SELENIUM CONCENTRATIONS IN LEAF MATERIAL FROM *ASTRAGALUS OXYPHYSUS* (DIABLO LOCOWEED) AND *ATRIPLEX LENTIFORMIS* (QUAIL BUSH) IN THE INTERIOR COAST RANGES AND THE WESTERN SAN JOAQUIN VALLEY, CALIFORNIA

By John A. Izbicki and T.F. Harms

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 86-4066

Prepared in cooperation with the

CALIFORNIA DEPARTMENT OF WATER RESOURCES and the

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

Sacramento, California
1986

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Federal Building, Room W-2234
2800 Cottage Way
Sacramento, CA 95825

Copies of this report
may be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, CO 80225
Telephone: (303) 236-7476

CONTENTS

	Page
Abstract	1
Introduction	2
Purpose and scope	2
Acknowledgments	2
Description of study area	2
Selenium in soils and plants	4
Approach and methods	5
Results	8
Discussion and conclusions	10
References cited	13

ILLUSTRATIONS

		Page
Figure 1.	Map showing location of study area	3
2.	Photograph showing typical *Astragalus oxyphysus* (Diablo locoweed), in flower, and part of plant sampled	7
3.	Photograph showing typical *Atriplex lentiformis* (quail bush) and part of plant sampled	8
4.	Map showing location of sample sites for leaf material from *Astragalus oxyphysus*	9
5.	Map showing location of sample sites for leaf material from *Atriplex lentiformis*	11

TABLES

		Page
Table 1.	Selenium concentrations of leaf material from *Astragalus oxyphysus* at selected sites	8
2.	Selenium concentrations of leaf material from *Atriplex lentiformis* at selected sites	10

CONVERSION FACTORS

For readers who prefer metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
ft (foot)	0.3048	meter
inch	25.40	millimeter
mi (mile)	1.609	kilometer

Air temperature is given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by the following equation:

$$°C = (°F-32)/1.8$$

ABBREVIATIONS

µg/L	microgram per liter
µg/g	microgram per gram
mg	milligram
mL	milliliter
M	molar

SELENIUM CONCENTRATIONS IN LEAF MATERIAL FROM *ASTRAGALUS OXYPHYSUS* (DIABLO LOCOWEED) AND *ATRIPLEX LENTIFORMIS* (QUAIL BUSH) IN THE INTERIOR COAST RANGES AND THE WESTERN SAN JOAQUIN VALLEY, CALIFORNIA

By John A. Izbicki[1] and T.F. Harms[2]

ABSTRACT

Leaf material from selenium accumulating plants was collected and analyzed for selenium to obtain a relative indication of selenium concentrations in soils and identify sites suitable for further soil study. Selenium concentrations of 14 samples of leaf material from *Astragalus oxyphysus* ranged from 0.08 to 3.5 μg/g (micrograms per gram, dry weight) and had a median concentration of 0.25 μg/g. Five replicate samples of *A. oxyphysus* had a mean selenium concentration of 0.22 μg/g and a standard deviation of 0.07. Selenium concentrations of 17 samples of leaf material from *Atriplex lentiformis* ranged from 0.08 to 7.5 μg/g and had a median concentration of 0.35 μg/g. As a general guideline, the National Academy of Sciences recommends a maximum safe tolerance level of 2 μg/g of selenium in animal feeds. One sample of *A. oxyphysus*, collected in the Panoche Creek drainage, exceeded 2 μg/g. Three samples of *A. lentiformis*, collected in Klipstein Canyon, Tumey Fan, and Panoche Fan, equaled or exceeded 2 μg/g. These sites may be suitable for further study.

[1]Hydrologist, U.S. Geological Survey, Water Resources Division, San Diego, California.

[2]Chemist, U.S. Geological Survey, Geologic Division, Branch of Exploration Geochemistry, Denver, Colorado.

INTRODUCTION

Selenium concentrations have exceeded 1,000 μg/L in agricultural drainage water from the west side of the San Joaquin Valley near Mendota, California (Presser and Barnes, 1984). The abnormal development of bird embryos and chicks at Kesterson Reservoir may be related to elevated concentrations of selenium (U.S. Bureau of Reclamation, 1984). Limited evidence indicates that selenium is naturally occurring in soils derived from the interior Coast Ranges (Lakin and Byers, 1941). However, as late as 1982, maps showing the geographical distribution of seleniferous soils in the United States did not include the San Joaquin Valley and interior Coast Ranges of California, but did indicate that white-muscle disease, a disease associated with selenium deficiency, may be a problem in part of the San Joaquin Valley (Brown and Shrift, 1982). Deverel and others (1984) described the distribution of selenium in the shallow ground-water system of the San Joaquin Valley, but were unable to draw any conclusions about selenium distribution near the western margin of the San Joaquin Valley or in the foothills of the interior Coast Ranges because of the great depth to ground water and the lack of suitable wells.

Purpose and Scope

The purpose of this report is to assess, on a reconnaissance basis, the areal distribution of selenium concentrations in selenium-accumulating plants in the interior Coast Ranges and the western San Joaquin Valley (fig. 1). This report provides an indication of where potentially toxic plants are found, and where seleniferous soils may occur. This report also includes a brief review of the occurrence of selenium in soils and plants and assesses if more detailed studies of this type are warranted. The scope of this report includes a description of the identification and collection of plant material for laboratory analyses.

This report does not address the natural variability of selenium concentrations in individual plants in the same area or the relation between selenium concentrations in plant materials and soils. For these reasons, results in this report are preliminary.

Acknowledgments

This work was done by the U.S. Geological Survey in cooperation with the California Department of Water Resources and California State Water Resources Control Board. The assistance of personnel of the U.S. Geological Survey's Branch of Exploration Geochemistry and Denver Central Laboratory, and the many landowners and residents of the study area is gratefully acknowledged.

DESCRIPTION OF STUDY AREA

Irrigated agriculture is the dominant land use on the west side of the San Joaquin Valley. Ranching is the dominant land use in the foothills of the interior Coast Ranges, although much land remains unused.

The climate of the study area is arid and divided into two seasons (Harradine, 1950; Harradine and others, 1956). Average annual precipitation in the San Joaquin Valley ranges from 6 to 14 inches and increases from south to north. The dry season extends from May to October and is characterized by low humidity and by daily maximum temperatures of 100 to 110°F. The wet season extends from November to April; about 85 percent of the total precipitation occurs during the wet season. Fog in winter is common, and temperatures may occasionally dip below freezing.

The climate of the foothills of the interior Coast Ranges is similar to that of the San Joaquin Valley. Annual precipitation increases with altitude and exceeds 25 inches in the mountains. Summer high temperatures and winter low temperatures decrease with altitude.

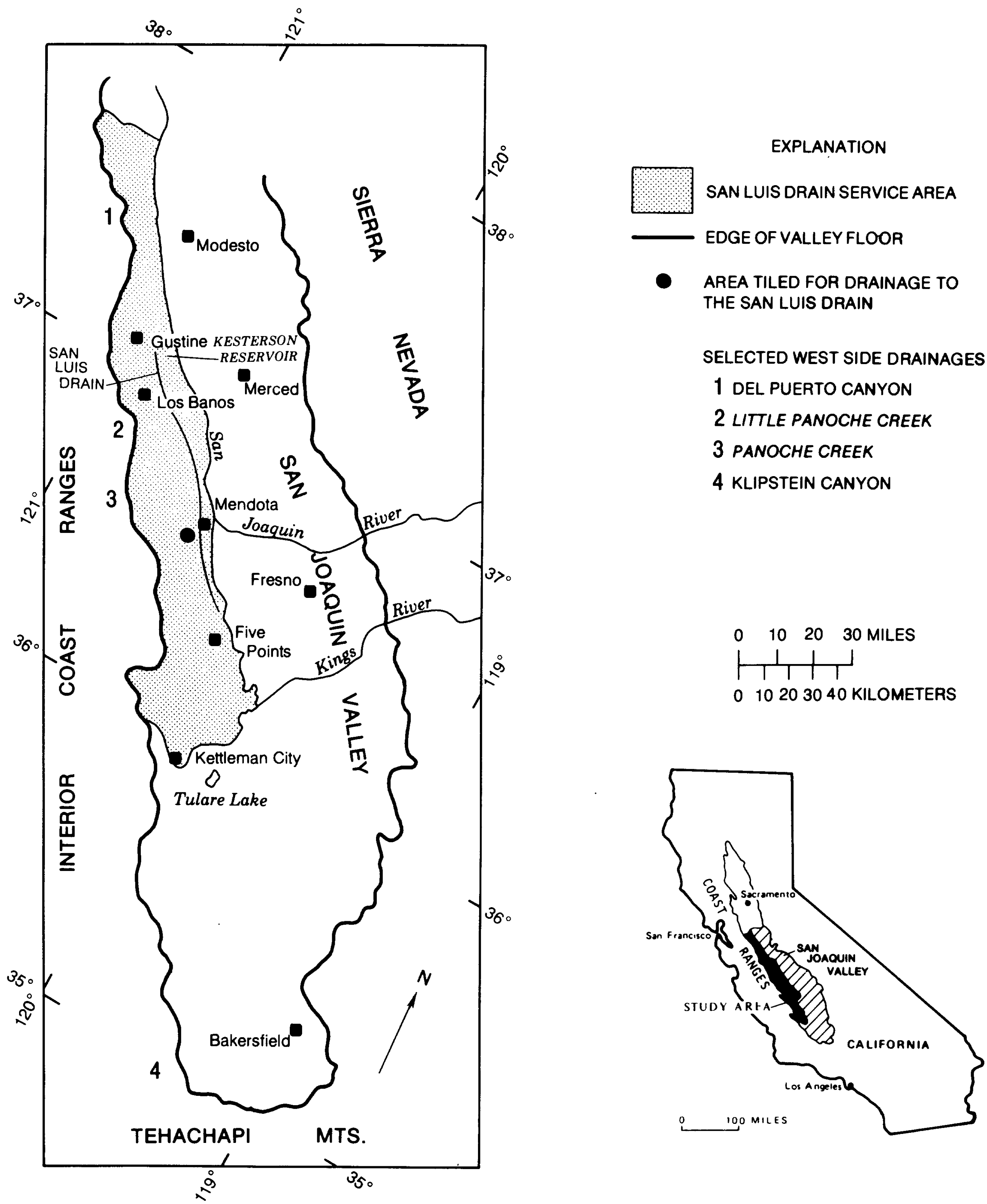

FIGURE 1.— Location of study area.

The only trees native to the San Joaquin Valley are willows and cottonwoods growing as phreatophytes along the banks of the San Joaquin River and other streams. Under predevelopment conditions, the lower altitudes of the San Joaquin Valley were covered with a dense growth of tules and tule grasses; where soils are salty, salt grass, alkali bunch grass, and alkali sacaton dominated. On the outer edges of the west-side alluvial fans, where the salt content is variable but still high, various species of saltbush (*Atriplex* spp.) predominate. Farther up the alluvial fans, annual grasses and associated herbaceous plants dominate. The terraces and foothills of the interior Coast Ranges are treeless and support only a scant cover of annual grasses, herbs, and brush (Harradine, 1950).

SELENIUM IN SOILS AND PLANTS

Selenium is widely distributed in the Earth's crust and has an average concentration of about 7×10^{-5} percent by weight. This is a low concentration--about the same as that of cadmium and of antimony--but less than that of gold (Cooper and others, 1974).

Analyses of several thousand soil samples from seleniferous areas in the United States indicate that the highest selenium concentrations are less than 100 $\mu g/g$ and that the majority of these soils contain less than 2 $\mu g/g$ of selenium (Rosenfield and Beath, 1964). Similar studies in Canada indicate that soils from seleniferous areas contain between 0.1 and 6 $\mu g/g$ of selenium (Byers and Lakin, 1939). Soil sampling to obtain quantitative data on the areal distribution of selenium is complicated because of variations in the vertical distribution of selenium within the soil profile (Lakin, 1972), and because at any point within the soil profile, selenium may be (1) weakly adsorbed and readily exchangeable, (2) bound to carbonates, (3) bound to manganese and iron oxides, (4) bound to or incorporated in organic matter, (5) substituted within sulfur minerals, or (6) present in soil solution (U.S. Bureau of Reclamation, 1984). In addition, selenium may exist in any of four oxidation states. Direct sampling of soils to obtain quantitative data on the areal distribution of selenium and an indication of the amount of selenium, which may be mobilized by agricultural drainage water, may require many samples throughout the soil profile and the determination of how selenium is stored in the soil at each sample location within the soil profile.

The chemical form in which selenium is available affects selenium uptake by plants. Generally, selenate is more readily absorbed than selenite, and calcium selenate more than sodium selenate (Moxon and others, 1950). In addition, an abundant source of selenium available to plants is the recycling of organic selenium from decomposed seleniferous vegetation. Thus, it is not possible to obtain a quantitative relation between selenium in plant tissues and selenium in the soil. Assessments of selenium concentrations in soil made on the basis of plant-material analyses are qualitative, and are best used to indicate areas suitable for further soil studies.

Certain plants are known to accumulate selenium from soils and to concentrate it in their tissues. Plants that accumulate selenium may be divided into two categories: obligate and facultative accumulators (Kingsbury, 1964). A third category, nonaccumulators, includes all plants that do not accumulate selenium. Obligate accumulators are plants that grow only where soils contain enough selenium to support the metabolic needs of the plant. The presence of an obligate selenium accumulator is evidence of seleniferous soils. In one study samples of plant material from obligate accumulators of the genera *Astragalus* and *Stanleya* that were collected from seleniferous soils in Wyoming had selenium concentrations ranging from 3,939 to 199 µg/g with an average concentration of 689 µg/g (dry weight) (Cooper and others, 1974). Facultative accumulators are plants that can accumulate selenium in their tissues but can also grow in soils that contain little or no selenium. Some species in the genera *Astragalus, Atriplex, Grindelia,* and *Grayia* are facultative accumulators. In general, obligate accumulators concentrate selenium relative to the soil they are growing in by a factor of 1,000, facultative accumulators by a factor of 100, and nonaccumulators by a factor of 1 to 10 (Kingsbury, 1964). For example, at one location in Wyoming obligate accumulators of the genera *Astragalus* and *Stanleya* had selenium concentrations of 5,530 and 1,190 µg/g (dry weight), while at the same site, a facultative accumulator of the genera *Atriplex* had a selenium concentration of 300 µg/g and grass of unspecified genera, a nonaccumulator, had a selenium concentration of 23 µg/g (dry weight) (Cooper and others, 1974).

Reviews of toxicity problems associated with selenium are available in Gough and others (1979), National Academy of Sciences (1980), and Cooper and Glover (1974). Trelease and Beath (1949) present a history of selenium poisoning which goes back to 1857 in South Dakota and perhaps to 1295 in an area of western China described by Marco Polo. The description of the disease symptoms, such as sloughing hooves, leaves little doubt that many of these cases were the result of selenium intoxication. Acute poisoning of cattle and sheep occurs when herds are driven long distances from one pasturage to another. Animals, under these conditions eat forage indiscriminately and many may die overnight (Lakin, 1972). In such cases, there may be some confusion between selenium toxicity and death from other toxic vegetation. Church and others (1971) summarized numerous studies and reported that acute selenium toxicity can be produced in cattle and sheep by feeding them plants that supply about 2 mg of selenium per kilogram of body weight. Subacute poisoning (known as blind staggers or loco disease) may be induced by large doses of selenium insufficient to kill the animal. Chronic selenium poisoning in cattle and sheep is caused by daily ingestion of forage containing 5 to 20 µg/g of selenium. Ducks and coots in Kesterson Reservoir exhibit reproductive failure and abnormal development in embryos and chicks, which match symptoms of chronic selenium poisoning described by Moxon and Olsen (1974) and the National Academy of Sciences (1976). Subchronic selenium poisoning of animals has been recognized (Brown and de Web, 1962) and is characterized by a generally weakened condition and an increased susceptibility to other diseases.

APPROACH AND METHODS

The approach used in this study was to sample and analyze leaf material for selenium from selenium-accumulating plants to obtain a relative indication of the selenium concentration of the soil. Plants that have smaller concentrations of selenium are assumed to be growing in soils that have smaller concentrations of selenium. Plants that have larger concentrations of selenium are assumed to be growing in soils that have larger concentrations of selenium; these sites may be suitable for future soil studies. This approach is not limited by the distribution and construction of existing wells or the presence of a shallow ground-water table. Members of the genus *Astragalus* have been used in this way to identify seleniferous soils in Wyoming, Colorado, and Canada (Cannon, 1971; Cooper and others, 1974).

Several species of *Astragalus* are in the San Joaquin Valley and the interior Coast Ranges; the most common is *Astragalus oxyphysus* Gray (Diablo locoweed). *A. oxyphysus* is a small (about 2 feet tall), perennial, herbaceous plant.

A. oxyphysus is known to be toxic to livestock (Twisselmann and others, 1967; Armstrong, 1984) and is actively destroyed by ranchers. At the beginning of this study it was uncertain whether *A. oxyphysus* was an obligate or facultative selenium accumulator, but study findings reported herein suggest that it is a facultative accumulator. *A. oxyphysus* is generally found in the upper alluvial fans and the terraces and foothills of the interior Coast Ranges; it is not commonly found on the lower alluvial fans and the floor of the San Joaquin Valley. Because of limitations in the distribution of *A. oxyphysus*, samples from other plant species were needed to assess the entire study area.

Other species in the San Joaquin Valley that accumulate selenium include members of the following genera: *Atriplex, Grindelia, Grayia,* and *Stanleya* (Carlisle and Cleveland, 1958; Kingsbury, 1984). *Atriplex lentiformis* Gray (quail bush) is a shrub (about 5 to 8 feet tall). *A. lentiformis* is important to wildlife for the cover and forage it provides and is known to be a facultative selenium accumulator. *A. lentiformis* was selected for study because of its wide distribution in the San Joaquin Valley. *A. lentiformis* is most common along the outer edges of the west side alluvial fans but is also found in the upper alluvial fans, the terraces and foothills of the interior Coast Ranges, and in the floor of the San Joaquin Valley.

Leaf material was collected from *A. oxyphysus* in the foothills of the interior Coast Ranges, and from *A. lentiformis* in the San Joaquin Valley. Between Kettleman City and Modesto, samples were collected at intervals of about 10 miles. In the vicinity of Mendota and the Panoche Fan, where shallow ground water was known to contain high concentrations of selenium, the sampling frequency was increased to intervals of about 5 miles. A statistically rigorous sampling schedule was not possible because plants were not always available at the desired locations. Two sample sites south of Kettleman City were selected at random. Plants collected in this study were identified using keys prepared by Jepson (1923) and Twisselmann and others (1967).

At each sample site, 10 grams of material from new growth were collected from healthy, vigorous plants. Leaflets were collected from *A. oxyphysus* (fig. 2), and entire leaves, excluding the petiole, were collected from *A. lentiformis* (fig. 3). Because most plants obtain maximum selenium concentrations in new growth at the time of flowering (Carlisle and Cleveland, 1958), samples were collected from March through April, which is the time of the reproductive cycle. Samples were collected from *A. lentiformis* at the same time because this shrub tends to lose its leaves during the hot, dry summer months. Samples were packed in resealable bags, quick frozen in the field using dry ice, and shipped to the U.S. Geological Survey laboratory in Denver, Colorado.

Analyses of leaf material was by two methods. In method 1, ground leaf material was digested in a sealed combustion bomb at 150°C for 2 hours with a 1:1 nitric-hydrochloric acid mixture (Jennis and others, 1980; Kensaku and Keiichiro, 1984). When the bomb cooled, its contents were transferred to a beaker containing 10 mL (milliliter) of 6 molar hydrochloric acid and the digestion was continued using the method described by the Association of Official Analytical Chemists (1980) for preparation of plant materials for fluorometric analyses of selenium. Analyses were completed by automated atomic absorption with hydride generation (Fishman and Bradford, 1982). The detection limit of 1 µg/g (dry weight) was limited by the amount of material that could fit in the combustion bomb. For quality control, analytical blanks as well as standards of certified plant material, NBS1571 orchard leaves were included in the sample suite.

APPROXIMATE SCALE

0 1 2 3 INCHES

0 25 50 MILLIMETERS

FIGURE 2. – Typical *Astragalus oxyphysus* (Diablo locoweed), in flower, and part of plant sampled. (Photograph taken March 30, 1984.)

Standard additions of calcium selenate were used to insure that the hydride generation step reduced selenate to selenite.

In method 2, ground leaf material was digested in nitric and perchloric acids and hydrogen peroxide was used to help break down the oils and waxes. The selenium was complexed with 2,3-diaminophthaline, and the resulting complex was extracted into 5 mL of cyclohexane. The fluorescence of the extract was measured and compared to that obtained from selenium standards to determine the amount of selenium present in the sample. With a 1-gram sample, the detection limit is 0.02 μg/g (dry weight). This method had been described in detail by Harms and Ward (1975). For quality control, analytical blanks as well as standards of certified plant material, NBS1567 wheat flour, were included in the sample suite.

Using method 1, most of the samples had selenium concentrations less than the detection limit of 1 μg/g. Results from method 2 were more satisfactory because of the lower detection limit. Both methods obtained satisfactory recovery of selenium from National Bureau of Standards certified plant material, so that the primary limitations seem to be the amount of material that can fit into the combustion bomb used in method 1 and the omission of the cyclohexane extraction and the 2,3 diaminonapthalene complexation steps. Future studies involving analyses of plant tissue for selenium should use a digestion procedure that allows an appropriate amount of mate-

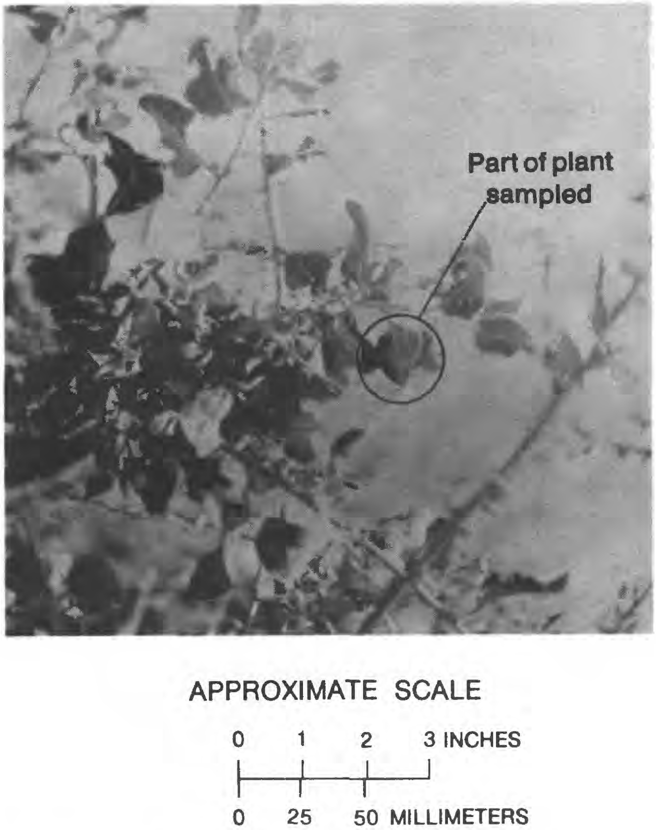

FIGURE 3.— Typical *Atriplex lentiformis* (quail bush) and part of plant sampled. (Photograph taken March 28, 1984.)

TABLE 1.--Selenium concentrations of leaf material from *Astragalus oxyphysus* at selected sites

[<, less than. Selenium concentration in microgram per gram, dry weight]

Site identi-fication (fig. 4)	Latitude ° ′ ″	Longitude ° ′ ″	Selenium concentration: Date of sample	Selenium concentration: Method 2
1A	355218	1200207	3-21-84	0.45
1B	355558	1195554	3-21-84	.45
1C	361227	1202653	3-22-84	.08
1D	361748	1201801	3-22-84	.85
1E	362429	1202853	3-22-84	.40
1F	363727	1203940	3-16-84	3.5
1G	364717	1204613	3-16-84	.15
			3-30-84	.15
			3-30-84	.30
			3-30-84	.25
			3-30-84	.25
			3-30-84	.15
1H	364730	1204500	3-30-84	.15
1I	370214	1203451	3-23-84	[1]<1.0
1J	372827	1211356	3-30-84	1.0

[1]Analysis by method 1, analysis using method 2 was not done on this sample.

rial to be analyzed and insures a suitable detection limit. Only the results obtained using method 2 are discussed in the remainder of this report.

RESULTS

Selenium concentrations of leaf material from 14 samples of *Astragalus oxyphysus* ranged from 0.08 to 3.5 µg/g (dry weight), and had a median concentration of 0.25 µg/g (table 1). The highest concentration of selenium was from a plant growing in the alluvial fill of the Panoche Creek drainage at site 1F (fig. 4). Many plants were observed at this site growing along the edge of a stream cut terrace. The only other sample to exceed 0.99 µg/g was collected on a shale outcrop in Del Puerto Canyon (fig. 1) at site 1J (fig. 4). Many other plants growing at this site had been destroyed by the landowner.

Selenium concentrations of leaf material from 17 samples of *Atriplex lentiformis* ranged from 0.08 to 7.5 µg/g (dry weight), with a median concentration of 0.35 µg/g (table 2). The highest concentration of selenium was from a plant growing in alluvial fill in Klipstein Canyon at site 2A (fig. 5). Four other plants had selenium concentrations greater than 0.99 µg/g. The location of these plants is shown in the inset in figure 5.

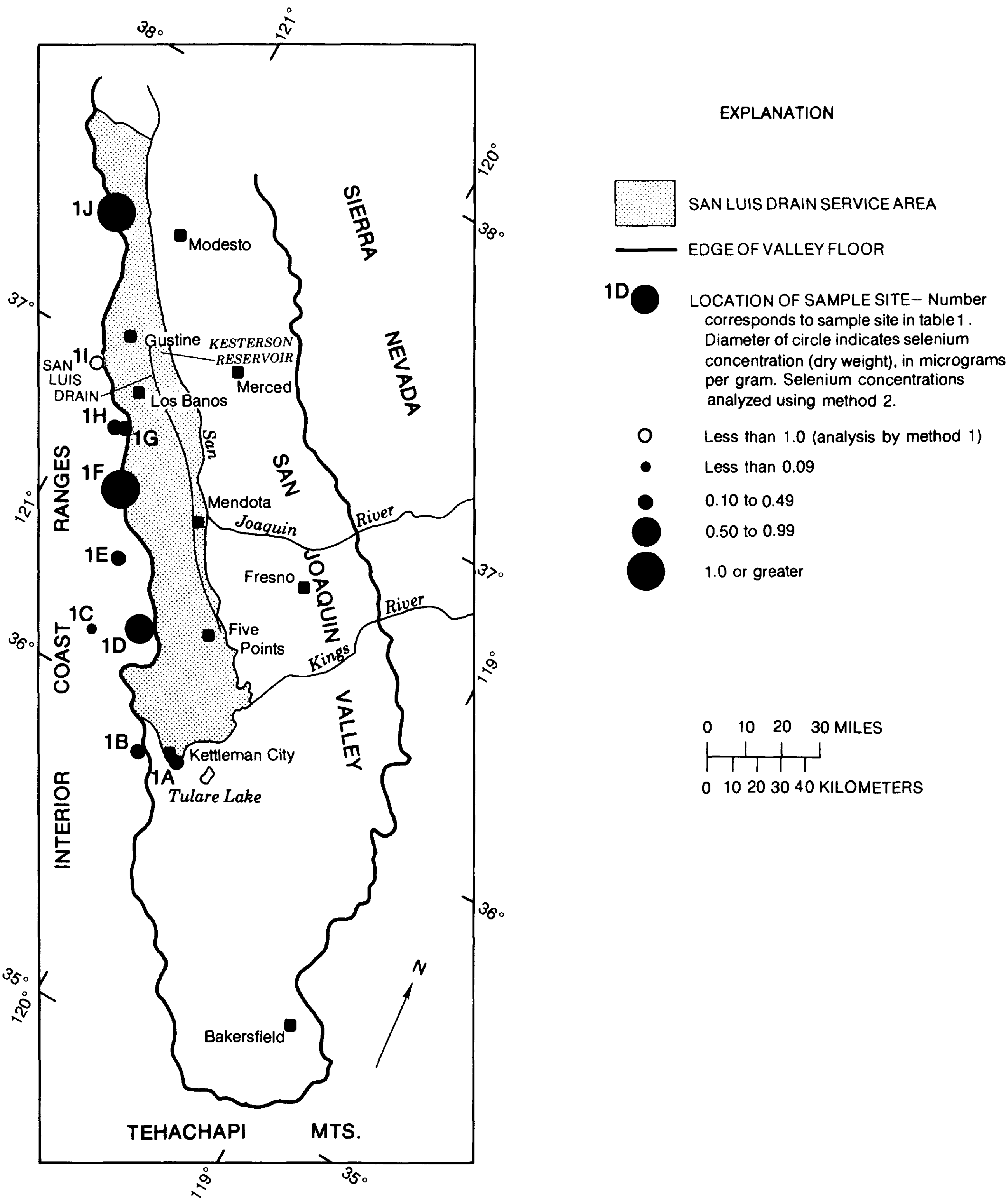

FIGURE 4.– Location of sample sites for leaf material from *Astragalus oxyphysus.*

TABLE 2.--Selenium concentrations of leaf material from *Atriplex lentiformis* at selected sites

[<, less than. Selenium concentration in microgram per gram, dry weight]

Site identification (fig. 5)	Latitude ° ' "	Longitude ° ' "	Selenium concentration: Date of sample	Selenium concentration: Method 2
2A	345905	1192417	3-21-84	7.5
2B	350600	1190240	3-28-84	.15
2C	361452	1200606	3-22-84	.08
2D	362939	1202527	3-22-84	1.5
2E	363149	1202921	3-22-84	1.0
2F	363216	1202331	3-29-84	.70
2G	363336	1200908	3-28-84	.08
2H	363553	1203446	3-22-84	2.4
2I	363733	1201642	3-28-84	.10
2J	363819	1202001	3-29-84	[1]<1.0
2K	364245	1203356	3-29-84	2.0
2L	364351	1202132	3-29-84	.40
2M	364500	1202335	3-29-84	.25
2N	364828	1202937	3-29-84	.70
2O	365504	1203911	3-29-84	.20
2P	370222	1204614	3-24-84	.35
2Q	370930	1205301	3-24-84	.20
2R	371355	1205552	3-24-84	.15

[1]Analysis by method 1, analysis using method 2 was not done on this sample.

DISCUSSION AND CONCLUSIONS

Astragalus oxyphysus was just entering its reproductive cycle when sample collection began; many plants had not begun to flower, and flowers, when present, were fresh. *A. oxyphysus* was just ending its reproductive cycle when sample collection ended; many plants had developed seed pods, and flowers, when present, were wilted. Replicates were collected from six plants growing in the alluvial fill of the Little Panoche Creek drainage at site 1G (fig. 4). One sample was collected March 16, 1984, and five samples were collected March 30, 1984. The mean selenium concentration of the five samples collected on March 30 was 0.22 µg/L, and the standard deviation was 0.07. Using the t-test (Neter and Wasserman, 1974) with a confidence level of $\alpha = 0.05$, the selenium concentration of the sample collected on March 16 (0.15 µg/g) was not significantly different from the mean of the data collected on March 30. Although not conclusive, these data indicate that the selenium concentration of *A. oxyphysus* remained constant at the site tested during the sample collection period, and that variations associated with differences in plant maturity were minimal.

Many factors determine the level of selenium in forage and feeds that are toxic to animals. As a general guideline, the National Academy of Sciences (1980) recommends a maximum safe tolerance level of 2 µg/g (dry weight) of selenium in animal feeds. One sample of *A. oxyphysus* exceeded 2 µg/g at site 1F (fig. 4) in the Panoche Creek drainage. Three samples of *A. lentiformis* equaled or exceeded 2 µg/g at sites in Klipstein Canyon (site 2A), Tumey Fan (site 2H), and the Panoche Fan (site 2K) (fig. 5). On the basis of the results of this study, at least some vegetation in Klipstein Canyon, Tumey Fan, the Panoche drainage, and the Panoche Fan can be considered seleniferous. These sites may be suitable for further soil study.

Because selenium is also an essential micronutrient, Underwood (1971) recommended a dietary intake of 0.10 µg/g (in dry feeds) to prevent selenium deficiency in sheep and cattle. One sample of *A. oxyphysus* collected in the Los Gatos drainage at site 1C (fig. 4) had less than 0.1 µg/g of selenium. Two samples of *A. lentiformis* collected in the San Joaquin Valley at sites 2C and 2G (fig. 5) had selenium concentrations less than the recommended dietary intake of 0.1 µg/g.

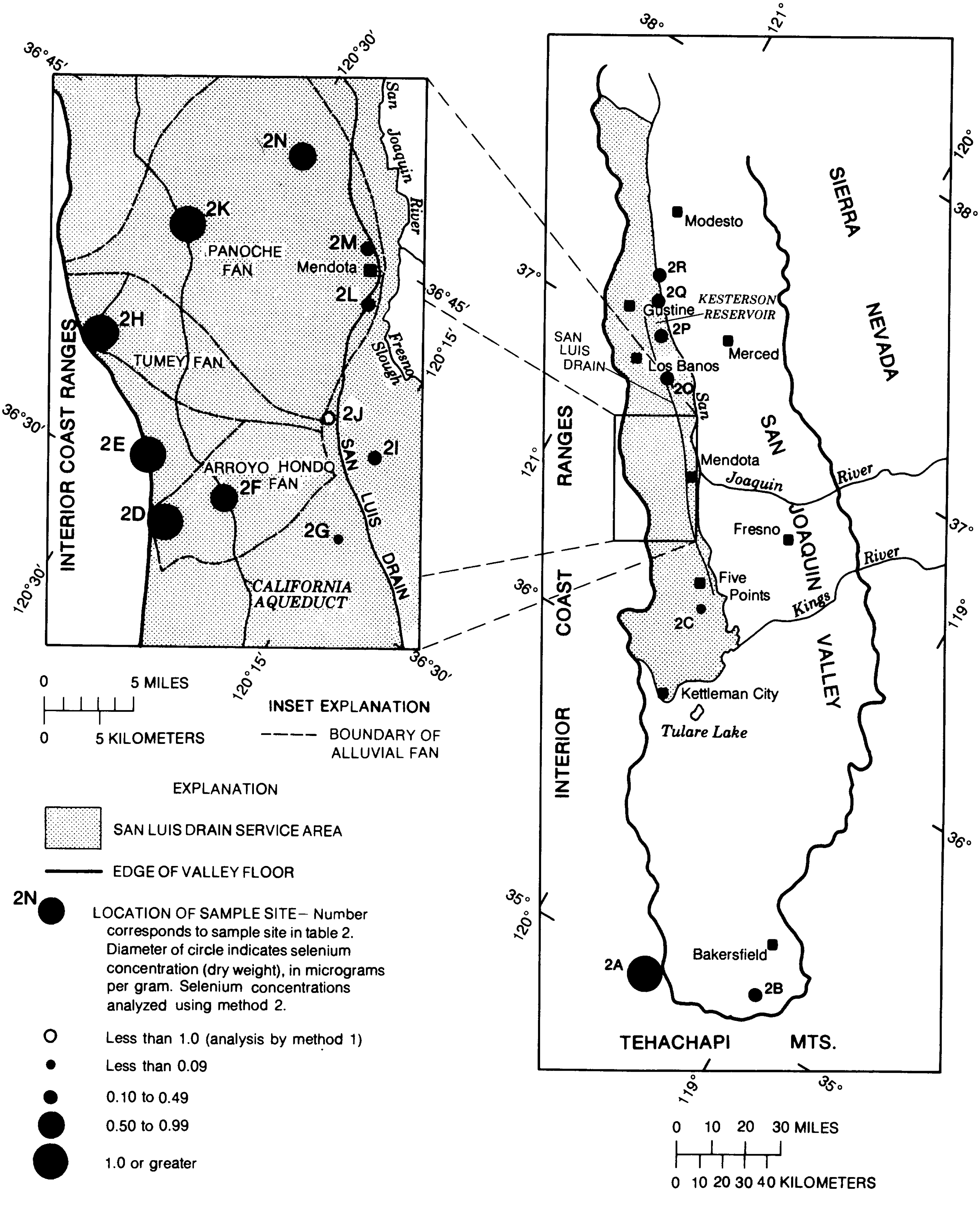

FIGURE 5.—Location of sample sites for leaf material from *Atriplex lentiformis*.

The use of plants to identify seleniferous areas is most effective when an obligate selenium accumulator is available. These plants can only grow where soils contain enough selenium to support the metabolic needs of the plant. Brown and Shrift (1982) list 22 species and 14 varieties of *Astragalus* from around the United States, Canada, and Mexico which are obligate accumulators and whose presence is an indication of seleniferous soils. Seven additional species are in a similar list compiled by Cannon (1971). Most of these species do not grow in the study area and none of the species that are reported to grow in the study area were observed during this study. Because of the relatively low concentrations obtained during this study, *A. oxyphysus* should not be added to these lists of obligate selenium accumulators; and toxicity associated with *A. oxyphysus* (Twisselman and others, 1967) may be related to causes other than the presence of selenium. For example, Molyneux and James (1982) have demonstrated that certain species in the genera *Astragalus* produce alkaloids that are toxic to livestock.

Facultative selenium accumulators can be used to identify seleniferous soils if collection and identification of plants is accompanied by tissue analyses. To be an effective indicator of seleniferous soils a facultative selenium accumulator must be easily identified, have a distribution which is not greatly limited by environmental factors, and be relatively common within the study area. Both *A. oxyphysus* and *A. lentiformis* are easily identified and individual specimens can be seen at a distance. Although intensive agriculture, ranching, and other activities of man have altered the predevelopment distribution of both species, neither species was scarce within the study area.

For smaller scale studies, the distribution of these plants may pose severe limitations. Other selenium accumulating species may be more suitable for such studies. Some members of the genus *Grindelia* are known to be facultative selenium accumulators (Carlisle and Cleveland, 1958). *Grindelia camporum* Greene (Great Valley gumplant) is a common species on the west side of the San Joaquin Valley and in the interior Coast Ranges. *G. camporum* is commonly observed along roadsides and as a weed in agricultural areas. It is most obvious in late summer when in flower, although individual specimens may flower at any time during the year. Leaf material from *G. camporum* was collected near sites 2Q and 2R on March 24, 1984. Both samples had a selenium concentration of 0.30 μg/g (dry weight). Leaf material from *A. lentiformis* collected at sites 2Q and 2R had selenium concentrations of 0.20 and 0.15 μg/g, respectively. Despite the small concentrations obtained from this limited sampling, *G. camporum* may be useful in identifying seleniferous areas because of its wide distribution in the San Joaquin Valley.

Further work is necessary before plants can be used as indicators of seleniferous soils in the San Joaquin Valley. Different plant species need to be tested for selenium concentration, and the natural variability of selenium concentrations in individual plants at the same site needs to be determined. The use of plants as indicators of seleniferous soils will be most effective when and if an obligate selenium accumulator is identified.

REFERENCES CITED

Association of Official Analytical Chemists, 1980, Official methods of Analysis [13th ed.]: Washington, D.C., Association of Official Analytical Chemists, 1018 p.

Armstrong, W.P., 1984, Locoweed--a wild and crazy plant: Pacific Discovery, v. 37, no. 3, p. 4-9.

Brown, J.M., and Web, P.J. de, 1962, A preliminary report on the occurrence of selenosis in South Africa and its possible role in the aetiology of tribulosis, enzooticicterus and some other disease conditions encountered in the Karoo areas: Onderstepoort Journal of Veterinary Research, v. 29, no. 1, p. 11-135.

Brown, T.A., and Shrift, A., 1982, Selenium: toxicity and tolerance in higher plants: Biological Review, v. 55, p. 59-84.

Byers, H.G., and Lakin, H.W., 1939, Selenium in Canada: Canadian Journal of Research, v. 17, sec. B, no. 11, p. 364-369.

Cannon, H.L., 1971, The use of plant indicators in ground-water surveys, geologic mapping, and mineral prospecting: Taxon, v. 20, nos. 2-3, p. 227-256.

Carlisle, Donald, and Cleveland, G.B., 1958, Plants as a guide to mineralization: California Division of Mines and Geology Special Report 50, 31 p.

Church, D.C., Smith, G.C., Fantenat, J.P., and Ralston, A.T., 1971, Digestive physiology and nutrition of ruminants, v. 2--Nutrition: D.C. Church, Publisher, 693 p. [available from O & B Books, 1215 NW Kline Place, Corvallis, Oregon 97330.]

Cooper, W.C., Bennett, K.G., and Croxton, F.C., 1974, The history, occurrence, and properties of selenium, p. 1-30, *in* Zingaro, R.A., and Cooper, W.C., eds., Selenium: New York, Van Norstrand Reinhold Co., 835 p.

Cooper, W.C., and Glover, J.R., 1974, The toxicology of selenium and its compounds, p. 654-674: *in* Zingaro, R.A., and Cooper, W.C., eds., Selenium: New York, Van Norstrand Reinhold Co., 835 p.

Deverel, S.J., Gilliom, R.J., Fujii, Roger, Izbicki, J.A., and Fields, J.C., 1984, Areal distribution of selenium and other organic constituents in shallow ground water of the San Luis Drain service area, San Joaquin Valley, California: A preliminary study: U.S. Geological Survey Water-Resources Investigations Report 84-4319, 67 p.

Fishman, M.J., and Bradford, W.L., 1982, A supplement to methods for the detemination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Open-File Report 82-272, 136 p.

Gough, L.P., Shacklette, H.L., and Case, A.A., 1979, Element concentrations toxic to plants, animals, and man: U.S. Geological Survey Bulletin 1466, 80 p.

Harms, T.F., and Ward, F.N., 1975, Determination of selenium in vegetation, p. 37-42, *in* Ward, F.N. ed., New and refined methods of trace analysis useful in geochemical exploration: U.S. Geological Survey Bulletin 1408. 105 p.

Harradine, F.F., 1950, Soils of western Fresno County, California: Berkeley, University of California, College of Agriculture, 86 p.

Harradine, F.F., Gardner, R.A., Rooke, L.G., and Knecht, E.A., 1956, Soil survey of the Mendota area, California: Berkeley, University of California, College of Agriculture, 96 p.

Jennis, S.W., Katz, S.A., and Mount, T., 1980, Determination of cadmium and lead in sewage sludges: American Laboratory, p. 20-23.

Jepson, W.L., 1923, A manual of the flowering plants of California: Berkeley, University of California, 1238 p.

Kensaku, Okamoto, and Keiichiro, Fuwa, 1984, Low concentration digestion bomb methods using a teflon double-wall vessel for biological materials: American Chemist, p. 1758-1760.

Kingsbury, J.M., 1964, Poisonous plants of the United States and Canada, [3d ed.]: Englewood Cliffs, New Jersey, Prentice-Hall, 626 p.

Lakin, H.W., 1972, Selenium accumulation in soils and its absorption by plants and animals: Geological Society of America Bulletin, v. 83, p. 181-190.

Lakin, H.W., and Byers, H.G., 1941, Selenium occurrence in certain soils in the United States, with a discussion of related topics [sixth report]: U.S. Department of Agriculture Technical Bulletin 783, 27 p.

Molyneux, R.J., and James, L.F., 1982, Loco intoxication: indolizidine alkaloids of spotted locoweed (Astragalus lentiginosus): Science, v. 216, p. 190-191.

Moxon, A.L., and Olson, D.E., 1974, Selenium in agriculture, p. 675-707, *in* Zingaro, R.A., and Cooper, W.C., eds., Selenium: New York, Van Norstrand Reinhold Co., 835 p.

Moxon, A.L., Olson, D.E., and Searight, W.V., 1950, South Dakota agricultural experiment station revised technical bulletin No. 2.

National Academy of Sciences, 1976, Medical and biological effects of environmental pollutants, selenium: Washington D.C., Division of Medical Science, National Research Council, National Academy of Sciences.

National Academy of Sciences, 1980, Mineral tolerance of domestic animals: Washington D.C., National Research Council, National Academy of Sciences, 577 p.

Neter, John, and Wasserman, William, 1974, Applied linear statistical models: Homewood, Illinois, Richard S. Irwin, Inc., 842 p.

Presser, T.S., and Barnes, Ivan, 1984, Selenium concentrations in waters tributary to and in the vicinity of Kesterson National Wildlife Refuge, Fresno and Merced Counties, California: U.S. Geological Survey Water-Resources Investigations Report 84-4122, 26 p.

Rosenfield, I., and Beath, O.A., 1964, Selenium--geobotany, biochemistry, toxicity, and nutrition: New York, Academic Press, Inc.

Trelease, S.F., and Beath, O.A., 1949, Selenium, its geological occurrence and its biological effects in relation to botany, chemistry, agriculture, nutrition, and medicine: New York, published by authors, 292 p.

Twisselmann, Ernest, McMillan, Eben, and McMillan, Gladys, 1967, A flora of Kern County, California: San Francisco, California, University of San Francisco.

Underwood, E.J., 1971, Trace elements in human and animal nutrition [3d ed.]: New York and London, Academic Press, 543 p.

U.S. Bureau of Reclamation, 1984, Conference on toxicity problems at Kesterson Reservoir: Sacramento, California, U.S. Bureau of Reclamation, Mid-Pacific Region, 71 p.