SOME HYDROGEN AND CARBON ISOTOPE STUDIES ON PLANTS AND THEIR ENVIRONMENTS

Ray Franklin Weiss

May 18, 1964

Some Hydrogen and Carbon Isotope Studies on Plants and Their Environments

Abstract

The ratios D/H and C^{13}/C^{12} were determined for plants from locations varying in position and elevation. In this respect plants of the same species were shown to behave similarly. Carbon results suggest that plants closely reflect the composition of atmospheric CO_2. Hydrogen results, however, seem affected by local variations in ground-water composition, with large plants and plants removed from contact with ground moisture showing the least effect. A general decrease in hydrogen and carbon isotopic weights was observed in plants from the western slopes of the Sierra Nevada, while plants from the western slopes of the White Mountains were observed to be relatively constant in this respect. The general eastward motion of air masses over the Sierra and into Owens Valley before reaching the White Mountains is a possible explanation for this difference. Differences between hydrogen isotopic compositions of ground-waters and their associated plants are suggested as possible indicators of climatic condition.

Introduction

Variations in the isotopic ratios of D/H and C^{13}/C^{12} have been successfully demonstrated as useful tools in the study of a number of physical, chemical and biological systems. The study of D/H and C^{13}/C^{12} ratios in plants was therefore undertaken with the intent of investigating isotopic correlations between plant species and the many variables of environment.

Isotopic ratios reported in this paper are in the common δ notation:

$$\delta = \left[\frac{R_{sample}}{R_{standard}} - 1 \right] n$$

For hydrogen R is the ratio D/H and n is chosen as 100 to yield δ values in per cent. For carbon R is the ratio C^{13}/C^{12} and n is chosen as 1000 to yield δ values in per mil. In both cases the standard is the working standard of the Mudd Laboratory at the California Institute of Technology. In cases where Δ values are reported, they represent the numerical difference between two δ values.

Procedures

In order to incorporate large variations in elevation, location, and other environmental conditions, samples were collected along California highways 41 and 120 crossing the Sierra Nevada through Yosemite National Park, as well as in the southern White Mountains in the vicinity of Westgard Pass. Collections were made on the 6th and 7th of August, 1963 by S. Epstein, B. Hirt, and the writer.

Samples were stored in a Silica-Gel dessicator after collection, and were then placed under vacuum at room temperature and dried to constant weight. Samples were combusted in quartz vessels at 650°C in a circulating stream of oxygen at 10 to 15 mm. Hg pressure for approximately 3/4 hour. Green tree moss samples were wrapped in a weighed length of nichrome wire to prevent their being carried away by the oxygen stream. H_2O and CO_2 combustion products were collected in dry ice and liquid nitrogen traps, respectively. After combustion, the H_2O combustion product was slowly passed through a powdered uranium furnace at 700°C. In such a furance H_2O oxidizes uranium to produce H_2 with a 100 per cent yield.

TABLE 1

LOCATIONS OF SAMPLE COLLECTION

Location	Elevation (ft.)	Position	Description
5	910	119°42' W. 37°05' N.	Open foothills, largely grassland.
6	2950	119°39' W. 37°18' N.	Foothill slope, wooded.
8	5130	119°38' W. 37°30' N.	South entrance to Yosemite National Park.
9	4050	119°40' W. 37°32' N.	Bank of the South Fork of the Merced River at Wawona.
10	4000	119°39' W. 37°43' N.	Yosemite Valley floor at bank of Merced River.
11	5600	119°45' W. 37°43' N.	Mountain slope north of Valley, heavily wooded.
13	7020	119°47' W. 37°46' N.	Flat above north rim of Valley, wooded.
14	8040	119°40' W. 37°51' N.	Bank of Siesta Lake.
15	8141	119°27' W. 37°50' N.	Bank of Tenaya Lake.
16	9941	119°15' W. 37°54' N.	Tioga Pass, level and moist, sparse vegetation.
17	9600	119°14' W. 37°54' N.	North bank of Tioga Lake.
18	10150	118°10' W. 37°23' N.	University of California White Mountain Station.
19	10600	118°10' W. 37°23' N.	Top of ridge above White Mountain Station.
20	8900	118°11' W. 37°21' N.	Southern slope of White Mountains Dry.
21	7780	118°10' W. 37°19' N.	Southern slope of White Mountains Near Westgard Pass. Dry.
22	6200	118°11' W. 37°15' N.	Western slope of White Mountains at bottom of ravine. Dry.

Both D/H and C^{13}/C^{12} ratios were determined mass-spectrometically on instruments of the type designed by Nier and modified by McKinney. Experimental error here is estimated to be within ± 0.2 per mil for C^{13}/C^{12} and within ± 0.2 per cent for D/H. In the cases where more than one independent run was made on a sample it was shown that random sampling errors for large pines are of the order of experimental errors, while sampling errors for the smaller lichens and sage may be as large as 3 or 4 times the experimental errors.

In all cases except the green tree moss and lichens, only 1963 growth was analyzed to avoid the complications of yearly variations in isotopic composition.

Results and Discussion

Results from samples collected in the White Mountains are presented in Tables 2 and 3 and are displayed graphically in Figure 1. Of interest here is the relatively parallel form of plots of the C^{13}/C^{12} ratios of *pinus monophylla*, lichens, and *artemesia tridentata*. Because plants derive all their carbon from the atmosphere, and because all plants collected in the same location are exposed to the same atmospheric carbon dioxide, several valuable conclusions may be drawn from these plots. Although each plant seems to have a different isotopic fractionation with atmospheric carbon dioxide, the difference remains constant for plants of the same species collected at different locations. This parallel behavior suggests that with respect to carbon isotope fractionation, different plants of the same species can be expected to behave similarly. Furthermore, it seems clear that variations in the isotopic composition of atmospheric carbon with changes in location,

TABLE 2

HYDROGEN ISOTOPIC ANALYSES OF WATER SAMPLES

Location	Description of Source	δ (D/H)%
8	Drinking fountain fed by 7000 ft. spring located 4 miles east.	-2.54
9	South Fork of the Merced River	-2.17
10	Merced River	-3.52
14	Siesta Lake	-1.46
15	Tenaya Lake	-3.07
16	Pond at Tioga Pass	-2.85
17	Tioga Lake	-4.85
18	Pond at the University of California White Mountain Station	-5.85

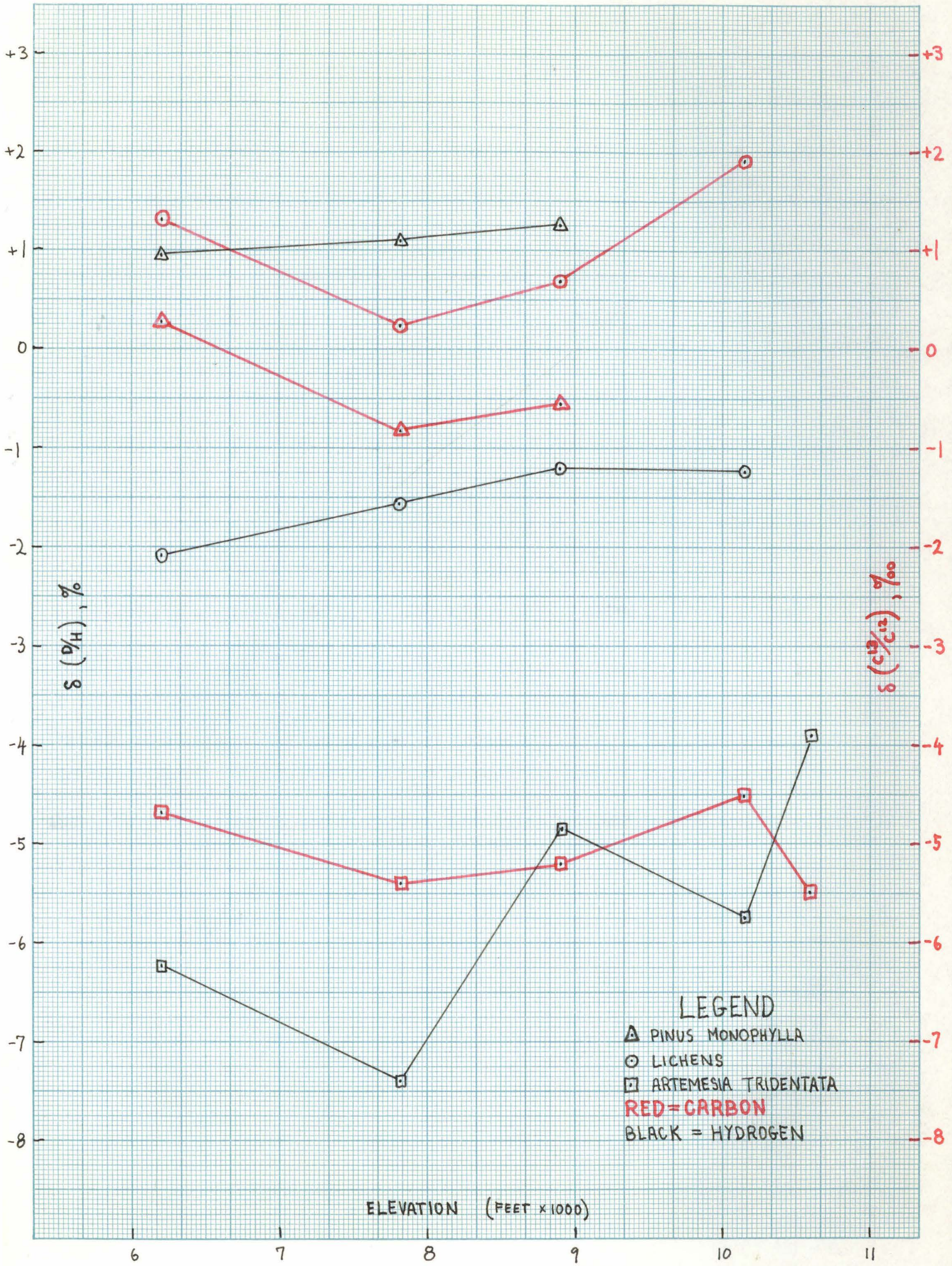
TABLE 3

SAMPLES FROM THE WHITE MOUNTAINS, CALIFORNIA

Location	Wt. loss on drying (mg)	H_2 yield (ml/mg)	δ (D/H)%	CO_2 yield (ml/mg)	δ (C^{13}/C^{12})‰
Artemesia Tridentata (Sage), 1963 Growth					
18	1.0	0.61	-5.74	0.86	-4.52
19	1.0	0.59	-3.89	0.85	-5.51
20	1.0	0.57	-4.84	0.81	-5.21
21*	0.9	0.60	-7.38	0.87	-5.40
22	1.5	0.57	-6.23	0.81	-4.69
Pinus Monophylla (Piñon Pine), 1963 Growth					
20	0.4	0.59	+1.26	0.85	-0.55
21	0.5	0.62	+1.09	0.88	-0.82
22	0.5	0.61	+0.96	0.88	+0.28
Lichens Collected from Rocks					
18	2.7	0.41	-1.22	0.55	+1.91
20	-	0.55	-1.20	0.73	+0.68
21	4.8	0.54	-1.54	0.72	+0.23
22*	3.7	0.45	-2.06	0.63	+1.30

*Analyses designated by an asterisk represent the average of two independent samplings and analyses.

Figure 1. Samples from the White Mountains, California.



elevation, and temperature are reflected in the carbon isotopic composition of local plants. Here, however, it is important to point out that, because of changes in plant carbon dioxide transpiration rates in various environments, this effect might well be non-linear.

Because plants derive a large portion of their water from the ground, analysis of their hydrogen isotopic compositions is not nearly so simple as it is for carbon. The main reasons for this are the considerable local isotopic variation of ground moisture caused by evaporation and other local effects, and the varying degree to which plants transpire water from the ground to the atmosphere. Of the three samples selected, *pinus monophylla* is a large tree with a deep root system and as such is exposed to deeper and more stable sources of moisture in the ground, the lichens collected grow on rocks and have no contact with ground moisture, and *artemesia tridentata* has a small, shallow root system and is quite subject to the effects of local relief and evaporation on the isotopic composition of ground moisture. *Pinus monophylla* and the lichens both reflect their relative isolation from these effects in the parallel form of the plots of their D/H δ values. In contrast, however, the plotted D/H δ values for *artemesia tridentata* show considerable variation which might well be attributed to variations in local relief.

Results from samples collected in Yosemite National Park are presented in Tables 2 and 4 and are displayed graphically in Figure 2. Because of the considerable range in elevation and position of collection locations, and because of the limited range of any particular species collected, three different species were required to cover the entire range. At locations where these ranges meet, samples of both species were collected. Thus,

TABLE 4

SAMPLES FROM YOSEMITE NATIONAL PARK

Location	Wt. loss on drying (mg)	H_2 yield (ml/mg)	δ (D/H)%	CO_2 yield (ml/mg)	δ (C^{13}/C^{12})%
Pinus Ponderosa, 1963 Growth					
5	0.8	0.64	-0.08	0.88	-3.20
6	0.8	0.57	-2.72	0.84	-4.80
9	0.8	0.59	-2.59	0.83	-5.09
Green Tree Moss					
9	3.8	0.55	+0.07	0.74	-2.36
10	3.8	0.60	+0.65	0.80	-2.47
11	3.7	0.58	+0.14	0.78	-1.35
13	3.8	0.60	-0.07	0.81	-1.85
14	3.3	0.60	-1.92	0.81	-3.72
Pinus Murrayana, 1963 Growth					
14	0.8	0.59	-3.41	0.87	-1.24
15	0.8	0.59	-3.22	0.87	-2.61
16	0.8	0.60	-0.15	0.86	-3.71
17	0.7	0.63	-2.39	0.91	-4.73

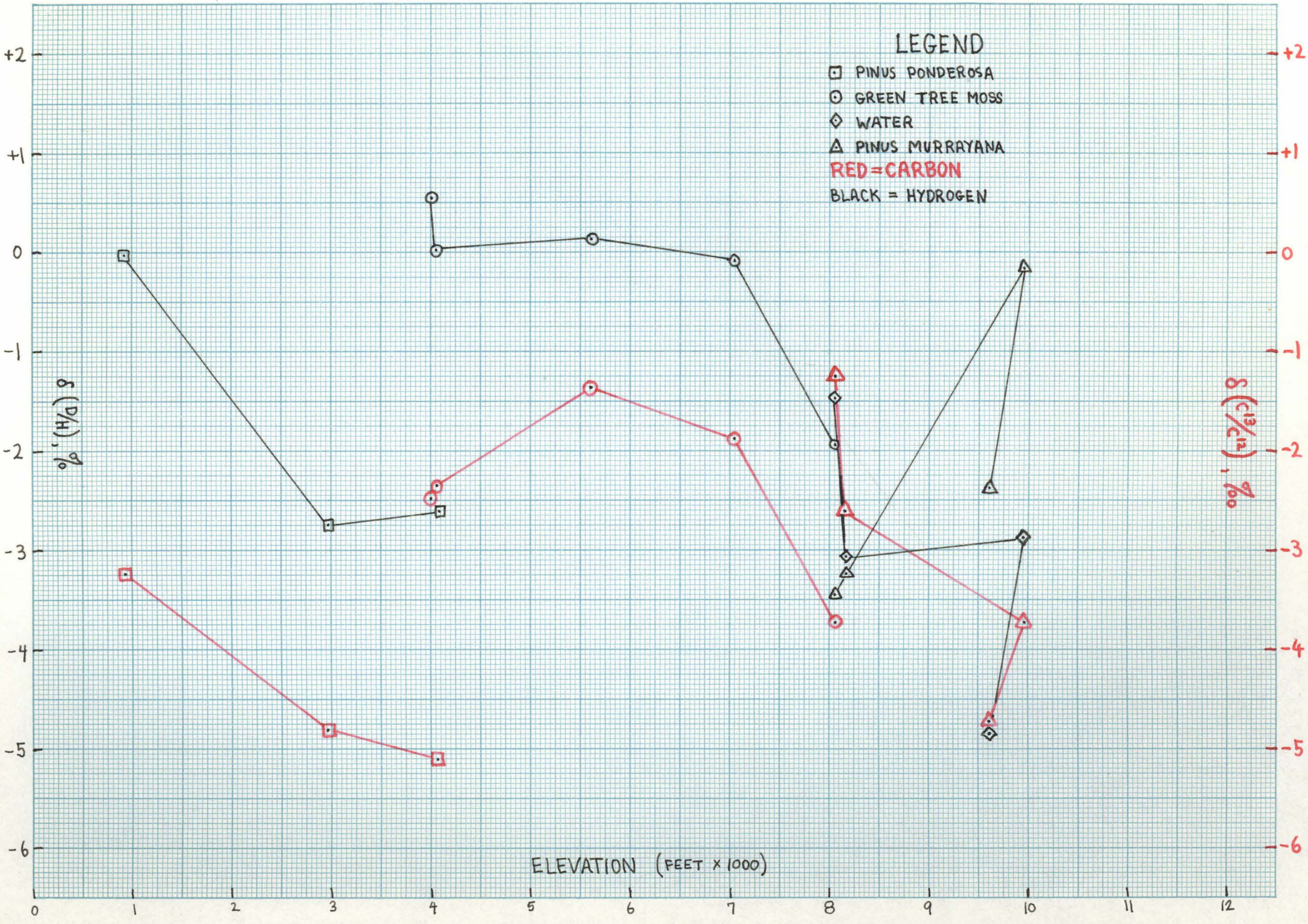
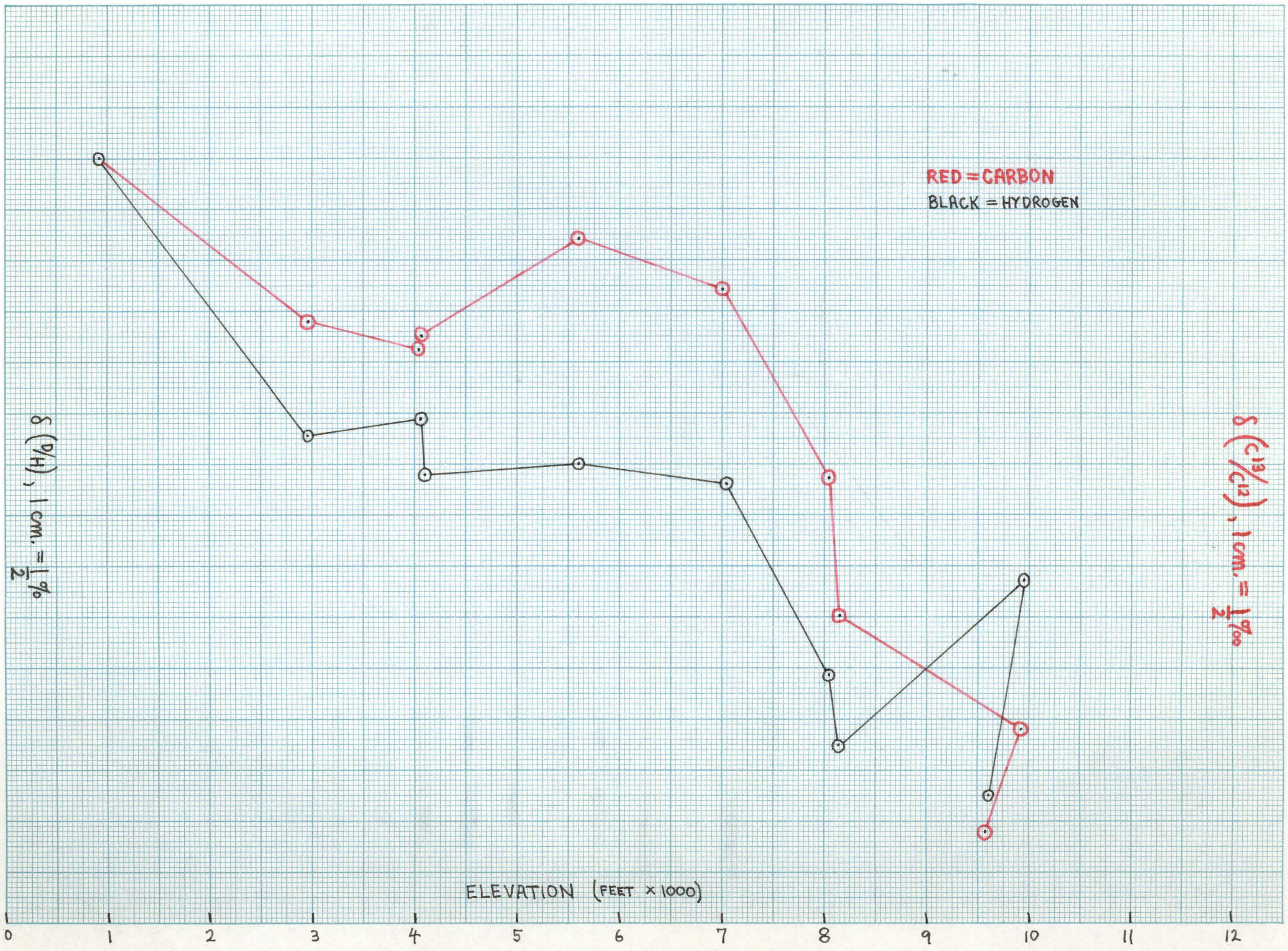


Figure 2. Samples from Yosemite National Park.

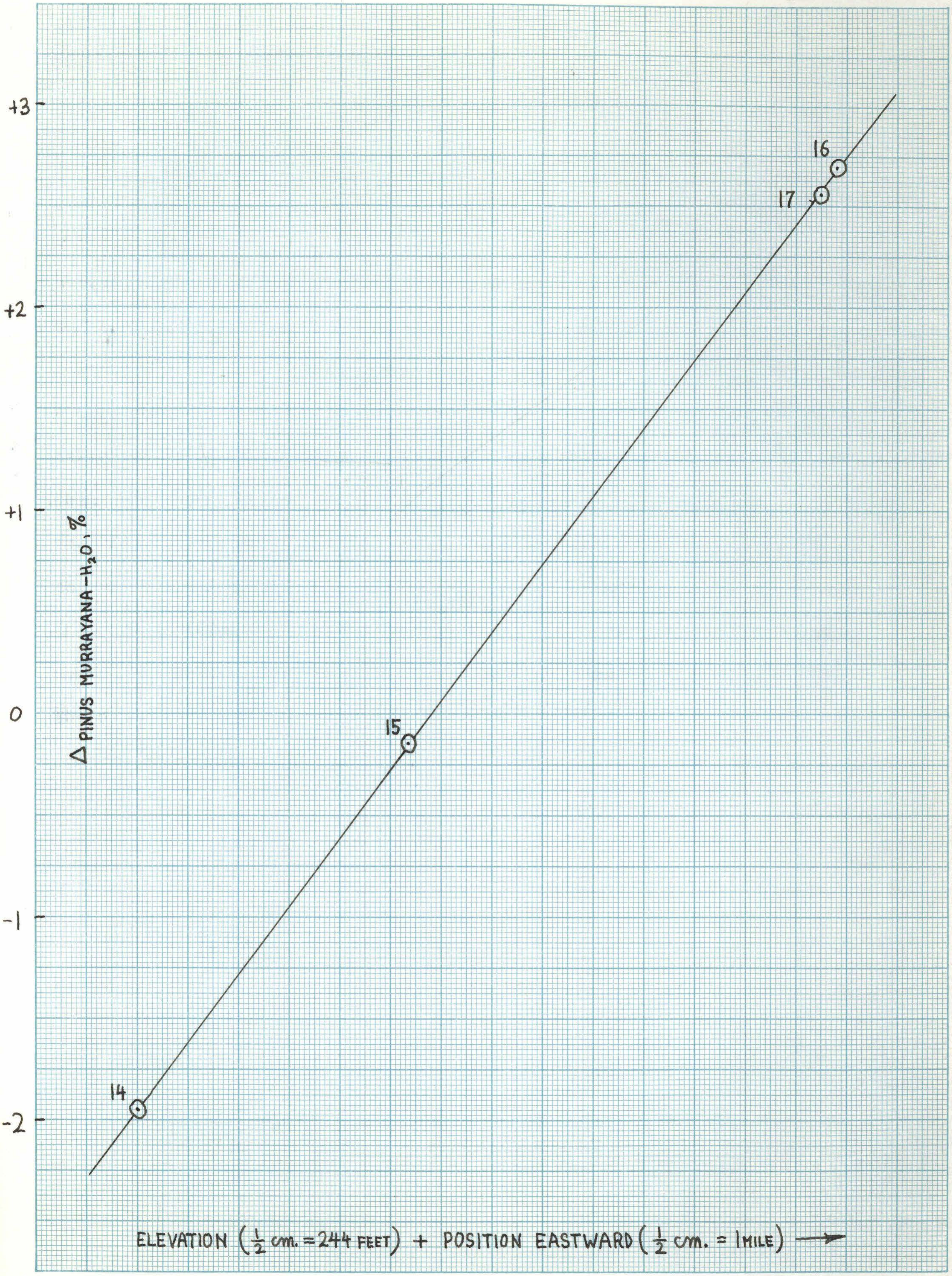
Figure 3. Adjusted values for Yosemite National Park samples.



by shifting the δ values for a particular species of plant up or down so as to begin one range of points at the point which terminates the previous range, one can construct a plot which has no meaning in terms of absolute value, but which does represent changes in δ value from location to location across the entire range of points. If one performs this operation on the data in Figure 2 and averages the concurrent water and <u>pinus murrayana</u> hydrogen determinations, Figure 3 results. Here the trend of decrease in isotopic weight with increase in elevation is unmistakable for both hydrogen and carbon, with carbon showing approximately one tenth the effect shown by hydrogen. It would be premature, however, to assign these observations to particular causes except to suggest that a major factor is the change in statistical distribution of heavy and light molecules with increasing elevation caused by increasing gravitational energy and decreasing thermal energy.

In comparing Figures 1 and 3 it is interesting to note that while samples from Yosemite show a general decrease of carbon and hydrogen isotopic weight with increasing elevation, samples from the western slopes of the White Mountains are of relatively constant isotopic composition and show no such dependence. This can be better understood if one realizes that Owens Valley is actually a narrow depression between the White Mountains on the east and the Sierra Nevadas on the west. Generally eastward moving air masses tend to supply the valley with air that has already passed over the high Sierras and therefore is isotopically representative of the higher altitudes. Because the climate in Owens Valley is by no means mild, one would expect considerable mixing of air masses, leaving little opportunity for an isotopic gradient to become established.

Figure 4. Δ values compared to elevation and eastward position.



Differences between D/H δ values for pinus murrayana and water samples collected simultaneously at locations 14 through 17 suggest interesting comparisons to elevation and position eastward. As can be seen in Figure 2, the difference in these δ values becomes larger with increasing elevation, but in a non-linear way. The effect can, however, be linearized if one assumes that differences in these δ values are a function of both elevation and eastward position. The problem is solved graphically in Figure 4 by assuming an eastward position change of one mile as equivalent to an elevation change of approximately 250 feet. Since water samples in these cases were taken in the immediate area of the tree sampled, it is reasonable to assume that this water represents the isotopic composition of ground-water supplying the tree. Thus, variations in the Δ value between water and tree reflect the role played by the tree in the removal of moisture from the ground and the transpiration of this moisture to the atmosphere. Changes in climatic conditions such as humidity and temperature are possible explanations for the observed variations.