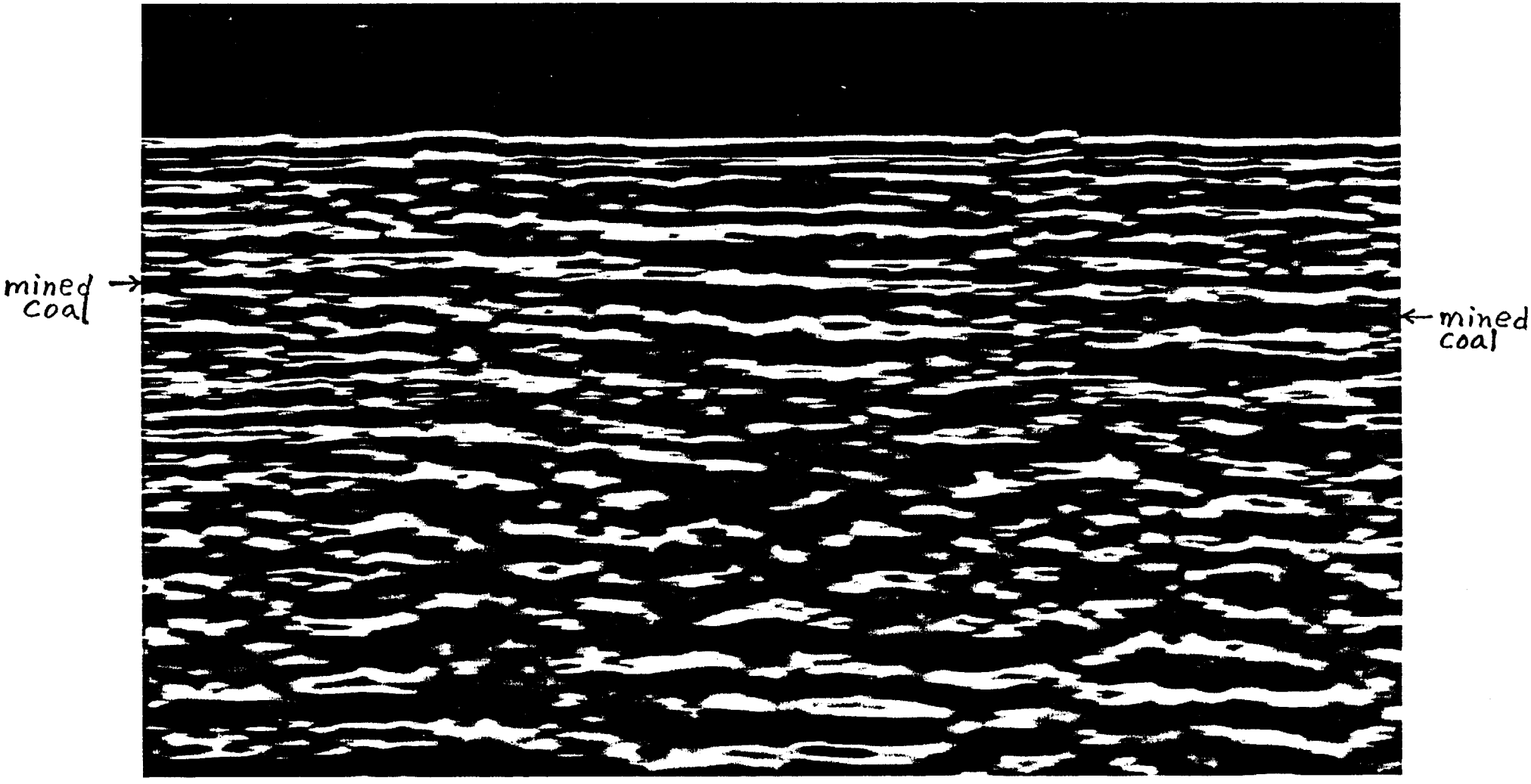

Figure 3. HRS profile in vacant lot near Cody Street. Coal horizon is probably mined.

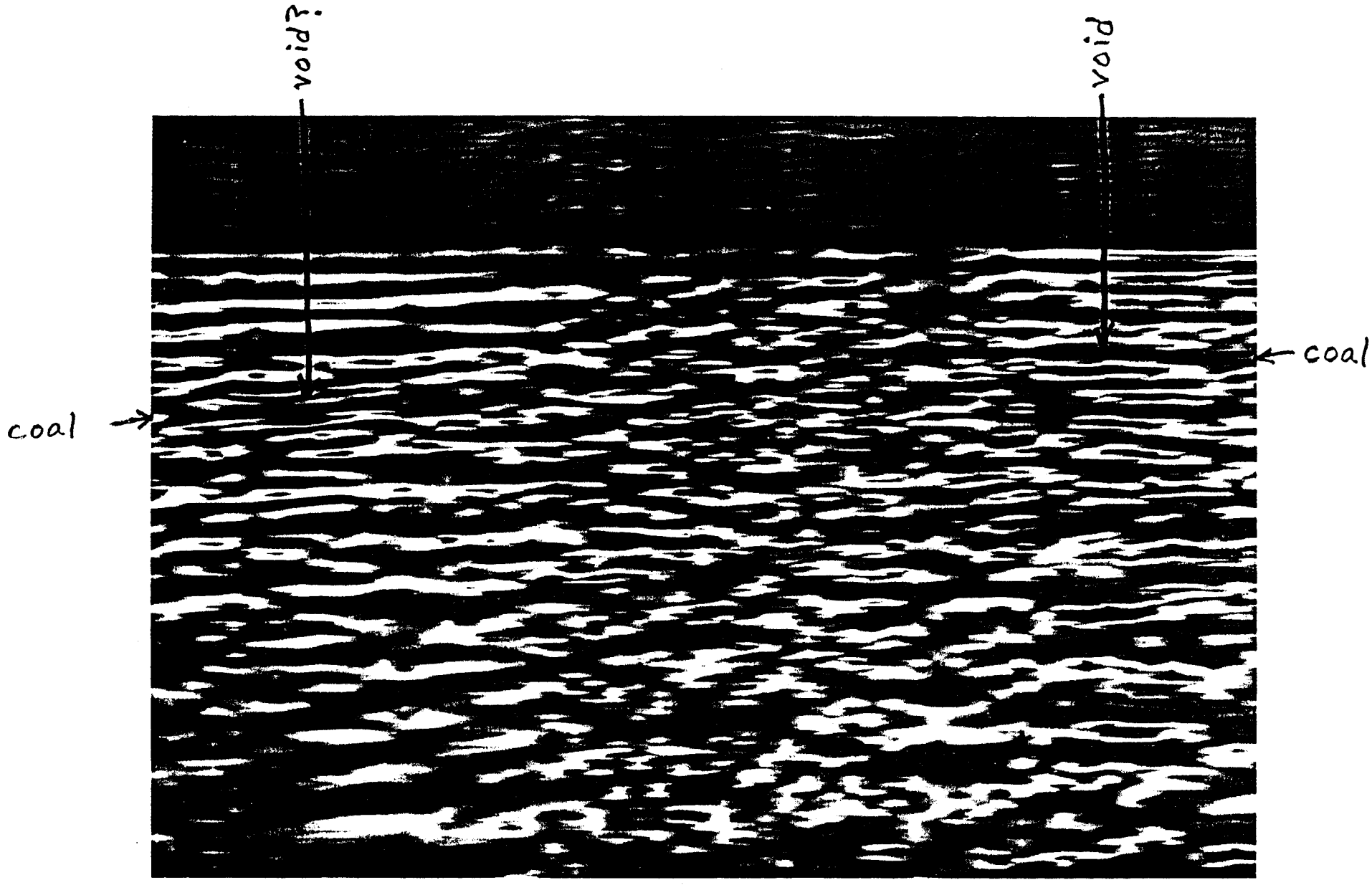

Figure 4. HRS profile at the new water tank by the Beltway. Dark lines may be mined-out voids.

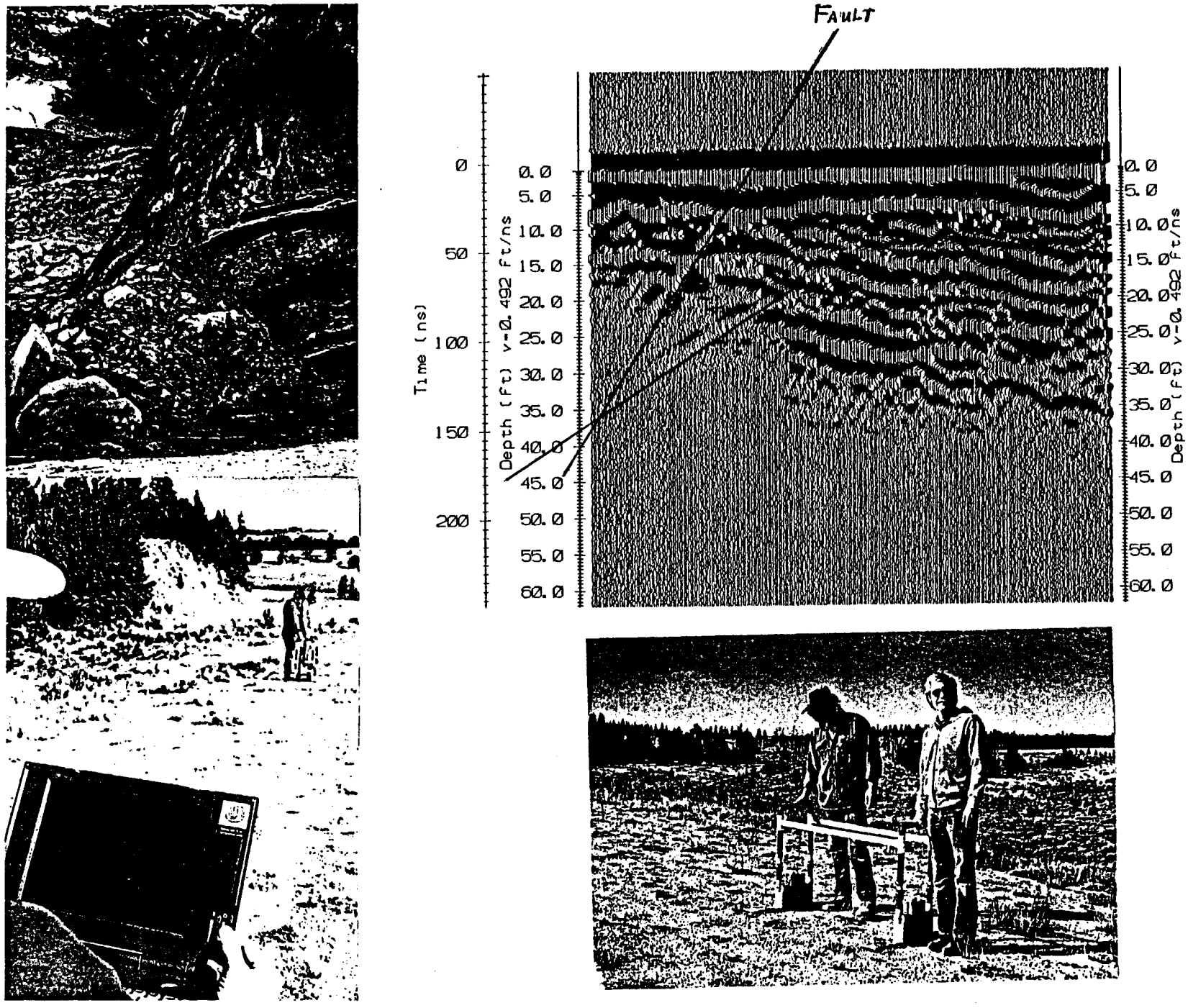

Figure 5. Example of GPR profiling over faulted coal and sandstone beds (upper left) and GPR image upper right with fault plane reflections at edge of Rock Springs. Operation of GPR system showing laptop (lower left) and GPR transmitter and receiver (lower right) in operation.

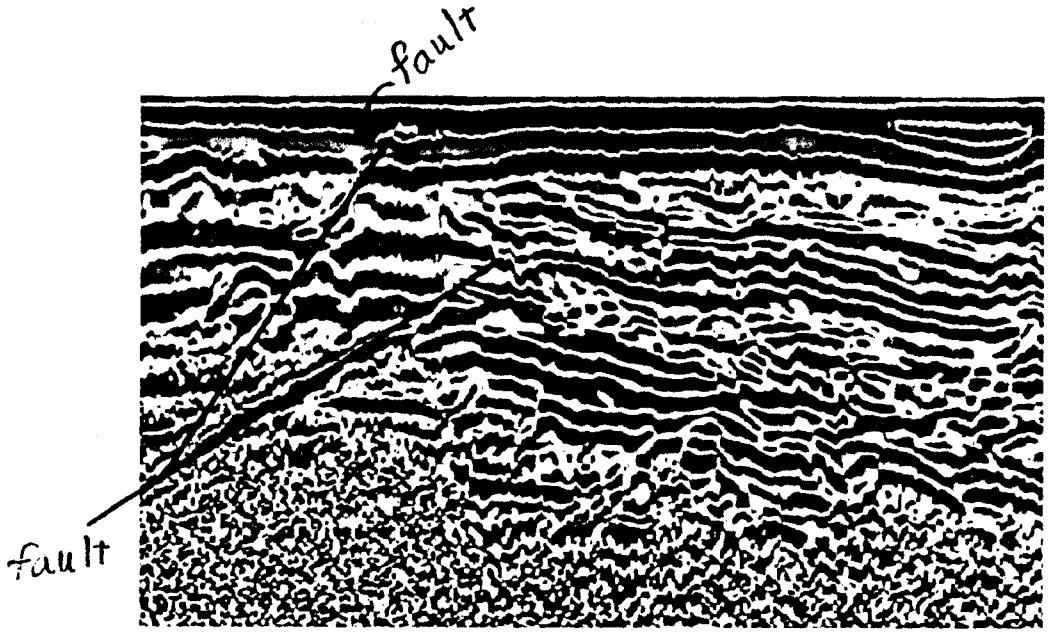

Figure 6. Plot of GPR image from Figure 5. Note fault-plane reflections.

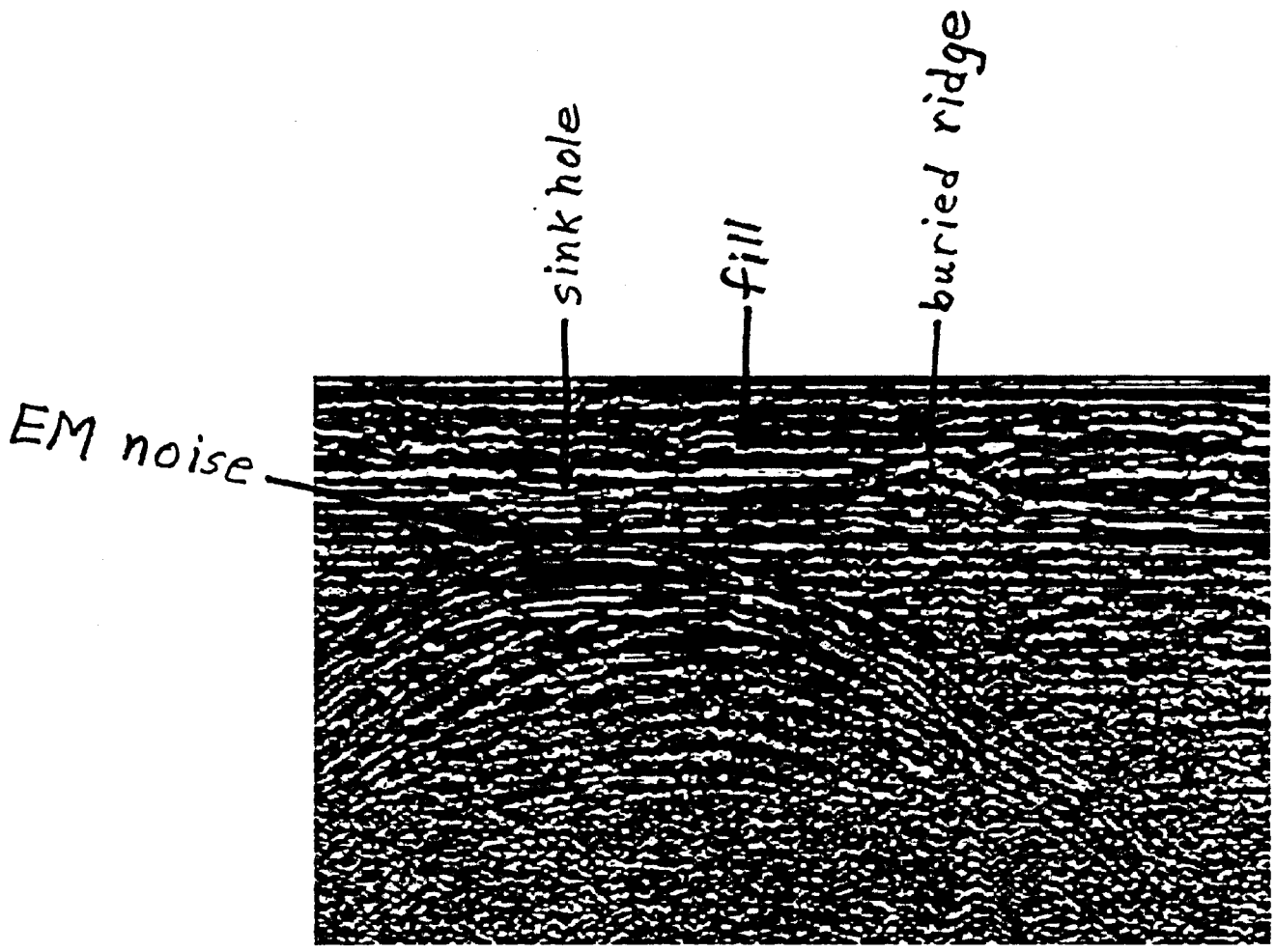

Figure 7. Plot of GPR image of back-fill over a sink hole and underlying cavity by Beltway. Plot also shows a buried topographic ridge and interference pattern from three overhead power lines.

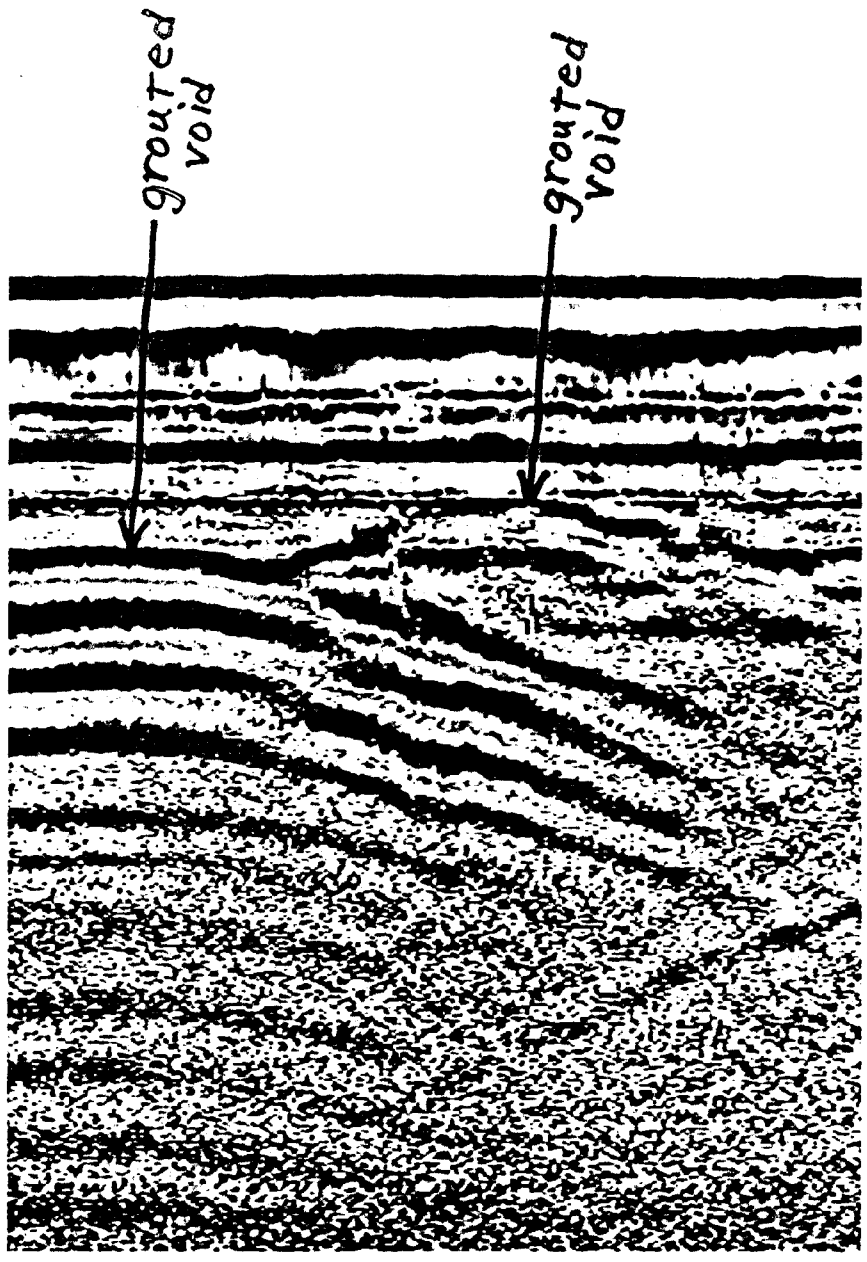

Figure 8. GPR image of grout filled voids at slightly different depths at Alder Street.

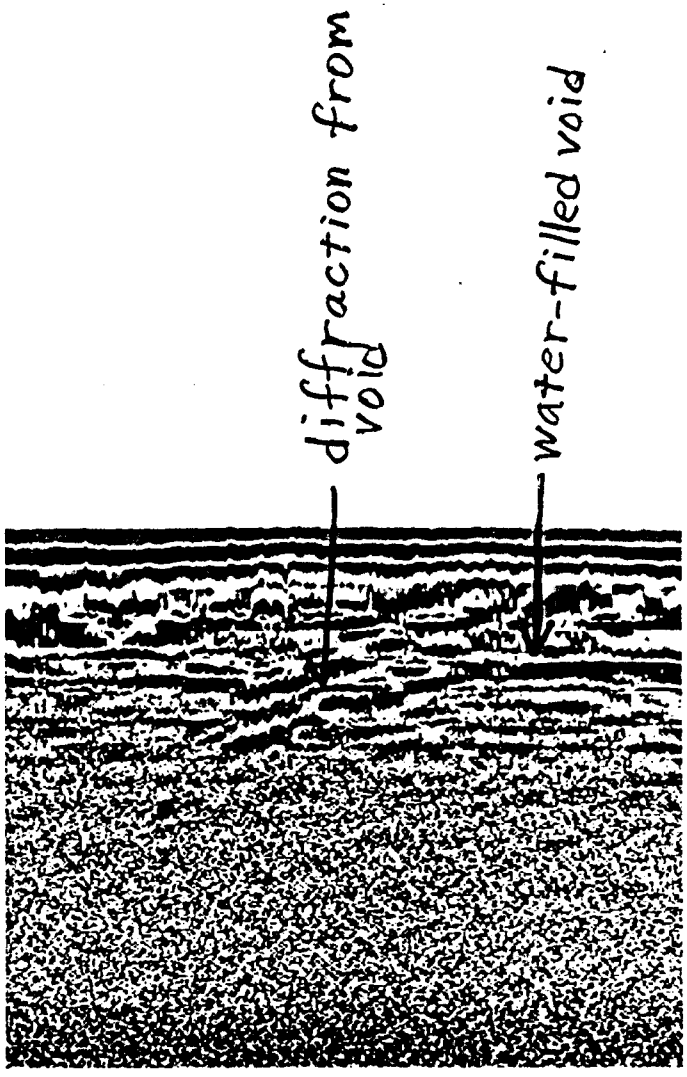

Figure 9. GPR image of water-filled voids at Alder Street. Note void and diffraction from top and bottom of void.

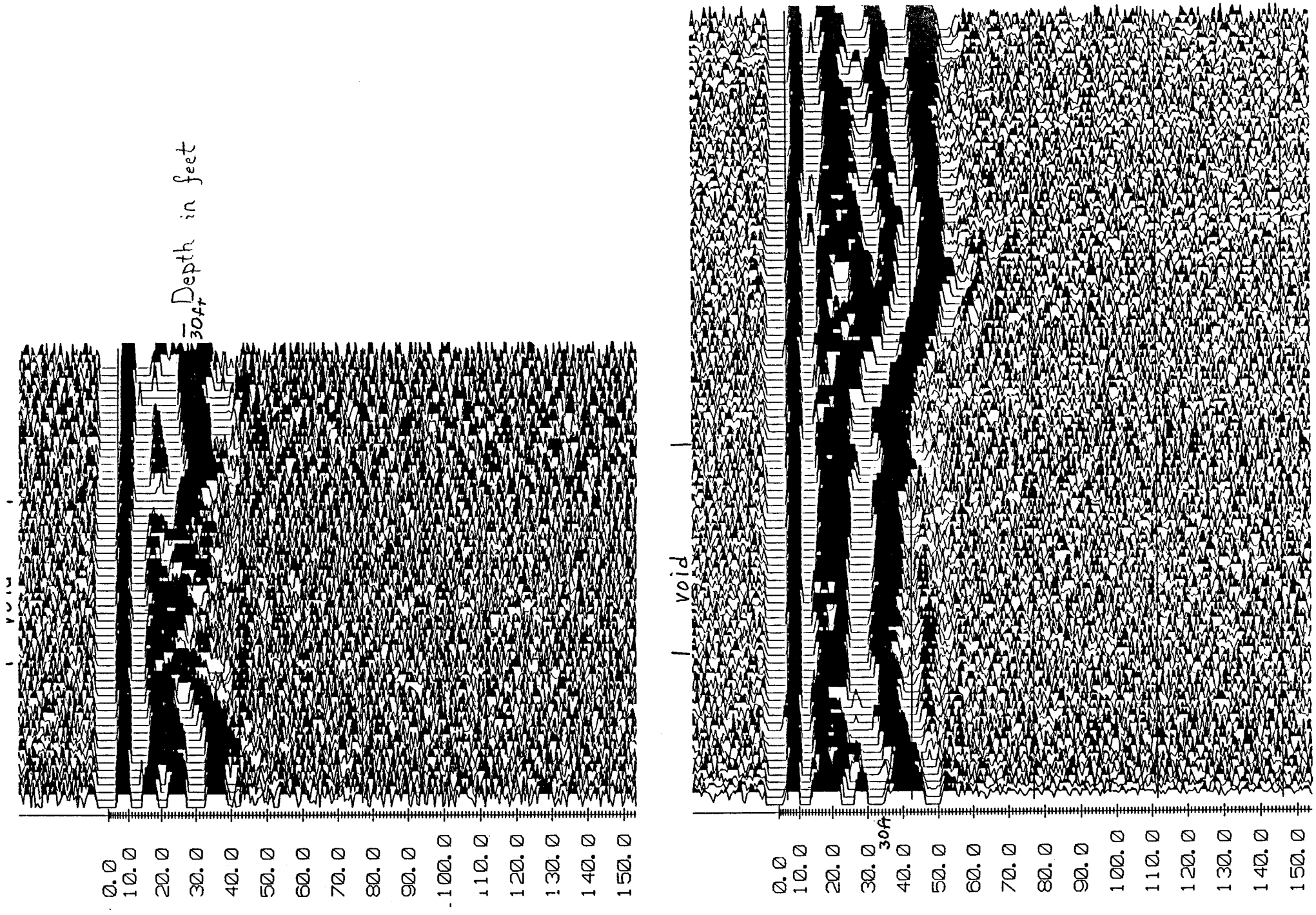

Figure 10. GPR profiles over two coal-mine adits at adepths of 30 to 35 ft. Position of adit is indicated by upward deflection of reflection (heavy dark line).

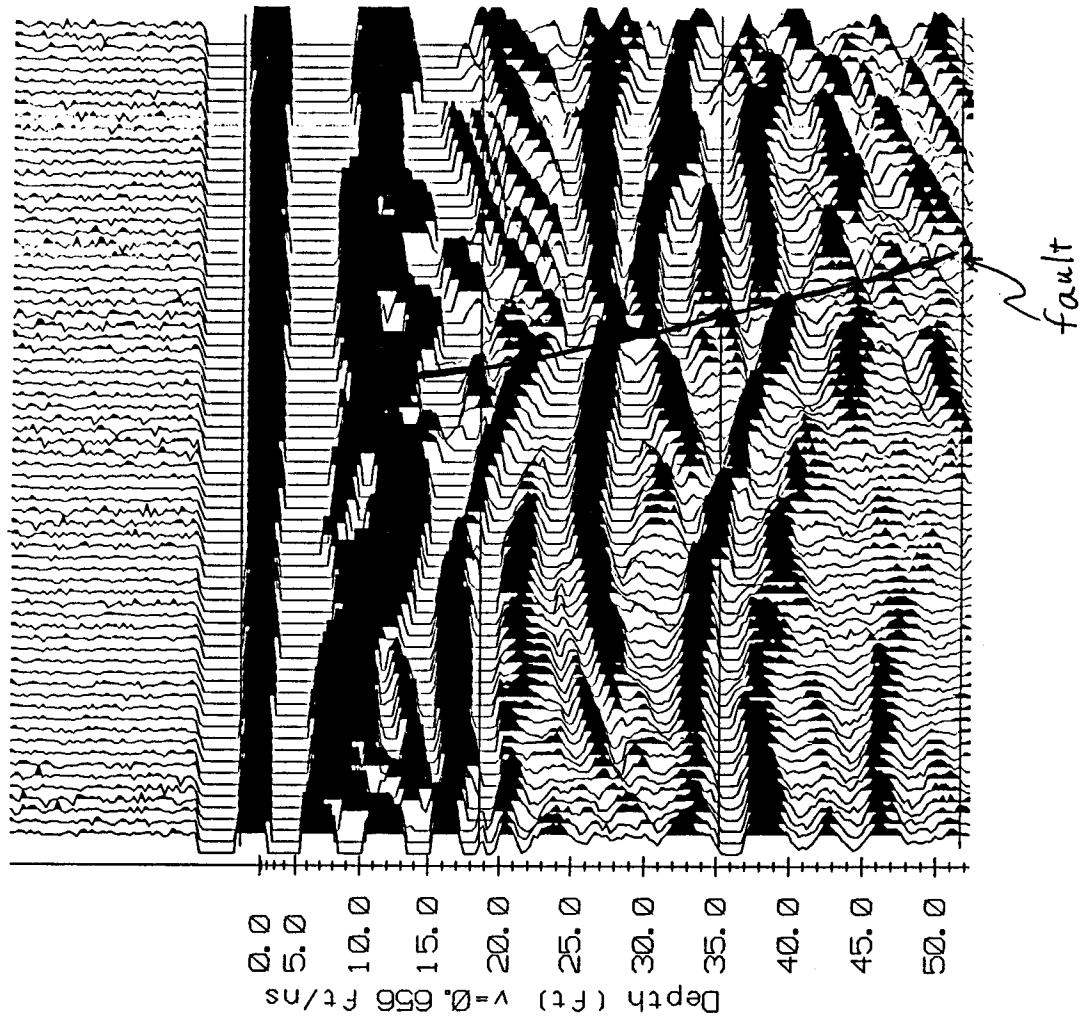

Figure 11. GPR profile over fault at Pioneer Street.