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GEOLOGICAL SURVEY

SELENIUM IN SOILS AND PLANTS FROM NATIVE
AND IRRIGATED LANDS AT THE KENDRICK
RECLAMATION PROJECT AREA, WYOMING

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

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INTRODUCTION

The Kendrick Reclamation Project Area was one of nine areas selected in 1985 by the Department of Interior for a field-screening study to investigate the possibility of elevated selenium (Se) concentrations in irrigation drainage. This reconnaissance investigation showed anomalous levels of Se in bottom sediments (Severson and others, 1987), water, and biota (Peterson, Jones, and Morton, 1987) from the Kendrick area.

Based on these findings, the Department of Interior's Irrigation Drainage Task Group selected Kendrick as one of four areas for more detailed study. Detailed studies focus on the following goals: (1) determine the magnitude and extent of irrigation-induced water quality problems, and (2) provide the scientific understanding needed to mitigate or resolve identified problems. The working objective for each of the four detailed studies was to determine the extent, magnitude, and effects of contaminants associated with agricultural drainage, and, where effects are documented, to determine the sources and exposure pathways that cause contamination.

In the mid-1930's, the Bureau of Reclamation began the Kendrick irrigation and drainage project in Natrona County, Wyoming (fig. 1). An area of approximately 24,000 acres near Casper, Wyoming has been under irrigation since about 1946.

Two detailed geochemical surveys were conducted in 1988 to study the distribution of Se and other elements in native and agricultural soils and plants of the Kendrick Reclamation Project Area (hereafter abbreviated to "Kendrick Project").

The native, non-irrigated soils have developed on different geologic units, including several marine Cretaceous formations containing carbonaceous shales and coals (Mesaverde Formation, Lance Formation, Meeteeste Formation and Lewis Shale [combined], and the Niobrara Formation), and several Tertiary formations containing bentonite, claystone, shale, and sand- or siltstone (White River Formation, Wind River Formation, and the Fort Union Formation). A study that focused on the local geology was judged essential to identify specific geologic units as sources of the elevated Se found in the screening studies. A geologic map of the Kendrick Project, simplified from a map of Natrona County (Lageson, 1980), is shown in figure 2.

The agricultural portion of the Kendrick Project comprises a patchwork of irrigated land surrounded by uncultivated native rangeland. Irrigated soils are generally confined to two dominant geologic units: Cody Shale of Cretaceous age and Quaternary alluvial deposits. The alluvium is derived largely from the Cody Shale. We felt that information on agricultural soils and alfalfa might reveal the extent of mobilization, transport, and concentration of Se and other trace elements resulting from irrigation.

A synthesis of the results from both detailed geochemical studies might serve to segregate the effects of irrigation from those attributed to natural environmental processes.

These soil and plant surveys were conducted concurrently with independent water and wildlife surveys by personnel of the Water Resources Division (USGS) and the U.S. Fish and Wildlife Service, respectively. A future summary report will integrate the results of this multidisciplinary effort.

The intent of the present report is to release the Se data and discuss their significance.

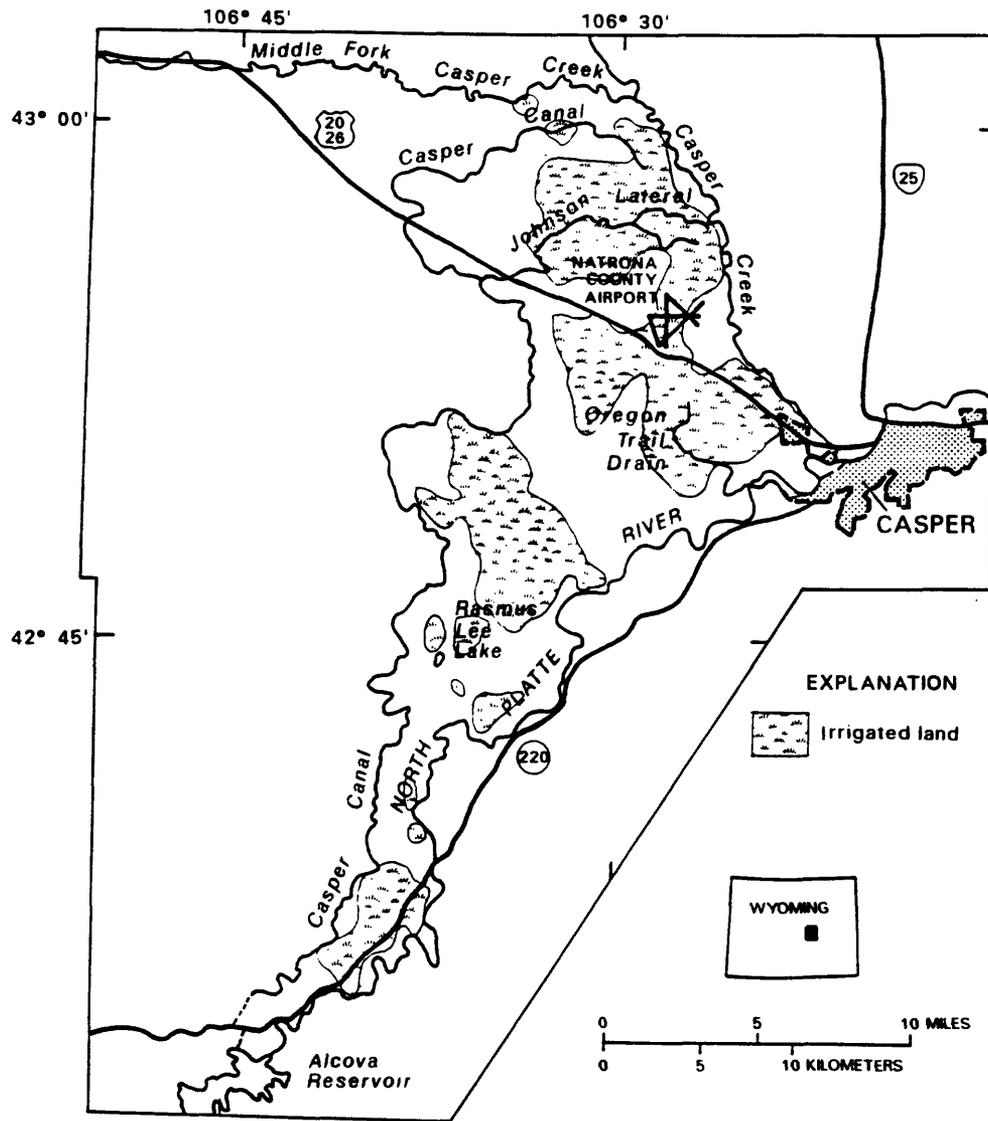


Figure 1. Index map of the Kendrick Reclamation Project Area.

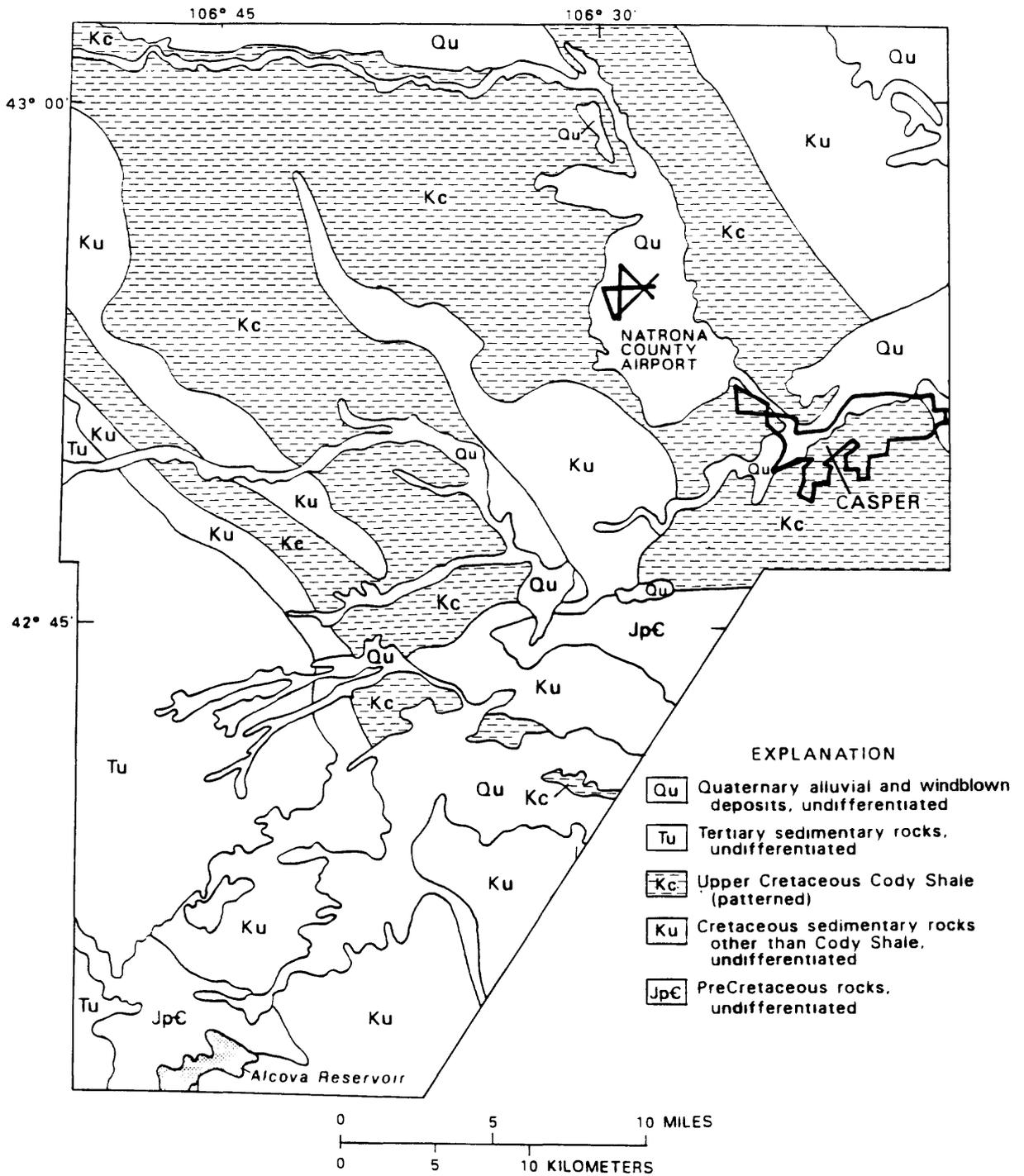


Figure 2. Simplified geologic map of the Kendrick Reclamation Project Area (adapted from Lageson, 1980).

METHODS

Field Sampling

Separate sampling plans were designed for the irrigated agricultural lands and the surrounding uncultivated native rangelands. Field sampling was conducted by Severson, Erdman, and Crock during the spring and early summer of 1988.

Native Soils and Big Sagebrush

A four-level, stratified random sampling design was used to assess the variability in trace element content of native soils and big sagebrush (*Artemisia tridentata* Nutt.) among and within geologic units that occur in the Kendrick Project. The Kendrick Project area encompasses approximately 25 townships. Twelve of the townships were selected randomly for sampling (fig. 3). A total of 14 geologic units was identified for sampling within the area, but not all geologic units occurred in each township. The distribution of geologic units occurring within each township is shown in table 1. Within a township, each of the geologic units present was sampled at two randomly selected locations. A sampling location was chosen by randomly selecting a section with reasonable accessibility and by identifying the geologic units within that section. Successive sections were selected randomly within each township until all geologic units occurring within the township had been sampled twice.

The purpose of this geochemical survey was to identify the possible source rocks of Se, not to produce geochemical maps. Two questions we sought to answer were: (1) Is a specific geologic formation more seleniferous than others? (2) If so, is the Se uniformly distributed throughout the unit?

Field work began April 12, 1988, and lasted almost the balance of the month. At each of the 120 sites selected, we used a 3.5-inch bucket auger to collect a sample of the uppermost meter of the soil horizon. The one-meter channel sample was then mixed in the field and a 1-kg sample collected. Only 101 of the sites supported big sagebrush, thus resulting in 19 "non-response" sites for the plant portion of the study. The previous year's growth was clipped from several shrubs within about a 10-m radius of the soil-auger hole and placed in cloth HUBCO bags. Most plants were still essentially dormant at the time and many had been heavily browsed by antelope.

Estimates of analytical precision for the soils and sagebrush analyses were based on 15 splits and 10 splits, respectively.

Agricultural Soils and Alfalfa

Geobotanical mapping of areas of Se deficiency and excess is a proven technique, as described recently by Combs and Combs (1986, p. 29):

* * * Kubota et al. (1967) surveyed the distribution of Se in more than 1000 samples of forages (primarily alfalfa) from different parts of the USA. They used the results of the survey to produce a generalized map of the distribution of Se in U.S. crops. Because their map was based upon crop Se data, it has greater relevance to considerations of nutritional aspects of Se than would one based upon geological data, inasmuch as it represents the distribution of Se in the particular terrain (i.e., valleys and plains) used for food and feed production.

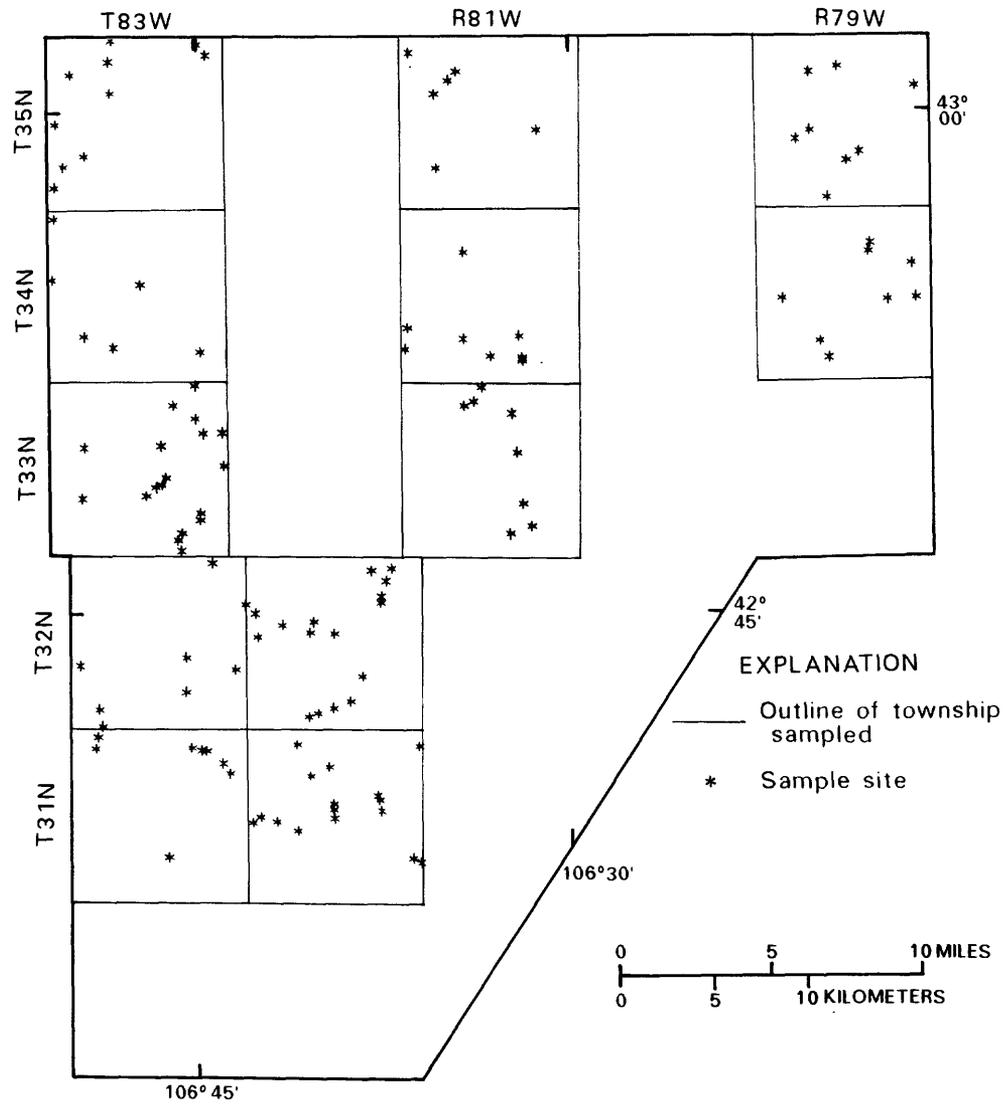


Figure 3. Locations of townships and sites sampled in the geologic-source study.

Table 1. Distribution of geologic units sampled from randomly selected townships at the Kendrick Reclamation Project Area.

[Numbers in body of table indicate number of sample sites from each geologic unit within each township. Explanation of geologic units: Qal, Quaternary alluvium; Qs, Quaternary sand dunes; Twru; Tertiary White River upper unit; Twrl, Tertiary White River lower unit; Twdr, Wind River Formation; Tfu, Tertiary Fort Union Formation; Kl, Cretaceous Lance Formation; Kfh, Cretaceous Fox Hills sandstone; Kml, Cretaceous Meeteetse Formation; Kmv, Cretaceous Mesaverde Formation; Kc, Cretaceous Cody shale; Ks, Cretaceous Steele shale; Kf, Cretaceous Frontier Formation; Kmt, Cretaceous Mowry and Thermopolis shale.]

Township	Range	Geologic Units													
		Qal	Qs	Twru	Twrl	Twdr	Tfu	Kl	Kfh	Kml	Kmv	Kc	Ks	Kf	Kmt
35	79	-	2	-	-	-	-	-	2	2	2	-	-	-	-
35	81	2	2	-	-	-	-	-	-	-	-	2	-	-	-
35	83	2	2	-	-	-	-	-	-	-	-	2	-	2	2
34	83	-	-	-	-	-	-	-	-	-	-	2	-	2	2
34	81	2	2	-	-	-	-	-	-	-	-	2	-	2	-
34	79	-	2	-	-	-	-	-	-	2	2	2	-	-	-
33	81	2	-	-	-	-	-	-	-	-	-	2	-	2	2
33	83	2	-	-	-	2	2	2	-	2	2	2	-	2	2
32	83	2	-	-	2	2	2	-	-	-	-	-	-	-	-
32	82	2	-	-	-	2	2	2	-	2	2	2	-	2	-
31	82	2	-	-	2	2	1	2	-	2	3	-	2	-	-
31	83	2	-	2	2	2	-	-	-	-	-	-	-	-	-

On a much smaller but more detailed scale, we collected samples on an approximate grid-interval of one mile that would allow the preparation of geochemical maps identifying areas of low and high concentrations of Se and other environmentally important trace elements, based on soils and alfalfa throughout the irrigated lands. An efficient sampling plan is dictated by an optimum grid size which, in turn, depends on knowing where most of the geochemical variation occurs spatially throughout the landscape. Because this information was unavailable for the Kendrick Project, we selected a grid size of one mile based on previous studies in the northern Great Plains (Severson, and Tidball, 1979) and in the San Joaquin Valley (Severson, Tidball, and Wilson, 1987).

Although the irrigated lands of the Kendrick Project encompass about 38 square miles (sections), only portions of most sections are currently irrigated, and those portions under irrigation are not contiguous. We superposed a map of irrigated areas (1:24,000 scale), which lacked essential access details, over the appropriate topographic maps of the same scale. Sections that contained less than 40 acres of irrigated land were rejected. For the most part the locality selected in the office proved to be suitable to sample when we arrived at the site.

From June 7-17, 1988 we collected samples of soils and associated alfalfa (Medicago sativa L.), mostly in the 10% bloom stage, from fields in 109 sections, beginning at the south end of the Kendrick Project and completing the sampling at the north end. Four sections lacked any alfalfa, although evidence of previous irrigation required that we sample at least the soils (field #s 2, 12, 64, and 104, fig. 4). The only other "hole" in our design was at a section arbitrarily numbered 78; permission was not granted to sample the entire section. Thus, a field #78 is missing from the analytical tables and the field-locality map. Alfalfa was sampled from 105 fields and soils from 109 fields.

Within each field, two sites approximately 100 meters apart were selected and sampled. In later preparation of the samples, half of each soil and alfalfa sample from the two within-field sites was retained for possible separate analysis while the other half was blended with its field pair; this composite sample was then analyzed. Each alfalfa sample was a collection of several individual plants within a few meters of the soil-auger hole. The top 20 cm of the plants were sampled. The 1-m soil core sample was similar to that described above for the native soils, but sampling often proved to be more time consuming especially in clay-rich soils that had been heavily irrigated.

A three-level analysis-of-variance design was incorporated into this geochemical study to estimate the within-field variance and analytical error. For the soils, the estimate of within-field variance was based on site pairs from eight fields, and analytical error was based on 15 analytical splits. For the alfalfa, site duplicates from seven fields were retained; each of the 14 samples was split in order to estimate the analytical error.

Field-sampling conditions were optimum: first cutting of the alfalfa was not to begin for another week, access to most fields was ideal, weather conditions were virtually perfect, and the Se indicator plants, mainly two-grooved poisonvetch (Astragalus bisulcatus [Hook.] Gray) and woody aster (Xylorrhiza glabriuscula Nutt.), were at their peak bloom period.

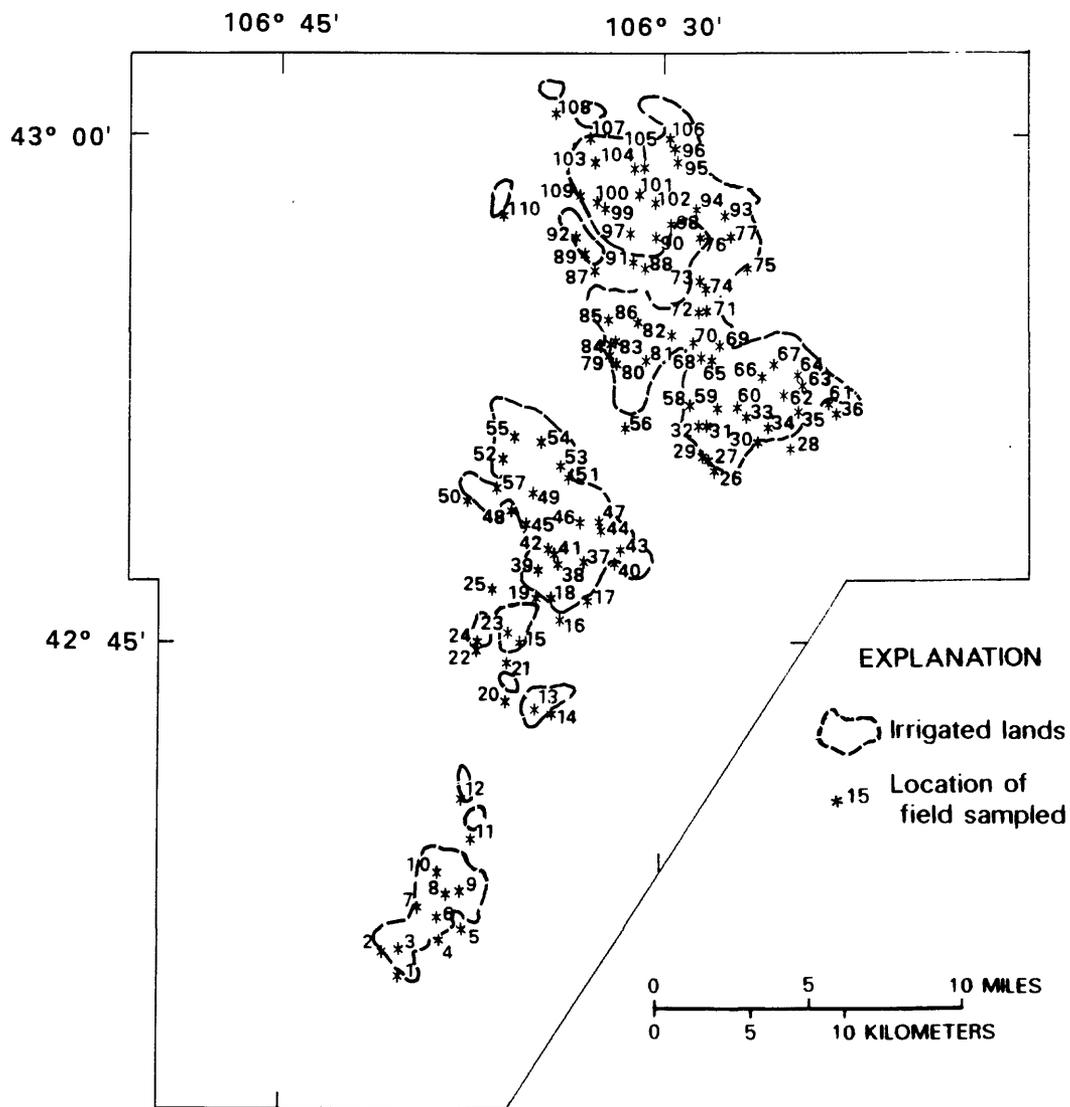


Figure 4. Locations and identification numbers of fields sampled in irrigated-lands study.

On June 6, 1989, field sampling was repeated by H. Mayland in two localities where alfalfa, sampled in 1988, contained 15 and 25 ppm Se. Both localities occur on Cretaceous Cody shale. The forage mixtures contained about 85 percent alfalfa and 15 percent smooth brome grass (Bromus inermis Leyss.). Plants were 30- to 35-cm tall and were in early bud and flower stage, respectively. The first harvest of the season occurred 2 weeks after sampling. Selenium indicator plants in this area were in early bloom stage.

Two to four tillers (above 4-cm stubble height) each of alfalfa and brome grass were collected from each of approximately 50 subsites on each of four sampling sites. One of these sites was a 40-acre field having 1.5 percent slope and easterly aspect. The three remaining sites were part of a 40-acre field containing 10 acres having 2 to 3 percent slope on a northerly aspect and an upper and lower site on the other 30 acres, having a 2 to 4 percent slope and a southeasterly aspect.

Laboratory Methods

Sample Preparation

Soil samples were sent to the U.S. Geological Survey laboratories in Denver for preparation and analysis. After the samples were air dried under forced air at ambient temperatures, they were disaggregated with a mechanical mortar-and-pestle, sieved at 2 mm (10 mesh), and the minus 2 mm material saved for analyses. A split of the minus 2 mm material was ground in a ceramic plate grinder to minus-100 mesh, and this material was used for all chemical analysis.

All plant samples were washed (to avoid any possible surface contamination), dried, and pulverized to a 2-mm size in a Wiley mill by the sample preparation laboratory of Minerals Exploration Geochemistry, Carson City, Nevada. Drying was at ambient temperature for 24 hours followed by 15 minutes in a microwave oven. The alfalfa samples were mailed in the cloth sample bags to the preparation laboratory within 1-2 days of collection.

After milling, ten of the 101 sagebrush samples collected from the native rangeland were split into two parts in the laboratory to provide an estimate of the analytical precision. The total number of sagebrush samples, then, was 111; these were submitted for analysis in a randomized sequence.

The alfalfa samples from each site (two sites per field) were separated into two parts with a Jones splitter, and one part of each field pair was then combined for analysis. The other part of each pair was placed in the original sample bag to allow for later analyses of the site samples, if needed. Alfalfa samples from two sites in each of seven fields were analyzed separately in order to estimate local variation. Splits of these 14 samples were made to estimate analytical error. The total number of alfalfa samples was 126; these samples came from 105 fields.

The 1989 forage samples were cut into 1- to 2-cm lengths, mixed thoroughly, subdivided into approximately 200 g subsamples, and submitted to one of three drying methods: (1) oven drying in forced draft (100°C for 90 minutes followed by 65°C for 30 hours), (2) microwave drying (200 g sample for 15 minutes in 1.22 kw household microwave oven at 2450 MHz), and (3) freeze drying. Samples were then ground to pass a 1-mm sieve in an intermediate Thomas-Wiley mill.

Analytical Techniques

The Se analyses were performed by two techniques: continuous flow hydride generation atomic absorption spectroscopy (HGAAS) for soils (Crock and Lichte, 1982; Sanzolone and Chao, 1987), and fluorometry for plants (Harms and Ward, 1975).

A 0.25-gram soil sample was digested with nitric, perchloric, and hydrofluoric acids. After digestion, the sample was diluted to 50 mL with 6N HCl. Selenium was determined using a continuous-flow system. In the procedure, the sample solution was reacted with sodium borohydride in order to generate the gaseous hydride which was swept into the heated quartz furnace of an atomic absorption spectrometer. Selenium was determined using an aqueous standard calibration curve. The determination limit for Se in soils is 0.1 ppm. The relative standard deviation for duplicate determinations was about ten percent.

Selenium in vegetation was determined fluorometrically after complexing with 2, 3-diaminonaphthalene and extraction into an organic solvent. One gram of dried, ground vegetation was digested with 10 ml nitric and 2 ml perchloric acids; hydrogen peroxide was used to help break down resistant waxes. Selenium was then complexed with 2, 3-diaminonaphthalene and the complex extracted into cyclohexane. The determination limit for Se in plants is 0.01 ppm; the relative standard deviation for duplicate determinations was 10-15 percent.

Selenium concentrations in the 1989 forage samples were determined by HG-AAS after a similar digestion used for the fluorometric determination. Several forage samples, including the two collected from the same areas in 1988, were included as unknowns with the 1989 sample set.

Quality Control

Soil Materials

Statistical techniques and reference samples were used to assess accuracy and precision of the Se analyses. Subsets of samples from each of the two geochemical studies were selected to be split into two parts after grinding and analyzed separately to estimate errors associated with sample preparation and analysis (often referred to as procedural error rather than analytical error). The samples from each study, plus sample splits, were arranged in a randomized sequence and prepared and analyzed in that sequence to convert any systematic errors in preparation and analysis to random errors, and to estimate relative laboratory precision. Samples of U.S. Geological Survey standard reference material SCo-1 Cody Shale were inserted at random intervals into the soil-sample sequence to estimate laboratory accuracy. Reported consensus values from the literature, when compared with our laboratory determinations (table 2), show that the determinations were highly accurate.

Plant Materials

Several biological standard reference materials from the National Bureau of Standards were analyzed for Se by fluorometry. Gladney (1980) analyzed these same materials by neutron activation analysis. The close agreement between the certified values, the values determined by Gladney (1980), and those determined by the U.S. Geological Survey laboratories are shown in table 2.

Table 2.--Analysis of standard reference materials for selenium.

[All values are expressed in parts per million.]

Reference materials	National Bureau of Standards Certified values	Literature values	This study Determined values
SCo-1 (Cody shale) ¹	Not determined	0.89 \pm (0.06) ⁴	0.82 \pm (0.117) ⁶
#1567 Wheat flour ²	1.1 \pm (0.2)	1.12 \pm (0.01) ⁵	0.97
#1571 Orchard leaves ²	0.08 \pm (0.01)	0.08 \pm (0.009) ⁵	0.075
#1575 Pine needles ²	Not determined	0.049 \pm (0.004) ⁵	0.056
#1570 Spinach ²	Not determined	0.039 \pm (0.015) ⁵	0.032
#1572 Citrus leaves ²	0.025 ³	Not determined	0.038 \pm (0.002) ⁷

- ¹ U.S. Geological Survey reference materials
² National Bureau of Standards reference materials
³ Non-certified value
⁴ Gladney and Roelands, 1988
⁵ Gladney, 1980
⁶ Based on six analyses
⁷ Based on five analyses

RESULTS AND DISCUSSION

Geologic Units in Native Rangeland

Native Soils

Background ranges for Se in soils of the northern Great Plains, as well as those for soils from three other regional studies in the West, are given in table 3. An explanation of the data in table 3 is necessary before any comparisons can be made. The computed values are referred to as baselines rather than backgrounds because they represent the concentration measured at some point in time. Background values, in contrast, are intended to represent natural concentrations that exclude man's influence, and are rarely obtainable. The sampling media for each of the studies in table 3 differ from one study to another. Samples from the western half of the United States (Shacklette and Boerngen, 1984) were collected from the B horizon, or below 20 cm where the B horizon was undefined. Surface or A-horizon samples were collected for the northern Great Plains study (Severson and Tidball, 1979).

Table 3.--Geochemical baselines for selenium in soils from selected studies in the western United States.

[Detection ratio, number of samples in which the element was found in measurable concentrations to number of samples analyzed; GM, geometric mean; GD, geometric deviation; baseline, expected 95-percent range]

Reference and general location of the study area	Detection ratio	GM	GD	Baseline	Observed range
Shacklette and Boerngen (1984) western half of the United States	590:733	0.23	2.43	0.039-1.4	<0.1-4.3
Severson and Tidball (1979) northern Great Plains, parts of Montana, Wyoming, and N. Dakota	104:136	0.45	2.72	0.061-3.3	<0.1-20
McNeal (unpublished) San Joaquin Valley, California	240:328	0.14	2.56	0.021-0.92	<0.1-2.8
Severson, Tidball, and Wilson (1987) Panoche Fan, San Joaquin Valley	713:721	0.68	1.94	0.1-2.2	<0.1-4.5

And the surface 0-20 cm was collected for the San Joaquin Valley study (J.M. McNeal, U.S. Geological Survey, Reston, VA, unpubl. data). Samples of soils from a depth of 66-72 inches were collected from the Panoche Fan, located on the west side of the San Joaquin Valley, California (Severson, Tidball, and Wilson, 1987). These baselines are valid for comparing analyses of the same kind of sample from within the area where the baseline was developed. They should be applied with caution to different sample media or to samples collected outside of the baseline area. They are presented here to show what ranges in Se values have been determined in soils from different parts of the western United States.

All of the native, rangeland soils that we sampled contained total Se within the 3.3 ppm norm established for soils from the northern Great Plains (fig. 5), the most appropriate baseline with which to compare our data. The relative normalcy of the Kendrick soils is quite surprising in light of the clearly anomalous concentrations of Se found in the associated sagebrush collected in our study. A comparison of the ranges and means for Se in soils collected from the various geologic units (fig. 5) shows that soils from the Cody Shale are higher in Se than those from the other units and only the mean from the Cody Shale exceeds that for soils from the northern Great Plains. This is also shown in the raw data given in table 4.

Results of the analysis-of-variance, expressed as a percent of the total variance, are as follows:

	<u>Geologic Units</u>	<u>Townships</u>	<u>Sections</u>	<u>Analyses</u>
Native soils	34*	11	45*	10

*Differences within category are significant at the .05 level.

A. Baseline-Soils, northern Great Plains

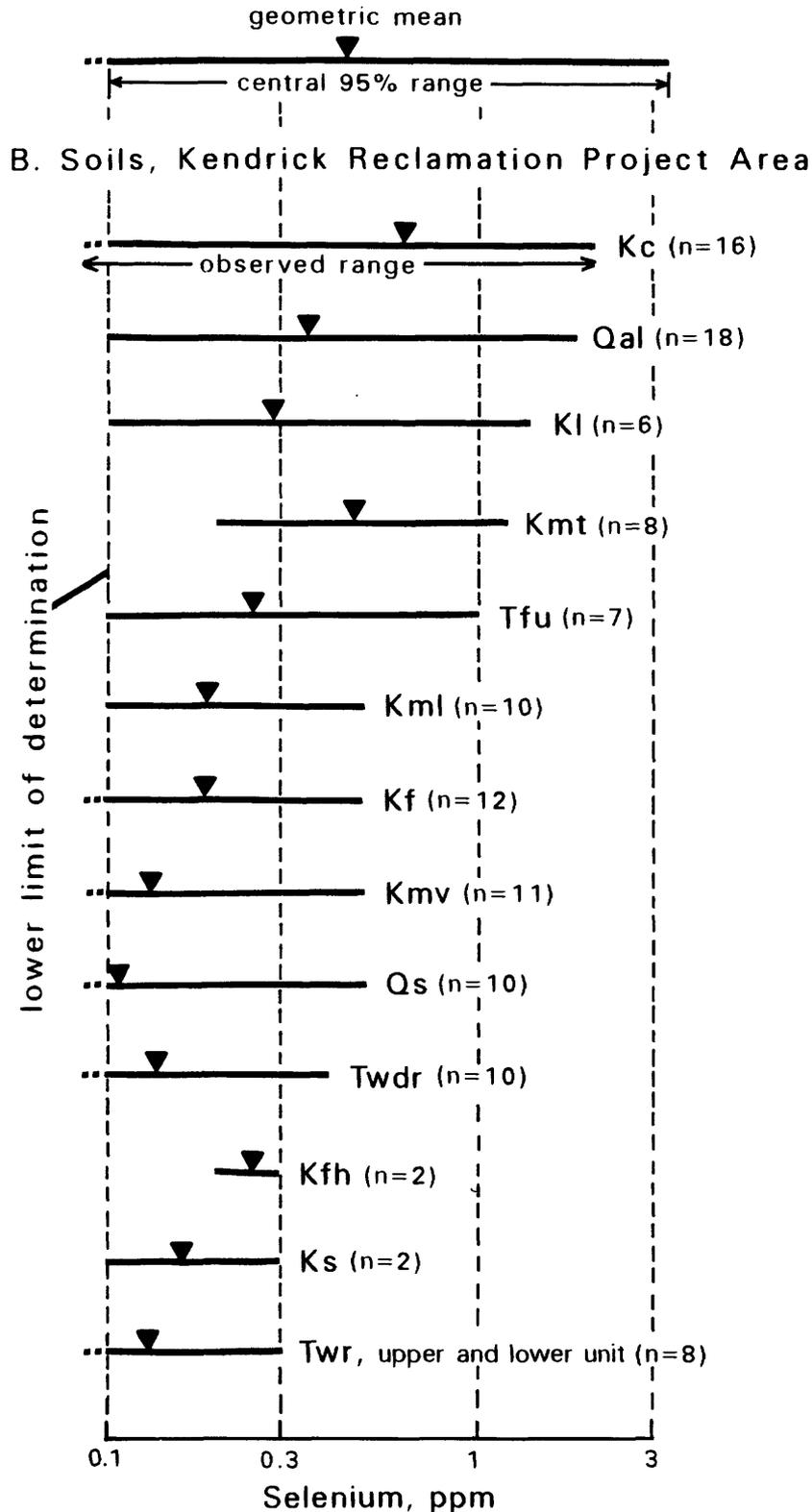


Figure 5. Bar plots of selenium in native soils from geologic units in the Kendrick Reclamation Project Area, arranged in order of decreasing maximum concentrations. Baseline data are from Severson and Tidball (1979). Dashes indicate that the lower end of the range was below the 0.1 ppm lower limit of determination. (See table 1 for explanation of geologic symbols.)

Table 4.--Selenium in samples of native soils collected from geologic units at the Kendrick Reclamation Project Area.

["R" prefix in Sample ID denotes analytical splits; the multi-letter suffix attached to each Sample ID denotes the geologic unit mapped for the site--geologic units are identified in Table 1]

Sample ID	Latitude	Longitude	Se, ppm	Sample ID	Latitude	Longitude	Se, ppm	Sample ID	Latitude	Longitude	Se, ppm
K031Qal	430059	1063445	0.3	K221Twdr	424105	1064106	0.1	K031Kc	425926	1063115	0.6
R031Qal	430055	1063445	0.4	K222Twdr	424009	1064033	0.3	R031Kc	425926	1063115	0.3
K032Qal	425819	1063518	0.7	K231Twdr	424055	1064442	<0.1	K032Kc	430031	1063520	0.3
K051Qal	430143	1064431	0.2	K232Twdr	424015	1064337	<0.1	K051Kc	430036	1064821	0.8
K052Qal	430133	1064824	0.7					K052Kc	430109	1064957	2.1
K081Qal	425317	1063203	0.3	K151Tfu	424715	1064548	0.1	K061Kc	425454	1064717	1.8
K082Qal	425233	1063153	0.5	K152Tfu	425002	1064932	1.0	R061Kc	425454	1064715	1.8
K131Qal	424736	1063133	0.1	K161Tfu	424633	1064426	0.2	K062Kc	425251	1064452	1.4
K132Qal	424723	1063225	0.3	K162Tfu	424517	1064308	0.2	K081Kc	425549	1063416	1.8
K151Qal	424928	1064357	0.5	K171Tfu	424441	1064141	0.3	K082Kc	425253	1063639	0.9
K152Qal	425004	1064628	0.3	R171Tfu	424441	1064141	0.1	K101Kc	425305	1062001	2.1
K161Qal	424320	1064333	0.3	K172Tfu	424155	1064037	0.1	R101Kc	425305	1062001	3.5
K162Qal	424241	1064530	0.8	K221Tfu	424026	1063948	0.5	K102Kc	425423	1062133	0.3
K171Qal	424600	1063729	0.7					K131Kc	425145	1063333	<0.1
K172Qal	424307	1063826	0.2	K151Kl	424728	1064538	0.1	K132Kc	424817	1063154	1.2
K221Qal	424101	1063609	0.6	K152Kl	424836	1064704	0.2	K151Kc	425150	1064505	0.5
K222Qal	423741	1063625	1.9	K171Kl	424426	1064032	1.4	K152Kc	424907	1064616	0.2
K231Qal	424056	1064455	0.1	K172Kl	424201	1064014	0.1	K171Kc	424623	1063714	0.6
K232Qal	424033	1064403	0.1	K221Kl	423933	1063751	0.4	K172Kc	424531	1063739	0.2
				K222Kl	423919	1063937	0.4				
K011Qs	430042	1061609	0.1					K221Ks	423733	1063605	0.3
K012Qs	430117	1061909	<0.1	K011Kfh	430108	1062019	0.2	R221Ks	423733	1063605	0.4
K031Qs	430145	1063621	0.1	K012Kfh	425845	1061820	0.3	K222Ks	423832	1064105	0.1
R031Qs	430145	1063621	<0.1								
K032Qs	430111	1063425	0.3	K011Kml	425924	1062019	0.1	K051Kf	425942	1065035	0.1
K051Qs	430202	1064453	<0.1	K012Kml	425830	1061851	0.1	K052Kf	425841	1064926	0.1
K052Qs	430212	1064817	0.1	K101Kml	425602	1061758	0.1	K061Kf	425321	1064931	0.1
K081Qs	425240	1063311	0.1	K102Kml	425525	1061620	0.1	K062Kf	425300	1064821	0.4
K082Qs	425237	1063155	0.5	K151Kml	424751	1064454	0.2	K081Kf	425312	1063417	0.5
R082Qs	425237	1063155	0.5	K152Kml	424850	1064640	0.3	K082Kf	425332	1063632	0.4
K101Qs	425424	1061609	0.1	K171Kml	424446	1064024	0.5	R082Kf	425332	1063632	0.5
R101Qs	425424	1061609	<0.1	K172Kml	424210	1063037	0.4	K131Kf	425119	1063353	0.2
K102Qs	425235	1061939	<0.1	R172Kml	424210	1063937	0.4	K132Kf	425058	1063221	0.4
				K221Kml	423926	1063746	0.3	K151Kf	425025	1064446	<0.1
K231Twrw	424101	1064909	<0.1	K222Kml	423909	1063937	0.2	K152Kf	425115	1064558	0.3
K232Twrw	423747	1064614	0.1					K172Kf	424617	1063804	0.2
				K011Kmv	425908	1062053	0.1	K171Kf	424520	1063741	0.1
K161Twrw	424212	1064859	0.1	K012Kmv	425724	1061939	0.1				
K162Twrw	424141	1064851	0.2	K101Kmv	425546	1061803	0.1	K051Kmt	425749	1065038	0.3
K221Twrw	423847	1064253	0.1	K102Kmv	425421	1061717	0.1	K052Kmt	425825	1065017	1.2
K222Twrw	423857	1064233	0.3	K151Kmv	424803	1064453	0.2	R052Kmt	425825	1065017	1.3
K231Twrw	424122	1064903	0.1	K152Kmv	424855	1064626	0.1	K061Kmt	425652	1065041	0.6
K232Twrw	424101	1064518	0.1	R152Kmv	424855	1064626	0.1	K062Kmt	425503	1065046	1.0
				K171Kmv	424424	1063934	0.5	K131Kmt	425111	1063416	0.3
K151Twdr	424656	1064540	0.1	K172Kmv	424222	1063855	0.1	R131Kmt	425111	1063416	0.3
K152Twdr	424831	1064938	0.2	K221Kmv	423906	1063741	0.1	K132Kmt	424949	1063208	0.6
K161Twdr	424343	1064529	0.1	R221Kmv	423906	1063741	0.2	K151Kmt	425027	1064401	0.2
K162Twdr	424329	1064945	0.1	K222Kmv	423854	1063935	0.3	K152Kmt	425052	1064505	0.3
K171Twdr	424420	1064239	0.4	K223Kmv	423849	1064155	<0.1				
K172Twdr	424502	1064244	0.2								

An F-test of the variance components shows statistically significant differences in Se concentrations in the native soils among geologic units and between sections within townships. This result suggests that the geology plays an important role as a source of selenium, but a specific unit, such as the Cody Shale, is not uniformly seleniferous. In fact, the small-scale variation that occurs between sites from randomly selected sections in townships exceeds that between geologic units. (For the few samples in which selenium was reported to be less than the detection limit, we replaced the "less than" values with an arbitrary value of 0.07 ppm; non-censored data are required in the analysis-of-variance.) Analytical error contributed only ten percent of the total variance; the analytical precision, then, was quite satisfactory. The generally excellent agreement between splits can also be seen in table 4.

Big Sagebrush

In the Kendrick Project, the geometric mean for Se in big sagebrush is 0.41 ppm--four times higher than the norm of 0.11 reported by Gough and Erdman (1983) for big sagebrush from the western United States. Concentrations of Se in sagebrush from the Kendrick Project range from 0.06-9.5 ppm (fig. 6), the maximum value far exceeding the 1.1 ppm upper baseline threshold. A total of 13 samples exceeded the normal range expected, and the four clear outliers-- 9.5, 7.5, 6.5, and 5.5 ppm--came from sites mapped as Cody Shale (table 5). Our results indicate that sagebrush from the Cody Shale typically contains Se at levels close to the upper limit of the normal range (fig. 6).

If we look at Se in big sagebrush from the nearby Powder River Basin, however, the concentrations in sagebrush from the Kendrick Project are not quite so extreme. In a reconnaissance study of the Powder River Basin of Wyoming and Montana, Connor and others (1976) reported a geometric mean of 0.43 ppm Se, almost identical to that for sagebrush from the Kendrick Project, and an observed range of 0.08-4.8 ppm for samples of sagebrush from 41 localities.

As with the native soil results detailed in table 4, the most seleniferous vegetation appears to come from areas underlain by Cody Shale. In contrast to the soil results, many of the sagebrush samples contained anomalous levels of Se when compared to norms. Yet some of the sagebrush sampled from the Cody Shale contained the lowest concentrations. Sagebrush from five other geological units, including alluvial deposits of Quaternary age, also contained Se that exceeded the established baseline. Low-selenium sagebrush tended to occur at sites mapped as Quaternary alluvial or dune-sand deposits.

Results of the analysis-of-variance, expressed as a percentage of the total variance, are given as follows:

	<u>Geologic Units</u>	<u>Townships</u>	<u>Sections</u>	<u>Analyses</u>
Big Sagebrush	10*	18	70*	3

*Differences within category are significant at the .05 level; test result among geologic units was performed on a pooled variance estimate.

A. Baseline-Sagebrush, western United States

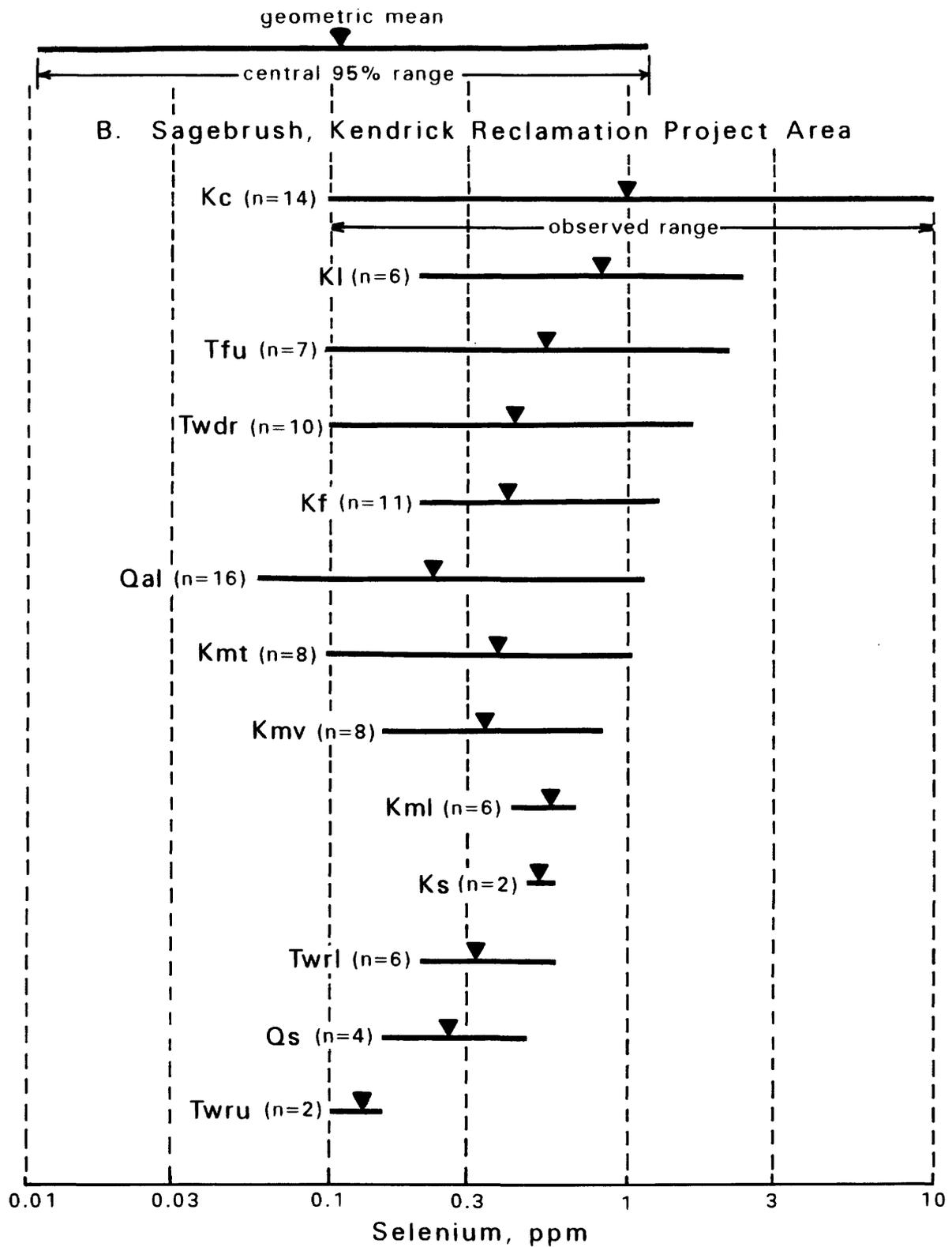


Figure 6. Bar plots of selenium in big sagebrush from geologic units in the Kendrick Reclamation Project Area, arranged in order of decreasing maximum concentrations. Baseline data are from Gough and Erdman (1983). (See table 1 for explanation of geologic symbols.)

Table 5.--Selenium in sagebrush (dry-weight basis) collected from geologic units at the Kendrick Reclamation Project Area.

["R" prefix denotes analytical splits; the multi-letter suffix attached to each Sample ID denotes the geologic unit mapped for the site--geologic units are identified in Table 1]

Sample ID	Latitude	Longitude	Se, ppm	Sample ID	Latitude	Longitude	Se, ppm	Sample ID	Latitude	Longitude	Se, ppm
K031Qal	430055	1063445	0.30	K171Twdr	424420	1064239	2.0	K031Kc	425926	1063115	0.25
K032Qal	425819	1063518	0.20	K172Twdr	424502	1064244	1.2	K032Kc	430031	1063520	0.50
K081Qal	425317	1063203	0.15	R172Twdr	424502	1064244	1.2	K051Kc	430036	1064821	1.0
K082Qal	425233	1063153	0.06	K221Twdr	424105	1064106	0.55	K052Kc	430109	1064957	7.5
K131Qal	424736	1063133	0.25	K222Twdr	424009	1064033	0.60	K061Kc	425454	1064715	0.35
K132Qal	424723	1063225	0.20	K231Twdr	424055	1064442	0.40	K062Kc	425251	1064452	5.5
K151Qal	424928	1064357	0.10	K232Twdr	424015	1064347	0.35	K081Kc	425549	1063416	0.36
K152Qal	425004	1064628	1.1	R232Twdr	424015	1064347	0.35	K082Kc	425253	1063639	0.10
K161Qal	424320	1064333	0.15					R082Kc	425253	1063639	0.10
K162Qal	424241	1064530	0.15	K151Tfu	424715	1064548	0.60	K131Kc	425145	1063333	0.10
K171Qal	424600	1063729	0.25	K152Tfu	425002	1064932	2.2	K132Kc	424817	1063154	9.5
K172Qal	424307	1063826	0.15	K161Tfu	424633	1064426	0.10	K151Kc	425150	1064505	1.0
K221Qal	424101	1063609	0.40	K162Tfu	424517	1064308	0.35	K152Kc	424907	1064616	1.2
K222Qal	423741	1063625	1.2	K171Tfu	424441	1064141	0.50	K171Kc	424623	1063714	6.5
R222Qal	423741	1063625	1.2	K172Tfu	424155	1064037	0.80	K172Kc	424531	1063739	1.2
K231Qal	424056	1064455	0.20	K221Tfu	424026	1063948	0.55				
K232Qal	424033	1064403	0.10					K221Ks	423733	1063605	0.55
				K151Kl	424728	1064538	1.0	K222Ks	423832	1064105	0.45
K031Qs	430145	1063621	0.30	K152Kl	424836	1064704	2.2				
K032Qs	430111	1063425	0.20	K171Kl	424426	1064032	0.65	K051Kf	425942	1065035	0.30
K081Qs	425240	1063311	0.15	K172Kl	424201	1064014	1.2	K052Kf	425844	1064926	0.25
K082Qs	425237	1063155	0.45	K221Kl	423933	1063751	0.20	K061Kf	425321	1064931	0.20
				K222Kl	423919	1063937	0.70	K062Kf	425300	1064821	0.45
K231Twrw	424101	1064909	0.15	R222Kl	423919	1063937	0.80	K081Kf	425312	1063417	0.35
R231Twrw	424101	1064909	0.10					R081Kf	425312	1063417	0.35
K232Twrw	423747	1064614	0.10	K011Kfh	430108	1062019	0.30	K082Kf	425332	1063632	1.6
								K131Kf	425119	1063353	0.40
K161Twrw	424212	1064859	0.55	K151Kml	424751	1064454	0.55	K132Kf	425058	1063221	0.20
K162Twrw	424141	1064851	0.25	K152Kml	424850	1064640	0.45	K152Kf	425115	1064558	0.60
K221Twrw	423847	1064253	0.30	K171Kml	424446	1064024	0.60	K171Kf	424520	1063741	0.55
K222Twrw	423857	1064233	0.35	K172Kml	424210	1063937	0.40	K172Kf	424617	1063804	0.35
R222Twrw	423857	1064233	0.45	K221Kml	423926	1063746	0.59				
K231Twrw	424122	1064903	0.25	K222Kml	423909	1063937	0.65	K051Kmt	425749	1065038	0.10
R231Twrw	424122	1064903	0.15					K052Kmt	425825	1065017	0.50
K232Twrw	424101	1064518	0.20	K102Kmv	425421	1061717	0.20	K061Kmt	425652	1065041	0.35
				K151Kmv	424803	1064453	0.80	K062Kmt	425503	1065046	0.90
K151Twdr	424656	1064540	0.25	K152Kmv	424855	1064626	0.65	K131Kmt	425111	1063416	0.30
K152Twdr	424831	1064938	0.10	K171Kmv	424424	1063934	0.15	K132Kmt	424949	1063208	1.0
K161Twdr	424343	1064529	0.35	K172Kmv	424222	1063855	0.25	K151Kmt	425027	1064401	0.20
R161Twdr	424343	1064529	0.35	K221Kmv	423906	1063741	0.40	K152Kmt	425052	1064505	0.30
K162Twdr	424329	1064945	0.15	K222Kmv	423854	1063935	0.25				
				K223Kmv	423849	1064155	0.30				

Unlike the results given for the native soils, the largest variation for Se in sagebrush occurred between sections, with the largest disparities from sites in the Cody Shale (see table 5).

In brief, then, the Cody Shale is the most seleniferous of the geologic units in the Kendrick Project, especially in terms of availability; but it is clearly not uniformly so. The four most selenium-rich sagebrush samples were taken from fairly widespread localities. This precludes narrowing the source in the non-irrigated native rangelands to a specific area.

We found a significant ($p=.05$) but low correlation ($r=0.34$, $n=101$ pairs) for Se in soils versus sagebrush. Such poor correlations have been widely reported in the literature. Olson and others (1942) even found a poor correlation between water-soluble Se in the surface soil and the Se content of plants growing in the soil. Still, three of the four sites where sagebrush contained extremely high Se also had soils with elevated Se.

Summary statistics for Se in the native soils and big sagebrush from the various geologic units are given in table 6.

Irrigated Lands

Agricultural Soils

Results of the analysis-of-variance for Se in agricultural soils, expressed as a percentage of the total variance, are as follows:

	<u>Fields (sections)</u>	<u>Sites</u>	<u>Analyses</u>
Agricultural soils	75*	13	12

*Differences within category are significant at the .05 level.

As 75 percent of the variance can be attributed to differences among irrigated fields, we can contour the concentrations of Se in soils with reasonable certainty that the map pattern is real. The map contours were computed by averaging the four nearest neighbors and applying an inverse-distance-squared algorithm. Only a small percentage of the variance observed can be attributed to analytical error.

A contour map of Se in the irrigated soils (fig. 7) shows four areas where peak values exceeded 2 ppm (see table 7 and fig. 4 to locate these extreme samples): the southernmost field in the irrigated area (Se value, 2.2 ppm); Rasmus Lee Lake (a single-point anomaly of 3.6 ppm), Oregon Trail Drain, west of the confluence of Casper Creek with the North Platte River (a single-point anomaly of 3.8 ppm--the maximum observed), and the Johnson Lateral northwest of the Natrona County Airport (a multipoint anomaly with values ranging from 2.2-3.2 ppm). We have used 2 ppm as a threshold because soils in North America that are associated with selenosis usually contain 2-6 ppm or more of total Se (Thornton, 1981, p. 14). Compositated soils from only seven of the fields sampled contained Se in excess of the 2 ppm threshold. As with the results from the native soils in the project area, the concentrations of Se from the irrigated soils, by themselves, would probably not arouse much interest when compared with the baselines reported for the northern Great Plains (table 3). However, total Se in soil may not directly reflect irrigation-induced effects such as increased solubility, transport, and accumulation by an irrigation drainage, nor would it reflect Se uptake by native and agricultural plants and subsequent utilization by wildlife and livestock.

Table 6.--Average and range in selenium concentrations (ppm) in soil and sagebrush determined from stratified random sampling of geologic units at the Kendrick Reclamation Project Area.

[Analytical duplicates not included; Explanation of geologic units: Qa1, Quaternary alluvium; Qs, Quaternary sand dunes; Twr, White River Formation, upper and lower units combined; Twdr, Wind River Formation; Tfu, Fort Union Formation; K1, Lance Formation; Kfh, Fox Hills Sandstone; Km1, Meeteetse Formation; Kmv, Mesaverde Formation; Kc, Cody Shale; Ks, Steele Shale; Kf, Frontier Formation; Kmt, Mowry and Thermopolis Shale. Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed.]

Geologic unit	-----Native soil-----			-----Sagebrush-----		
	Detection ratio	Geometric Mean	Observed Range	Detection ratio	Geometric Mean	Observed Range
Qa1	18:18	0.35	0.1-1.9	16:16	0.22	0.06-1.2
Qs	7:10	0.11	<0.1-0.5	4:4	0.25	0.15-0.45
Twr	7:8	0.14	<0.1-0.3	8:8	0.24	0.1-0.55
Twdr	8:10	0.14	<0.1-0.4	10:10	0.41	0.1-2.0
Tfu	7:7	0.25	0.1-1.0	7:7	0.52	0.1-2.2
K1	6:6	0.28	0.1-1.4	6:6	0.79	0.2-2.2
Kfh	2:2	0.24	0.2-0.3	1:1	0.3	0.3-0.3
Km1	10:10	0.19	0.1-0.5	6:6	0.53	0.4-0.65
Kmv	10:11	0.13	<0.1-0.5	8:8	0.32	0.15-0.8
Kc	15:16	0.64	<0.1-2.1	14:14	0.96	0.1-9.5
Ks	2:2	0.17	0.1-0.3	2:2	0.50	0.45-0.55
Kf	11:12	0.19	<0.1-0.5	11:11	0.39	0.2-1.6
Kmt	8:8	0.47	0.2-1.2	8:8	0.36	0.1-1.0

Alfalfa

Selenium levels in alfalfa ranged from 0.1-40 ppm; the median was 0.9 ppm and 25th and 75th percentiles were 0.4 ppm and 2.0 ppm, respectively. Highly elevated concentrations of Se in alfalfa were found in three of the four areas identified by the irrigated soil results: Rasmus Lee Lake; near the terminus of the Oregon Trail Drain; and an extensive area underlain by Cody Shale west of the airport (fig. 8) and offset slightly to the south of the seleniferous (≥ 2 ppm) soil area. The extensive area consists of 11 contiguous sections where selenium in alfalfa ranged from 4-40 ppm, concentrations that are potentially hazardous to livestock when consumed over extended periods of time (see Kingsbury, 1964, p. 47; Church and others, 1971, p. 506; Lakin, 1973, p. 96; and Combs and Combs, 1986, p. 26). According to Church and others (1971), alkali disease (manifested by, loss of hair and sloughing of hooves) is due to consuming hays and grasses with Se levels of 10-30 ppm.

The only evidence of selenosis in cattle and horses on the two farms sampled again in 1989 was some hardening of the horses' hoofs. Infrequent incidences of selenosis (alkali disease) are reported on the Kendrick Project. Tolerance to high selenium levels varies considerably between individual animals. In addition, experimental evidence suggests that some animals may be able to accommodate high levels of dietary selenium after evidencing some symptoms of chronic toxicosis like lameness and hair loss

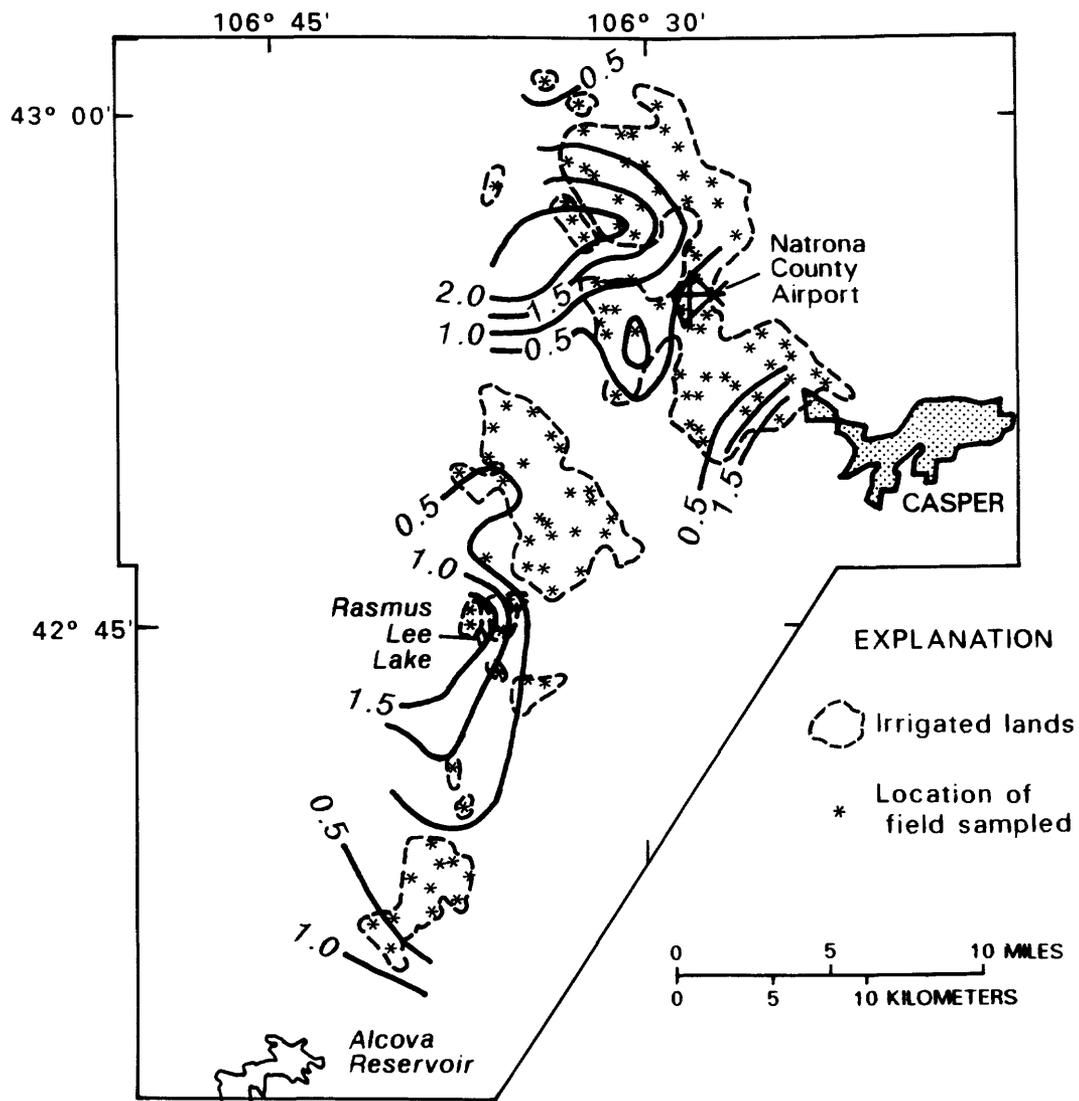


Figure 7. Contour map showing the distribution of total selenium (ppm) in agricultural soils collected from irrigated lands.

Table 7.--Selenium (ppm) in agricultural soils collected from irrigated lands at the Kendrick Reclamation Project Area.

["R" prefix denotes analytical splits; #1 and #2 suffix denotes uncomposited samples from two sites within a field]

Sample ID	Latitude	Longitude	Se, ppm	Sample ID	Latitude	Longitude	Se, ppm	Sample ID	Latitude	Longitude	Se, ppm
K001S	423507	1064018	2.2	K037S	424721	1063305	0.1	K071S	425447	1062820	0.2
K002S	423550	1064057	0.9	K038S	424717	1063405	0.3	K072S	425444	1062839	0.7
R002S	423550	1064057	0.7	R038S	424717	1063405	0.4	R072S	425444	1062839	1.0
K003S	423556	1064015	0.2	K039S	424706	1063451	<0.1	K073S	425540	1062835	0.6
K004S	423611	1063841	0.2	K040S	424718	1063154	0.2	K074S	425525	1062821	0.2
K005S	423631	1063747	0.1	K041S	424734	1063413	0.8	K075S	425601	1062645	0.1
K006S	423653	1063846	0.2	R041S	424734	1063413	0.8	K076S	425656	1062837	1.0
K007s1	423709	1063931	0.1	K041s1	424734	1063413	0.3	K077S	425658	1062725	1.0
K007s2	423709	1063931	0.1	K041s2	424734	1063413	1.1	K079S	425326	1063208	0.1
K008S	423733	1063824	0.1	K042S	424743	1063427	0.1	K080S	425311	1063150	0.3
K009S	423738	1063753	0.2	K043S	424742	1063139	0.1	K081S	425318	1063042	1.5
K010S	423810	1063844	0.1	K044S	424816	1063226	0.5	K082S	425402	1062943	0.6
K011s1	423910	1063726	0.2	K045S	424828	1063521	0.5	K083S	425352	1063154	0.3
K011s2	423710	1063726	<0.1	K046S	424830	1063315	0.5	K084S	425347	1063206	0.2
R011s2	423910	1063726	0.1	K047S	424832	1063231	0.3	K085S	425432	1063210	1.0
K012S	424021	1063750	1.5	K048S	424851	1063556	0.6	K086S	425430	1063102	1.0
K013S	424300	1063458	<0.1	R048S	424851	1063556	1.0	K087S	425559	1063241	2.5
R013S	424300	1063458	0.4	K048s1	424851	1063556	0.5	R087S	425559	1063241	2.5
K014S	424251	1063418	0.1	K048s2	424851	1063556	1.3	K088S	425602	1063044	1.0
K015S	424458	1063534	0.4	K049S	424922	1063505	0.5	K089s1	425628	1063305	3.2
K016S	424538	1063359	0.1	K050S	424908	1063738	0.4	K089s2	425657	1063020	2.8
K017S	424611	1063256	0.3	K051S	424949	1063342	0.3	R089s2	425657	1063020	3.0
R017S	424611	1063256	0.3	K052S	425023	1063616	0.2	K090S	425657	1063020	1.8
K018S	424617	1063421	0.2	K053S	425010	1063400	0.1	K091S	425613	1063113	0.7
R018S	424617	1063421	0.2	K054S	425052	1063445	0.4	K092S	425657	1063325	2.3
K019S	424617	1063454	0.2	K055s1	425102	1063547	0.2	K093S	425735	1062738	1.0
K020S	424314	1063606	0.9	R055s1	425102	1063547	0.2	K094S	425746	1062845	1.1
K021S	424423	1063605	0.2	K055s2	425102	1063547	0.2	K095S	425842	1062857	0.3
K022S	424443	1063715	3.6	K056S	425117	1063130	0.1	K096S	425909	1062928	0.7
K023S	424516	1063603	1.8	K057s1	424931	1063630	0.2	K097S	425704	1063119	2.2
K024S	424459	1063713	0.7	K057s2	424931	1063630	0.4	K098S	425720	1062944	0.6
K025S	424632	1063638	0.2	K058S	425157	1062859	0.4	K099S	425748	1063218	1.6
K026S	425001	1062802	0.1	K059S	425152	1062754	0.3	R099S	425748	1063218	1.5
R026S	425001	1062802	0.2	K060S	425153	1062709	<0.1	K100S	425759	1063237	1.4
K027S	425020	1062816	0.2	K061S	425158	1062335	0.4	K101S	425813	1063059	0.7
K028S	425039	1062504	3.8	K062S	425214	1062520	0.1	K102S	425759	1063022	1.0
K029S	425026	1062829	0.2	K063S	425231	1062437	0.1	K103S	425909	1063242	0.7
R029S	425026	1062829	0.2	K064S	425250	1062449	0.1	K104S	425859	1063111	1.1
K030S	425051	1062621	0.8	K065s1	425317	1062808	0.1	K105S	425901	1063046	1.1
K031S	425121	1062819	0.2	K065s2	425317	1062808	0.2	R105S	425901	1063046	0.8
K032S	425121	1062838	0.2	K066S	425246	1062610	0.2	K106S	425951	1062946	0.4
K033S	425137	1062647	0.3	K067S	425309	1062543	0.2	K107S	425952	1063253	0.5
K034S	425118	1062556	0.1	K068S	425323	1062833	0.3	K108S	430036	1063413	0.4
K035S	425145	1062445	0.4	K069S	425343	1062749	0.3	K109S	425811	1063317	0.8
K036S	425142	1062316	0.3	K070S	425349	1062852	<0.1	K110S	425736	1063616	1.6

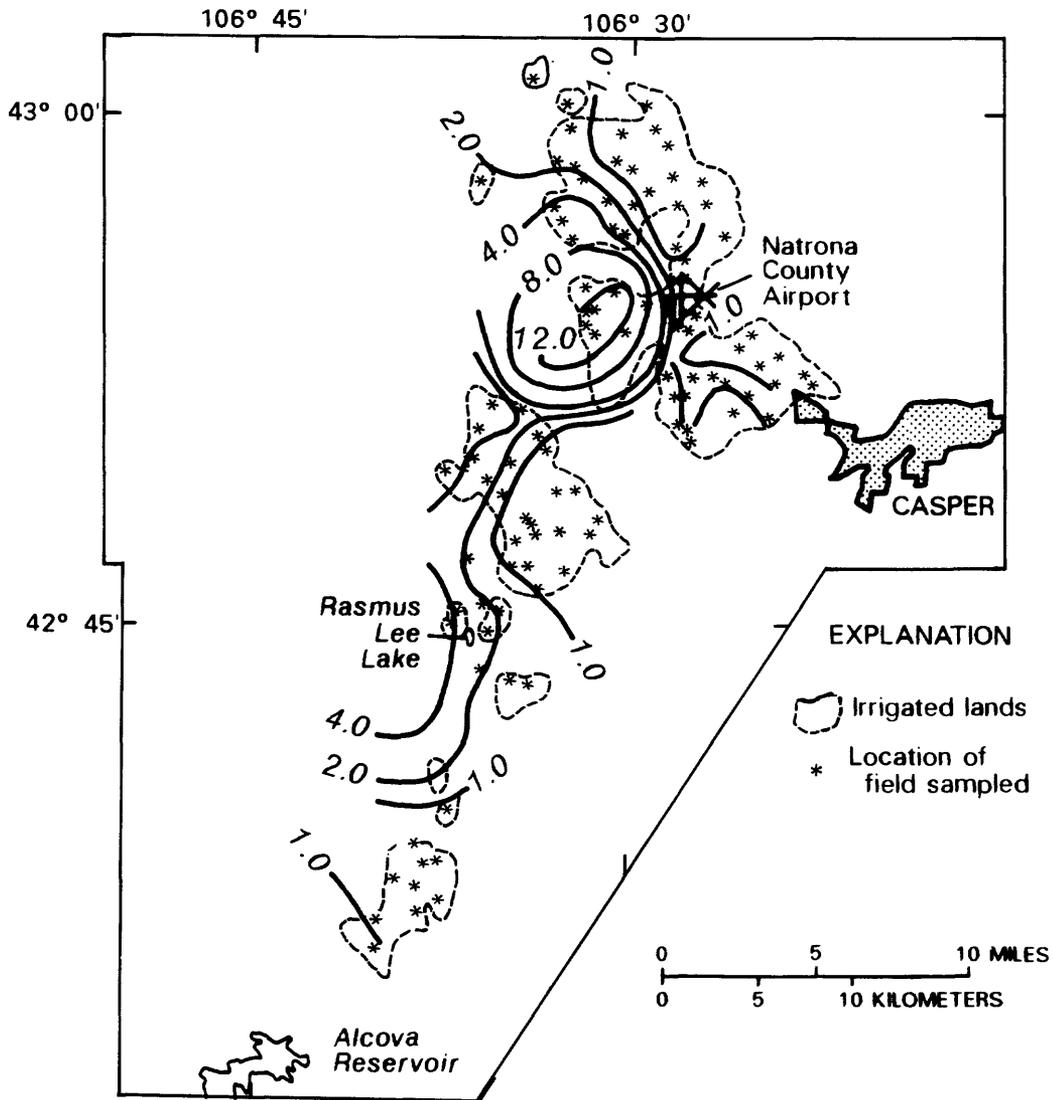


Figure 8. Contour map showing the distribution of selenium (ppm, dry-weight basis) in alfalfa collected from irrigated lands.

(L.F. James, Poisonous Plant Research Laboratory, USDA-ARS, 1989 oral commun.).

The extensive Se anomaly in alfalfa west of the airport was independently confirmed by water-quality data provided by D. Naftz and his associates with the Water Resources Division of the USGS. Dissolved Se concentrations ranged from 0.12-0.98 mg/L in drain-water samples and 1.7-5.3 mg/L in ponded-water samples. These concentrations exceed the 0.100 mg Se/L guideline for irrigation water used in the production of alfalfa (Albasel and others, 1989). Drinking water and domestic-livestock water standards are 0.01 mg/L and 0.05 mg/L, respectively (U.S. Environmental Protection Agency, 1977).

Clearly, some of the alfalfa produced in the Kendrick area (table 8) contains Se above most reported concentrations. It is difficult to assess the importance of the high values because most published studies on Se in alfalfa are from Se-deficient or non-seleniferous regions (Ihnat and Wolf, 1989). Several exceptions include an early study by Byers and others (1938) which reports a maximum concentration of 7 ppm Se in alfalfa from southeastern Colorado. A second exception is reported of up to 44 ppm Se in alfalfa grown in Israel (Ravikovitch and Margolin, 1957). We also have a record (O. Olson, South Dakota State University, 1975, written commun.) of an alfalfa sample that contained 27.3 ppm Se. Concentrations of 12 and 13 ppm were found in two samples of alfalfa collected from Wallace Meadows northeast of Lusk, Wyoming (by H. Mayland, unpubl. data).

On the other hand, we found alfalfa from eight fields that is marginally deficient (0.10-1.20 ppm) in Se. According to Allaway and Hodgson ((1964), Westermann and Robbins (1974) and Fisher and others (1987), minimal dietary Se concentrations--critical levels needed to prevent white muscle disease (a form of muscular dystrophy) in livestock--are about 0.1 ppm. Alfalfa that contained Se below 0.5 ppm generally came from fields in the southern half of the Kendrick Project.

Results of the analysis-of-variance simply confirm the strong differences among fields shown in figure 8 and also reflected in the soils, although not quite so strongly. The distribution of the variance, expressed as a percentage of the total variance, follows:

	<u>Fields (sections)</u>	<u>Sites</u>	<u>Analyses</u>
Alfalfa	60	39*	<1

*Differences within category are significant at the .05 level.

Our results from the Rasmus Lee Lake area provide an example of the extreme differences observed among fields. The composite alfalfa sample from a pasture just northwest of the lake contained 15 ppm Se, whereas a sample from a heavily irrigated hay field to the east contained only 0.25 ppm.

Of nine bottom-sediment samples collected from the Kendrick area during an earlier field-screening study (Severson and others, 1987), the sediment from Rasmus Lee Lake contained 17 ppm, second only to a sample from the mouth of Poison Spring Creek that contained 25 ppm. Recent unpublished results of pore-space analyses (David Naftz, oral communication, April 1989) showed 30 mg/L dissolved Se in a sample of pore water 15 feet below land surface in a sand lens near the field where the alfalfa contained 15 ppm Se. In marked contrast, a pore-water sample contained only 0.150 mg Se/L from the field in which the alfalfa sample contained 0.25 ppm. Alfalfa, a deep-rooted plant,

Table 8.--Selenium (ppm) in alfalfa (dry-weight basis) from irrigated lands at the Kendrick Reclamation Project Area.

["R" prefix denotes seven fields where samples from two sites were not composited; #1 and #2 suffix denotes uncomposited samples from two sites within a field; "X" suffix denotes analytical splits]

Sample ID	Latitude	Longitude	Se, ppm	Sample ID	Latitude	Longitude	Se, ppm	Sample ID	Latitude	Longitude	Se, ppm
K001A	423507	1064018	2.4	K039A	424706	1063451	0.80	K070A	425349	1062852	1.2
K003A	423556	1064015	0.85	K040A	424718	1063154	0.45	K071A	425447	1062820	1.8
K004A	423611	1063841	0.40	R041A1	424734	1063413	0.40	K072A	425444	1062839	1.2
K005A	423631	1063747	0.40	R041A1X	424734	1063413	0.40	K073A	425540	1062835	0.40
K006A	423653	1063846	0.45	R041A2	424734	1063413	0.80	K074A	425525	1062821	0.35
R007A1	423709	1063931	0.95	R041A2X	424734	1063413	0.85	K075A	425601	1062645	1.8
R007A1X	423709	1063931	1.0	K042A	424743	1063427	0.80	K076A	425656	1062837	0.20
R007A2	423709	1063931	0.50	K043A	424742	1063139	0.30	K077A	425658	1062725	1.0
R007A2X	423709	1063931	0.55	K044A	424816	1063226	1.8	K079A	425326	1063208	25
K008A	423733	1063824	0.40	K045A	424828	1063521	2.0	K080A	425311	1063150	5.5
K009A	423738	1063753	0.25	K046A	424830	1063315	0.15	K081A	425318	1063042	5.5
K010A	423810	1063844	0.30	K047A	424832	1063231	0.25	K082A	425402	1062943	40
R011A1	423910	1063726	1.4	R048A1	424851	1063556	0.85	K083A	425352	1063154	10
R011A1X	423910	1063726	1.4	R048A1X	424851	1063556	1.0	K084A	425347	1063206	15
R011A2	423910	1063726	0.80	R048A2	424851	1063556	7.0	K085A	425432	1063210	10
R011A2X	423910	1063726	0.90	R048A2X	424851	1063556	7.5	K086A	425430	1063102	6.5
K013A	424300	1063458	0.35	K049A	424922	1063505	0.30	K087A	425559	1063241	15
K014A	424251	1063418	2.0	K050A	424908	1063738	0.95	K088A	425602	1063044	4.0
K015A	424458	1063534	1.8	K051A	424949	1063342	0.40	R089A1	425628	1063305	4.0
K016A	424538	1063359	2.0	K052A	425023	1063616	0.35	R089A1X	425628	1063305	4.5
K017A	424611	1063256	0.50	K053A	425010	1063400	0.50	R089A2	425628	1063305	3.0
K018A	424617	1063421	0.95	K054A	425052	1063445	2.8	R089A2X	425628	1063305	3.5
K019A	424617	1063454	0.25	K055A	425102	1063547	2.2	K090A	425657	1063020	2.4
K020A	424314	1063606	2.0	K056A	425117	1063130	0.35	K091A	425613	1063113	2.0
K021A	424423	1063605	0.25	R057A1	424931	1063630	0.50	K092A	425657	1063325	2.4
K022A	424443	1063715	15	R057A1X	424931	1063630	0.50	K093A	425735	1062738	2.2
K023A	424516	1063603	2.4	R057A2	424931	1063630	0.10	K094A	425746	1062845	1.2
K024A	424459	1063713	1.2	R057A2X	424931	1063630	0.15	K095A	425842	1062857	0.50
K025A	424632	1063638	1.6	K058A	425157	1062859	0.20	K096A	425909	1062928	0.80
K026A	425001	1062802	0.45	K059A	425152	1062754	3.0	K097A	425704	1063119	1.6
K027A	425020	1062816	0.25	K060A	425153	1062709	0.85	K098A	425720	1062944	0.45
K028A	425039	1062504	1.6	K061A	425158	1062335	0.45	K099A	425748	1063218	0.90
K029A	425026	1062829	0.15	K062A	425214	1062520	0.40	K100A	425759	1063237	1.4
K030A	425051	1062621	5.0	K063A	425231	1062437	0.20	K101A	425813	1063059	0.50
K031A	425121	1062819	0.55	R065A1	425317	1062808	0.80	K102A	425759	1063022	0.50
K032A	425121	1062838	0.25	R065A1X	425317	1062808	0.75	K103A	425909	1063242	1.8
K033A	425137	1062647	1.8	R065A2	425317	1062808	1.2	K105A	425901	1063046	0.60
K034A	425118	1062556	0.10	R065A2X	425317	1062808	1.4	K106A	425951	1062946	0.45
K035A	425145	1062445	2.4	K066A	425246	1062610	0.30	K107A	425952	1063253	1.2
K036A	425142	1062316	2.2	K067A	425309	1062543	0.25	K108A	430036	1063413	0.95
K037A	424721	1063305	0.10	K068A	425323	1062833	1.2	K109A	425811	1063317	0.40
K038A	424717	1063405	0.45	K069A	425343	1062749	1.2	K110A	425736	1063616	2.4

seems to provide a good indirect measure of soluble Se in the pore spaces at depth. As Fisher and others (1987, p. 124) stressed: "the ability of Se-accumulating plants to absorb Se from sources deep within the soil profile indicate that surface soil elemental analyses have serious limitations as a means of forecasting toxicity problems."

Unlike the results for Se in the agricultural soils, we found strong differences in Se from alfalfa taken within the same field. The largest disparity occurred between the two sites from field #48 (table 8) where the sample from the first site contained only 0.85 ppm Se whereas the sample from the second site contained 7.0 ppm. These results, although disturbing, simply support those reported by Olson and others (1942) who also found large variations in the Se content of plants over relatively short distances on soils derived from the same parent material. Differences between site pairs from the other six fields where such comparisons can be made were considerably less extreme.

Results of a correlation analysis that compared total selenium in the agricultural soils with Se in alfalfa from the same fields were similar to those found between native soils and sagebrush. The correlation coefficient in this case was 0.43 (n=105 pairs); although the correlation is significant (p=.05), the soil Se explains only about 16 percent of that found in the alfalfa.

The offset or displacement of a large zone of seleniferous alfalfa and selenium-laden surface waters from a possible source area of slightly seleniferous soils to the north is difficult to explain. Almost 50 year ago, however, Olson and others (1942) seemed to have dealt with similar patterns. They concluded (p. 52):

During the weathering of seleniferous rock to soil in the region in which these studies were made, a large part of the selenium is oxidized to the selenate form. As the selenate, it is leached from the surface to subsurface soils or removed by run-off waters and redeposited at lower elevations, where it may finally leach from the surface and be deposited in subsurface soil. [emphasis added.]

Much more recently, Tidball and others (1989) reported what appears to be a very similar situation in an irrigated area of the San Joaquin Valley, California. Elevated levels of Se in soils have been dispersed downslope toward areas where the water table is close to the surface and where the groundwater is extremely seleniferous.

At present this displacement seems to be the only explanation for the major Se anomaly at Kendrick.

Selenium concentrations in the alfalfa samples collected from the two fields in June 1989 were less than 5 percent of the concentrations found in alfalfa sampled from the same fields in June 1988. In the field where the 1988 sample contained 25 ppm Se, the three 1989 samples contained only ~0.2 ppm; whereas in the field where the 1988 sample contained 15 ppm, the single 1989 composite sample had 0.7 ppm. Differences in Se concentrations owing to drying methods were not significant at the 0.05 probability level. The analyses were verified by data obtained from six laboratory-reference alfalfa samples, two of which were from the 1988 sampling of these two fields.

This large temporal variation, as measured at the two fields sampled in 1988 and again in 1989, was entirely unexpected. The following examination of weather patterns and managerial practices may, however, explain the results. Discussions with the owners of both farms revealed that the fields were quite

dry during the 1987-88 winter and were not irrigated until after the initial sampling in early June 1988. Irrigation water management was then improved by installation of gated pipe on one farm and more timely and adequate irrigations on both farms. Fields were watered in late 1988 and twice again during the subsequent spring before the June 6, 1989 sampling. On one field, alfalfa hay yields were fair in 1988 and very good in 1989, whereas the 1989 yields on the second field were expected to quadruple those of 1988 because of better water management.

We suggest that selenate Se may have been concentrated in the minimal pore water in the soil profiles preceding the 1988 sampling and that the Se was readily absorbed by the alfalfa plants. The relatively dry soils limited plant growth to the extent that the selenate was concentrated in the plant tissue collected in early June 1988. Subsequent irrigations in the late fall of 1988 and twice before sampling on June 6, 1989 may have leached the selenate below the rooting zone. Soil-moisture profiles were likely saturated in early 1989, which resulted in further dilution of soluble Se. The vigorously growing plants absorbed less total Se than in the previous year and further diluted that which was absorbed because of the greater production of dry matter. The net effect would explain the precipitous drop in Se concentrations in the 1989 alfalfa compared to that from the previous year.

These results underscore the importance of irrigation practices on Se concentrations in crops grown in arid environments and clearly point to the need to design detailed studies of the possible change in Se levels in alfalfa between same-year cuttings and from year-to-year cuttings.

SUMMARY

Probably the most important result of the soil sampling at Kendrick is the fact that, with but few exceptions, none of the samples were abnormally high in total Se. Selenium tended to be elevated in soils derived from the Cody Shale, but was not uniformly so.

In contrast, Se in many samples of big sagebrush tended to be considerably higher than the norm, and some samples from 6 of the 14 geologic units exceeded the maximum baseline established for this species.

Large differences in Se concentrations were found in samples of alfalfa from different fields in the Kendrick Project. Some of the samples (15 percent of the total) contained Se at levels potentially hazardous to livestock if fed over prolonged periods. However, reported incidences of selenosis are not common in the study area.

Seleniferous alfalfa and surface and drain waters were found in an extensive area west of the Natrona County Airport. However, significant temporal variation in Se concentration in alfalfa were documented. These changes may be attributed to hydrologic and crop management factors.

The agricultural soils just to the north of this seleniferous area had slightly higher levels of Se compared to those elsewhere in the study area. This may relate to the lesser amount of irrigation water available or applied to soils. Forage production is generally restricted on some of the farms northwest of the airport by low soil fertility and inadequate irrigation.

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