UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Remote Detection of Metal Anomalies on Pilot Mountain, Randolph County, North Carolina

by

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

Abstract

A biogeophysical technique used successfully to delineate mineralized zones under coniferous forests has been extended to a deciduous region in the Piedmont physiographic province of North Carolina. Pilot Mountain, a hydrothermally altered monadnock within the Carolina slate belt, contains areas of anomalously high amounts of Cu, Mo, and Sn in the soils. Leaves of canopy trees in the mineralized zone also contain significant amounts of Cu. Spectral data acquired from a high-resolution airborne spectroradiometer were processed using a waveform analysis technique to minimize background noise caused by canopy variations and slope effects. Areas containing anomalous metals were detected by spectral changes in the chlorophyll absorption region.

Introduction

Changes in the vegetation growing in mineralized areas have been used since ancient times as a prospecting tool. Recent developments in remote sensing have enabled geobotanists to use the spectral reflectance characteristics of plants to separate metal-stressed vegetation from unstressed vegetation. The potential applications of such techniques are of world-wide importance in areas of total vegetation cover in humid tropical and subtropical regions.

The high resolution spectroradiometer developed by scientists at Columbia University (Chiu and Collins, 1978) provides one of the most promising of the new techniques. The instrument is especially sensitive in the visible spectral region, where metal-stress effects occur. In particular, changes along the edges of the chlorophyll absorption band centered near 680 nm can be detected by analysis of both field and laboratory data (Collins and others, 1980; Chang and Collins, 1980). These changes in reflectance have been shown by laboratory experiments to be related to changes in chlorophyll content caused by metal in the soil (Chang and Collins, 1980; Horler and others, 1980).

The technique has proven effective in the detection of mineralized areas in such diverse terrain as Washington, Montana, and Maine (Collins and others, in press). In each of these areas, the vegetation cover is near 100%, composed primarily of dense coniferous forests in Washington and Montana, of coniferous and deciduous forests in Maine. In each case, the known mineralized zones were well defined with high resolution spectral data collected from the airborne instrument and analyzed using a waveform analysis technique developed at Columbia University (Collins and Chiu, 1979; Collins and others, 1978; 1980).

In the present study, the research technique was tested in a mineralized area of central North Carolina which contains a mixed deciduous forest with a few conifers. The study area was chosen because of the complexity of the vegetation and because areas of strong hydrothermal alteration and areas of anomalous metals in soils have been established by recent study by U. S. Geological Survey geologists. In addition to the remote sensing study, ground geobotanical methods were used to relate plant species distribution and plant metal uptake to the geologic and geochemical data as well as to the spectral data. We consider it important to point out that the persons conducting the radiometer survey did not know the location of any of the surface data anomalies until the airborne survey maps were completed.

Geology and Geochemistry of the Study Area

Pilot Mountain is a prominent isolated monadnock located in the Piedmont physiographic province in Randolph County, North Carolina, 13 km southeast of Asheboro (fig. 1). Pilot Mountain is situated within the Carolina slate belt, a thick sequence of low grade metamorphic rocks derived from volcanic tuffs, flows and volcanic sediments deposited in late Precambrian and early Paleozoic time.

Within the slate belt, perhaps mostly in andesitic pyroclastic rocks, large highly altered zones have formed by intense hydrothermal action. These altered zones are mostly highly silicified rock within which pods and lenses of very aluminous material have been identified at many places. One such altered zone is at Pilot Mountain where extensive silicification is present on much of the monadnock and also extends westward into the lowland, covering an area 4 x 1.5 km (fig. 2). Within the silicified area are several pods containing abundant high alumina minerals, including kaolinite, sericite, andalusite, pyrophyllite, topaz, and diaspore. Pyrite and lesser amounts of the other sulfides have been important constituents throughout all the alteration zones but are now mostly oxidized and leached from near-surface rocks.

Small but distinctly anomalous amounts of Cu, Mo, and Sn are present in soils on Pilot Mountain within the area known to have undergone hydrothermal alteration, and anomalous copper is found in an adjacent area interpreted to be unaltered or less altered sulfide-bearing rock north of Pilot Mountain (table 1 and figs. 3-4). Soils of much of the anomalous area overlie highly siliceous rock that was formerly sulfide-bearing. The soils are residual and have been subjected to strong acid leaching, first by H_2SO_4 formed on oxidation of the widespread sulfide, and later by organic acids produced by the decomposition of forest litter, largely oak leaves. In general, values for all metals drop significantly away from the alteration area on Pilot Mountain. Control samples were taken of soils on other high rocky ridges, some of them having small amounts of disseminated sulfide in the bedrock; analyses of Cu, Mo, and Sn from these control samples were very low (table 2). The highest measurements of Mo and Sn occur mostly on the area of strong andalusite-pyrophyllite development, but they also extend eastward and southeastward to include a larger area where the main rock alteration is strong silicification plus development of a little pyrophyllite and sulfide. The analytical values for copper can be interpreted to form linear high zones that trend northeastward and northwestward, but shaping of contour lines is very subjective and might be considerably modified by use of a different or more extensive sampling pattern.

There are at least three groups of long-abandoned gold mines and prospects on the flanks of Pilot Mountain. A pyrophyllite-andalusite body northwest of the crest has been evaluated for mining several times, the latest in 1978-80 by Piedmont Minerals Company, Inc. Additional sites where pyrophyllite and lesser amounts of andalusite are present extend westward from the mountain, occupying an area 4 km long in an east-west direction and 1.5 km wide. All of the altered masses are presumed to be part of the same hydrothermal alteration.

Geobotany of the Study Area

Pilot Mountain is within the humid subtropical climatic zone, having 100-150 cm annual precipitation. Although surrounded by Piedmont vegetation, the flora is more like that of the mountains further west. Braun (1950) included the monadnock vegetation in the Oak-Chestnut association of the Blue Ridge and northern Piedmont rather than in the Oak-Pine association of the southern Piedmont. The major species present include chestnut-oak, blackjack oak, Spanish oak, hickory, red maple, and Virginia pine. Red maple, black gum, sassafras, black cherry, and dogwood are often found in the understory, and the groundcover is typically composed of heaths. Scientific names of plants are listed in table 3.

The forest community at the top of Pilot Mountain, like that on nearby monadnocks, is composed primarily of chestnut-oak with some Virginia pine, and occasional hickory. Unlike nearby ridges without alteration zones, chestnut-oak growing on part of the altered rock on Pilot Mountain appears to be slow growing, and the subcanopy is very sparse, with saplings and a few stems of black gum and dogwood. The understory is also very sparse and contains mostly blueberry and huckleberry. Spanish oak occurs in increasing numbers down the mountain slopes, and the other species mentioned in the previous paragraph become more common. Slow growing or even stunted chestnut-oaks and a flora of low diversity are also present on several other similar hydrothermally altered zones in the slate belt. Though we suspect that these areas of stressed vegetation are related in some way to the zones of most intense alteration, we do not know what specific factors are responsible for the stress.

The vegetation at various sites on the mountain was sampled using the variable-radius plot method developed by Bitterlich (Grosenbaugh, 1952). Ten measurements at each site were averaged to give a composite sample. Table 4 shows the results of the Bitterlich sampling, and the sampling sites are located on figure 5. Distribution of some individual canopy species and of total canopy vegetation and total oaks are shown in figures 6-14. The highest total canopy measurements occur on east and west facing slopes (fig. 6). Comparison of figures 6 and 8 shows that the highest total canopy sites are also generally those sites with the most Virginia pine. Concentrations of oak, on the other hand, are south and west of the crest. Chestnut-oak concentration decreases from the crest in all directions (fig. 9) and is very low on topographically flat lowlands (sites 6, 13, 19, fig. 9). Spanish oak, white oak, and post oak, in contrast, are lowest at high elevations and increase with distance from the crest (figs. 10-12). Blackjack oak is most commonly found on intermediate slopes and least commonly on flat upland or flat lowland sites (fig. 13). The percentage of the canopy composed of chestnut-oak is greatest on the crest (fig. 14).

The vegetation on Shepherd Mountain, a nearby unaltered monadnock, is composed of the same canopy species with the addition of yellow poplar on lower slopes. The subcanopy and understory, however, are of moderate to heavy density even on the crest and around noses with large outcrops. The subcanopy is composed of saplings of canopy species, dogwood, sourwood, black gum, sassafras, and red maple. In the understory are shrubs such as blueberry, huckleberry, and maple-leaf viburnum, and vines such as grape, poison ivy, and Japanese honeysuckle.

Leaves were collected for laboratory analysis of metal content in September, 1980, and September, 1981. Collections were made on a transect across the mountain from the bottom of the southeast slope across the crest to the bottom of the northwest slope (fig. 15). Whenever possible, leaves were collected from all sides of the tree, and leaves from 2-3 adjacent trees of the same species were combined. Species collected included chestnut-oak, red maple, blackjack oak, and hickory. The leaves were washed in mild soap within hours of collection, rinsed in distilled water, and air dried. In the laboratory, the leaves were ashed at 500°C for at least 10 hours. Measurements of Cu, Zn, and Mo were made in the laboratory of T. Harms, USGS, Denver, using methods developed or adapted in that laboratory. The volume of sample was insufficient for measuring tin. Future samples and measurements will include this metal.

With only one exception, molybdenum measurements were less than 4 ppm. Molybdenum measurements from deciduous trees in humid subtropical regions as reported by Connor and Shacklette (1975) were also generally low. Copper and zinc measurements for leaf samples from Pilot Mountain and Shepherd Mountain are summarized in Table 5. In all cases except Zn in hickory leaves, metal concentrations are higher at Pilot Mountain than at Shepherd Mountain. The non-parametric Mann-Whitney-Wilcoxon test (Gibbons, 1976) was used to evaluate the differences between the two sites. The p values for the zinc measurements are high, indicating no significant difference in the zinc levels. The p values for copper, on the other hand, indicate significant differences between the two sites for all four species, especially for blackjack oak and red maple. Since red maple is nearly ubiquitous, it may prove to be the most promising species to use in leaf metal analyses in this area.

Airborne Spectroradiometer Data

The Pilot Mountain site was surveyed with the new MARK II airborne spectroradiometer system on October 4, 1981. The instrument takes high-resolution spectral measurements at .0015 micrometer bandwidth, in 512 bands, between .4 micrometer and 1.0 micrometer. This is the important chlorophyll absorption band region. The new instrument system also covers the 1.5 micrometer to 2.5 micrometer region with 64 bands of 0.16 micrometer bandwidth. This near infrared region contains vegetation water content information, which can be used for filtering out unwanted canopies that can be confused with canopies under mineral-induced stress.

The instrument was flown over the Pilot Mountain site at 610 meters altitude and 190 kilometers per hour ground speed. The instantaneous field-of-view was 20 meters square. Data were acquired and recorded in a continuous line profile technique along the aircraft ground track and were calibrated in radiance received at the instrument aperture. A traverse grid of seven parallel lines up to 6 kilometers long with two additional crossing traverses was flown. The survey spectral data along each traverse were analyzed on a computer using the waveform analysis method of detecting shifts on the near-infrared absorption edge of the chlorophyll bands (Collins and others, in press; Chang and Collins, in press).

The waveform analysis has indicated two zones of highly anomalous vegetation on Pilot Mountain (figure 16). These zones are on the south and north slopes of the mountain in areas of heavy forest canopy. Several traverses crossed the zones of anomalous soil metal content. The data analysis results for three of the traverses are shown in figures 17-19. The survey lines crossed several kinds of canopy, including forest cover, grassy farmland, and brush-covered areas of recently logged forest. The waveform analysis filters all of these various canopy effects and identifies the anomalous forest canopy.

Figure 17 shows the filtering and stress detection results. The upper curve is sensitive to a spectral shift in the chlorophyll bands. This shift, however, is often present in the spectra of various farmlands with grass or young crop cover, as shown in the first two high peaks in the upper curve of figure 17. This non-stress-related effect is filtered out using the thin canopy discriminant in the middle curve, which is obtained from the waveform analysis of the chlorophyll spectra. The areas of thin canopy and grassland are filtered also using the 1.5 to 2.5 micrometer data in which the ratios of broad bands near 1.6 micrometer and 2.2 micrometer are very sensitive to grass or soil. The mineral-induced chlorophyll anomalies are indicated by the high values in the upper curve sensitive to the spectral shift and by low values in the two lower curves that separate heavy forest canopy from other kinds of ground targets. Similar results are shown in figures 18 and 19. The stronger chlorophyll anomalies are mapped in cross hatched pattern in figure 16. The weaker anomalies are mapped in the open contour pattern.

The methods and interpretation used here are the same as those developed in earlier surveys over western conifer terrain (Collins and others, in press). The mapping results showing the mineral-induced forest canopy stress are also very much the same as those obtained in the western surveys. The accumulating results of successful biogeophysical mapping in different terrain and vegetation cover indicate that the mineral-induced stress is a widespread phenomenon that is a reliable indicator of hidden ore deposits.

Discussion

Comparison of the extent of hydrothermal alteration (fig. 2) with the distribution of chestnut-oak (fig. 14) shows that the highest chestnut-oak values occur within the altered area. The maximum chestnut-oak occurs on the area with pyrophyllite and andalusite ore bodies, which area is also a topographic high. Vegetation in a much altered area west of the 30% chestnut-oak contour has been cut and planted to pine, so that the prevalence of chestnut-oak in the natural forest there is unknown. Chestnut-oak measurements outside the altered area are at or near zero.

The highest copper content of leaves coincides with the highest soil measurements, both occurring on the upper southeast slope of the mountain (table 6 and fig. 15). The association of copper values in soils and plants collected at the same sites was tested using the Spearman coefficient (Gibbons, 1976). The degree of association between soils and red maple leaves is 0.554, which gives a probablility of 0.10 that there is no association between the samples. The results of samples from the other tree species have a lower probability of association.

The highest copper measurements in red maple leaves (sites 3, 4, 8, figs. 15 and 19) can be compared with the radiometric anomaly (fig. 16). Sites 3 and 8 occur within the area of anomalous vegetation, whereas site 4 is just downslope from it. Sites 1 and 2 are lower in copper and are also outside and between the radiometric anomalies. Site 6 was not flown.

Comparison of the radiometer-detected vegetation anomaly (fig. 16) with the area of visual stress as defined by the amount of chestnut-oak in the canopy (fig. 14) shows little correspondence between the two except that the maximum anomaly falls within the area of greater than 30% chestnut-oak.

The maximum radiometric anomaly falls within the area of hydrothermal alteration (figs. 2 and 16). However, several weakly anomalous areas are outside the altered area, and much of the altered area does not have anomalous vegetation.

The radiometric anomaly coincides with the area of high copper measurements in the soil on the south and east slopes of the mountain (figs. 3 and 16). However, the copper soil anomaly in the lowland to the north was not detected by the radiometer. The radiometer experiment was most successful in delimiting the area of high Mo and Sn in the soils (figs. 4 and 16).

Table 1. Soil sample analyses from NW-SE transect across Pilot Mountain. [Sites correspond to leaf collections. Values in parts per million.]

Sample Number	Distance From Mountain Crest	Cu	Mo	Sn
161	0-(crest)	19	6.0	8.5
162	220 m SE	14	3.5	5.0
163	440 m SE	20	14.0	3.0
164	660 m SE	<32	2.0	3.2
165	880 m SE	18	<1.0	<1.5
168	220 m NW	<32	10.0	11.0
169	500 m NW	14	1.2	6.0
170	1220 m NW	67	<1.0	<1.5

Table 2. Analyses of 12 soil samples from unaltered felsic rock monadnocks. [Values in parts per million.]

Monadnock	Latitude North	Longitude West	Sample Number	Cu	Mo	Sn
Shepherd Mt.	35°45.11	79°57.0′	27	9.4	<1.0	3.2
	35°45.25	79°57.0′	28	24.	<1.0	3.4
	35°45.32	70°57.2′	30	7.	<1.0	2.0
	35°45.05′	79°57.3′	33	17.	<1.0	3.8
	35°45.27	79°57.1′	68	6.2	<1.0	1.9
	35°45.06	79°56.9′	69	3.9	<1.0	1.8
Stackrock Mt.	35°39.8′	79°48.3′	66	6.5	<1.0	1.6
Caraway Mt.	35°45.1′	79°53.4′	67	6.3	<1.0	1.6
Buck Mt.	35°24.4′	79°59.9′	71	8.	<1.0	<1.5
"Pine" Mt.	35°30.65′	79°29.5′	73	13.	<1.0	<1.5
	35°30.58′	79°29.6′	74	26.	<1.0	3.1
Worth Mt.	35°46.2′	79°46.9′	79	13.	<1.0	<1.5

Table 3. Scientific and common names of plants. Scientific nomenclature follows Radford and others (1968).

Acer rubrum L.	Red maple
Carya sp.	Hickory
Cornus florida L.	Dogwood
Gaylussacia sp.	Huckleberry
Liriodendron tulipifera L.	Yellow poplar
Lonicera japonica Thunberg	Japanese honeysuckle
Nyssa sylvatica Marshall	Black gum
Oxydendrum arboreum (L.) DC.	Sourwood
Pinus virginiana Miller	Virginia pine
Prunus serotina Ehrhart	Black cherry
Quercus alba L.	White oak
Q. falcata Michaux	Spanish oak
Q. marilandica Muenchh.	Blackjack oak
Q. prinus L.	Chestnut-oak
Rhus radicans L.	Poison ivy
Sassafras albidum (Nuttall) Nees.	Sassafras
Vaccinium sp.	Blueberry
Viburnum acerifolium L.	Maple-leaf viburnum
Vitis sp.	Grape

Table 4. Basal area of canopy trees in f^2/acre. Vegetation sites are located in Figure 5.

Site	Total Canopy	Total Oaks	Virginia Pine	Chestnut Oak	Spanish Oak	White Oak	Post Oak	Blackjack Oak
1	107	103		91		2		
2	94	92	3	82				10
3	110	95	15	58		9	8	11
4	161	135	12	57	17	38	2	11
5	120	107	10	48	23	8	1	21
6	100	69	29		9	31	1	
7	67	59	8	48	2	3		
8	109	91	18	83			7	2
9	95	66	2	32	1	6	15	21
10	95	81		56		4	1	16
11	83	71	2	28	7	6	3	14
12	89	76		40		15	3	6
13	67	51		6	12	15	5	7
14	98	82		48	4	15	4	8
15	85	71	5	38		3	3	27
16	98	71			5	37		5
17	96	82		59		9		2
18	91	77		32	12	16	9	5
19	84	64			22	24	3	8

Table 5. Comparison of copper and zinc levels in Pilot Mountain and Shepherd Mountain leaf samples. [P value derived from Mann-Whitney-Wilcoxon test (Gibbons, 1976).]

	Copper (ppm)				
	Pilot Mountain		Shepherd Mountain		
	mean	range	mean	range	p value
Chestnut-oak	101	90-121	85	67-101	.05
Blackjack oak	152	128-190	117	74-144	.0015
Hickory	107	74-167	73	63- 90	.022
Red maple	192	147-271	117	67-178	.003

	Zinc (ppm)				
	Pilot Mountain		Shepherd Mountain		
	mean	range	mean	range	p value
Chestnut oak	264	215-317	252	172-288	.198
Blackjack oak	562	514-598	520	352-595	.433
Hickory	395	337-499	491	281-664	.206
Red maple	576	401-754	474	364-583	.128

Table 6. Measurements of copper in soils and leaves collected at the same sites on Pilot Mountain. [Sites located on figure 15. Values in parts per million.]

Plant site #	Cu soil	Cu red maple
1	19	147
2	14	147
3	20	244
4	<32	271
5	18	167
6	17	167
8	14	205

Copper analyses of soils at sites 1 and 2 are the lowest values of several samples taken from the same area; nearby Cu analyses have ranged up to 75 ppm. The soil copper analysis at site 3 was also lower than 3 nearby sites. Thus, the value for site 3 does not correspond to the contoured values on fig. 3.

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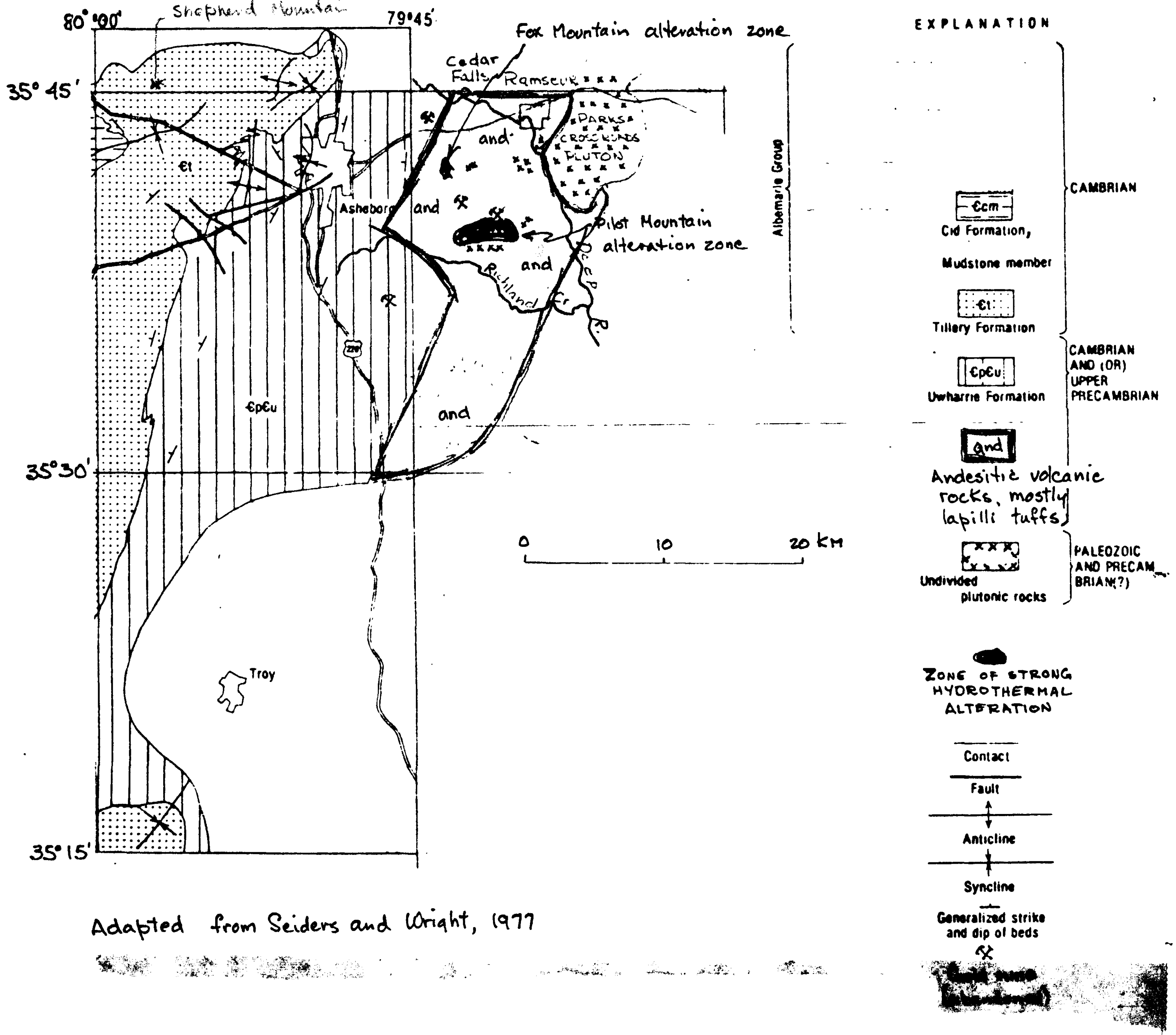


Figure 1. Reconnaissance map of Asheboro area, North Carolina, showing setting of Pilot Mountain.

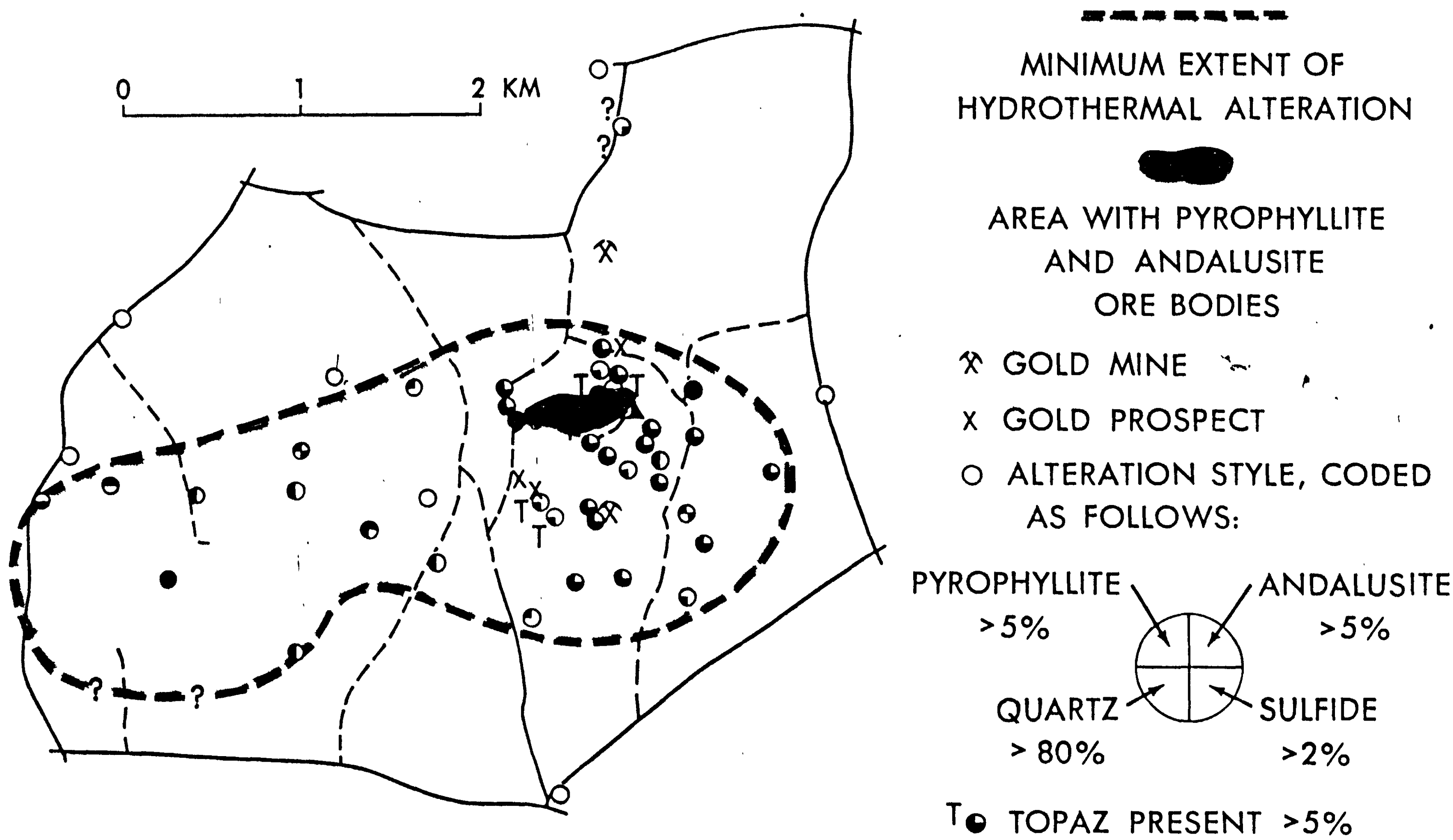


Figure 2. Extent of alteration on Pilot Mountain.

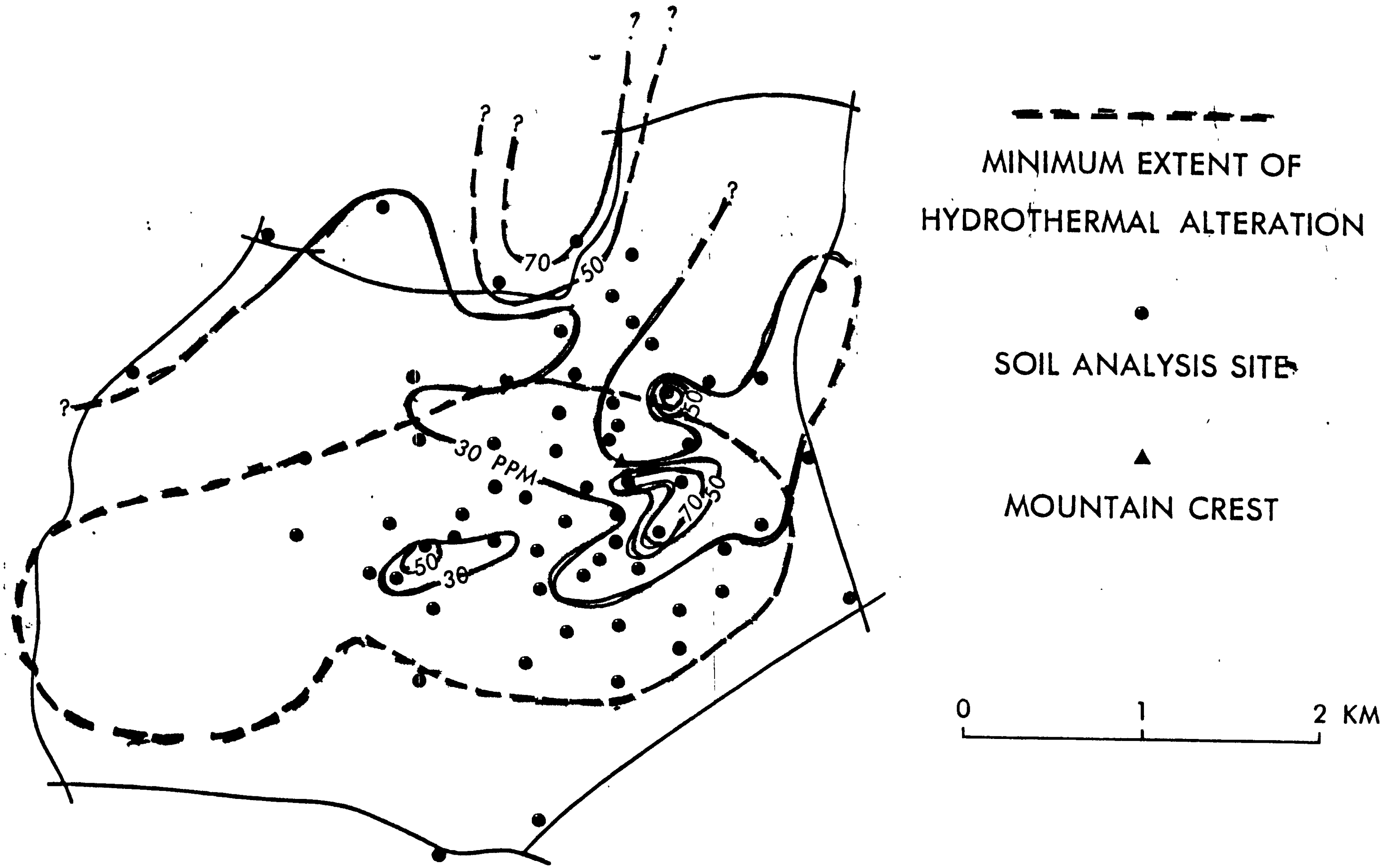


Figure 3. Soil sample analyses for copper, Pilot Mountain area. [Values in parts per million.]

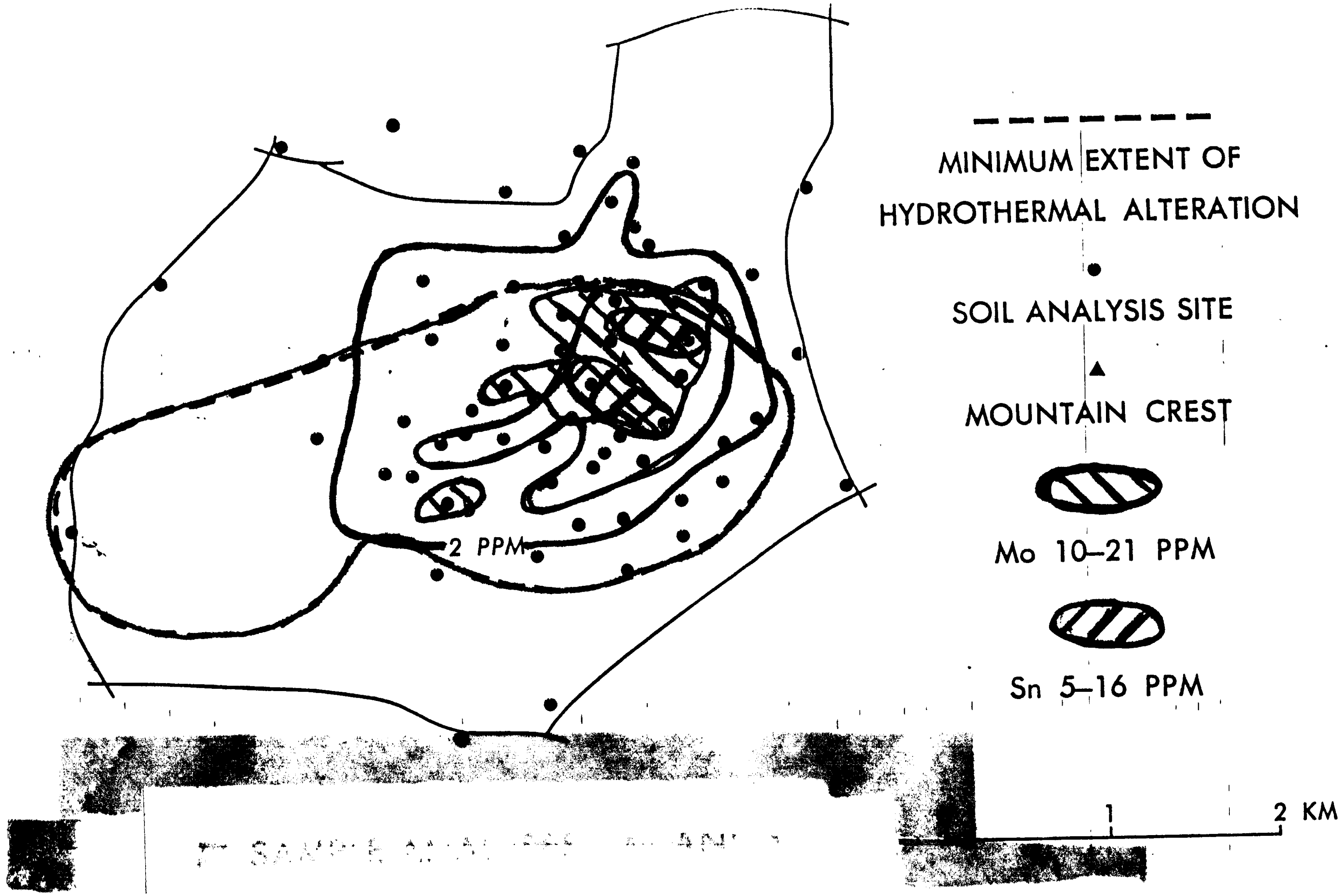


Figure 4. Soil sample analyses for molybdenum and tin, Pilot Mountain area. [Values in parts per million.]

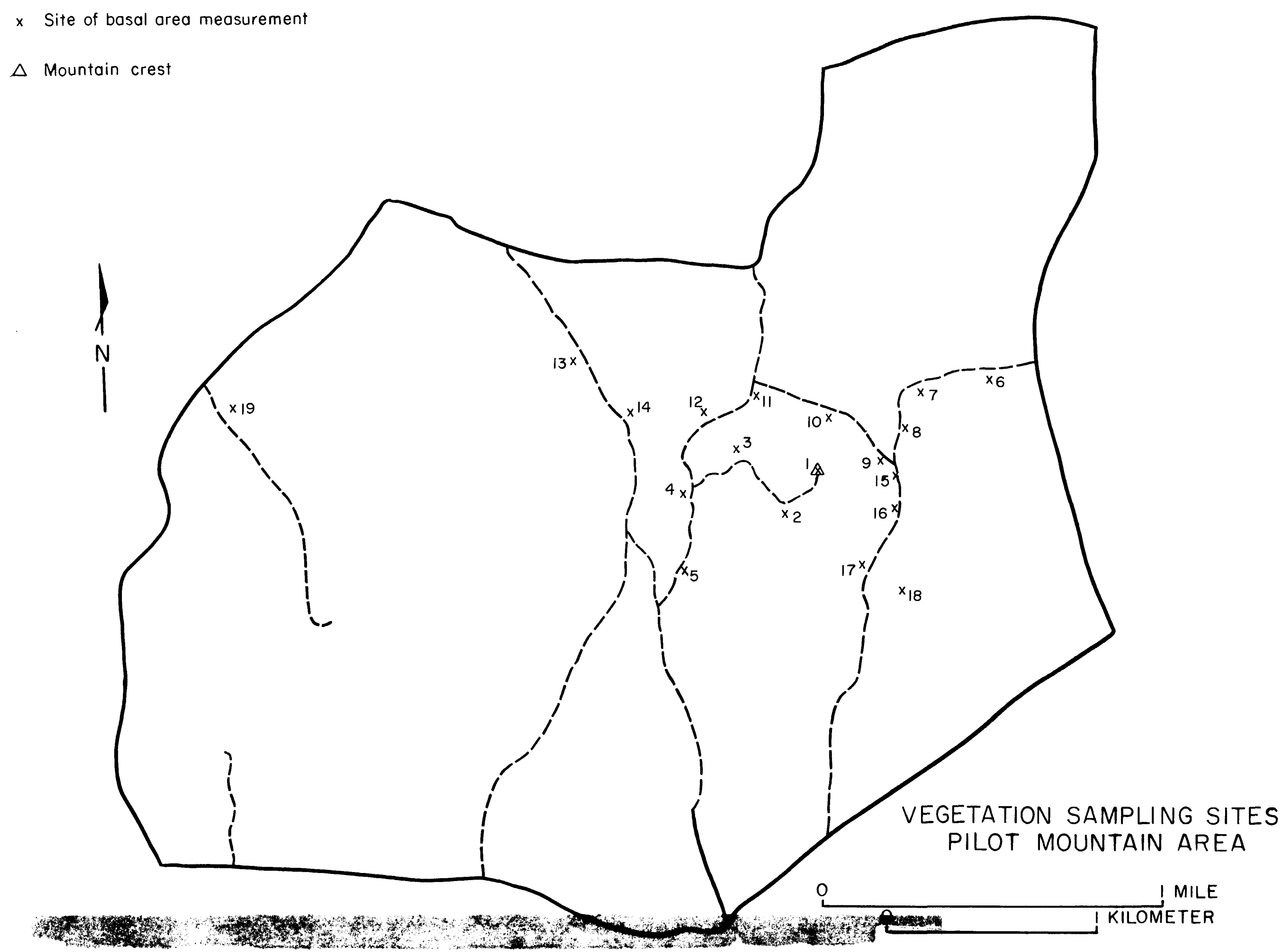


Figure 5. Vegetation sampling sites, Pilot Mountain area.

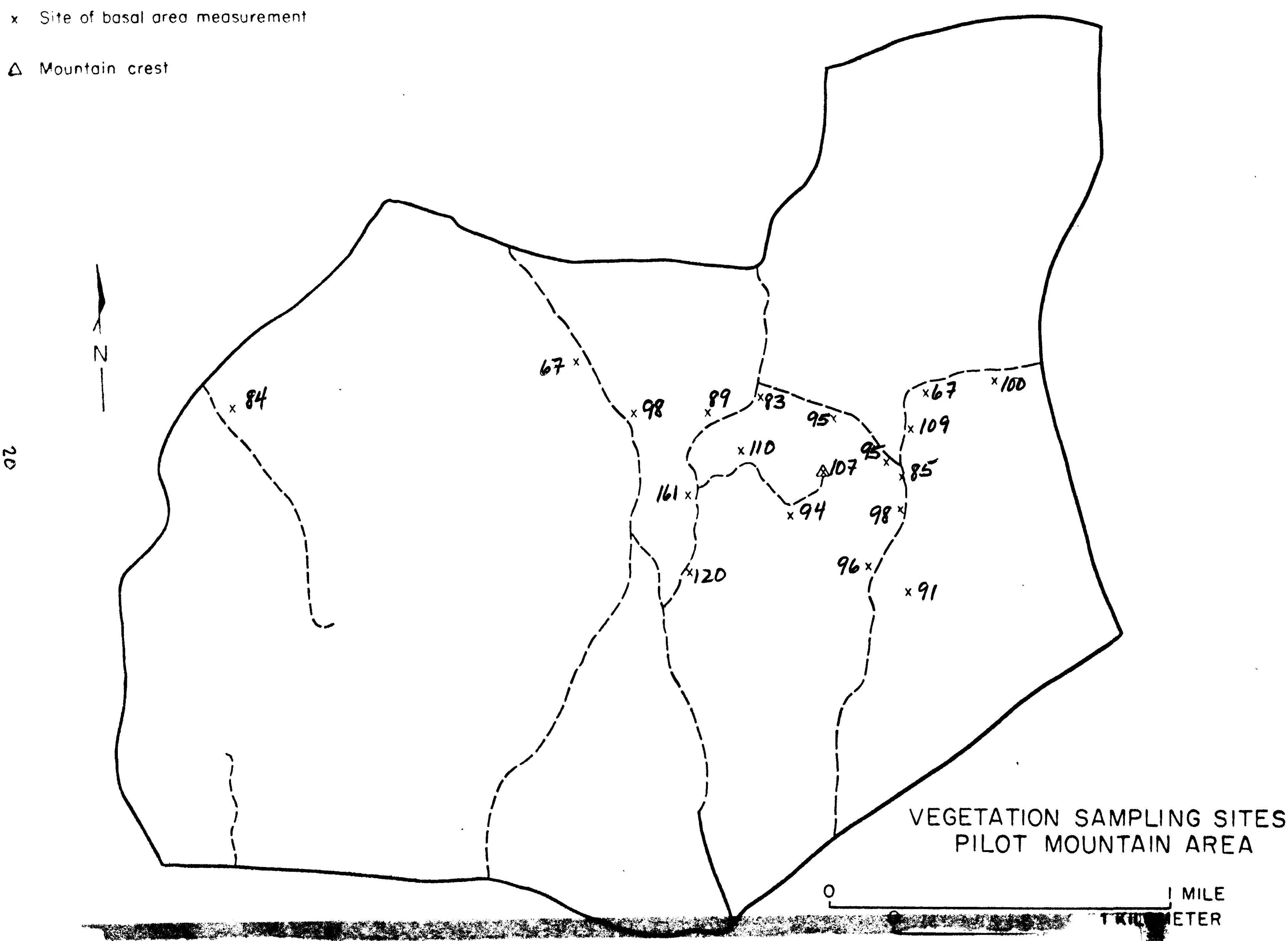


Figure 6. Basal area of all canopy species. [Values in square feet per acre.]

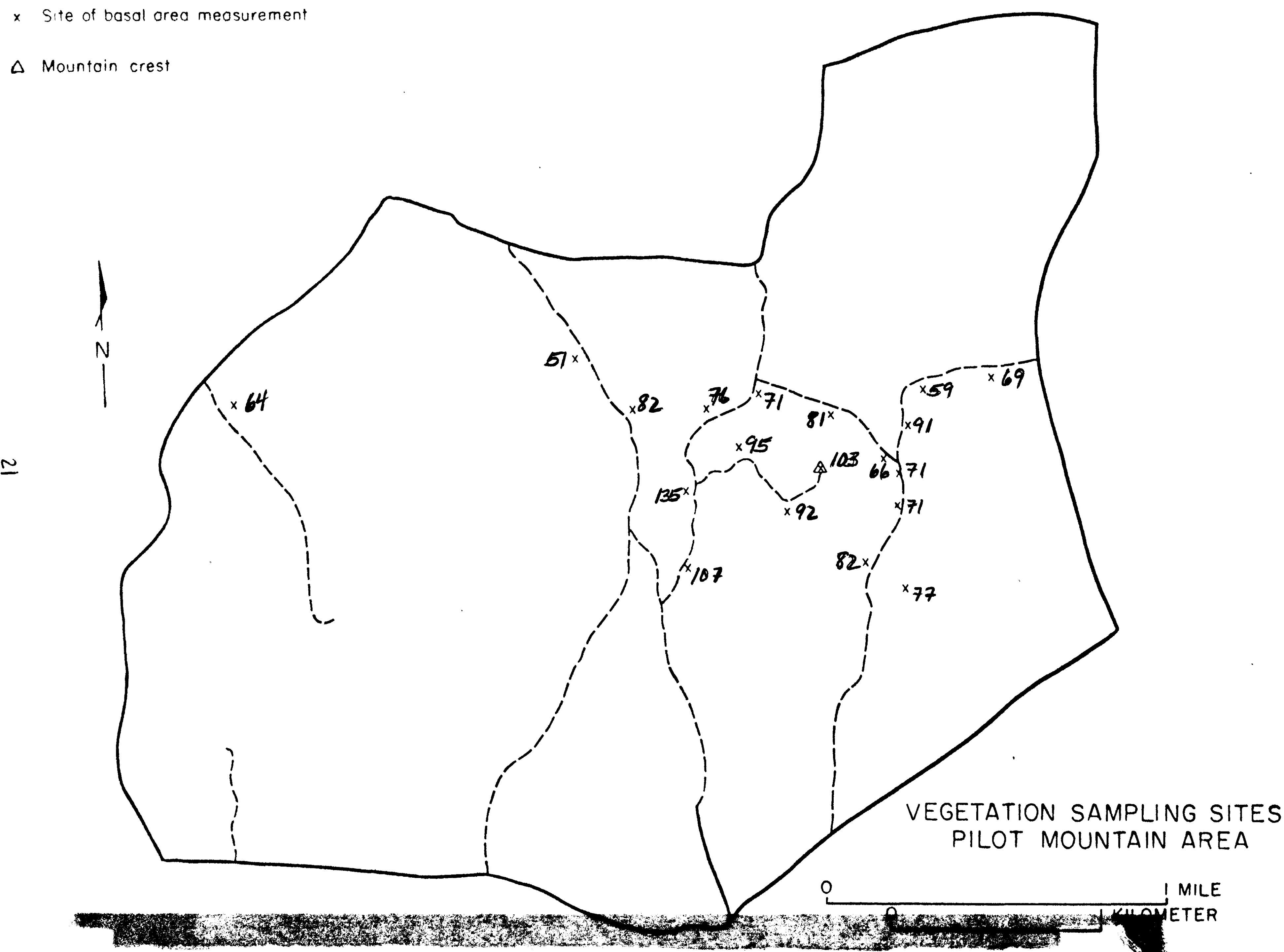


Figure 7. Basal area of all oak species. [Values in square feet per acre.]

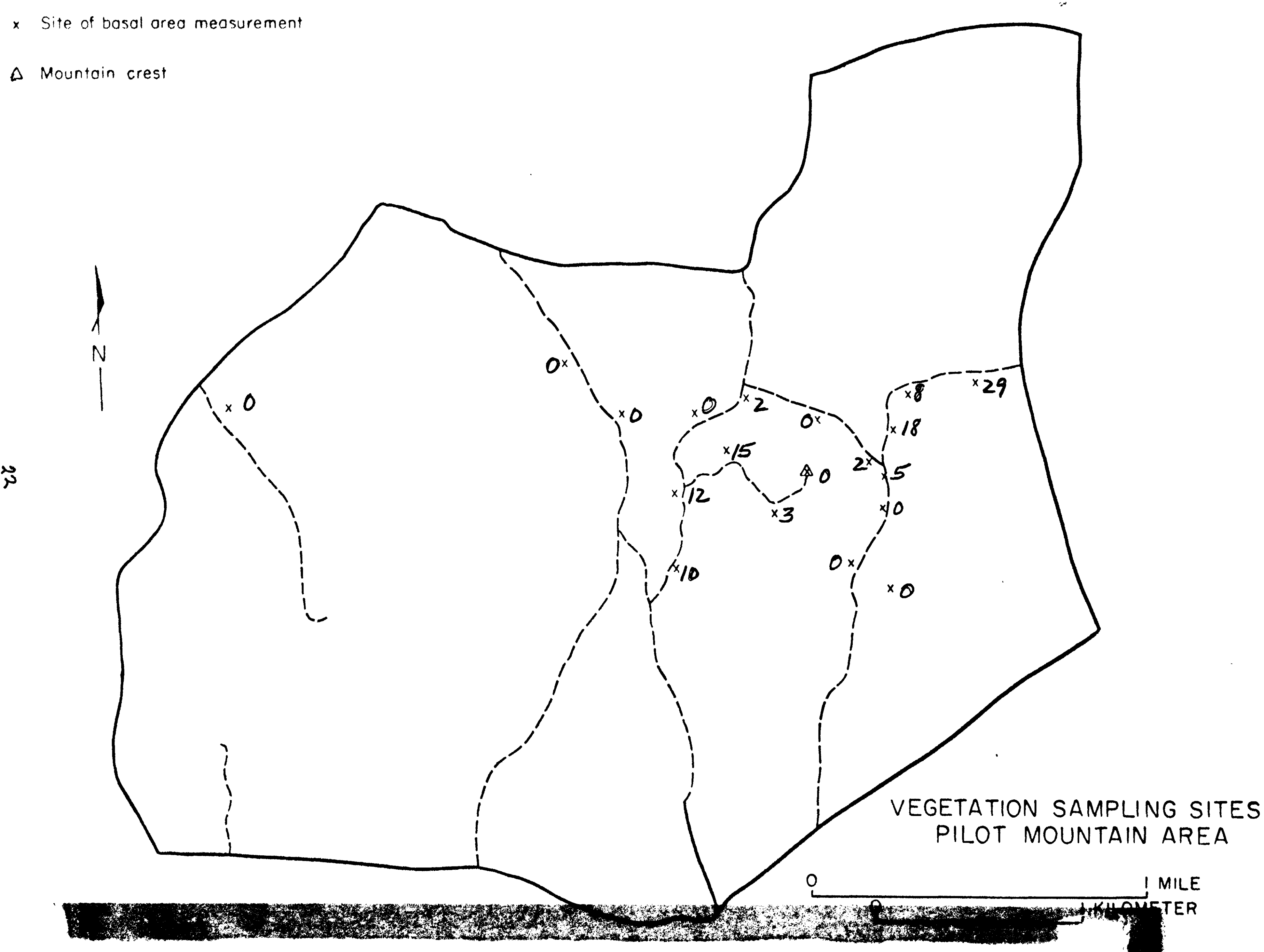


Figure 8. Basal area of Virginia pine. [Values in square feet per acre.]

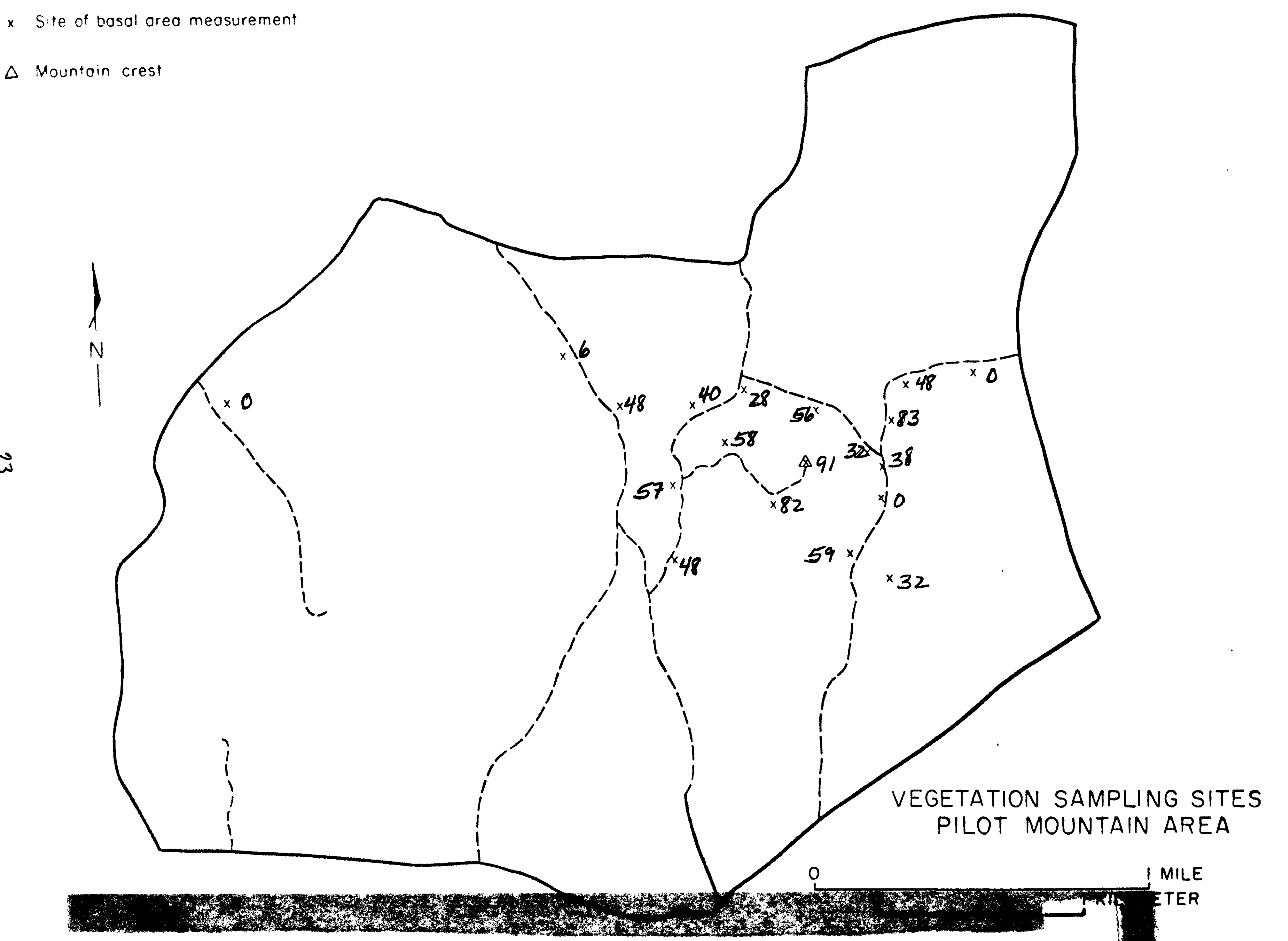


Figure 9. Basal area of chestnut-oak. [Values in square feet per acre.]

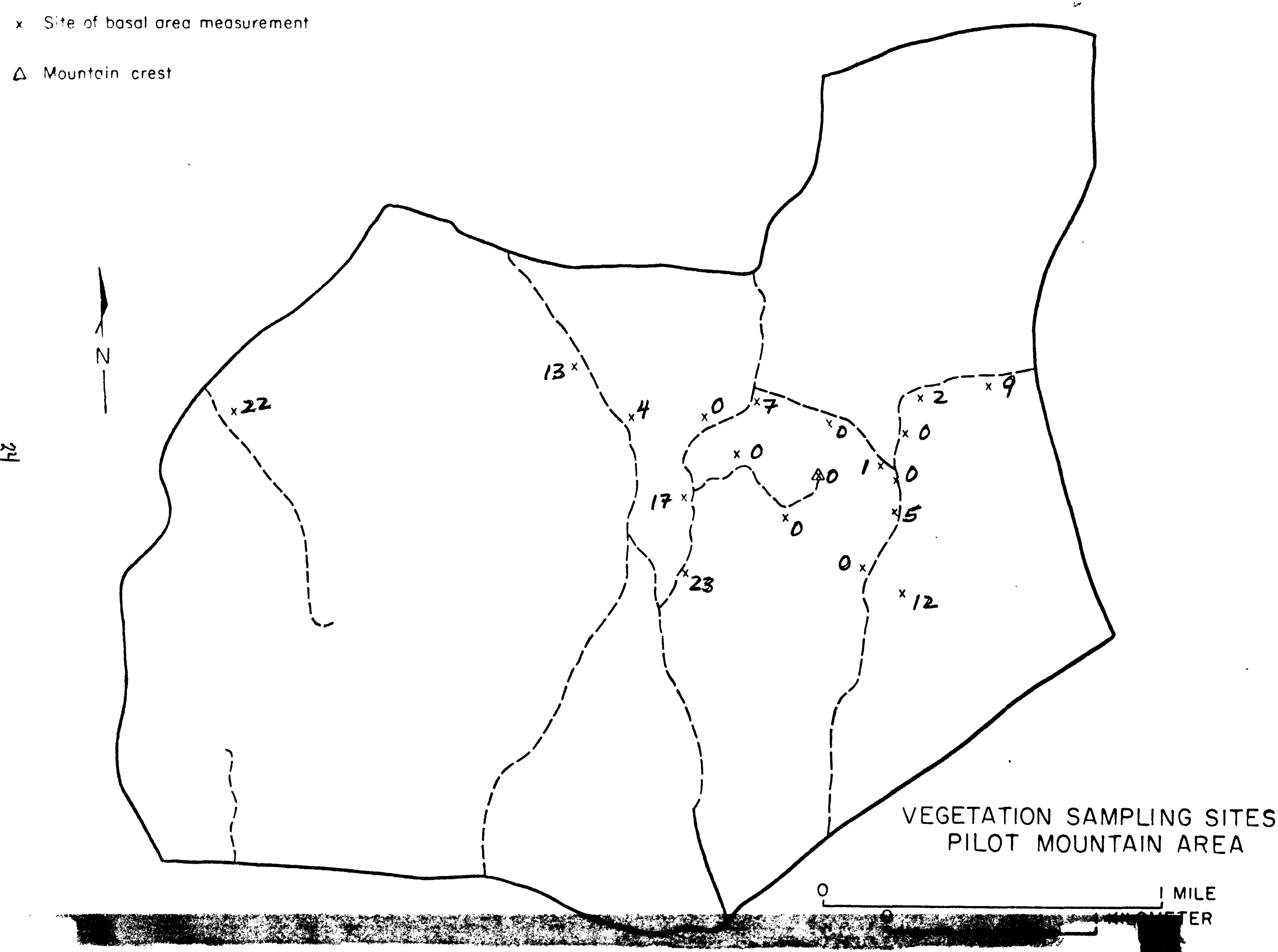


Figure 10. Basal area of Spanish oak. [Values in square feet per acre.]

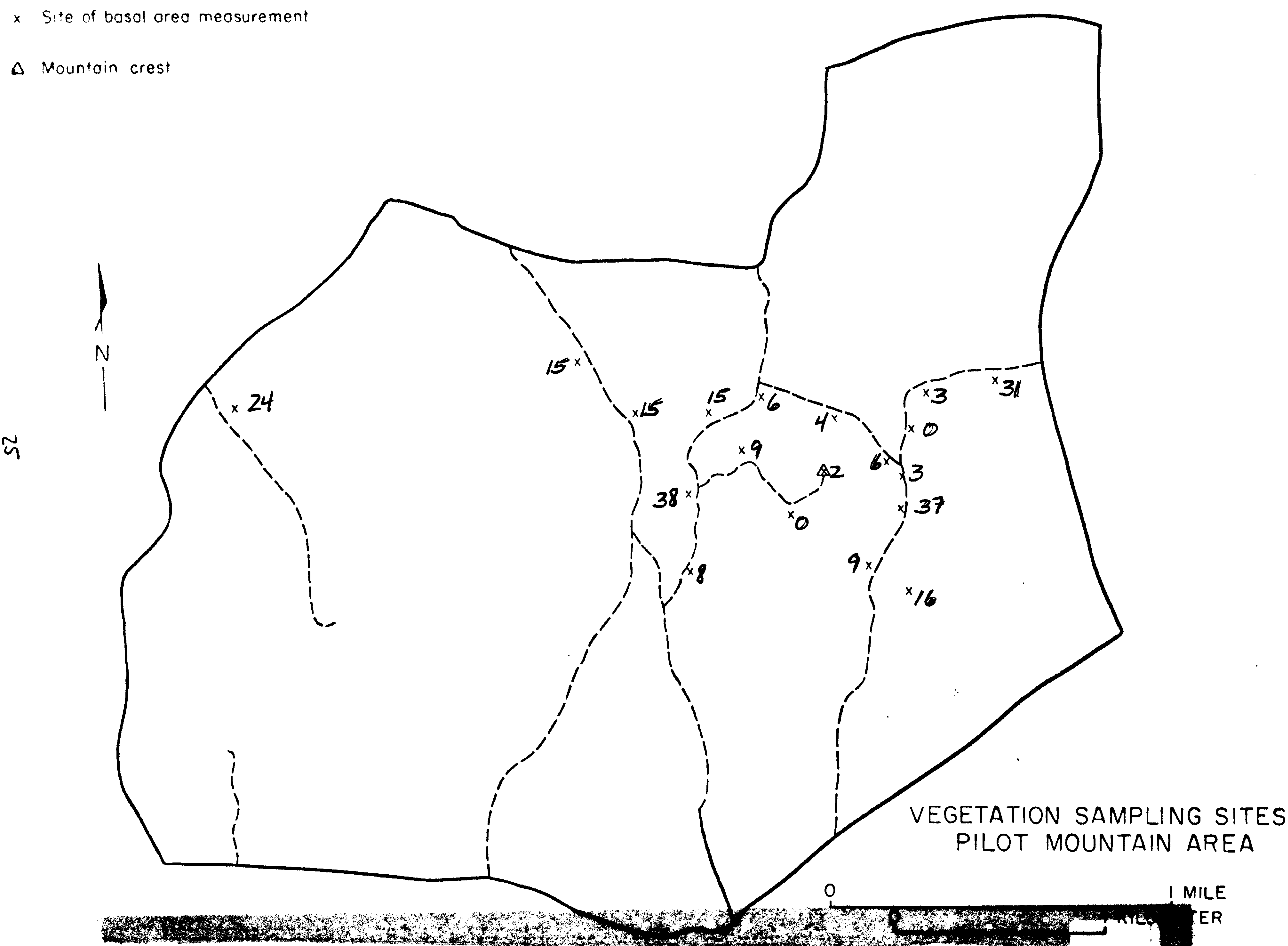


Figure 11. Basal area of white oak. [Values in square feet per acre.]

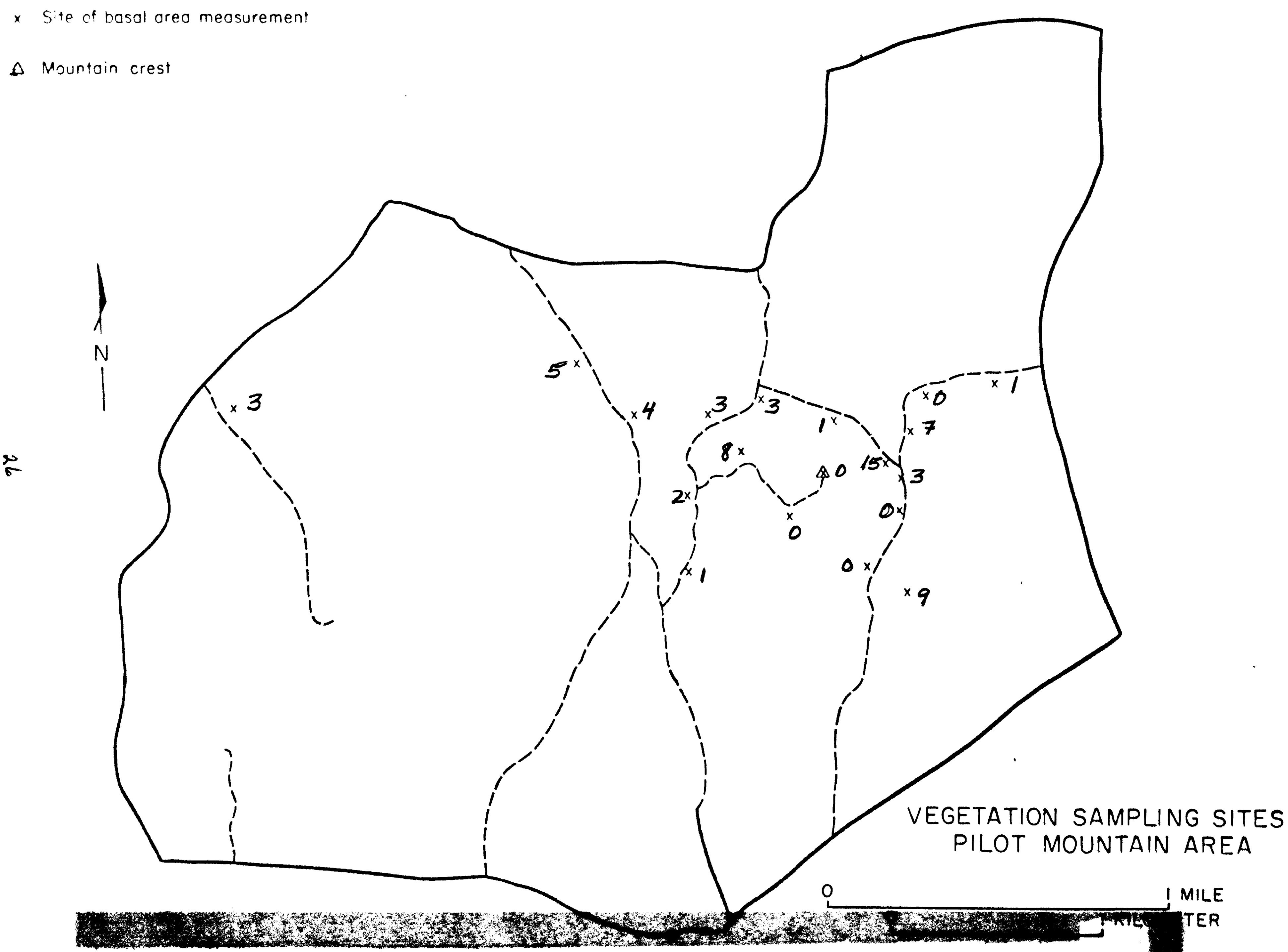


Figure 12. Basal area of post oak. [Values in square feet per acre.]

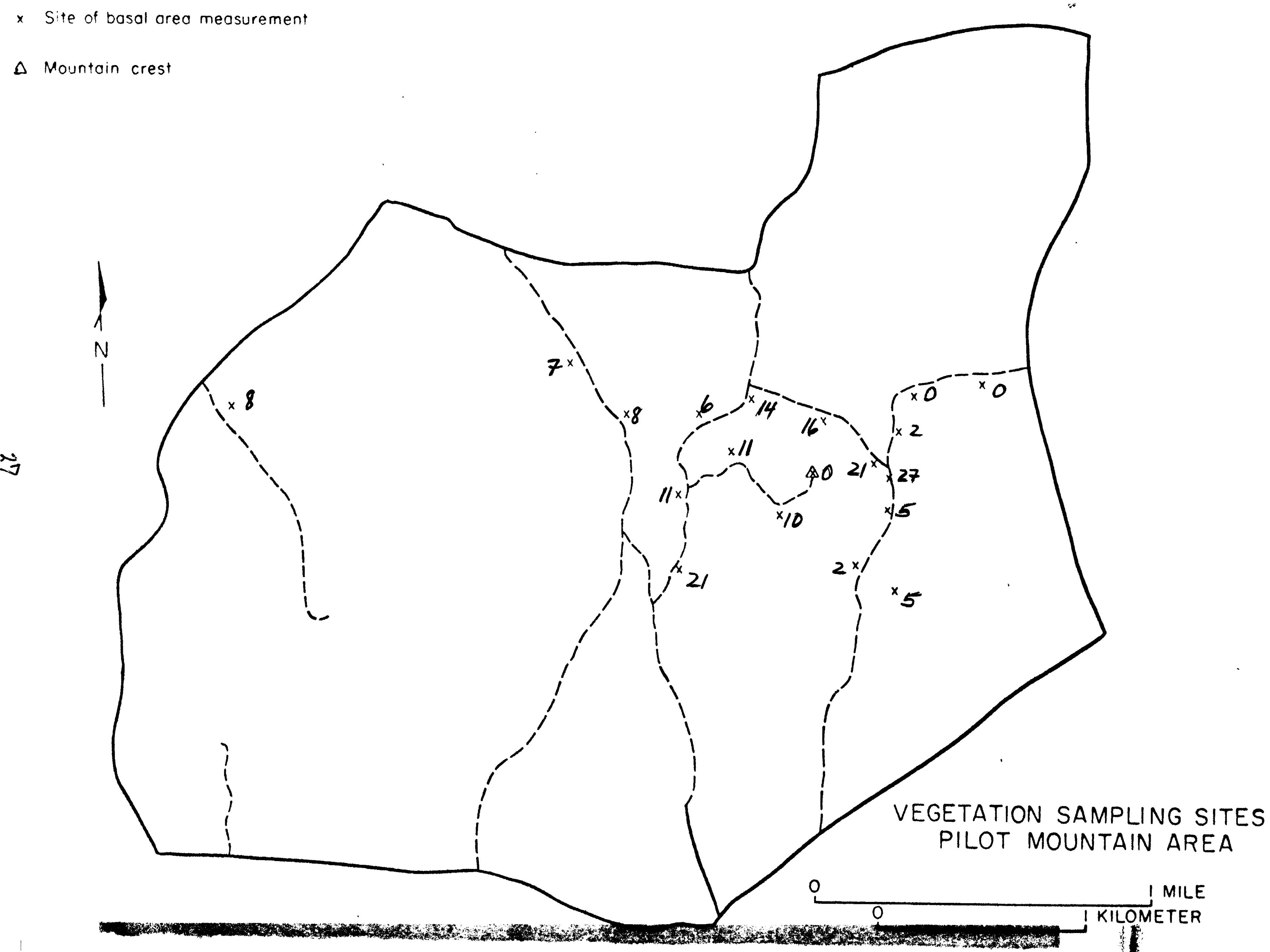


Figure 13. Basal area of blackjack oak. [Values in square feet per acre.]

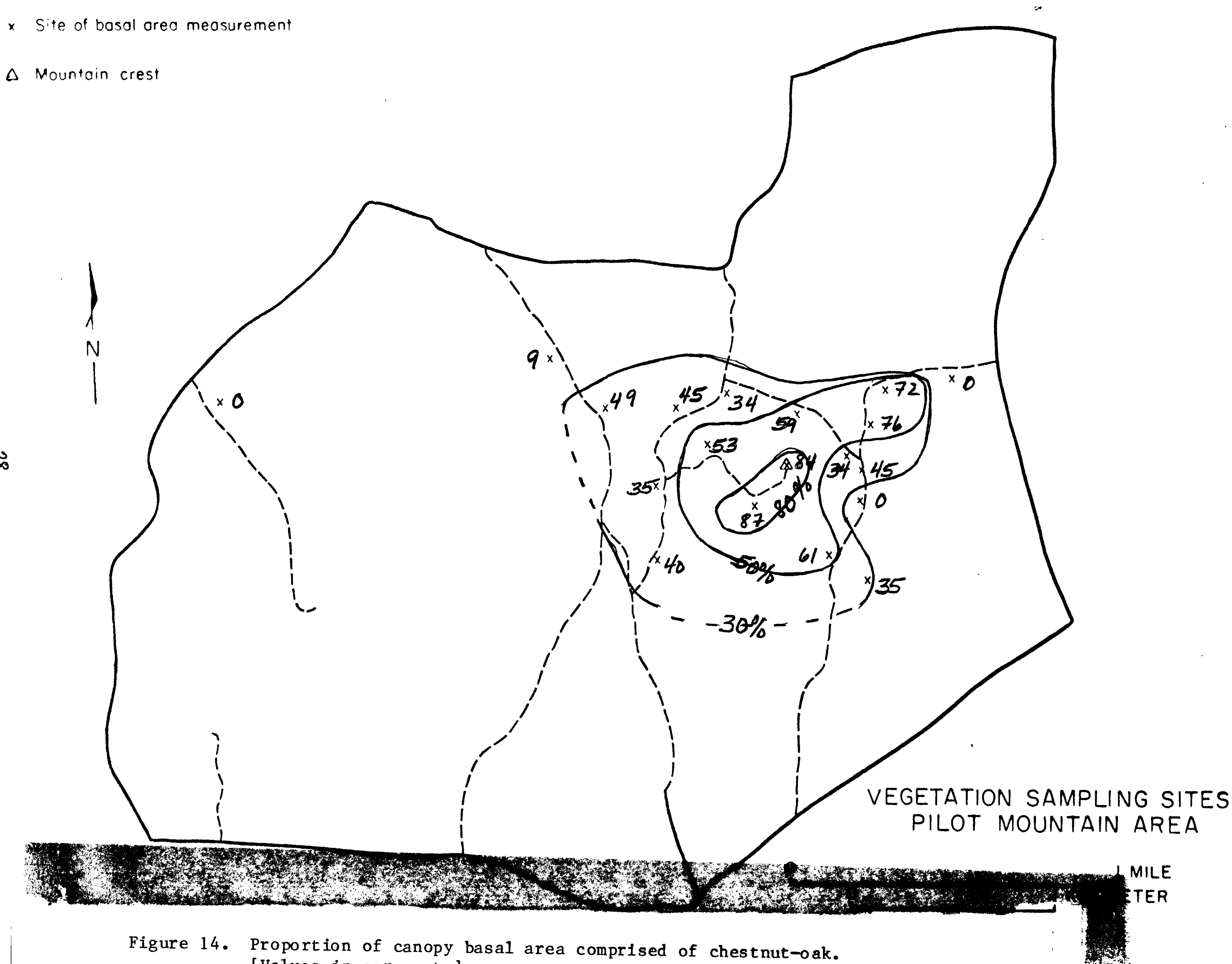


Figure 14. Proportion of canopy basal area comprised of chestnut-oak. [Values in per cent.]

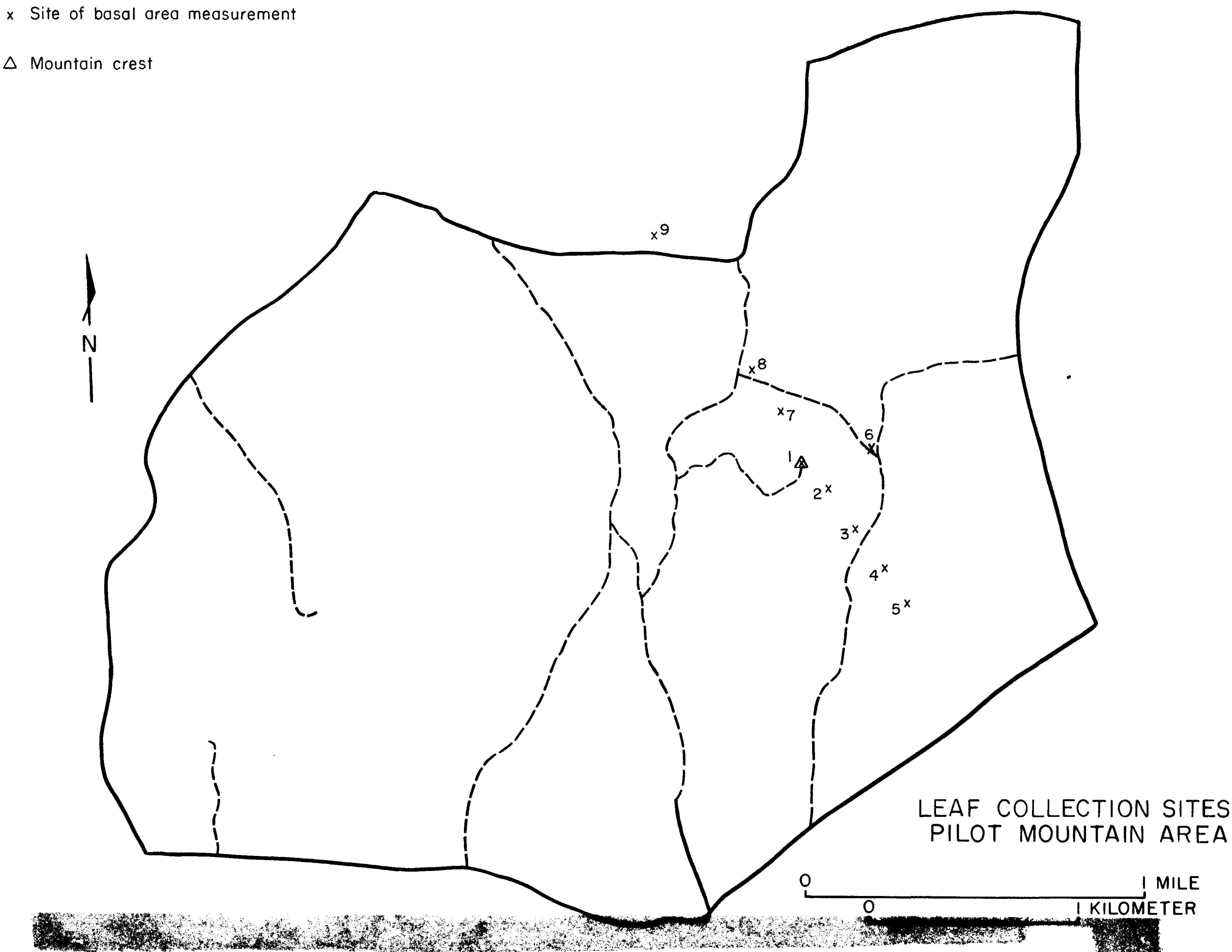
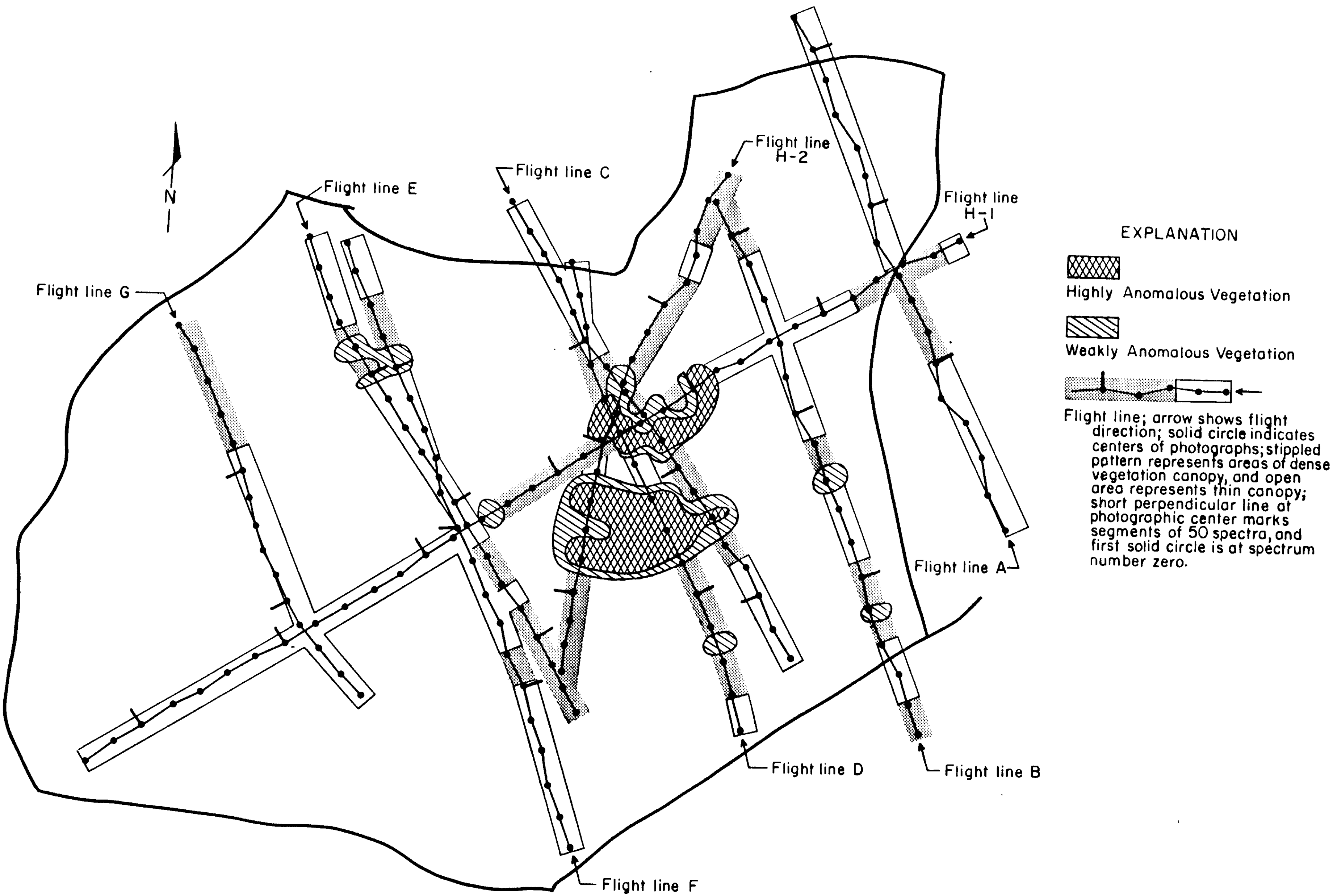


Figure 15. Leaf collection sites, Pilot Mountain area.

Figure 16. Airborne radiometer data showing areas of strong and weak anomalies of vegetation reflectance.



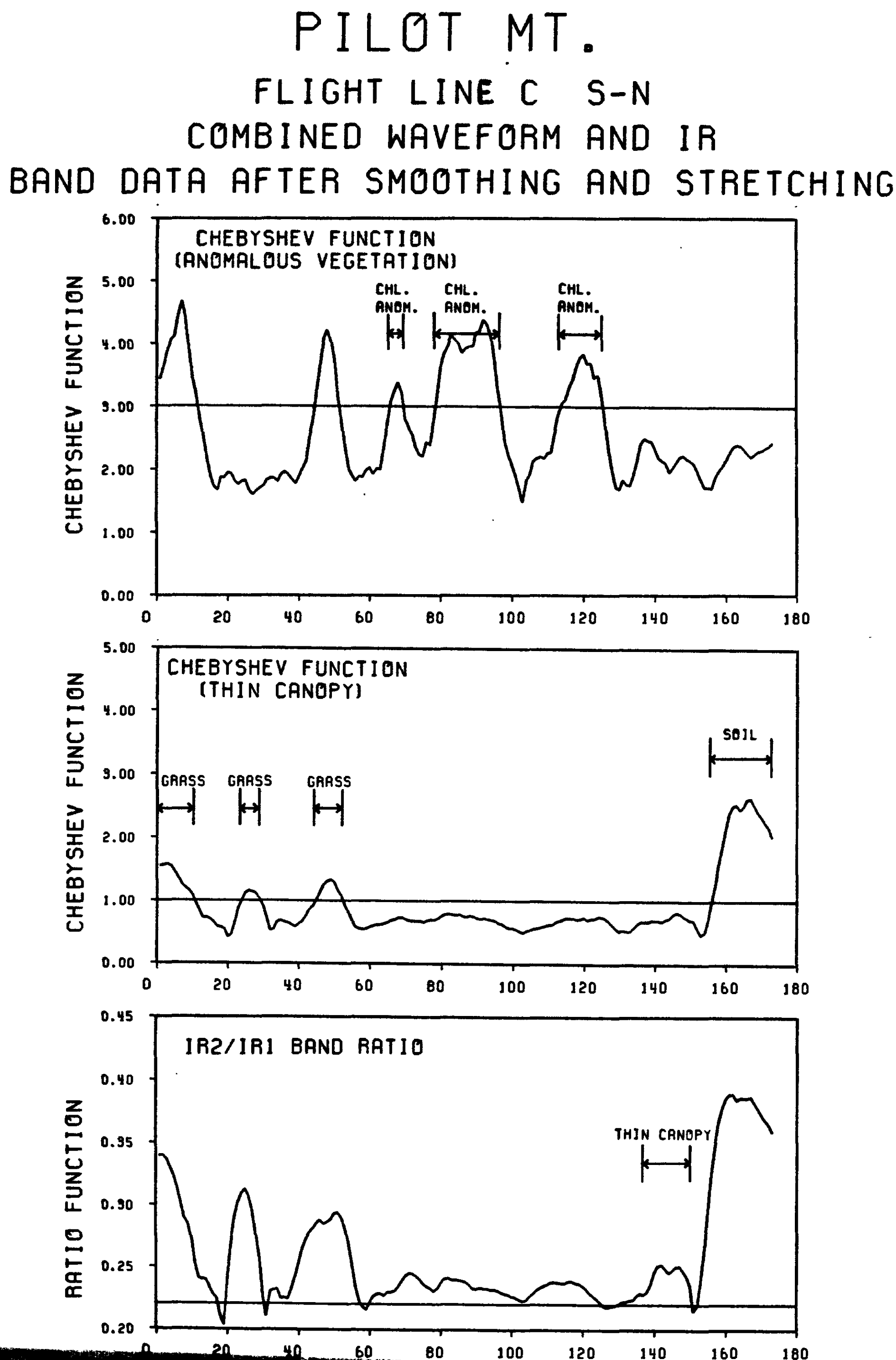
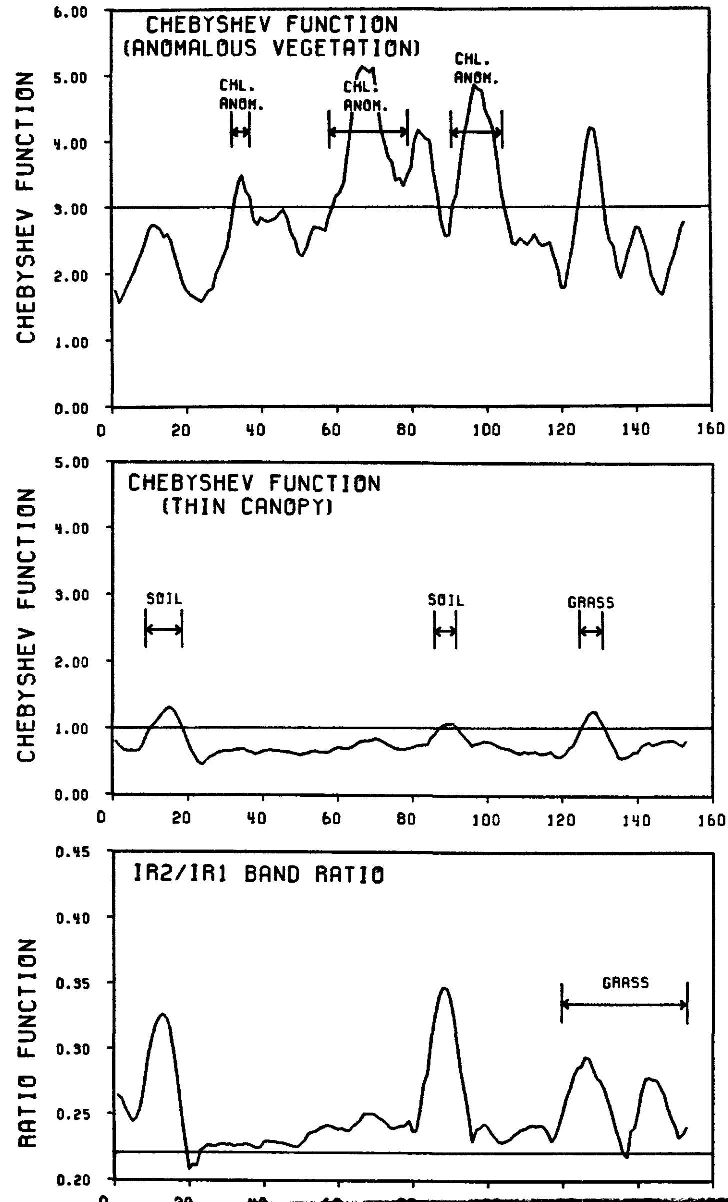


Figure 17. Results of analysis of Traverse C across the Pilot Mountain canopy anomaly. The upper curve data is high when the chlorophyll band infrared edge shifts toward shorter wavelengths. Either grass or stress can be the source of the shift. The lower curves separate the grass and thin canopy effects.

PILOT MT.

FLIGHT LINE D S-N
COMBINED WAVEFORM AND IR
AND DATA AFTER SMOOTHING AND STRETCHING



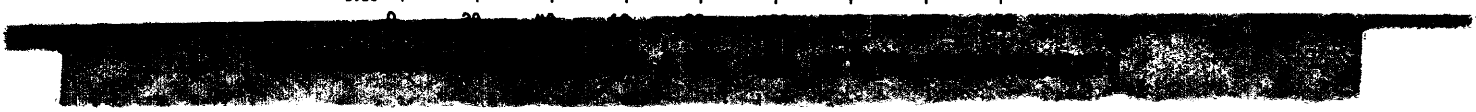
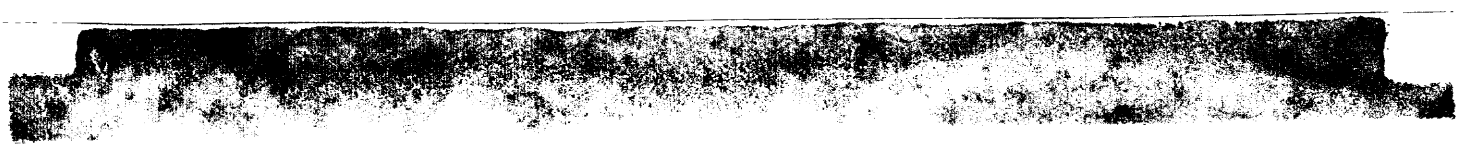


Figure 18. Traverse D crosses two zones of strong forest canopy stress between measurements 60 and 110.



PILOT MT.
FLIGHT LINE H2 S-N
COMBINED WAVEFORM AND IR
BAND DATA AFTER SMOOTHING AND STRETCHING

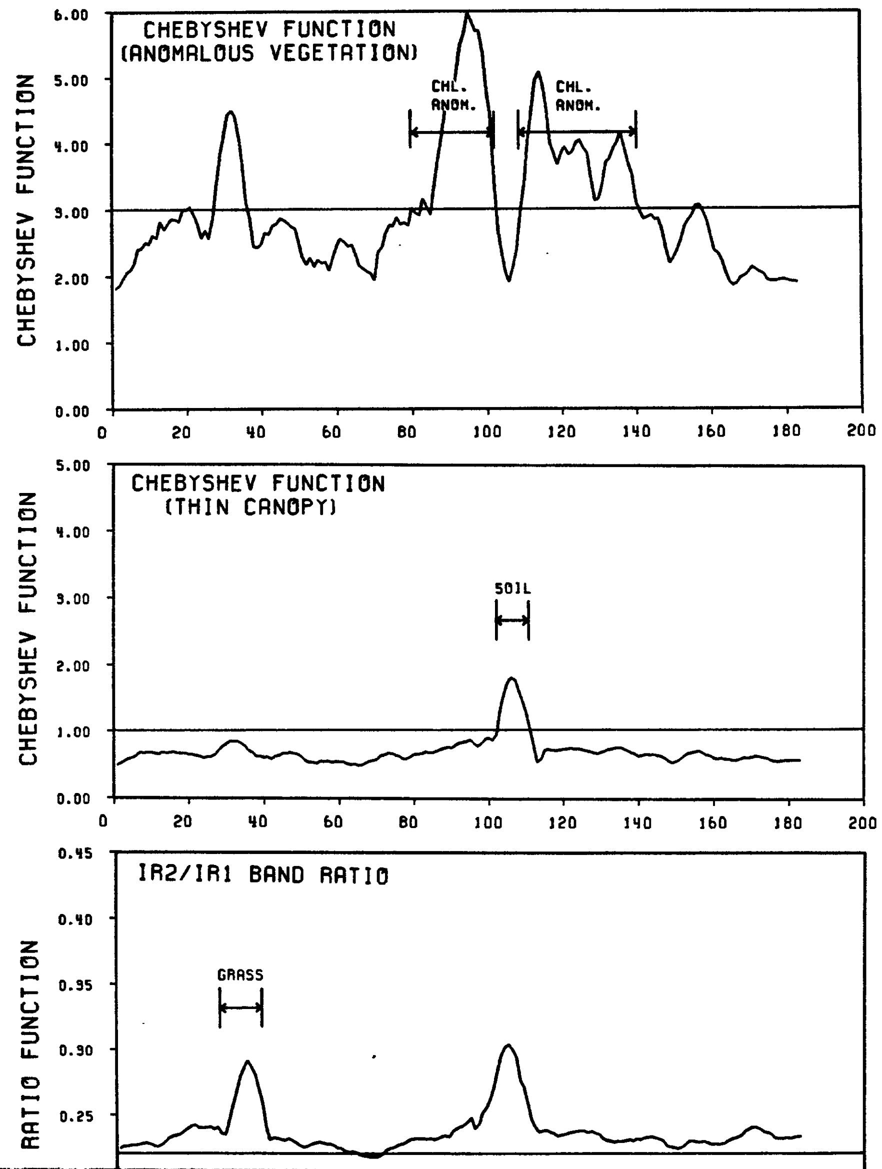


Figure 19. Traverse H2 crosses the strong forest canopy stress between measurements 90 and 140.