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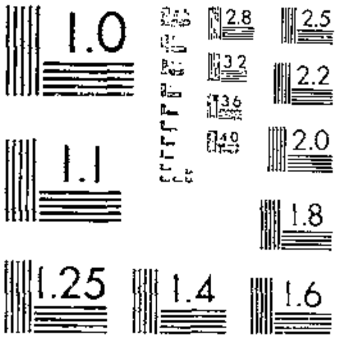


MICROCOPY RESOLUTION TEST CHART
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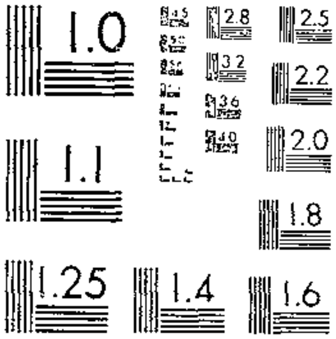


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NATIONAL BUREAU OF STANDARDS 1963-A

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# SELENIUM OCCURRENCE IN CERTAIN SOILS IN THE UNITED STATES WITH A DISCUSSION OF RELATED TOPICS: THIRD REPORT[1]

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CONTENTS



## INTRODUCTION

In Technical Bulletins 482 and 530 (*5, 6*)[2] have been summarized the results of the selenium studies carried out in the Soil Chemistry and Physics Research Division up to and including the calendar year 1935. The present report presents the results obtained in 1936. Included in these reports as a primary object is the result of the survey of areas the soils of which are affected by selenium to such an extent as to produce vegetation toxic to animals. In addition to the survey data such information is included as was gained upon collateral subjects. In the present report are presented additional data upon selenium in water, sources of selenium in soil parent materials, relations between soil content of selenium and vegetation content, origin of selenium concentrations, irrigation in selenium areas, forms of selenium in the soil, changes in survey methods, and miscellaneous data. Since a fairly complete review of the literature is included in the previous bulletins, only such additional references are included in this report as bear directly upon the data as presented.

[1] Received for publication May 20, 1937.

[2] Italic numbers in parentheses refer to Literature Cited, p. 72.

During the period reported upon, M. A. McCall, of the Bureau of Plant Industry, called attention to a reference in The Travels of Marco Polo which is of exceptional interest. The following is the passage as taken from the translation of Komroff (*23, ch. 43, p. 8*).

It is a fact that when they take that road they cannot venture among the mountains with any beast of burden excepting those accustomed to the country on account of a poisonous plant growing there, which if eaten by them has the effect of causing the hoofs of the animals to drop off. Those of the country, however, being aware of its dangerous quality, take care to avoid it.

This quotation taken together with various references to similar occurrences by Stein (*30, v. 1, pp. 220, 260; v. 2, pp. 303, 306*) leave but little doubt of the existence of a seleniferous area in the valleys of the Kunlun Mountains in western China and eastern Turkestan. One of these references is as follows:

I was just gleefully reflecting how our ponies would revel in their alpine pasture when Sahid Bai . . . came up with alarmed mien to report that five of the animals were standing about benumbed and refusing to touch grass or fodder. I at once suspected that they had eaten of the poisonous grass which infests certain parts of the Nan Shan and about which old Marco has much to tell in his chapter on Sukchur, or Su-Chou. The Venetian's account had proved quite true; for while my own ponies showed all the effects of this inebriating plant, the local animals had evidently been wary of it. . . .

The avoidance of seleniferous vegetation by animals observed by Franke and Potter (*12*) in South Dakota in 1931 was observed in Turkestan at least as early as 1275 A. D.

Also, it may perhaps be worthy of note that Sprengel (*29*) as early as 1839 lists lead, arsenic, copper, selenium, and bromine as injurious to plant growth. No data as evidence are furnished.

## METHODS OF EXAMINATION

No new methods of examination have been used, but it seems desirable to restate the procedures employed in examining the various kinds of materials. With normal well-decomposed soil a sample of 50 g is ground to a fineness of 2 mm and placed in an all-glass distilling apparatus (fig. 1) and treated with 100 cc of hydrobromic acid (sp. gr. 1.50) which contains 2 cc of bromine. If the soil is highly organic, additional bromine is added until, after refluxing for a few minutes and warming, a few droplets of bromine condense in the receiving flask. The distillation is continued until about 50 to 60 cc of distillate is obtained. The distillate must be bright red from bromine. The determination of the selenium is carried out as described below. When only traces of selenium are present in the soil, and it is desired to determine quantities as small as 1 part per 100,000,000, the operation is repeated with fresh soil samples until from 1 to 2 kg of soil have been treated. In this case the distillate is added to each successive sample, and only the quantity of hydrobromic acid needed to bring up the total to 100 cc is added. If the soil is rich in clay or carbonates, sulphuric acid (sp. gr. 1.84) must be added in quantity sufficient to produce a distillate of specific gravity at least as high as 1.4.

In case shales, raw soils, or pyrites (*35*) are to be examined, the samples of material, ground to pass a 100-mesh sieve, are treated with concentrated nitric acid in excess (sp. gr. 1.42) and 50 cc of sulphuric acid, and then warmed until evolution of nitric oxide ceases. The treated samples are then digested with hydrobromic acid and bromine as before. If nitric acid has not been completely expelled, the distillate will be black instead of red and will not be readily reduced.

In the examination of vegetation the air-dry sample is ground to pass a 2-mm sieve, and a 10-g sample is slowly added to a mixture of 50 cc of sulphuric acid (sp. gr. 1.84) and 100 cc of nitric acid (sp. gr. 1.42) contained in a 600-cc beaker. The mixture is digested slowly at a temperature not exceeding 120° C. until a brownish-yellow liquid is obtained and brown fumes of oxides of nitrogen cease to evolve. The cooled residue is transferred to a distilling flask, and the beaker rinsed with not to exceed 30 cc of water and also with

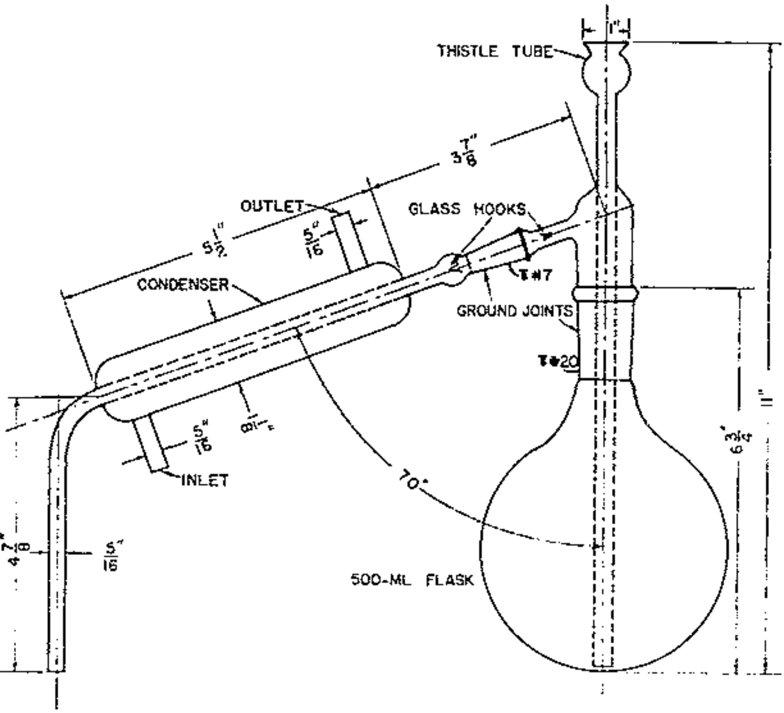


FIGURE 1.—Apparatus employed in the distillation procedure.

100 cc of hydrobromic acid containing 1 cc of bromine, and the distillation carried out as with soil. Here again for estimation of minute amounts the integration procedure may be used.

With water the procedure followed is to evaporate the sample (2 to 4 liters), after rendering it alkaline with sodium peroxide, to complete dryness on the water bath and subjecting the residue to distillation with hydrobromic acid and bromine as with other materials. In the case of sea water, because of the large quantity of chlorides, it is preferable to treat the sample with 10 g of ferric chloride and precipitate with an excess of ammonium hydroxide (*21*). The ferric hydroxide precipitate contains all the selenium present in the selenite form. The filtered precipitate is treated with hydrobromic acid and bromine and distilled. In case selenium is present in forms other than selenite (*38*) the salt water is evaporated, after additions of sodium hydroxide, to incipient crystallization and treated with an excess of nitric acid. The subsequent treatment is the same as that used with shales.

Where free sulphur or material suspected of containing it is to be examined, it has been found convenient to digest the material in concentrated sulphuric acid in an all-glass distilling apparatus (fig. 1) and pass all evolved gases through a bromine-hydrobromic acid liquid layer in the receiver. When all evolution of gases, other than sulphur trioxide, has ceased the flask is cooled. To it are added 20 percent of its volume of water, the collected distillate, and 100 cc of the hydrobromic acid solution. The selenium is collected by distillation as before.

In all cases the distillate of bromine and hydrobromic acid is treated with 20 cc of water, and sulphur dioxide is passed into it in the cold until essentially saturated; 0.25 of a gram of hydroxylamine hydrochloride is added, and the precipitated selenium is allowed to collect in the bottom of the flask. The flocculation of the precipitate may be hastened, without injury, by warming for 15 minutes on the water bath. In routine practice it is found desirable to allow the flask to stand 2 to 3 days to insure complete coagulation. The precipitate is collected on an asbestos Gooch filter. The filtrate is available for quantitative determination of arsenic if desired. The precipitated material is washed with alcohol, if necessary, to remove waxy material, and redissolved in a small quantity of bromine-hydrobromic acid (1 to 100). According to the quantity present it is reprecipitated, refiltered, and weighed on a tared filter, or it is precipitated in a 25-cc flask, after addition of a few cubic centimeters of water, and made up to volume. The colorimetric-turbidimetric estimation is made in any convenient colorimeter by comparison with standards similarly prepared.

## RECONNAISSANCE

In the early part of the summer of 1936 Miller and Byers made an inspection of several areas with the object of ascertaining which of these required detailed examination. The selection of areas was based upon the geologic map of the United States[3] and various other sources of information. The plan was to visit the areas under suspicion and collect a sufficient number of samples of shales, soils, and vegetation to gain, through their examination, a general idea of the intensity of intoxication and, through observation of the soil topography and texture and of the probable parent material to the soil, to gain an approximate idea of the extent of the area affected. The major results of the observations made are given below.

### KANSAS

In Hamilton County, Kans., the geologic map[3] shows a small outcrop of Colorado shale which may or may not be seleniferous. The samples from this county already reported (*5*) showed no high toxicity. The State geologic map,[4] however, shows a few outcrops of Niobrara shale north of the Arkansas River and near the Colorado line. One of the spots, located in sec. 3, T. 22 S., R. 43 W., was visited, and 10

[3] UNITED STATES GEOLOGIC SURVEY. GEOLOGIC MAP OF THE UNITED STATES, 1932. Prepared by G. W. Stose and O. A. Ljungstedt. 1933.

[4] KANSAS GEOLOGICAL SURVEY. GEOLOGIC MAP OF KANSAS. Prepared by R. C. Moore and K. K. Landes. 1936.

samples were collected. The Smoky Hill section of the exposed Niobrara was found to contain considerable selenium, 6 to 14 parts per million, and the Fort Hays chalk (lower Niobrara) contained very much less, 0.2 and 1.5 parts per million. One sample of *Astragalus racemosus* growing on soil which at the surface contained 1.5 p. p. m. was found to contain 1,220 and one of *A. mollissimus* but 3 p. p. m. These results are quite in harmony with those obtained in the similar areas along the Smoky Hill River in Wallace, Logan, Gove, and Trego Counties, Kans. The other small outcrops were not visited. It is apparent that a small area of seleniferous soils exists in Hamilton County, but no further examination will be made until opportunity offers.

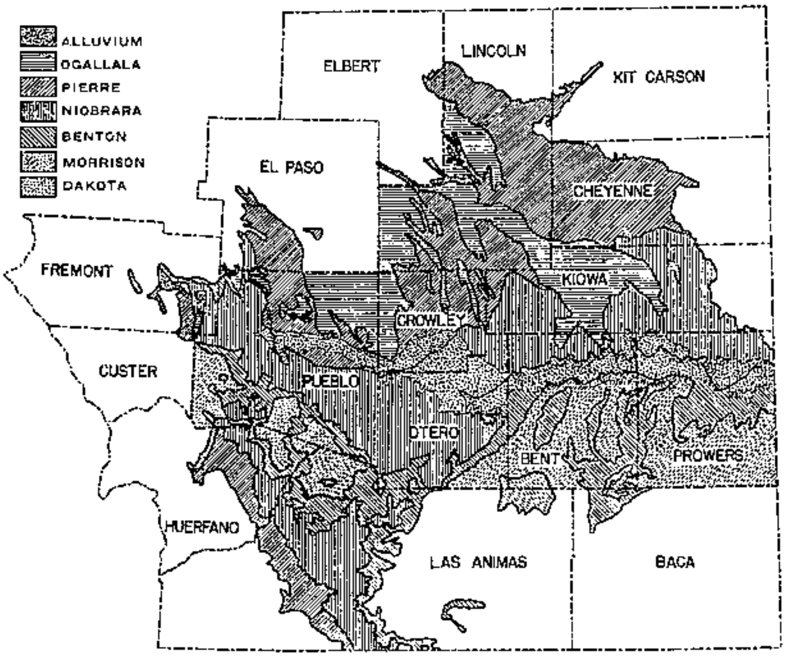


FIGURE 2.—Sketch map showing location of areas of geologic material in eastern Colorado.

## EASTERN COLORADO

A very different picture was afforded by the examination of the area of soils developed upon Niobrara and Pierre shales in the eastern portion of Colorado along the Arkansas River and running in irregular fashion north to the South Platte River. A sketch map of this area is given in figure 2. It must be kept in mind that even when the geologic maps are accurate with respect to exposure of formations, it by no means follows that the soils of the same areas are derived from the underlying strata. Also, the surface may be covered, over wide areas, by materials such as water-borne gravels, wind-blown loess, and residual material from overlying strata. It does not even follow that all soils developed from the Pierre shales are toxic, since the upper part of the Pierre is relatively low in selenium (*5*). The lower portion of the Niobrara, corresponding to the Fort Hays limestone, is in general not capable of producing toxic soils. Table 1 contains the results obtained from a series of selected samples. By no means are all the samples examined included. The purpose of the selection is to show the general situation which exists.

TABLE 1.—*Selenium content of soils and vegetation from eastern Colorado*

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P. p. m.* | *P. p. m.* |
| B18127 | 1 | Prowers County on Granada Creek. | Clay over Greenhorn [1] limestone. | 0.3 | |
| B18128 | 1x | do | Greenhorn [1] limestone | .4 | |
| B18104 | 1 | Kiowa County, 4½ miles west of Sheridan Lake. | Niobrara [1] silt loam, 0–8 inches. | .4 | |
| B18105 | 1a | do | *Astragalus racemosus* | | 90 |
| B18108 | 4 | Kiowa County, 1 mile west of Chivington. | Pierre clay alluvium | 1.5 | |
| B18110 | 4a | do | *A. racemosus* | | 750 |
| B18112 | 6 | Kiowa County, 6 miles south of juncture of State Roads 96 and 59. | Niobrara [1] clay | .5 | |
| B18113 | 6a | do | Narrowleaf milkvetch | | 1,120 |
| B18123 | 9 | Kiowa County, ½ mile south of Haswell. | Niobrara [1] shale | 54.0 | |
| B18134 | 11 | Kiowa County, 2 miles west of Haswell. | Goldenweed | | 550 |
| B18139 | 1 | Bent County, 1¼ miles north of Fort Lyon. | Carlile [1] clay, 0–6 inches | 2 | |
| B18140 | 1a | do | Alfalfa | | 2 |
| B18143 | 3 | Bent County, ½ mile east of Adobe Lake. | Wind-blown sand, 0–6 inches (about an *Astragalus* plant). | 10 | |
| B18144 | 3 | do | Clay loam, 12–16 inches | 2.5 | |
| B18145 | 3a | do | Narrowleaf milkvetch | | 1,410 |
| B18146 | 1 | Otero County, 2.7 miles east of Rocky Ford. | Alluvial clay, 18–24 inches | .3 | |
| B18368 | 23 | Otero County, 47 miles northeast of Walsenburg. | Clay loam, 0–6 inches | .7 | |
| B18369 | 20a | do | Silky sophora | | 3 |
| B18341 | 3 | Pueblo County, 1 mile west of Pueblo, on United States Route 50. | Yellow concretions (in Pierre). | 18 | |
| B18342 | 4 | do | Upper Niobrara [1] shale | 3.5 | |
| B18344 | 6 | Pueblo County, 3 miles west of Pueblo, on United States Route 50. | Yellow-brown shale (Niobrara) | 156 | |
| B18370 | 1 | Crowley County, 2 miles north of Ordway, on State Road 71. | Pierre clay loam, 0–6 inches | 2 | |
| B18371 | 1a | do | Drummond milkvetch | | 3 |
| B18372 | 2 | Crowley County, 6 miles north of Ordway, on State Road 71. | Pierre clay loam, 18–24 inches | 1.5 | |
| B18373 | 2a | do | *A. racemosus* | | 150 |
| B18374 | 3 | Lincoln County, 39 miles north of Ordway, on State Road 71. | Pierre clay, 0–6 inches | .7 | |
| B18375 | 3a | do | *Astragalus* sp | | 15 |
| B18377 | 5 | Lincoln County, 8 miles northwest of Hugo, on United States Route 40. | Alluvial clay, 0–6 inches | .6 | |
| B18378 | 5a | do | Two-groove poisonvetch | | 30 |
| B18379 | 5b | 100 feet from 5a | Narrowleaf milkvetch | | 480 |
| B18382 | 7 | Washington County, 27 miles north of Limon, on State Road 71. | Pierre clay loam, 0–6 inches | .7 | |
| B18383 | 7a | do | Two-groove poisonvetch | | 130 |
| B18386 | 9 | Morgan County, 67 miles north of Limon, on State Road 71. | Pierre clay, 0–6 inches | 3 | |
| B18387 | 9a | do | Two-groove poisonvetch | | 1,380 |
| B18388 | 9b | 3 feet from 9a | Alfalfa | | 3 |
| B18337 | 1 | El Paso County, 20 miles south of Colorado Springs, on United States Route 85. | Alluvial clay, 0–6 inches | 3.5 | |
| B18338 | 1a | do | Silky sophora | | 20 |
| B18339 | 2 | El Paso County, 24 miles south of Colorado Springs, on United States Route 85. | Clay loam, 0–6 inches | 6 | |
| B18340 | 2a | do | Two-groove poisonvetch | | 3,730 |

[1] Geologic formation.

TABLE 1.—*Selenium content of soils and vegetation from eastern Colorado*—Contd.

| Laboratory no. | Field no. | Location | Material | Selenium in— | |
|---|---|---|---|---|---|
| | | | | Soil or shale | Vegetation |
| | | | | *P. p. m.* | *P. p. m.* |
| B18354 | 11 | Fremont County, 20 miles west of Pueblo, on United States Route 50. | Shaly loam, 0–6 inches | 1 | |
| B18355 | 11a | do | *A. racemosus* | | 1,220 |
| B18357 | 13 | Fremont County, 7 miles east of Florence, on United States Route 50. | Shaly clay loam, 0–6 inches | 3 | |
| B18358 | 13a | do | Two-groove poisonvetch | | 410 |
| B18360 | 14a | 10 feet from 13a | Stanleya | | 630 |
| B18361 | 15 | Huerfano County, 38 miles south of Pueblo, on United States Route 85. | Pierre shale | .8 | |
| B18365 | 18a | Huerfano County, 10 miles east of Walsenburg, on State Road 10. | *A. racemosus* | | 410 |
| B18366 | 19 | Huerfano County, 15 miles east of Walsenburg, on State Road 10. | Clay loam, 0–6 inches | 1 | |
| B18367 | 19a | do | Narrowleaf milkvetch | | 1,620 |

From the data presented in table 1 it is apparent that selenium exists in the soils and vegetation over a wide area in eastern Colorado. It is evident that its distribution is by no means uniform. It seems, also, with respect to a considerable portion of the area involved that the toxicity is seriously modified not only by reason of the portions of the shales which are parent materials of the soils but by residual material from overlying strata, by outwash from the mountains, by loessial mixing, and by methods of soil utilization, particularly irrigation. Therefore it was planned to make a closer examination of the area, the report of which appears on page 11. No examination was made of the shale exposures in northeastern Colorado along the South Platte River.

## NEW MEXICO

The reconnaissance was continued by inspection of certain areas in New Mexico. The United States Geological Survey map of the United States[6] shows the existence of numerous areas of outcropping cretaceous shales without differentiating them into the subgroups. Among these areas there are three which for various reasons are of particular interest. The largest lies in the northeastern portion of the State and for the most part is in Colfax and San Miguel Counties between Raton and Las Vegas. Another is to the north of Santa Fe in the vicinity of Tierra Amarilla. This outcrop extends into southern Colorado and is connected through a narrow band with a wider area in northwestern New Mexico and southwestern Colorado between Cortez, Colo., and Shiprock, N. Mex. These areas were scouted. A number of smaller indicated areas exist but have not been visited. The data obtained through examination of the samples collected are given in part in table 2. A considerable number of samples were obtained in southwestern Colorado which are considered elsewhere (p. 65).

[6] UNITED STATES GEOLOGIC SURVEY. See footnote 3.

TABLE 2.—*Selenium content of soils and vegetation from New Mexico*

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P. p. m.* | *P. p. m.* |
| B18150 | 2 | At Raton, on United States Route 85. | Pierre shale | 0.8 | |
| B18151 | 2a | do | Red clover | | 7 |
| B18153 | 4 | 5 miles south of Raton | Pierre clay loam, 0–6 inches | 2.5 | |
| B18154 | 4 | do | Pierre clay loam, 18–24 inches | 1.5 | |
| B18155 | 4a | do | *Astragalus racemosus* | | 003 |
| B18156 | 5 | 7 miles south of Raton | Shale concretions, 4 feet | 14 | |
| B18159 | 6 | 9 miles south of Raton | Pierre shale in concretionary zone. | 2.5 | |
| B18160 | 7 | 14 miles south of Raton | Niobrara [1] clay loam, 0–4 inches | 12 | |
| B18161 | 7a | do | Two-groove poisonvetch | | 2,580 |
| B18162 | 8 | 43 miles south of Raton | Niobrara [1] limestone | 1 | |
| B18163 | 9 | 56 miles south of Raton | Greenhorn [1] limestone | 1 | |
| B18164 | 10 | do | Pierre shale | 1 | |
| B18165 | 11 | 9 miles northeast of Las Vegas | Pierre clay loam, 0–6 inches | 1 | |
| B18166 | 11a | do | *Astragalus* sp. | | 1,110 |
| B18239 | 1 | 14 miles north of Santa Fe, on United States Route 285. | Clay loam, 0–6 inches | .5 | |
| B18240 | 1a | do | *Astragalus* sp. | | 190 |
| B18241 | 2 | 15 miles south of Tierra Amarilla. | Clay loam, 0–6 inches | 1 | |
| B18242 | 2a | do | *Astragalus* sp. | | 40 |
| B18244 | 4 | Near Colorado-New Mexico line, northwest of Chama. | Clay loam, 0–6 inches | 1 | |
| B18247 | 4b | do | Larkspur | | 3 |
| B18170 | [illegible] | 2½ miles west of Waterflow | Sandy loam, 0–6 inches | .2 | |
| B18172 | | do | Alfalfa | | 1 |
| B18173 | 3 | 7 miles north of Shiprock, on United States Route 66. | Clay loam, 0–6 inches | 1.5 | |
| B18174 | 3a | do | Stanleya | | 150 |
| B18197 | 17 | 3 miles south of Colorado-New Mexico border. | Desert silt loam, 0–6 inches | 1 | |
| B18198 | 17a | do | Stanleya | | 200 |
| B18199 | 18 | 4 miles south of Colorado-New Mexico border on United States Route 66. | Desert silt loam, 0–6 inches | 2 | |
| B18200 | 18a | do | Stanleya | | 830 |
| B18201 | 19 | 4 miles northwest of Shiprock | Silty clay loam, 0–6 inches (with salt incrustation). | 10 | |
| B18204 | 21 | 6 miles south of Shiprock. | Desert clay loam, 0–6 inches | 1 | |
| B18205 | 21a | do. | Stanleya | | 430 |

[1] Geologic formation.

Consideration of the geologic map [6] in the light of the information outlined in table 2 leads to the following inferences: There is a very large area in northeastern New Mexico lying on the relatively smooth plain between Las Vegas and Raton which is seleniferous. This area is not continuous. It is broken by exposures of formations not belonging to the Cretaceous period which have not been shown to be markedly seleniferous and also by exposures of cretaceous shales which are not sufficiently seleniferous to produce soils of toxic character. It is clear, however, that much of the area may produce vegetation of toxic type and that a closer investigation is needed in order to determine how extensive this area is and to what degree the known existence of poisonous range plants is to be ascribed to the presence of selenium (p. 45). The area north of Santa Fe is very rough, and the narrow valleys are fairly well wooded. The rainfall appears to be sufficient to keep the selenium content of plants at a low level. These facts and the relatively small economic importance of the possibly affected area would seem to warrant postponement of further study until a more convenient period. The same conclusion was reached with respect to the study of the area lying to the north

[6] UNITED STATES GEOLOGIC SURVEY. See footnote 3.

and south of Shiprock. This area is large. It has at present a very sparse population both of men and animals, except along the San Juan River where irrigation is possible. It has already been shown, and further confirmation is found in this bulletin, that irrigation reduces selenium injury to probably negligible amounts. No further study of this area (fig. 3) is contemplated in the near future.

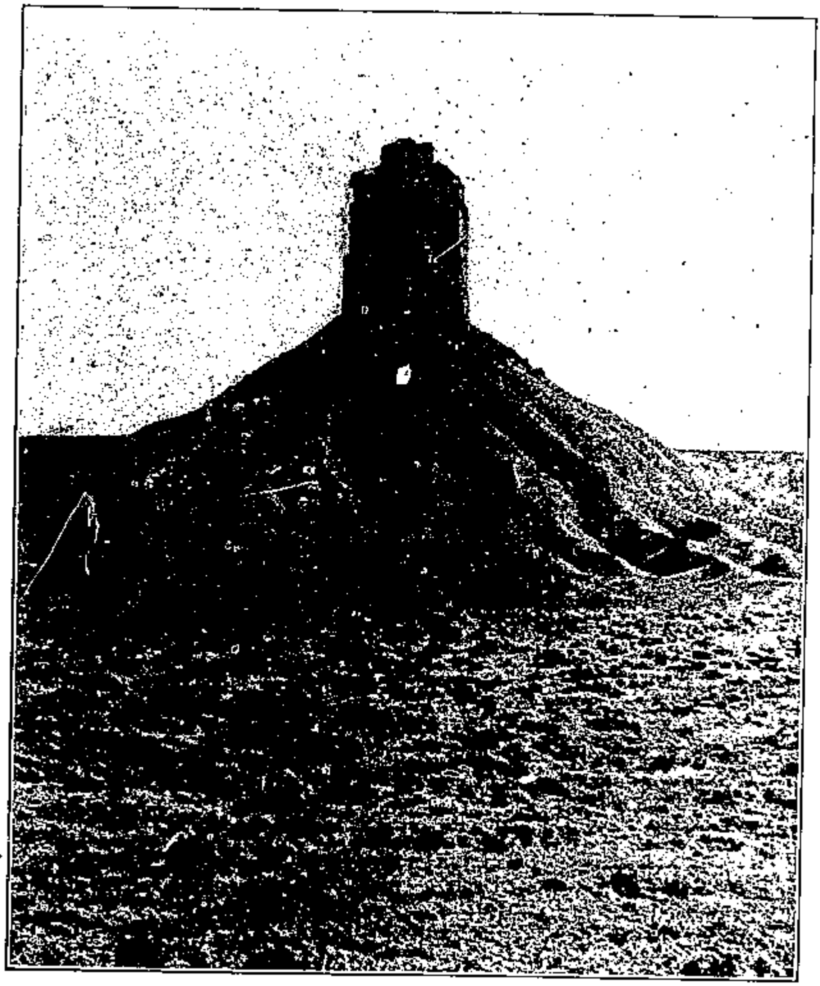

FIGURE 3.—*a*, Mesaverde formation; *b*, Mancos formation. The latter produces a more seleniferous soil.

## ARIZONA AND UTAH

The reconnaissance was continued through a large area of Upper Cretaceous outcrop north of Holbrook in Arizona and one in southern Utah. The geologic map does not show any differentiation of this area. There is also a very large area of exposure of Colorado shales extending in a generally westerly direction from the similar area in western Colorado already reported upon (*6*). These areas were traversed, and sufficient samples were collected to serve as a general index of the character and extent of the influence of the selenium present. A selection of the data so obtained is presented in table 3.

TABLE 3.—*Selenium content of soils and vegetation from Arizona and Utah*

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P. p. m.* | *P. p. m.* |
| B18231 | 2 | 39 miles north of Holbrook, Ariz. | Sandy loam, 0–4 inches (over lava). | Trace | |
| B18232 | 2a | do | *Astragalus* sp. | | 2 |
| B18234 | 4 | At bridge at Polacca, Ariz. | Salt incrustation, 0–6 inches | 1 | |
| B18235 | 5 | ½ mile west of Pinon | Alkali soil, 8–10 inches | .3 | |
| B18237 | 7 | 25 miles west of Pinon | Red sandy loam, 8–12 inches | .1 | |
| B18238 | 7a | do | *A. racemosus* | | 300 |
| B18219 | 2 | 2 miles south of Tropic, Utah | Shale | .3 | |
| B18220 | 3 | 3 miles south of Tropic | Carbonaceous shale | 12 | |
| B18221 | 4 | 3 miles north of Tropic | Clay loam, 0–6 inches | .5 | |
| B18222 | 5 | 1 mile north of Tropic | Salty clay, 0–6 inches | 1 | |
| B18223 | 6 | 1 mile west of Escalante, Utah | Sandy clay, 0–6 inches | .2 | |
| B18224 | 6a | do | *A. goniatus* | | 5 |
| B18226 | 8 | 5 miles west of Escalante | Gray shale | 1 | |
| B18227 | 9 | 14 miles west of Escalante | do | 1 | |
| B18271 | 11 | 2 miles south of Price, Utah | Shaly clay | 1 | |
| B18272 | 11a | do | *A. drummondii* | | 60 |
| B18279 | 16 | 2 miles east of State Road 10 (on road to Cleveland). | Clay, 0–6 inches | .8 | |
| B18280 | 16a | do | Prairie daisy | | 25 |
| B18289 | 23 | 2 miles northwest of Wellington, Utah. | Sandy loam, 0–6 inches | .3 | |
| B18290 | 23a | do | Alfalfa | | 100 |
| B18301 | 29a | 15 miles east of Wellington | *A. racemosus* | | 520 |
| B18303 | 31 | 25 miles east of Wellington | Clay loam, 0–6 inches | 2 | |
| B18304 | 31a | do | *Astragalus* sp. | | 270 |
| B18306 | 32 | 42 miles east of Wellington | Clay, 0–6 inches | 1 | |
| B18309 | 34x | 5 miles east of Green River | Shale | 8 | |

The data of table 3, together with unreported data, indicate a seleniferous area in northeastern Arizona. The very cursory investigation does not give any definite information as to its extent and intensity. Closer investigation does not seem warranted at present because of more pressing work elsewhere. Eventually this area may be very useful in tracing the primary sources of selenium. The same statement in general applies to the areas about Tropic and Escalante, Utah. Both these areas are of extremely rough topography, and the extent of actually toxic soil is probably very small.

The situation to the southwest and east of Price, Utah, is quite different as respects extent of area. A broad band of soil derived wholly or in part from the Mancos formation covers an irregular strip of territory probably aggregating 1,000 square miles and extends eastward to the Colorado line and continues over the area in western Colorado already reported upon (*6*). There are several reasons for deferring a closer investigation of this area to a more convenient season. Among these are the dearth of vegetation, at least in the early summer of 1936, over the greater portion and the relatively low concentration of selenium found in the samples examined. It is extremely likely that a study of the selenium content of this area may be useful in differentiating the subdivisions of the Mancos shales and in relating these to the corresponding shales in the Great Plains areas. Their detailed study will also contribute to a knowledge of the sources and means of distribution of selenium. It is the writers' opinion that while local spots may exist in which actively toxic vegetation grows or may grow, yet over the area in general such forage crops as are grown do not constitute a serious range problem. In those portions of the area which are irrigated no evidence is at hand to indicate probable serious injury from selenium. Closer study of the area might, however, materially alter these opinions.

Further data connected with the reconnaissance survey in Colorado is presented in another portion of this bulletin (p. 64.)

## SURVEY IN EASTERN COLORADO

It having been determined, through reconnaissance, that an extensive area of seleniferous soils exists in eastern Colorado, a more detailed study was undertaken. The area being so very large it was at once apparent that a close examination, such as that carried out in Lyman and Gregory Counties in South Dakota (*5*), was impracticable and even the less intensive examination, such as was followed in western Kansas (*6*), could not be followed if the whole area were to be examined in a single season. Only the areas indicated in figure 2 were examined. Samples were taken at intervals of approximately 3 miles, except where local conditions indicated that closer examination was desirable for particular purposes. In general a sample representative of the surface 8 inches of soil was collected along with a sample of vegetation growing in the soil. In addition to these a considerable number, one or more per county, of profile samples extending to or into the parent shales was taken. Occasionally all the types of vegetation found growing in the immediate vicinity of a soil sample were collected.

A consideration of the details of the area presented in figure 2 will show that almost the entire area from Fremont County on the west to the Kansas border is crossed by an irrigated belt along the Arkansas River. A considerable number of samples was taken in this area, in many cases in such locations as to permit comparison with similar samples adjacent to but not on the irrigated land. Also examination of figure 2 reveals the fact that in the area represented the outcropping geological formations range from those underlying the cretaceous formations up to and including formations overlying the youngest of the Cretaceous period.

In figure 4 is given a generalized section of these formations, in their sequence, and their correlation with formations elsewhere in areas known to be seleniferous. In general figure 2 shows that the outcrops are of increasing age from northwest to southeast but that a rather confusing irregularity of outcrops occurs in places due to various causes, among which are intrusion of igneous material and capping with outwash and loessial materials. In sampling the area the effort was made to cross section the area in such a manner that samples were secured outside the area of expected selenium occurrence on each side of the belts of outcropping of Pierre and Niobrara formations. In general the selected samples showed the results anticipated, but the unexpected occurrence of toxic areas the soils of which are derived from other formations somewhat distorted the orderly occurrence of successive belts of poisonous vegetation shown elsewhere, particularly in Kansas, and in the areas about the Black Hills (*6*). Intensive examinations are no longer essential, except for local

| AGE | | | CONVENTIONAL SECTIONS | WESTERN KANSAS | NORTHEASTERN NEW MEXICO | EASTERN COLORADO | WESTERN COLORADO NORTHWESTERN NEW MEXICO |
|---|---|---|---|---|---|---|---|
| QUATERNARY | | | | LOESS | | LOESS | |
| TERTIARY | | | | OGALLALA | | OGALLALA | |
| CRETACEOUS | UPPER CRETACEOUS | MONTANA GROUP | FOX HILLS | ABSENT | ABSENT | ABSENT | ABSENT |
| | | | PIERRE SHALES | ABSENT | VERMEJO SANDSTONE AND SHALE TRINIDAD SANDSTONE | TRINIDAD SANDSTONE | MESAVERDE GROUP SANDSTONE AND SHALES |
| | | | | PIERRE SHALES | PIERRE SHALES | PIERRE SHALES | |
| | | COLORADO GROUP | NIOBRARA | SMOKY HILL CHALKY SHALE | APISHAPA CHALKY SHALE | APISHAPA CHALKY SHALE | MANCOS SHALE |
| | | | | FORT HAYS LIMESTONE | TIMPAS LIMESTONE | TIMPAS LIMESTONE AND SHALE | |
| | | | BENTON GROUP | CARLILE SHALE | CARLILE SHALE | CARLILE SHALE | |
| | | | | GREENHORN LIMESTONE | GREENHORN LIMESTONE | GREENHORN LIMESTONE | |
| | | | | GRANEROS SHALE | GRANEROS SHALE | GRANEROS SHALE | |
| | LOWER CRETACEOUS | | | DAKOTA SANDSTONE | DAKOTA SANDSTONE | DAKOTA SANDSTONE | DAKOTA SANDSTONE |
| | | | | PURGATOIRE | PURGATOIRE | PURGATOIRE | PURGATOIRE |
| CRETACEOUS ? | | | | MORRISON | MORRISON | MORRISON | MORRISON |
| UPPER JURASSIC | | | | | NAVAJO | LYKINS | |

FIGURE 4.—Generalized geologic relations for the areas examined.

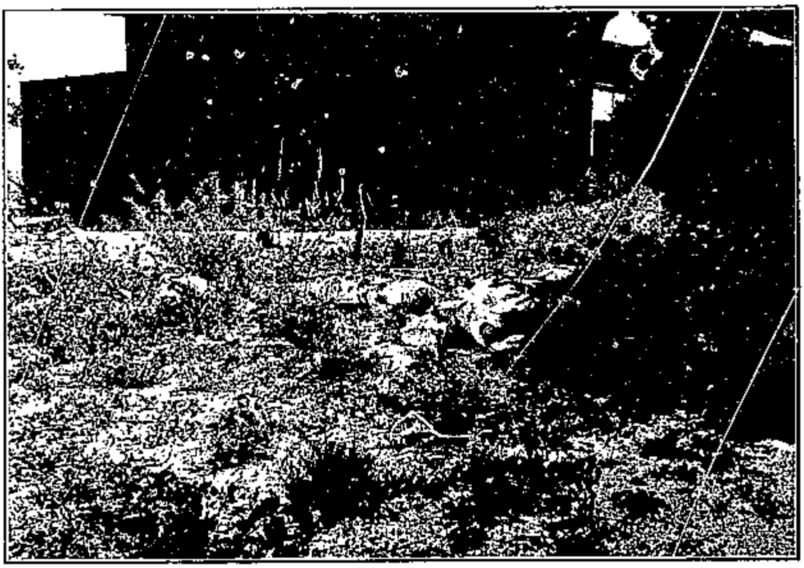

FIGURE 5.—An abandoned farmhouse with *Stanleya* in the foreground. S¼ corner sec. 22, T. 23 S., R. 64 W., Pueblo County, Colo.

reasons, because the general relations have become sufficiently well recognized to warrant general conclusions from less detailed data.

It became evident rather early in the course of the work that in southeastern Colorado, at least in the 1936 growing season, cultivated crops outside the irrigated area could not be secured which would offer a fair representation of the variations within the area. The native grasses are in general so low in selenium content that variations shown by them would also fail to present the situation in proper perspective. In general then the plants collected were those already known or found to be particularly prone to selenium absorption when it is available. In the Colorado area those most frequently found are *Astragalus racemosus*, *A. bisulcatus*, *A. pectinatus*, *Stanleya pinnata* (fig. 5), and *Aplopappus fremontii*. Numerous other plants, however, were examined, and in the tables of data the names of these plants employed are the common names where available, and to facilitate comparison and identification, by the reader, with like data from other publications, the botanical terms and common names are brought together in the following tabulation.

| *Botanical name* | *Common name* |
|---|---|
| *Agropyron pseudorepens* | Seepgrass. |
| *A. smithii* | Western wheatgrass. |
| *Agrostis hiemalis* | Tickle grass. |
| *Allium cepa* | Onion. |
| *Amaranthus blitoides* | Prostrate pigweed. |
| *Ambrosia elatior* (*A. artemisiaefolia*) | Common ragweed. |
| *Anthemis cotula* | Dogfennel. |
| *Aplopappus fremontii* | Goldenweed. |
| *A. spinulosus* | |
| *Aristida longiseta* | Red three-awn. |
| *Artemisia frigida* | Sagebrush. |
| *Asclepias galioides* | Poison milkweed. |
| *A. speciosa* | Milkweed. |
| *Asparagus officinalis* | Asparagus. |
| *Aster ericoides* (*A. multiflorus*) | Wreath aster. |
| *A. fendleri* | Aster. |
| *A. Parryi* | Woody aster. |
| *Astragalus bisulcatus* | Two-groove poisonvetch. |
| *A. carolinianus* | |
| *A. Drummondii* | Drummond milkvetch. |
| *A. flexuosus* | |
| *A. goniatus* | |
| *A. missouriensis* | |
| *A. mollissimus* | Woolly loco. |
| *A. pectinatus* | Narrowleaf milkvetch. |
| *A. racemosus* | |
| *Beta vulgaris* | Sugar beet. |
| *Bidens bipinnata* | Spanish-needles. |
| *Bouteloua curtipendula* | Side-oats grama. |
| *B. gracilis* | Blue grama. |
| *Brassica* sp | Wild mustard. |
| *Cannabis sativa* | Wild hemp. |
| *Chenopodium* sp | Lambsquarters. |
| *Chrysopsis villosa* | Golden-aster. |
| *Delphinium* sp | Larkspur. |
| *Distichlis stricta* | Desert saltgrass. |
| *Dyssodia papposa* | Stinkweed. |
| *Elymus* sp | Wild-rye. |

| *Botanical name* | *Common name* |
|---|---|
| *Erigeron* sp | Fleabane. |
| *Euphrobia* sp | Spurge. |
| *Glycyrrhiza lepidota* | Wild licorice. |
| *Grindelia squarrosa* | Gumweed. |
| *Gutierrezia sarothrae* | Turpentineweed. |
| *Hedeoma* sp | Pennyroyal. |
| *Helianthus annuus* | Sunflower. |
| *Hilaria jamesii* | Galleta grass. |
| *Hordeum vulgare* | Barley. |
| *Iva axillaris* | Povertyweed. |
| *Lepidium* sp | Peppergrass. |
| *Lupinus argenteus* | Lupine. |
| *L. pusillus* | Do. |
| *Lygodesmia juncea* | Skeletonweed. |
| *Malva* sp | Mallow. |
| *Malvastrum coccineum* | Scarlet mallow. |
| *Medicago hispida* | Burr clover. |
| *M. sativa* | Alfalfa. |
| *Melilotus alba* | Sweetclover. |
| *Mentzelia decapetala* | Stickleaf. |
| *Munroa squarrosa* | False buffalo grass. |
| *Oreocarya* sp | |
| *Parosela jamesii* | |
| *Pentstemon* sp | Pentstemon. |
| *Phaseolus vulgaris* | Garden bean. |
| *Physalis lanceolata* | Groundcherry. |
| *Psoralea tenuiflora* | Scurf-pea. |
| *Salsola pestifer* | Russian-thistle. |
| *Senecio riddellii* | Groundsel. |
| *Senecio* sp | |
| *Setaria italica* | Foxtail millet. |
| *Sophora sericea* | Silky sophora. |
| *Sorghum vulgare caffrorum* | Kafir. |
| *S. vulgare sudanense* | Sudan grass. |
| *Stanleya pinnata* and *S. bipinnata* | Stanleya. |
| *Stipa robusta* | Sleepy grass. |
| *Tetradymia glabrata* | Coal-oil brush. |
| *Townsendia grandiflora* | |
| *Trifolium pratense* | Red clover. |
| *Triticum aestivum* | Wheat. |
| *Xanthium* sp | Cocklebur. |

All the plants named have been collected and analyzed, but in some cases the data obtained do not appear in the tables because no significant amounts of selenium were found. In the Colorado area approximately 900 samples of soils and shales and 800 samples of vegetation were examined. In view of the fact that data have been given in full (*6*) for all soils, shales, and plants examined and that exactly the same variations are observed in Colorado, the attempt is made here to present an adequate picture of the situation by means of selected data, the total number of samples reported being about 400. For convenience of examination and for ready reference the data reported in table 4 are presented by counties, and the discussion of general relations is followed by discussion of certain special items and data referring to them in particular. Table 4 includes only samples not from irrigated areas. Samples from irrigated areas are reported separately (table 5).

TABLE 4.—*Selenium content of soils, shales, and vegetation from southeastern Colorado*

PROWERS COUNTY

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P. p. m.* | *P. p. m.* |
| B18400 | 1 | SE¼ sec. 17, T. 23 S., R. 41 W. | Niobrara[1] clay loam, 0-8 inches | 1 | |
| B18401 | 1a | do. | *Astragalus racemosus* | | 210 |
| B18413 | 8 | 200 feet north of E¼ corner sec. 19, T. 21 S., R. 41 W. | Niobrara[1] clay loam, 0-8 inches | 5 | |
| B18414 | 8a | do. | Narrowleaf milkvetch | | 2,110 |
| B18432 | 18 | 150 feet south of E¼ corner sec. 14, T. 21 S., R. 43 W. | Niobrara[1] silt loam, 0-8 inches | 2 | |
| B18433 | 18a | do. | Narrowleaf milkvetch | | 490 |
| B18438 | 21 | East side sec. 13, T. 24 S., R. 44 W. | Silt loam, 0-8 inches | .8 | |
| B18439 | 21a | do. | Narrowleaf milkvetch | | 90 |
| B18442 | 23x | 80 rods east of center sec. 13, T. 23 S., R. 44 W. | Timpas[1] limestone | .2 | |
| B18444 | 24 | 80 rods south of center sec. 1, T. 23 S., R. 44 W. | Alluvial silt loam, 0-8 inches | .8 | |
| B18445 | 24a | do. | Wreath aster | | 18 |
| B18460 | 31 | NW corner sec. 19, T. 23 S., R. 44 W. | Silt loam, 0-8 inches | 1 | |
| B18461 | 31a | do. | Narrowleaf milkvetch | | 2,070 |
| B18467 | 34 | 300 feet north of E¼ corner sec. 25, T. 21 S., R. 45 W. | Silt loam, 0-8 inches | 3 | |
| B18468 | 34a | do. | Narrowleaf milkvetch | | 610 |
| B18544 | 43 | 80 rods west of SE corner sec. 7, T. 22 S., R. 46 W. | Clay loam, 0-8 inches | 1.5 | |
| B18545 | 43a | do. | *A. racemosus* | | 130 |
| B18546 | 43b | do. | Wreath aster (2 feet from soil) | | 6 |
| B18547 | 43c | do. | Scarlet mallow | | 4 |

KIOWA COUNTY

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| B18500 | 1 | 200 feet north of SE corner sec. 32, T. 20 S., R. 42 W. | Silt loam, 0-8 inches | .6 | |
| B18501 | 1a | do. | Narrowleaf milkvetch | | 390 |
| B18512 | 7 | 80 rods south of NW corner sec. 26, T. 20 S., R. 45 W. | Silt loam, 0-8 inches | 1 | |
| B18513 | 7a | do. | Narrowleaf milkvetch | | 970 |
| B18518 | 10 | Center sec. 3, T. 19 S., R. 45 W. | Sandy loam, 0-8 inches | 3 | |
| B18519 | 10a | do. | Narrowleaf milkvetch | | 2,670 |
| B18595 | 15 | 500 feet south of center sec. 30, T. 20 S., R. 47 W. | Silt loam, 0-8 inches | 1.5 | |
| B18596 | 15a | do. | Narrowleaf milkvetch | | 1,160 |
| B18605 | 21 | 70 rods north of SW corner sec. 18, T. 20 S., R. 46 W. | Silt loam, 0-8 inches | 5 | |
| B18606 | 21a | do. | Narrowleaf milkvetch | | 210 |
| B18708 | 25 | 150 feet north of SW corner sec. 9, T. 20 S., R. 48 W. | Clay loam, 0-8 inches | .7 | |
| B18709 | 25a | do. | Narrowleaf milkvetch | | 160 |
| B18710 | 26 | 80 rods south of center sec. 28, T. 19 S., R. 48 W. | Clay loam, 0-8 inches | .7 | |
| B18711 | 26a | do. | Woolly loco | | 1 |
| B18726 | 32 | 500 feet north of E¼ corner sec. 15, T. 11 S., R. 49 W. | Ogallala[1] clay loam, 0-8 inches | .5 | |
| B18727 | 32a | do. | Woolly loco | | 2 |
| B18776 | 35 | 500 feet south of NW corner sec. 7, T. 19 S., R. 51 W. | Niobrara[1] silt loam, 0-8 inches | 2.5 | |
| B18777 | 35a | do. | Stanleya | | 140 |
| B18785 | 40 | 100 feet east of NW corner sec. 20, T. 19 S., R. 52 W. | Clay loam, 0-8 inches | 16 | |
| B18786 | 40a | do. | Narrowleaf milkvetch | | 2,680 |
| B18787 | 41 | 80 rods south of NE corner sec. 3, T. 19 S., R. 52 W. | Niobrara[1] clay loam, 0-8 inches | 3 | |
| B18788 | 41a | 80 rods south of NE corner sec. 3, T. 19 S., R. 52 W. | Stanleya | | 140 |
| B18789 | 41b | do. | Goldenweed | | 420 |
| B18807 | 50 | 80 rods north of SW corner sec. 21, T. 19 S., R. 53 W. | Niobrara[1] silt loam, 0-8 inches | 2.5 | |
| B18808 | 50a | do. | Stanleya | | 180 |
| B19526 | 63 | 80 rods south of NW corner sec. 6, T. 19 S., R. 51 W. | Niobrara[1] clay loam, 0-6 inches | 2 | |
| B19531 | 63a | | Blue grama | | 2 |
| B19532 | 63b | | Russian-thistle | | 5 |
| B19536 | 63f | | Corn | | 10 |
| B19537 | 63g | | Stanleya | | 330 |

[1] Geologic formation.

TABLE 4.—*Selenium content of soils, shales, and vegetation from southeastern Colorado*—Continued

CHEYENNE COUNTY

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P. p. m.* | *P. p. m.* |
| B18490 | 1 | E ¼ corner sec. 22, T. 16 S., R. 45 W. | Ogallala[1] clay loam, 0-8 inches | 0.5 | |
| B18491 | 1a | do | Russian-thistle | | 2 |
| B18498 | 3 | NW corner sec. 4, T. 14 S., R. 45 W. | Loessial silt loam, 0-8 inches | .4 | |
| B18499 | 3a | do | Russian-thistle | | 3 |
| B18616 | 5 | 20 rods south of NW corner sec. 9, T. 15 S., R. 48 W. | Pierre clay loam, 0-8 inches | .5 | |
| B18617 | 5a | do | Narrowleaf milkvetch | | 220 |
| B18620 | 7 | 20 rods south of NE corner sec. 8, T. 14 S., R. 48 W. | Pierre and Ogallala sandy loam, 0-8 inches | 1.5 | |
| B18621 | 7a | do | Narrowleaf milkvetch | | 540 |
| B18622 | 8 | 1,000 feet north of E¼ corner sec. 20, T. 13 S., R. 48 W. | Pierre clay loam, 0-8 inches | .7 | |
| B18623 | 8a | do | Alfalfa | | 5 |
| B18631 | 14 | 200 feet south of NW corner sec. 8, T. 15 S., R. 46 W. | Silt loam, 0-8 inches | 2 | |
| B18632 | 14a | do | Narrowleaf milkvetch | | 790 |
| B18633 | 15 | 80 rods south of NW corner sec. 29, T. 14 S., R. 46 W. | Clay loam, 0-8 inches | 1.5 | |
| B18634 | 15a | do | Narrowleaf milkvetch | | 3,890 |
| B18647 | 21 | NW corner sec. 22, T. 15 S., R. 47 W. | Silt loam, 0-8 inches | 1 | |
| B18648 | 21a | do | Narrowleaf milkvetch | | 1,150 |
| B18649 | 21b | do | Alfalfa | | 7 |
| B18654 | 24 | 200 feet south of NE corner sec. 7, T. 13 S., R. 47 W. | Clay loam, 0-8 inches | 5 | |
| B18655 | 24a | do | *A. racemosus* | | 690 |
| B19233 | 27 | NE corner sec. 29, T. 13 S., R. 47 W. | Pierre clay loam, 0-8 inches | 3 | |
| B19234 | 27a | do | Goldenweed | | 70 |
| B19239 | 30 | 80 rods north of SE corner sec. 33, T. 13 S., R. 50 W. | Pierre clay, 0-8 inches | .5 | |
| B19240 | 30a | do | *A. racemosus* | | .7 |
| B19241 | 31 | SE corner sec. 33, T. 12 S., R. 50 W. | Pierre clay loam, 0-8 inches | .7 | |
| B19242 | 31a | do | *A. racemosus* | | 160 |
| B19251 | 36 | 500 feet north of SE corner sec. 8, T. 14 S., R. 49 W. | Sandy loam, 0-8 inches | .3 | |
| B19252 | 36a | do | Narrowleaf milkvetch | | 1,390 |
| B19253 | 37 | Sec. 33, T. 14 S., R. 49 W. | Clay loam, 0-8 inches | .4 | |
| B19254 | 37a | do | Western wheatgrass | | 1 |
| B19255 | 37b | Sec. 33, T. 14 S., R. 49 W. (4 feet from no. 37). | Narrowleaf milkvetch | | 780 |

BENT COUNTY

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| B18660 | 1 | 300 feet south of N¼ corner sec. 1, T. 23 S., R. 48 W. | Loamy sand, 0-8 inches | 0.3 | |
| B18661 | 1a | do | Narrowleaf milkvetch | | 330 |
| B18673 | 7 | 200 feet north of E¼ corner sec. 35, T. 21 S., R. 48 W. | Clay loam, 0-8 inches | 2 | |
| B18674 | 7a | do | Narrowleaf milkvetch | | 125 |
| B18675 | 7b | do | Wreath aster | | 100 |
| B18680 | 9 | 80 rods south of NE corner sec. 10, T. 23 S., R. 49 W. | Las Animas clay loam, 0-8 inches | 1 | |
| B18681 | 9a | do | *A. racemosus* | | 120 |
| B18689 | 13 | S¼ corner sec. 10, T. 21 S., R. 49 W. | Niobrara[1] clay alluvium, 0-8 inches | 1.5 | |
| B18690 | 13a | do | *A. racemosus* | | 640 |
| B18693 | 15 | N¼ corner sec. 25, T. 21 S., R. 50 W. | Clay loam, 0-8 inches | .7 | |
| B18694 | 15a | do | Narrowleaf milkvetch | | 400 |
| B18699 | 17 | 1,000 feet south of NE corner sec. 25, T. 22 S., R. 50 W. | Niobrara[1] clay loam, 0-8 inches | 1 | |
| B18700 | 17a | do | Wreath aster | | 70 |
| B18738 | 23 | 300 feet south of NW corner sec. 21, T. 23 S., R. 51 W. | Ogallala[1] silt loam, 0-8 inches | .7 | |
| B18739 | 23a | do | Narrowleaf milkvetch | | 35 |
| B18740 | 23b | do | Woolly loco | | 4 |

[1] Geologic formation.

TABLE 4.—*Selenium content of soils, shales, and vegetation from southeastern Colorado*—Continued

BENT COUNTY—Continued

| Laboratory no. | Field no. | Location | Material | Selenium in— | |
|---|---|---|---|---|---|
| | | | | Soil or shale | Vegetation |
| | | | | *P. p. m.* | *P. p. m.* |
| B18742 | 24 | NW corner sec. 1, T. 24 S., R. 52 W. | Sandy loam, 0-8 inches | .7 | |
| B18743 | 24a | do | Narrowleaf milkvetch | | 790 |
| B18750 | 28 | 1,000 feet south of NW corner sec. 19, T. 24 S., R. 52 W. | Silt loam, 0-8 inches | .7 | |
| B18751 | 28a | do | Woolly loco | | 2 |
| B18754 | 30 | 1,000 feet south of NW corner sec. 2, T. 21 S., R. 52 W. | Niobrara[1] silt loam, 0-8 inches | 3.5 | |
| B18755 | 30a | do | Narrowleaf milkvetch | | 1,390 |
| B18756 | 31 | N¼ corner sec. 3, T. 21 S., R. 52 W. | Gray clay loam, 0-8 inches | | |
| B18757 | 31a | do | *A. racemosus* | | 1,630 |
| B18762 | 34 | W¼ corner sec. 6, T. 24 S., R. 53 W. | Niobrara[1] clay loam, 0-8 inches | 2 | |
| B18763 | 34a | do | Stanleya | | 90 |
| B18764 | 34b | W¼ corner sec. 6, T. 24 S., R. 53 W. (50 feet from no. 34). | Goldenweed | | 40 |
| B18813 | 40 | SW¼ corner sec. 20, T. 21 S., R. 53 W. | Niobrara[1] clay loam, 0-8 inches | 2.5 | |
| B18814 | 40a | do | Goldenweed | | 240 |
| B18815 | 40b | SW¼ corner sec. 20, T. 21 S., R. 53 W. (50 feet from no. 34). | Narrowleaf milkvetch | | 720 |
| **OTERO COUNTY** | | | | | |
| B18951 | 1 | SW corner sec. 13, T. 20 S., R. 54 W. | Clay loam alluvium, 0-8 inches. | 2 | |
| B18952 | 1a | do | Poison milkweed | | 4 |
| B18956 | 4 | 300 feet east of NW corner sec. 14, T. 25 S., R. 54 W. | Clay loam, 0-8 inches | 1.5 | |
| B18957 | 4a | do | Stanleya | | 80 |
| B18967 | 9 | 1,000 feet south of NW corner sec. 33, T. 22 S., R. 54 W. | Otero sandy loam, 0-8 inches | 5 | |
| B18968 | 9a | do | Narrowleaf milkvetch | | 1,980 |
| B18975 | 12 | E¼ corner sec. 32, T. 21 S., R. 54 W. | Clay loam, 0-8 inches | 5 | |
| B18976 | 12a | do | Narrowleaf milkvetch | | 1,540 |
| B18983 | 16 | 80 rods north of SW corner sec. 14, T. 25 S., R. 56 W. | Silt loam, 0-8 inches (lower Timpas[1] limestone). | .5 | |
| B18984 | 16a | do | Turpentineweed | | 1 |
| B18994 | 21 | NW corner sec. 12, T. 23 S., R. 55 W. | Niobrara[1] silt loam | 2.5 | |
| B18995 | 21a | do | Narrowleaf milkvetch | | 2,270 |
| B19004 | 26 | 80 rods north of SE corner sec. 21, T. 26 S., R. 56 W. | Benton[1] clay loam, 0-8 inches | .8 | |
| B19005 | 26a | do | Goldenweed | | 280 |
| B19010 | 29 | W¼ corner sec. 2, T. 25 S., R. 56 W. | Benton[1] silt loam, 0-8 inches | .5 | |
| B19011 | 29a | do | Goldenweed | | 18 |
| B19043 | 40 | N¼ corner sec. 34, T. 25 S., R. 57 W. | Clay loam, 0-8 inches | 1 | |
| B19044 | 40a | do | Goldenweed | | 35 |
| B19107 | 53 | 200 feet south of NE corner sec. 27, T. 25 S., R. 58 W. | Silt loam, 0-8 inches | .4 | |
| B19108 | 53a | do | Stanleya | | 180 |
| B19113 | 56 | 1,000 feet south of E¼ corner sec. 25, T. 26 S., R. 58 W. | Benton[1] clay loam, 0-8 inches | .3 | |
| B19114 | 56a | do | Russian-thistle | | 1 |
| B19126 | 61 | SW¼ sec. 23, T. 27 S., R. 59 W. | Greenhorn[1] silt loam, 0-8 inches. | 1.5 | |
| B19127 | 61a | do | Stanleya | | 250 |
| B19138 | 64 | E¼ corner sec. 36, T. 26 S., R. 59 W. | Timpas[1] clay loam, 0-8 inches | .8 | |
| B19139 | 64a | do | Goldenweed | | 10 |
| B19152 | 71 | E¼ corner sec. 24, T. 23 S., R. 59 W. | Clay loam, 0-8 inches | 3 | |
| B19153 | 71a | do | Stanleya | | 1,280 |
| B19109A | 70 | Center sec. 6, T. 26 S., R. 54 W. | Greenhorn[1] silt loam | .5 | |
| B19109B | 70b | do | Goldenweed | | 40 |

[1] Geologic formation.

TABLE 4.—*Selenium content of soils, shales, and vegetation from southeastern Colorado*—Continued

CROWLEY COUNTY

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P. p. m.* | *P. p. m.* |
| B19256 | 1 | 80 rods north of SW corner sec. 22, T. 21 S., R. 55 W. | Clay loam, 0–8 inches | 2.5 | |
| B19257 | 1a | do | Narrowleaf milkvetch | | 570 |
| B19260 | 3 | 500 feet north of SW corner sec. 16, T. 20 S., R. 55 W. | Clay loam, 0–8 inches | 3.5 | |
| B19261 | 3a | do | Goldenweed | | 760 |
| B19273 | 9 | NW corner sec. 34, T. 21 S., R. 56 W. | Niobrara [1] clay loam | 1.6 | |
| B19274 | 9a | do | *A. racemosus* | | 40 |
| B19281 | 12 | NE corner sec. 20, T. 20 S., R. 56 W. | Pierre clay | 12 | |
| B19282 | 12a | do | Goldenweed | | 180 |
| B19291 | 17 | 80 rods north of SE corner sec. 26, T. 21 S., R. 57 W. | Clay loam, 0–8 inches (terrace phase). | 2 | |
| B19292 | 17a | do | Poison milkweed | | 7 |
| B19299 | 20 | SW corner sec. 16, T. 20 S., R. 57 W. | Clay loam, 0–8 inches | 2.5 | |
| B19300 | 20a | do | Silky sophora | | 1 |
| B19303 | 22 | SE corner sec. 7, T. 19 S., R. 57 W. | Pierre clay loam, 0–8 inches | .7 | |
| B19304 | 22a | do | *A. racemosus* | | 280 |
| B19305 | 23 | 1,000 feet west of NE corner sec. 30, T. 18 S., R. 57 W. | Pierre clay loam, 0–8 inches | 2 | |
| B19306 | 23a | do | *A. racemosus* | | 230 |
| B19309 | 25 | 500 feet south of E¼ corner sec. 14, T. 21 S., R. 58 W. | Clay loam, 0–8 inches | 1.5 | |
| B19310 | 25a | do | Goldenweed | | 35 |
| B19311 | 26 | Center sec. 4, T. 20 S., R. 58 W. | Clay shale, 0–8 inches | 1 | |
| B19312 | 26a | do | *A. racemosus* | | 140 |
| B19313 | 27 | 1,000 feet north of SW corner sec. 9, T. 18 S., R. 58 W. | Clay loam, 0–6 inches | .4 | |
| B19314 | 27 | do | Shaly clay loam, 0–12 inches | .6 | |
| B19315 | 27 | do | Black shale | .4 | |
| B19316 | 27a | do | *A. racemosus* | | 80 |
| B19317 | 27b | do | Russian-thistle | | 0 |

LINCOLN COUNTY

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| B19319 | 1 | 80 rods north of SE corner sec. 29, T. 17 S., R. 55 W. | Pierre clay loam, 0–8 inches | 0.4 | |
| B19320 | 1a | do | Cocklebur | | 1 |
| B19327 | 5 | 500 feet south of NW corner sec. 29, T. 16 S., R. 56 W. | Pierre clay loam, 0–8 inches | 3.0 | |
| B19328 | 5a | do | *A. racemosus* | | 40 |
| B19331 | 7 | N¼ corner sec. 19, T. 15 S., R. 56 W. | Sandy loam, 0–8 inches | 10 | |
| B19332 | 7a | do | Narrowleaf milkvetch | | 1,340 |
| B19335 | 9 | 500 feet south of NE corner sec. 31, T. 14 S., R. 56 W. | Ogallala [1] sandy loam, 0–8 inches | .5 | |
| B19336 | 9a | do | Russian-thistle | | 0 |
| B19341 | 12 | 80 rods north of SW corner sec. 18, T. 17 S., R. 54 W. | Ogallala [1] sandy loam, 0–8 inches | .3 | |
| B19342 | 12a | do | Woolly loco | | 1 |
| B19345 | 14 | 500 feet north of W¼ corner sec. 31, T. 15 S., R. 54. | Pierre clay loam, 0–8 inches | 1 | |
| B19346 | 14a | do | *A. racemosus* | | 30 |
| B19352 | 17 | W¼ corner sec. 31, T. 10 S., R. 54 W. | Pierre clay loam, 0–8 inches | 1 | |
| B19353 | 17a | do | Two-groove poisonvetch | | 45 |
| B19354 | 18 | NW corner sec. 21, T. 10 S., R. 54 W. | Pierre clay loam, 0–8 inches | 10 | |
| B19355 | 18a | do | Narrowleaf milkvetch | | 820 |
| B19360 | 21 | SW corner sec. 14, T. 10 S., R. 53 W. | Ogallala [1] clay loam, 0–8 inches | .7 | |
| B19361 | 21a | do | Two-groove poisonvetch | | 10 |
| B19369 | 23 | 500 feet north of E¼ corner sec. 24, T. 11 S., R. 53 W. | Pierre clay loam, 0–8 inches | 2 | |
| B19370 | 23a | do | Two-groove poisonvetch | | 45 |
| B19379 | 28 | 80 rods east of SW corner sec. 24, T. 13 S., R. 53 W. | Pierre clay loam, 0–8 inches | .7 | |
| B19380 | 28a | do | Goldenweed | | 200 |

[1] Geologic formation.

TABLE 4.—*Selenium content of soils, shales, and vegetation from southeastern Colorado*—Continued

LINCOLN COUNTY—Continued

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P. p. m.* | *P. p. m.* |
| B19385 | 31 | 500 feet east of NW corner sec. 34, T. 12 S., R. 52 W. | Pierre clay loam, 0-8 inches | .4 | |
| B19386 | 31a | do | Narrowleaf milkvetch | | 1,380 |
| B19412 | 34 | NE corner sec. 32, T. 17 S., R. 52 W. | Ogallala[1] clay loam, 0-8 inches | .4 | |
| B19413 | 34a | do | Gumweed | | 10 |
| B19414 | 34b | do | Turpentineweed | | 2 |

LAS ANIMAS COUNTY

| Laboratory no. | Field no. | Location | Material | Soil or shale | Vegetation |
|---|---|---|---|---|---|
| B19420 | 3 | NE corner sec. 2, T. 29 S., R. 60 W. | Benton[1] clay loam, 0-8 inches | 1 | |
| B19421 | 3a | do | Goldenweed | | 6 |
| B19424 | 5 | NW corner sec. 36, T. 29 S., R. 61 W. | Timpas[1] loam, 0-8 inches | .4 | |
| B19425 | 5a | do | Russian-thistle | | 1 |
| B19432 | 9 | SW¼ sec. 12, T. 30 S., R. 62 W. | Silt loam, 0-8 inches | 1.5 | |
| B19433 | 9a | do | Narrowleaf milkvetch | | 290 |
| B19446 | 13 | SW¼ sec. 31, T. 33 S., R. 61 W. | Benton[1] loam, 0-8 inches | 6 | |
| B19447 | 13a | do | *A. racemosus* | | 50 |
| B19448 | 13b | SW¼ sec. 31, T. 33 S., R. 61 W. (15 feet from no. 13). | Stanleya | | 470 |
| B19457 | 17 | NW corner sec. 24, T. 31 S., R. 61 W. | Niobrara[1] silt loam, 0-8 inches | .5 | |
| B19458 | 17a | do | Gumweed | | 12 |
| B19805 | 21 | 80 rods south of NW corner sec. 15, T. 27 S., R. 63 W. | Greenhorn[1] clay loam, 0-8 inches. | .4 | |
| B19806 | 21a | do | Stanleya | | 180 |
| B20046 | 31 | Center sec. 12, T. 32 S., R. 64 W. | Pierre gravelly clay loam, 0-8 inches. | 3.5 | |
| B20047 | 31a | do | Goldenweed | | 130 |
| B20054 | 36 | W¼ corner sec. 16, T. 32 S., R. 63 W. | Pierre shaly clay loam, 0-8 inches. | 1.5 | |
| B20055 | 36a | do | Two-groove poisonvetch | | 25 |
| B20058 | 38 | SW corner sec. 4, T. 31 S., R. 63 W. | Pierre clay, 0-8 inches | 2.5 | |
| B20059 | 38a | do | Two-groove poisonvetch | | 8 |
| B20068 | 43 | SW corner sec. 18, T. 30 S., R. 63 W. | Pierre clay loam, 0-8 inches | 1 | |
| B20069 | 43a | do | Stanleya | | 390 |
| B20083 | 50 | SW corner sec. 10, T. 28 S., R. 63 W. | Greenhorn[1] clay loam, 0-8 inches. | .8 | |
| B20084 | 50a | do | Goldenweed | | 60 |
| B20090 | 53 | 80 rods south of N¼ corner sec. 34, T. 31 S., R. 59 W. | Greenhorn[1] clay loam, 0-8 inches. | 3 | |
| B20091 | 53a | do | Two-groove poisonvetch | | 170 |
| B20222 | 55 | SW corner sec. 20, T. 33 S., R. 62 W. | Pierre clay, 0-8 inches | .5 | |
| B20223 | 55a | do | *A. racemosus* | | 60 |

HUERFANO COUNTY

| Laboratory no. | Field no. | Location | Material | Soil or shale | Vegetation |
|---|---|---|---|---|---|
| B19815 | 1 | SW¼ sec. 13, T. 25 S., R. 67. W. | Silt loam, 0-8 inches | 0.5 | |
| B19816 | 1a | do | Gumweed | | 5 |
| B19817 | 2 | E¼ corner sec. 7, T. 26 S., R. 66 W. | Niobrara[1] clay loam (Apishapa). | 1 | |
| B19818 | 2a | do | Goldenweed | | 70 |
| B19819 | 3 | NE corner sec. 4, T. 26 S. | Silt loam, 0-8 inches | .5 | |
| B19820 | 3a | do | Corn (ears) | | 4 |
| B19821 | 3b | do | Gumweed | | 2 |
| B19826 | 6 | NE¼ sec. 35, T. 26 S., R. 65 W. | Greenhorn[1] silt loam, 0-8 inches. | .6 | |
| B19827 | 6a | do | Goldenweed | | 50 |
| B19832 | 9 | SW¼ of NW¼ sec. 27, T. 25 S., R. 66 W. | Niobrara[1] silt loam, 0-8 inches (Apishapa). | 3 | |
| B19833 | 9a | do | Woody aster | | 1,750 |
| B19834 | 9b | do | Lambsquarters | | 890 |

[1] Geologic formation.

TABLE 4.—*Selenium content of soils, shales, and vegetation from southeastern Colorado*—Continued

HUERFANO COUNTY—Continued

| Laboratory no. | Field no. | Location | Material | Selenium in— | |
|---|---|---|---|---|---|
| | | | | Soil or shale | Vegetation |
| | | | | *P. p. m.* | *P. p. m.* |
| B19835 | 10 | SW¼ of NW¼ sec. 27, T. 25 S., R. 69 W. (40 rods north of no. 9). | Niobrara[1] silt loam, 0–8 inches (Apishapa). | 5 | |
| B19836 | 10a | do | *A. racemosus* | | 680 |
| B19837 | 11 | S¼ corner sec. 34, T. 26 S., R. 68 W. | Niobrara[1] clay loam, 0–8 inches | 10 | |
| B19838 | 11a | do | Goldenweed | | 240 |
| B19839 | 11b | do | Russian-thistle | | 2 |
| B19840 | 12 | SE¼ sec. 40, T. 28 S., R. 67 W | Pierre shaly clay, 0–8 inches | .7 | |
| B19841 | 12a | do | Goldenweed | | 3 |
| B19845 | 14 | NE¼ sec. 20, T. 26 S., R. 66. W. | Pierre clay, 0–8 inches | .7 | |
| B19846 | 14a | do | Goldenweed | | 20 |
| B19850 | 16 | N¼ corner sec. 10, T. 29 S., R. 65 W. | Alluvial clay loam, 0–8 inches | 2 | |
| B19851 | 16a | do | Goldenweed | | 10 |
| B19854 | 18 | NE¼ sec. 32, T. 28 S., R. 65 W | Mesaverde sandy loam, 0–8 inches. | .8 | |
| B19855 | 18a | do | *A. racemosus* | | 35 |
| **PUEBLO COUNTY** | | | | | |
| B19571 | 1 | 80 rods east of NW corner sec. 5, T. 22 S., R. 60 W. | Pierre stony clay, 0–8 inches | 4 | |
| B19572 | 1a | do | Russian-thistle | | 3 |
| B19578 | 4 | SW corner sec. 29, T. 23 S., R. 60 W. | Very fine sandy loam, 0–8 inches. | .5 | |
| B19579 | 4a | do | Goldenweed | | 130 |
| B19587 | 8 | NW corner sec. 33, T. 25 S., R. 60 W. | Benton[1] clay loam, 0–8 inches | .3 | |
| B19588 | 8a | do | Sunflower (heads) | | 1 |
| B19595 | 12 | NE corner sec. 18, T. 22 S., R. 61 W. | Niobrara[1] clay loam, 0–8 inches | .5 | |
| B19596 | 12a | do | Russian-thistle | | 35 |
| B19603 | 16 | NE corner sec. 20, T. 24 S., R. 61 W. | Niobrara[1] clay loam, 0–8 inches | .5 | |
| B19604 | 16a | do | Goldenweed | | 10 |
| B19609 | 19 | SE corner sec. 10, T. 24 S., R. 62 W. | Niobrara[1] silt loam, 0–8 inches | .4 | |
| B19610 | 19a | do | Goldenweed | | 10 |
| B19614 | 21 | 1,000 feet southwest of NE corner sec. 22, T. 23 S., R. 62 W. | Niobrara clay loam | .8 | |
| B19615 | 21a | do | Stanleya | | 150 |
| B19625 | 23 | 3.6 miles west of United States Route 85, on United States Route 50. | Gravelly clay loam, 0–8 inches | 6 | |
| B19626 | 23a | do | Stanleya | | 510 |
| B19627 | 23b | 3.6 miles west of United States Route 85, on United States Route 50 (25 feet from no. 23). | Goldenweed | | 4,320 |
| B19628 | 23c | do | Side-oats grama | | 10 |
| B19629 | 23d | do | Blue grama | | 4 |
| B19630 | 23e | do | Galleta grass | | 12 |
| B19736 | 26 | 500 feet west of E¼ corner sec. 7, T. 22 S., R. 62 W. | Pierre clay loam, 0–8 inches | 1 | |
| B19737 | 26a | do | Goldenweed | | 20 |
| B19742 | 29 | E¼ corner sec. 17, T. 22 S., R. 63 W. | Niobrara[1] clay loam, 0–8 inches | .5 | |
| B19743 | 29a | do | Gumweed | | 420 |
| B19744 | 29b | E¼ corner sec. 17, T. 22 S., R. 63 W. (20 feet from no. 29). | Corn (ears) (irrigated) | | 2 |
| B19747 | 31 | 500 feet south of N¼ corner sec. 16, T. 23 S., R. 63 W. | Greenhorn[1] silt loam, 0–8 inches. | 5 | |
| B19748 | 31a | do | Stanleya | | 1,020 |
| B19753 | 34 | 500 feet southeast of center sec. 2, T. 23 S., R. 64 W. | Niobrara[1] silt loam, 0–8 inches | .4 | |
| B19754 | 34a | do | Sunflower | | 2 |
| B19766 | 39 | SW corner sec. 29, T. 21 S., R. 64 W. | Niobrara[1] alluvial silt loam, 0–8 inches. | 10 | |
| B19767 | 39a | do | Stanleya | | 1,000 |
| B19771 | 41 | 80 rods west of SE corner sec. 20, T. 22 S., R. 65 W. | Clay loam, 15–23 inches | .2 | |
| B19772 | 41a | do | *Aplopappus spinulosus* | | 10 |

[1] Geologic formation.

TABLE 4.—*Selenium content of soils, shales, and vegetation from southeastern Colorado*—Continued

PUEBLO COUNTY—Continued

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P. p. m.* | *P. p. m.* |
| B19778 | 44 | NE¼ sec. 26, T. 23 S., R. 66 W. | Greenhorn[1] clay loam, 0–8 inches. | .4 | |
| B19779 | 44a | do | Stanleya | | 190 |
| B19785 | 47 | Center sec. 27, T. 24 S., R. 67 W. | Niobrara[1] shale, 0–8 inches | 3.5 | |
| B19786 | 47a | do | Stanleya | | 1,390 |
| B19793 | 52 | SE¼ sec. 30, T. 21 S., R. 66 W. | Greenhorn[1] silt loam, 0–8 inches | 4 | |
| B19794 | 52a | do | Stanleya | | 1,250 |
| B19796 | 54 | NE¼ sec. 5, T. 23 S., R. 67 W. | Stony silt loam, 0–8 inches | .5 | |
| B19797 | 54a | do | Stanleya | | 2 |
| B19864 | 59 | 80 rods east of N¼ corner sec. 28, T. 21 S., R. 67 W. | Greenhorn[1] clay loam, 0–8 inches. | .6 | |
| B19865 | 59a | do | Stanleya | | 400 |
| B19873 | 63 | S¼ corner sec. 34, T. 20 S., R. 67 W. | Greenhorn[1] stony loam, 0–8 inches. | 2 | |
| B19874 | 63a | do | Stanleya | | 300 |
| B19875 | 63b | do | Sweetclover | | 3 |
| B19882 | 67 | NW corner sec. 22, T. 21 S., R. 61 W. | Pierre clay, 0–8 inches | 2.5 | |
| B19884 | 67a | do | Russian-thistle | | 2 |
| B19891 | 71 | SE¼ sec. 24, T. 19 S., R. 64 W. | Pierre colluvium, 0–8 inches | 2.5 | |
| B19892 | 71a | do | *A. racemosus* | | 60 |
| B19896 | 74 | 500 feet north of center sec. 12, T. 20 S., R. 65 W. | Niobrara[1] silt loam, 0–8 inches | 2.5 | |
| B19897 | 74a | do | Goldenweed | | 100 |
| B19899 | 76 | 80 rods north of center sec. 25, T. 19 S., R. 65 W. | Pierre shaly loam, 0–8 inches | 4 | |
| B19900 | 76a | do | *A. racemosus* | | 470 |
| B19909 | 81 | Center sec. 31, T. 19 S., R. 63 W. | Pierre clay, 0–8 inches | 2.5 | |
| B19910 | 81a | do | *A. racemosus* | | 660 |
| B19916 | 84 | E¼ corner sec. 12, T. 20 S., R. 67 W. | Niobrara[1] shale | 2.5 | |
| B19917 | 84 | do | Limonite concretion | 54 | |
| B19918 | 84a | do | *Astragalus* (leaves) | | 160 |
| B19928 | 89 | 500 feet east of center sec. 19, T. 18 S., R. 66 W. | Greenhorn[1] silt loam, 0–8 inches | 1.5 | |
| B19929 | 89a | do | Stanleya | | 550 |
| B19935 | 92 | SE corner sec. 7, T. 18 S., R. 67 W. | Morrison[1] clay loam, 0–8 inches | .7 | |
| B19936 | 92a | do | *A. racemosus* | | 7 |

EL PASO COUNTY

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| B19955 | 1 | 500 feet south of N¼ corner sec. 31, T. 17 S., R. 66 W. | Greenhorn[1] silt loam, 0–8 inches | 2 | |
| B19956 | 1a | do | Stanleya | | 280 |
| B19957 | 2 | W¼ corner sec. 26, T. 17 S., R. 65 W. | Pierre and Ogallala[1] clay, 0–8 inches. | 1 | |
| B19958 | 2a | do | Aster | | 1 |
| B19959 | 3 | SE¼ sec. 9, T. 17 S., R. 65 W. | Pierre clay loam, 0–8 inches | 3.5 | |
| B19960 | 3a | do | Two-groove poisonvetch | | 590 |
| B19961 | 3b | do | Blue grama | | 2 |
| B19964 | 5 | Center sec. 15, T. 15 S., R. 65 W. | Pierre clay loam, 0–8 inches | 5 | |
| B19965 | 5a | do | Two-groove poisonvetch | | 1,140 |
| B19966 | 5b | do | Sweetclover | | 2 |
| B19967 | 5c | Center sec. 15, T. 15 S., R. 65 W. (100 feet from no. 5.) | Sudan grass | | 2 |
| B19970 | 7 | S¼ corner sec. 31, T. 14 S., R. 66 W. | Pierre clay, 0–8 inches | .5 | |
| B19971 | 7a | do | Gumweed | | 60 |
| B19972 | 8 | SW corner sec. 17, T. 15 S., R. 66 W. | Pierre clay, 0–8 inches | 1.5 | |
| B19973 | 8a | do | Aster | | 6 |
| B19976 | 10 | S¼ corner sec. 14, T. 16 S., R. 66 W. | Pierre alluvial clay loam, 0–8 inches. | 2 | |
| B19977 | 10a | do | Two-groove poisonvetch | | 150 |
| B19981 | 12 | N¼ corner sec. 34, T. 17 S., R. 66 W. | Niobrara[1] silt loam, 0–8 inches | 8 | |
| B19982 | 12 | do | Shale from outcrop | 8 | |
| B19983 | 12a | do | Goldenweed | | 30 |
| B19984 | 12b | do | Galleta grass | | |

[1] Geologic formation.

TABLE 4.—*Selenium content of soils, shales, and vegetation from southeastern Colorado*—Continued

FREMONT COUNTY

| Laboratory no. | Field no. | Location | Material | Selenium in— | |
|---|---|---|---|---|---|
| | | | | Soil or shale | Vegetation |
| | | | | *P. p. m.* | *P. p. m.* |
| B19634 | 2 | 1 mile north of United States Route 50, on Guffey Road. | Pierre shale | 2 | |
| B19635 | 3 | do | Bentonite in shale | 3 | |
| B19637 | 5 | 80 rods north of United States Route 50, on Guffey Road. | Gravelly clay loam, 0.8 inches | 2.5 | |
| B19638 | 5a | do | Two-groove poisonvetch | | 340 |
| B19639 | 5b | 80 rods north of United States Route 50, on Guffey Road. (6 feet from no. 5). | Stanleya | | 200 |
| B19666 | 10 | 300 feet east of center sec. 21, T. 18 S., R. 70 W. | Pierre clay, 8–16 inches | 8 | |
| B19667 | 10a | do | Goldenweed | | 270 |
| B19668 | 10b | do | Corn (ears) | | 2 |
| B19947 | 15 | SW¼ sec. 22, T. 18 S., R. 65 W | Bentonitic shale | 1.5 | |
| B19948 | 15a | do | Stanleya | | 5 |
| B19954 | 18 | 80 rods south of E¼ corner sec. 4, T. 19 S., R. 68 W. | Niobrara [1] shaly silt loam, 0–8 inches. | 3.5 | |
| B19954a | 18a | do | Stanleya | | 360 |
| B19809 | 20 | NW corner sec. 15, T. 20 S., R. 68 W. | Pierre clay loam, 0–8 inches | .4 | |
| B19810 | 20a | do | Turpentineweed | | 12 |
| B19811 | 21 | NW¼ corner sec. 22, T. 20 S., R. 68 W. | Silt loam, 0–8 inches | 2 | |
| B19812 | 21a | do | Stanleya | | 690 |
| B19989 | 24 | N¼ corner sec. 4, T. 19 S., R. 69 W. | Pierre silt loam, 0–8 inches | .5 | |
| B19990 | 24a | do | Goldenweed | | 15 |

[1] Geologic formation.

Data obtained in this survey show that occurrence of vegetation containing toxic quantities of selenium exists over a very wide area extending from township 8 south on the north to 34 south and from range 41 west on the east to range 69 west. By no means is it to be understood that the whole area is injuriously affected or that the portions adversely affected are equally so. It is estimated by John T. Miller, as a result of field examination, that approximately 1,100 square miles of soils are developed, wholely or in large part, from Pierre shales and about 2,000 square miles from the Niobrara formation and 300 square miles from the Greenhorn formation. No accurate determination of the area is possible because of the shifting materials from and to areas of soil derived chiefly from loessial, Ogallala rubble areas, and from subdivisions of the Benton formation, other than Greenhorn, which are normally low in selenium content. The condition is made more complicated by local accumulations of selenium in excess of normal, which possibly are the result of leaching from one area and retention in another. In table 4 the name assigned to soil samples is that of the geologic formation presumed to be the parent material of the soil, and where no such name is prefixed to the class term the source of the soil is either obscure or was not noted. In connection with the relation between table 4 and figure 3, it is to be noted that the term Niobrara in table 4 includes both Apishapa and Timpas formations unless otherwise indicated. In Kansas the lower portion of the Niobrara formation, the Fort Hays, was found to be relatively low in selenium, as were also the soils derived from it (*6*). The same appears to be true for the massive portions of the Timpas limestone.

### VARIATIONS IN SELENIUM CONTENT OF PLANTS

A detailed study of the data of table 4 confirms and emphasizes certain observations previously reported (*6*). There is a wide variation between the quantities of selenium absorbed by different plants, and even for a given species there is no constant relation between the quantity found in the plant as compared with that in the surface soil. Only one or two illustrations from many in the table need be cited. The sample of narrowleaf milkvetch B18461 (p. 15) contains 2,070 p. p. m. when growing in a soil containing but 1 p. p. m., while B18401 (p. 15) contains but 210 p. p. m. when growing in a soil containing 1 p. p. m., and B19355 (p. 18) has but 820 p. p. m. to 10 p. p. m. in the soil. Again, B19960 (p. 21), a sample of two-groove poisonvetch, contains 590 p. p. m. of selenium when a sample of blue grama grass growing in the same soil has but 2 p. p. m. Still again, B19254 (p. 16), a sample of western wheatgrass, contains but 1 p. p. m. of selenium, while a sample of narrowleaf milkvetch 4 feet distant has 780 p. p. m. Such variations are usual.

The variation between species of plants is definite and very wide, even within genera. This is perhaps not surprising even though unexplained. For the variations within a given species in different soils a number of explanations are at hand, all of which appear to have application in specific instances. Among these are the variations due to differences in the sulphur-selenium ratio (*15*) and differences due to variation in the root systems of the plants and to the variations in the selenium concentration of the soil solution derived from different soil levels. This last variation is very marked and is without any definite regularity as is shown by the variations within profiles illustrated by table 8. The most effective cause of variation in plant content is probably to be found in differences in the forms of selenium present in the soil. Attention has been called (*6*) to the influence of rainfall upon the selenium content of given plant species but without any definite conclusion being reached. This cause of variation is particularly intriguing because of the very marked decrease of selenium in plants when grown in humid soils or under irrigation. It was noted that in Kansas the selenium content of given plant species was less in the more easterly portions of the seleniferous area and became negligible as one reached areas of higher rainfall. It was not possible, however, to ascribe these variations to rainfall alone because not only did soils and parent materials alter but there were also differences in plant content of selenium dependent on the season when the plant samples were taken.

It seemed possible that light might be thrown upon these relations by the investigations in eastern Colorado, where conditions were similar to those in Kansas. In Prowers County, where samples were collected in June, the ratio of selenium in the surface soil to the mean content of 10 samples of narrowleaf milkvetch is as 1:549, while a similar ratio for 10 samples of the same plant species collected in Crowley and Lincoln Counties in August and September is 1:317. The mean annual rainfall at Holly in Prowers County is given by the United States Weather Bureau as 15.04 inches and at Pueblo as 11.66 inches. It would seem, therefore, improbable that such differences as shown by this relation could be due to rainfall, since this relation is reversed in Kansas. Too much stress is not be be placed upon the ratios themselves, since the variations within each group are wider than between the groups of plants.

A more specific illustration is furnished by a series of samples of a single clump of *Astragalus racemosus* at 150 feet north of the S¼ corner sec. 24, T. 21 S., R. 44 W. The plant was carefully sampled, only one-half of it being taken on June 4 and the remainder left to mature. It was again sampled on October 26. Unfortunately, at the latter date no seeds were available. The results obtained from the examination of the samples were as follows, in parts per million: June 4, young seeds, 90; flowers, 90; leaflets, 60; and stems, 15; October 26; leaflets, 3; stems, 3; roots, 2. It is clear from such and similar data that there is wide variation in plant content and that results obtained at one stage of growth of a plant are not directly comparable

FIGURE 6.—*Astragalus pectinatus* growing on seleniferous soil.

with those obtained at other periods. This may be due to the usual decreased relative ash content characteristic of plants with increase in total dry matter toward maturity. This may also explain the fact that late-season material is less toxic because it is composed of older plants.

Variation in the selenium content of different parts of the plant has already been noted (*6*). This becomes of interest in connection with the seasonal variation above noted and because of the recent publication of variation of lead and arsenic in different portions of plants by Vandecaveye and coworkers (*34*). Sufficient data are not at hand to warrant any definite conclusions. The following may be taken as representative of the relations for two species of *Astragalus* which have been examined, results being given as parts per million. In a sample of narrowleaf milkvetch (fig. 6) from Prowers County the seeds and pods had 1,630; flowers, 1,450; leaflets, 810; stems, 670;

and roots, 210. In a sample of *A. racemosus* the relations were: Seeds and pods, 310; flowers, 530; leaflets, 120; stems, 20, and roots, 25. A similar relation is shown by a sample of *Stanleya pinnata* which had in the seeds and flowers 340; in the leaflets, 120; in the stems, 10; and in the roots only 5 p. p. m. Another plant of the same species from Fremont County had 2,860 in the tops and 1,390 p. p. m. in the roots. On the other hand, a sample of goldenweed from Bent County showed the reversed relation of but 260 in the tops and 1,070 p. p. m. in the roots. It appears safe to state that in general selenium

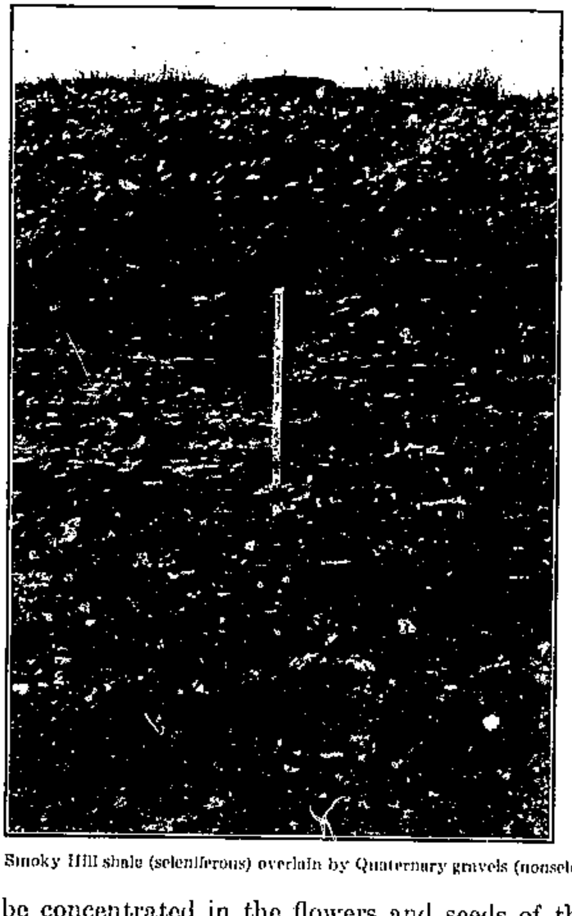

FIGURE 7.—Smoky Hill shale (seleniferous) overlain by Quaternary gravels (nonseleniferous).

is likely to be concentrated in the flowers and seeds of these plants and is less abundant in the stems and roots. It also appears that this may not be true of all plants or at all seasons. Work of Hurd-Karrer on certain plants shows that selenium may be higher in leaves than in seed (*16*, *17*). The general observation that plants contain less selenium in the late summer and fall is not in harmony with Beath's observation (*4*) that range poisoning is more severe in the late summer. Both observations may be accurate, however, if, due to change in character of forage grasses in the summer, or to limited forage, poisonous plants become less offensive to stock.

17823°—38——4

### IRRIGATED SOILS

A very large number of analyses of samples from eastern Colorado are omitted from table 4 which have to do with the irrigated area indicated in figure 2. This is a very extensive area and offers an extremely good opportunity to determine if the previous observations (*5*, *6*) with respect to seleniferous irrigation areas are of general validity.

A soil survey of this area was published in 1926 (*32*). In this survey various soil series were identified and named. In the course of the present examination John T. Miller examined these various series with reference to their parent material, and the resulting comparison of series with parent material is given in the following tabulation.:

| *Series* | *Parent materials* |
|---|---|
| Prowers | Loess. |
| Fort Lyon | Reworked Niobrara and loess. |
| Otero | Pleistocene deposits and loess. |
| Rocky Ford | Old alluvium (largely Pleistocene). |
| Minnequa and Ordway clay | Sandy shales (Niobrara). |
| Penrose | Shaly limestone (Niobrara). |
| Ordway clay loam | Pierre shale. |
| Billings | Reworked Pierre shales. |
| Manvel | Recent alluvium from loess. |
| Las Animas and Laurel | Gravel and sands (recent). |
| Apishapa | Niobrara limestone and shale (Apishapa and Timpas). |

Many samples were secured from the different soil series and, where possible, both normal irrigated crop samples and nonirrigated native vegetation were secured. The comparison is not so satisfactory as could be wished because usually the forms of vegetation particularly prone to take up selenium were not obtainable on the irrigated areas. Seldom was it possible to secure the same vegetative types on both irrigated and nonirrigated soil. In table 5 is given a portion of the results obtained in Prowers, Bent, and Otero Counties. They are representative of the results secured elsewhere as well. One of the causes of the variation in the selenium content of the soil is illustrated by figure 7.

TABLE 5.—*Selenium content of soils and vegetation from irrigated areas in Colorado*

PROWERS COUNTY

| Laboratory no. | Field no. | Location | Material | Selenium in— | |
|---|---|---|---|---|---|
| | | | | Soil or shale | Vegetation |
| | | | | *P. p. m.* | *P. p. m.* |
| B18410 | 11 | W¼ corner sec. 33, T. 22 S., R. 42 W. | Prowers clay, 0-8 inches | 1 | |
| B18420 | 11a | do | Young wheat | | 3 |
| B18424 | 14 | SW corner sec. 12, T. 23 S., R. 43 W. | Las Animas alluvial clay, 0-8 inches. | 1 | |
| B18425 | 14a | do | Alfalfa | | 4 |
| B18448 | 26 | 60 rods north of S¼ corner sec. 25, T. 22 S., R. 44 W. | Las Animas clay, 0-8 inches (irrigated by ditch tailing). | 1.5 | |
| B18449 | 26a | do | Narrowleaf milkvetch | | 1,220 |
| B18450 | 27 | N¼ corner sec. 13, T. 22 S., R. 44 W. | Prowers sandy loam, 0-8 inches. | 1 | |
| B18451 | 27a | do | Alfalfa | | 3 |
| B18462 | 32 | 300 feet south of NW corner sec. 31, T. 22 S., R. 44 W. | Las Animas clay loam, 0-8 inches | 1 | |
| B18463 | 32a | do | Alfalfa | | 3 |
| B18464 | 32b | do | Wreath aster | | 2 |

TABLE 5.—*Selenium content of soils and vegetation from irrigated areas in Colorado*—Continued

PROWERS COUNTY—Continued

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P. p. m.* | *P. p. m.* |
| B18471 | 36 | 50 feet east of N¼ corner sec. 30, T. 22 S., R. 43 W. | Fort Lyon silt loam, 0–6 inches (not irrigated). | .7 | |
| B18472 | 36 | do. | Fort Lyon silt loam, 6–12 inches (not irrigated). | .8 | |
| B18473 | 36 | do. | Fort Lyon silt loam, 12–24 inches (not irrigated). | .8 | |
| B18474 | 36 | do. | Fort Lyon silt loam, 24–36 inches (not irrigated). | .8 | |
| B18475 | 36 | do. | Fort Lyon silt loam, 36–48 inches (not irrigated). | 1 | |
| B18476 | 36 | do. | Fort Lyon silt loam, 48–60 inches (not irrigated). | 1 | |
| B18477 | 36a | do. | *Astragalus racemosus* | | 160 |
| B18478 | 37 | 50 feet east of S¼ corner sec. 10, T. 22 S., R. 43 W. (75 feet north of no. 36). | Fort Lyon silt loam, 0–6 inches. | 1.5 | |
| B18479 | 37 | do. | Fort Lyon silt loam, 6–12 inches. | 1 | |
| B18480 | 37 | do. | Fort Lyon silt loam, 12–24 inches. | 1 | |
| B18481 | 37 | do. | Fort Lyon silt loam, 24–36 inches. | 2 | |
| B18482 | 37 | do. | Fort Lyon silt loam, 36–48 inches. | 2.5 | |
| B18483 | 37 | do. | Fort Lyon silt loam, 48–60 inches. | 2.5 | |
| B18484 | 37a | do. | *A. racemosus* | | 110 |
| B18548 | 44 | SE corner sec. 30, T. 21 S., R. 46 W. | Prowers clay loam, 0–8 inches (irrigated, poorly drained). | .8 | |
| B18549 | 44a | do. | Young wheat | | 3 |
| B18589 | 53 | 300 feet north of W¼ corner sec. 36, T. 22 S., R. 46 W. | Las Animas clay loam, 0–8 inches. | 1.5 | |
| B18590 | 53a | do. | Seepweed | | 5 |
| B18591 | 53b | do. | Young oats | | 3 |

BENT COUNTY

| Laboratory no. | Field no. | Location | Material | Soil or shale | Vegetation |
|---|---|---|---|---|---|
| B18662 | 2 | ½ mile north of Prowers, sec. 34, T. 22 S., R. 48 W. | Las Animas silt alluvium, 0–8 inches. | 1 | |
| B18663 | 2a | do. | Alfalfa | | 0 |
| B18667 | 4 | 1,000 feet north of SE corner sec. 10, T. 22 S., R. 48 W. | Prowers silt loam, 0–8 inches | 1 | |
| B18668 | 4a | do. | Alfalfa | | 1 |
| B18669 | 4b | do. | Wreath aster | | 12 |
| B18671 | 6 | 200 feet north of E¼ corner sec. 35, T. 21 S., R. 48 W. | Prowers clay loam, 0–8 inches. | .7 | |
| B18672 | 6a | do. | Alfalfa | | 2 |
| B18676 | 8 | NW corner sec. 13, T. 21 S., R. 48 W. | Prowers clay loam, 0–8 inches. | .7 | |
| B18676 | 8a | do. | Young wheat | | 1 |
| B18677 | 8b | do. | Alfalfa | | 2 |
| B18679 | 8c | do. | Wreath aster | | 2 |
| B18732 | 21 | 150 feet south of NE corner sec. 20, T. 22 S., R. 51 W. | Fort Lyon silt loam, 0–8 inches | 1 | |
| B18733 | 21a | do. | Wreath aster | | 10 |
| B18767 | 36 | S¼ corner sec. 33, T. 22 S., R. 53 W. | Las Animas clay loam, 0–8 inches. | 1 | |
| B18768 | 36a | do. | Alfalfa | | 0 |
| B18822 | 43 | NE corner sec. 21, T. 22 S., R. 48 W. | Minnequa clay loam, 0–6 inches. | 1 | |
| B18823 | 43 | do. | Minnequa clay loam, 6–12 inches. | 1 | |
| B18824 | 43 | do. | Minnequa clay loam, 12–20 inches. | 1 | |
| B18825 | 43 | do. | Minnequa clay loam, 20–30 inches. | 1 | |
| B18826 | 43 | do. | Minnequa clay loam, 30–48 inches. | 1 | |
| B18827 | 43a | do. | Young corn | | 2 |
| B18828 | 43b | NE corner sec. 21, T. 22 S., R. 48 W. (10 feet from no. 43.) | Beans | | 0 |

TABLE 5.—*Selenium content of soils and vegetation from irrigated areas in Colorado*—Continued

BENT COUNTY—Continued

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P. p. m.* | *P. p. m.* |
| B18829 | 43c | NE corner sec. 21, T. 22 S., R. 48 W. (20 feet from no. 43.) | Radish (leaves) | | 1 |
| B18830 | 43d | NE corner sec. 21, T. 22 S., R. 48 W. (50 feet from no. 43.) | Young peas | | 1 |
| B18831 | 43e | NE corner sec. 21, T. 22 S., R. 48 W. (30 feet from no. 43.) | Lettuce | | 1 |

OTERO COUNTY

| Laboratory no. | Field no. | Location | Material | Soil or shale | Vegetation |
|---|---|---|---|---|---|
| B18970 | 10 | 1,000 feet south of NW corner sec. 33, T. 22 S., R. 54 W. | Otero sandy loam, 0-8 inches | 2 | |
| B18971 | 10a | do | Young wheat (heads) | | 3 |
| B18973 | 11 | 500 feet north of SW corner sec. 9, T. 22 S., R. 54 W. | Minnequa clay loam, 0-8 inches. | 1 | |
| B18974 | 11a | do | Alfalfa | | 2 |
| B18989 | 19 | 80 rods east of W¼ corner sec. 23, T. 24 S., R. 55 W. | Gravelly silt loam | 1 | |
| B18990 | 19a | do | Gumweed | | 1 |
| B18991 | 19b | do | Alfalfa | | 1 |
| B18996 | 22 | SW corner sec. 24, T. 22 S., R. 55 W. | Otero clay loam, 0-8 inches | .8 | |
| B18997 | 22a | do | Young beets (tops) | | 2 |
| | | | Young beets (roots) | | 1 |
| B19012 | 30 | 1,000 feet south of NW corner sec. 14, T. 24 S., R. 56 W. | Minnequa clay loam, 0-8 inches. | 2 | |
| B19013 | 30a | do | Young corn | | 2 |
| B19014 | 30b | 1,000 feet south of NW corner sec. 14, T. 24 S., R. 56 W. (20 feet from no. 30.) | Young beans | | 1 |
| B19015 | 30c | 1,000 feet south of NW corner sec. 14, T. 24 S., R. 56 W. (20 feet from no. 30.) | Wheat (heads) | | 1 |
| B19016 | 30d | 1,000 feet south of NW corner sec. 14, T. 24 S., R. 56 W. (15 feet from no. 30.) | Wreath aster | | 4 |
| B19017 | 30e | 1,000 feet south of NW corner sec. 14, T. 24 S., R. 56 W. (25 feet from no. 30.) | Turkey pea | | 1 |
| B19018 | 30f | 1,000 feet south of NW corner sec. 14, T. 24 S., R. 56 W. | Poison milkweed | | 3 |
| B19019 | 31 | 500 feet north of SW corner sec. 35, T. 23 S., R. 56 W. | Minnequa clay loam, 0-8 inches. | 2 | |
| B19020 | 31a | do | Alfalfa | | 1 |
| B19021 | 32 | W¼ corner sec. 23, T. 23 S., R. 53 W. | Rocky Ford sandy loam, 0-8 inches. | 1.5 | |
| B19022 | 32a | do | Sugar beets (tops) | | 1 |
| | | | Sugar beets (roots) | | 1 |
| B19024 | 33 | 500 feet southeast of NW corner sec. 11, T. 23 S., R. 56 W. | Otero sandy loam, 0-8 inches | .5 | |
| B19025 | 33a | do | Young corn | | 2 |
| B19026 | 34 | 500 feet south of W¼ corner sec. 36, T. 22 S., R. 57 W. | Las Animas clay loam, 0-8 inches. | 1.5 | |
| B19027 | 34a | do | Sugar beets (tops) | | 3 |
| B19028 | 34b | 500 feet south of W¼ corner sec. 36, T. 22 S., R. 57 W. (10 feet from no. 34). | Onions (tops) | | 2 |
| | | | Onions (roots) | | 2 |
| B19029 | 34c | 500 feet south of W¼ corner sec. 36, T. 22 S., R. 57 W. (250 feet from no. 34). | Young beans | | 2 |
| B19030 | 35 | 500 feet south of NW. corner sec. 35, T. 23 S., R. 57 W. | Rocky Ford loam, 0-8 inches | .5 | |
| B19031 | 35a | do | Young corn | | 1 |
| B19032 | 36 | NE corner sec. 35, T. 23 S., R. 57 W. | Otero silt loam | .3 | |
| B19033 | 36a | do | Young Russian-thistle | | 1 |
| B19034 | 37 | 80 rods south of NE corner sec. 14, T. 24 S., R. 57 W. | Minnequa clay loam, 0-8 inches. | 1 | |
| B19035 | 37a | do | Barley (heads) | | 1 |
| B19036 | 37b | 80 rods south of NE corner sec. 14, T. 24 S., R. 57 W. (25 feet from no. 37). | Poison milkweed | | 3 |

TABLE 5.—*Selenium content of soils and vegetation from irrigated areas in Colorado*—Continued

OTERO COUNTY—Continued

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P. p. m.* | *P. p. m.* |
| B19037 | 37c | 80 rods south of NE corner sec. 14, T. 24 S., R. 57 W. | Sugar beet (tops) | | 0 |
| B19038 | 37d | 80 rods south of NE corner sec. 14, T. 24 S., R. 57 W. (25 feet from no. 37). | Cane | | 0 |
| B19039 | 38 | S¼ corner sec. 26, T. 24 S., R. 57 W. | Minnequa clay loam, 0–8 inches. | 2.5 | |
| B19040 | 38a | do | Wheat (heads) | | 2 |
| B19055 | 46 | NW¼ corner sec. 20, T. 23 S., R. 56 W. | Rocky Ford clay loam | 1 | |
| B19056 | 46a | do | Wild hemp | | 0 |
| B19057 | 46b | NW¼ corner sec. 20, T. 23 S., R. 56 W. (20 feet from no. 46). | Oat (heads) | | 2 |
| B19163 | 75 | 800 feet west of NE corner sec. 35, T. 23 S., R. 56 W. | Apishapa clay, 0–12 inches | 1.5 | |
| B19164 | | | Apishapa clay, 12–24 inches | 1 | |
| B19165 | | | Apishapa clay, 24–36 inches | 1 | |
| B19166 | | | Apishapa clay, 36–48 inches | 1 | |
| B19167 | | | Apishapa clay, 48–60 inches | .7 | |
| B19168 | 75a | do | Poison milkweed | | 1 |
| B19169 | 75b | 800 feet west of NE corner sec. 35, T. 23S., R. 56 W (4 feet from no. 75) | Silky sophora | | 1 |
| B19170 | 75c | 800 feet west of NE corner sec. 35, T. 23 S. R. 56 W. | Alfalfa | | 1 |
| B19171 | 75d | 800 feet west of NE corner sec. 35, T. 23 S., R. 56 W. (6 feet from no. 75). | Onions (tops) | | 1 |
| | | | Onions (bulbs) | | 0 |
| B19172 | 75e | 800 feet west of NE corner sec. 35, T. 23 S., R. 56 W. (50 feet from no. 75). | Young barley (heads) | | 1 |
| B19173 | 75f | 800 feet west of NE corner sec. 35, T. 23 S., R. 56 W. (75 feet from no. 75). | Wild-rye | | 1 |
| B19174 | 75g | do | Western wheatgrass | | 1 |
| B19175 | 75h | 800 feet west of NE corner sec. 35, T. 23 S., R. 56 W. (150 feet from no. 75). | Young beans | | 1 |
| B19176 | 75i | do | Sugar beets (tops) | | 0 |
| | | | Sugar beets (roots) | | 0 |

Examination of table 5 brings out the fact that in only two cases is notably toxic vegetation produced on irrigated soil. One of these is 26a in Prowers County, and here the soil is irrigated by water which has already leached soil which is seleniferous, and the selenium probably is derived from the water rather than from the soil. The other number, 37a, also in Prowers County, is a sample of *Astragalus racemosus* growing in soil inadequately irrigated and rather high in selenium. Even so, it contains less than a corresponding sample 75 feet away which is growing in an unirrigated soil the profile of which contains much less selenium. Two samples of wreath aster, nos. 4b and 21a in Bent County, contain 12 and 10 p. p. m., respectively, but these quantities are low for this plant when growing in seleniferous soil. None of the other samples of vegetation in the irrigated areas contain more than 5 p. p. m., and in many cases the quantity found closely approaches zero. In all cases the soil contains quantities of selenium which in observed cases in nonirrigated areas have produced toxic vegetation in abundance. In view of these results and those previously published (*5*, *6*) the writers feel warranted in suggesting that irrigation provides a remedy for seleniferous soils wherever it can be practiced, particularly if adequate underdrainage is provided.

The explanation of the reduction in selenium content of the vegetation grown on irrigated soils previously given (*5, 6*) is to be repeated here with certain changes of emphasis. The sulphate content of the irrigation water derived from the Arkansas River is not exceptionally high and is probably low as compared with that of the soil solution and may not be expected to greatly increase the retardation of selenium absorption over that in the nonirrigated areas. Data on the salinity of the Arkansas River are given by Clarke (*9, 10*), and Collins and his coworkers (*11*). The information is not detailed but indicates a wide variation in sulphate, both seasonally and according to the point of sampling. Thus at Deerfield, Kans., the range was from 65 to 201 p. p. m. at different times through the year 1906–07, and at Pueblo from 68 to 271 p. p. m. in June 1919 and in March 1925, respectively.

On the other hand, that selenium is removed by leaching is indicated by the contrast between irrigation and drainage waters, reported in previous publications (*5, 6*) as well as by the data given in table 6. It will be noted from the data in table 5 that there is abundant residual selenium in the soils even after long irrigation. The inference to be drawn is obviously that this residual selenium is essentially unavailable to plants. This inference is abundantly supported by the facts reported under Forms of Selenium in the Soil (p. 56).

TABLE 6.—*Selenium content of irrigation water and drainage waters*

| Laboratory no. | Field no. | Location | Drainage water | Selenium |
|---|---|---|---|---|
| | | | | *P. p. billion* |
| B18658 | | Sec. 1, T. 18 S., R. 51 W., Kiowa County, Colo. | Red Lake | 0.0 |
| B18659 | | Sec. 33, T. 20 S., R. 52 W., Kiowa County, Colo. | Adobe Lake Reservoir | 4 |
| B19405 | | Near S¼ corner sec. 12, T. 28 S., R. 52 W., Las Animas County, Colo. | Well water | 15 |
| B18254 | | ½ mile west and ½ mile north of Holly, Colo. | Drainage ditch | 10 |
| B18255 | | 8 miles north of Lamar, Colo. | Nee Grande Reservoir | 10 |
| B18259 | | 6 miles south of Haswell, Colo. | Pond water in Niobrara soil | 4 |
| B19681 | | 500 feet north of S¼ corner sec. 12, T. 22 S., R. 63 W., Pueblo, Colo. | Water from depression in Niobrara. | 1 |
| B19802 | 27 | Sec. 3, T. 19 S., R. 68 W., Pueblo, Colo. | Drainage ditch | 200 |
| B19804 | 28 | do | Irrigation water supply of B19803. | 1 |
| B20212 | 13 | 500 feet southeast of NW corner sec. 33, T. 30 N., R. 25 E., Colfax, N. Mex. | Pond in Pierre | .0 |
| B20213 | 31 | Sec. 34, T. 27 N., R. 27 E., Colfax, N. Mex. | "Poison spring" | .0 |
| B18256 | | Farmington, N. Mex. | Irrigation water | 1 |
| B18258 | | 4 miles northwest of Shiprock, N. Mex. | San Juan River | 700 |
| B18260 | | Shiprock, N. Mex. | Irrigation water | .0 |
| B18257 | | 3½ miles south of Cortez, Colo. | Drainage from irrigation area | 400 |
| B19550 | | Lacreek Migratory Waterfowl Refuge, S. Dak. | Reservoir 9 | 1 |
| B20529 | | Crescent Lake Wildlife Refuge, Garden County, Nebr. | Gimlet Lake | .0 |
| B20220 | | Near Laramie, Wyo | Bamforth Lake | 1 |

Included in the analyses given in table 6 are several which require special comment. It will be noted that the water of the Adobe Lake Reservoir, B18659, contains more selenium than is ordinarily found in surface waters even in seleniferous areas. The writers were informed that no new supply of water had been brought into this reservoir for several years. If this be the case the present sample not only represents a considerable concentration of soluble material but also the supply from leaching of nearby territory, which is fairly high in selenium. (See also nos. B18754–B18756 in Bent County and nos. B18776, B18777, and B19526 in Kiowa County, table 4). The same statement applies to sample B18255 and sample B18259, except that no local information was obtained. The drainage ditch waters in seleniferous areas are uniformly high, as compared with irrigation waters. A notable illustration is found in the contrast between nos. B19803 and B19804 and in nos. B18256 and B18258, which practically represent the concentration of selenium in the San Juan River above Farmington after it had received the early spring drainage of the irrigation area from Farmington to and beyond Shiprock. (See also section on the Colorado River Basin.)

## SURVEY IN NEW MEXICO

As mentioned previously, the reconnaissance survey in New Mexico showed the presence of at least three areas with more or less toxic conditions. The indications from various sources are that there are more than three. One of these, between Raton and Las Vegas, was examined somewhat more closely. The season was so far advanced before the work in Colorado could be completed that work in New Mexico did not begin until September 15, and due to cold weather was stopped about October 25. As a consequence, samples of *Astragalus* were hard to find, and those found, as well as the other plants sent in, should be expected to be lower in selenium content than they would be earlier in the season. Also the plants actually examined are less well marked as absorbers of selenium. The examination made was limited to Colfax and Mora Counties and small portions of San Miguel County north and northeast of Las Vegas and to a small area in Harding County. In Colfax County the Pierre shale giving rise to soils is largely confined to the area lying between the Raton-Las Vegas Road (United States Route 85) and the mountainous area to the northwest. Over a considerable belt near the mountains the Pierre is deeply covered by rubble, so that in general the soils are not seleniferous. In places the Pierre is covered by igneous outcrops. To the south and east of the Pierre are outcrops of Niobrara, but in general they are so covered by igneous material that only a small area of soil wholly developed from Niobrara is found. This area lies to the east of Maxwell. In Mora County the seleniferous area is confined for the most part to an area of Niobrara soils lying south of Ocate Creek in the vicinity of Nolan and Levy. This area is connected by a narrow band with the similar area in Colfax County near French and Maxwell.

In both Colfax and Mora Counties areas of soil exist which are derived wholly or in part from the Greenhorn formation. These are usually less seleniferous than soils derived from the lower Pierre and upper Niobrara formations but are not to be ignored in any study of seleniferous soils. In general, in this area, the Greenhorn exposures lie to the south and east of the Niobrara. In Mora County two areas of Greenhorn soils are found; one of these is southwest of Wagon Mound and the other east of Springer. This formation also appears in the northwestern portion of Harding County in the vicinity of Abbott and Mills. In San Miguel County an area of Greenhorn and related shales appears north and northeast of Las Vegas and extends as far as the

Cebolla Creek. There is also an area of exposed Greenhorn in the northwestern portion of Harding County adjoining a similar area in the flats to the east and south of Abbott. Altogether it is estimated that upward of 600 square miles of soil are to be found in these four counties which are capable of producing vegetation which may be toxic to animals by reason of selenium content. The data in table 7 represent 114 samples from a total of about 300 examined.

TABLE 7.—*Selenium content of soils and vegetation from New Mexico*

COLFAX COUNTY

| Laboratory no. | Field no. | Location | Material | Selenium in— | |
|---|---|---|---|---|---|
| | | | | Soil or shale | Vegetation |
| | | | | *P. p. m.* | *P. p. m.* |
| B20143 | 1 | 1½ miles west of Raton | Dakota[1] sandy, loam 0-8 inches. | 0.3 | |
| B20144 | 1a | do | Turpentineweed | | 1 |
| B20147 | 3 | SW¼ sec. 5, T. 31 N., R. 25 E | Pierre clay loam, 0-8 inches | 5 | |
| B20148 | 3a | do | Two-groove poisonvetch | | 80 |
| B20154 | 6 | Center sec. 33, T. 32 N., R. 27 E | Pierre and igneous silt loam, 0-8 inches. | .8 | |
| B20155 | 6a | do | Two-groove poisonvetch | | 2 |
| B20167 | 12 | 300 feet north of SW corner sec. 14, T. 30 N., R. 24 E. | Pierre clay loam, 0-8 inches | 2.5 | |
| B20168 | 12a | do | Two-groove poisonvetch | | 300 |
| B20169 | 13 | 500 feet southeast of NW corner sec. 33, T. 30 N., R. 25 E. | Pierre clay loam, 0-8 inches | 2.5 | |
| B20170 | 13a | do | Two-groove poisonvetch | | 450 |
| B20171 | 14 | S¼ corner sec. 27, T. 30 N., R. 25 E. | Pierre clay alluvium, 0-8 inches. | 10 | |
| B20172 | 14a | do | *Astragalus racemosus* | | 1,650 |
| B20177 | 17 | 1,000 feet west of NE corner sec. 4, T. 29 N., R. 27 E. | Greenhorn[1] silt loam, 0-8 inches. | .5 | |
| B20178 | 17a | do | Gumweed | | 1 |
| B20179 | 17b | do | Two-groove poisonvetch | | 2 |
| B20182 | 19 | W¼ corner sec. 2, T. 28 N., R. 26 E. | Niobrara[1] clay loam, 0-8 inches | 3 | |
| B20183 | 19a | do | Stanleya | | 10 |
| B20196 | 26 | W¼ corner sec. 23, T. 29 N., R. 24 E. | Niobrara[1] silt loam | .8 | |
| B20207 | 26a | do | Stanleya | | 70 |
| B20230 | 35 | W¼ corner sec. 10, T. 28 N., R. 22 E. | Pierre clay alluvium, 0-8 inches. | 2 | |
| B20231 | 35a | do | Two-groove poisonvetch | | 4 |
| B20232 | 35b | do | *A. carolinianus* | | 3 |
| B20238 | 38 | S¼ corner sec. 9, T. 28 N., R. 25 E. | Niobrara[1] silt loam, 0-8 inches. | 1 | |
| B20239 | 38a | do | *A. carolinianus* | | 270 |
| B20240 | 38b | do | Surface mulch | | 100 |
| B20246 | 42 | 2 miles northeast of Colfax, T. 28 N., R. 21 E. | Pierre clay, 0-4 inches | 1.5 | |
| B20247 | 42 | 2 miles northeast of Colfax, T. 28 N., R. 21 E. | Pierre clay, 4-9 inches | 1.5 | |
| B20248 | 42 | 2 miles northeast of Colfax, T. 28 N., R. 21 E. | Pierre clay, 9-13 inches | 1 | |
| B20249 | 42 | 2 miles northeast of Colfax, T. 28 N., R. 21 E. | Shaly clay, 13-20 inches | .8 | |
| B20250 | 42 | 2 miles northeast of Colfax, T. 28 N., R. 21 E. | Weathered shale, 20-32 inches | 1 | |
| B20251 | 42 | 2 miles northeast of Colfax, T. 28 N., R. 21 E. | Pierre shale, 32+ inches (with concretions). | 1 | |
| B20252 | 42a | do | Turpentineweed | | 12 |
| B20253 | 42b | do | *Chrysopsis villosa* | | 110 |
| B20254 | 42c | 2 miles northeast of Colfax, T. 28 N., R. 21 E. (50 feet from no. 42). | Scarlet mallow | | 3 |
| B20255 | 42d | 2 miles northeast of Colfax, T. 28 N., R. 21 E. | Blue grama | | 0 |
| B20256 | 42e | do | Ticklegrass | | 2 |
| B20261 | 45 | S¼ corner sec. 21, T. 27 N., R. 20 E. | Pierre clay loam, 0-8 inches. | 1 | |
| B20262 | 45a | do | Turpentineweed | | 120 |
| B20280 | 51 | E¼ corner sec. 25, T. 28 N., R. 22 E. | Pierre clay, 0-8 inches | 1.5 | |
| B20281 | 51a | do | Two-groove poisonvetch | | 520 |
| B20282 | 52 | SE corner sec. 13, T. 27 N., R. 22 E. | Pierre clay, 0-8 inches | 5 | |
| B20283 | 52a | do | Turpentineweed | | 350 |
| B20287 | 54 | S¼ corner sec. 14, T. 27 N., R. 21 E. | Pierre clay loam, 0-8 inches | 1 | |
| B20288 | 54a | do | Two-groove poisonvetch | | 70 |

[1] Geologic formation.

TABLE 7.—*Selenium content of soils and vegetation from New Mexico*—Continued

COLFAX COUNTY—Continued

| Laboratory no. | Field no. | Location | Material | Selenium in— | |
|---|---|---|---|---|---|
| | | | | Soil or shale | Vegetation |
| | | | | *P. p. m.* | *P. p. m.* |
| B20293 | 57 | E¼ corner sec. 13, T. 26 N., R. 19 E. | Pierre clay loam, 0–8 inches | 2.5 | |
| B20294 | 57a | do | Turpentineweed | | 4 |
| B20299 | 60 | SW corner sec. 26, T. 26 N., R. 21 E. | Pierre clay loam, 0–8 inches | 2 | |
| B20300 | 60a | do | Gumweed | | 150 |
| B20309 | 65 | SE corner sec. 22, T. 25 N., R. 20 E. | Pierre clay loam, 0–8 inches (irrigated). | 1 | |
| B20310 | 65a | do | Oat (heads) | | 3 |
| B20313 | 67 | SW corner sec. 25, T. 25 N., R. 19 E. | Pierre clay loam, 0–8 inches | 2 | |
| B20314 | 67a | do | Turpentineweed | | 40 |
| B20326 | 74 | W¼ corner sec. 17, T. 26 N., R. 26 E. | Basaltic clay loam, 0–8 inches | .5 | |
| B20327 | 74a | do | Turpentineweed | | 1 |
| B20332 | 77 | SW corner sec. 23, T. 26 N., R. 23 E. | Carlile[1] clay loam, 0–8 inches | .7 | |
| B20333 | 77a | do | Common ragweed | | 1 |
| B20334 | 78 | SW corner sec. 22, T. 26 N., R. 23 E. | Niobrara[1] silt loam 0–8 inches | 1 | |
| B20335 | 78a | do | *A. carolinianus* | | 90 |
| B20338 | 80 | 80 rods north of center sec. 31, T. 27 N., R. 23 E. | Niobrara[1] silt loam, 0–8 inches | 1 | |
| B20339 | 80a | do | Two-groove poisonvetch | | 80 |
| B20340 | 81 | SW corner sec. 25, T. 27 N., R. 22 E. | Niobrara[1] silt loam, 0–8 inches | 5 | |
| B20341 | 81a | do | Two-groove poisonvetch | | 460 |
| B20344 | 83 | W¼ corner sec. 20, T. 25 N., R. 23 E. | Greenhorn[1] clay loam, 0–8 inches. | .7 | |
| B20345 | 83a | do | Two-groove poisonvetch | | 130 |
| B20352 | 88 | Center sec. 8, T. 24 N., R. 22 E. | Greenhorn[1] silt loam, 0–8 inches. | .8 | |
| B20353 | 88a | do | Turpentineweed | | 3 |
| B20356 | 90 | S¼ corner sec. 19, T. 24 N., R. 22 E. | Greenhorn[1] silt loam, 0–8 inches. | 1 | |
| B20357 | 90a | do | *A. racemosus* | | 180 |
| B20364 | 94 | S¼ corner sec. 25, T. 24 N., R. 19 E. | Pierre clay loam, 0–8 inches | 1 | |
| B20365 | 94a | do | *A. carolinianus* | | 80 |
| B20368 | 96 | 500 feet west of SE corner sec. 9, T. 24 N., R. 24 E. | Greenhorn[1] silt loam, 0–8 inches | .1 | |
| B20369 | 96a | do | Turpentineweed | | 1 |

MORA COUNTY

| Laboratory no. | Field no. | Location | Material | Soil or shale | Vegetation |
|---|---|---|---|---|---|
| B20396 | 1 | NW corner sec. 30, T. 23 N., R. 21 E. | Surface litter | | 15 |
| B20397 | | | Pierre silt loam, 0–2 inches | 4 | |
| B20398 | | | Pierre silt loam, 2–6 inches | 1 | |
| B20399 | | | Pierre silt loam, 6–12 inches | .7 | |
| B20400 | | | Pierre silt loam, 12–22 inches | .7 | |
| B20401 | | | Pierre silt loam, 22–30 inches | .6 | |
| B20402 | | | Pierre silt loam, 30–36 inches | .7 | |
| B20403 | | | Pierre silt loam, 36–48 inches | .6 | |
| B20404 | | | Pierre silt loam, 40–56 inches | .5 | |
| B20405 | | | Pierre silt loam, 56–60 inches | .7 | |
| B20406 | | | *A. carolinianus* | | 80 |
| B20407 | 2 | 2 miles west of Nolan | Niobrara[1] silt loam, 0–8 inches | 1 | |
| B20408 | | | Niobrara[1] clay shale, 36–48 inches. | 3 | |
| B20409 | 2a | do | Turpentineweed | | 320 |
| B20410 | 3 | 1 mile east of Nolan | Niobrara[1] silt loam, 0–8 inches | .4 | |
| B20411 | 3a | do | Two-groove poisonvetch | | 3 |
| B20414 | 5 | 5 miles east of Nolan | Lower Niobrara clay shale | 3 | |
| B20415 | 5a | do | *Astragalus* sp. | | 1 |
| B20417 | 7 | 2 miles east of Levy | Niobrara[1] silt loam, 0–8 inches | .2 | |
| B20418 | 7a | do | Turpentineweed | | 1 |
| B20420 | 9 | 8 miles east and 1 mile south of Levy. | Greenhorn[1] silt loam, 0–8 inches | .6 | |
| B20421 | 9a | do | Turpentineweed | | 1 |
| B20422 | 10 | 1¼ miles north of Nolan | Niobrara[1] silt loam, 0–8 inches | .6 | |
| B20423 | 10a | do | Two-groove poisonvetch | | 7 |
| B20427 | 13 | 5 miles south of Wagon Mound on United States Route 85. | Greenhorn[1] silt loam, 0–8 inches | .5 | |
| B20428 | 13a | do | Turpentineweed | | 1 |

[1] Geologic formation

TABLE 7.—*Selenium content of soils and vegetation from New Mexico*—Continued

SAN MIGUEL COUNTY

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P. p. m.* | *P. p. m.* |
| B20429 | 1 | SE corner sec. 26, T. 17 S., R. 16 E. | Greenhorn[1] silt loam, 0-8 inches. | 0.5 | |
| B20430 | 1a | do | Turpentineweed | | 1 |
| B20433 | 3 | SE corner sec. 3, T. 17 S., R. 17 E. | Greenhorn[1] clay loam, 0-8 inches. | .4 | |
| B20434 | 3a | do | Gumweed | | 0 |
| B20437 | 6 | SE corner sec. 30, T. 17 S., R. 17 E. | Greenhorn[1] clay loam, 0-8 inches. | .5 | |
| B20438 | 6a | do. | Turpentineweed | | 1 |
| B20441 | 8 | SW corner sec. 10, T. 16 S., R. 17 E. | | .5 | |
| B20442 | 8a | do. | Sweetclover | | 0 |
| B20449 | 12 | NE corner sec. 24, T. 16 S., R. 19 E. | Greenhorn[1] silt loam, 0-8 inches. | .3 | |

HARDING COUNTY

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| B20388 | 1 | 1.6 miles south of county line on State Road 39. | Greenhorn[1] silt loam, 0-8 inches. | 1 | |
| B20390 | 1a | do | Turpentineweed | | 5 |
| B20391 | 2 | 2.5 miles south of county line on State Road 39. | Greenhorn[1] silt loam, 0-8 inches. | 2.5 | |
| B20392 | 2 | do | Greenhorn[1] silt loam, 20-30 inches. | .6 | |
| B20393 | 2a | do | *A. racemosus* | | 180 |
| B20394 | 3 | 1 mile west of mills | Greenhorn[1] silt loam, 0-8 inches. | .5 | |
| B20395 | 3a | do | Turpentineweed | | 1 |

[1] Geologic formation.

Examination of the data of table 7 reveals the fact that exceedingly toxic vegetation exists over the area reported upon. In general the quantities found are not so high as appear in other areas where the same plant species were obtained. The quantities are low perhaps by reason of the late period of growth when collected. It is to be noted that in the samples from San Miguel County no toxic plants are reported. None of these are good absorbers of selenium. Nevertheless the soil analyses show the presence of small quantities of selenium sufficient to produce toxic vegetation under favorable conditions, and sample no. B18166 (table 2) is from this area. The sample probably is *Astragalus carolinianus* and had 1,110 p. p. m. of selenium.

Of special interest in this series of samples are samples B20253 in Colfax County and B20409 in Mora County (table 7). The former sample is a plant of high absorptive capacity which has not previously been reported. The latter is the most highly selenized turpentineweed which the writers have examined. Also of special interest are the numerous samples of soil derived from the Greenhorn formation which contain material quantities of selenium and give rise to toxic vegetation (p. 41.)

## SOIL PROFILES

The selenium content of a number of soil profiles was reported (*5, pp. 19, 38*), and from the data it appeared that no uniformity of distribution of selenium within the profile can be anticipated in advance of examination. An additional group of profiles have also been reported (*6*). These also show no uniformity of distribution of the selenium. In view of the statements by Beath, Eppson, and Gilbert

(4) concerning selenium accumulation in subsoils, it seems desirable to present the analyses of a number of profiles from various parts of eastern Colorado and to restate what appear to be the causes of variation in soil and plant content of selenium. The results are shown in table 8.

TABLE 8.—*Selenium content of selected profiles from eastern Colorado*

PROFILE 1, FORT LYON SILT LOAM FROM 50 FEET EAST OF N¼ CORNER SEC. 30, T. 22 S., R. 43 W., PROWERS COUNTY

| Laboratory no. | Depth | Selenium | Laboratory no. | Depth | Selenium |
|---|---|---|---|---|---|
| | *Inches* | *P. p. m.* | | *Inches* | *P. p. m.* |
| B18471 | 0-6 | 0.7 | B18474 | 24-36 | 0.8 |
| B18472 | 6-12 | .8 | B18475 | 36-48 | 1 |
| B18473 | 12-24 | .8 | B18476 | 48-60 | 1 |

PROFILE 2, FORT LYON SILT LOAM FROM 50 FEET EAST OF S¼ CORNER SEC. 19, T. 22 S., R. 43 W., PROWERS COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B18478 | 0-6 | 1.5 | B18481 | 24-36 | 2 |
| B18479 | 6-12 | 1 | B18482 | 36-48 | 2.5 |
| B18480 | 12-24 | 1 | B18483 | 48-60 | 2.5 |

PROFILE 3, LAS ANIMAS CLAY LOAM FROM 80 RODS SOUTH OF NW CORNER SEC. 30, T. 22 S., R. 44 W., PROWERS COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B18487 | 0-6 | 1 | B18490 | 20-30 | 0.4 |
| B18488 | 6-10 | .7 | B18491 | 30-48 | .3 |
| B18489 | 10-20 | .3 | | | |

PROFILE 4, MINNEQUA CLAY LOAM FROM 75 FEET WEST OF SE CORNER SEC. 18, T. 22 S., R. 43 W., PROWERS COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B18538 | 0-6 | 2 | B18541 | 18-26 | 1.5 |
| B18539 | 6-12 | 3 | B18542 | 26-36 | 2 |
| B18540 | 12-18 | 3 | | | |

PROFILE 5, PROWERS CLAY LOAM FROM 325 FEET SOUTH OF N¼ CORNER SEC. 25, T. 21 S., R. 44 W., PROWERS COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B18560 | 0-½ | 1.5 | B18565 | 30-48 | 1 |
| B18561 | ½-6 | 1.5 | B18566 | 48-72 | .6 |
| B18562 | 6-12 | 2 | B18567 | 72-84 | .5 |
| B18563 | 12-18 | 1.5 | B18568 | 84-96 | .4 |
| B18564 | 18-30 | 1 | B18569 | 96-120 | .4 |

PROFILE 6, SILT LOAM FROM SW CORNER SEC. 26, T. 13 S., R. 46 W., CHEYENNE COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B18637 | 0-8 | 1 | B18639 | 16-24 | 0.9 |
| B18638 | 8-16 | .7 | B18640 | 24-48 | .4 |

PROFILE 7, MINNEQUA CLAY LOAM FROM NE CORNER SEC. 21, T. 22 S., R. 48 W., BENT COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B18822 | 0-6 | 1 | B18825 | 20-30 | 1 |
| B18823 | 6-12 | 1 | B18826 | 30-48 | 1 |
| B18824 | 12-20 | 1 | | | |

PROFILE 8, SILT LOAM [1] FROM 500 FEET SOUTH OF E¼ CORNER SEC. 21, T. 19 S., R. 47 W., KIOWA COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B18609 | 0-8 | 0.3 | B18612 | 32-48 | 1.5 |
| B18610 | 8-14 | .5 | B18613 | 48-60 | 1.5 |
| B18611 | 14-32 | .2 | | | |

[1] No name has been assigned.

TABLE 8.—*Selenium content of selected profiles from eastern Colorado*—Continued

PROFILE 9, SILT LOAM [1] FROM CENTER SEC. 23, T. 15 S., R. 51 W., KIOWA COUNTY

| Laboratory no. | Depth | Selenium | Laboratory no. | Depth | Selenium |
|---|---|---|---|---|---|
| | *Inches* | *P. p. m.* | | *Inches* | *P. p. m.* |
| B19510 | 0–6 | 0.2 | B19513 | 24–36 | 0.2 |
| B19511 | 6–12 | .2 | B19514 | 36–48 | .2 |
| B19512 | 12–24 | .2 | B19515 | 48–72 | .2 |

PROFILE 10, CLAY LOAM [1] FROM 80 RODS SOUTH OF NW CORNER SEC. 6, T. 19 S., R. 51 W., KIOWA COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B19526 | 0–6 | 2 | B19529 | 24–36 | 4 |
| B19527 | 6–12 | 3.5 | B19530 | 36–48+ | 3.5 |
| B19528 | 12–24 | 4 | | | |

PROFILE 11, SILT LOAM [1] FROM 80 RODS NORTH OF SE CORNER SEC. 37, T. 23 S., R. 58 W., OTERO COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B19090 | 0–½ | 10 | B19092 | 6–12 | 14 |
| B19091 | ½–6 | 12 | B19093 | 12–18 | 10 |

PROFILE 12, SILT LOAM [1] FROM 1,000 FEET SOUTH OF NE CORNER SEC. 25, T. 27 S., R. 58 W., OTERO COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B19117 | 0–6 | 2.5 | B19119 | 16–24 | 1 |
| B19118 | 6–16 | 1.5 | B19120 | 24–36+ | 1.5 |

PROFILE 13, MINNEQUA CLAY LOAM FROM 500 FEET EAST OF WEST SECTION LINE OF SEC. 33, T. 23 S., R. 54 W., OTERO COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B19158 | 0–6 | 2.5 | B19160 | 12–18 | 1 |
| B19159 | 6–12 | 2 | B19161 | 18–36+ | .7 |

PROFILE 14, APISHAPA CLAY FROM 800 FEET WEST OF NE CORNER SEC. 35, T. 23 S., R. 56 W., OTERO COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B19163 | 0–12 | 1.5 | B19166 | 36–48 | 1 |
| B19164 | 12–24 | 1 | B19167 | 48–60 | .7 |
| B19165 | 24–36 | 1 | | | |

PROFILE 15, MINNEQUA SILT LOAM FROM 500 FEET WEST OF SE CORNER SEC. 28, T. 23 S., R. 56 W., OTERO COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B19181 | 0–6 | 0.7 | B19184 | 24–36 | 2 |
| B19182 | 6–12 | 1 | B19185 | 36–48 | 2.5 |
| B19183 | 12–24 | 1.5 | B19186 | 48–60 | 3 |

PROFILE 16, PIERRE CLAY LOAM FROM 1,000 FEET NORTH OF SW CORNER SEC. 31, T. 19 S., R. 52 W., CROWLEY COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B19362 | 0–1 | 2 | B19365 | 12–24 | 1 |
| B19363 | 1–6 | 2 | B19366 | 24–36 | 10 |
| B19364 | 6–12 | .8 | B19367 | 36–48 | 5 |

PROFILE 17, NIOBRARA [2] SILT LOAM FROM 3.6 MILES WEST OF UNITED STATES ROUTE 85, ON UNITED STATES ROUTE 5, PUEBLO COUNTY

| | | | | | |
|---|---|---|---|---|---|
| B19616 | 0–6 | 5 | B19620 | 36–48 | 3 |
| B19617 | 6–12 | 5 | B19621 | 48–58 | 3 |
| B19618 | 12–24 | 4 | B19622 | 58–62 | 12 |
| B19619 | 24–36 | 5 | | | |

[1] No name has been assigned.
[2] Geologic formation.

TABLE 8.—*Selenium content of selected profiles from eastern Colorado*—Continued

PROFILE 18, NIOBRARA[a] SILT LOAM FROM 300 FEET NORTH OF W¼ CORNER SEC. 9, T. 18 S., R. 70 W., FREMONT COUNTY

| Laboratory no. | Depth | Selenium | Laboratory no. | Depth | Selenium |
|---|---|---|---|---|---|
| | *Inches* | *P. p. m.* | | *Inches* | *P. p. m.* |
| B19644 | 0-1 | 38 | B19648 | 10-14 | 42 |
| B19645 | 1-4 | 26 | B19649 | 14-26 | 54 |
| B19646 | 4-6 | 22 | B19650 | 26-32 | 98 |
| B19647 | 6-10 | 24 | B19651 | 36-40 | 48 |

PROFILE 19, NIOBRARA[a] SILT LOAM FROM 80 RODS WEST OF CENTER SEC. 3, T. 19 S., R. 68 W., FREMONT COUNTY

| Laboratory no. | Depth | Selenium | Laboratory no. | Depth | Selenium |
|---|---|---|---|---|---|
| B19991 | 0-6 | 1.5 | B19994 | 24-36 | 1 |
| B19992 | 6-12 | 1.5 | B19995 | 36-48 | 1 |
| B19993 | 12-24 | 1 | | | |

PROFILE 20, NIOBRARA[a] SILT LOAM FROM S¼ CORNER SEC. 3, T. 19 S., R. 69 W., FREMONT COUNTY

| Laboratory no. | Depth | Selenium | Laboratory no. | Depth | Selenium |
|---|---|---|---|---|---|
| B20000 | 0-6 | 2.5 | B20003 | 24-36 | 3.5 |
| B20001 | 6-12 | 3 | B20004 | 36-48 | 3 |
| B20002 | 12-24 | 2.5 | | | |

[a] Geologic formation.

A study of the data of these 20 profiles, especially if considered in conjunction with those previously reported (*5*, *6*), will make clear that any uniform variation with depth does not exist. It is true that in some instances there is evidence of some concentration at a point below the surface followed by a decrease at a lower level. An example is profile 4. There is no particular depth at which this apparent concentration occurs nor is it always followed by a lower value at increased depths. In other profiles there is a very definite uniformity of concentration of the selenium throughout the profile. Examples are profiles 7 and 9. In still other cases there is in general a progressive decrease from the surface downward—examples are profiles 3 and 13—or a progressive increase from the surface downward—an example is profile 15. In some instances there is no uniformity of relative content; examples are profiles 2 and 18. Profile 18 shows intense selenization, and the lowest three samples are essentially shale layers.

It would seem probable that a satisfactory explanation of these seemingly erratic variations is found in the following considerations. As will be shown (p. 56) there may be present in a given soil one or more of four different selenium compounds. Two of these are extremely insoluble and essentially immobile. These are the pyritic form and the basic ferricselenite. Two are fairly soluble, the selenate and the organic selenium compounds or the decomposition products derived from the latter forms. Undoubtedly this residual soluble selenium is distributed through the soil profile, as are other soluble salts. Undoubtedly also, however, the chief cause of variation in the soil is the variation of selenium content of the shale which is the parent material of the soil. This variation is so wide and the mixing of soil material by colluvial and loessial movements is so extensive that no uniformity of selenium content either in respect to depth or surface distribution is to be expected. Certainly none is found.

## THE GREENHORN FORMATION

In previous publications from this Bureau (*5*, *6*) the study of the distribution of selenium was first confined to soils presumably derived from Pierre shales, although it was early learned, as a result of the examination of certain portions of the Niobrara formation (*5*), that this formation was likely to be parent material of soils even more toxic than those from the Pierre. This suspicion was amply confirmed by the results of the examination of Niobrara-derived soils in South Dakota, Wyoming, and particularly in Kansas (*6*). During the progress of this work sporadic instances of toxic samples of vegetation growing on soils from other formations were obtained, and also

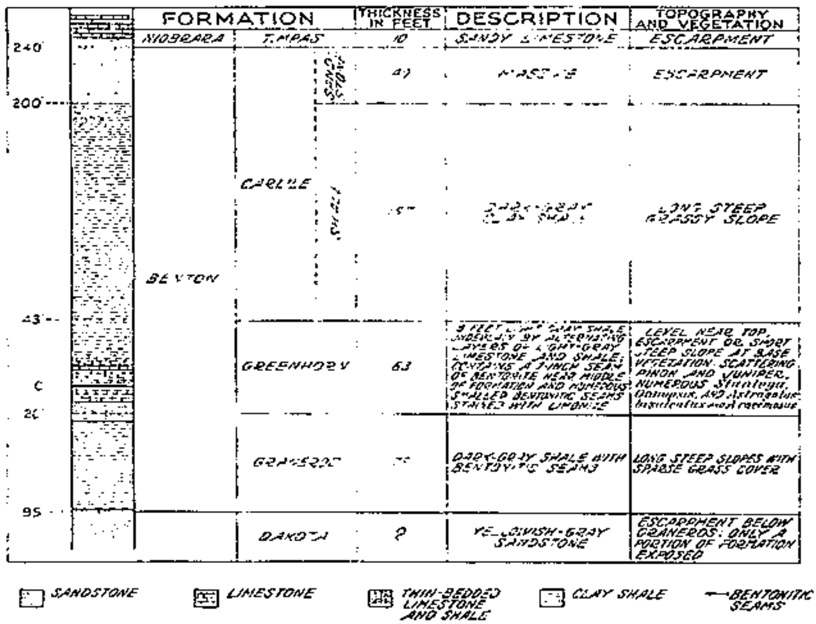


FIGURE 8.—The geologic column through the Greenhorn formation in sec. 18, T. 22 S., R. 66 W., Pueblo County, Colo.

samples of shales and soils were examined which contained quantities of selenium which seemed potentially dangerous. Beath (*1*) also obtained evidence of toxic possibilities in other geologic formations. In general it appeared that the post-Cretaceous materials were relatively low in selenium, although in some instances quite significant quantities were found (*6*). Also in general it appeared that the lower portion of the Niobrara formation, the Fort Hays (*6*), is essentially nonseleniferous so far as its effect on soils is concerned. As a rule, also, only moderate quantities of selenium were found in the various portions of the Benton shales (fig. 3), though occasional samples presumably of Greenhorn were fairly rich. During the current investigations an unusual opportunity was found by John T. Miller for the study of this relation. His description is as follows:

During the course of the survey a complete geologic section extending from the Dakota sandstone through the Benton formations to the Timpas (Fort Hays) limestone was observed along the Pueblo-Beulah road in Pueblo County. This section was measured and sampled in detail.

A description of the geologic column is given in figure 8.

Where these formations are exposed at other locations the topographic relations are very similar to those described in figure 8. The Timpas limestone and Carlile sandstone combine to form a barren cliff 40 to 60 feet high. This is underlain by a long steep slope where a shallow soil has developed from the dark-gray Carlile shale. This soil has a fair grass cover and some pinon pine except in the steeper gullies. Near the Carlile-Greenhorn contact the slope usually merges into a

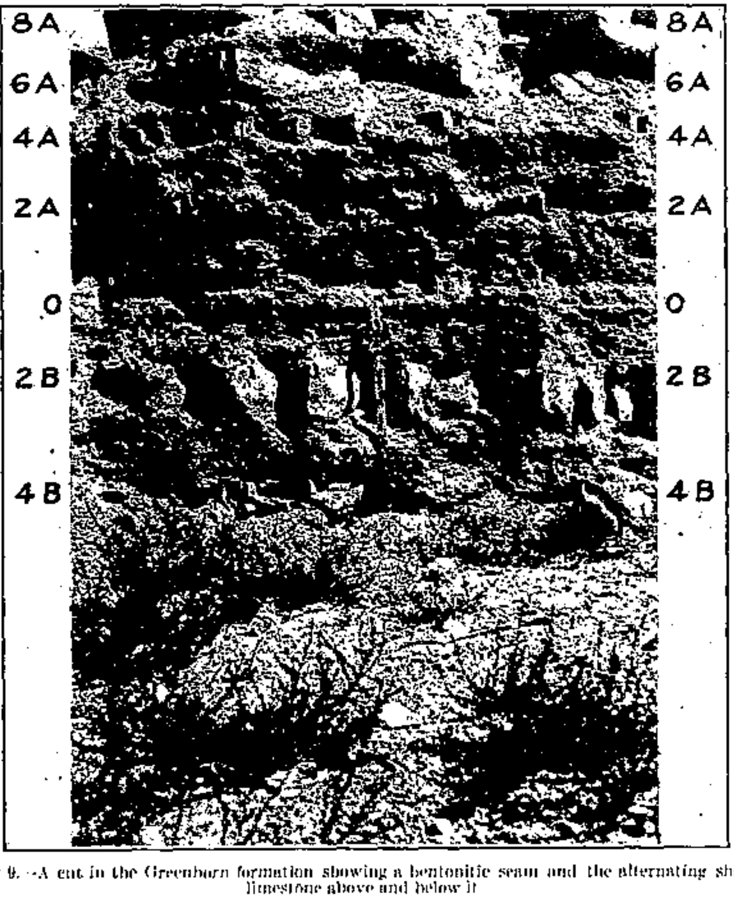


FIGURE 9.—A cut in the Greenhorn formation showing a bentonitic seam and the alternating shale and limestone above and below it

nearly level terrace. Here the soil is chiefly developed from the calcareous Greenhorn shale. This terrace is grassy and has some characteristic seleniferous vegetation. The lower Greenhorn forms a short steep slope or, in many places, a cliff. The soil is shallow and is a stony silt loam. On this soil the vegetation consists of juniper and pinon pine with a scattering growth in places of *Astragalus* and *Stanleya*. The long steep slopes from the Greenhorn to the Dakota sandstone support a fair grass cover.

Figure 9 is a view of the exposure described. The materials collected from the exposure are described in figure 8, and the analyses of them are given in table 9.

TABLE 9.—*Selenium content of samples from a Greenhorn exposure in Pueblo County, Colo., sec. 18, T. 22 S., R. 66 W.*

THE BENTONITIC SEAM AND SAMPLES ABOVE IT

| Laboratory no. | Field no. | Location with reference to 7-inch bentonitic seam | Material | Selenium |
|---|---|---|---|---|
| | | | | *P. p. m.* |
| B19682 | 0 | 7-inch seam | Bentonite (with gypsum crystals) | 1 |
| B19683 | 1a | 0-12 inches | Gray shale (with 1-inch seam of gypsum). | .4 |
| B19685 | 2a | 12-15 inches | Gray limestone | .1 |
| B19687 | 3a | 15 inches to 2 feet 4 inches | Gray clay shale | .7 |
| B19689 | 4a | 2 feet 4 inches to 2 feet 9 inches | Gray limestone | .2 |
| B19691 | 5a | 2 feet 9 inches to 3 feet | Gray clay shale | .4 |
| B19693 | 6a | 3 feet to 3 feet 7 inches | Gray dense limestone | 1 |
| B19695 | 7a | 3 feet 7 inches to 4 feet 4 inches | Gray clay shale | 1 |
| B19697 | 8a | 4 feet 4 inches to 5 feet 6 inches | Dark-gray dense limestone | 1 |
| B19699 | 9a | 5 feet 6 inches to 6 feet 8 inches | Dense dark-gray shale | .8 |
| B19701 | 10a | 6 feet 8 inches to 7 feet 4 inches | Dense gray limestone | .4 |
| B19703 | 11a | 7 feet 4 inches to 8 feet 8 inches | Gray sandy shale | 1 |
| B19705 | 12a | 8 feet 11 inches to 11 feet 8 inches | Limestone (with some sandy shale). | .7 |
| B19707 | 13a | 11 feet 8 inches to 12 feet 5 inches | Light-gray clay shale (streaked with brown). | 1 |
| B19709 | 14a | 12 feet 5 inches to 18 feet 5 inches | Shale with thin shale streaks of bluish limestone: | |
| | | | Shale | 2.5 |
| | | | Limestone | 1 |
| B19712 | 15a | 33 feet above bentonitic seam (shale layer 18 feet 5 inches to 43 feet). | Clay shale | 3 |
| B19714 | 16a | 70 feet above bentonitic seam | Gray Carlile[1] shale | .7 |
| B19713 | 16½a | Just below sandstone | Carlile[1] shale | 1 |
| B19716 | 17a | 200 feet above seam | Yellow Carlile[1] sandstone | .2 |
| B19724 | 1aa | At level of 14a | Shaly clay loam, (0-8 inches) | 1 |
| B19725 | 1aa | do | *Astragalus racemosus* | 8 |
| B19726 | 1ab | At level of 14a (2 feet from 1aa) | Gumweed | 7 |
| B19727 | 1ac | At level of 14a | Stanleya | 90 |
| B19728 | 1ad | do | *Townsendia grandiflora* | 1 |

SAMPLES BELOW THE BENTONITIC SEAM

| Laboratory no. | Field no. | Location with reference to 7-inch bentonitic seam | Material | Selenium |
|---|---|---|---|---|
| B19684 | 1b | 0-11 inches | Dark-gray shale (with thin seam of limonite). | 2.5 |
| B19686 | 2b | 11 inches to 1 foot 9 inches | Dense gray limestone | .2 |
| B19688 | 3b | 1 foot 9 inches to 2 feet 8 inches | Gray shale (streaked with limonite). | 1 |
| B19690 | 4b | 2 feet 8 inches to 5 feet 4 inches | Dense gray limestone | 1.5 |
| B19692 | 5b | 5 feet 4 inches to 6 feet | Dark-gray shale | .8 |
| B19694 | 6b | 6 feet to 6 feet 7 inches | Dense gray limestone | .4 |
| B19696 | 7b | 6 feet 7 inches to 7 feet 3 inches | Gray clay shale | 1 |
| B19698 | 8b | 7 feet 3 inches to 8 feet | Dense dark-gray limestone | 1 |
| B19700 | 9b | 8 feet to 9 feet 1 inch | Gray sandy shale | 1 |
| B19702 | 10b | 9 feet 1 inch to 9 feet 3 inches | Limonite (with bentonite) | 8 |
| B19704 | 11b | 9 feet 3 inches to 9 feet 11 inches | Gray shale | 1.5 |
| B19706 | 12b | 9 feet 11 inches to 10 feet 5 inches | Dark bluish dense limestone | 2 |
| B19708 | 13b | 10 feet 5 inches to 13 feet 11 inches | Composite of gray shale (with bluish limestone). | 1.5 |
| B19711 | 14b | 13 feet 11 inches to 14 feet 2 inches | Limonite-bentonite (with gypsum). | 3 |
| B19713 | 15b | 14 feet 2 inches to 17 feet 6 inches | Gray clay shale | 1 |
| B19715 | 16b | 17 feet 6 inches to 17 feet 7 inches | Limonitic-bentonitic seam | 2 |
| B19717 | 17b | 17 feet 7 inches to 20 feet | Gray shale (with limestone streaks) (Greenhorn). | 1.5 |
| B19719 | 18b | 20 feet to 24 feet | Dark-gray shale (gypsum crystals) (Graneros). | 2.5 |
| B19720 | 19b | 24 feet to 24 feet 6 inches | Yellowish clay shale (with gypsum). | 1 |
| B19721 | 20b | 24 feet 6 inches to 25 feet | Grayish bentonite | .3 |
| B19722 | 21b | 25 feet to 25 feet 6 inches | Gray shale (with yellow stains) | 1 |
| B19723 | 22b | At 60 feet | Dark-gray shale | 3 |
| B20133 | 23b | At 80 feet | Dark-gray clay shale | 1.5 |
| B20134 | 24b | At 90 feet | Bentonitic layer | 3 |
| B20135 | 25b | At 92½ feet | Dark-gray clay shale | .8 |
| B20136 | 26b | At 95 feet | Dakota[1] sandstone | 1.5 |
| B19729 | 1ba | At about 25 feet | Soil from lower Greenhorn,[1] 0-8 inches. | 1 |
| B19730 | 1ba | do | Gumweed | 25 |
| B19731 | 1bb | At about 25 feet (4 feet from no. 1ba) | *Stanleya pinnata* | 200 |
| B19732 | 1bc | At about 25 feet (25 feet from no. 1ba) | Turpentineweed | 70 |
| B19733 | 1bd | At about 25 feet (20 feet below bentonitic seam). | *A. racemosus* | 15 |

[1] Geologic formation.

The data in table 9 reveal that selenium is present in all the sections of the Greenhorn formation at this point. It is also somewhat more abundant, on the average, below rather than above the largest bentonite stratum. This observation has significance when considered in connection with the section dealing with the origin of selenium. Comparison of the quantities of selenium with those reported in the lower Pierre shales and in the upper Niobrara in previous bulletins (*5*, *6*) will show that there is relatively less in the Greenhorn. Indeed it is about the same shown, by unpublished

FIGURE 10.—*Stanleya pinnata* growing on Greenhorn formation (sample B19731, table 9).

data, by the upper portions of the Pierre formation in South Dakota and by the upper portions of the Mancos shales in western Colorado. That these quantities, small as they are, may result in soils capable of producing toxic vegetation is clear from the data of table 9. It is true that the plants represented are not intensely toxic, as compared with the same plants elsewhere, yet they are capable of causing serious trouble (fig. 10). There are many indications of losses presumably due to seleniferous vegetation growing on soils developed from the Greenhorn formation. A disturbing factor in table 9, of which something will be said in the general discussion, is the occurrence of measurable quantities of selenium in the Carlile, above the Greenhorn, and in the Graneros immediately beneath it. Up to the present there is no proof of the occurrence of toxic vegetation from soils definitely derived from the Carlile or Graneros, but these data clearly indicate the possibility of such occurrence.

## THE MORRISON FORMATION

The results of the examination of three samples of Morrison limestone and shale from near Laramie, Wyo., have been reported (*6, p. 72*) in which selenium was present only to the extent of 0.1 p. p. m., while a poisonvetch nearby contained 1,350 p. p. m. and cattle losses were reported on pastures consisting in major part of soils presumably derived from Morrison shale. It was there stated that so large a quantity of selenium in the poisonvetch might be due to residual overlying shale or to spottiness in the Morrison formation. Beath and his coworkers (*4*) report a sample of Morrison shale with 1.3 p. p. m. of selenium. The matter is of considerable importance because the Morrison is the earliest of the Cretaceous formations, and if soils derived from it are seleniferous then it would appear that the whole Cretaceous period must be examined in detail in order to secure adequate data on selenium distribution in soils.

The geologic map[7] indicates an outcrop of approximately 100 square miles of Morrison in southwestern Bent County, Colo., and in the adjoining portions of Las Animas and Otero Counties. In this area the Morrison consists almost wholly of varicolored reddish to gray clay shale. The soils developed upon it are mostly gray to reddish silt loams. Due to cultivation, subsequent abandonment, and overgrazing the present vegetative cover is scanty. In this area early settlers reported toxic conditions, as usual assigned to certain water supplies. In his field work Miller found definite cases of alkali disease and the report of the death of 10 cattle from acute poisoning, and of many losses in periods of short pasturage. He also found many samples of narrowleaf milkvetch and goldenweed. The water of one of the wells was examined and found to contain 0.015 p. p. m. of selenium. It is not probable that water of this type would account for the losses reported. Therefore, the area was examined in some detail, and the results obtained are given in table 10. Included in this table are four samples from T. 27 S., R. 53 W. in Bent County adjoining Las Animas County.

TABLE 10.—*Selenium content of soils and vegetation related to the Morrison formation*

| Laboratory no. | Field no. | Location | Material | Selenium in— | |
|---|---|---|---|---|---|
| | | | | Soil or shale | Vegetation |
| | | | | *P. p. m.* | *P. p. m.* |
| B19465 | 20 | 500 feet north of S¼ corner sec. 12, T. 28 S., R. 53 W. | Morrison[1] clay loam, 0-8 inches. | 0.4 | |
| B19466 | 20a | do | Goldenweed | | 60 |
| B19467 | 20b | 500 feet north of S¼ corner sec. 12, T. 28 S., R. 53 W. (80 rods from no. 20) | Narrowleaf milkvetch | | 2,320 |
| B20025 | 21 | NW¼ sec. 11, T. 28 S., R. 53 W. | Morrison[1] silt loam, 0-8 inches. | .4 | |
| B20026 | 21a | do | Russian-thistle | | t |

[1] Geologic formation.

[7] UNITED STATES GEOLOGICAL SURVEY. GEOLOGIC MAP OF COLORADO. Prepared by W. S. Burbank, T. S. Lovering, E. N. Goddard, E. B. Eckel, and G. W. Stose. 1935.

TABLE 10.—*Selenium content of soils and vegetation related to the Morrison formation*—Continued

| Laboratory no. | Field no. | Location | Material | Selenium in— | |
|---|---|---|---|---|---|
| | | | | Soil or shale | Vegetation |
| | | | | *P. p. m.* | *P. p. m.* |
| B20028 | 22 | 300 feet east of NW corner sec. 2, T. 28 S., R. 53 W. | Morrison [1] silt loam, 0-8 inches | 1 | |
| B20029 | 22a | do | Goldenweed | | 60 |
| B20030 | 23 | 500 feet south of NW corner sec. 2, T. 28 S., R. 53 W. | Morrison [1] silt loam, 0-8 inches | 4 | |
| B20031 | 23a | do | Narrowleaf milkvetch | | 320 |
| B20032 | 24 | W¼ corner sec. 10, T. 28 S., R. 52 W. | Lykins [1] silt loam, 0-8 inches (below the Morrison). | .4 | |
| B20033 | 24a | do | "Cane" | | 1 |
| B20034 | 25 | Center sec. 10, T. 28 S., R. 52 W. | Morrison [1] silt loam, 0-8 inches | 3.5 | |
| B20035 | 25a | do | Narrowleaf milkvetch | | 1,170 |
| B20036 | 26 | NE corner sec. 15, T. 29 S., R. 52 W. | Morrison [1] clay, 0-8 inches | .2 | |
| B20037 | 26a | do | Turpentineweed | | 1 |
| B20038 | 27 | Center sec. 26, T. 28 S., R. 52 W. | Morrison [1] silt loam, 0-8 inches | .3 | |
| B20039 | 27a | do | "Cane" | | 1 |
| B20040 | 28 | W¼ corner sec. 25, T. 28 S., R. 52 W. | Morrison [1] silt loam, 0-8 inches | 3.5 | |
| B20041 | 28a | do | Narrowleaf milkvetch | | 610 |
| B20042 | 29 | E¼ corner sec. 30, T. 28 S., R. 51 W. | Morrison [1] silt loam, 0-8 inches | 12 | |
| B20043 | 29a | do | Narrowleaf milkvetch | | 80 |
| B19406 | 46 | W¼ corner sec. 33, T. 27 S., R. 53 W. | Morrison [1] clay, 0-8 inches | .3 | |
| B19407 | 46a | do | Goldenweed | | 60 |
| B19010 | 48 | N¼ corner sec. 31, T. 27 S., R. 53 W. | Morrison [1] clay loam, 0-8 inches | .3 | |
| B19011 | 48a | do | Goldenweed | | 1 |

[1] Geologic formation.

It appears from the data of table 10, and from field observation, that in the area examined there are at least five townships which have soils capable of producing toxic vegetation. It also appears that, as in other formations which give rise to seleniferous soils, the distribution is sporadic. It would seem clearly evident that the injury to animals reported from this area is due primarily to the seleniferous vegetation. The fact that in this area the seleniferous narrowleaf milkvetch appears is of interest in connection with the points brought out in a discussion of the plant associations on seleniferous soils. Since it is clearly evident that Morrison-derived soils may be seleniferous and since, as indicated in figure 3, the Purgatoire formation lies above it, both formations must be examined more fully. The outcrops of Purgatoire shown on the geologic map [8] in Las Animas County have not been examined nor, indeed, have the Morrison formations themselves been adequately examined.

## THE SAN ISABEL NATIONAL FOREST

At various points on the eastern slope of the Rockies the geologic map of Colorado [8] shows small outcrops of Pierre and Niobrara shales. They usually appear as narrow bands upon the map. Their investigation has been deferred in general until the larger areas of soils presumably derived from these and similar sources shall have been examined. One of these became of particular interest. It lies in Tps. 25 and 26 S., R. 69 W., in Huerfano County. The forest supervisor at Pueblo, Fritz J. Poch, related to John T. Miller that woody aster had been reported from this general location. Since

[8] United States Geological Survey. See footnote 7.

woody aster is a very serious range poison plant in Wyoming but had not been found by the authors in South Dakota, Nebraska, and Kansas, nor in the other portions of Colorado so far examined. Miller located the area referred to which was on the outcrop of Niobrara and consisted topographically of a narrow valley at an elevation of 8,100 feet. The greater portion of the outcrop is covered by soil derived from colluvial materials from various formations. An area of about 320 acres of soil formed a small gulch and appeared to be derived from Apishapa shale (upper Niobrara). In this were growing numerous plants of woody aster, *Astragalus racemosus*, and lambsquarters and scanty vegetation of other kinds (fig. 11). The local ranger stated that in September 1931 a herder drove 200 sheep into this gulch in the evening and in the morning 197 were dead. In 1932

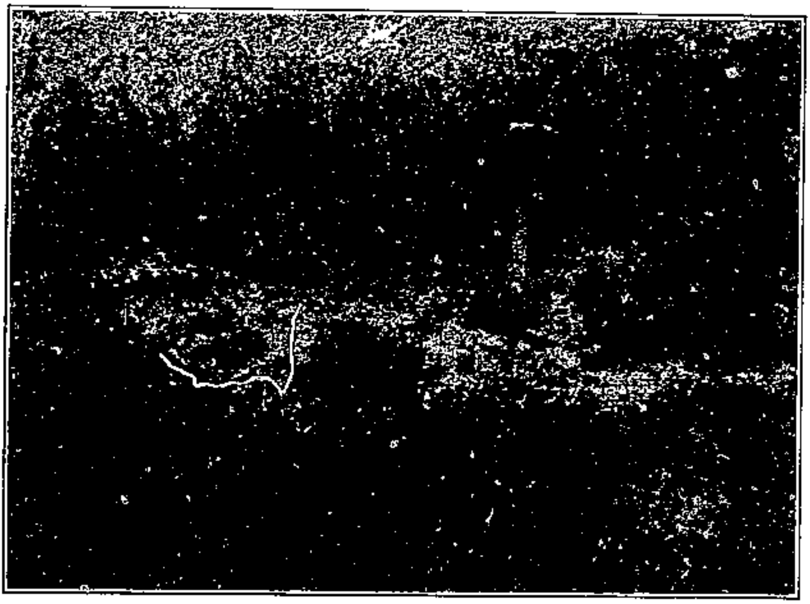

FIGURE 11.—Woody aster on Niobrara soil, San Isabel National Forest, Huerfano County, Colo.

71 out of 157 sheep died overnight in the same gulch. These were reported as actual counts. The samples collected were analyzed, and the results obtained are given in table 11.

TABLE 11.—*Selenium content of soils and vegetation from San Isabel National Forest, Huerfano County, Colo.*

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P. p. m.* | *P. p. m.* |
| B19832 | 9 | SW¼ of NW¼ sec. 27, T. 25 S., R. 69 W. | Niobrara[1] silt loam alluvium, 0-8 inches. | 3 | |
| B19833 | 9a | do. | Woody aster | | 1,750 |
| B19834 | 9b | do. | Lambsquarters | | 890 |
| B19835 | 10 | 40 rods north of no. 9 | Niobrara[1] silt loam | 5 | |
| B19836 | 10a | do. | *Astragalus racemosus* | | 830 |

[1] Geologic formation.

The data of table 11, taken in conjunction with the added information (*3*), have some points of special interest. They demonstrate in very definite fashion the validity of the finding that selenium is the primary cause of many instances of range losses. They form the most convincing single piece of field data connecting cause and effect and, considering the evidence of the forest ranger, of the lethal character that seleniferous vegetation may assume. It is also worth noting that this particular point is the first forested area, even though but sparsely forested, in which toxic selenium conditions have been found to exist. It is perhaps, also, the area of highest rainfall where such conditions have been met. The mean annual rainfall is supposed to be about 21 inches.

## AN OLD SALT WELL

A second example of exceptional conditions is found in an area in El Paso County, Colo. Numerous cases of "alkali disease" were reported from a district within a large ranch, and the source of the trouble was supposed to be a spring on what is known as the Parker Ranch in and about sec. 23, T. 17 S., R. 66 W., and possibly also an old salt well located about 1½ miles distant in the same pasture in section 25. This area also was examined and was a nearly level area the soil of which is developed for the most part from the lower Pierre and upper Niobrara shales. The spring in question was in the bank of a temporary stream and the well in a second drainage line. Samples of water were taken from both spring and well and a salt incrustation from the well, a sample of soil from near the well, and a sample of mud from the spring. Also, a series of samples of vegetation was collected from the vicinity. The vegetation cover over the pasture is fair to sparse, and the area immediately about the salt well consists of about 40 acres of exposed Pierre shale. The results of the examination of these samples are given in table 12. A view of the salt well is given in figure 12, and an example of chronic (mild) selenium poisoning is shown in figure 13.

TABLE 12.—*Selenium content of samples from and about a salt well in El Paso County, Colo.*

| Laboratory no. | Field no. | Location | Material | Selenium |
|---|---|---|---|---|
| | | | | *P. p. m.* |
| B20109 | 14 | NW¼ sec. 29, T. 17 S., R. 66 W | Pierre clay loam, 0–8 inches | 14 |
| B20110 | 14x | do | Salt crust from well | 12 |
| B20111 | 14a | Between no. 14 and no. 15 | Galleta grass | 3 |
| B20112 | 14b | | Scarlet mallow | 60 |
| B20113 | 14c | | Blue grama | 2 |
| B20114 | 14d | | Mallow | 2 |
| B20115 | 14e | | Stinkweed | 2 |
| B20116 | 14f | | Fleabane | 2 |
| B20117 | 14g | | Gumweed | 4 |
| B20118 | 14h | | Salt bush (*Atriplex* sp.) | 50 |
| B20119 | 14i | | Sunflower | 1 |
| B20120 | 14j | | Goldenweed | 90 |
| B20121 | 14k | | Silky sophora | 5 |
| B20122 | 14l | | Wreath aster | 40 |
| B20123 | 14m | | Lambsquarters | 3 |
| B20124 | 14n | | Cocklebur | 2 |
| B20125 | 14o | | Sleepy grass | 2 |
| B20126 | 14p | | Two-groove poisonvetch | 200 |
| B20127 | 14q | | Russian-thistle | 2 |
| B20210 | 14 | | Water from well | .025 |
| B20211 | 15 | NE¼ sec. 23, T. 17 S., R. 66 W | Water from spring | 1 |
| B20128 | 15 | NE¼ sec. 23, T. 17 S., R. 66 W | Mud from spring | 6 |

FIGURE 12.—Taking a sample of water from the old salt well.

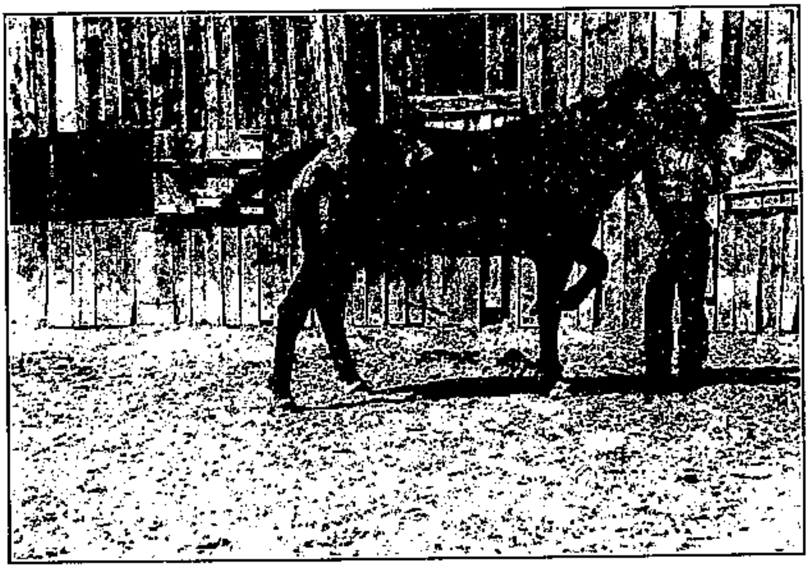

FIGURE 13.—A chronic case of mild selenium poisoning.

The data in table 12 form a strong contrast with those given in table 11. In the former all available vegetation has a very high selenium content. The effect upon animals, as reported, is violently toxic and immediately lethal. In the reports received concerning the Parker Ranch the effects are those of the chronic type represented by the alkali disease. All the vegetation contains selenium, but in only a relatively small portion is the quantity sufficiently high for a single feeding to produce immediate death. Chronic trouble would have been expected had the analyses alone been known.

A second feature of the data should be noted. The selenium present in the water of the salt well is not abnormal for waters draining from a seleniferous area, but that from the spring is very unusual. Indeed among the several hundred samples of water examined, this is exceeded only by that found in water from drainage ditches from seleniferous irrigated areas and in only two instances by these (*5*, *6*). Until this sample was found, the writers were inclined to believe that in all cases where water is presumed to be the cause of serious selenium poisoning (alkali disease) the presumption is in error. They are not so sure now. If it be assumed that a lethal dose of soluble selenium salt is 2 mg per animal pound, it would require but 2,000 mg to kill a 1,000-pound steer. This water would furnish in 20 gallons approximately 80 mg or one twenty-fifth of a lethal dose. Such a quantity if consumed daily would most certainly produce physiological disturbances, and if added to that furnished by consumption of such vegetation as is reported in table 12 would be a real factor in the toxic relationships involved. Even so, this water would scarcely be consumed in large quantity since its total solids amount to 6,500 p. p. m., and animals would refrain from it were any better available. The writers expect to continue the search to see if any really lethal waters of this type exist.

## DRAINAGE WATERS OF THE COLORADO RIVER BASIN

As reported previously (*6*) in the course of the study of the irrigation districts in Montrose, Delta, and Mesa Counties, the selenium content of the Uncompahgre, Gunnison, and Colorado Rivers was determined at points before they had received any drainage of irrigation waters from areas of seleniferous soil. They were then found to contain no selenium, or at best quantities less than 1 part per billion of water. After receiving irrigation drainage all had a measurable selenium content. Indeed the Colorado, despite its tributaries, had still 3 parts per billion at Topock, Ariz. (*36*). It was also found that at the time sampled the Green River and the Dolores contained only traces of selenium and the San Juan at Bluff, Utah, had 6 parts per billion. The latter stream had opportunity, however, before reaching Bluff to receive irrigation drainage from the large irrigation tracts between Durango and Cortez in Colorado and Farmington and Shiprock in New Mexico. It seemed desirable therefore to examine this question more fully and not only because of its relation to irrigation but because of its relation to the question of selenium in sea water.

Partly through the efforts of the writers but chiefly through the cooperation of the Quality of Water Division of the United States Geological Survey and the personal interest of C. S. Howard of that Division, samples of water were secured from all the important tributaries of the Colorado below its confluence with the Eagle River in

Colorado. The data obtained while still somewhat fragmentary are sufficient to present a reasonably clear picture of the movement of selenium in the main drainage systems of this area. They are given in table 13.

TABLE 13.—*Selenium content of water from the Colorado River Basin*

| Laboratory no. | Stream | Location | Date | Type of sample | Selenium |
|---|---|---|---|---|---|
| | | | | | *Parts per billion* |
| B20269 | Colorado River | Cameo, Colo. | Apr. 11-30, 1936 | Daily composite | 0 |
| B20270 | Colorado River | Cameo, Colo. | May 1-31, 1936 | do | 0 |
| B20271 | Colorado River | Cameo, Colo. | June 1-30, 1936 | do | 0 |
| B20272 | Colorado River | Cameo, Colo. | July 1-31, 1936 | do | 0 |
| B20469 | Colorado River | Cameo, Colo. | Aug. 1-31, 1936 | do | 1 |
| B20470 | Colorado River | Cameo, Colo. | Sept. 1-30, 1936 | do | 1 |
| B20273 | Colorado River | Grand Junction, Colo. | Apr. 11-30, 1936 | do | 5 |
| B20274 | Colorado River | Grand Junction, Colo. | May 1-31, 1936 | do | 2 |
| B20275 | Colorado River | Grand Junction, Colo. | June 1-30, 1936 | do | 0 |
| B20276 | Colorado River | Grand Junction, Colo. | July 1-31, 1936 | do | 1 |
| B20467 | Colorado River | Grand Junction, Colo. | Aug. 1-31, 1936 | do | 5 |
| B20468 | Colorado River | Grand Junction, Colo. | Sept. 1-30, 1936 | do | 10 |
| B19565 | Gunnison River | Grand Junction, Colo. | Apr. 1-30, 1936 | do | 15 |
| B19566 | Gunnison River | Grand Junction, Colo. | May 1-31, 1936 | do | 5 |
| B19567 | Gunnison River | Grand Junction, Colo. | June 1-30, 1936 | do | 10 |
| B20277 | Gunnison River | Grand Junction, Colo. | July 1-31, 1936 | do | 25 |
| B20465 | Gunnison River | Grand Junction, Colo. | Aug. 1-31, 1936 | do | 25 |
| B20466 | Gunnison River | Grand Junction, Colo. | Sept. 1-30, 1936 | do | 55 |
| | Dolores River | Cisco, Utah | 1935 | Single sample | (1) |
| | Green River | Green River, Utah | 1935 | do | (1) |
| B19203 | Navajo River [2] | Edith, Colo. | June 30, 1936 | do | 0 |
| B19204 | San Juan River | Rosa, N. Mex. | June 29, 1936 | do | 0 |
| B19202 | do | Pagosa Springs, Colo. | do | do | 0 |
| B17825 | do | Bluff, Utah | Oct. 30, 1935 | do | 6 |
| B18031 | do | do | Mar. 25, 1936 | do | 1 |
| B18258 | do | Shiprock, N. Mex. | May-June 1, 1936 | do [3] | 400 |
| B18090 | Paria River | Lees Ferry, Ariz. | Apr. 8, 1936 | do | 1 |
| B18089 | Little Colorado River. | Grand Falls, Ariz. | Mar. 18, 1936 | do | 1 |
| B18063 | Williams River | Planet, Ariz. | Mar. 28, 1936 | do | 0 |
| B20528 | Salt River [4] | Roosevelt Dam, Ariz. | Nov. 10, 1936 | do | 0 |
| B20536 | Gila River | Coolidge Dam, Ariz. | Nov. 5, 1936 | do | 1 |
| B20537 | do | Gillespie Dam, Ariz. | Nov. 14, 1936 | do | 2 |
| B20535 | Colorado River | Yuma, Ariz. | Nov. 13, 1936 | do | 4 |

[1] Trace.
[2] Tributary of San Juan River.
[3] In a sandy shallow below irrigated area.
[4] Tributary of the Gila River.

The striking feature of the data of table 13 is the freedom of the streams from selenium at points above the influx of irrigation drainage from soils derived from Mancos shales and its presence in the Colorado, Gunnison, and San Juan Rivers at points below such drainage. It is not necessarily true that all the selenium leached out of the seleniferous soils remains dissolved. At least selenium in quantities as high as 1 p. p. m. has been found in the silt deposited in the water samples. It is probable, therefore, that the alluvial deposits of streams may, in certain instances, be seleniferous to some degree. This observation is of importance in connection with the presence of selenium in Nevada.

It is of interest to note the extraordinarily high selenium content of the San Juan River below Shiprock. This is probably an evanescent condition brought about by the fact that the early irrigation on the areas above the sampling point had been started but a few days before. Naturally the sample was taken in a quiet baylet and without any thought that this might be receiving a special contribution.

Perhaps the most important point in the study of these waters is the demonstration of the presence of selenium in the Colorado River at

Yuma and the presumption that considerable quantities of selenium are being carried into the Gulf of California. It is fair to assume that, if such is the case, similar behavior is to be expected of other streams draining seleniferous areas. No other basins have as yet been examined.

## SELENIUM AND OCEAN WATER

Since selenium is being brought into the sea by rivers it was to have been expected that it could be found in ocean waters. Indeed Strock (*31*) has reported 3 and 4 parts per billion of selenium in the waters of the North Sea off Helgoland. On the other hand the presence of selenium has been demonstrated in the deep-sea deposits of the Bering Sea and Arctic Ocean (*37*). It seemed of interest therefore to determine how much selenium remains dissolved in sea water. For this purpose sea water was secured from the Atlantic Ocean off Ocean City, Md., and through the kindness of T. G. Thompson, of the oceanographic laboratories of the University of Washington, a "profile" of water from the Pacific Ocean at lat. 46°39′ and long. 147°47′ was obtained. This profile consisted of samples taken at the surface and at 25, 100, 1,000, and 2,000 m. A similar profile of water from Puget Sound, off Point No Point, was furnished at depths of 0, 10, 25, 50, 100, and 190 m. These samples were examined with extreme care using the method employed by Strock (*31*). Since no selenium was found in any of these samples by adding ferric chloride and ammonia and examination of the resulting precipitate, this procedure was supplemented by examination of the filtrate. The filtrate was treated with sodium peroxide and evaporated to about 300 cc and then treated with an excess of nitric acid and warmed on the steam bath until chlorine evolution ceased. The residue was treated with sulphuric acid and heated until free from nitric acid. The usual procedure for determination of selenium was then carried out.

No selenium was found in any sample of ocean water. It was demonstrated that the Strock procedure is adequate to recover quantitatively 0.01 mg of selenium, as sodium selenite, from 4 liters of distilled water—this corresponds to 2.5 parts per billion—and qualitative detection as low as 0.25 part per billion. The supplemental procedure is evidence that no selenium is present in forms other than selenite, at least in quantities in excess of 1 part per billion. In the sample from Puget Sound a quantity of selenium was detected of the order of magnitude of 0.25 part per billion. The absence of selenium from sea water perhaps finds explanation in the facts presented in the section dealing with the forms of selenium in the soil.

## SELENIUM IN GERMAN WATERS

Since no measurable amount of selenium was detected in the water from either the Atlantic or Pacific Oceans, and it was reported by Strock (*31*) as present in the North Sea, it seemed possible that a selenium source might exist in the rivers flowing into the Bight of Helgoland. To obtain some light upon this question, and because the Elbe rises in a cretaceous area, and both it and the Weser flow through highly industrialized areas using coal for fuel, which may be a source of selenium, a series of water samples was obtained from Germany through the kindly cooperation of J. J. Meily, the American consul at Hamburg, and the courtesy of the Deutsche Seewarte. The location of the samples is shown in figure 14. Two of them are from the Elbe, one above, the other below, Hamburg; one from the Weser below Bremen; one from the bay below the mouth of the Weser and Elbe; and two from the North Sea. These samples were very carefully examined for selenium, using 5-liter samples for testing in each case. The results are given in table 14.

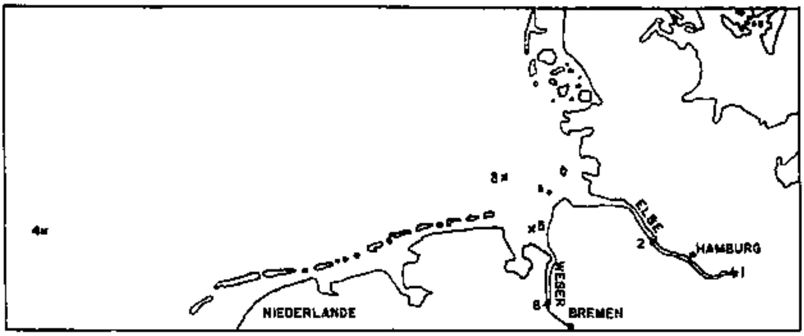


FIGURE 14.—Location, indicated by X, from which samples of German waters were obtained.

The data given in table 14 are of exceptional interest. The presence of selenium in the Elbe is definitely shown, small as is the quantity found, and contrasts with its absence from the Weser. The influence of Hamburg and Bremen on the selenium content of the rivers is not detectable within current limits of accuracy. Equally clear is the absence of selenium from North Sea water within the limit stated. That none was found was surprising both by reason of its presence in the Elbe and its presence reported by Strock (*31*). It is true that Strock does not locate exactly the source of his sample, and in view of the writers' data on sulphuric acid it may be that his sample was contaminated from a local source. It seems clear from the data in tables 13 and 14 that selenium is not present in ocean waters to an amount in excess of 1 part per billion. This raises the question of the fate of that carried into it by rivers or received from other sources, for example, rains and winds. A tentative answer is found in the sections of this report dealing with the forms of selenium in the soil and the origin of seleniferous soils.

TABLE 14.—*Selenium content of water from the North Sea and the Elbe and Weser Rivers*

| Laboratory no. | Field no. | Location | Material | Selenium |
|---|---|---|---|---|
| | | | | *Parts per billion* |
| B10212 | 1 | Elbe River, near Geesthacht | Fresh water | 1 |
| B19213 | 2 | Elbe River, near Brunshausen | do | 1 |
| B19214 | 3 | 54° N. and 8° E., North Sea | Salt water | 0 |
| B19215 | 4 | 53°31′ N. and 8°14′ E., North Sea | do | 0 |
| B10216 | 5 | 53°43.5′ N. 8°17′ E., at Robbensteert | do | 0 |
| B19217 | 6 | Lower Weser, near Elsfleth | Fresh water | 0 |

## SELENIUM IN HAWAII

During the course of the work C. A. Browne of this Bureau called attention to the existence of "selenio-sulphur" in Hawaii. The suggestion resulted in an investigation, the results of which have been published in part (*8*). They are here recapitulated, with additional data. A sample of volcanic sulphur on lava from the island of Hawaii was sent by T. A. Jagger and another was furnished by E. S. Shepherd of the Geophysical Laboratory of the Carnegie Institution. A sample of gas collected from the Kilauea Crater in 1917 was also made available by E. S. Shepherd. Through cooperation with the Hawaii Agricultural Experiment Station, the Soil Conservation Service, and the Soil Survey Division, a considerable number of profiles of soils from various islands were made available. There were also made available a few samples of vegetation growing upon areas presumably containing selenium. Unfortunately, simultaneous collection of soil and vegetation was not effected. In addition to the sulphur samples from Hawaii, M. Perret furnished, through E. S. Shepherd, a sample of sulphur containing selenium from Montserrat in the Leeward Islands of the West Indies. This is included with the Hawaiian data for reasons which will appear. Attention is also directed to the demonstration of selenium in the volcanic emanations from the Valley of Ten Thousand Smokes (*39*). The results of the examination of the samples are given in table 15. Names given for various soil series have not yet been correlated, so it is possible that some of the names may later be revised to correspond with previously established series names.

TABLE 15.—*Selenium content of soils*[1] *and other materials from Hawaii*

ISLAND OF HAWAII

| Laboratory no. | Field no. | Location | Material | Selenium |
|---|---|---|---|---|
| | | | | *P.p.m.* |
| B17980 | | Kilauea | Gas (600 cc) | [2] 0.005 |
| B17910 | | | Lava and sulphur | 1,400 |
| B17985 | | | Volcanic sulphur | 2,200 |
| B20562 | | Montserrat, West Indies. | do | 5 |
| C1188 | 610101 | 3.1 miles west by northwest of Hakalau. Elevation, 200 feet; rainfall, 150 inches. | Kaiwiki silty clay loam, 0–9 inches. | 4 |
| C1190 | 610102 | | Kaiwiki silty clay loam, 9–14 inches. | 2 |
| C1191 | 610103 | | Kaiwiki silty clay loam, 14–26 inches. | 3.5 |
| C1192 | 610104 | | Kaiwiki silty clay loam, 26–28 inches. | 3 |
| C1193 | 610105 | | Kaiwiki silty clay loam, 28–38 inches. | 3 |
| C1194 | 610106 | | Kaiwiki silty clay loam, 38–50 inches. | 5 |
| C1194 | 610107 | 1 mile north of Papaikou. Elevation, 1,100 feet; rainfall, 200 inches. | Hilo silty clay loam, 0–9 inches. | 3.5 |
| C1195 | 610108 | | Hilo silty clay loam, 9–19 inches. | 4 |
| C1196 | 610109 | | Hilo silty clay loam, 19–22 inches. | 3 |
| C1197 | 610110 | | Hilo silty clay loam, 22–25 inches. | 3 |
| C1198 | 610111 | | Hilo silty clay loam, 25–35 inches. | 5 |
| C1199 | 610112 | | Hilo silty clay loam, 35–54 inches. | 3 |
| C1200 | 610113 | | Hilo silty clay loam, 54–67 inches. | 3 |
| C1344 | 610131 | 0.6 miles toward Waimea from Hawi Junction. Elevation and rainfall not given. | Puu Huo silt loam, 0–6 inches | 1.5 |
| C1345 | 610132 | | Puu Huo silt loam, 6–10 inches | .5 |
| C1346 | 610133 | | Puu Huo silt loam, 10–22 inches | .5 |
| C1347 | 610134 | | Puu Huo silt loam, 22–28 inches | .4 |
| C1348 | 610135 | | Puu Huo silt loam, 28–40 inches | .4 |
| C1349 | 610136 | ½ mile seaward from Upolu airport junction. Elevation and rainfall not given. | Hawi silty clay loam, 0–12 inches | 1.5 |
| C1350 | 610137 | | Hawi silty clay loam, 12–17 inches | 1.5 |
| C1351 | 610138 | | Hawi silty clay loam, 17–27 inches | 1.5 |
| C1352 | 610130 | | Hawi silty clay loam, 27–34 inches | 1 |
| C1353 | 610140 | | Hawi silty clay loam, 34–40 inches | .6 |
| C1361 | 610148 | 1½ mile east of Kukuihaele. Elevation 1,100 feet; rainfall, 100 inches. | Hamakua heavy loam, 0–9 inches | 1.5 |
| C1362 | 610140 | | Hamakua heavy loam, 9–25 inches | 1 |
| C1363 | 610150 | | Hamakua heavy loam, 25–32 inches | .5 |
| C1364 | 610151 | | Hamakua heavy loam, 32–40 inches | 1 |

[1] Soil names used in this table are tentative, since the soil survey of the Territory is now in progress and the classification is incomplete.
[2] Milligram in 600 cc.

TABLE 15.—*Selenium content of soils and other materials from Hawaii*—Continued

ISLAND OF HAWAII—Continued

| Laboratory no. | Field no. | Location | Material | Selenium |
|---|---|---|---|---|
| | | | | *P.p.m.* |
| C1354 | 610141 | 1.1 miles inland from Kukuihaele. Elevation, 1,500 feet; rainfall, 120 inches. | Okala silty clay loam, 0-9 inches | 3.5 |
| C1355 | 610142 | | Okala silty clay loam, 9-13 inches | 4 |
| C1356 | 610143 | | Okala silty clay loam, 13-20 inches | 2 |
| C1357 | 610144 | | Okala silty clay loam, 20-30 inches | 1 |
| C1358 | 610145 | | Okala silty clay loam, 30-36 inches | 2.5 |
| C1359 | 610146 | | Okala silty clay loam, 36-42 inches | 3 |
| C1360 | 610147 | | Okala silty clay loam, 42-50 inches | 3 |
| C1333 | 610120 | Kaiwiki plantation, 1½ miles southwest of Ookala. Elevation, 1,300 feet; rainfall, 120 inches. | Okala clay loam, 0-9½ inches | 5 |
| C1334 | 610121 | | Okala clay loam, 9½-17 inches | 8 |
| C1335 | 610122 | | Okala clay loam, 17-25 inches | 4 |
| C1336 | 610123 | | Okala clay loam, 25-32 inches | 3.5 |
| C1337 | 610124 | | Okala clay loam, 32-40 inches | 2 |
| C1338 | 610125 | | Kaula clay loam, 0-4 inches | 3 |
| C1339 | 610126 | | Kaula clay loam, 4-9 inches | 3 |
| C1340 | 610127 | | Kaula clay loam, 9-14 inches | 3 |
| C1341 | 610128 | | Kaula clay loam, 14-24 inches | 3 |
| C1342 | 610129 | | Kaula clay loam, 24-32 inches | 2.5 |
| C1343 | 610130 | | Kaula clay loam, 32-36 inches | 3 |
| C1327 | 610114 | Kaiwiki plantation, southwest of Ookala. Elevation, 400 feet; rainfall, 120 inches. | Koholalele clay loam, 0-2 inches | 2 |
| C1328 | 610115 | | Koholalele clay loam, 2-6 inches | 1 |
| C1329 | 610116 | | Koholalele clay loam, 6-12 inches | 4 |
| C1330 | 610117 | | Koholalele clay loam, 12-16 inches | 1 |
| C1331 | 610118 | | Koholalele clay loam, 16-32 inches | 2.5 |
| C1332 | 610119 | | Koholalele clay loam, 32-36 inches | 2 |

ISLAND OF MAUI

| Laboratory no. | Field no. | Location | Material | Selenium |
|---|---|---|---|---|
| B5787 | 9306 | 156°39′40″ W. 20°56′20″ N. Elevation, 2,600 feet; rainfall, 100 inches. | Red clay, 0-6 inches | 7 |
| B5788 | 9307 | | Red clay, 6-9 inches | 15 |
| B5789 | 9308 | | Red clay, 9-30 inches | 18 |
| B5790 | 9309 | | Lava and soil, 30-40 inches | 8 |
| C938 | H. T. 56 | 5 miles north by northeast of Lahaina. Elevation, 2,550 feet; rainfall, 100 inches. | Silty clay loam, 0-7 inches | 8 |
| C939 | H. T. 57 | | Silty clay loam, 7-15 inches | 26 |
| C940 | H. T. 58 | | Silty clay loam, 15-22 inches | 3 |
| C941 | H. T. 59 | | Silty clay loam, 22-30 inches | 2 |
| C942 | H. T. 60 | About 5 miles north by northeast of Lahaina. Elevation, 1,950 feet; rainfall unknown. | Reddish silty clay loam, 0-7 inches | 14 |
| C943 | H. T. 61 | | Reddish silty clay loam, 7-19 inches | 18 |
| C944 | H. T. 62 | | Reddish silty clay loam, 19-31 inches | 14 |
| C945 | H. T. 63 | | Reddish silty clay loam, 31+ inches | 14 |
| C946 | H. T. 64 | About 5 miles north by northeast of Lahaina. Elevation, 1,250 feet; rainfall unknown. | Reddish silty clay loam, 0-7 inches | 1.5 |
| C947 | H. T. 65 | | Reddish silty clay loam, 7-13 inches | 2 |
| C948 | H. T. 66 | | Reddish silty clay loam, 13-25 inches | 2 |
| C949 | H. T. 67 | | Reddish silty clay loam, 25-41 inches | 1 |
| C950 | H. T. 68 | | Reddish silty clay loam, 41-60 inches | 1 |
| C951 | H. T. 69 | | Reddish silty clay loam, 60+ | 1 |
| B5791 | 9302 | 156°40′24″ W., 20°58′24″ N. Elevation, 450 feet; rainfall, 20 inches. | Clay loam, 0-2 inches | 1 |
| B5792 | 9303 | | Clay loam, 2-7 inches | 3 |
| B5793 | 9304 | | Clay loam, 7-28 inches | .6 |
| B5794 | 9305 | | Clay loam, 28-50 inches | 1 |

ISLAND OF MOLOKAI

| Laboratory no. | Field no. | Location | Material | Selenium |
|---|---|---|---|---|
| B3712 | | 157°14′30″ W., 21°8′30″ N. Elevation, 500 feet; rainfall, 20 inches. | Red silty clay, 0-3 inches | 1 |
| B3713 | | | Red silty clay, 3-13 inches | 2.5 |
| B3714 | | | Red silty clay, 13-35 inches | 3 |
| B3715 | | | Red silty clay, 35-46 inches | 3 |
| B3716 | | | Red silty clay, 46-60 inches | 1 |

ISLAND OF OAHU

| Laboratory no. | Field no. | Location | Material | Selenium |
|---|---|---|---|---|
| B17048 | A-1 | Wahiawa Erosion Experiment Station. Elevation unknown; annual rainfall, presumably about 50 inches. | Soil profile, top section | 10 |
| B17049 | A-2 | | Soil profile, middle section | 10 |
| B17050 | A-3 | | Soil profile, bottom section | 10 |
| B17966 | 1 | | Soil profile, top section | 12 |
| B17967 | 2 | | Soil profile, middle section | 10 |
| B17968 | 3 | | Soil profile, bottom section | 12 |

TABLE 15.—*Selenium content of soils and other materials from Hawaii*—Continued

ISLAND OF KAUAI

| Laboratory no. | Field no. | Location | Material | Selenium |
|---|---|---|---|---|
| | | | | *P.p.m.* |
| B3717 | A | 159°27′48″ W., 22°12′36″ N. Elevation, 500 feet; rainfall, 100 inches. | Red clay, 0–4 inches | 15 |
| B3718 | $A_2$ | | Red clay, 4–16 inches | 15 |
| B3719 | B | | Red clay, 16–33 inches | 12 |
| B3720 | C | | Red clay, 33–50 inches | 12 |
| B3721 | D | | Red clay, 20 feet | .4 |
| C784 | 37158 | 2 miles south of Kalihiwai. Rainfall, 90 inches. | Kalihikai silty clay, 0–6 inches | 10 |
| C785 | 37159 | | Kalihikai silty clay, 12–20 inches | 6 |
| C786 | 37160 | | Kalihikai silty clay, 20–54 inches | 2 |
| C787 | 37161 | Highlands above Waimea Canyon. Rainfall, 100 inches. | Kainamanu silt loam, 0–5 inches | 6 |
| C788 | 37162 | | Kainamanu silt loam, 5–9 inches | 14 |
| C789 | 37163 | | Kainamanu silt loam, 9–15 inches | 16 |
| C790 | 37164 | | Kainamanu silt loam, 15–20 inches | 12 |
| C791 | 37165 | | Kainamanu silt loam, 20–40 inches | 1.5 |
| C1201A | 37166 | 2 miles southwest of Kilohana Lookout. Rainfall, 100 inches. | Kumuweia gravelly loam, 0–1 inch (dead vegetation and soil). | 7 |
| C1201 | 37167 | | Kumuweia gravelly loam, 1–3 inches | 20 |
| C1202 | 37168 | | Kumuweia gravelly loam, 3–9 inches | 20 |
| C1203 | 37169 | | Kumuweia gravelly loam, 9–15 inches | 12 |
| C1204 | 37170 | | Kumuweia gravelly loam, 15–41 inches | 20 |
| C792 | 37171 | 0.75 mile north of Hanapepe. Rainfall, 25–30 inches. | Hanapepe, 0–8 inches | 1 |
| C793 | 37172 | | Hanapepe, 8–14 inches | 1 |
| C794 | 37173 | | Hanapepe, 14–32 inches | 1 |
| C795 | 37174 | | Hanapepe, 32–42+ inches | 1 |

A number of comments may be made upon the data of table 15. It would appear that selenium is a component of volcanic gaseous emanations in Hawaii. From other sources, not quoted, it appears that this is always the case. Whether or not there is wide variation in relative quantity in different eruptions and between different volcanic sources cannot be determined from available data. The difference between the quantities found in the Hawaiian and Montserrat samples is not conclusive. Methods sufficiently delicate are not available for such determinations, could satisfactory samples be secured, yet the resulting data might prove of considerable interest in connection with geologic correlation studies.

Since the Hawaiian Islands present wide variations in rainfall, it is possible to connect the rainfall with the quantity of selenium found in the soil profiles. The results of this comparison were wholly unexpected. In the areas previously examined the lower the mean annual rainfall the greater, in general, is the soil selenium, where the soils are of comparable character. In the Hawaiian soils the reverse is most decidedly the case. The relation of the rainfall to the selenium content is particularly clearly defined in the samples from the island of Maui. These were all taken on the same hillside and from elevations ranging from 2,550 to 450 feet. The two soils from the higher elevations have the following mean contents: At 2,500 feet, 12 p. p. m.; at 2,550 feet, 9.7. The estimated annual rainfall is upwards of 100 inches. The profiles at 1,950 and 1,250 feet have a mean content of 15 and 1.4 p. p. m., respectively. The rainfall at these points is unknown to the writers, but certainly the samples at 1,250 feet have the lower rainfall. The samples taken at 450 feet are under an annual rainfall of but 20 inches, and the mean selenium content of this profile is but 1.4 p. p. m. These profiles, as well as the one from the island of Molokai and the profile listed first from the island of Kauai, have been carefully examined with respect to texture and the chemical composition of both soils and colloids (*14*). All are highly weathered soils and contain much free iron oxide.

It appears from their analyses that those soils developed under high rainfall are more laterized than those developed under lower rainfall. It is not difficult to imagine that these soils obtain their selenium not from parent lava but through rainfall. Lavas so far examined contain very little selenium. The greater the rainfall, then, the greater should be the quantity of selenium available to the soil. The data of the table in general are in accord with these assumptions. The question, of course, arises as to why selenium remains in these soils since it is certain from evidence collected elsewhere that percolating waters, whether from rain or irrigation, tend to decrease the selenium

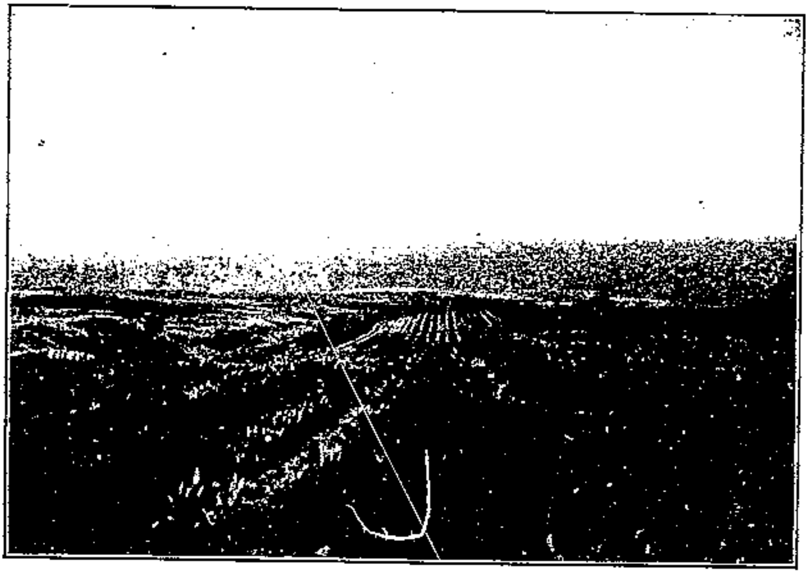

FIGURE 15.—A pineapple plantation on the island of Maui. (Photograph by C. E. Kellogg).

content of soils. It is believed that a satisfactory answer to this question is found in the data submitted on the forms of selenium in the soil. Anticipating the discussion of this topic, attention is called to the fact that the selenium present in volcanic emanations should, at least for the most part, be present as selenium dioxide or as salts of selenious acid.

No data for vegetation are given in table 15. Some 20 samples have been examined, but unfortunately most of these were unidentified with respect to location or name or had been sterilized by steam at the plant quarantine station in Hawaii. In no case, however, was any sample found to contain in excess of 3 p. p. m. of selenium and that only in one sample. Included among the samples were several legumes, including koa haloe (*Leucaena glauca*). This plant is reported as responsible for the loss of hair of horses and mules in the Bermudas and in Hawaii. It also is found in Puerto Rico. In no case has it been found to contain significant quantities of selenium. It is not certain that any of the Hawaiian types of vegetation (fig. 15) examined are efficient absorbers of selenium. It seems, however, probable that in Hawaii no seriously toxic forms of vegetation are present even on soils which contain quantities of selenium which in the soils of Colorado, Wyoming, Kansas, Nebraska, and South Dakota would produce intensely poisonous plants. This conclusion is based not only upon the results obtained from the samples examined but also upon the character of the soils.

That these soils are not likely to produce seleniferous vegetation is also shown by two experiments conducted by Gile.[9] Millet is a more than fair absorber of selenium when grown on seleniferous soils, yet when grown on the soil from Oahu (B17948, table 15) no measurable quantity of selenium was found in 7.7g of green plants. When grown on the soil from Kauai (B3717, table 15) it contained but 1 p. p. m.

## SELENIUM IN PUERTO RICO

During the course of the soil survey of Puerto Rico a series of samples of soil derived from Cretaceous formations was furnished us by R. C. Roberts of the Soil Survey Division and also a series collected by J. O. Carrero of the Agricultural Experiment Station at Mayaguez. The results are given in table 16.

TABLE 16.—*Selenium content of soils and vegetation from Puerto Rico*

| Laboratory no. | Field no. | Location | Material | Selenium in— | |
|---|---|---|---|---|---|
| | | | | Soil or shale | Vegetation |
| | | | | *P.p.m.* | *P.p.m.* |
| B17033 | 1 | | Soil, 1–12 inches | 0.7 | |
| B17934 | 2 | Hacienda Mercidita, Ponce Isabella Poniente district. | Soil, 12–24 inches | .3 | |
| B17935 | 3 | | Soil, 1–12 inches | 1 | |
| B17936 | 4 | | Soil, 12–25 inches | .3 | |
| B18060 | | | Soil, 0–7 inches | 1 | |
| B18061 | | L. Fajardo farm, Maricao | Soil, 7–16 inches | 1.5 | |
| B18062 | | | Soil, 16–27 inches | .4 | |
| B18066 | | Puerto Rico Experiment Station farm, Mayaguez. | Soil, 0–6 inches | .5 | |
| B18067 | | | Soil, 6–15 inches | 1.5 | |
| B18068 | | | Soil, 15–27 inches | .2 | |
| B19490 | 1a | | Mucara silty clay loam, 0–11 inches. | .3 | |
| B19491 | 1b | | Parent shale at 4 feet | .4 | |
| B19492 | 1c | 1 km southwest of Dolores | Hedionda (*Lonchocarpus latifolius*). | | 0 |
| B19493 | 1d | | Hediondilla (*Leucaena glauca*) | | 0 |
| B19494 | 1e | | Pigeonpea (stalks) | | 0 |
| B19495 | 1f | | Pigeonpea (seeds and pods) | | 0 |
| B19496 | 2a | | Yunes clay, 0–8 inches | .4 | |
| B19497 | 2b | | Parent rock at 2 feet | 2.5 | |
| B19498 | 2c | Guaynabo filtration plant | Escoba dulce (*Sida rhombifolia*). | | 1 |
| B19499 | 2d | | Hediondilla | | 0 |
| B19500 | 3a | | San Germán clay, 0–6 inches | .4 | |
| B19501 | 3b | 2 km south of Cabo Rojo | Parent limestone | .0 | |
| B19502 | 3c | | Hediondilla | | 1 |
| B19503 | 4a | | San Germán clay, 0–4 inches | .5 | |
| B19504 | 4b | | Reddish-brown clay, 5–6 inches | .4 | |
| B19505 | 4c | Guanica quarry | Parent limestone | .0 | |
| B19506 | 4d | | Zarzarilla (*Leptoglottis portoricenses*). | | 0 |
| B19507 | 5a | | Meros sand, 0–6 inches (calcareous). | .4 | |
| B19508 | 5b | Southwest of Central Aguirre | Meros sand, 6–20 inches (calcareous). | .3 | |
| B19509 | 5c | | Zarzarilla ((seeds and pods) | | 1 |
| B2957 | 5802105 | | Fajardo silty clay, 12–28 inches | 1.5 | |
| B2997 | 5802141 | San Juan area | Yunes clay, 0–6 inches | 1 | |
| B2998 | 5802142 | | Yunes clay, 6–9 inches | 1.5 | |
| B2999 | 5802143 | | Yunes clay, 9–30 inches | 1.5 | |
| B3000 | 5803115 | | Yunes clay, 0–4 inches | 1.5 | |
| B3001 | 5803116 | Fajardo area | Yunes clay, 4–18 inches | 2 | |
| B3002 | 5803117 | | Yunes clay, 14–28 inches | 10 | |

[9] Studies on the relation between soil composition and selenium absorption by plants. Unpublished data.

The data of table 16 are very much worth reporting despite their generally negative character. The soils samples examined are all of cretaceous origin, and some of them are from cretaceous shales. The geological relations are somewhat uncertain. The absence of selenium from the few plants examined indicates that no selenium problem probably exists in the island, even though the red soils about Mayaguez contain appreciable quantities of selenium and the Yunes clay, particularly in the Fajardo area, would under favorable conditions produce toxic plants.

## FORMS OF SELENIUM IN THE SOIL

In the previous bulletins (*5, 6*) of this division dealing directly with the distribution of selenium in the soil only incidental attention has been directed to the actual forms of its existence in the soil. Sufficient data have now been accumulated to render a discussion of this topic possible and probably useful as an explanation of a part of the seemingly erratic character of the relation between the selenium content of soils and of vegetation growing upon them. A sample of crude sulphur from Colorado is reported (*5, table 9*) as containing 8,350 p. p. m. of selenium, and in this bulletin are reported samples of crude sulphur containing 1,400, 2,200, and 5 p. p. m. of selenium. In this laboratory several samples of soils have been examined which had received the spray residues of the insecticide known as Selocide. In all such cases measurable quantities of selenium have been found. This spray material, being a mixed selenide-sulphide, when acted upon by air and moisture may be expected to produce elemental selenium. In view of these facts it is to be expected that under certain conditions soils may contain free selenium. No effort has as yet been made to demonstrate its actual presence in any soil. If present, however, it is to be expected that it would follow the general behavior of sulphur and ultimately be converted to selenium compounds related to selenious acid or selenites. In the absence of air and moisture it may be expected to behave as does sulphur and ultimately be converted to the selenium analogs of the sulphides.

In the examination of several hundred samples of sulphide ores for selenium in this laboratory no case has been found in which selenium is wholly absent (*35*). It follows therefore that soils containing pyrites will necessarily contain selenium. In the shales and like formations in which selenium occurs pyritic nodules are often found, and several of these have been examined for selenium. The soils of the semiarid areas are usually very immature and have not undergone extensive weathering. It is reasonable to assume therefore that such soils may have a portion of their selenium content in the form of insoluble selenides. Such occurrence is relatively unimportant, except for its bearing upon the problem of the sources of selenium, for in pyrites certainly selenium is not available either as a plant food or poison. It is possible that this statement while true in general may not apply to cases where the sulphide is in a form analogous to marcasite, which weathers rapidly and may release selenium in water-soluble form.

In the course of examination of hundreds of samples of shale, of which only a small portion has been reported, analyses of separate limonitic concretions or of limonitic pseudomorphs frequently showed a selenium content greater than that of the immediately adjacent strata. For example, an iron oxide concretion in the Niobrara shale had a selenium content of 48 p. p. m., while the adjacent shale had but 3. Again the concretionary material of sample no. B18344 (table 1) from Pueblo County, Colo., has a selenium content of 156 p. p. m., while adjacent samples of material in the same profile (table 8, profile 17) showed a maximum quantity of 12 p. p. m. It was therefore assumed that in such cases the high result in the concretion represented residual selenium from weathered pyrites. This assumption, even if correct, does not establish the chemical form in which the selenium remains in the concretions or in the soil itself.

The solution of the problem is not an easy one, since the quantity of selenium present in soils is extremely small. Indeed, the maximum quantity of selenium found as a result of the examination of several thousand soil samples is 82 p. p. m. or 0.008 percent. The normal quantity found in soils which are considered "seleniferous" is much less, and in most cases is only from 1 to 6 p. p. m. or 0.0001 to 0.0006 percent.

Approximately 100 samples of soil were extracted with water. The procedure was to add to 60 g of the soil 600 cc of water, shake overnight in a mechanical shaker, and filter off 500 cc of the liquid by aid of a Pasteur-Chamberland filter. The selenium content of the water extract from the samples used ranged from less than 0.1 to 38 p. p. m. of soil sample. In about 80 percent of the extracts no selenium in excess of 0.1 p. p. m. could be detected when subjected to the usual process of examination. One of these, a sample of raw shaly soil found in Gove County, Kans., was selected for careful examination. It contained 22 p. p. m. of selenium. This sample was orange in color and contained 57 percent of calcium carbonate, 4.4 percent of iron oxide, and but 0.2 percent of organic matter. It also contained 0.6 percent of water-soluble matter, mostly calcium sulphate, with traces of chlorides and bicarbonates. Extraction of this material with water, as described, brought into solution only 0.2 p. p. m. of selenium, or approximately 1 percent of that present. When treated with a quantity of hydrochloric acid, just insufficient to dissolve the limestone present, no increased removal of selenium was effected. The residual material was freed from chloride by repeated washing and then refluxed for 5 hours with a 10-percent solution of potassium sulphite. The filtered extract contained 0.4 p. p. m. of selenium or about 2 percent of the original content. This treatment may be considered as effecting removal of any selenium present in the elemental form (*22*). It should also remove any "exchangeable anions" by double decomposition.

The result obtained seems to indicate that the free element is essentially absent and also that the compound present is exceedingly insoluble in water. This latter indication is emphasized by the fact that refluxing the sample with 10-percent sodium sulphate and then with 10-percent disodium phosphate likewise removed practically no selenium. On the other hand, refluxing the residue with 6 normal sulphuric acid effected the solution of all but 0.7 p. p. m. of the selenium, or approximately 95 percent of that originally present. The sulphuric acid treatment was sufficiently drastic to dissolve all iron oxide present and leave a grayish-white residue. It therefore seems probable that the selenium in this material is associated with iron oxide in a very insoluble form.

To determine whether soils containing iron oxide render selenium insoluble, solutions containing 1.2 mg of selenium as sodium selenite in 600 cc were shaken overnight with 60 g of Cecil sandy clay loam (11 percent of iron oxide) (*7*) and Nipe clay (70.6 percent of iron oxide). In neither case was a quantity of selenium in excess of 0.01 mg found in 500 cc of the filtered liquid. On the contrary, when the experiment was repeated, using 1 mg of selenium as sodium selenate, 0.6 mg of selenium was recovered from 500 cc of the filtered liquid. Ferric hydroxide gave similar results under like treatment. Further evidence of the same relation is indicated by the fact that the selenium in the 6 normal sulphuric acid extract of the soil sample is completely reduced to elementary selenium by sulphur dioxide. This reaction does not occur with selenates (*38*).

In order to determine the form of ferric selenite probably present in the soils, an attempt was made to synthesize a compound having the required properties by reaction between ferric chloride and selenites. This reaction has been studied by Berzelius and many others (*24, v. 10, pp. 938–940*), and the insoluble material has been shown to be of variable composition according to the conditions of precipitation but approximates the composition of the neutral salt $Fe_2(SeO_3)_3$. Unpublished data show that this salt is, however, not sufficiently insoluble in water to account for the remarkable persistence of selenium in ferruginous humid soils. Ferric chloride and sodium selenite were mixed in varying ratios and in differing, but always great, dilutions. In all cases a precipitate was formed though, in the more dilute mixtures, recourse was had to salting out with sodium chloride in order to effect coagulation. The precipitated material was then analyzed, and the iron-selenium ratios were determined. The concentrations employed and the resulting ratios are given in table 17.

TABLE 17.—*Products of reaction between dilute solutions of sodium selenite and of sodium selenate with ferric chloride* [1]

| Experiment no. | Elements in reagents | | Elements in precipitates | | Atomic ratios of precipitates Fe/Se | pH of filtrate |
|---|---|---|---|---|---|---|
| | Fe as $FeCl_3$ | Se as $Na_2SeO_3$ | Fe | Se | | |
| | *Mg* | *Mg* | *Mg* | *Mg* | | |
| 1 | 8 | 8 | 6.9 | 5.5 | 2:1.13 | 3.12 |
| 2 | 8 | 8 | 6.9 | 5.3 | 2:1.00 | 2.99 |
| 3 | 8 | 16 | 8 | 6.6 | 2:1.17 | 3.40 |
| 4 | 8 | 24 | 8 | 6.7 | 2:1.18 | 3.27 |
| 5 | 8 | 5 | 6.6 | 4.4 | 2:0.94 | 3.20 |
| 6 | 8 | 7 | 6.6 | 5.7 | 2:1.22 | 3.10 |
| 7 | 16 | 5.9 | 10 | 4.3 | 2:0.61 | 2.80 |
| 8 | 32 | 5.9 | 2.6 | .7 | 2:0.38 | 2.63 |
| 9 | 16 | [2] 15 | 13.9 | 3 | 2:0.31 | 2.95 |
| 10 | 16 | [2] 24 | 14.1 | 3.3 | 2:0.33 | 2.95 |

[1] The quantities of ferric chloride indicated were made up to 450 cc in water and the selenium salts added at a dilution of 50 cc.
[2] Selenium as sodium selenate.

The data show that when extremely dilute solutions of selenites react with ferric chloride a very insoluble precipitate is formed and that it approximates the composition of basic ferric selenite, $Fe_2(OH)_4SeO_3$, though the relation of iron to selenium is not constant. Corresponding reactions take place between selenates and ferric chloride, but the product is by no means so insoluble in water (experiments 9 and 10, table 17). Experiment 8 in the table is of special interest, since it indicates incomplete precipitation of selenium when the reaction mixture is sufficiently acid. This is quite in accord with observations previously reported on a profile developing under acid conditions (*35*).

The general conclusion from available data seems warranted that soil may contain selenium in the form of exceedingly insoluble basic ferric selenites.

As already mentioned, about 20 percent of the soils examined for water-soluble selenium gave appreciable quantities. When this quantity exceeds 0.1 p. p. m. of the soil it may be safely assumed that some form other than basic ferric selenite is present.

Treatment of the aqueous extracts with barium chloride is, in general, effective for essentially complete removal of selenium from solution. In all soils examined in this manner the aqueous solution contained much soluble sulphate, chiefly calcium sulphate, with or without accompanying chlorides. These solutions when made 5 to 6 normal with sulphuric acid gave no precipitate of selenium with sulphur dioxide, but when made strongly acid with hydrobromic acid the selenium was completely precipitated. Synthetic mixtures of selenates and sulphates behave similarly in all respects. Selenite and sulphate mixtures are also essentially freed from selenium by treatment with barium chloride, but in 6 normal sulphuric acid the selenium is precipitated by treatment with sulphur dioxide.

These observations indicate that soils containing water-soluble selenium may have it present in the form of selenates, and in the samples examined as calcium selenate. Also, the soils examined which showed the presence of water-soluble selenium were gray or dark dray and were therefore not highly ferruginous, at least with free iron oxide or hydroxide. These considerations indicate that the presence of selenates in humid soils is very unlikely.

The study of the selenium content of organic matter (*2*, *26*) has brought out a number of important facts. It has been shown that in seeds the greater portion, at least, of the selenium content is present in the protein portion of the seeds and is ordinarily insoluble in water, nonvolatile with steam, and insoluble in ether. These compounds hydrolyze through decay or otherwise as do other proteins, and the selenium-bearing products are water-soluble. These appear to be amino acids containing selenium (*13*). On the other hand, the green portions of the plants contain a selenium compound which is water-soluble, steam-volatile, and somewhat soluble in ether. In one sample studied in this laboratory, which contained 2,400 p. p. m. of selenium, digestion with hot water removed 2,400 p. p. m. This water extract contained a seleniferous compound, or compounds, which is not precipitated by lead acetate but is nearly completely precipitated by mercuric chloride. From this precipitate no pure substance has as yet been isolated. It appears probable that one or more seleniferous amino acids are present. From these and other facts it appears that when seleniferous plants decay in the soil the soluble organic selenium compounds, present or produced by decay, are to be found in the soil until and if they are removed by leaching or conversion to inorganic compounds. A part of this organic selenium may be volatilized, as is indicated by the exceedingly noxious odors from decaying plants which have a high selenium content.

These volatile compounds appear from their odor to be related at least to one synthesized by Phillips [10] by heating lignin with selenium. This material is nearly pure methyl hydroselenide, $CH_3SeH$, which has a boiling point of 155° C. and a selenium content of 81.5 percent. In view of these facts it would appear that Beath (*4*) is justified in his view that certain perennials, through their decay, "promote" the selenization of other plants by concentrating the selenium in available form in the surface soils.

Summarizing the ideas and facts of the immediately preceding paragraphs, it appears that selenium may be present in soils in three forms which become available to plants only by slow processes of hydrolytic action. These are free selenium, pyritic selenium, and basic ferric selenites. The last seems to be the more common. It may also be present in forms immediately available to plants as selenates, and as more or less evanescent organic compounds probably of the general order of amino acids. These last forms seem to be those which are subject to eluviation and to the removal of which, by percolating water, is to be ascribed the low content of selenium in plants grown in irrigated and humid soils even when selenium is fairly abundant in the soils.

## ORIGIN OF SELENIUM IN SOILS

In connection with the work on the presence of selenium in the soils of Hawaii (*8*), there was developed an hypothesis concerning the primary source of selenium in the soils of the United States. This hypothesis should be reconsidered in the light of the data in this bulletin.

Since it is shown that selenium is present in relatively considerable quantities in the soils of Hawaii and is not present in adequate quantities in the soil parent material to account for its presence in the soils, and since it is further known that the volcanic emanations contain selenium, it is a logical deduction that these soils derive their selenium by absorption from materials carried down by rain. This deduction is strengthened by the fact that in general the selenium content of the Hawaiian soils is greater in areas of greater rainfall (table 15), and also by the fact that these soils are highly ferruginous (*14*), and the further fact that selenious acid and selenites are made very insoluble in ferruginous soils (p. 58).

It would seem to follow that, if this process is going on in Hawaii, then the distribution of selenium in soils is world wide, provided only the conditions in a particular case are such as to enable the soil to retain any selenium it may have received from the effect of rain upon the world-wide distribution of volcanic dust. This assumption seems to be borne out by the fact that no true soils or shales have as yet been examined in which the presence of selenium has not been demonstrated. If such occur they may be expected to be only extremely sandy and exceptionally leached soils.

The questions then are: Why are the soils of certain areas sufficiently seleniferous to produce toxic vegetation, while in other soils in the

[10] Unpublished data. Orally communicated to the senior author by Max Phillips, Bureau of Chemistry and Soils.

same areas less selenium is found? Why is it that some soils produce more toxic vegetation than others containing as much or more selenium per unit of soil material? It is thought that the answers to these questions are to be reached through the following considerations.

It is a tenet of geology that the shales of the Great Plains areas and the corresponding shales on the western side of the Rockies are the result of deposition in water of material derived largely at least from volcanic and similar disturbances and by erosion from the Rocky Mountains when seas impinged more closely upon them than at the present time. It is believed also that the volcanic activity in these areas was particularly violent during the Cretaceous period and that immediately following it. It therefore seems highly probable that the shales of this period derive their selenium from volcanic material brought down by rain into the Cretaceous seas. If this be correct, then apparently those formations in which selenium is most abundant were deposited contemporaneously with periods of high volcanic activity.

Support is given to this hypothesis by the fact that the upper portion of the Niobrara formation and the lower portion of the Pierre formation which are particularly rich in selenium are characterized by numerous strata of bentonite. Bentonite is presumed to be derived from volcanic ash or similar material (*8*). It may be presumed therefore that deposits of such material should be preceded, accompanied, and followed by material absorbed from volcanic gases and dust, formed by cooling of moderately volatile material. It may be interpolated at this point that bentonite itself if pure need not be expected to contain more than traces of selenium, since clays of high silica-alumina molecular ratios have no chemical properties which will permit strong adsorption of acid ions. If, however, it is limonitic, selenium may be present in relatively fairly large quantities. Through the courtesy of L. W. Stevenson of the United States Geological Survey a sample of bentonite from New Jersey was made available. It contained 1 p. p. m. of selenium. The facts reported in this bulletin with reference to the extreme insolubility of ferric selenites (p. 58) and the absence of selenium from sea water (p. 49) also are in harmony with the views expressed above, since any selenium carried into the sea would be deposited with the embryonic shales. That it is so deposited is shown by its presence in the sea-bottom deposits (*37*).

The present report in the section dealing with the Greenhorn formation (p. 38) calls attention to the existence in the Greenhorn in the area studied of a bentonite seam, and the selenium data given in table 9 check very nicely with the assumptions made above. It is to be remarked, also, that the special examination made of the Greenhorn was made largely because of the presence in it of this seam of bentonite.

The concentration of selenium in certain shales by the processes outlined being granted, a part of the cause of variations in soils is already clear. With variations in the character of the selenium in the shales and in the rainfall, variations in the quantities of hydrolyzed material and the extent of its removal would inevitably occur. Mixing of seleniferous material with that less or more seleniferous must occur as the result of translocation of material by wind and water. These alterations would be further affected by the effects of vegetation upon soil content. In those areas where no effective percolation by water occurred any soluble selenium produced by weathering would remain within the soil profile. Where percolation is excessive, soluble selenium is removed as fast as formed. The result of such conditions ought to be that serious selenization of plants ought to occur only in arid and semiarid areas. This appears to be the case. The fate of selenium carried out of a given area is not wholly clear. The result when carried to the sea has been discussed. In case it is carried but a short distance and deposited as a result of evaporation of the water, it would seem possible that the result might be either local concentration, as appears to be the case in some of the salt incrustations reported from the Montrose and Grand Junction areas in Colorado, or its dispersal in minute quantities in what would otherwise be less seleniferous areas. The result of the former process might easily be locally toxic areas. There are indications that such areas exist, and may account for the sporadic cases of seleniferous vegetation in areas usually not toxic. Such cases have been reported in several areas (*5*, *6*). It remains true that so far as soils are concerned, severely toxic conditions have not been found except in arid and semiarid areas.

## PLANT ASSOCIATIONS ON SELENIFEROUS SOILS

In the course of the work reported in this and previous bulletins, observations were made with reference to the plant associations existing in the areas known to be seleniferous. As a result, a considerable quantity of data has been accumulated and prepared for publication (*25*). It appears to be necessary here to present only an abstract of this report.

For purposes of illustration two closely adjacent spots in Kiowa County, Colo., were selected. One of these is an area in which the soil is developed over Apishapa (upper Niobrara) shale. This area is seleniferous, as shown by the analyses given in table 18. It is located 80 rods north of the southwest corner of sec. 6, T. 19 S., R. 51 W. The other area is of soil developed over the Ogallala formation (a slightly consolidated sandstone of Tertiary age). This area is as free from selenium as is to be expected of any portion of the general region. It is located near the center of sec. 23, T. 18 S., R. 51 W. and therefore approximately 5½ miles from the seleniferous area. Both areas are topographically similar and are smooth and uniform. At each point a plot 100 feet square was selected, and the kinds of vegetation were studied and sampled. At each point a profile of the soil was taken. All the samples were examined for selenium. The results are given in table 18.

The seleniferous area (table 18) was part of a virgin area which apparently has never been overgrazed. The total cover was estimated at 50 percent. It consisted chiefly of blue grama grass (20 percent), turpentineweed (10 percent), spurge (3 percent), and miscellaneous plants (17 percent). This miscellaneous vegetation included 12 goldenweed plants, 10 stanleya, and 1 narrowleaf milkvetch. The nonseleniferous area was a portion of a virgin area but had apparently been overgrazed. It was selected for this reason, because the overgrazing provided opportunity for the development of a variety of plants. The total cover was about 75 percent and consisted chiefly of buffalo grass and grama grasses (50 percent), Russian-thistle (15 percent), and miscellaneous vegetation (10 percent).

TABLE 18.—*Selenium content of soil profiles and vegetation from a nonseleniferous and a seleniferous area*

NONSELENIFEROUS AREA

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| | | | | *P.p.m.* | *P.p.m.* |
| B19510 | 62 | Kiowa County, Colo., near center sec. 23, T. 18 S., R. 51 W. | Heavy silt loam, 0–6 inches | 0.2 | |
| B19511 | 62 | | Gritty clay loam, 6–12 inches | .2 | |
| B19512 | 62 | | Stiff clay loam, 12–24 inches | .2 | |
| B19513 | 62 | | Clay loam, 24–36 inches | .2 | |
| B19514 | 62 | | Silt loam, 36–48 inches | .2 | |
| B19515 | 62 | | Sandy loam, 48–72 inches | .2 | |
| B19516 | 62a | | Blue grama | | 0 |
| B19517 | 62b | | Russian-thistle | | 1 |
| B19518 | 62c | | Scarlet mallow | | 1 |
| B19519 | 62d | | Silky sophora | | 1 |
| B19520 | 62e | | Sunflower | | 1 |
| B19521 | 62f | | Corn [1] | | 1 |
| B19522 | 62g | | Sagebrush | | 1 |
| B19523 | 62h | | Cocklebur | | 2 |
| B19524 | 62i | | Spurge | | 0 |
| B19525 | 62j | | False buffalo grass | | 1 |

SELENIFEROUS AREA

| Laboratory no. | Field no. | Location | Material | Selenium in— Soil or shale | Selenium in— Vegetation |
|---|---|---|---|---|---|
| B19526 | 63 | Kiowa County, Colo., 60 rods north of SW corner sec. 8, T. 19 S., R. 51 W. | Gritty clay loam, 0–6 inches | 2 | |
| B19527 | 63 | | Gritty clay loam, 6–12 inches | 3.5 | |
| B19528 | 63 | | Silty clay loam, 12–24 inches | 4 | |
| B19529 | 63 | | Shaly clay loam, 24–36 inches | 4 | |
| B19530 | 63 | | Apishapa shale, 36–48 inches | 3.5 | |
| B19531 | 63a | | Blue grama | | 2 |
| B19532 | 63b | | Russian-thistle | | 5 |
| B19533 | 63c | | Scarlet mallow | | 1 |
| B19534 | 63d | | *Oreocarya* (?) sp. | | 1 |
| B19535 | 63e | | Sunflower | | 2 |
| B19536 | 63f | | Corn [2] | | 10 |
| B19537 | 63g | | Stanleya | | 330 |
| B19538 | 63h | | Cocklebur | | 6 |
| B19539 | 63i | | Spurge | | 10 |
| B19540 | 63j | | False buffalo grass | | 4 |
| B19541 | 63k | | Turpentineweed | | 70 |
| B19542 | 63l | | Goldenweed | | 320 |
| B19543 | 63m | | Narrowleaf milkvetch | | 4,000 |

[1] Growing under similar conditions on an adjacent cultivated field.
[2] Volunteer plant growing under similar conditions at edge of plot.

The data of table 18 show the general presence of but 0.2 p. p. m. of selenium in the nonseleniferous area with no plant on it with more than 2 p. p. m. of selenium and even in that amount in but one plant. In the seleniferous area, with tenfold to twentyfold the quantity of selenium in the soil profile, the selenium in the plants ranges from 1 to 4,000 p. p. m. This is an excellent example of the range of absorption by different plants. It is to be noted that no sample of goldenweed or of narrowleaf milkvetch was found on the nonseleniferous area. This observation is in harmony with numerous others of the same general order.

In a reconnaissance carried out in the spring of 1935, occurrence of two-groove poisonvetch and *Astragalus racemosus* was noted in an area in Wyoming not suspected of being seleniferous, and yet selenium was found in considerable quantities in both soil and plants. In the examination of the areas in Kansas reported in Technical Bulletin 530, it was observed that not only were the plants growing upon the soils developed from Pierre and Niobrara shales much more seleniferous than those upon adjacent soils but that there appeared abrupt changes in plant associations and degree of vegetative cover and that certain plants, notably the two-groove poisonvetch and the narrowleaf milkvetch, appeared to be confined to the seleniferous area. In the course of the reconnaissance survey made in the spring of 1936 (p. 4), it was noted that frequently it was possible to recognize seleniferous soil types as readily by the appearance of certain species of plants as by the study of the geologic maps or the observation of soil types. This was notably the case with the two vetches above mentioned and *A. racemosus* and with *Stanleya pinnata*. A notable example of this relationship appeared in an area in the vicinity of Wolcott, Eagle County, Colo., where *A. racemosus* was found growing on a small exposure of Niobrara shale and the plant contained 2,820 p. p. m. of selenium. Neither *A. racemosus* nor selenium-bearing soil were observed within many miles of this spot either east or west along United States Route 40 S. Coincident with the appearance of these plants there was frequently observable the disappearance or decrease in abundance of certain other plants, notably prairie grasses and particularly buffalo grass.

It is not to be asserted with too great emphasis that these variations are due wholly to selenium. It nevertheless appears to be the case that plants may be grouped with reference to their relation to selenium absorption. In the first groups are plants which absorb selenium only in small quantities when growing on seleniferous soil and which have but a very limited tolerance of selenium. In consequence they either do not appear on seleniferous soils or have but poor growth. Included in this group are grasses in general and buffalo grass and grama grass in particular. In the second group are plants which grow fairly well on seleniferous soils, though not without injury [11] (*15, 16*) and are able to absorb moderate to large quantities of selenium. Among such plants are the common cereals and a number of native plants, such as wreath aster, blue aster, turpentineweed, sunflower, and others. The third group includes plants which absorb selenium readily and which grow abundantly on seleniferous soils. It might be inferred that selenium plays some role in their physiological activities. The study of the various areas leads the authors to include in this group *Astragalus racemosus*, *A. pectinatus*, *A. bisulcatus*, *A. carolinianus*, *A. grayii*, and perhaps others, but by no means all of the *Astragalus;* also, *Stanleya pinnata*, *S. bipinnata*, *Aploppapus fremontii*, *Aster parryi* and probably others. In almost every area where these plants are found growing on seleniferous soil they are absent or very rare on adjacent nonseleniferous soil. Since analyses of these plants have always shown the presence of selenium and they appear to grow vigorously even when of very high selenium content, it seems probable that selenium may be of some importance in their physiological processes. This probability has as yet not been subjected to rigid experimental proof.

[11] Unpublished data in the Bureau of Chemistry and Soils.

## MISCELLANEOUS DATA

During the progress of the work reported above, numerous samples were examined for special reasons which were not a part of the survey as planned. Some of these have a general bearing upon the problem or have a particular interest of their own. Those considered worthy of special mention are discussed very briefly.

Two samples of water were furnished by C. S. Scofield of the Division of Western Irrigation Agriculture, Bureau of Plant Industry. One of these was from a deep well of the artesian type near Stillwater, Nev. Examination of this water showed no selenium, at least in excess of 0.1 part per billion. The other was well 15 from the Newland Field Station at Fallon, Nev. This sample contained 560 parts per billion. This somewhat unexpectedly high result led to the examination of the irrigation water from the farm. This contained no selenium. The water from a drain contained 4 parts per billion. Among the 25 samples of water from a series of shallow wells on the farm was a second sample from well 15. This sample contained 500 parts per billion of selenium. Of the remaining 24 wells, 8 showed no selenium and the remainder quantities ranging from 1 to 60 parts per billion. This range of selenium concentration in the subsurface water over so limited an area and its apparent absence from the deep well indicated a very spotty distribution in the soil. Consequently a number of soil samples were secured through cooperation with Scofield and his coworkers. Examination of these samples showed a range from a mere trace to 1 part per million of selenium. The significance of these observations is in the demonstration that seleniferous spots may be found in the areas of alluvial Pliocene deposits shown on the geologic map [12] as occurring over a large portion of Nevada and particularly in the Carson and Humboldt Sinks. From this area come many reports of range poisoning, and it deserves fuller investigation.

A topic of perhaps more geological and botanical significance than of soil importance is the existence of a seleniferous area in Montezuma County in southwestern Colorado between Mesa Verde and the vicinity of Cortez. One phase of geological interest attaches to the fact that this area lies between the larger Cretaceous area in northwestern New Mexico and is, with interruptions of high mountains, connected through a similar area in Dolores and San Miguel Counties with the extensive area in Montrose, Delta, and Mesa Counties reported upon (*6*). A series of samples was collected in this area beginning with the top of the Mesa Verde itself. The location of these and the results obtained from their examination are given in table 19.

[12] United States Geologic Survey. See footnote 3.

TABLE 19.—*Selenium content of samples from Montezuma County in southwestern Colorado*

| Laboratory no. | Field no. | Location | Material | Selenium |
|---|---|---|---|---|
| | | | | *P. p. m.* |
| B18178 | 5 | Near top of Mesa Verde at Cedar Tree Tower. | Red clay loam | 0.3 |
| B18179 | 5a | do | Wild mustard | 2 |
| B18175 | 4 | On Mesa Verde 10 miles from entrance of Mesa Verde National Park at Fairview. | Red clay (Mesaverde) | .3 |
| B18177 | 4a | do | Lupine | 3 |
| B18180 | 6 | 13 miles from entrance to Mesa Verde National Park. | Lignite in Mesaverde | 2 |
| B18181 | 7 | 12 miles from entrance to Mesa Verde National Park. | Dark shale interbedded with sandstone. | .7 |
| B18182 | 8 | 10 miles from entrance to Mesa Verde National Park. | Lignite in Mesaverde | 2.4 |
| B18183 | 9 | 7 miles from entrance to Mesa Verde National Park. | Thin-bedded clay shale | 1 |
| B18184 | 10 | do | Shale with efflorescent salts | .5 |
| B18185 | 11 | 3 miles from entrance to Mesa Verde National Park. | Shale with gypsum | 1 |
| B18186 | 12 | 2 miles from entrance to Mesa Verde National Park, on flat at base of Mesa. | Shaly clay, 0–8 inches | 4 |
| B18187 | 12a | do | *Astragalus racemosus* | 600 |
| B18188 | 13 | 2 miles west of Mesa Verde National Park entrance, on United States Route 160. | Silt loam, 0–8 inches | .8 |
| B18190 | 13x | do | Limestone | .3 |
| B18189 | 13a | do | Mountain pentstemon | 1 |
| B18191 | 14 | 3½ miles south of Cortez, on United States Route 666. | Efflorescent silt loam, 0–6 inches | 2.5 |
| B18192 | 15 | 17 miles south of Cortez, on United States Route 666. | Mancos[1] desert clay, 0–4 inches | 1.5 |
| B18193 | 15 | do | Mancos[1] desert clay, 4–10 inches | 3 |
| B18194 | 15 | do | Mancos[1] desert clay, 20–24 inches | 8 |
| B18195 | 16 | 23 miles south of Cortez, on United States Route 666. | Mancos[1] desert soil, 0–6 inches | 1 |
| B18196 | 16a | do | Stanleya | 200 |

[1] Geologic formation.

The botanical interest attaching to this series of observations lies in the fact that neither *Stanleya* nor *Astragalus racemosus* was found either on the Mesaverde formation or elsewhere except where the seleniferous portion of the Mancos (which apparently roughly correlates with the Pierre shales) also appears as the probable soil parent material. There are a number of other points of scientific interest which attach to this and contiguous seleniferous areas which are well worthy of study.

In the course of these investigations numerous blank tests have been made on the sulphuric acid employed as a reagent in the analyses. No selenium has been found in any of these tests. This is perhaps not surprising when the sulphuric acid is made by the contact process and especially if made from secondary sulphur in which the absence of selenium has been repeatedly demonstrated. If, however, sulphuric acid is made from pyrites or from volcanic sulphur, in both of which selenium is apparently always present, it would appear possible that selenium in measurable quantities could find its way into the final product. The opportunity was therefore welcomed to test a series of samples from a sulphuric acid plant in Baltimore which uses Spanish, Portuguese, or Cuban pyrites as a source of sulphur dioxide. The samples examined and the quantities of selenium found are given in table 20.

TABLE 20.—*Selenium content of materials used in and products of a sulphuric acid plant*

| Laboratory no. | Material | Selenium | Laboratory no. | Material | Selenium |
|---|---|---|---|---|---|
| | | *P.p.m.* | | | *P.p.m.* |
| B20009 | Spanish pyrites, concentrated. | 45 | B20013 | Acid from lead chamber 2 | 1 |
| B20010 | Portuguese pyrites | 105 | B20014 | Acid from lead chamber 3 | .2 |
| B20011 | Cuban pyrites | 15 | B20015 | Acid from lead chamber 4 | 1 |
| B20009a | Cinders from Spanish concentrates. | 8 | B20016 | Composite of 50° B. shipping acid. | 2.5 |
| B20023 | Flue dust | 10 | B20021 | Dust from Cottrell precipitator. | 1.5 |
| B20020 | Mud from Glover tower | 240 | B20024 | Run-off from water scrubber | 1.5 |
| B20017 | Mud from lead chamber 1 | 4,020 | B20022 | Mud from mist Cottrell process. | 17,000 |
| B20018 | Mud from lead chamber 2 | 2,590 | | Contact acid | 0 |
| B20019 | Mud from lead chamber 3 | 3,220 | | | |
| B20012 | Acid from lead chamber 1 | 4 | | | |

These data have a special significance in that they indicate the effectiveness of the final removal of selenium before the actual oxidation of the sulphur dioxide and suggest that the presence of selenium may be an important consideration in the poisoning of catalysts. The manufacturers have calculated that the total selenium present in 1 day's consumption of ore amounts to 30.4 pounds and that the above analyses account for 26.5 pounds.

Two series of samples were examined to test the influence of a commercial insecticide which utilizes a water-soluble selenio-sulphide containing approximately 8 percent of selenium. One of these series consisted of grapevine cuttings and soil from a vineyard where the insecticide had been used for a period of 2 or more years. The grapes contained 10 p. p. m. of selenium, and the soil beneath the vines to a depth of 4 inches contained 5 p. p. m. In the same vineyard a sample of grapes from vines not sprayed in 1936 but sprayed previously had but 0.2 p. p. m., the vine cuttings a trace, and the surface soil (0–4 inches) 2 p. p. m. In a portion of the vineyard never sprayed, the grapes contained no selenium and the vine cuttings a barely detectable trace and the soil but 0.2 p. p. m. A second series of samples was from Michigan where the insecticide was used as a spray on roses. A sample of the rose leaves contained 170 p. p. m. of selenium, but when the insecticide was used in the soil in quantities corresponding to 2.5, 5, and 10 p. p. m. of selenium the quantities found in the rose leaves was only 2 p. p. m. as a maximum. It is probable that the larger quantities of selenium reported above were due to spray residues and not to transfer of selenium from the soil to the grapes and rose leaves. The data given are not to be interpreted as comment either favorable or unfavorable to the use of the insecticide. No opinion, because of insufficient data, is expressed upon this point. Since it seems certain that the selenio-sulphide used liberates the selenium as the element when it reacts with the soil, the results point to very small absorption of elemental selenium by the plants.

Twomey and Twomey (*33*) showed that selenium in the form of sodium selenite when fed to ducks produced physiological symptoms similar to those shown by the destructive western duck sickness reported and described by Kalmbach and Gunderson (*20*). As a result the Bureau of Biological Survey, through J. E. Shillinger, made available a series of samples of water and of soil from areas in which duck sickness was known to prevail. The examination of these samples revealed the presence in a sample of water from Lacreek Migratory Waterfowl Refuge in South Dakota of not to exceed 1 part per billion of selenium in the water and a maximum quantity in four soil samples of 0.6 p. p. m. In a sample of water from Bamforth Lake, Wyo., there was less than 1 part per billion, and in the salt crust from the lake shore there was 0.6 p. p. m. A sample of water from near Jackson, Wyo., showed evidence of selenium in a sample of 150 cc volume. In the area of the Crescent Lake Wildlife Refuge in Nebraska, in a sample from Gimlet Lake, the water likewise showed a quantity of less than 1 part per billion, and five samples of salt crusts from adjacent lakes had a maximum quantity of 0.3 p. p. m. Unfortunately no vegetation representative of the actual food eaten by ducks or of their crop contents or tissues was made available for examination. The matter is of interest because the available data indicate no probability that the disease in question is due to selenium in the water.

In connection with observations reported by Hurd-Karrer and Poos (*19*) on the toxic effects of selenium-bearing plants on aphids, it seems desirable to report the following facts: Accompanying a large sample of narrowleaf milkvetch from near Adobe Lake, Colo., were a considerable number of flies (possibly, though not certainly, *Pseudotephritis*). These were caught and examined for selenium. They contained 20 p. p. m., live-fly weight. They were living and apparently thriving on the plant, which contained approximately 1,800 p. p. m. of selenium. From Colfax County, N. Mex., a sample of fly larvae, presumably corresponding to the flies above mentioned, which infested the roots of an *Astragalus racemosus* plant, were examined. They had a selenium content of 7.5 p. p. m. They were inhabiting roots which contained 190 p. p. m. A second sample of the same larvae from Bent County, Colo., had a selenium content of 10 p. p. m., while infesting roots containing 420 p. p. m. These results are reported without prejudice as indicating that these particular organisms have or have not developed an immunity against selenium. The whole question of the selenium-insect relation deserves fuller study.

## RECAPITULATION

An attempt is here made to give a résumé of the general statements which appear to be warranted by the data presented in this series of bulletins, and by Slater and others (*27*), supplemented by data from other sources and by unpublished data in the files of this Bureau.

The distribution of selenium in soils appears to be general. No true soils containing colloids in any significant quantity have been found in which the presence of selenium cannot be demonstrated. The amounts found range from fractional parts per million to quantities which exceed 80 p. p. m. The source of the selenium is believed to be the residual selenium derived from the soil parent material, supplemented by that derived by direct absorption from the air by rain. The presence of selenium in normal air has not yet been demonstrated, but its presence in volcanic emanations has been shown. It has been shown that absorption of selenium by soils from precipitation is the chief apparent source of selenium in certain soils (Hawaiian). It has been demonstrated that selenium may exist in soils as the element; as a substituent in sulphide minerals, particularly pyrites; as selenite, particularly basic ferric selenite; as selenate, particularly as calcium selenate; and as organic selenium compounds of undemonstrated composition. Of these forms apparently those most available to the soil solution are the organic and selenate forms.

It seems very probable that the concentration of selenium in sedimentary geological formations is due to absorption of volcanic selenium and its deposition along with the other shale materials. When, due to the subsequent geologic changes, these shales become parent material for soils, the selenium remains in the soil partly in "available" and partly in "unavailable" forms in semihumid or arid areas. In humid areas the leaching of the soils removes "available" selenium. Whether these assumptions are correct in detail or not, it remains true that up to the present the soils so far found to contain considerable quantities of selenium are those derived from the shales and limestones of the Cretaceous period. This is especially the case with those formations known as the Pierre, Niobrara, and Greenhorn, and Morrison, and the corresponding formations locally named otherwise. It also appears that these formations contain notable quantities of bentonite, which is believed to be derived from volcanic ash. It is probable therefore that selenium accumulations may be found in other geological formations in other geological periods.

The leaching of the soils and other materials containing selenium has resulted in the removal of selenium, as has been demonstrated in the studies reported of the Colorado River and its tributaries. Since also the demonstration of the presence of selenium in ocean water has not been possible, it would appear to follow that selenium is being deposited in sea-bottom deposits. Its presence in sea-bottom deposits in the Bering Sea has been shown. It would seem to follow also that the leaching of selenium from seleniferous soils may result in local concentrations in areas not otherwise exceptionally seleniferous. Some evidence of the existence of such local areas is already available.

The distribution of selenium within the soil profile is extremely variable, and definite general statements are not possible concerning these variations. It seems that the distribution depends upon a number of factors, among which may be listed the maturity of the soil, the texture of the soil, the parent materials, the rainfall, and, perhaps most important, the chemical composition and quantity of the colloid in the soil.

When plants grow upon seleniferous soil they seemingly absorb selenium to some degree in all cases, though under many circumstances the quantity so absorbed is vanishingly small. Under favorable conditions the quantity absorbed becomes relatively large, and in a few instances quantities approaching 1 percent of the air-dry weight of the plant have been found. For a given plant species the quantity found by analysis appears to depend upon a number of variables. These include at least the following: The quantity and character of the selenium in the soil (*16*) and its distribution in the soil; the portion of the plant examined, whether seed, blossom, leaves, stem, or root; the stage of maturity of the plant, and seasonable variations which might be attributed to rainfall (*6*). It is also certain that variations in selenium absorption are brought about by variation of available sulphur, as is shown by the work of Hurd-Karrer (*18*). Variations in other relations not now evident also may produce effects. After four summers devoted to extensive field observations in several States, it is believed that certain plants suffer relatively little, if at all, and show a very high tolerance to the presence of selenium. The variation in tolerance to the presence of selenium would seem at least a reasonable assumption to explain in part the variation in plant associations upon soils of similar type which show an increase in relative quantities of tolerant plants in seleniferous areas.

When animals consume seleniferous vegetation definite physiological disturbances are produced which are recognized as symptoms of definite diseases or as causes of immediate death. Whether the violence of the effects are directly proportional to selenium content has not been determined. It seems unlikely that the effects are directly proportional to the selenium content, since the green vegetation contains a selenium compound, or compounds, which is water-soluble and the seleniferous protein of seeds (wheat) is not.

Areas of soil which produce vegetation more or less virulently toxic have been definitely determined to exist in nine States. The total area affected aggregates several thousand square miles. The data at hand indicate the probable existence of numerous other areas, some of them small and others of considerable extent.

The damage of various kinds caused by the existence of seleniferous soils may never be known and cannot as yet be estimated. While the influence upon crop yields is not evident, there is a specific injury to domestic animals. That the injury may to some degree extend to human beings is shown in a recent publication of the United States Public Health Service (*28*).

The seriousness of the situation is somewhat relieved by a number of ameliorating influences. Among these the following appear definitely determined by observation or experiment: In all the seleniferous areas so far examined there is no uniform density of concentration of selenium and consequently no uniformity in the degree of injury to plants or in their selenium content. In no area does it appear that all kinds of vegetation growing upon it are seriously toxic; that is, there is a very strongly selective power manifested by plants. In nearly all the areas seriously affected the density of population of both men and animals is relatively low. In the case of animals there is a clearly indicated tendency to avoid seleniferous vegetation. To a considerable degree plants likely to be strongly seleniferous are not normal forage or food crops. There are some exceptions to this statement.

Added to these naturally ameliorating conditions it is found that the absorption of selenium in serious quantity does not occur in properly irrigated areas even when these are seleniferous. Decrease in density of animal population, or increase of available forage, tend automatically to decrease injury by giving free pasturage. In smaller areas absorption of selenium may be decreased by use of proper adjustment of the soil solution by use of soluble sulphates and possibly by other methods. To perhaps a smaller degree injury may be decreased by eradication of plants capable of high selenium absorption. Where economically practicable, nonfood crops may possibly be substituted for those now produced.

As this brief résumé indicates, the relation of selenium to the soil and its products bristles with unsolved problems despite what may properly be considered as a rapid development of the subject.

## SUMMARY

There is reported in the preceding pages an observation by Marco Polo of what appears to have been cases of selenium poisoning.

A brief résumé of the methods used for examination of soils and vegetation for selenium is given.

There are reported the results of a reconnaissance survey of parts of Kansas, Colorado, New Mexico, Arizona, and Utah which establish the existence of seleniferous areas in these States.

A more detailed examination of eastern Colorado reveals the existence of a soil area of upwards of 3,000 square miles which is capable of producing vegetation toxic to animals. A similar though less extensive area is shown to exist in northeastern New Mexico.

Additional evidence is presented indicating wide differences in the selenium content of different parts of the same plant and between different plants on the same soil. Also there is indicated a seasonal variation in the selenium content of plants.

Data are given which show that irrigation is a remedial measure for seleniferous soils and that irrigation drainage waters remove soluble selenium from soils which contain it.

The selenium content of 20 soil profiles is reported, and the evidence shows no constant relation in the distribution of the selenium within the soil profile.

It is shown by the examination of a geologic section through the Greenhorn formation that selenium is present in all parts of it, at the location examined, and soils developed upon it produce toxic vegetation.

An examination of an area of outcropping Morrison formation in southeastern Colorado revealed the presence of seleniferous soils and vegetation, and in this area cases of alkali disease were observed.

A seleniferous area of small extent but of intensely toxic degree is reported in a part of the San Isabel National Forest in Colorado. Also, a spring of toxic type in El Paso County, Colo., was investigated, and the examination of water, soil, and adjacent vegetation indicates the primary source of injury to be the toxic vegetation.

An extension of the examination of the selenium content of the Colorado River and its tributaries is reported, and it is shown that relatively large quantities of selenium are being discharged into the Gulf of California and that the chief sources of this selenium are irrigated seleniferous soils. No selenium could be found in the samples of sea water from the Pacific Ocean, Puget Sound, Atlantic Ocean, and the North Sea. Selenium was found in the water of the Elbe River but not in the Weser River.

A study is reported of the distribution of selenium in a large number of soil profiles from Hawaii and a smaller number from Puerto Rico. A study is also reported of the forms of selenium present in the soil, and evidence is cited that the more important of these are basic ferric selenite, calcium selenate, and organic compounds derived from decayed vegetation. On the basis of these and related data an hypothetical explanation of the sources of selenium accumulations in the soil is offered. The chief source is assumed to be volcanic emanations.

A summary is presented of observations of the plant associations found in seleniferous areas, from which it is inferred that the relative quantities of plant species and perhaps also the presence of certain species are influenced by the selenium present in soils.

Several miscellaneous items are reported, among which are some indicating possible seleniferous spots in areas otherwise nontoxic.

There is included a recapitulation, which offers a general outline of the facts established by, and of certain inferences which may be drawn from, available data.

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