LICHEN BIOMONITORING PROGRAM IN THE DOLLY SODS AND OTTER CREEK WILDERNESSES OF THE MONONGAHELA NATIONAL FOREST: A RESURVEY OF LICHEN FLORISTICS AND ELEMENTAL STATUS

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SUMMARY

In 1987, a lichen biomonitoring program was initiated in the Otter Creek and Dolly Sods Wildernesses of the Monongahela National Forest, West Virginia. This was a baseline study designed to accomplish the following objectives: (1) To characterize the lichen floras of the two wildernesses and note patterns characteristic of air pollution damage; (2) To establish permanent photographic study plots within which to record aspects of lichen community composition; (3) To establish permanent quadrats throughout the two wildernesses within which to collect samples of a single lichen species for elemental analysis.

Lichen communities were sampled in each wilderness and found to include numerous species known to be pollution-sensitive, indicating the lichen flora was not adversely affected by air pollution at that time. In addition, specimens of the lichen _Flavoparmelia caperata_ were sampled within 121 1-km^2 sections (80 in Otter Creek and 41 in Dolly Sods) and analyzed for sulfur and 23 other elements to provide baseline information about the air quality in the two wildernesses. Results of elemental analysis indicated sulfur and metal concentrations in test lichens were relatively low, although a significant positive correlation between sulfur concentration and elevation was noted.

In 1992, a reassessment of the air quality in the wildernesses was done using lichen floristic and elemental data. This follow-up study had objectives similar to the baseline study: (1) To collect additional floristic information about the

lichen communities representing the two wildernesses and to note patterns indicating air quality problems; (2) To re-photograph the permanent photo plots and note changes in lichen community structure; (3) To collect specimens of F. caperata for elemental analysis (sulfur, nitrogen and 23 other elements) so that comparisons could be made with data collected in 1987.

The resurvey yielded new floristic information for each wilderness. A total of 129 lichen species was identified from the collections made in the wildernesses; 101 were found in Otter Creek and 88 in Dolly Sods, but many were common to both wildernesses. These results represent nearly a doubling of the lichens identified in 1987, probably a consequence of a more extensive sampling effort, and include many species known to be pollution-sensitive. The present species-rich lichen flora indicates little (if any) adverse effect of pollution at the present time.

The results of the lichen element analysis indicate changes in the ambient air quality since the 1987 baseline study was done. Seven elements (Na, Mn, Ti, Fe, Cu, Pb, Al) were found in significantly lower concentrations in 1992; three (Ba, Sr, S) were found in significantly higher concentrations. Concentrations of sulfur and nitrogen (components of acidic precipitation) were significantly higher in Dolly Sods than Otter Creek, probably a consequence of the higher elevations in Dolly Sods since significant positive correlations with elevation were obtained for each of these elements. The number of permanent sampling sites with lichen sulfur concentrations exceeding 0.20% dry wt. also doubled since 1987 (from 4 to 8). These elemental data indicate a reduction during the past five years in the impact of certain pollutants (metals); however, the increases in sulfur concentrations since 1987 and the elevational gradients observed for S and N indicate a potential air quality problem and the need to continue monitoring in the two wildernesses.

It is recommended that resurveys of the lichen communities of Otter Creek and Dolly Sods be done at five-year intervals to continue to monitor changes in the floras and the element status of test species. Such information, when combined with other monitoring data, will be valuable in documenting adverse effects on the air quality related values of the two wildernesses.

INTRODUCTION

Lichens are fungi that use captured photosynthetic cyanobacteria or green algae as a source of food. As "dual organisms", they are studied to understand the physiological and evolutionary basis of symbiosis, the intimate association of unrelated organisms. They are also "air plants" which obtain their water and essential element requirements from the atmosphere. Ever since the early 1950's, lichens and other "air plants" have been used as indicators of atmospheric quality around cities and various point sources of air pollution. The reasons lichens are especially useful in this regard are numerous: (1) many species are sensitive to the toxic effects of air pollutants, caused primarily by damage to the photosynthetic symbiont of the lichen; (2) the distribution of some especially pollution-tolerant species has been known to increase dramatically in polluted environments, eliminating pollution-sensitive species; (3) lichens accumulate pollutants from the atmosphere so that analysis of the element concentrations within lichens provides information about ambient air quality conditions in the habitat; (4) lichen thalli (a term for the plant body) are easily transplanted from one habitat to another, allowing collection of air quality data for prescribed locations and lengths of time; (5) lichen recolonization of formerly-polluted environments has been documented in several cases following improvements to air quality; (6) comparison of lichens collected and analyzed for pollutant elements in the past with recently-collected specimens permits a retrospective view of pollution patterns for an area.

Given their usefulness as biological monitors of air quality, the U. S. Forest Service and National Park Service have undertaken a number of lichen studies on Federal lands. Many of these studies have been done at sites designated Class I areas under the Clean Air Act Amendments of 1977. These areas are to be closely monitored to prevent significant deterioration of air quality related values (scenic beauty, vegetation, water, wildlife, odor). To date, nearly 30 lichen biomonitoring programs have been done in areas managed by the National Park Service; around 25 have been done in Forest Service sites. All of these studies attempted to establish baseline conditions for lichen floristics (identification and listing of species and notation of sensitivity to pollution); in addition, some involved collecting elemental, physiological or transplant data, and some included establishment of permanent sampling or photographic plots.

In 1987, a lichen biomonitoring program was initiated in the Dolly Sods and Otter Creek Wildernesses of the Monongahela National Forest. These two wildernesses were established by Public Law 93-622 on January 3, 1975 and are therefore designated Class I areas under the Clean Air Act Amendments of 1977. The objective of the 1987 program was to establish a baseline for lichen floristic and elemental data against which future resurvey data could be compared.

Results of the 1987 survey (Lawrey & Hale, 1988a) established that the lichen communities of the two wildernesses were representative of those that would be expected in unpolluted environments; most included pollution-sensitive species that would not be observed in areas disturbed by high levels of pollution. The 1987 study included analysis of a single ubiquitous lichen species, *Flavoparmelia caperata*, for sulfur and 23 other elements (some potential pollutant elements, especially metals). Results of these element analyses indicated that the air quality was better in the two wildernesses than in the Northern District of Shenandoah National Park (SNP) in Virginia, where a similar study had just been completed (Lawrey, 1987). Concentrations of sulfur, lead and some metals were frequently higher in Dolly Sods than in Otter Creek (possibly a result of the higher elevations in Dolly Sods), but represented relatively low values when compared with those obtained from polluted environments (Lawrey & Hale, 1988a).

In the summer of 1992, a resurvey of the lichen communities of Dolly Sods and Otter Creek wildernesses was done to document any changes in floristics and element status that had occurred during the intervening five years. The methods used in the resurvey were identical to those used in the baseline study (except that nitrogen analysis was included for the first time). The management questions addressed by this study were also similar to those of the initial study:

(1) What is the distribution and species richness of the lichen communities found?

(2) How does community distribution, species richness and relative species abundance, and the results of the elemental analysis, compare with what is expected to be found in ecologically similar areas of the eastern United States?

(3) What evidence is there that the lichen communities of Dolly Sods and Otter Creek Wildernesses are under stress?

(4) If there is evidence of stress, what factors are (or could be) contributing to this stress? Is air pollution a contributing factor? If so, are specific air pollutants involved?

(5) What evidence is there that air pollution is the cause of any observed deviation in community structure from that which is expected in an unperturbed ecosystem?

(6) What evidence is there (from species richness, community composition or elemental data) of air pollution trends over time? Is a five-year sampling schedule adequate to yield information of value to wilderness management?

In this report, I will discuss these questions insofar as it is possible from the data obtained. Since this study was one of the first to resurvey the lichen communities in areas where baseline information had previously been collected, it was anticipated that it would also indicate the value of periodic monitoring of air quality related values using lichens.

In the sections that follow, I will discuss the results of four tasks:

(1) A floristic survey similar to that which was undertaken in 1987, listing all species observed in the two wildernesses and including an assessment of sensitivity to air pollution;

(2) Rephotographing previously-established permanent study plots to document changes in lichen communities at each site;

(3) Collecting specimens of *Flavoparmelia caperata* from previously-established field quadrats and analyzing for sulfur, nitrogen and metals;

(4) Comparing the floristic and element status of lichens observed in the two wildernesses by location (Otter Creek vs Dolly Sods) and by sampling time (1987 vs 1992).

METHODS

Floristic Field Work

All field work was done in the summer of 1992 in the Dolly Sods and Otter Creek Wildernesses of the Monongahela National Forest. Dolly Sods is a 10,215 acre area of rugged, rocky terrain dominated by second-growth hardwoods with areas of shrubby heath barrens and patches of aspen and red spruce in the higher elevations. Much of the understory consists of dense *Rhododendron* thickets, and there are wetland bogs and beaver impoundments. Northern hardwood and Allegheny mixed hardwood communities dominate the vegetation, and there are separate components of oak, heath and associated species; red spruce dominates at higher elevations. Otter Creek is approximately 20,000 acres and includes most of the drainage area of Otter Creek and Shavers Lick Run. The area is dominated by 50- to 100-year-old second-growth forest with Rhododendron thickets in the understory. Northern hardwood and Allegheny mixed hardwood communities dominate the vegetation; red spruce communities are found at higher elevations. Interesting vegetative features include a 59-acre patch of virgin red spruce and hemlock on Shavers Mountain, which remains from the prelogging era, and a nearby 50-year-old Norway spruce planation of approximately 200 acres (Adams et al., 1991).

Lichens were collected throughout each wilderness from all appropriate habitats (rocks, tree bark, felled trees, soil, stumps, etc.). All lichens were packeted and returned to George Mason University, where they were identified, labelled and placed in the lichen collection as voucher specimens. Species lists were developed for each wilderness and organized by vegetation/habitat type. Nomenclature followed Egan (1987). Since quantitative sampling of the lichen communities was not done, the lists reflect the lichens observed, but not necessarily their commonness or rarity. Notes were made of the dominant species in each community type, however, and particular attention was given to species known to be sensitive to atmospheric pollution.

Permanent Photographic Plots

Twelve permanent photoplots established in 1988 (six in each wilderness) were visited again in 1992 and photographed to document changes in growth and composition of the attached lichens. At each site location, a 20 X 28 cm quadrat marked on a suitable flat rock with drill holes was located, and a B/W photograph of the plot taken with Kodak Tri-X film. For reference, color slides (Ektachrome 400) of the quadrat were also taken. The B/W negatives were enlarged to approximately 1X (a millimeter rule is included in each photo for reference) on Kodak Polycontrast photo paper.

The site locations of each permanent photoplot are as follows:

<u>Dolly Sods</u>

Site 101 Entered abandoned road at junction of Trail 517 with Forest Road 19 at SE corner of wilderness. Walked 100 m NW on abandonded road. Horizontal rock approximately 1 X 2 m located on NE side of trail; 20 X 28 cm quadrat marked with drill holes. The area is dark with abundant mosses and ferns.

Site 102 Parked at BM 2838 ft on Forest Road 19 at SW corner of wilderness. Walked into wilderness N30W 100 m to large group of rocks covered with mosses and lichens. Vertical (slightly S-facing) sample rock face approximately 2 X 3 m located; 20 X 28 quadrat marked with drill holes. The area is dark with birches and maples in the overstory; abundant mosses and ferns.

Site 103 Parked at Laneville Cabins parking lot at SW corner of wilderness and entered wilderness on Little Stonecoal Run Trail (552) heading north. Walked approximately 300 m to where rockslide has covered the trail. Located horizontal sample rock (approximately 1 X 1 m) on E side of trail and propped up by other rocks below. A 20 X 28 cm quadrat was marked with drill holes. The area is open with numerous lichens; birches and maples in the overstory, Rhododendron in the understory.

Site 104 Entered wilderness from Forest Road 75 on Wildlife Trail (560) on E side and walked NW about 800 m. Located a flat rock (0.5 X 1 m) on N side of trail; 20 X 28 cm quadrat marked with drill holes. The area is open near trail with maples in the overstory.

Site 105 Parked at trail head of Fisher Spring Run Trail (510) on Forest Road 75 and walked on 510 to junction with 508. About 12 m S70E from junction marker, located a flat S-facing rock face about 1 X 2 m; 20 X 28 cm quadrat marked with drill holes. The area is open with numerous lichens on trees and rocks. Overstory dominated by birches and maples.

Site 106 Parked at Red Creek Campground and entered wilderness on Trail 511 heading W to Trail 514; south on 514 to wilderness boundary. About 75 m south of wilderness boundary is a large rock outcrop area. Located small (0.3 X 0.5 m) S-facing rock on NW side of trail about

10 m across the trail from a large table-shaped rock; 20 X 28 cm quadrat marked with drill holes. The area is dark and dominated by birches and maples and some hemlocks.

Otter Creek

Site 201 Entered on Mylius Trail (228) from the Kuntzville Road (162) on the east flank of Shavers Mountain. Followed Mylius Trail to Shavers Mt. Trail (130) and headed N 200 m to large rock outcrop area alongside trail. Selected large (2 X 4 m) E-facing vertical rock about 15 m W of trail; established 20 X 28 cm quadrat on N end of rock. The area is dark with beeches and birches in overstory; many mosses and ferns.

Site 202 From junction of Mylius Trail and Shavers Mt. Trail, 1.25 km N along Shavers Mt. Trail (228). Located small (20 X 28 cm) horizontal rock approximately 10 m to E of trail in rock outcrop area; quadrat took up most of the rock surface. Area very dark with numerous mosses and ferns; birches and maples in overstory.

Site 203 Entered wilderness at south end from Forest Road 303 off 91 and took trail (165) east to junction with Shavers Mt. Trail (130). Located large (3 X 3 X 3 m) gumball-shaped rock about 50 m NW of junction; 20 X 28 cm quadrat located on SE face and marked with drill holes. The area is open with hemlocks and maples in overstory. Some evidence of recent campfires in area, which could have an effect on the lichens nearby.

Site 204 Forest Road 303 to Otter Creek Trail head at S end of wilderness; took Otter Creek Trail (131) to Yellow Creek Trail junction. Yellow Creek Trail (135) west approximately 650 m to large open area on N side of trail. Large (1 X 2 m) nearly horizontal rock located approximately 25 m N of trail; 20 X 28 cm quadrat marked with drill holes. The area is dark and damp with hemlock, maples and _Rhododendron_ dominating the vegetation.

Site 205 Entered wilderness at NW corner from Turkey Run Trail head (150) off Forest Road 701 and followed logging road 1.3 km to rock outcrop on W side of road. Small (1 X 1 m), flat, E-facing rock located directly off road to W; 20 X 28 cm quadrat marked with drill holes. Dark, wet area dominated by maples, tuliptree and basswood in the overstory.

Site 206 From Moore Run Trail (138) head at junction with Forest Road 324, 200 m S along Forest Road 324. At a rock outcrop area on E side of road, a small (0.5 X 1.0 m) horizontal rock was located about 20 m from road;; 20 X 28 cm quadrat marked with drill holes. Dark, wet area dominated by maples and birches and some hemlocks in the overstory and _Rhododendron_ in the understory.

Elemental Analysis Quadrats

In 1987, 169 permanent 10 X 10 m quadrats were established in the Dolly Sods and Otter Creek wildernesses, within which lichens were sampled for elemental analysis. Of these, 121 were located within 1 km^2 sections established systematically in the two wildernesses, 80 in Otter Creek (Fig. 1) and 41 in Dolly Sods (Fig. 2). The remaining 48 quadrats were replicates located at least 100 m from the original quadrat in every tenth section, four per section. Therefore, in each 1 km^2 section, there is at least one quadrat, and in every tenth section, there are five. The reason for including replicate quadrats in some of the 1 km^2 sections is to measure the within-section variability of pollutant element concentrations in lichens.

Since each quadrat was marked at the corners with aluminum tags, it was possible to accurately relocate most of the sites. In some cases, the original markers could not be relocated and lichens were collected as close as possible to the original collecting locations. Numbers for the 1 km^2 sections are given in the site location maps (Appendix 1) and for all the permanent quadrats in the elemental data summaries (Appendix 3).

In 1992, each permanent elemental analysis quadrat was revisited, and mature specimens of <u>Flavoparmelia caperata</u> were collected and returned to the laboratory for elemental analysis. In cases where insufficient quantities of the test lichen were available in the quadrat, material was collected just outside of the quadrat.

<u>Laboratory Analysis</u>

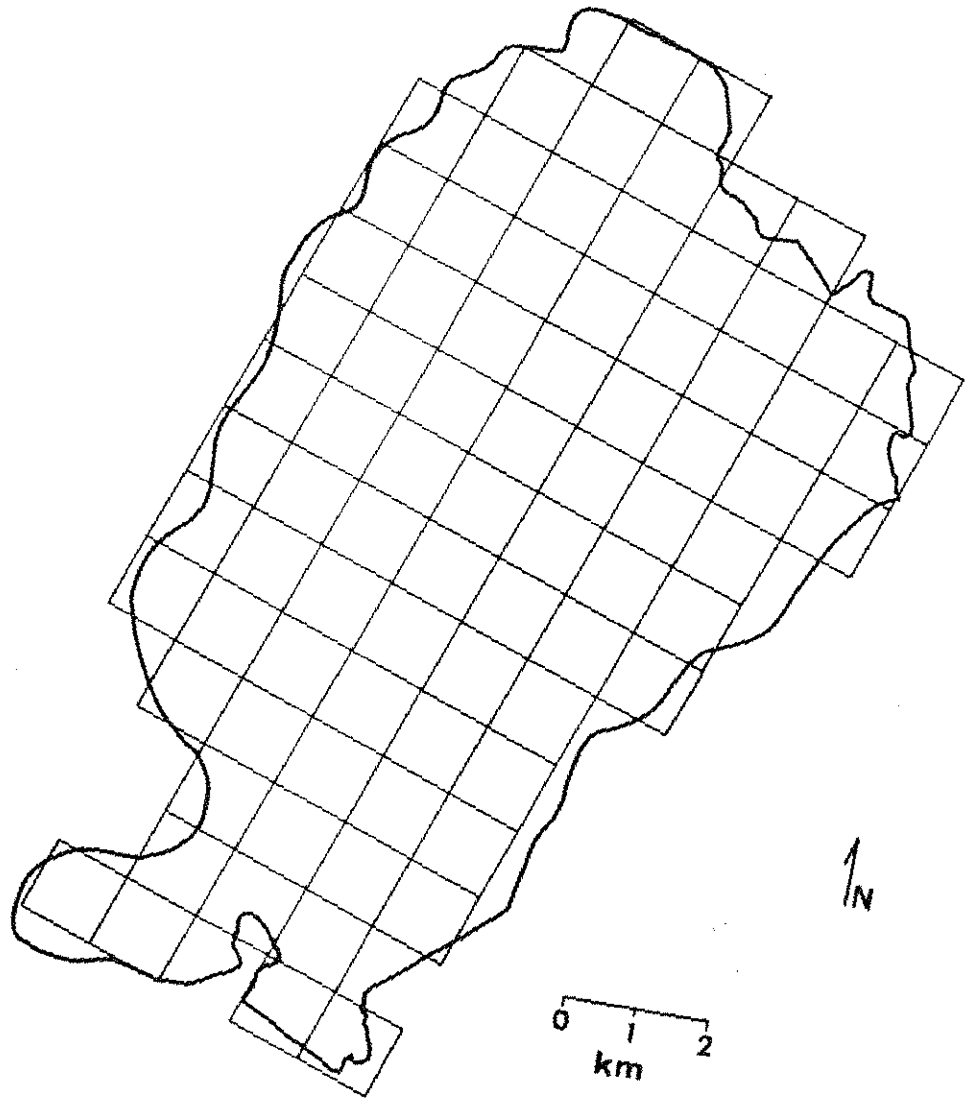
Lichen material collected in each quadrat was cleaned of tree or rock debris and ground in a Wiley mill. Samples were then sent to the Ohio Agricultural Research and Development Center (OARDC) in Wooster, Ohio, for elemental analysis. Samples of reference material (peach leaves, NBS 1547) from the National Bureau of Standards were also sent to insure reliability of results. All lichen samples were analyzed at OARDC for total concentrations of 23 elements (P, K, Ca, Mg, Na, Mn, Cu, Zn, B, Ni, Cr, Pb, Cd, Al, Mo, Sr, Ba, V, Ti, Be, Sn, Co) using an Inductively Coupled Plasma Spectrophotometer. Total sulfur was also determined for each sample using a Leco sulfur analyzer; total nitrogen was determined from a micro-Kjedalhl digestion.

RESULTS AND DISCUSSION

Floristic Analysis Summary

In total, 430 lichen specimens were collected in the 1992 survey, 270 from Otter Creek and 160 from Dolly Sods. Many collections were duplicates, however, since 129 lichen species were identified (Table 1; species lists in Appendix 2), an increase from 67 species collected in 1987 by Mason Hale (Lawrey & Hale, 1988a). This nearly doubling of the species list resulted from an increased effort to sample all available vegetation/habitat types in each wilderness. It is expected that continued sampling in the wildernesses will yield additional new collections.

FIGURE 1. Permanent 1-km^2 sections in the Otter Creek Wilderness, West Virginia. Exact locations are given in Appendix 1.



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0 1 2
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FIGURE 2. Permanent 1-km^2 sections in the Dolly Sods Wilderness, West Virginia. Exact locations are given in Appendix 1.

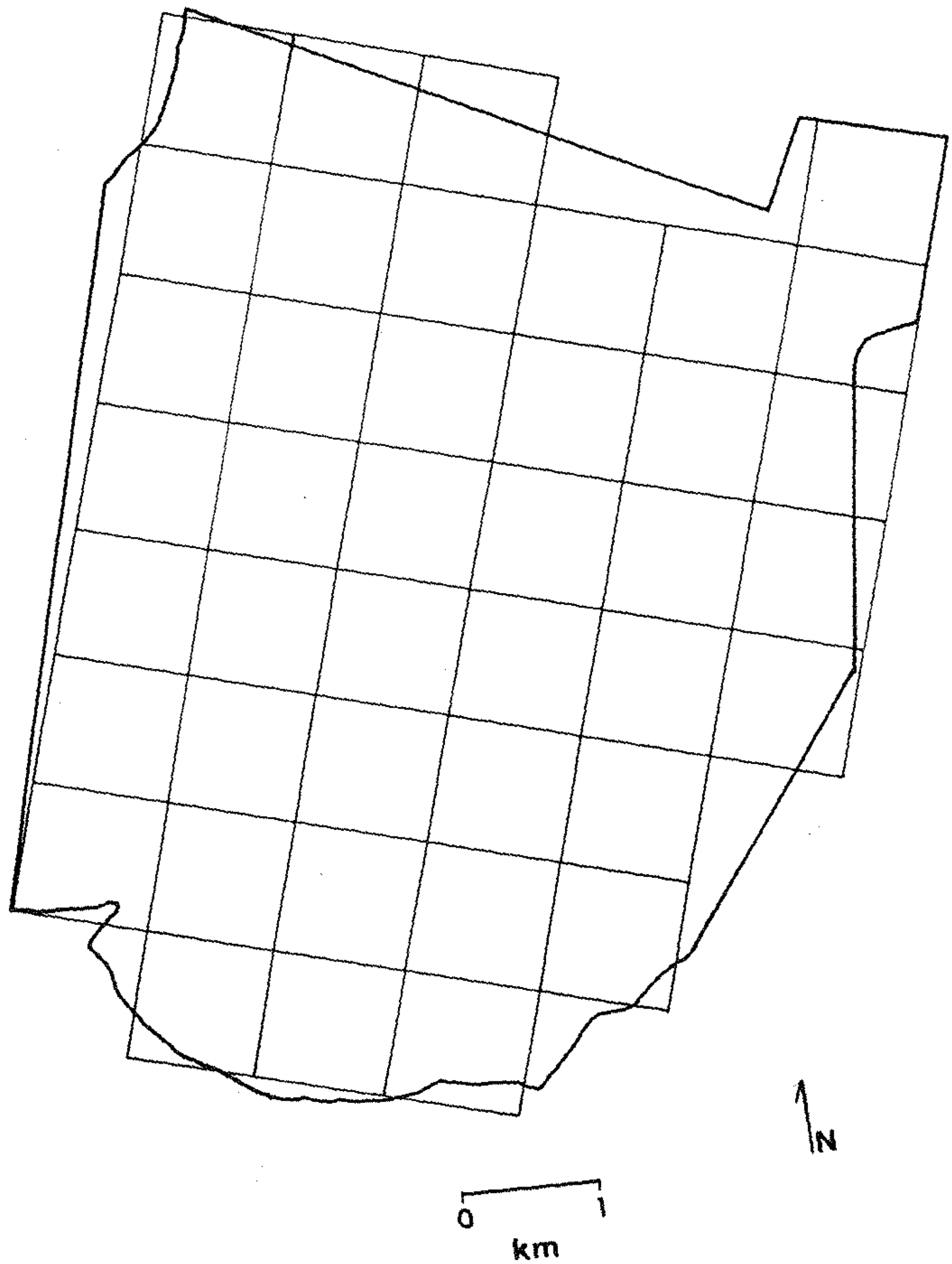
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Table 1. Total numbers of lichen species collected and identified in the Dolly Sods and Otter Creek Wildernesses, Monongahela National Forest, West Virginia, 1987 and 1992.

Site	Year	Sensitive Species	Total Species
Dolly Sods	1987	6	59
	1992	17	88
Otter Creek	1987	5	44
	1992	21	101
Combined	1987	7	67
	1992	28	129

Of the 129 total lichen species collected, 88 were from Dolly Sods and 101 from Otter Creek (Table 1). However, most of the collected species were not restricted to a single wilderness, suggesting that the lichen floras of Dolly Sods and Otter Creek are not distinct but rather part of a larger, homogeneous flora characteristic of the northern Allegheny Mountains. Certain species found only in one wilderness were restricted to habitats available only in that wilderness. For example, a diverse lichen community restricted to limestone substrates was discovered on outcrops near the confluence of Otter Creek and Dry Fork River at the northern end of Otter Creek Wilderness. Similarly, some high-elevation species (e.g., Tuckermannopsis pinastri) were found only in Dolly Sods where high-elevation sites were encountered and sampled more frequently. These differences in habitat conditions help to explain many of the floristic differences observed between the two wildernesses.

A total of 28 lichens with known sensitivities to air pollution (Wetmore, 1983; Mason Hale, pers. comm.) was observed in the wildernesses (Table 1); 21 were collected in Otter Creek and 17 in Dolly Sods. This relatively large number of sensitive species indicates that the lichen floras of the two wildernesses are not presently experiencing stress caused by air pollution.

One of the conclusions of the 1987 baseline study (Lawrey & Hale, 1988a) was that the lichen communities of the Dolly Sods and Otter Creek Wildernesses had species diversities and compositions indicative of normal, unpolluted habitat conditions.

This conclusion was strengthened by the 1992 survey, which identified numerous additional species, many of which are known to be sensitive to pollution. The fact that more species were collected in Otter Creek than in Dolly Sods may be a result of a greater diversity of unique habitats available in Otter Creek (e.g., limestone outcrops in northern Otter Creek). The differences are not likely to be due to pollution effects. It is recommended that periodic resurveys (approximately every five years) be done in the two wildernesses to document changes in the lichen floras indicative of pollution damage. Given the pollution sensitivity of many of lichens presently inhabiting the two wildernesses, surveys that focus particular attention on these species would be especially desirable.

Description of Most Common Lichen Communities

The lichen communities encountered most frequently in the two wildernesses are associated with the vegetation/substrate types commonly found in each wilderness. This section briefly describes the dominant lichen species associated with each of these vegetation/substrate types and includes those unique or unusual communities worthy of special attention.

(1) Communities in sugar maple-beech-yellow birch stands. This vegetation type occurs frequently throughout each wilderness and supports a diverse community of epiphytic (tree-dwelling) lichens. The most obvious and dominant species on tree bark are the large foliose lichens *Flavoparmelia caperata*, *Hypogymnia physodes*, *Punctelia rudecta*, *P. subrudecta*, *Parmelia sulcata*, and

Tuckermannopsis oakesiana. In addition, the smaller-lobed (and less obvious) foliose lichens *Heterodermia speciosa*, *H. squamulosa*, *Phaeophyscia rubropulchra*, *Physcia aipolia* and *Pyxine sorediata*, and the crustose species *Bacidia schweinitzii*, *Buellia stillingiana*, *Graphis scripta*, *Lecanora strobilina* and numerous *Pertusaria* species are commonly collected in this vegetation type. This (along with the community associated with the mixed oak vegetation type) is perhaps the most diverse of the epiphytic lichen communities encountered in the two wildernesses. It is also composed of many species known (or considered) to be sensitive to atmospheric pollution (e.g., *Heterodermia*, *Physcia*, *Lobaria*, *Peltigera*, *Tuckermannopsis* species). *Usnea* species are more common in mixed oak stands, but are also found frequently in stands dominated by other hardwood species.

(2) Communities in mixed oak stands. Epiphytic lichens growing on oaks include all those mentioned above with the addition of many large-lobed lichens (*Parmotrema*, *Platismatia*, *Cetrelia* species) that are found more commonly in the open habitats of mature oak stands. Smaller-lobed *Myelochroa* spp. and the foliose *Pseudevernia consocians* are also quite common. Many of the lichens known to be especially pollution-sensitive are found in mixed oak stands. The pollution-sensitive *Usnea* species are found most commonly on trunks and fallen branches of oak trees; *Pseudevernia* and *Evernia* species are also sensitive.

(3) Communities in conifer stands. The most widely-distributed conifer stands in the two wildernesses are dominated by red spruce, although pine plantations and hemlock are also commonly observed. Epiphytic lichens found in these vegetation types are all quite similar and notable for their paucity of species. The most common lichens are the foliose Hypogymnia physodes, Imshaugia aleurites, Pseudevernia consocians and Parmelia sulcata; crustose species (especially Lepraria spp.) and squamules of Cladonia species (representing underdeveloped thalli) are also common. The much-reduced diversity of lichens on conifers is probably due to a combination of factors including acidic substrates, reduced light intensity and the allelopathic effect of volatile compounds produced by many conifers (Brodo, 1973). The ability of these lichens to withstand acidic substrate conditions suggests they are probably less sensitive to certain pollutants (S and N) than other species; however, some taxa (e.g., Pseudevernia consocians) are sensitive to pollution and others (most notably Hypogymnia physodes) are used extensively as pollution monitors in Europe.

(4) Riparian communities. A unique lichen community is found almost exclusively on rocks in or near the streams that run through the two wildernesses. These lichens tend to require open light conditions and can tolerate periodic inundation. Some species (notably the Verrucaria spp., Protoblastenia rupestris and Dermatocarpon fluviatile) are restricted to these types of habitats; others (e.g., Porpidia macrocarpa and Endocarpon pusillum) are not totally restricted to these habitats but are found frequently enough to be indicators of riparian site conditions. Little is known about the sensitivity of these species to air pollution.

(5) Noncalcareous rock communities. Most of the rock outcroppings in Dolly Sods and Otter Creek are noncalcareous and support similar lichen communities in each wilderness. Differences in species composition are caused mainly by variation in light intensity and moisture. The most common rock-inhabiting lichens are the large foliose Flavoparmelia baltimorensis, Tuckermannopsis oakesiana, Parmelia sulcata, Cetrelia species and Xanthoparmelia species. The umbilicate species Umbilicaria mammulata and Lasallia papulosa are also quite common here and throughout the Appalachian Mountains. Numerous rock-inhabiting crustose lichens are found in the wildernesses, the most common being Lepraria zonata, Porpidia albocaerulescens and P. cinereoatra, Aspicilia species, and the endolithic Sarcogyne similis. In areas where mosses and lichens co-occur on rocks, various Cladonia species (notably C. squamosa, C. furcata, C. coniocraea, C. caespiticia) and Cladina species (C. subtenuis, C. rangiferina, C. mitis) make up a recognizable community. These species are not considered especially sensitive to air pollution.

(6) Calcareous rock communities. A unique calcareous rock-inhabiting community was observed on limestone near the confluence of Otter Creek and Dry Fork River in the northeastern corner of Otter Creek Wilderness. The species found there are common inhabitants of open, calcareous substrates, including Lecanora muralis, Pannaria taveresii, Endocarpon pusillum, Protoblastenia rupestris. On partially inundated rocks, Verrucaria calkinsiana and V. calciseda are also found. Little is known about the sensitivity of these particular species to air pollution, but it is possible that their preference for basic substrate conditions would make them especially sensitive to the acidifying effects of certain pollutants (S and N).

(8) Soil communties. Numerous soil-inhabiting lichens are found throughout the two wildernesses, and they make up recognizable communities depending on elevation, light intensity and thickness/chemistry of the leaf litter. The most common soil-inhabiting species are in the genera Cladonia and Cladina. These species usually co-occur with various terricolous mosses and vascular plants in the understory of open hardwood stands. In conifer stands, the species diversity is reduced, but many of the same species can be found. Species more restricted in substrate preference include Baeomyces absolutus, which is found on open, hard-packed soils along hiking paths and Cladonia grayii, which is found on in extensive mats in open areas, especially in the open boggy environments in Dolly Sods. Other unique substrate-specific species include Trapeliopsis viridescens, which inhabits rotting wood in open environments, Cladonia cristatella, C. capitata, C. verticillata, C. macilenta, which are common in similar environments (fence posts, rotting logs or the bases of trees) in shadier environments, and Cladonia squamules (usually unidentifiable because they are in an immature stage of development) on wood in dark environments. Certain pollution-sensitive species (Lobaria species) are restricted to moss-covered soil substrates; however, most terricolous lichens are not considered especially useful as pollution monitors. The relatively diverse communities observed in the two wildernesses indicate clean air quality at the present time.

(7) High elevation communities. In general, the lichen communities of high elevation sites are not much different from those at mid-elevations; however, certain taxa are more common at high elevations (e.g., Tuckermannopsis pinastri). Although I have not collected them in the wildernesses, certain high elevation species (Bryoria and Stereocaulon species, Pseudevernia cladonia, Parmelia saxatilis) have been collected nearby and may eventually be found (especially in Dolly Sods, which has generally higher elevations) as more collecting is done. Inasmuch as air pollution problems may be more severe at high elevations, these species should prove useful in future biomonitoring efforts.

Permanent Photographic Plots

Twelve permanent photoplots of saxicolous lichen assemblages photographed in 1988 (six in each wilderness) were relocated and photographed again in 1992 to document changes in size and number of individual lichen thalli in each plot. Xerographic copies of the 1988 and 1992 photos (1/2X) of each plot are appended to this report (Appendix 4). One set of 1X 1992 prints is included with the original copy of the final report. Analysis of the photos indicated that in most plots, there was obvious growth of the thalli, although the growth rates varied considerably from species to species. There was also evidence of new colonizations of bare rock surfaces by juvenile thalli. Taken together, the data indicate little effect of severe pollution damage at these sites.

Dolly Sods Photoplots

Site 101 Quadrat contains numerous *Lasallia papulosa* thalli and some *Umbilicaria mammulata* thalli. These species are not considered to be pollution-sensitive. The *L. papulosa* thalli have nearly doubled in size since 1988, indicating little stress from air pollution. The *U. mammulata* thalli have grown more slowly, but there is evidence of new juvenile colonists in the plot, again indicating little efffect from air pollution.

Site 102 Quadrat contains *Flavoparmelia baltimorensis*, *Parmelia sulcata*, *Tuckermannopsis oakesiana* and the moss *Grimmia apocarpa*. Of these, *T. oakesiana* is most pollution-sensitive. All of the foliose lichens named above exhibited some growth since 1988. The crustose species in the background (mostly *Lepraria zonata* and *Aspicilia* spp.) have not changed much in size; however, these species are far more slow-growing than the large, foliose species. From the changes evident in the photos, air quality conditions appear good at this site.

Site 103 Quadrat contains one large foliose Xanthoparmelia conspersa thallus and numerous crustose Aspicilia cinerea and Lepraria zonata thalli and the moss Grimmia apocarpa. These species are not considered to be pollution-sensitive. The large X. conspersa thallus has grown considerably since 1988; however, many of the juvenile thalli in the plot in 1988 have disappeared. No change was evident in the crustose species. The changes do not indicate effects of air pollution.

Site 104 Quadrat contains two large foliose Xanthoparmelia conspersa thalli and numerous thalli of a crustose Pertusaria sp. with concentric rings. These species are not considered to be pollution-sensitive. Changes in the plot since 1988 indicate a radial growth of the X. conspersa thalli of approximately 0.5 cm per year; there have also been numerous colonizations of juvenile X. conspersa thalli and considerable overgrowth of the crustose species in the plot. These changes would not be expected in polluted environments.

Site 105 Quadrat contains numerous small Lasallia papulosa and Umbilicaria mammulata thalli, one large Xanthoparmelia conspersa thallus, and several thalli of Aspicilia species. These species are not considered to be pollution-sensitive. Although the X. conspersa thallus is showing signs of deteriorating at its center, this is normal and the radial growth is about the same (0.5

cm/year) as that measured at other plots in the wildernesses. As would be expected, the crustose species have not changed much in size since 1988; however, thalli of the umbilicate species Lasallia papulosa and Umbilicaria mammulata) have apparently changed positions since 1988 (indicating losses of some juvenile thalli and recolonizations by other thalli). This is normal for these species. Taken together, the evidence from the photos does not indicate poor air quality at the site.

Site 106 Quadrat contains several small thalli of Lasallia papulosa, Xanthoparmelia conspersa and Aspicilia cinerea. These species are not considered to be pollution-sensitive. Of all the Dolly Sods photoplots, this site exhibits the most obvious losses of lichens. Many of the thalli of X. conspersa have disappeared, especially at the center (although there is evidence of continued radial growth at the thallus peripheries). There are also numerous losses of thalli observed for the umbilicate species (especially U. mammulata); however, the thalli that survived since 1988 exhibited good growth. These changes indicate a physical abrasion of the rock surface (which is possible from hikers); poor air quality is not as likely a cause given the results obtained at the other photoplots.

Otter Creek

Site 201 Quadrat contains thalli of umbilicate species (mostly Umbilicaria mammulata and some Lasallia papulosa) and some crustose species (mostly Lepraria zonata). These species are not considered to be pollution-sensitive. The thalli of U. mammulata have grown considerably in size since 1988, especially the juvenile colonists in the center of the plot. As expected, the crustose species have shown little growth. These results indicate little effect of air pollution at the site.

Site 202 Quadrat contains many thalli of the foliose species Tuckermannopsis oakesiana and the rock surface is covered with various crustose species (mainly Lepraria zonata and Aspicilia spp.). Various mosses Dicranum fulvum, Thuidium erectum, Hypnum imponens, and Atrichum undulatum are also observed. Of these, T. oakesiana is the most pollution-sensitive. The most obvious changes since 1988 are seen in the moss cover, with a large section of the Dicranum mat having disappeared. The T. oakesiana thalli have shown some growth and new colonizations, however, suggesting the loss of mosses is not caused by air pollution. Also, the edge of the moss mat has extended since 1988 indicating the mosses are also continuing to grow at the site.

Site 203 Quadrat contains Flavoparmelia baltimorensis and Parmelia sulcata thalli around the edges and Lasallia papulosa, several crusts (Aspicilia spp. and Porpidia albocaerulescens) and the moss Dicranum fulvum in the center. These species are not considered to be pollution-sensitive. Thalli of Lasallia papulosa not eaten by slugs appear to have more than doubled in size since 1988; however, there is considerable damage from slugs in this plot. Indeed, most of the thalli have been eaten and many slime trails are evident on the rock surface. One entire region of the plot (lower right-hand corner) which supported P. sulcata thalli in 1988 is bare in 1992. These changes are not caused by air pollution; they do, however, indicate the sorts of natural changes that can be expected in permanent lichen photoplots.

Site 204 Quadrat contains numerous small Lasallia papulosa thalli and a large thallus of the crustose Porpidia albocaerulescens. There are also several small moss plants (Dicranum fulvum). These species are not considered to be pollution-sensitive. Although no changes are evident in P. albocaerulescens, the mosses and lichens all evidenced some growth since 1988. These changes indicate little effect of air pollution at the site.

Site 205 Quadrat contains mosses (Dicranum fulvum and Thuidium erectum) around the edges and crustose lichens (Porpidia albocaerulescens and Aspicilia cinerea) in the center. These species are not considered to be pollution-sensitive. Although crustose lichens grow very slowly, there is some evidence of growth by _P. albocaerulescens_ and _A. cinerea_ thalli since 1988. The moss plants have also increased in size. These changes indicate little negative effect of air pollution at the site.

Site 206 Quadrat contains small _Lasallia papulosa_ thalli, the crustose species _Aspicilia cinerea_, the endolithic _Sarcogyne similis_ (only the black dots of the fruiting structures are evident in the photo) and the central thallus of _Porpidia albocaerulescens_ with a small moss plant (_Dicranum fulvum_) nearby. These species are not considered to be pollution-sensitive. The foliose _L. papulosa_ thalli have changed the most since 1988, most exhibiting nearly a doubling of their original size. The moss plant also grew somewhat. These changes indicate little effect of air pollution at the site.

Based on an analysis of the 1992 photos of the permanent plots in the Dolly Sods and Otter Creek Wildernesses, there is no indication of air pollution damage to the communities at the present time. All species contained within the photoplots are shade-tolerant species common on rock surfaces throughout the two wildernesses. In most cases, the lichens (and mosses) exhibited growth since 1988 at rates expected in unpolluted areas. In rare cases, damage to the lichens (or mosses) could be attributed to abrasion of the rock surface or to slug damage.

It is anticipated that the quadrats will be rephotographed at 5-year intervals in the future to assess changes in the lichen growth and recoloniztion rates indicative of air quality changes in the wildernesses.

Elemental Analysis Quadrats: Elemental Analysis of Test Lichens

Analysis of *Flavoparmelia caperata* specimens collected from each 10 X 10 m elemental analysis quadrat (121 from 1 km^2 sections and 48 replicate quadrats in every tenth section) yielded concentrations for 16 elements; nine elements (Cr, B, Mo, Cd, Ni, Co, V, Be, Sn) were observed at concentrations below the limits of detection with the ICP analyzer (summary in Table 2; all element data are provided in Appendix 3). In general, the concentrations of elements (especially the metals, sulfur and nitrogen, which are indicative of pollution) are relatively low (Table 3) and reflect good to moderate air quality conditions.

The concentrations of four elements (K, Zn, S and N) were significantly higher in lichens from Dolly Sods than in those from Otter Creek; Sr had a significantly higher mean concentration in Otter Creek than in Dolly Sods. The differences in mean element concentration observed between the two wildernesses are not profound and are probably (for S and N especially) a reflection of the higher elevations of sampling sites in Dolly Sods.

All elements exhibited some variability in concentration from site to site. An analysis of variance of the element

Table 2. Summary of elements measured in <u>Flavoparmelia</u> <u>caperata</u> specimens collected in 1992 from the Otter Creek and Dolly Sods Wildernesses, West Virginia. Arranged according to distribution pattern exhibited.

<u>Elements for which no significant difference in concentration was detected between Otter Creek and Dolly Sods lichens in 1992:</u>

P Ca Na Mn Ba Mg Pb Cu Al Ti Fe

<u>Elements for which concentrations were below limits of instrument detection in 1992:</u>

Cr B Mo Cd Ni Co V Be Sn

<u>Elements for which mean concentrations were significantly higher in specimens from Dolly Sods than from Otter Creek in 1992:</u>

K Zn S N

<u>Elements for which mean concentrations were significantly higher in specimens from Otter Creek than from Dolly Sods in 1992:</u>

Sr

<u>Elements for which mean concentrations were significantly higher in 1992 than in 1987 for both wildernesses:</u>

Ba Sr S

<u>Elements for which mean concentrations were significantly lower in 1992 than in 1987 for both wildernesses:</u>

Na Mn Ti Fe Cu Pb Al

Table 3. Range and mean values of 16 elements in Flavoparmelia caperata specimens collected from Otter Creek and Dolly Sods Wildernesses, West Virginia in 1992. Elements found at concentrations below detection limits are not included.

		Mean Element Conc. ± S.E.[1]		
	Range (site number)	Otter Creek	Dolly Sods	alpha[2]
P	369.8 (75) - 1810.5 (24)	874.9 ± 29.1	890.9 ± 33.5	ns
K	1287.8 (75) - 5114.1 (33)	2616.1 ± 74.1	3382.9 ± 88.4	0.01
Ca	1817.0 (104) - 71187.5 (28)	18763.8 ± 1342	19462.5 ± 1938	ns
Mg	109.2 (50) - 757.7 (6)	272.5 ± 12.3	324.8 ± 12.8	ns
Na	6.53 (75) - 140.9 (110)	18.7 ± 1.3	21.8 ± 2.2	ns
Mn	16.5 (11) - 688.6 (28)	155.0 ± 8.8	176.4 ± 10.2	ns
Sr	3.0 (82) - 112.4 (13)	24.1 ± 2.1	14.33 ± 1.1	0.01
Ba	9.82 (82) - 436.6 (87)	90.5 ± 6.7	99.8 ± 10.6	ns
Ti	3.0 (77) - 76.5 (6)	17.6 ± 0.9	23.3 ± 1.4	ns
Pb	2.1 (62) - 69.8 (46)	27.87 ± 1.3	31.7 ± 1.8	ns
Cu	3.6 (77) - 16.9 (24)	6.9 ± 0.3	7.0 ± 0.2	ns
Zn	18.4 (75) - 156.6 (25)	40.3 ± 2.1	60.7 ± 4.9	0.01
Fe	105.8 (31) - 1530.3 (7)	351.7 ± 15.9	452.0 ± 23.7	ns
Al	238.0 (13) - 2463.6 (7)	585.9 ± 25.4	622.7 ± 32.6	ns
N	0.780 (62) - 2.014 (46)	1.347 ± 0.024	1.45 ±0.031	0.05
S	0.082 (11) - 0.211 (90)	0.145 ± 0.002	0.157 ± 0.003	0.01

[1] Concentrations of all elements except S and N are in μg/g dry wt. Sulfur and nitrogen concentrations are in percent dry wt.

[2] Alpha value indicates level at which significant difference in means between Otter Creek and Dolly Sods samples is detectable.

Table 4. Analysis of variance of 16 elements measured in Flavoparmelia caperata specimens collected in 1992 from 12 sites at which five replicate samples were taken in the Otter Creek and Dolly Sods Wildernesses, WV. All elements except S and N are reported in $\mu g/g$; sulfur and nitrogen are reported in percent. Complete ANOVA tables are not given; however, the F value of the ANOVA and alpha value at which a significant difference among the means is detectable are given. All of the values are means with the standard error of the mean given in parentheses.

Site	P	K	Ca	Mg	Mn	Na
10	693.75 (63.5)	2547.64 (214.2)	37798.2 (1637.6)	516.4 (16.5)	104.94 (2.53)	23.52 (0.33)
20	995.7 (44.01)	3109.45 (158.6)	31219.2 (1601.6)	412.6 (6.9)	201.75 (13.25)	17.5 (0.17)
30	880.16 (102.4)	2052.76 (128.1)	16813.4 (1124.7)	182.6 (4.1)	187.25 (11.38)	11.91 (0.23)
40	687.89 (34.4)	2297.08 (158.6)	19203.4 (308.3)	203.2 (2.4)	227.69 (2.48)	15.21 (0.34)
50	698.45 (93.3)	2217.59 (368.3)	8891.0 (824.6)	153.6 (5.0)	150.10 (4.66)	13.32 (0.42)
60	634.66 (20.1)	2298.42 (98.16)	13454.0 (909.7)	146.8 (1.5)	96.79 (2.24)	12.75 (0.09)
70	694.22 (70.4)	1752.66 (96.17)	21875.0 (1803.1)	176.7 (3.6)	192.46 (3.54)	11.94 (0.32)
80	785.95 (113.8)	2015.98 (209.1)	7651.4 (341.0)	203.2 (3.9)	115.08 (6.31)	13.22 (0.25)
90	1139.78 (23.0)	3332.86 (89.1)	14294.0 (161.2)	315.5 (2.0)	144.07 (1.81)	20.78 (0.49)
100	941.58 (148.6)	3641.93 (151.6)	16577.6 (1042.2)	416.4 (12.1)	226.22 (15.09)	20.20 (0.72)
110	1030.37 (174.2)	4079.70 (147.4)	24487.6 (1573.3)	408.0 (11.1)	284.81 (7.02)	42.2 (7.32)
120	944.12 (65.0)	3861.23 (221.8)	21437.8 (1303.3)	337.6 (12.6)	167.91 (9.0)	23.14 (0.80)
$F_{11,48}$	3.25	18.54	2.88	13.9	2.92	1.36
Alpha	0.01	0.001	0.05	0.001	0.01	ns

Table 4. (cont.)

Site	Sr	Ba	Ti	Pb	Cu	Zn
10	53.29 (1.71)	67.02 (1.92)	20.84 (1.18)	28.11 (0.79)	6.88 (0.15)	32.65 (0.55)
20	71.87 (2.05)	164.7 (3.76)	20.98 (1.26)	20.92 (0.52)	7.29 (0.11)	34.75 (0.42)
30	18.05 (1.02)	78.38 (3.54)	16.28 (0.77)	29.20 (0.83)	6.38 (0.07)	26.77 (0.61)
40	23.54 (0.34)	218.78 (4.71)	16.68 (0.46)	46.45 (1.05)	5.64 (0.07)	39.25 (0.42)
50	11.53 (0.29)	51.06 (2.03)	18.87 (0.75)	30.25 (1.92)	8.57 (0.14)	39.13 (0.61)
60	15.83 (0.69)	42.09 (1.58)	14.77 (0.63)	30.49 (0.65)	6.49 (0.06)	36.60 (0.30)
70	14.57 (0.52)	84.64 (4.22)	20.81 (1.15)	29.94 (0.89)	7.75 (0.20)	59.86 (2.86)
80	10.54 (0.18)	75.90 (2.74)	19.68 (0.51)	34.37 (1.8)	6.39 (0.08)	24.23 (0.50)
90	12.96 (0.15)	76.78 (1.98)	16.25 (0.58)	19.78 (0.39)	8.42 (0.11)	77.12 (2.25)
100	15.87 (0.65)	107.65 (11.17)	22.97 (1.02)	21.89 (0.77)	6.07 (0.13)	76.30 (6.82)
110	14.87 (0.64)	42.59 (2.28)	16.60 (1.36)	31.93 (1.97)	7.03 (0.18)	79.61 (7.87)
120	13.48 (0.94)	100.74 (5.72)	34.95 (1.33)	50.86 (0.82)	7.28 (0.11)	38.33 (0.28)
$F_{11,48}$	19.52	8.52	1.72	3.47	2.77	3.29
Alpha	0.001	0.001	ns	0.001	0.01	0.001

Table 4 (cont.)

Site	Fe	Al	S	N
10	437.53 (22.0)	623.21 (22.5)	0.122 (0.002)	1.090 (0.018)
20	470.01 (21.2)	740.73 (27.6)	0.122 (0.001)	1.189 (0.017)
30	331.87 (7.8)	418.57 (8.8)	0.144 (0.001)	1.183 (0.005)
40	319.71 (5.5)	538.67 (4.7)	0.164 (0.001)	1.504 (0.021)
50	327.19 (11.2)	509.68 (7.6)	0.170 (0.003)	1.453 (0.037)
60	272.67 (9.0)	474.50 (12.7)	0.150 (0.001)	1.317 (0.016)
70	383.42 (18.7)	518.71 (22.8)	0.147 (0.002)	1.389 (0.022)
80	366.77 (4.8)	502.25 (3.3)	0.168 (0.002)	1.444 (0.009)
90	355.38 (6.18)	483.81 (11.7)	0.167 (0.003)	1.431 (0.013)
100	420.30 (16.9)	528.03 (18.5)	0.163 (0.003)	1.332 (0.013)
110	346.54 (18.3)	509.35 (25.3)	0.143 (0.003)	1.572 (0.043)
120	615.14 (27.2)	742.83 (28.6)	0.184 (0.004)	1.642 (0.037)
$F_{11,48}$	1.88	1.66	3.12	2.73
Alpha	ns	ns	0.01	0.01

concentrations from the 12 replicated sites (Table 4) indicates that 12 of the 16 elements for which reliable values could be obtained exhibited significant differences among the replicated means. No consistent pattern emerged from the data, however, inasmuch as high values were observed at different sites for different elements. Site 120 (at the southern end of Dolly Sods) had the highest mean concentrations of S, N, Pb and Ti, which may have been a consequence of its relatively high elevation and/or its proximity to Forest Road 19; data from 1987 also showed high element concentrations for lichens from site 120 (Lawrey & Hale, 1988a).

Since this was a resurvey of the element status of lichens in the two wildernesses, it was possible to compare the 1992 results with those obtained earlier in 1987 (Lawrey & Hale, 1988a) using the same test lichens and analytical techniques. As a first step in this comparison, correlation analyses were done for each element using the 1987 and 1992 data from all sites (two wildernesses combined). Results of these analyses (Table 5) indicated that few elements were significantly correlated from one sampling time to another, probably a consequence of the high within-site variation in element concentration (mentioned earlier and described in Tables 3 and 4) observed for each data set. Of the elements that exhibited significant correlations (K, Mg, Mn, Sr, Pb, Fe), only Pb is an obvious indicator of air pollution. All of the correlation coefficients observed for these elements were positive but relatively low. The reason for the lack of

Table 5. Correlations between 1987 and 1992 element concentrations in Flavoparmelia caperata samples collected within 121 1 km^2 quadrats in the Dolly Sods and Otter Creek Wildernesses, WV.

Element	Correlation Coefficient	Significance Level[1]
P	0.06	ns
K	0.29	0.01
Ca	0.14	ns
Mg	0.29	0.01
Na	0.11	ns
Mn	0.19	0.01
Sr	0.26	0.01
Ba	-0.06	ns
Ti	0.03	ns
Pb	0.15	0.05
Cu	0.07	ns
Zn	0.11	ns
Fe	0.20	0.01
Al	0.15	ns
S	0.11	ns

1 Alpha value at which significant correlation between 1987 and 1992 concentrations is detectable.

high correlations between the 1987 and 1992 data are not clear, but probably have to do with the relatively low concentrations of elements observed and the site-to-site variability (background "noise") in the data.

Despite this variability in element concentration from site to site, however, several significant trends are evident from a comparison of the 1987 and 1992 data. The mean element concentrations observed in test lichens in 1987 and 1992 (both wildernesses combined; Table 6) were significantly reduced for several metal elements (Fe, Cu, Pb, Al) and significantly increased for sulfur. Similar patterns are observed when mean values are calculated separately for Otter Creek (Table 7) and Dolly Sods (Table 8). These results indicate that, despite their variability from site to site, mean element concentrations in F. caperata have changed meaningfully during the past five years, with metals generally showing a decline and sulfur showing an increase. This pattern has been observed before in lichen elemental studies. Lawrey and Hale (1988b), for example, did a comparative study of the sulfur and lead concentrations found in specimens of Flavoparmelia baltimorensis (a lichen closely related to F. caperata used in the present study) collected from Shenandoah National Park (SNP). Specimens of the lichen collected up to 50 years ago in SNP were located in the U.S. National Herbarium, and an attempt was made to collect fresh material from the same sampling locations; the historical and recently-collected samples were then analyzed for sulfur and

Table 6. Comparison of 1987 and 1992 mean element concentrations in Flavoparmelia caperata specimens collected within 121 1 km^2 quadrats in the Otter Creek and Dolly Sods Wildernesses, WV.

	Mean Concentration ± S.E.[1]		
	1987	1992	Alpha[2]
P	822.6 ± 23.3	880.3 ± 22.3	ns
K	2712.5 ± 57.7	2874.7 ± 63.7	ns
Ca	16064.8 ± 1090.3	18999.5 ± 1100.7	ns
Mg	290.9 ± 8.7	290.1 ± 9.4	ns
Na	35.9 ± 2.1	19.7 ± 1.2	0.01
Mn	179.6 ± 10.2	162.3 ± 6.8	0.01
Ti	23.0 ± 0.9	19.5 ± 0.7	0.05
Fe	422.5 ± 16.3	385.5 ± 13.6	0.05
Zn	48.7 ± 2.4	47.2 ± 2.3	ns
Cu	8.9 ± 0.2	6.9 ± 0.1	0.01
Pb	35.9 ± 1.2	29.2 ± 1.0	0.05
Sr	13.8 ± 0.8	20.8 ± 1.5	0.01
Ba	65.3 ± 4.7	93.6 ± 5.7	0.05
Al	762.6 ± 30.6	598.3 ± 20.1	0.01
S	0.131 ± 0.002	0.149 ± 0.003	0.05

[1] Concentrations of all elements except S are in μg/g dry wt. Sulfur concentrations are in percent dry wt.

[2] Alpha value indicates level at which significant difference in means between 1987 and 1992 samples is detectable.

Table 7. Comparison of mean element concentration in Flavoparmelia caperata specimens collected in Otter Creek Wilderness between 1987 and 1992.

	Mean Concentration ± S.E.[1]		
	1987	1992	Alpha[2]
P	787.3 ± 27.2	874.9 ± 29.1	ns
K	2613.7 ± 68.7	2616.1 ± 74.2	ns
Ca	17651.7 ± 1431.6	18763.8 ± 1342.0	ns
Mg	269.0 ± 9.7	272.5 ± 12.3	ns
Na	28.4 ± 1.6	18.7 ± 1.3	ns
Mn	157.4 ± 10.4	155.0 ± 8.8	ns
Ti	22.8 ± 1.1	17.6 ± 0.8	0.05
Fe	397.5 ± 15.4	351.7 ± 15.9	ns
Zn	41.1 ± 2.3	40.3 ± 2.1	ns
Cu	8.5 ± 0.2	6.9 ± 0.3	0.05
Pb	33.6 ± 1.4	27.9 ± 1.3	ns
Sr	14.6 ± 1.1	24.1 ± 2.0	0.01
Ba	64.1 ± 5.8	90.5 ± 6.7	ns
Al	669.6 ± 24.7	585.9 ± 25.4	ns
S	0.124 ± 0.002	0.145 ± 0.002	0.01

[1] Concentrations of all elements except S are in μg/g dry wt. Sulfur concentrations are in percent dry wt.

[2] Alpha value indicates level at which significant difference in means between 1987 and 1992 samples is detectable.

Table 8. Comparison of mean element concentration in *Flavoparmelia caperata* specimens collected in Dolly Sods Wilderness between 1987 and 1992.

	Mean Concentration ± S.E.[1]		
	1987	1992	Alpha[2]
P	891.8 ± 42.8	890.9 ± 33.6	ns
K	2906.9 ± 101.3	3382.0 ± 88.4	ns
Ca	12947.2 ± 1526.4	19462.6 ± 1937.8	ns
Mg	333.9 ± 15.9	324.8 ± 12.7	ns
Na	50.9 ± 4.9	21.8 ± 2.2	0.01
Mn	223.2 ± 21.4	176.4 ± 10.2	0.01
Ti	23.5 ± 1.9	23.3 ± 1.4	ns
Fe	471.7 ± 37.1	452.0 ± 23.7	ns
Zn	63.7 ± 4.9	60.7 ± 4.9	ns
Cu	9.7 ± 0.5	7.0 ± 0.2	0.01
Pb	40.6 ± 2.2	31.7 ± 1.7	ns
Sr	12.1 ± 1.3	14.3 ± 1.1	ns
Ba	67.7 ± 8.0	99.7 ± 10.6	ns
Al	945.4 ± 71.1	622.7 ± 32.6	0.01
S	0.147 ± 0.003	0.157 ± 0.003	ns

[1] Concentrations of all elements except S are in μg/g dry wt. Sulfur concentrations are in percent dry wt.

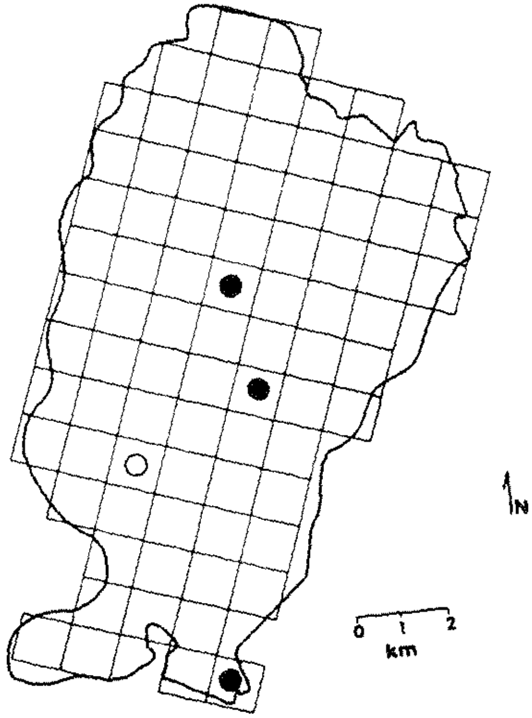
[2] Alpha value indicates level at which significant difference in means between 1987 and 1992 samples is detectable.

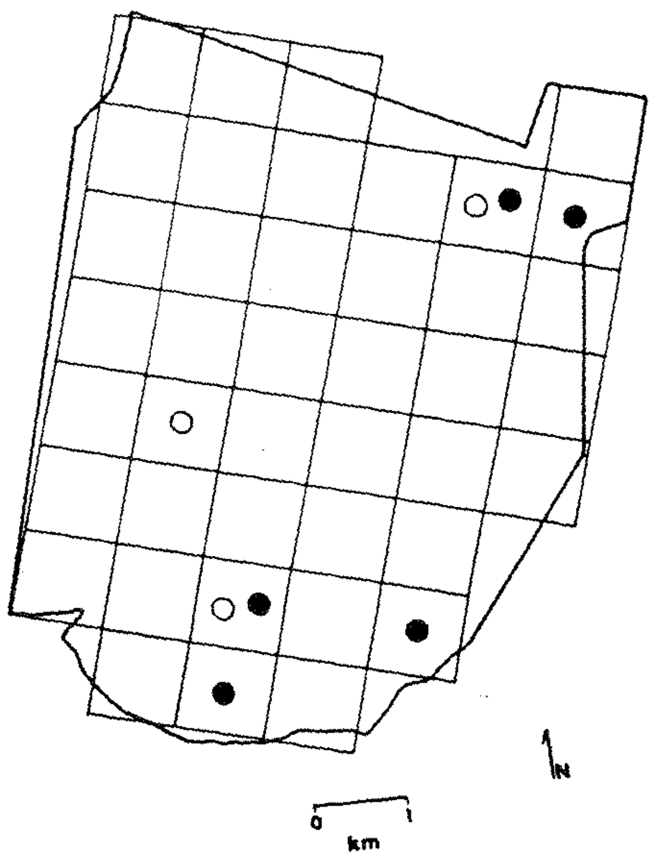
lead. Results indicated that, for every sampling location, the mean concentration of Pb in the test lichens declined significantly and that of sulfur increased, a pattern observed in numerous similar studies done in the eastern United States.

One difference between the present results and those of previous studies is the ability to detect a significant difference in element concentration in such a short time (five years in the present study as compared to 50 years in the SNP study). This indicates that lichens are sufficiently sensitive to changes in air quality that lichen monitoring at five-year intervals is able to detect these changes.

The spatial distribution of lichens containing the highest concentrations of sulfur (values exceeding 0.20%, Fig. 3) indicates that the number of "hot spots" has increased from four in 1987 to eight in 1992 (out of a total of 121 in each case); at two sites, high concentrations were observed in both 1987 and 1992. As was mentioned for the 1987 data, there is no discernible distribution pattern suggesting a single pollution source. However, the increased number of high concentrations sites in Dolly Sods, especially the southern and eastern-most locations in Dolly Sods, indicate that high sulfur may be associated with lichens from high-elevation sites. Still, the proportion of sites with high sulfur concentrations (8 of 121 or 6.6% for all sites; 3 of 80 or 3.75% in Otter Creek and 5 of 41 or 12.2% in Dolly Sods) is relatively low when compared with the northern district of SNP in which a similar study found 49 of 185

FIGURE 3. Locations of 1 km^2 sections in Otter Creek (top) and Dolly Sods (bottom) in which sulfur concentrations in *Flavoparmelia caperata* samples were 0.20% dry weight or greater.


N
0 1 2
km


N
0 1
km

1 km^2 sites (26.5%) with elevated sulfur concentrations (Lawrey, 1987).

It is not possible at present to determine the sulfur deposition patterns necessary to produce elevated (> 0.20% dry weight) sulfur concentrations in Flavoparmelia caperata samples. However, it is clear from values obtained from the literature (Table 9) that lichen sulfur values exceeding 0.20% dry wt. are seen only in regions receiving elevated sulfur pollution. It is interesting that many of the locations in Virginia with F. caperata lichens containing high sulfur have been high-elevation sites.

The idea that sulfur contents in lichens are associated with the elevation of the collecting site was tested statistically using correlation analysis. Although no significant correlation was observed in 1987 between sulfur content and elevation for either Dolly Sods or Otter Creek (Lawrey & Hale, 1988a), a subsequent re-analysis using a combined (two wilderness) data set revealed a slight but significant positive correlation between S and elevation for the 1987 data; this remained the case for 1992 as well (with a slightly higher correlation coefficient in 1992; Fig 4). This tendency for high-elevation lichens to have increased concentrations of sulfur has been observed before for lichens in SNP (Lawrey, 1987) and would appear to implicate long-distance transport of sulfur from a variety of sources.

Evidence from the 1992 survey indicated that nitrogen (Fig. 5) and lead (Fig. 7) were also positively correlated with

Table 9. Selected total sulfur concentrations reported from lichens sampled from various environments.

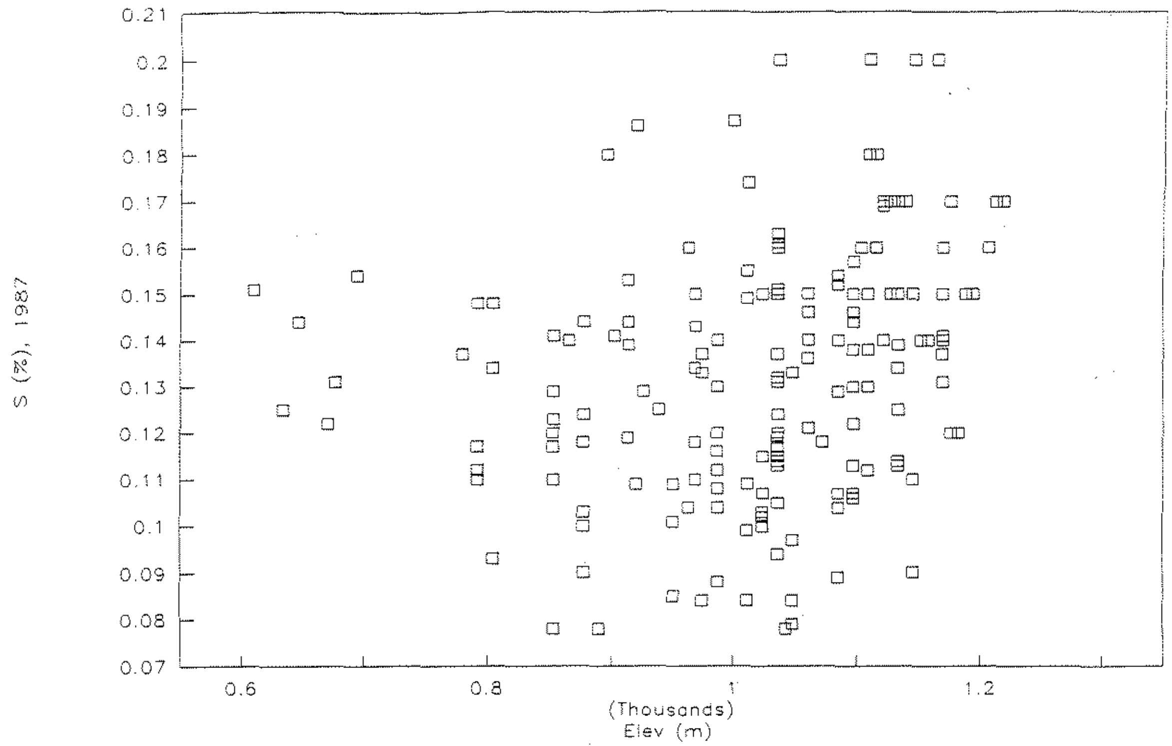
Species and Location	S, % dry wt.	Source
Cladina mitis		
Sudbury, Ontario	0.10	Tomassini, 1976
Cladina stellaris		
Sudbury, Ontario	0.09	Tomassini, 1976
Rural northern Finland	0.07	Kauppi, 1976
Transplant, urban center, Oulu, Finland	0.21	"
Transplant, fertilizer factory, Finland	0.29	"
Flavoparmelia caperata		
Northern district, Shenandoah National Park	0.085-0.29	Lawrey, 1987
Otter Creek and Dolly Sods Wildernesses, WV, 1987	0.078-0.20	Lawrey & Hale, 1988a
Otter Creek and Dolly Sods Wildernesses, WV, 1992	0.082-0.211	Present study
Whitetop Mountain, Virginia	0.096-0.222	Kinsman, 1990
Potomac River Basin, 1988	0.186-0.207	Lawrey, 1993
Potomac River Basin, 1992	0.156-0.180	"
Hypogymnia physodes		
Western Finland, near industrial complex	0.19	Laaksovirta & Olkkonen, 1977
Transplant to chlor-alkali plant, Norway	0.30	Steinnes & Krog, 1977
Transplant to aluminum smelter, Poland	0.14	Swieboda & Kalemba, 1978
Norway	0.14	Solberg, 1967
Fertilizer plant, central Finland	0.19-0.28	Tynnyrinen et al., 1992
Xanthoparmelia chlorochroa		
Powder River Basin, Wyoming and Montana	0.07	Erdman & Gough, 1977

Table 9. (cont.).

Species and Location	S, % dry st.	Source
Xanthoparmelia conspersa Sendai City, Japan	0.16	Saeki et al., 1977
Xanthoparmelia conspersa Flat Tops, Colorado	0.11-0.16	Hale, 1982
Umbilicaria deusta Sudbury, Ontario	0.25	Nieboer et al., 1977
Usnea sp. Flat Tops, Colorado	0.13-0.15	Hale, 1982
Various arctic lichens	0.005-0.02	Nieboer et al., 1977

FIGURE 4. Correlation between S concentration in *Flavoparmelia caperata* samples and elevation of sampling site in the Dolly Sods and Otter Creek Wildernesses, WV. Top: 1987 data; bottom: 1992 data.

S(1987) vs Elev, r=0.23, p<0.01



S(1992) vs Elev, r=0.27, p<0.01

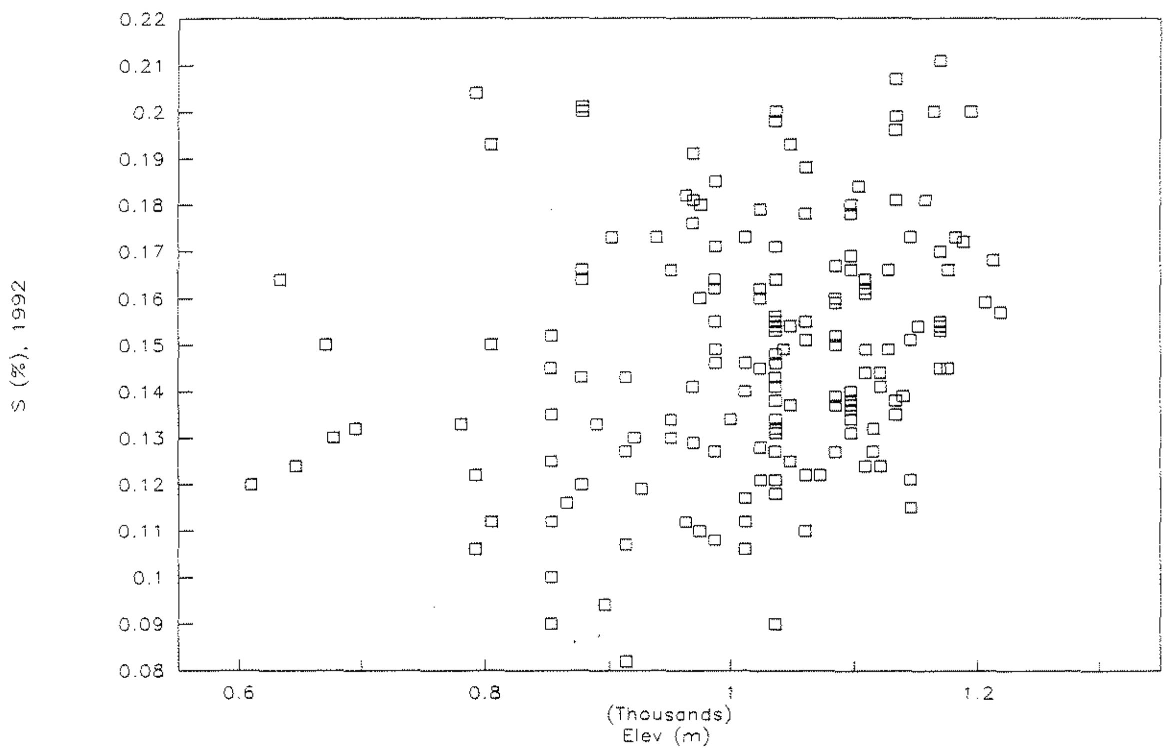
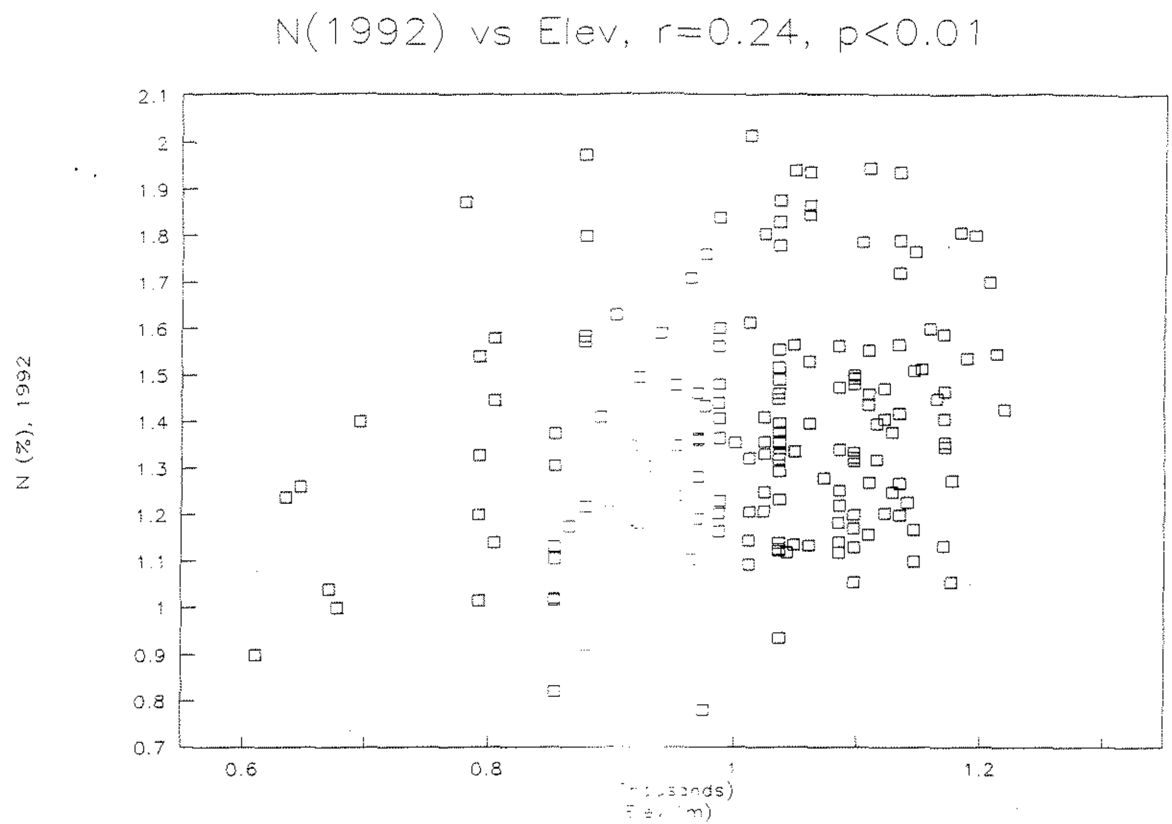


FIGURE 5. Top: Correlation between N concentration in *Flavoparmelia caperata* samples and elevation of the sampling site in the Dolly Sods and Otter Creek Wildernesses, WV, 1992. Bottom: Correlation between S and N concentrations in *F. caperata* samples collected in Dolly Sods and Otter Creek Wildernesses, WV, 1992.


N(1992) vs Elev, r=0.24, p<0.01
N (%), 1992
(Thousands)
Elev (m)

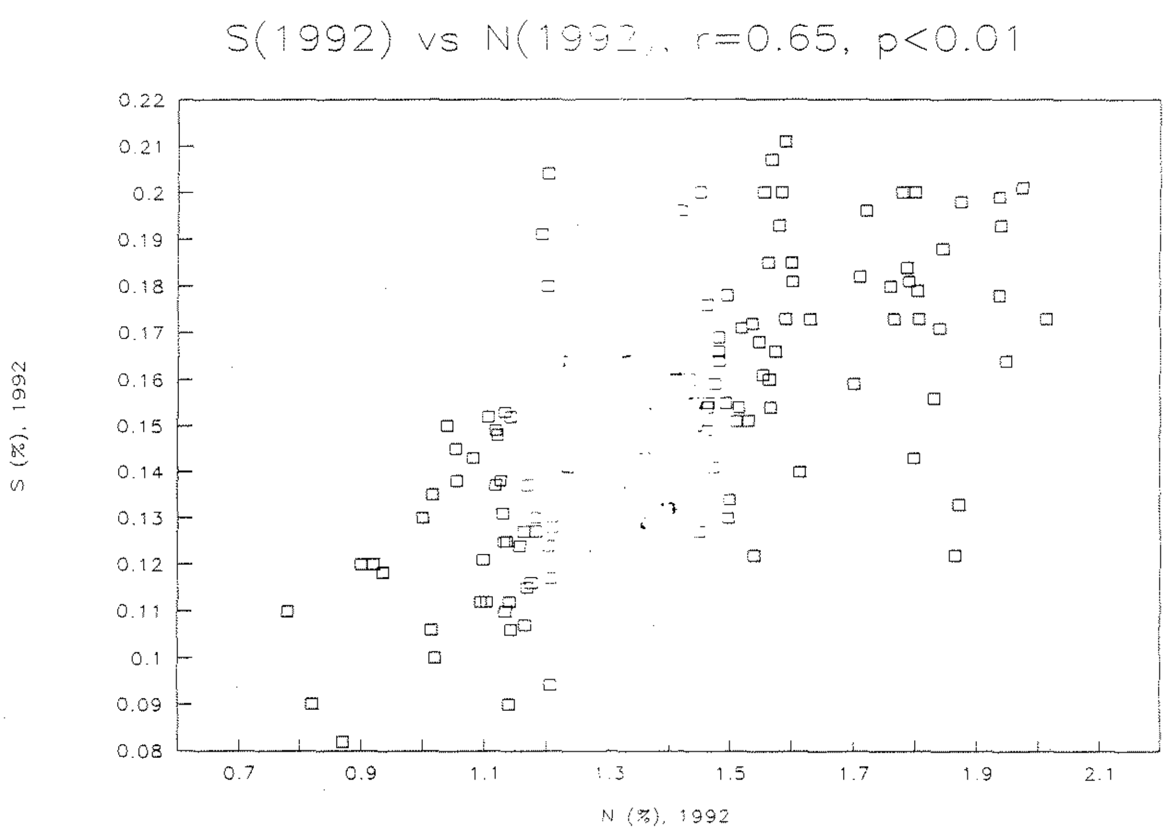
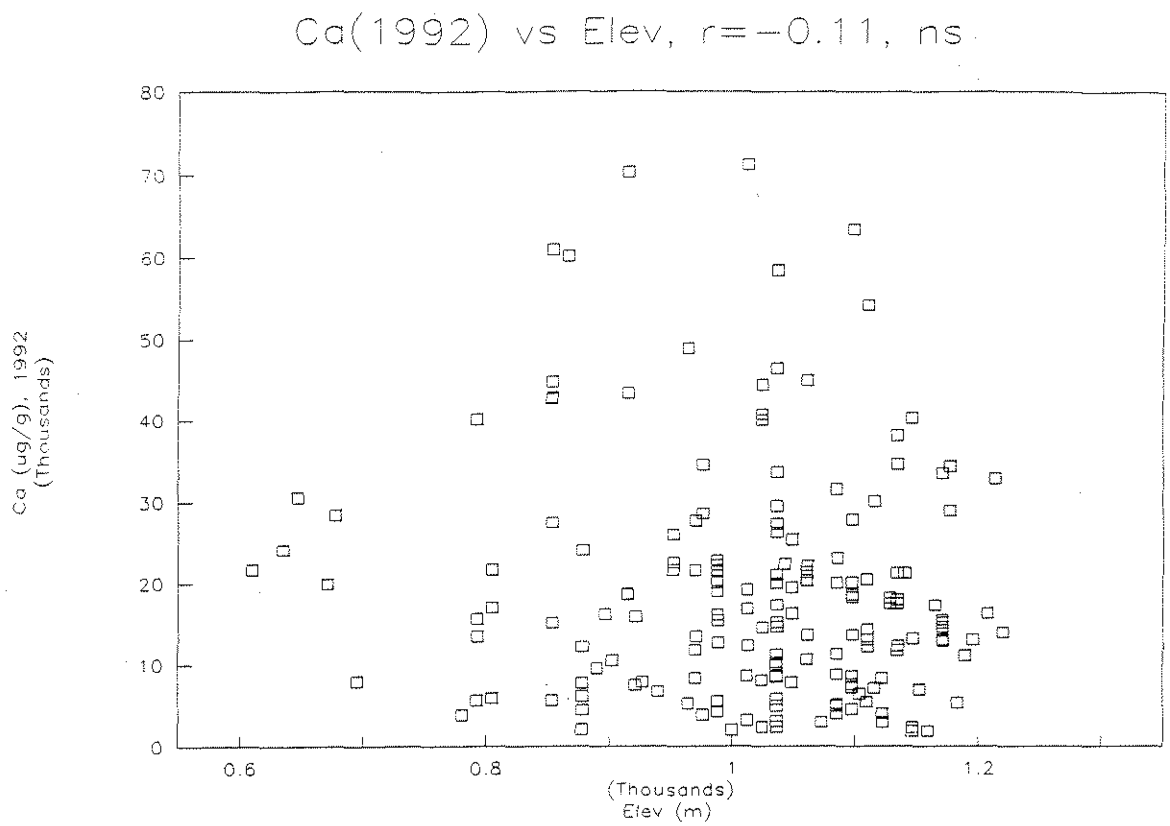

S(1992) vs N(1992), r=0.65, p<0.01
S (%), 1992
N (%), 1992

FIGURE 6. Top: Correlation between Ca concentration in <u>Flavoparmelia caperata</u> samples and elevation of the sampling site in Dolly Sods and Otter Creek Wildernesses, WV, 1992. Bottom: Correlation between S and Ca concentrations in <u>F. caperata</u> samples collected in Dolly Sods and Otter Creek Wildernesses, WV, 1992.


Ca(1992) vs Elev, r=-0.11, ns
Ca (ug/g), 1992
(Thousands)
0
10
20
30
40
50
60
70
80
0.6
0.8
1
1.2
(Thousands)
Elev (m)

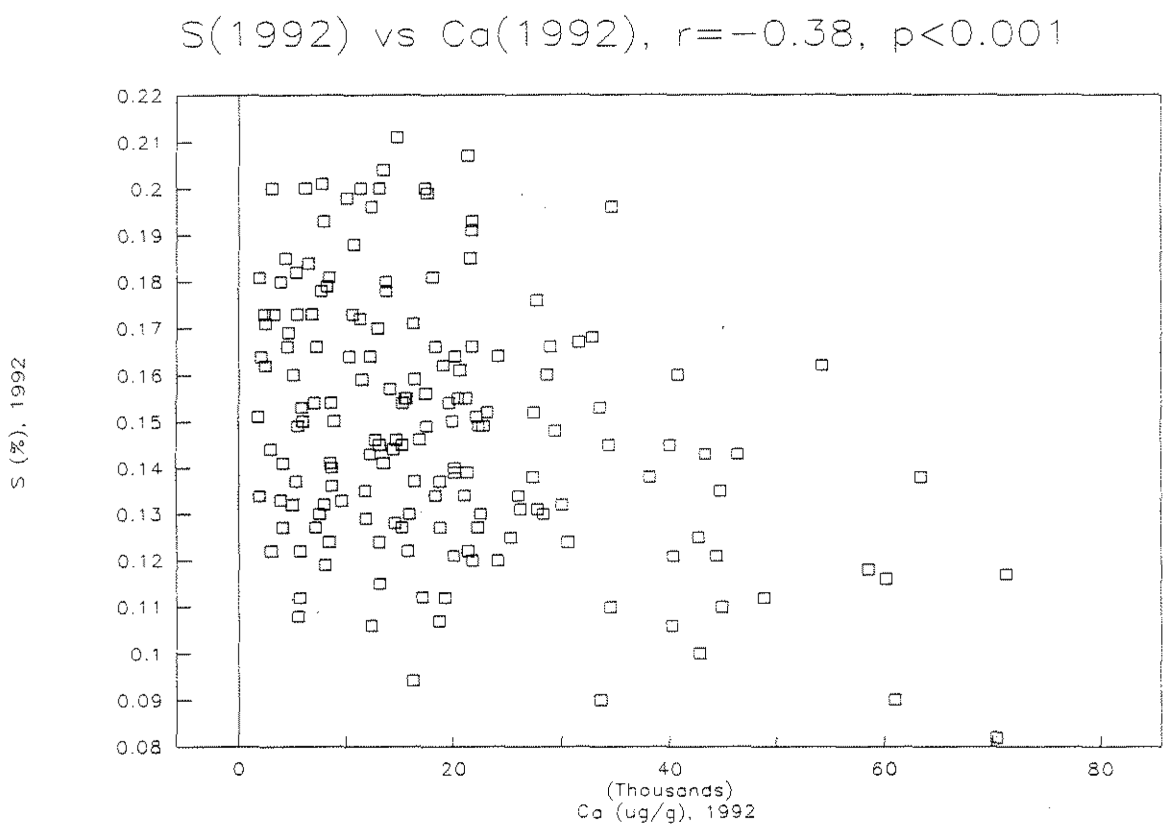
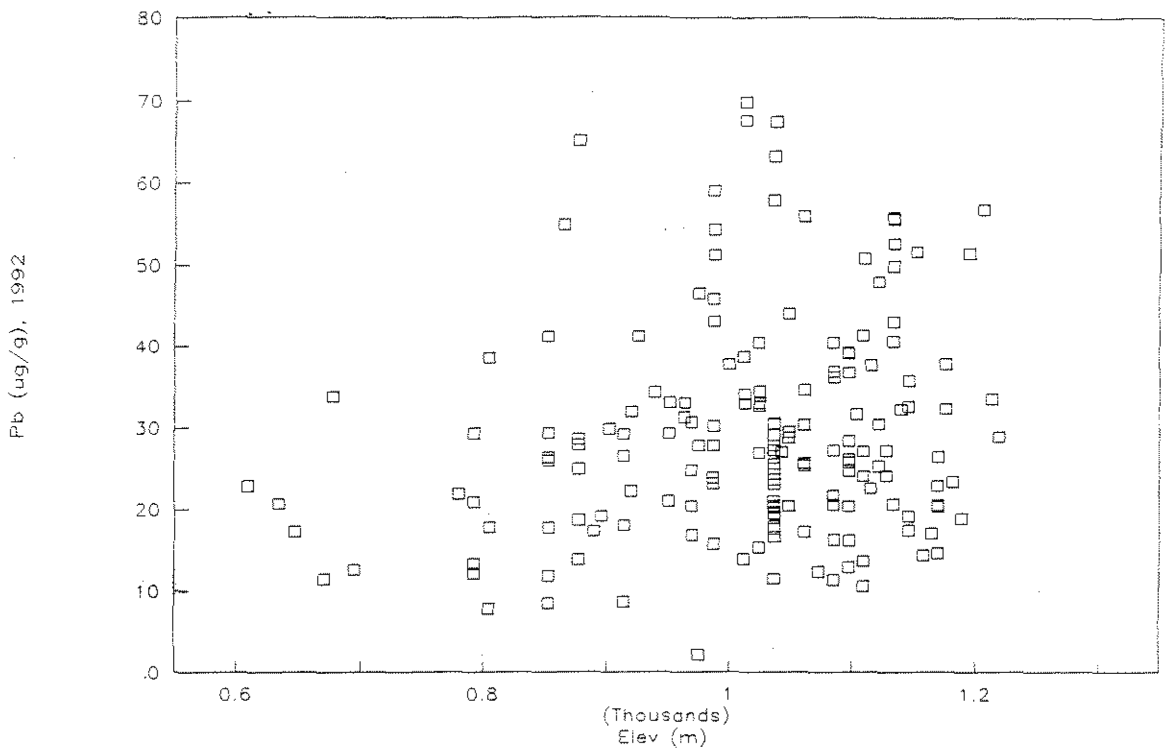
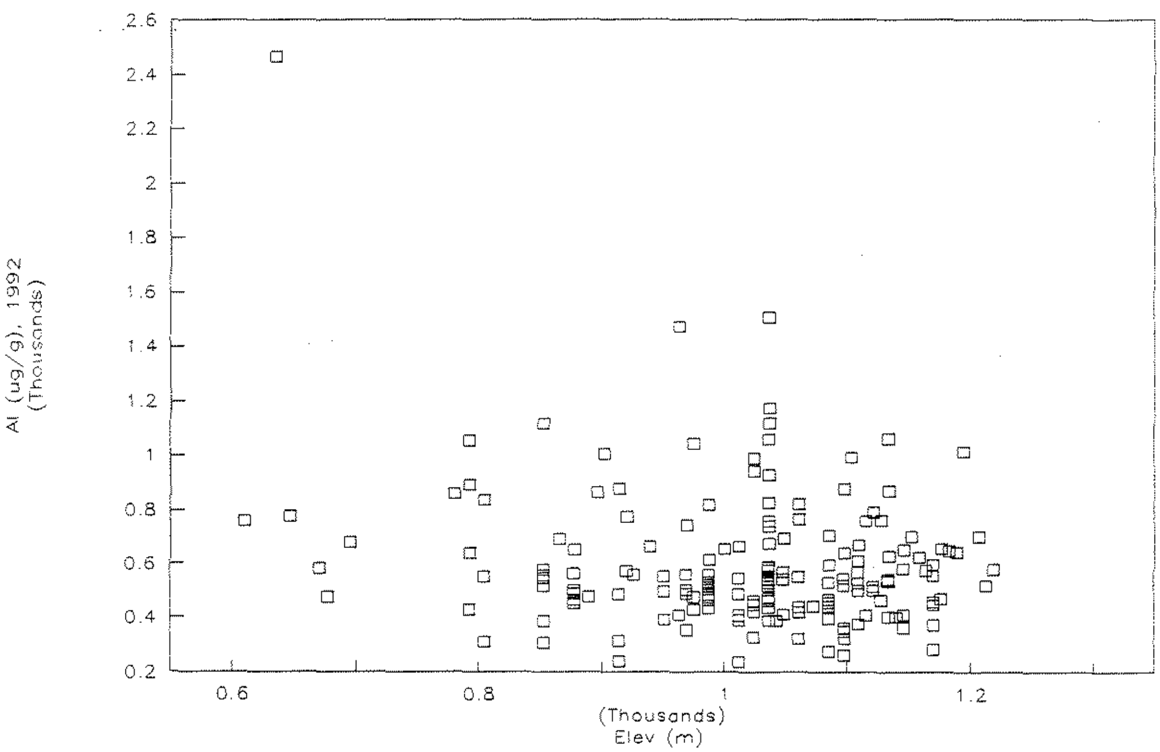

S(1992) vs Ca(1992), r=-0.38, p<0.001
S (%), 1992
0.08
0.09
0.1
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.2
0.21
0.22
0
20
40
60
80
(Thousands)
Ca (ug/g), 1992

FIGURE 7. Top: Correlation between Pb concentration in _Flavoparmelia_ _caperata_ samples and elevation of the sampling site in Dolly Sods and Otter Creek Wildernesses, WV, 1992. Bottom: Correlation between Al concentration in _F._ _caperata_ samples and elevation of sampling site in Dolly Sods and Otter Creek Wildernesses, WV, 1992.

Pb(1992) vs Elev (m), r=0.19, p<0.05



Al(1992) vs Elev (m), r=−0.21, p<0.01



elevation. Not unexpectedly, sulfur and nitrogen concentrations were highly correlated (Fig. 5); however, sulfur and lead were not. Of the remaining elements, Mg, Sr and Al all showed significant negative correlations with elevation; no other elements showed elevational patterns. In general, nonpollutant elements tended not to show elevational patterns (e.g., Ca vs elevation, Fig. 6) or correlations with pollutant elements. An interesting negative correlation between S and Ca in lichens (Fig. 6) was observed (and was also seen in 1987), which may reflect ecologically important acidification of soils in sites receiving the highest deposition of sulfur.

It is anticipated that continued monitoring of the lichen elemental status in the two wildernesses will permit increased resolution of the elevational trends in pollutant deposition (especially S and N) observed in this resurvey. Since these trends may be caused by long-distance transport of pollution from a variety of sources, it is expected that they will continue in the future, and an objective study of their effects requires a monitoring protocol that can be continued in the future. Therefore, results of lichen biomonitoring efforts like this one, combined with information from mechanical air quality monitoring, provide a continuous and relatively inexpensive information base upon which Forest Service land managers can rely to make regulatory decisions affecting the Class I areas in the Monongahela National Forest.

CONCLUSIONS

A five-year resurvey of the lichens of the Dolly Sods and Otter Creek Wildernesses yielded a number of important findings. Many of the results were obtainable only because baseline data were available for comparison.

(1) The lichen flora of the two wildernesses exhibits a species richness and community composition expected for natural areas undisturbed by air pollution. Numerous pollution-sensitive species are observed in good condition throughout the wildernesses, and no sites exhibit reductions in diversity that would be expected in pollution-damaged areas.

(2) The lichens in permanent photoplots generally exhibit growth and recolonization rates expected in pollution-free environments. There are isolated instances in which damage to lichens was observed; however, the damage could be attributed in each case to natural causes and not to pollution effects.

(3) Mean concentrations of many metals (Fe, Cu, Pb, Al) in lichens have declined in the two wildernesses since 1987; similar patterns have been observed before, but there is no definite explanation.

(4) Mean sulfur concentrations in lichens have increased from 0.131 to 0.149 % dry wt. in the two wildernesses since 1987.

(5) The number of sampling sites with elevated sulfur (0.20% and higher) has doubled since 1987, but still represents only 6.6% of all sites.

(6) In 1992, concentrations of both S and N are significantly higher in Dolly Sods than in Otter Creek, a trend that was seen for S in 1987 (nitrogen was analyzed for the first time in 1992).

(7) Significant positive correlations with elevation were observed for both sulfur and nitrogen concentrations in lichens, so the higher concentrations of sulfur in Dolly Sods may be the consequence of a higher average elevation of sampling sites there. Lead concentrations are also positively correlated with elevation.

(8) Nonpollutant elements tend not to exhibit significant elevational patterns; Mg, Sr and Al exhibit negative correlations with elevation.

(9) In general, the element data provide the most objective basis for assessing the effects of air quality changes in the two wildernesses. Increases in sulfur and nitrogen evident from the lichen elemental analysis are undoubtedly due to air pollution effects; however, there are no noticeable effects on the lichen flora or the growth rates of the lichens in the photoplots. This suggests that the continued monitoring of lichen elemental status will provide useful and important "early warning" of impacts to air quality related values in the two wildernesses.

RECOMMENDATIONS

Based on the results of this study, the following recommendations can be made:

(1) Follow-up floristic analysis should be done in five years to document any changes in lichen species diversity; this will also add to the present lichen species list for the two wildernesses.
(2) Elemental analysis quadrats should be resampled in five years to collect _F. caperata_ samples for element analysis. Element data collected in these permanent sites can then be compared to data collected in 1987 and 1992 to continue to resolve some of the important trends (especially elevational ones) evident from the present study.
(3) Permanent photographic study plots should be visited and rephotographed in five years to document changes in lichen growth and colonization rates indicative of air quality changes.
(4) New studies may be initiated to document changes in lichen community structure caused by air pollution effects. These would target high-elevation sites especially sensitive to pollution and concentrate on the long-term effects of air quality changes on sensitive species (especially _Usnea_ species). Since the resurveys are probably most valuable, these new studies would only be done if additional resources are available.

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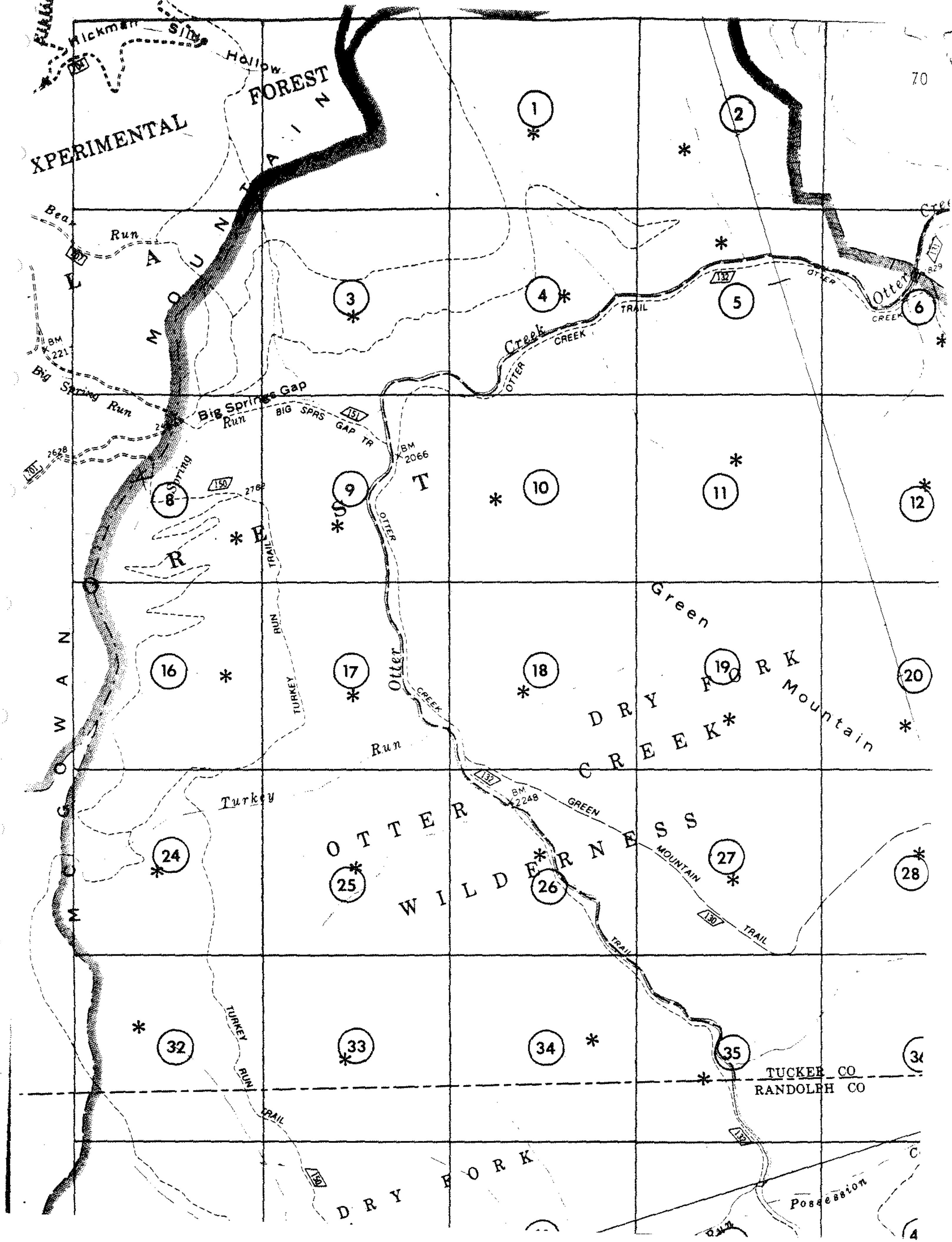
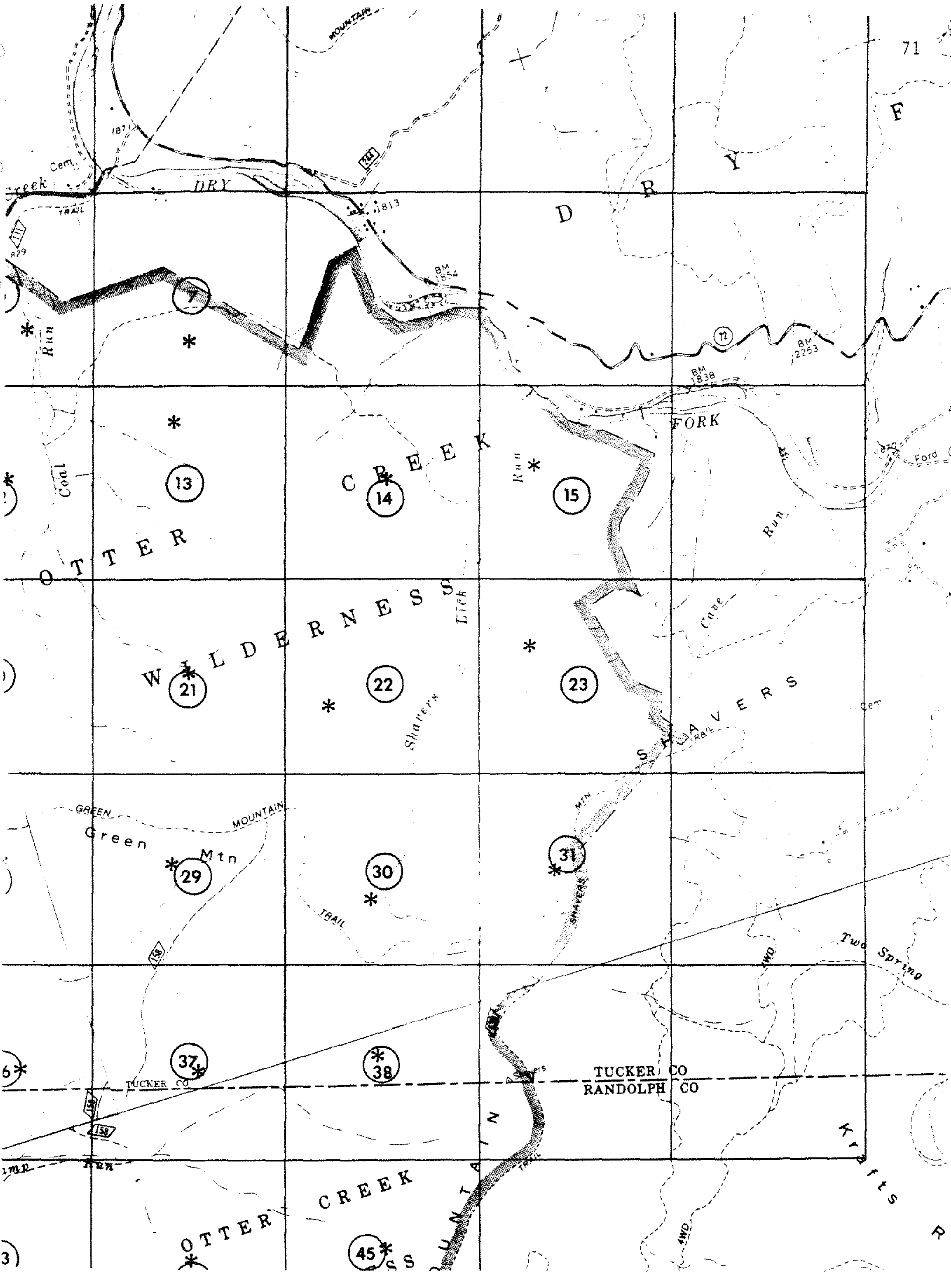
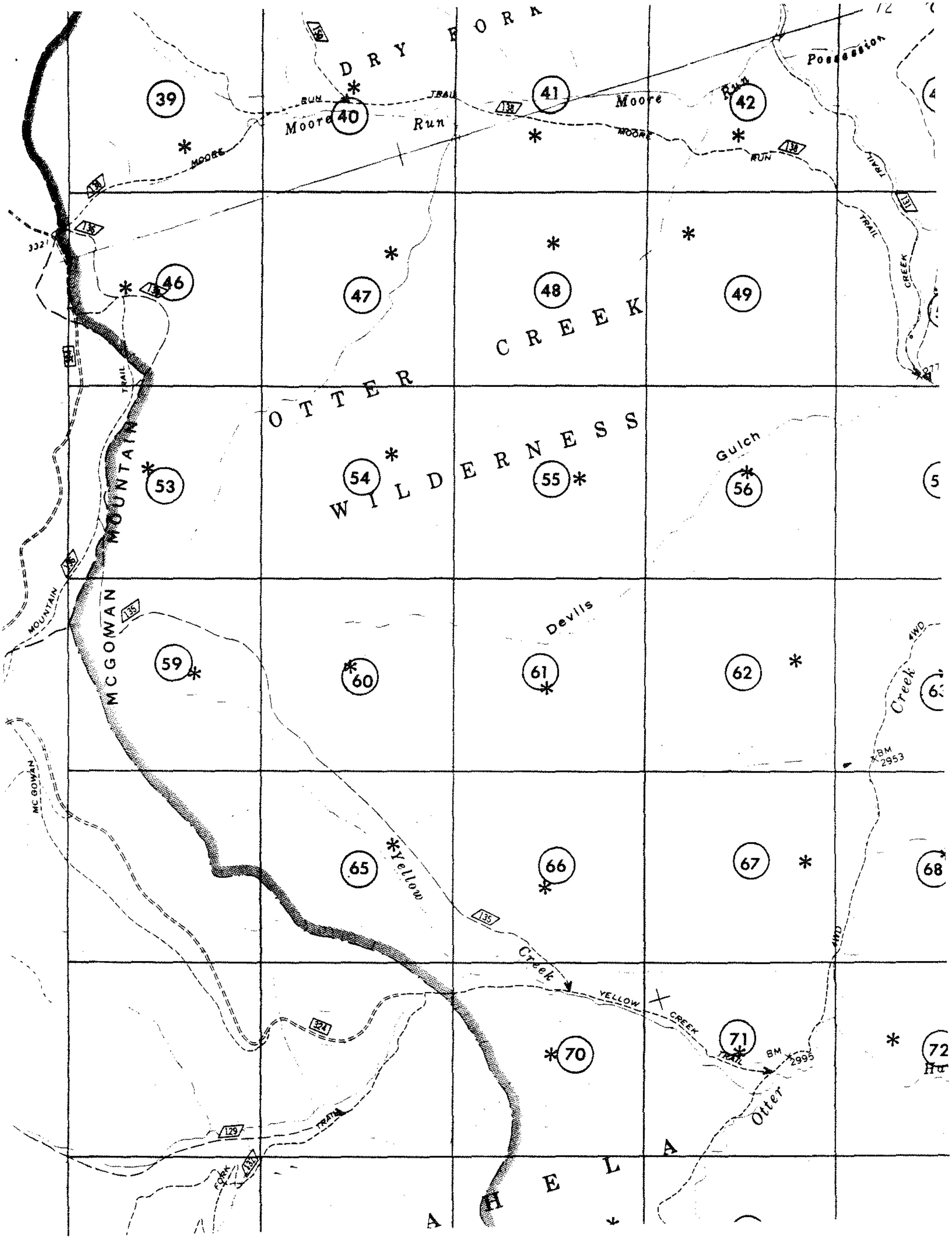
APPENDIX 1. Locations of elemental analysis quadrats in the Otter Creek (sites 1-80) and Dolly Sods (sites 81-121) study areas. Stars and asterisks mark the quadrat locations within each 1 km^2 section. Base maps are USGS 7.5 minute series maps (Otter Creek: Bowden, Harman, Parsons, Mozark Mtn., WV; Dolly Sods: Blackwater Falls, Blackbird Knob, Laneville, Hopeville, WV).

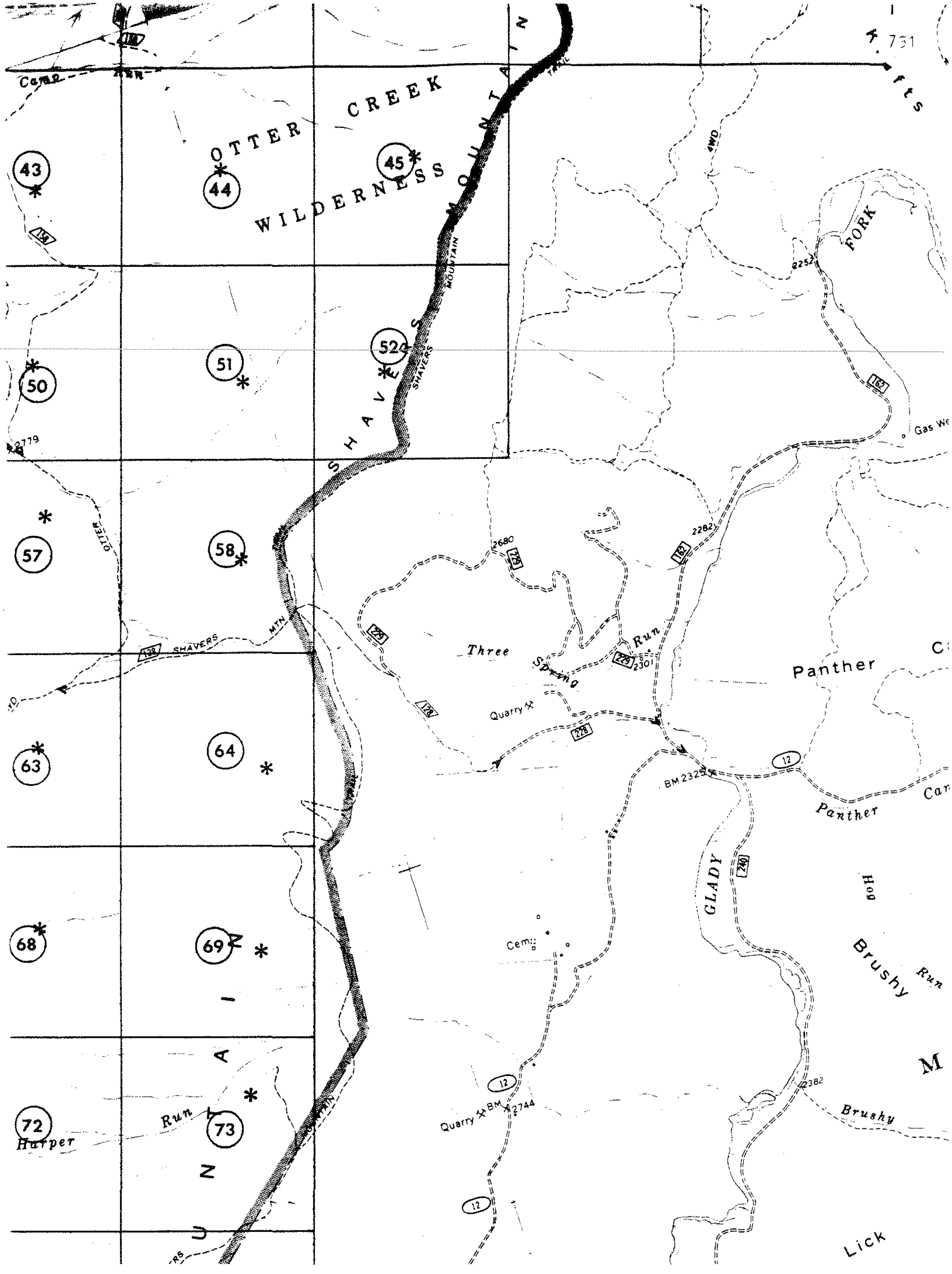

Hickman Slide Hollow
EXPERIMENTAL FOREST
Bear Run
Big Spring Run
Big Springs Gap
BIG SPRS GAP TR
BM 2066
Spring
OTTER CREEK TRAIL
Otter Creek
TURKEY RUN TRAIL
Turkey Run
Green Mountain
DRY FORK
CREEK
OTTER CREEK WILDERNESS
GREEN MOUNTAIN TRAIL
BM 2248
TUCKER CO
RANDOLPH CO
DRY FORK
Possession Run
1
2
3
4
5
6
8
9
10
11
12
16
17
18
19
20
24
25
26
27
28
32
33
34
35



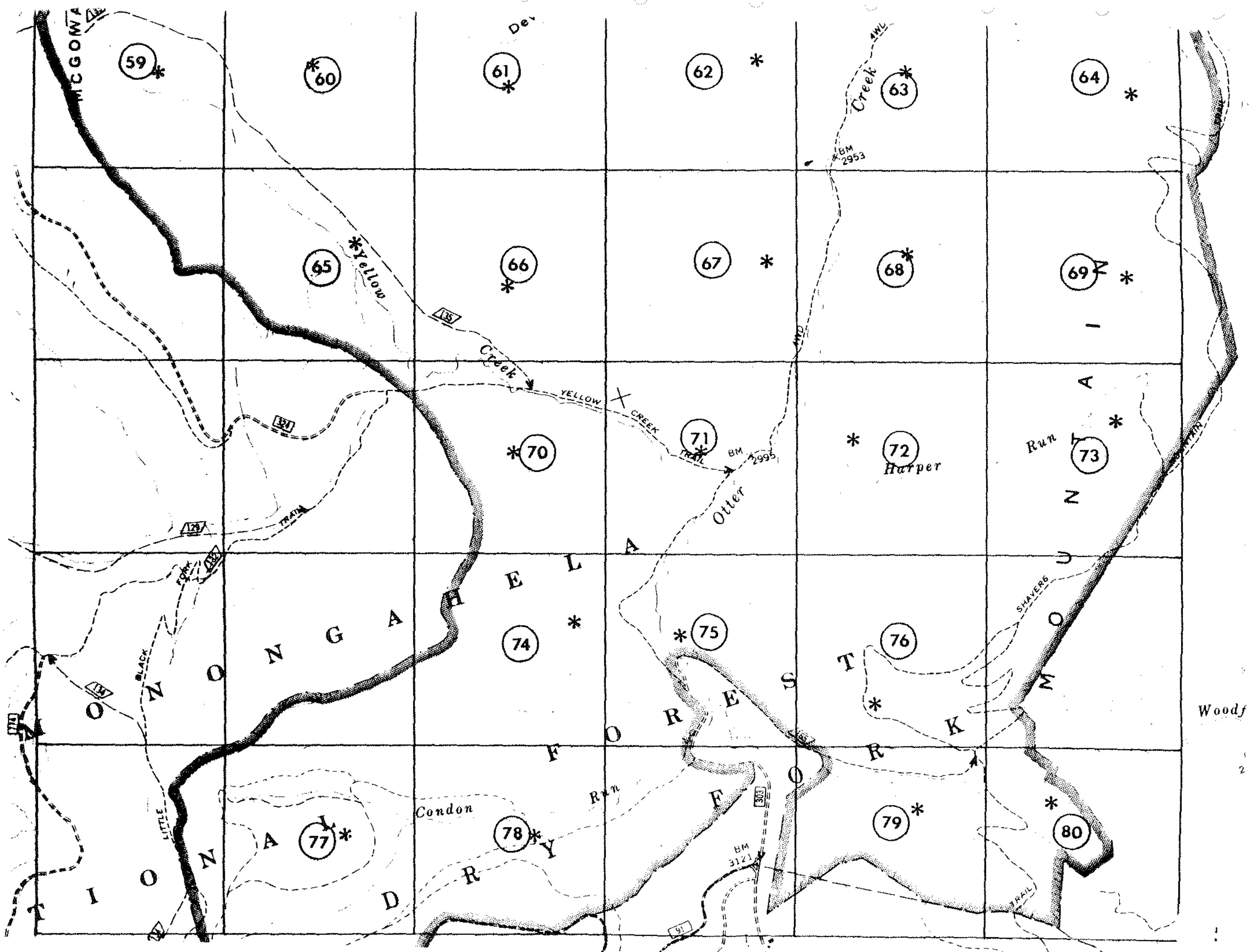
Creek
Cem
DRY
TRAIL
1871
1813
829
MOUNTAIN
BM 854
D R Y F
FORK
BM 2253
BM 838
Ford
Run
Coal Run
Cave
Lick
Shavers
OTTER CREEK WILDERNESS
SHAVERS
7
13
14
15
21
22
23
GREEN MOUNTAIN
Green Mtn
29
30
31
SHAVERS MTN TRAIL
158
Two Spring
4WD
37
38
TUCKER CO
RANDOLPH CO
OTTER CREEK
45

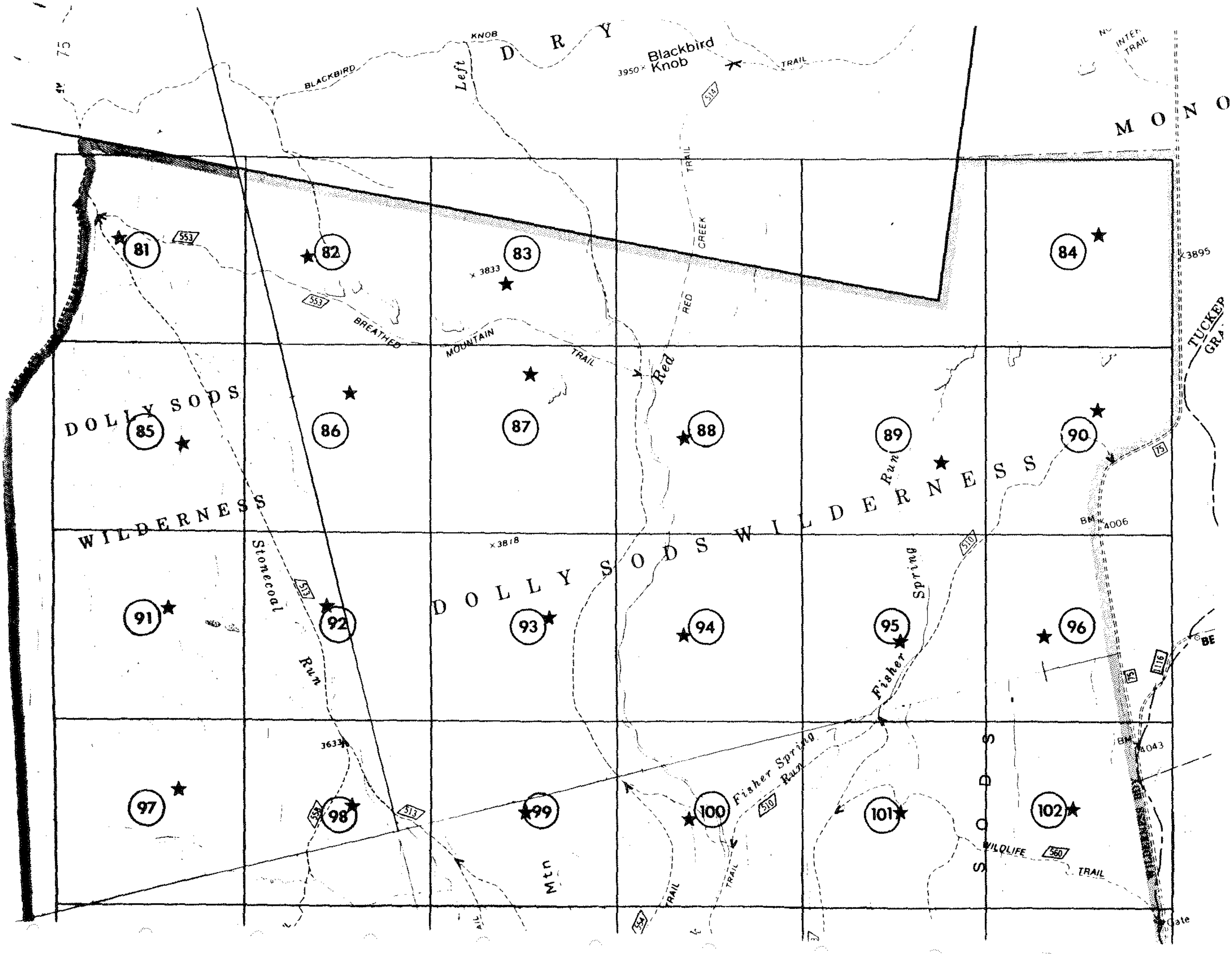


DRY FORK
Moore
Run
RUN
TRAIL
MOORE
Moore
Run
Possession
138
135
324
129
131
39
40
41
42
46
47
48
49
53
54
55
56
59
60
61
62
65
66
67
68
70
71
72
OTTER CREEK
WILDERNESS
MCGOWAN MOUNTAIN
MOUNTAIN
MC GOWAN
TRAIL
CREEK
Gulch
Devils
Creek
Yellow
Creek
YELLOW
CREEK
TRAIL
4WD
BM 2953
BM 2995
Otter
FORK



OTTER CREEK
WILDERNESS
SHAVERS MOUNTAIN
43
44
45
50
51
52
57
58
63
64
68
69
72
73
SHAVERS MOUNTAIN
SHAVERS MTN
OTTER
Camp
FORK
2252
162
2779
2680
2282
Three
Spring
Run
229
2301
Panther
Quarry
228
BM 2325
12
Panther
GLADY
240
Hog
Brushy
Run
Cem
M
2382
Brushy
Quarry
BM
2744
Harper
Run
Lick
4WD
Gas We


MCGOWAN
Dev
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
Creek
4WD
BM 2953
Yellow
Creek
135
YELLOW
CREEK
TRAIL
BM 2995
Otter
Harper
Run
MONONGAHELA NATIONAL FOREST
SHAVERS
MOUNTAIN
TRAIL
BLACK
FORK
LITTLE
Condon
Run
DRY FORK
BM 3121
303
91
Woodf



DOLLY SODS WILDERNESS
DOLLY SODS WILDERNESS
DRY
Left Knob
Blackbird Knob
3950
BLACKBIRD
TRAIL
514
MONO
RED CREEK TRAIL
Red
BREATHED MOUNTAIN TRAIL
553
3833
3818
Stonecoal Run
513
3633
558
Mtn
554
TRAIL
Fisher Spring Run
510
SODS
WILDLIFE
560
TRAIL
BM 4006
BM 4043
3895
75
1116
TUCKER
Gate
81
82
83
84
85
86
87
88
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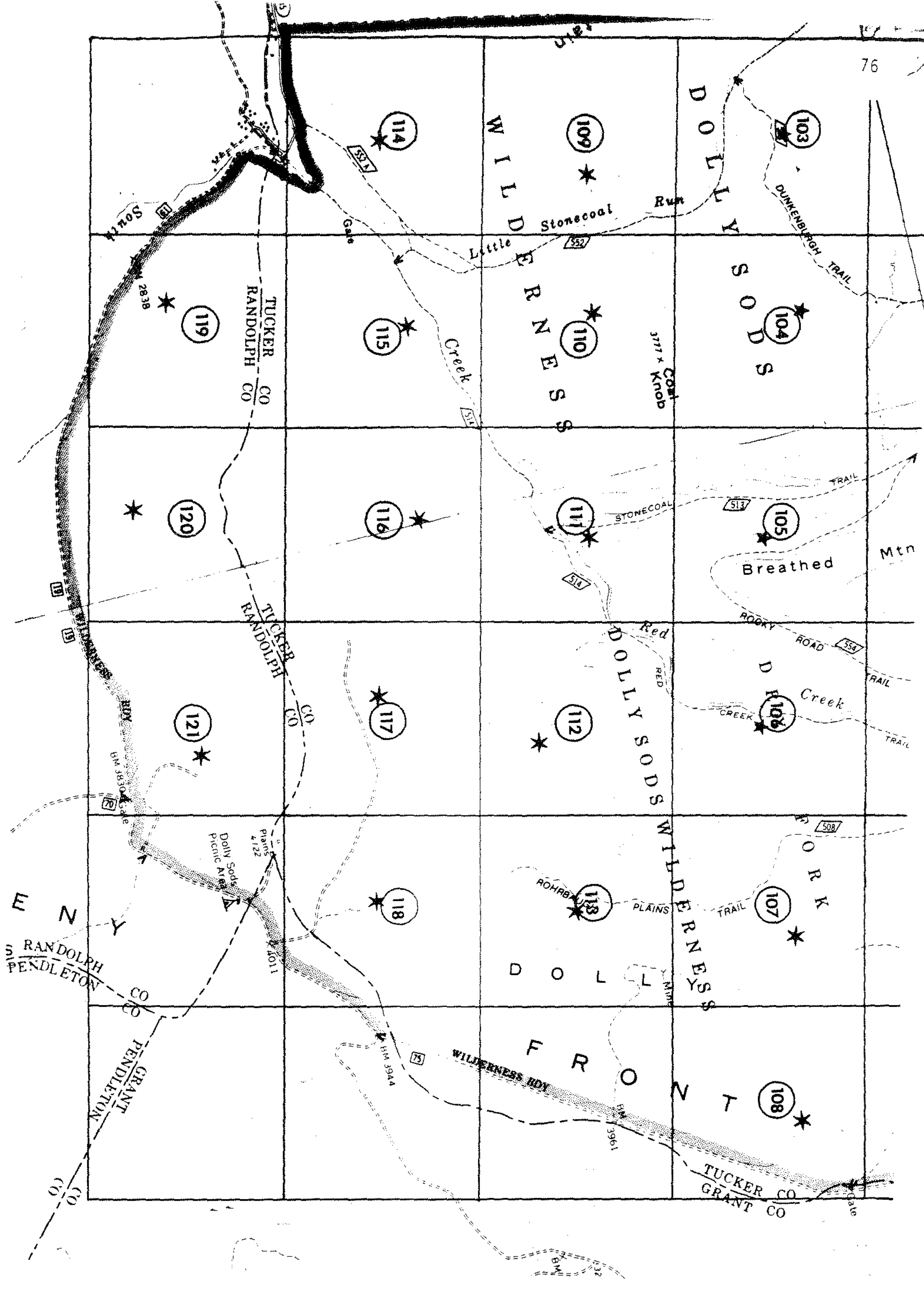
101
102



DOLLY SODS WILDERNESS
DOLLY SODS WILDERNESS
DOLLY SODS
DUNKENBURGH TRAIL
Little Stonecoal Run
552
553
TUCKER CO
RANDOLPH CO
Gate
Creek
514
3777 x Coal Knob
BM 2838
STONECOAL TRAIL
513
Breathed Mtn
ROCKY ROAD TRAIL
554
Red Creek
RED CREEK TRAIL
FORK
508
ROHRBAUGH PLAINS TRAIL
WILDERNESS RDY
BM 3830
Gate
70
19
Plains 4122
Dolly Sods Picnic Area
4011
RANDOLPH CO
PENDLETON CO
GRANT CO
PENDLETON CO
DOLLY
FRONT
75
BM 3944
BM 3961
TUCKER CO
GRANT CO
Gate
103
104
105
106
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108
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110
111
112
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121

APPENDIX 2. Lichen species lists for the Dolly Sods and Otter Creek Wildernesses, WV. Species are listed alphabetically for both the 1987 study (Lawrey & Hale, 1988a) and the present (1992) study. Sensitivity to air pollution is indicated by S (sensitive) and I (insensitive) based on Wetmore (1983) and Mason Hale (personal communication).

Appendix 2. List of lichen species collected in the Dolly Sods Wilderness in the 1987 and 1992 surveys. Sensitivity to pollution is indicated by I (insensitive), S (sensitive).

	1987	1992	Sensitivity
Acarospora badiofusca		X	
Anaptychia palmatula	X	X	
Aspicilia cinerea	X	X	
Aspicilia gibbosa group		X	
Bacidia schweinitzii	X	X	
Baeomyces absolutus		X	
Candelariella vitellina	X	X	S
Candelariella xanthostigma		X	S
Cetrelia chicitae	X	X	
Cetrelia olivetorum	X	X	
Cladina mitis		X	
Cladina rangiferina	X	X	
Cladina stellaris		X	
Cladina subtenuis		X	
Cladonia caespiticia		X	
Cladonia capitata		X	
Cladonia coniocraea	X	X	I
Cladonia conista		X	
Cladonia deformis	X		
Cladonia didyma		X	
Cladonia fimbriata		X	

pH ? like alkaline env. NH_3↑ nitrophytic

Cladonia furcata	X	X	I
Cladonia gracilis	X		
Cladonia grayi	X	X	
Cladonia macilenta	X	X	
Cladonia squamosa	X	X	
Cladonia verticillata		X	
Conotrema urceolatum	X	X	
Dermatocarpon miniatum	X		
Dimelaena oreina	X	X	
Flavoparmelia baltimorensis	X	X	
Flavoparmelia caperata	X	X	
Flavopunctelia flaventior	X	X	
Graphis scripta	X	X	I
Heterodermia obscurata		X	S
Heterodermia speciosa	X	X	S
Hypogymnia krogii	X	X	
Hypogymnia physodes	X	X	
Imshaugia aleurites	X	X	
Lasallia papulosa		X	
Lecanora piniperda		X	
Lecanora saligna		X	
Lecanora strobilina		X	
Lecanora subfusca group	X	X	
Lecanora symmicta		X	S
Lecidea albofuscesens		X	
Lepraria finkii		X	

Lepraria incana		X	
Lepraria zonata	X	X	I
Melanelia subaurifera	X	X	
Menegazzia terebrata		X	
Myelochroa aurulenta	X	X	
Myelochroa galbina	X	X	
Ochrolechia arborea	X	X	
Parmelia squarrosa	X	X	S
Parmelia sulcata	X	X	I
Parmelinopsis spumosa	X		
Parmeliopsis ambigua	X	X	S
Parmeliopsis hyperopta	X		
Parmotrema crinitum		X	
Parmotrema stuppeum	X	X	
Peltigera canina	X	X	S
Pertusaria amara		X	S
Phaeophyscia pusilloides	X		
Phaeophyscia rubropulchra	X	X	
Physcia aipolia	X	X	S
Physcia millegrana		X	
Physcia phaea	X		
Physcia stellaris	X	X	S
Physconia detersa		X	S
Platismatia tuckermanii	X	X	
Platismatia glauca		X	
Porpidia albocaerulescens	X	X	I

Porpidia cinereoatra		X	
Pseudevernia consocians	X	X	S
Punctelia appalachensis	X	X	
Punctelia rudecta	X	X	I
Punctelia subrudecta	X	X	I
Pyxine sorediata	X	X	
Sarcogyne similis	X	X	
Trapeliopsis viridescens		X	
Tuckermannopsis ciliaris	X	X	S
Tuckermannopsis oakesiana	X	X	S
Tuckermannopsis pinastri		X	S
Umbilicaria mammulata	X	X	
Usnea subfloridana		X	S
Xanthoparmelia conspersa	X	X	
Xanthoparmelia cumberlandia	X	X	
Xanthoparmelia plittii	X	X	

Appendix 2. List of lichen species collected in the Otter Creek Wilderness in the 1987 and 1992 surveys. Sensitivity to pollution is indicated by I (insensitive), S (sensitive).

	1987	1992	Sensitivity
Acarospora fuscata		X	
Anaptychia palmatula		X	
Aspicilia caesiocinerea		X	
Aspicilia cinerea		X	
Aspicilia gibbosa group		X	
Bacidia schweinitzii	X	X	
Buellia stillingiana		X	
Calicium sp.	X		
Caloplaca flavovirescens		X	
Cetrelia chicitae	X	X	
Cetrelia olivetorum	X	X	
Cladina rangiferina		X	
Cladina stellaris		X	
Cladina subtenuis		X	
Cladonia bacillaris	X	X	
Cladonia caespiticia	X	X	
Cladonia coniocraea	X	X	I
Cladonia cristatella		X	
Cladonia cylindrica		X	
Cladonia didyma		X	
Cladonia furcata	X	X	I

Cladonia incrassata		X	
Cladonia macilenta		X	
Cladonia squamosa	X	X	
Collema subfurvum	X		
Conotrema urceolatum	X		
Dermatocarpon fluviatile		X	
Dimelaena oreina		X	
Dimerella pineti		X	
Endocapron pusillum		X	
Evernia mesomorpha		X	S
Flavoparmelia baltimorensis	X	X	
Flavoparmelia caperata	X	X	
Flavopunctelia flaventior	X	X	
Graphis scripta	X	X	I
Heterodermia hypoleuca		X	S
Heterodermia obscurata		X	S
Heterodermia speciosa	X	X	S
Heterodermia squamulosa		X	S
Hypocenomyce scalaris	X		
Hypogymnia krogii		X	
Hypogymnia physodes	X	X	
Lasallia papulosa		X	
Lecanora caesiorubella		X	
Lecanora impudens		X	
Lecanora muralis		X	
Lecanora strobilina		X	

Lecanora subfusca group		X	
Lecanora varia	X		
Lepraria finkii		X	
Lepraria zonata	X	X	I
Lobaria quercizans	X	X	S
Melanelia exasperata		X	
Melanelia stygia		X	
Melanelia subaurifera		X	S
Menegazzia terebrata	X	X	
Myelochroa aurulenta	X	X	
Myelochroa galbina	X		
Pannaria taveresii		X	S
Parmelia squarrosa	X	X	S
Parmelia sulcata	X	X	I
Parmelina minarum	X	X	
Parmelinopsis spumosa	X		
Parmeliopsis ambigua		X	S
Parmotrema arnoldii	X		
Parmotrema hypotropum		X	S
Parmotrema reticulatum		X	S
Parmotrema stuppeum	X	X	
Peltigera canina		X	S
Peltigera polydactyla		X	S
Pertusaria amara		X	
Pertusaria multipunctoides		X	
Pertusaria neoscotica		X	

Pertusaria trachythallina		X	
Phaeophyscia rubropulchra	X	X	
Physcia aipolia		X	S
Physconia detersa		X	S
Platismatia tuckermanii	X	X	
Platismatia glauca		X	
Porpidia albocaerulescens	X	X	I
Porpidia macrocarpa		X	
Protoblastenia rupestris		X	S
Pseudevernia consocians	X	X	S
Punctelia appalachensis	X		
Punctelia rudecta	X	X	I
Punctelia subrudecta	X	X	I
Pyxine caesiopruinosa		X	
Pyxine sorediata	X	X	
Sarcogyne similis		X	
Trypethelium virens	X		
Tuckermannopsis ciliaris		X	S
Tuckermannopsis oakesiana	X	X	S
Umbilicaria mammulata	X	X	
Usnea rubicunda		X	S
Usnea strigosa		X	S
Verrucaria calciseda		X	
Verrucaria calkinsiana		X	
Xanthoparmelia conspersa	X	X	
Xanthoparmelia cumberlandia	X	X	

<u>Xanthoparmelia</u> <u>hyposila</u> X

APPENDIX 3. Concentration of trace elements in Flavoparmelia caperata samples collected from each elemental analysis quadrat in the Otter Creek and Dolly Sods Wildernesses, WV, 1992. Values are $\mu g/g$ in all cases except S and N, which are reported in percent dry weight. Some values were below limits of detection (nd). Site ID's following every tenth site are replicates of these sites.

SiteID	ELEV(M)	P-92	K-92	Ca-92	Mg-92
1	920.5000	1151.9700	3762.3100	7512.7700	302.7120
2	780.2880	1363.3600	4350.5700	3871.4500	450.2250
3	804.6720	1633.7500	3820.6800	21664.4000	363.9270
4	676.6560	422.7410	2078.9700	28344.6000	205.7880
5	609.6000	575.0970	2279.7700	21715.7000	252.4510
6	633.9840	876.0720	3431.3400	24116.3000	757.7090
7	792.2700	648.3698	2130.3500	5636.2900	334.0630
8	902.2000	651.4040	2227.3600	10512.2000	300.1070
9	670.5600	783.9700	2680.3200	19932.9000	372.9610
10	853.5000	782.9750	3113.2500	60934.4000	622.3770
166	853.5000	652.6460	2099.0800	15168.8000	472.4780
167	853.5000	504.6630	2019.7900	27466.4000	237.9400
168	853.5000	651.5350	2623.3300	42673.5000	561.0570
169	853.5000	877.0040	2882.7500	42732.2000	688.0650
11	914.4000	558.9170	1661.0500	70363.3000	201.5520
12	853.4400	791.5580	2064.3600	44720.8000	187.1690
13	914.4000	1025.9500	2983.9800	43305.3000	319.3410
14	804.6720	1034.1800	4014.7800	5925.3500	340.5210
15	646.1760	1174.8400	3000.6600	30554.0000	419.5230
16	1036.3200	635.0790	2429.1900	26199.1000	253.1150
17	792.4800	1193.6400	3056.0700	15710.9000	451.4330
18	792.4800	391.6700	1798.7800	40132.1000	220.5060
19	1036.3200	853.8780	3753.4100	17346.9000	485.3600
20	1036.3200	969.5710	3347.9000	20017.8000	419.8920
170	1036.3200	1068.1500	2799.9500	58442.6000	435.4640
171	1036.3200	1019.7000	2651.2700	29415.5000	483.6860
172	1036.3200	838.6020	3394.5800	14667.3000	407.2180
173	1036.3200	1082.5900	3353.5700	33555.8000	502.8840
21	1036.3200	879.3230	3125.7700	21053.5000	298.0110
22	1036.3200	859.3150	3385.5400	15219.5000	364.9650
23	804.6720	1540.0300	4046.9400	17055.0000	276.9910
24	1036.3200	1810.5600	4894.8800	4949.4200	473.9900
25	853.4400	1628.4200	3803.4400	5657.9100	502.1580
26	694.9440	1384.3300	4204.7800	7941.4500	393.9110
27	975.3600	671.3300	3200.8600	3818.7600	239.1610
28	1011.9360	1593.9100	3021.0600	71187.5000	228.8900
29	1048.5120	640.6910	2310.4400	19504.5000	162.0860
30	1085.0880	1188.7300	2502.8400	20066.9000	234.9090
174	1085.0880	583.3190	1844.6100	5211.8800	127.3240
175	1085.0880	818.8830	2027.1500	4039.6100	150.0570
176	1085.0880	1009.3100	2115.3400	31577.2000	205.6090
177	1085.0880	800.6170	1773.9000	23174.4000	195.1810
31	1097.2800	1509.8100	4144.0700	13687.3000	261.0040
32	1097.2800	1357.8400	4201.5900	18317.3000	415.4510
33	1085.0880	1535.6000	5114.1100	8852.8000	335.0680
34	914.4000	737.0370	2565.3300	18644.5000	517.0200
35	792.4800	1194.3700	2789.2700	13464.5000	369.9360
36	1011.9360	512.2210	1755.1400	16854.1000	133.7090
37	1048.5120	645.5480	2358.3700	16309.7000	181.8590
38	1097.2800	946.5270	2167.0300	20073.7000	186.5900
39	1036.3200	912.8640	2311.5100	21070.1000	251.0890
40	987.5520	791.8150	2619.5500	16154.8000	236.4460
150	987.5520	576.2860	1710.1100	15431.8000	172.1680
151	987.5520	686.9680	2240.8800	22776.1000	220.9140
152	987.5520	705.3800	2453.3500	20108.1000	189.1440
153	987.5520	679.0190	2461.5200	21548.5000	197.3640
41	950.9760	1462.3000	2804.9300	22551.9000	357.7190
42	890.0160	851.0980	2878.4000	9606.1700	303.1610
43	1048.5120	1017.2600	2641.9700	7815.5900	217.8610

44	1109.4720	1244.5100	3080.2000	12205.1000	412.3460
45	1072.8960	765.5460	1662.2000	2967.6900	129.3170
46	1011.9360	1057.7400	3761.4300	3125.8700	203.5580
47	1011.9360	1011.5400	3572.6500	19168.9000	227.5330
48	1048.5120	680.4790	2834.4100	25290.5000	159.1710
49	1011.9360	845.5660	2993.1700	12315.9000	152.8030
50	877.8240	471.7990	1609.6900	4448.4700	113.1870
154	877.8240	1028.1300	3329.2200	6141.3000	240.1840
155	877.8240	629.9370	1932.4900	24051.8000	141.7080
156	877.8240	614.9300	1400.1400	2087.0000	109.1760
157	877.8240	747.4550	2816.4100	7728.3600	197.9740
51	999.7440	621.7490	2062.1000	1938.4000	163.4730
52	1085.0880	1540.5900	3279.1500	11387.0000	338.8240
53	1121.6640	819.2440	3624.6700	4028.7800	238.0730
54	1109.4720	1051.2200	3298.1600	14375.7000	231.9350
55	1036.3200	406.6060	2159.4500	27309.2000	472.6160
56	987.5520	993.4250	2532.2100	12698.1000	175.5400
57	920.4960	923.5090	2132.0200	15916.8000	174.7920
58	1036.3200	1274.8900	3683.0400	8509.4200	335.2510
59	1133.8560	614.6920	1541.2800	11776.2000	131.8320
60	1097.2800	694.7670	2444.3900	8615.5900	159.2610
178	1097.2800	585.5330	2008.4800	27837.1000	123.7500
179	1097.2800	609.6190	2551.2700	4573.6000	166.1060
180	1097.2800	616.0530	2337.5800	18663.9000	137.3120
181	1097.2800	667.3340	2150.4400	7581.3300	147.4590
61	1109.4720	613.5180	1919.8500	13082.1000	137.4420
62	975.3600	605.0450	1671.6500	34504.3000	140.1530
63	950.9760	607.1230	1805.1200	26021.3000	242.0560
64	1060.7040	963.4320	2932.6300	10644.8000	213.0600
65	987.5520	656.3280	2400.9000	4270.2500	194.0960
66	1011.9360	1152.9900	2694.7800	8597.1700	260.0520
67	975.3600	851.0570	2239.5500	28554.7000	217.0130
68	950.9760	805.1450	2278.5800	21698.0000	208.7180
69	1133.8560	1022.0900	2444.3900	34618.5000	327.9650
70	1024.1280	471.9070	1547.7100	2378.7200	138.6100
158	1024.1280	666.5530	1605.9500	14550.5000	164.6790
159	1024.1280	881.0670	2087.2700	44335.7000	179.7660
160	1024.1280	803.5720	1829.6100	8104.9100	239.8180
161	1024.1280	647.9940	1692.7600	40008.5000	160.8260
71	926.5920	618.8210	2150.6900	7929.1300	183.9150
72	938.7840	736.1330	2047.0100	6715.4900	198.1880
73	1085.0880	924.0760	2548.4900	4993.0600	217.8910
74	987.5520	676.1620	1900.1800	22256.7000	179.8120
75	914.4000	369.7730	1287.8300	18750.9000	139.0490
76	1036.3200	901.3420	2603.7700	10008.5000	345.2920
77	1042.4160	1114.6000	2723.5700	22328.8000	250.2100
78	963.1680	696.9930	2138.8300	48832.0000	285.8740
79	987.5520	1011.2100	2295.2900	19002.6000	347.9470
80	1036.3200	1085.3200	2624.5200	8552.6000	264.0650
162	1036.3200	456.5200	1477.0100	10264.8000	172.6190
163	1036.3200	595.4070	1622.3000	5786.1400	164.5940
164	1036.3200	880.4810	2121.5800	2376.6300	227.1340
165	1036.3200	912.1050	2234.5100	11278.6000	187.8760
81	1146.0480	764.0750	2792.1000	2299.3200	265.7710
82	1158.2400	959.2760	3165.6500	1859.7900	314.6400
83	1152.1440	845.9270	3498.3900	6944.5800	259.5230
84	1188.7200	995.9210	3250.9000	11175.7000	251.9370
85	1127.7600	757.4510	4016.4000	18251.6000	294.0580
86	1176.5280	651.8900	3083.0000	28965.4000	301.3350
87	1170.4320	540.7160	2747.6600	33534.6000	267.3980

88	1097.2800	504.4500	2452.0400	63331.5000	220.4460
89	1164.3360	563.2340	3555.0200	17329.4000	291.6130
90	1170.4320	1187.0700	3551.4500	15554.8000	312.1540
131	1170.4320	1146.5600	3043.6400	14670.0000	335.5070
132	1170.4320	1141.8300	3451.8100	13090.3000	324.5300
133	1170.4320	1053.5800	3231.3200	15230.5000	310.1390
134	1170.4320	1169.8900	3386.1200	12926.0000	295.5290
91	1127.7600	836.7290	3334.0100	17515.8000	313.2920
92	1115.5680	741.9890	3323.6400	7118.3800	261.6690
93	1103.3760	1177.7000	4050.4000	6434.4000	413.6700
94	1097.2800	1105.8800	4462.9100	7182.6000	297.6320
95	1109.4720	1500.7400	4661.7400	20539.0000	325.1700
96	1176.5280	851.3810	2955.2000	34363.3000	354.2550
97	1139.9520	1094.8000	3178.2100	21266.2000	333.7510
98	1109.4720	540.8780	1859.3700	5452.3900	170.0700
99	1115.5680	998.6110	3759.6600	30081.2000	302.6360
100	969.2640	813.9010	3297.0400	11805.8000	378.8510
135	969.2640	778.2730	3292.5900	13459.5000	332.5310
136	969.2640	930.8960	3871.4400	8363.5300	342.8120
137	969.2640	1512.6100	4045.3200	21627.8000	535.4580
138	969.2640	672.2550	3703.2900	27634.2000	492.5530
101	1109.4720	1175.7100	4169.1300	54184.6000	571.6310
102	1213.1040	960.9440	3130.3300	32840.5000	261.7580
103	1121.6640	545.9570	2116.8900	2939.9900	205.4140
104	1146.0480	488.8880	2412.6800	1817.0000	250.7700
105	1036.3200	769.6410	3830.3700	46350.5000	313.7250
106	987.5520	624.0750	2771.6900	5468.1900	411.4380
107	1146.0480	427.2160	1902.5400	40234.3000	161.1550
108	1219.2000	937.1470	2786.4000	14012.1000	277.7110
109	1024.1280	734.0860	3679.2700	40687.9000	473.4540
110	1060.7040	745.3060	3639.4700	22191.9000	333.3110
139	1060.7040	914.6930	4241.3900	20366.5000	369.6920
140	1060.7040	638.9220	4107.5600	44863.6000	531.8230
141	1060.7040	1577.1700	4507.2200	21351.7000	348.1900
142	1060.7040	1275.7700	3902.8800	13665.7000	457.2940
111	865.6320	874.0710	3995.2600	60136.3000	345.9460
112	1121.6640	767.9190	2395.0800	8386.6900	174.8020
113	1146.0480	858.6620	2715.5100	13157.4000	172.5210
114	896.1120	934.5340	3434.9600	16204.7000	382.2290
115	877.8240	900.7980	3625.0100	12229.4000	499.6750
116	1036.3200	619.9240	2115.9600	3058.6300	213.6340
117	1182.6240	726.4790	2536.0200	5331.2400	227.2560
118	1194.8160	857.8930	3186.6800	13071.1000	253.1600
119	963.1680	987.2200	3691.7500	5279.6200	448.5010
120	1133.8560	757.1380	3784.5300	12310.0000	248.1970
143	1133.8560	1018.7500	4032.6400	17531.5000	257.4650
144	1133.8560	1133.9300	4369.9200	21254.6000	303.5290
145	1133.8560	855.5000	3055.2200	38081.2000	442.2690
146	1133.8560	955.3030	4063.5200	18013.2000	436.7930
121	1207.0080	878.7600	3610.4800	16337.4000	243.7820

SiteID	Na-92	Mn-92	B-92	Ba-92	Ti-92
1	16.5620	92.5330	nd	45.6720	16.1290
2	27.1760	123.6710	nd	56.1550	21.3300
3	14.7710	143.9520	nd	85.1060	18.7640
4	13.8230	49.5270	0.0000	111.7910	18.0210
5	38.2490	70.6170	0.7610	80.1590	31.3070
6	53.2660	119.2400	nd	211.5140	76.5230
7	15.1410	193.5750	nd	177.5240	37.9670
8	18.0850	167.7000	nd	169.1710	21.0280
9	27.8130	235.9840	nd	415.0810	20.9620
10	23.6360	137.6060	nd	43.2150	19.3220
166	28.3860	94.0890	6.0740	76.5390	42.8770
167	22.0670	66.1290	3.3830	58.0840	13.1980
168	24.7460	118.1730	8.0120	60.6050	15.1520
169	18.7860	108.7370	nd	96.6870	13.7100
11	13.0120	16.4620	nd	13.5630	11.1180
12	9.7480	141.4380	nd	108.4530	9.0420
13	13.8500	100.4280	nd	216.1390	9.8670
14	11.0600	96.0320	nd	61.0870	26.0100
15	24.9600	192.6640	nd	161.7740	19.7620
16	14.2050	70.8090	nd	99.6840	18.6170
17	99.4640	90.8700	nd	49.1350	19.4080
18	15.9360	42.3760	nd	123.5990	17.0110
19	53.0930	107.8180	nd	142.8490	20.1260
20	17.2830	137.3830	nd	153.3540	13.4590
170	20.7080	445.2040	8.5350	131.9270	8.8220
171	15.1290	183.9980	7.3910	193.9010	12.4570
172	17.2100	89.8240	3.9410	126.4080	39.4210
173	17.5450	152.3640	nd	217.9410	30.7670
21	11.3450	100.7010	nd	101.4540	12.3190
22	20.5940	99.1000	nd	132.0160	23.9820
23	10.7240	205.3150	0.6720	39.9690	13.9340
24	40.6760	56.1330	nd	61.1420	33.5170
25	23.7280	185.1610	nd	191.2380	16.6980
26	32.0450	116.5540	nd	125.8540	17.9520
27	34.2110	108.9830	nd	50.0000	18.9510
28	13.5050	688.6600	nd	54.0140	8.6390
29	9.7970	152.2540	nd	50.4910	15.8300
30	8.2490	195.3200	nd	75.2000	4.8250
174	10.6760	89.1260	4.2920	46.8390	23.3420
175	14.2990	70.3950	5.3500	38.3890	22.2980
176	12.5810	209.3090	9.2190	125.7720	20.3680
177	13.7750	372.1300	9.7370	105.7080	10.6140
31	8.9960	181.5790	nd	39.1600	4.2430
32	30.5040	111.9940	nd	31.2030	22.8560
33	16.0110	106.4850	nd	30.8800	13.1860
34	34.8870	56.0900	nd	53.5620	25.2740
35	62.8660	37.4540	nd	81.8080	20.5630
36	13.1320	137.6680	nd	36.2990	12.3650
37	12.7910	188.8470	nd	19.2060	21.5900
38	20.3970	290.8230	nd	37.3290	7.8240
39	10.8490	178.8680	0.4360	289.3850	15.3550
40	9.0470	226.2420	nd	234.1430	10.5610
150	15.4930	207.9840	8.8690	272.5070	19.1500
151	18.2800	258.8270	10.5940	242.5180	17.8220
152	16.7900	248.6460	8.1670	141.1800	22.9390
153	16.4370	196.7890	7.3970	203.5680	12.9540
41	17.0860	74.8470	2.2230	27.5600	8.8420
42	12.8190	129.2220	nd	28.5390	9.0400
43	8.4350	118.8000	nd	69.2700	11.9450

44	19.7350	274.0960	nd	19.7180	9.2590
45	40.5370	128.9880	nd	23.7030	16.9200
46	18.2960	100.8510	nd	25.3720	16.8570
47	11.2390	125.5490	nd	30.6650	13.6280
48	7.9500	117.2800	nd	47.6360	9.9100
49	12.1080	103.5110	nd	39.8940	17.9390
50	9.1070	162.8130	nd	44.2310	9.3460
154	19.9900	126.7040	7.3100	48.7940	31.4350
155	14.7030	225.5190	nd	33.1630	18.9640
156	9.3340	142.6730	5.1890	88.2090	16.8650
157	13.4740	92.8160	6.3560	40.9420	17.9040
51	25.7440	178.6070	nd	25.5130	16.8660
52	16.1710	171.9470	nd	42.1990	15.3860
53	15.3660	132.7280	nd	36.9040	24.9560
54	16.4110	174.9390	nd	51.3410	16.0320
55	84.1540	110.8910	2.1020	301.9160	17.2520
56	9.2760	133.9770	nd	114.4510	8.7330
57	13.5650	250.1010	nd	196.2110	15.8390
58	48.5480	369.2030	nd	83.3170	19.1670
59	10.1590	136.4890	nd	72.1230	7.0190
60	12.3680	87.3450	nd	34.9290	6.4430
178	12.0070	127.8580	4.6830	67.1230	11.9400
179	12.4450	68.4100	6.3270	26.3760	22.0140
180	14.4410	113.7470	2.5950	51.1400	12.1040
181	12.5300	86.6140	3.3260	30.9130	21.3600
61	12.4110	125.4660	nd	133.7060	6.6910
62	17.1440	129.0640	nd	82.4130	14.6570
63	8.8960	326.0480	nd	80.7880	10.1510
64	18.7010	90.8280	nd	30.6530	22.4170
65	7.3130	151.0950	nd	38.6430	18.2530
66	18.4370	57.7270	nd	31.3470	8.7310
67	13.4910	315.8290	nd	71.7920	7.8390
68	12.2910	124.1670	nd	43.7980	14.4460
69	14.8380	114.6200	nd	63.6590	17.4500
70	9.0230	127.9460	nd	83.6310	17.3000
158	8.6460	218.2470	7.5460	112.8750	14.3460
159	13.8660	199.6610	4.7290	36.9890	12.4320
160	16.5510	219.3070	5.6030	46.3990	42.2350
161	11.3300	197.1840	5.0620	143.3690	17.7580
71	13.8780	112.1260	nd	61.0260	15.0970
72	10.8210	136.4330	nd	55.7670	20.6930
73	11.8580	214.2280	nd	29.0280	23.2060
74	13.1710	436.8630	nd	116.0260	17.1000
75	6.5360	124.5050	nd	104.4860	9.2300
76	9.6770	164.0190	nd	40.4850	15.1470
77	8.1080	113.1860	nd	92.3560	3.0040
78	11.7990	179.9640	nd	39.0410	12.7190
79	14.3980	177.4480	nd	74.0880	20.4910
80	13.6490	77.0130	nd	44.2200	10.9350
162	17.5570	104.7990	6.6950	77.0220	18.2270
163	10.5560	72.0830	4.5270	84.8470	23.7170
164	11.4890	89.2570	6.6950	54.7260	24.0280
165	12.8090	232.3000	5.3090	118.6890	21.4920
81	12.2100	193.7680	nd	14.9880	13.1170
82	13.7580	211.7300	nd	9.8220	26.9500
83	15.6470	145.8970	nd	24.4430	15.3110
84	27.0490	143.4030	nd	120.9020	16.1310
85	20.1330	144.2160	nd	63.9200	13.0860
86	20.1430	183.2460	nd	104.6750	16.3260
87	16.8150	96.4280	nd	436.6300	10.4690

88	18.5530	114.4460	nd	392.6890	12.4920
89	19.2990	104.4990	nd	59.4930	14.3880
90	21.1140	128.4140	nd	74.2720	14.0620
131	21.6920	164.5390	12.1120	90.5260	11.2760
132	25.7520	146.6370	11.1520	68.4300	21.8500
133	16.2440	145.1800	8.8340	93.0700	19.8760
134	18.1030	135.6240	9.0640	57.6230	14.2390
91	15.7420	47.4450	nd	130.6350	15.5070
92	16.4040	65.1710	nd	134.7590	18.6190
93	18.3560	336.9500	nd	74.6480	28.3920
94	12.2240	190.2830	nd	40.0810	10.2190
95	14.6660	302.4250	nd	217.9830	20.3510
96	19.2780	94.2630	nd	182.9950	20.8910
97	19.1780	172.0660	nd	61.2090	19.3070
98	11.7620	248.8810	7.7010	111.6700	25.3460
99	20.0030	184.3540	8.2020	60.8230	16.6590
100	20.1340	179.7350	6.2580	85.2720	19.7660
135	28.7150	51.8280	6.3210	237.9100	21.3130
136	14.7140	254.4280	6.2930	137.3930	23.5830
137	21.1230	318.3020	6.8100	56.8540	35.4870
138	16.3460	326.8460	6.3670	20.8360	14.7290
101	22.1180	269.9160	11.2090	30.9170	22.0560
102	17.4610	163.7120	7.8510	37.3730	22.0740
103	43.8030	126.9730	6.7120	109.0250	27.0840
104	19.3830	118.6620	6.6090	51.8330	32.0540
105	28.4310	137.6900	10.0940	166.9830	51.1390
106	19.8150	238.3060	5.3960	62.1050	35.8280
107	18.3990	236.3060	7.6730	184.9380	15.3880
108	16.7950	82.4940	10.1220	28.5030	16.8400
109	22.3910	193.3940	9.9270	141.9840	36.9140
110	17.5350	319.9320	9.8230	50.1070	16.9720
139	15.9590	332.8890	7.8510	37.0190	9.2790
140	22.4600	308.6950	7.9950	17.3280	10.5080
141	140.9620	257.7420	10.3930	64.1620	34.2620
142	13.6900	255.6680	6.0050	44.3890	12.0490
111	23.7620	204.9100	7.7010	163.9030	25.2360
112	19.7810	147.5930	8.3050	128.0440	22.7300
113	13.1100	117.7870	6.7240	90.2980	18.0140
114	20.2190	115.8140	6.6150	80.0370	29.4660
115	16.6770	60.4090	8.5640	53.3450	19.1900
116	17.6770	124.5350	7.4940	80.1140	36.3450
117	17.5400	127.7920	8.4260	87.9490	31.2360
118	19.7070	121.8930	7.5520	165.3100	52.1460
119	26.4920	196.7290	6.4360	34.0900	41.9120
120	17.6770	102.1290	5.6430	67.6510	30.0470
143	18.8770	117.6110	7.2070	75.1520	30.6340
144	21.0710	140.1520	6.5460	77.2560	25.4630
145	32.6050	223.8210	17.5690	171.8250	51.1560
146	25.5080	255.8210	16.4530	111.8020	37.4390
121	20.2810	123.2820	7.9030	109.1640	23.1980

SiteID	S-92	Pb-92	Cr-92	Cu-92	Zn-92
1	0.1300	22.2210	nd	6.6200	58.5910
2	0.1330	21.9550	nd	6.6260	52.5520
3	0.1930	17.8280	nd	5.4450	35.7570
4	0.1300	33.7860	nd	6.4770	30.1930
5	0.1200	22.8980	nd	5.4240	34.8870
6	0.1640	20.7130	1.4690	11.6930	31.7420
7	0.1220	13.3490	nd	8.8960	26.8220
8	0.1730	29.8060	nd	7.7180	30.0980
9	0.1500	11.4850	nd	6.7450	65.7840
10	0.0900	17.7910	nd	9.6930	39.9210
166	0.1450	41.1690	nd	6.8130	37.4410
167	0.1520	26.3290	nd	5.7860	28.3390
168	0.1250	25.9460	nd	5.7910	26.1730
169	0.1000	29.3570	nd	6.3740	31.3800
11	0.0820	18.0620	nd	4.4860	18.8470
12	0.1350	8.5200	nd	6.2930	39.8330
13	0.1430	8.7020	nd	5.0140	25.7730
14	0.1500	7.8060	nd	4.5070	34.5290
15	0.1240	17.2880	nd	6.8130	36.4620
16	0.1310	24.9640	nd	6.5220	26.8730
17	0.1220	12.1860	nd	4.7770	25.3130
18	0.1060	29.3120	nd	12.5230	24.0450
19	0.1560	20.2320	nd	6.9040	31.3490
20	0.1210	19.4720	nd	8.0790	41.8340
170	0.1180	16.6390	nd	5.8410	31.3090
171	0.1480	20.4320	nd	6.1030	36.1850
172	0.1460	30.4740	nd	8.1940	33.0620
173	0.0900	17.5930	nd	8.2850	31.3920
21	0.1340	23.5920	nd	3.6720	33.3710
22	0.1270	11.5300	nd	5.7730	31.1950
23	0.1120	38.5310	nd	8.9020	36.1730
24	0.1320	27.7620	nd	16.9990	41.1760
25	0.1120	11.8550	nd	10.2600	156.5810
26	0.1320	12.6020	nd	6.5920	102.7940
27	0.1800	27.7850	nd	9.4770	50.4820
28	0.1170	13.9600	nd	5.0950	28.8510
29	0.1540	20.3900	nd	6.7240	41.4220
30	0.1390	27.1800	nd	5.3100	23.9380
174	0.1370	40.4340	nd	6.5990	37.6370
175	0.1270	21.6940	nd	6.2530	20.6410
176	0.1670	36.1510	nd	6.2820	25.0200
177	0.1520	20.5700	nd	7.4770	26.6130
31	0.1800	39.1420	nd	5.3080	33.8300
32	0.1340	16.2290	nd	7.6090	108.9790
33	0.1500	11.3890	nd	6.4450	106.5130
34	0.1070	26.5240	nd	8.9000	40.1340
35	0.2040	20.9020	nd	5.2420	23.1190
36	0.1460	32.9190	nd	6.6110	32.6130
37	0.1370	44.0130	nd	5.3390	36.1200
38	0.1400	12.9530	nd	5.4540	37.4030
39	0.1550	57.8890	nd	5.9040	33.7530
40	0.1710	43.0510	nd	5.8490	38.7430
150	0.1550	58.9790	nd	6.7690	31.9730
151	0.1490	45.7780	nd	5.8610	41.3150
152	0.1640	30.1600	nd	4.6800	44.0840
153	0.1850	54.3250	nd	5.0680	40.1320
41	0.1300	21.0190	nd	4.9320	21.2070
42	0.1330	17.3400	nd	5.9890	133.8490
43	0.1930	29.4160	nd	8.4780	37.2050

44	0.1640	10.5870	nd	5.2350	30.5290
45	0.1220	12.4200	nd	5.9170	35.8860
46	0.1730	69.7900	nd	9.8500	45.9020
47	0.1120	67.5540	nd	6.8940	34.6740
48	0.1250	28.7330	nd	6.4900	35.0670
49	0.1060	38.7490	nd	5.4860	37.3140
50	0.1660	13.8820	nd	8.0130	32.9560
154	0.2000	24.9600	nd	8.6910	47.0060
155	0.1200	65.1350	nd	6.5500	34.5640
156	0.1640	18.7110	nd	10.7770	35.9740
157	0.2010	28.6210	nd	8.8500	45.1700
51	0.1340	37.7440	nd	6.6880	20.4380
52	0.1590	16.3260	nd	7.5900	23.9160
53	0.1410	47.8540	nd	6.8130	41.7210
54	0.1440	41.2640	nd	8.0470	39.4550
55	0.1380	23.6250	nd	9.5350	34.3580
56	0.1460	15.7740	nd	4.5430	43.9250
57	0.1300	31.9310	nd	8.4330	37.1380
58	0.1410	20.9730	nd	6.8450	37.3710
59	0.1350	20.6480	nd	6.6220	27.3190
60	0.1360	39.1910	nd	6.5770	32.2090
178	0.1310	26.1090	nd	6.2600	34.8890
179	0.1690	25.7510	nd	7.0980	36.9620
180	0.1370	24.6830	nd	5.5100	38.5660
181	0.1780	36.7540	nd	7.0550	40.3790
61	0.1240	13.7130	nd	4.9190	28.0260
62	0.1100	2.1310	nd	6.8280	33.8930
63	0.1340	33.1070	nd	5.6710	36.4030
64	0.1880	30.3130	nd	7.9960	41.0360
65	0.1850	27.7780	nd	5.4430	28.3200
66	0.1400	34.1080	nd	4.7680	29.7680
67	0.1600	46.5290	nd	7.9430	51.0580
68	0.1660	29.3380	nd	8.3500	46.7530
69	0.1960	43.0190	nd	6.9510	22.6540
70	0.1620	15.3970	nd	4.9170	105.9390
158	0.1280	32.5960	nd	7.1100	51.9430
159	0.1210	34.4240	nd	7.0380	26.2220
160	0.1790	40.4210	nd	10.1940	70.7950
161	0.1450	26.8940	nd	9.4910	44.4110
71	0.1190	41.1800	nd	7.1000	62.9940
72	0.1730	34.2770	nd	9.7670	28.3960
73	0.1600	36.8580	nd	7.3950	40.4490
74	0.1270	23.1240	nd	7.3520	30.3370
75	0.1270	29.1750	nd	6.0630	18.4320
76	0.1980	23.0400	nd	8.0790	39.2320
77	0.1490	27.0180	nd	3.5940	87.6970
78	0.1120	31.2680	nd	5.0720	25.6510
79	0.1620	23.8130	nd	5.3200	67.8740
80	0.1540	67.3530	nd	6.2630	29.5380
162	0.1640	27.1700	nd	6.7210	18.7180
163	0.1530	30.3730	nd	6.0260	21.7070
164	0.1710	17.9010	nd	5.3600	20.8380
165	0.2000	29.0860	nd	7.6190	36.3550
81	0.1730	17.4700	nd	7.1040	20.7930
82	0.1810	14.4220	nd	6.2040	20.3800
83	0.1540	51.6240	nd	7.1800	39.9470
84	0.1720	18.9060	nd	6.1760	32.1030
85	0.1660	27.2260	nd	4.9340	116.3070
86	0.1660	37.7610	nd	4.6020	147.6470
87	0.1530	26.4520	nd	7.3650	27.5380

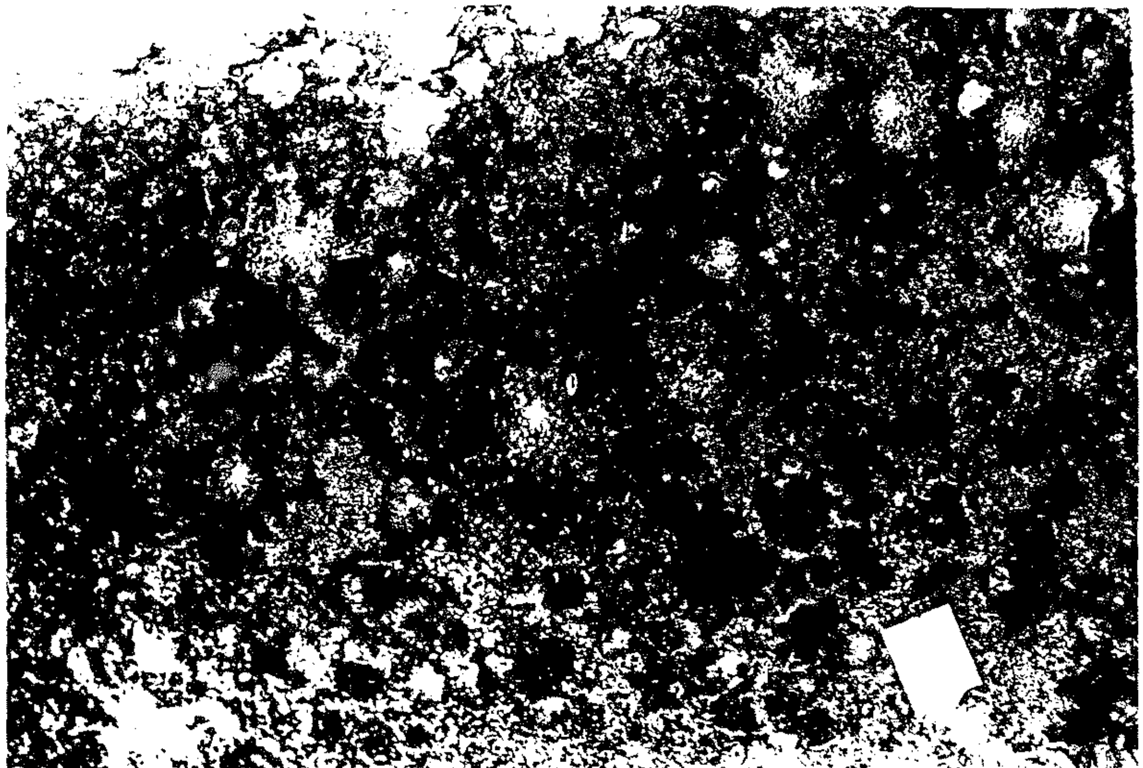
88	0.1380	20.3950	nd	5.3350	27.4530
89	0.2000	17.0930	nd	6.3250	105.0110
90	0.1550	14.7140	nd	7.3230	105.0110
131	0.2110	22.8560	nd	9.1120	75.3570
132	0.1450	20.5130	nd	9.4310	68.5800
133	0.1540	20.4760	nd	7.9730	76.7450
134	0.1700	20.3500	nd	8.2840	59.8820
91	0.1490	24.1320	nd	9.0810	88.0680
92	0.1270	22.5460	nd	6.0230	104.2390
93	0.1840	31.6000	nd	6.3650	108.5800
94	0.1660	28.3690	nd	5.3200	77.4400
95	0.1610	27.0960	nd	7.0760	35.1970
96	0.1450	32.2950	nd	6.1290	83.4620
97	0.1390	32.2070	nd	5.8660	109.1640
98	0.1490	50.7710	nd	7.7910	31.3260
99	0.1320	37.6270	nd	7.1300	36.7460
100	0.1290	16.8580	nd	5.4670	117.9010
135	0.1410	30.6240	nd	5.9710	41.9810
136	0.1810	24.7590	nd	4.9310	30.9100
137	0.1910	20.4070	nd	6.5370	45.8160
138	0.1760	16.8390	nd	7.4860	144.9270
101	0.1620	24.0620	nd	6.2900	85.4340
102	0.1680	33.4880	nd	8.1370	41.0580
103	0.1440	25.3180	nd	7.2050	22.6260
104	0.1510	35.7740	nd	7.4340	45.6400
105	0.1430	63.1300	nd	8.7350	36.0880
106	0.1080	51.2170	nd	6.7980	112.4300
107	0.1210	32.5840	nd	7.4860	35.1730
108	0.1570	28.8600	nd	7.6390	20.4080
109	0.1600	32.9600	nd	8.1820	28.7060
110	0.1510	34.5620	nd	5.2880	26.5320
139	0.1550	25.3300	nd	8.2090	143.1930
140	0.1100	17.2290	nd	7.1650	145.4170
141	0.1220	55.9330	nd	8.4310	45.3130
142	0.1780	25.6000	nd	6.0530	37.5960
111	0.1160	54.9280	nd	8.3560	57.9530
112	0.1240	30.3420	nd	5.9510	29.4680
113	0.1150	19.1690	nd	5.1580	33.1610
114	0.0941	19.2130	nd	6.5870	98.0770
115	0.1430	27.8480	nd	5.6520	28.1590
116	0.2000	25.5370	nd	8.1100	48.4070
117	0.1730	23.4210	nd	6.9180	43.8470
118	0.2000	51.4110	nd	9.0220	39.5040
119	0.1820	32.9790	nd	8.2640	45.8670
120	0.1960	55.7510	nd	6.3650	37.5770
143	0.1990	55.5940	nd	6.8310	41.2330
144	0.2070	40.5530	nd	6.9210	38.9570
145	0.1380	49.8230	nd	7.9780	35.2260
146	0.1810	52.6050	nd	8.3470	38.6600
121	0.1590	56.7560	nd	7.0980	39.6940

SiteID	Fe-92	Sr-92	Al-92	V-92	N-92
1	361.8570	10.1800	570.4870	nd	1.4960
2	387.5460	12.9190	858.0760	nd	1.8720
3	401.2630	21.1700	549.9630	nd	1.5790
4	328.1780	43.8460	475.0870	nd	1.0000
5	508.2950	22.3560	757.4580	nd	0.9000
6	1530.3400	86.6300	2463.5700	2.9840	1.2380
7	688.0110	27.1070	1053.3400	nd	1.5400
8	436.5740	22.3740	1004.4800	nd	1.6300
9	332.3540	28.6460	583.6020	nd	1.0400
10	348.4280	67.0550	513.6940	nd	0.8200
166	847.7160	35.8670	1115.2100	1.4670	1.3740
167	279.5080	32.0840	385.7860	0.2960	1.1050
168	397.0660	59.8110	554.8250	0.6980	1.1310
169	314.9520	71.6410	545.5320	nd	1.0200
11	226.6870	26.9210	313.9180	nd	0.8700
12	206.1270	42.2470	307.5510	nd	1.0160
13	248.7270	112.3780	238.0290	nd	1.0810
14	523.2470	18.0830	833.3420	nd	1.4460
15	475.0290	73.4470	774.4550	nd	1.2610
16	368.4670	36.4520	540.5340	nd	1.2930
17	418.0550	54.6600	889.8450	nd	1.3280
18	314.9320	86.1860	428.3540	nd	1.0150
19	420.2140	31.2400	926.8620	nd	1.8300
20	302.0610	59.7890	736.9310	nd	1.3970
170	270.1320	99.6050	386.4140	0.5940	0.9350
171	417.6220	75.4440	585.0130	0.4760	1.1220
172	826.4320	42.5940	1171.3600	1.2840	1.3550
173	533.8110	81.9360	823.9630	nd	1.1400
21	299.2270	39.1230	673.6900	nd	1.3770
22	500.0610	35.0220	1115.9500	nd	1.4490
23	220.2260	15.5950	309.2620	nd	1.1400
24	642.4640	13.1470	1056.8600	0.3470	1.3200
25	393.1830	17.2240	575.2270	nd	1.3050
26	415.1890	13.7460	678.6670	nd	1.4000
27	391.0520	6.2980	1040.6400	nd	1.7600
28	159.6140	20.6330	238.3620	nd	1.2070
29	306.9620	9.1830	539.5570	nd	1.5650
30	266.6560	22.2250	396.3090	nd	1.2520
174	423.8110	5.4360	527.9600	0.3070	1.1190
175	388.5480	7.5620	439.3770	nd	1.1830
176	352.7310	28.8000	453.7940	0.4220	1.2200
177	227.6450	26.2730	275.4690	nd	1.1410
31	105.8050	12.8830	261.1000	nd	1.2000
32	446.9880	14.3930	875.0530	nd	1.5000
33	235.4290	8.8620	465.6680	nd	1.3400
34	565.5340	39.5910	876.0740	nd	1.1660
35	385.6930	34.1080	637.3200	nd	1.2000
36	218.5330	8.0880	406.0580	nd	1.3220
37	366.9960	7.3550	692.9410	nd	1.3360
38	227.8330	10.6480	321.9680	nd	1.3330
39	388.4400	32.9660	587.7290	nd	1.4910
40	223.9720	22.9560	528.8480	nd	1.8390
150	351.7170	22.6110	557.5990	1.3730	1.4400
151	362.2340	29.4380	613.6580	1.5040	1.2020
152	356.7060	19.4300	482.0910	0.8820	1.4800
153	303.9200	23.2840	511.1940	0.9010	1.5610
41	277.4730	17.8710	390.0520	nd	1.3490
42	252.2010	8.7580	474.4570	nd	1.4100
43	287.8220	19.2650	567.1050	nd	1.9390

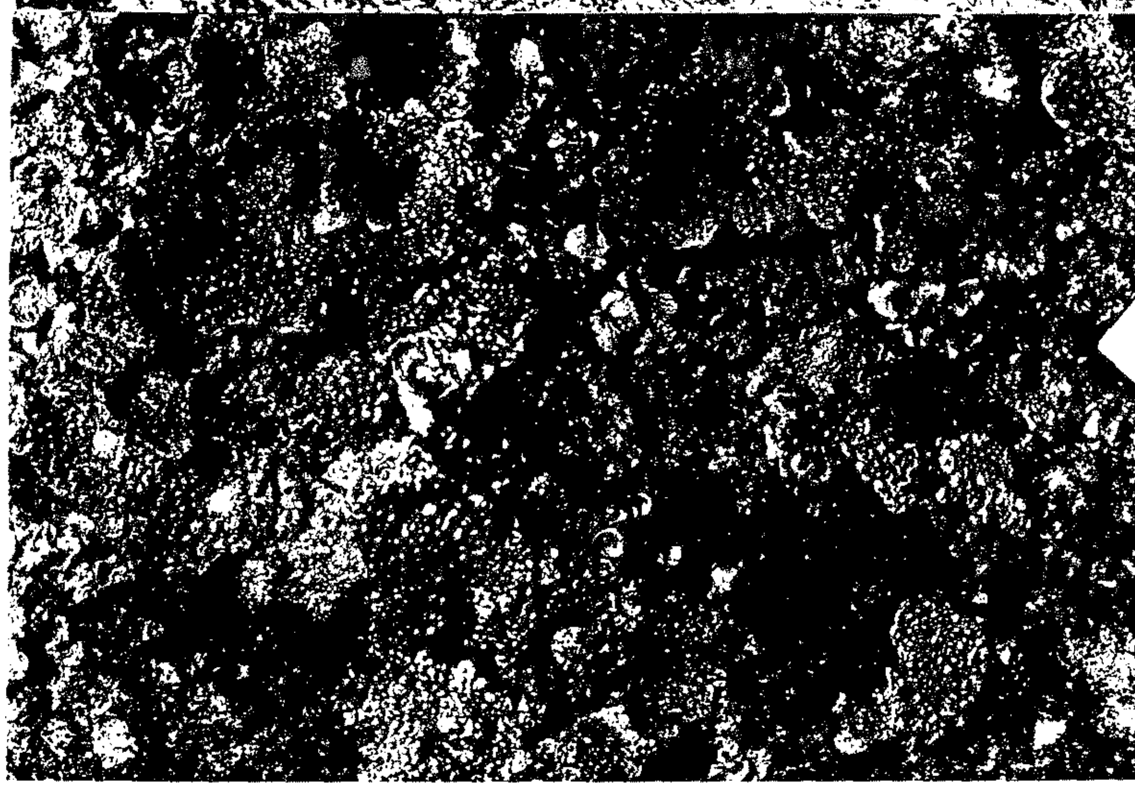
44	297.0230	12.2580	566.5700	nd	1.9460
45	316.9530	3.4400	442.4450	nd	1.2790
46	357.0680	4.9070	664.7300	nd	2.0140
47	255.5100	12.4870	389.8760	nd	1.0930
48	196.6780	13.7700	410.2240	nd	1.1350
49	335.9130	5.9180	484.2180	nd	1.1440
50	167.1850	8.6000	462.3800	nd	1.5720
154	502.5310	14.9320	650.6590	1.2740	1.5830
155	322.4070	9.4070	485.9510	nd	0.9200
156	313.7870	9.8150	450.9730	1.0810	1.2170
157	330.1080	14.9190	498.4650	1.0510	1.9730
51	299.0270	4.1890	653.8170	nd	1.3550
52	293.9520	10.7430	703.4070	nd	1.4740
53	452.0730	6.2190	788.6560	nd	1.4720
54	332.3000	10.5340	668.1450	nd	1.4390
55	292.9190	27.5140	433.9980	nd	1.1260
56	243.8440	9.7710	472.0630	nd	1.2300
57	274.8710	13.4010	773.0310	nd	1.1820
58	376.1250	16.1330	574.2720	nd	1.2330
59	207.6940	17.2930	403.0400	nd	1.2680
60	187.4030	12.2350	544.3020	nd	1.3160
178	212.7840	25.4160	349.3670	nd	1.1300
179	395.3000	8.1630	639.4550	nd	1.4800
180	212.4570	21.7510	323.1630	nd	1.1700
181	355.4430	11.5760	516.2530	nd	1.4930
61	176.8330	15.0600	375.6570	nd	1.1570
62	263.1660	26.1570	427.9030	nd	0.7800
63	201.0480	24.4130	492.2450	nd	1.2400
64	397.0150	7.0740	763.4420	nd	1.8450
65	304.3690	11.4770	501.5920	nd	1.6000
66	262.2620	24.0640	542.0840	nd	1.6130
67	203.8980	15.0000	474.1590	nd	1.4330
68	301.3610	11.8480	549.3500	nd	1.4790
69	350.7180	18.3260	541.5760	nd	1.4180
70	299.1980	11.0030	461.4310	nd	1.3570
158	288.7560	19.3770	419.0370	nd	1.2080
159	241.0760	14.4870	326.5270	0.6560	1.2490
160	730.1040	7.9200	939.8580	1.4500	1.8030
161	357.3060	20.9860	446.6870	0.7740	1.3310
71	283.2930	17.7960	557.1080	nd	1.3030
72	387.1000	9.7270	661.7120	nd	1.5900
73	383.6220	6.1180	594.3010	nd	1.5630
74	269.6410	16.2850	432.2990	nd	1.1630
75	174.9470	10.1940	483.9090	nd	1.3480
76	283.4840	19.8820	552.8150	nd	1.8740
77	212.8020	11.7520	386.4380	nd	1.1190
78	257.0680	19.9280	407.2550	nd	1.1040
79	341.8100	24.9860	462.5780	nd	1.4070
80	287.8850	9.0760	527.3250	nd	1.4610
162	344.3430	11.5210	470.9070	nd	1.3290
163	415.1700	12.0280	515.4610	nd	1.3570
164	403.5370	7.8230	460.1680	nd	1.5170
165	382.9260	12.2870	537.4230	0.2420	1.5550
81	284.7450	4.4950	579.6240	nd	1.7660
82	450.5040	3.0530	622.7540	nd	1.6010
83	335.5650	4.8400	699.6720	nd	1.5130
84	423.8860	9.7750	638.6880	nd	1.5360
85	348.5900	12.6870	460.5650	nd	1.3780
86	361.4990	21.0870	467.5270	nd	1.2730
87	197.7990	33.3350	281.7290	nd	1.1320

88	215.2870	38.3420	359.2380	nd	1.0550
89	292.1560	10.5360	573.1520	nd	1.4500
90	334.8690	12.7120	445.2760	nd	1.4640
131	358.2980	14.3650	592.9120	1.1830	1.5880
132	438.6370	12.2920	552.9200	1.2970	1.3460
133	348.5060	13.9150	455.8750	1.0860	1.3550
134	304.6500	11.5730	372.0690	0.9040	1.4060
91	357.5640	13.7120	757.1580	nd	1.2490
92	397.2420	8.9480	757.1850	nd	1.3190
93	712.6800	8.2510	991.3400	nd	1.7860
94	299.1420	4.8850	358.8620	nd	1.3220
95	330.8170	16.5150	525.6920	nd	1.5540
96	420.2020	39.3330	653.9710	nd	1.0540
97	350.4340	12.6210	400.7790	1.8060	1.2270
98	461.0710	7.9790	607.3290	2.3460	1.4600
99	312.9510	14.4960	407.1000	2.0520	1.3960
100	412.7480	10.5090	558.5220	1.3020	1.3610
135	386.1740	21.6320	486.8420	1.1450	1.2810
136	399.0890	11.0520	500.8080	1.0300	1.3650
137	627.9870	19.3510	740.7350	2.1170	1.1910
138	275.5260	16.4030	353.2670	1.4310	1.4610
101	441.3770	19.1770	498.2690	2.6890	1.2700
102	415.6500	11.1360	517.8430	2.7680	1.5460
103	462.9790	8.0700	512.8430	1.4020	1.4060
104	537.9780	4.4770	649.8150	2.0720	1.5090
105	873.9840	24.4000	1504.7300	4.4940	1.3580
106	658.2030	7.7160	816.0590	2.0890	1.3650
107	289.9300	23.2590	361.8920	2.1850	1.0990
108	391.2170	24.4680	577.7030	1.8720	1.4260
109	676.9130	24.9330	987.5650	2.9940	1.4100
110	355.0360	12.6280	548.8370	1.9500	1.5300
139	260.8540	10.2700	418.8020	1.2250	1.3970
140	227.4040	22.1520	322.2210	1.4170	1.1340
141	578.9840	11.8610	820.0120	2.2280	1.8650
142	310.4750	17.4400	436.8830	1.0060	1.9360
111	488.4740	30.7400	689.8070	3.0190	1.1750
112	399.0520	10.7080	497.8110	1.4980	1.2040
113	313.5210	10.0880	408.8220	1.0150	1.1680
114	680.9510	15.5920	861.9940	1.8730	1.2060
115	413.2220	16.8790	561.4870	1.7350	1.7980
116	645.5760	5.1850	755.8520	2.0650	1.7790
117	538.2340	5.3560	645.4430	1.7470	1.8060
118	852.2280	7.9550	1012.0500	2.8690	1.8000
119	987.0280	7.3920	1470.5300	2.5580	1.7100
120	480.9100	7.1180	626.2420	1.8050	1.7200
143	506.9180	8.5000	627.0540	2.0450	1.9360
144	434.5990	11.6950	533.0120	1.6760	1.5660
145	920.0440	24.0730	1059.5400	3.1850	1.1990
146	733.2710	15.2130	868.3420	2.9500	1.7900
121	451.8510	9.8000	699.7150	1.7250	1.7000

APPENDIX 4. Copies of 1988 and 1992 photographs (1/2X) of each permanent photoplot in the Dolly Sods (sites 101-106) and Otter Creek (sites 201-206) Wildernesses, WV.

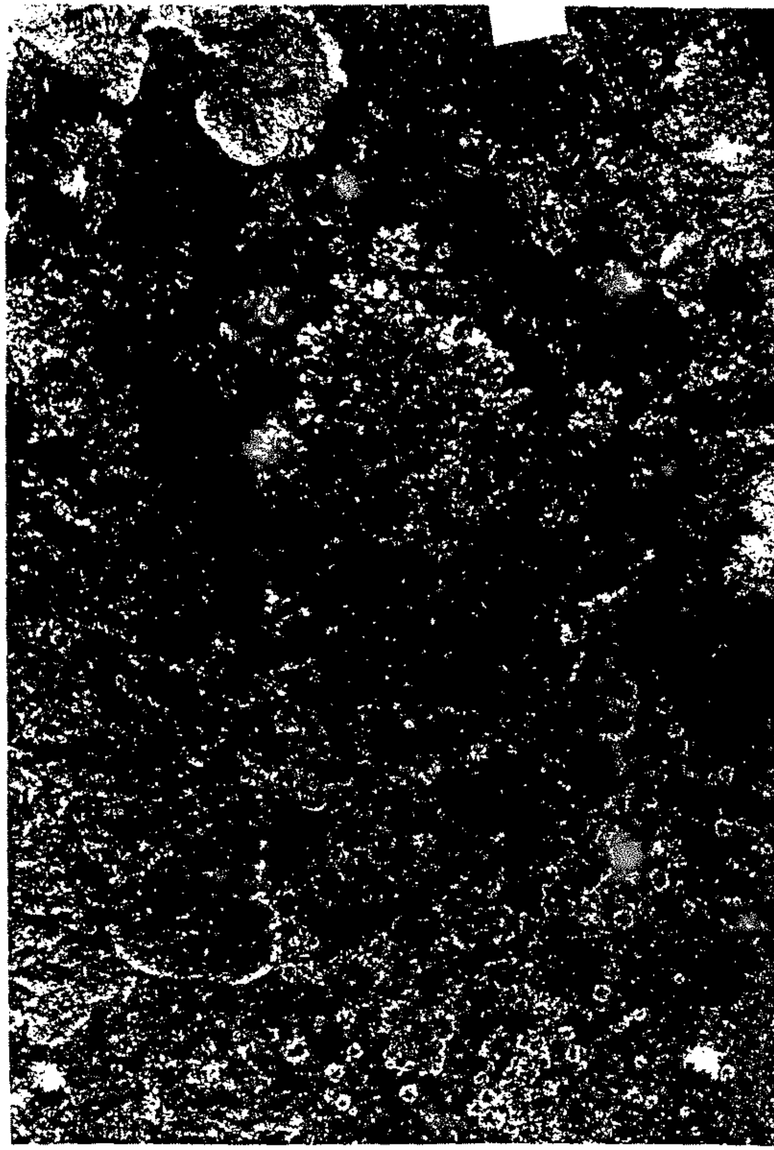


Site 101 - 1988



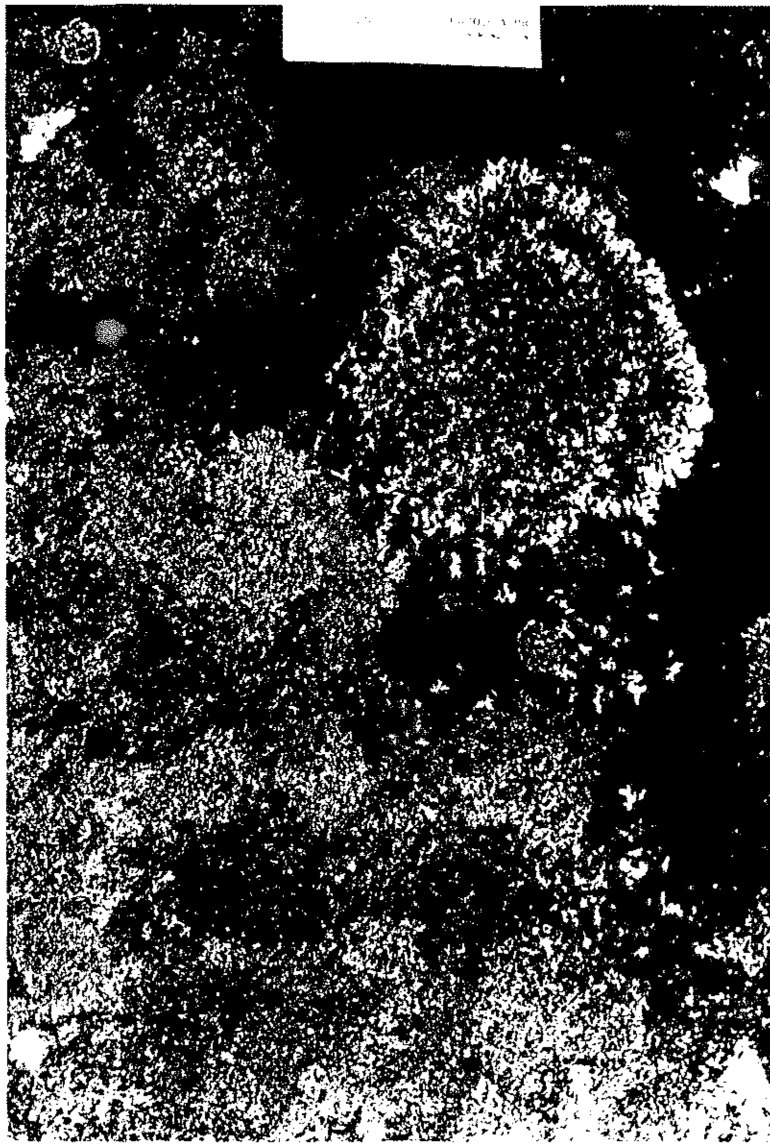
Site 101 - 1992

Site 102 - 1992

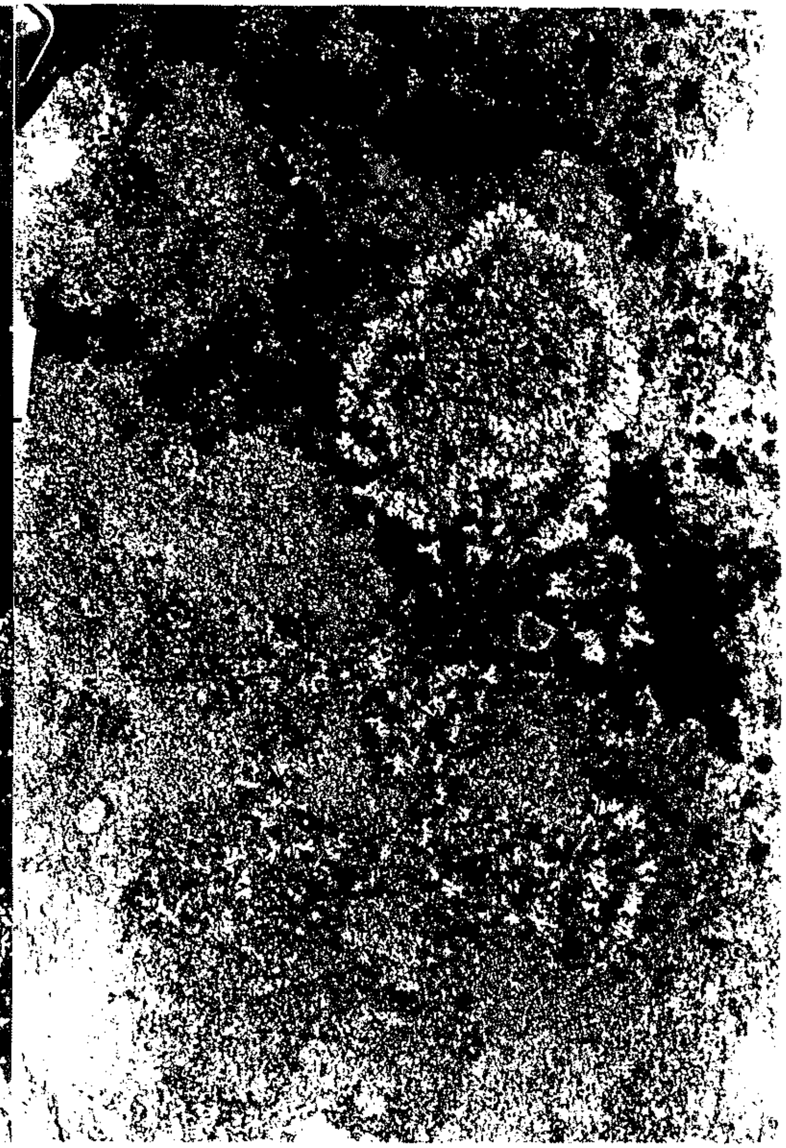


Site 102 - 1988

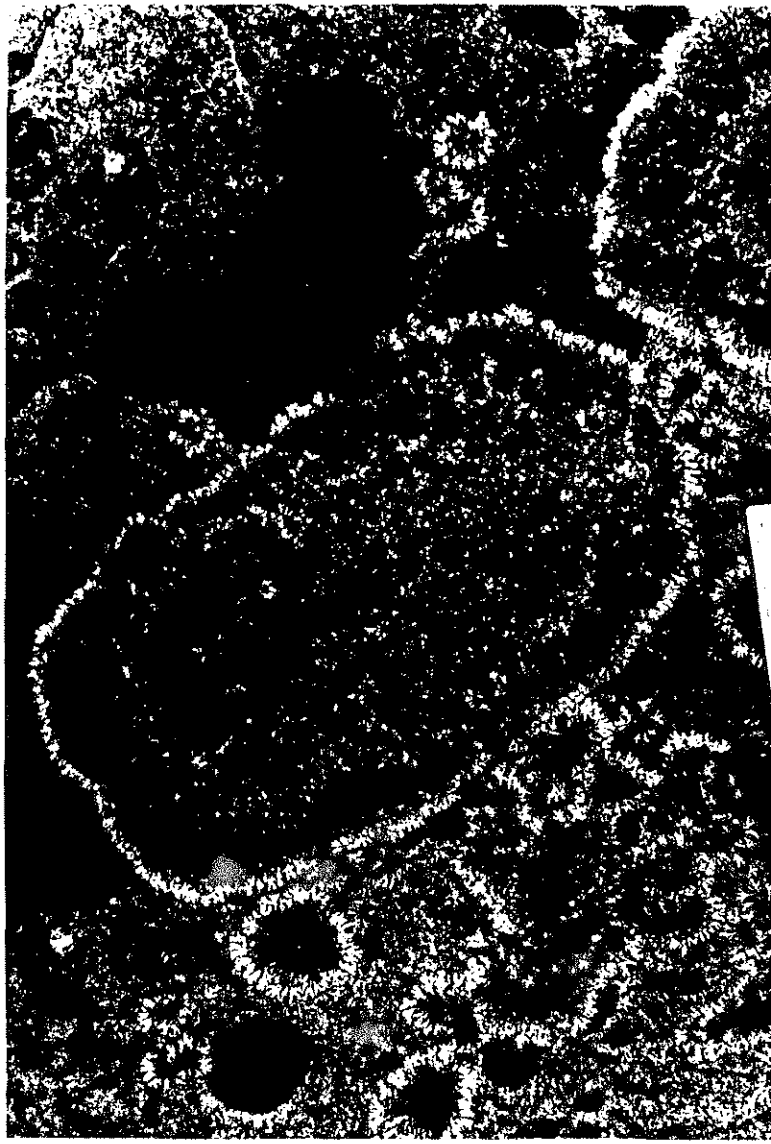
Site 103 - 1992



Site 103 - 1988

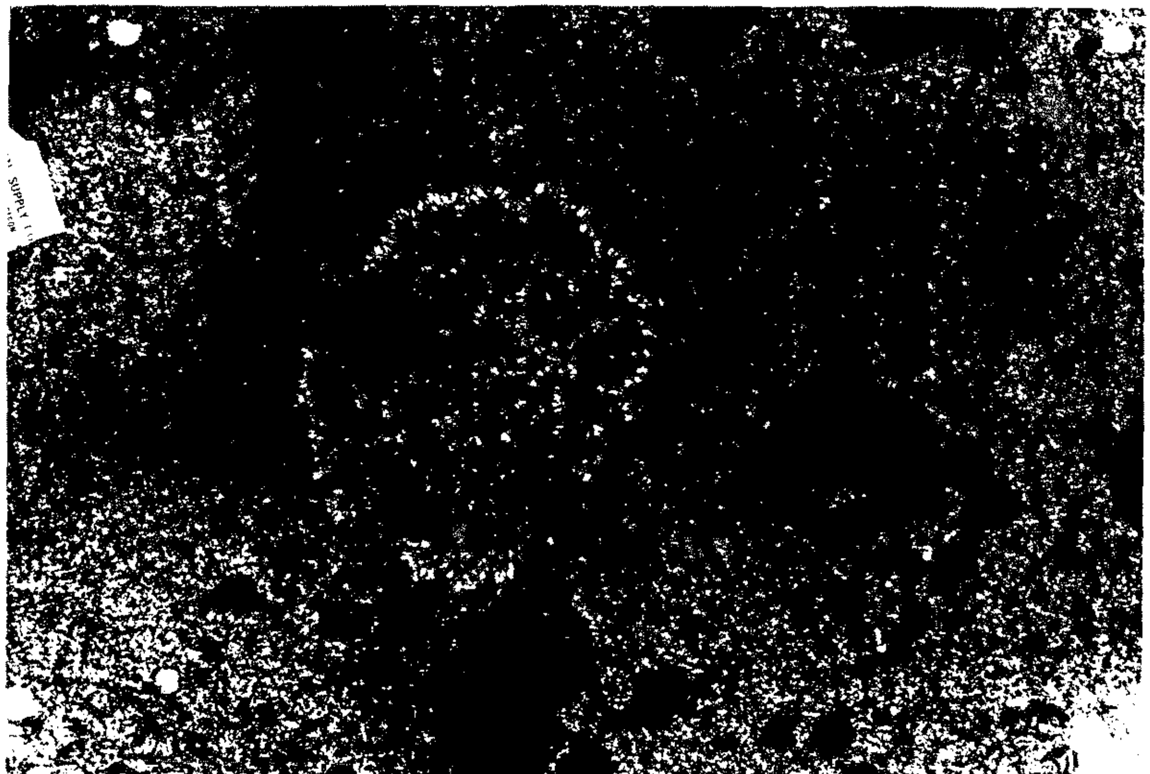


Site 104 - 1992

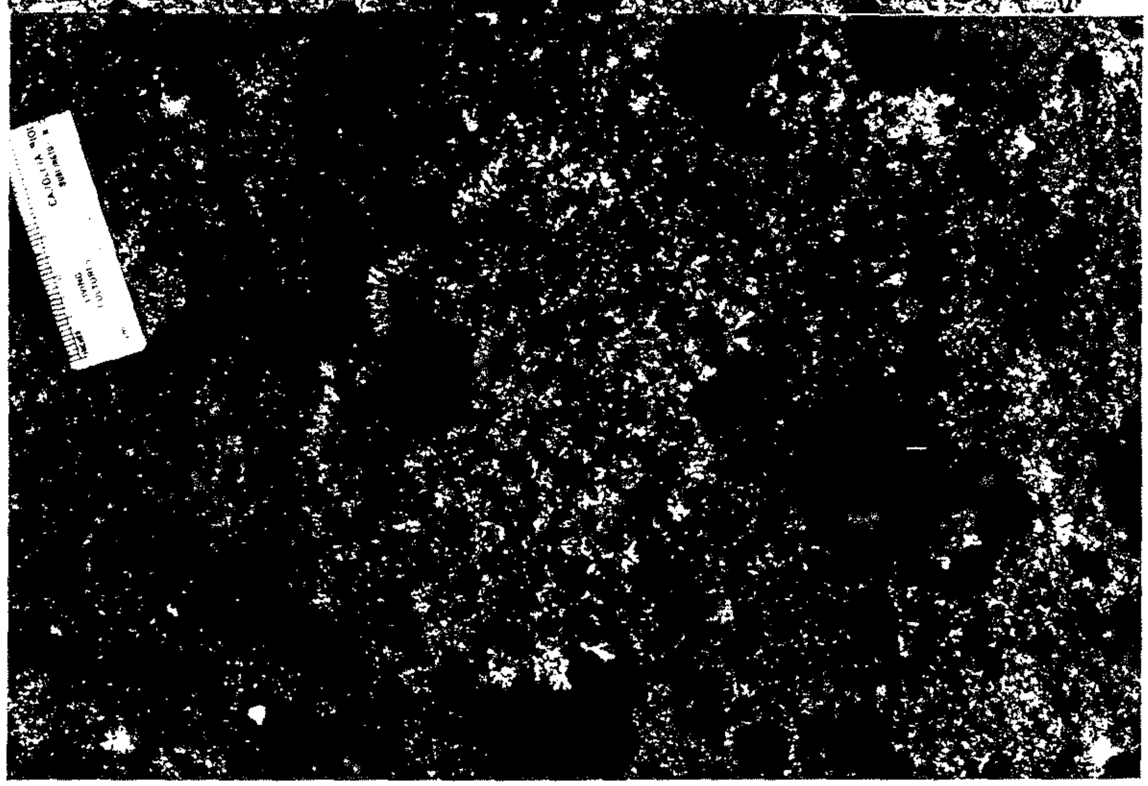


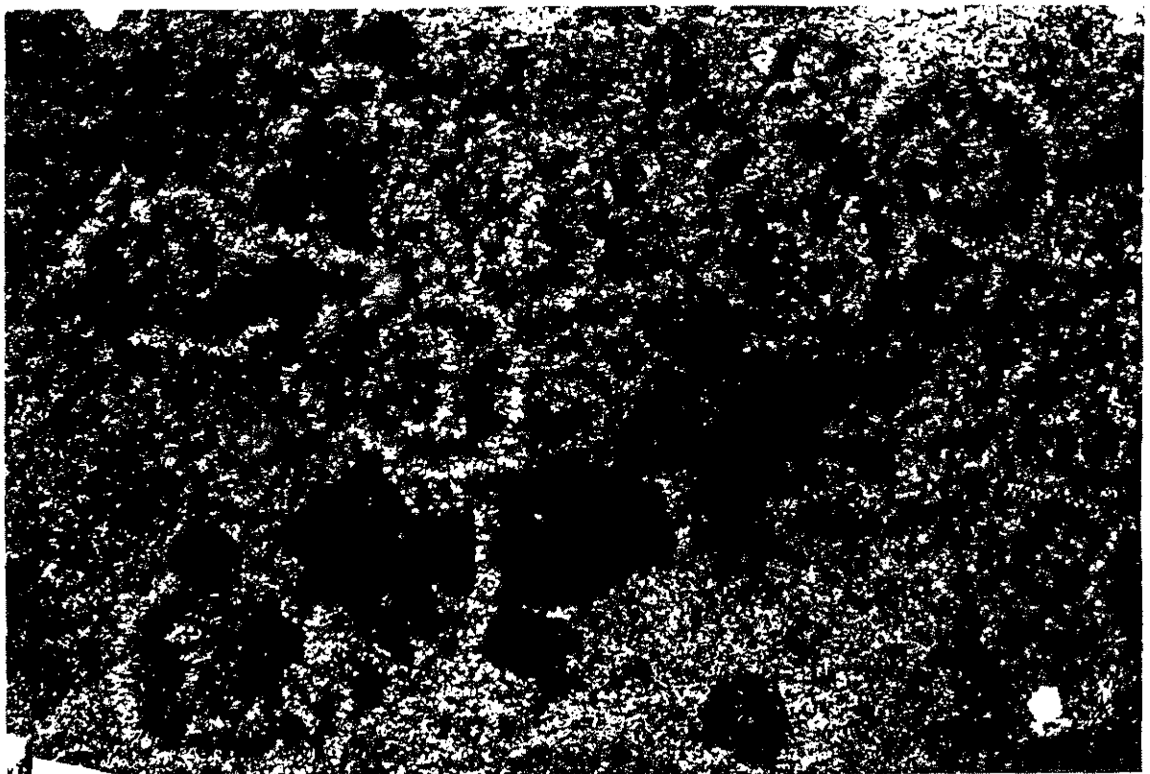
Site 104 - 1988

Site 105 - 1988

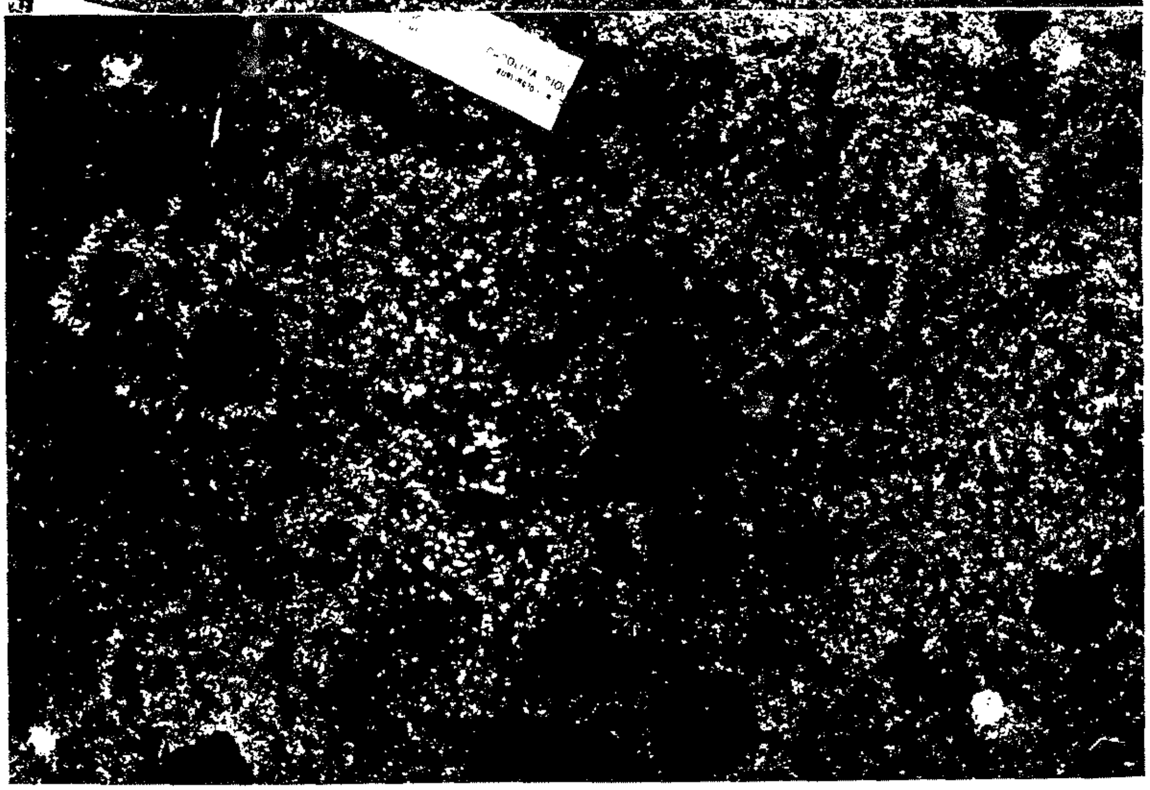


Site 105 - 1992





Site 106 - 1988

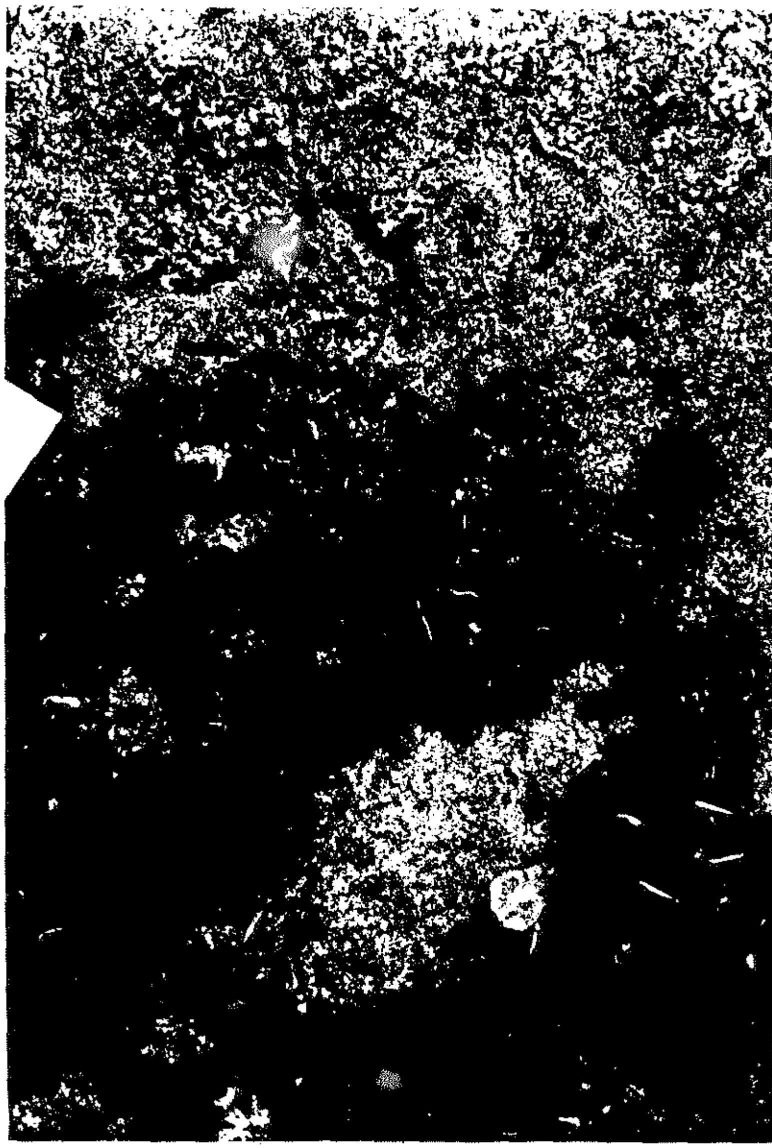


Site 106 - 1992

Site 201 - 1992

Site 201 - 1988

Site 202 - 1992

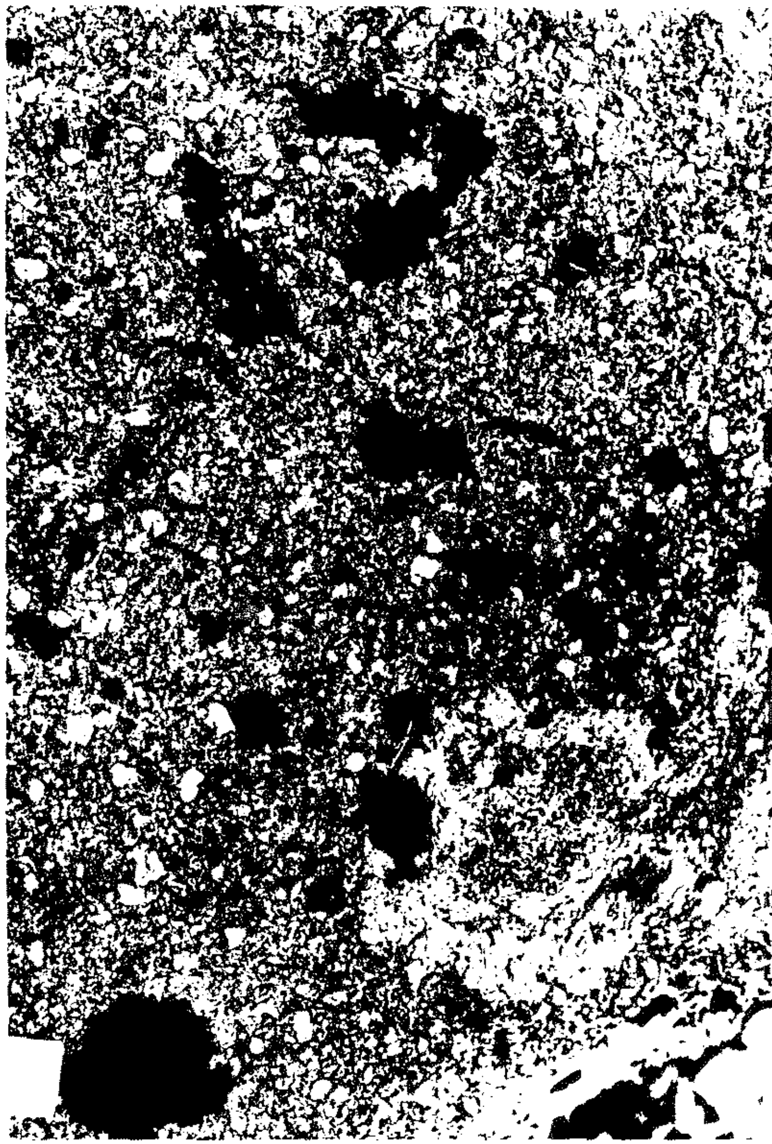


Site 202 - 1988

Site 203 - 1992

Site 203 - 1988

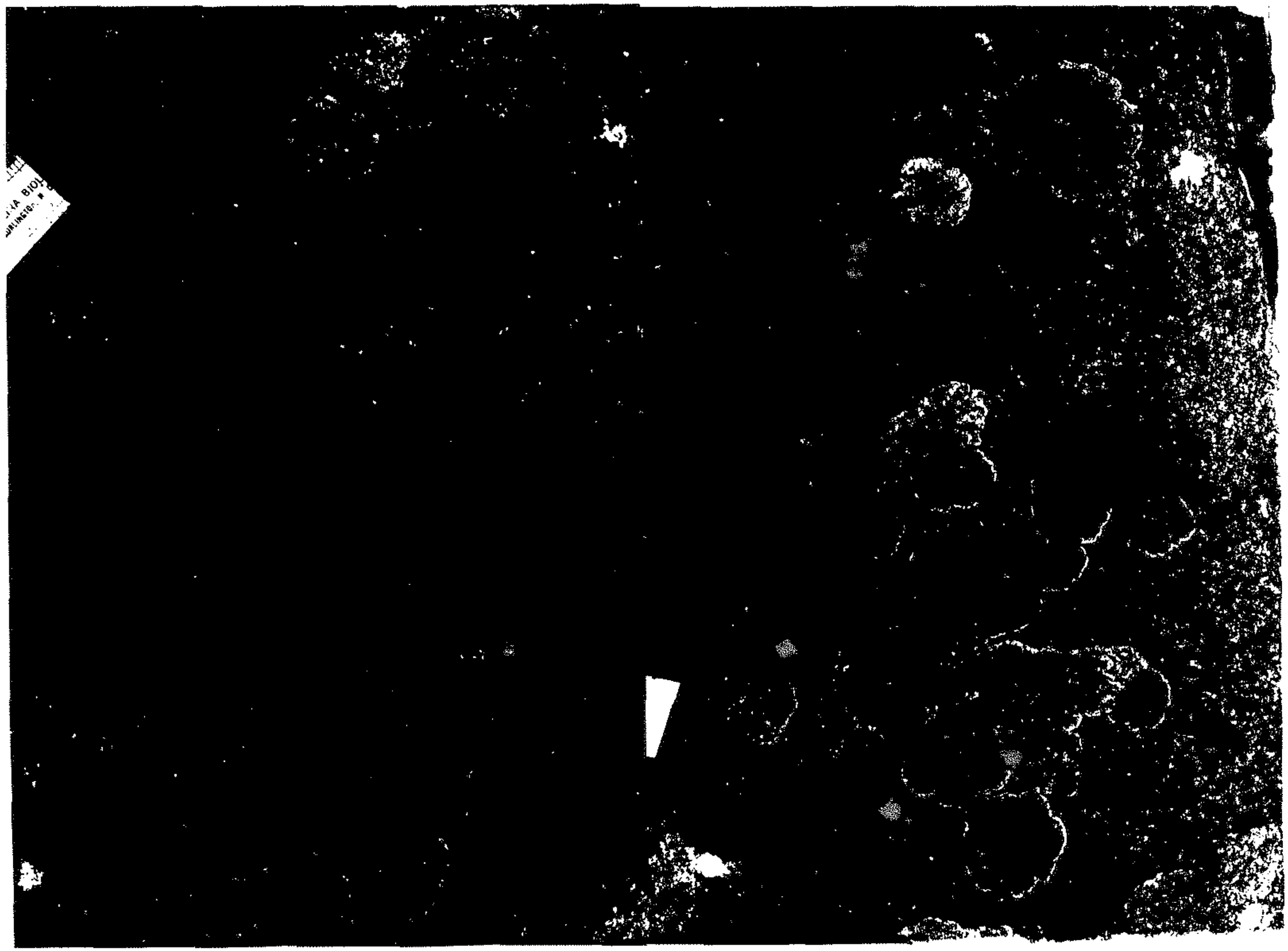
Site 204 - 1992



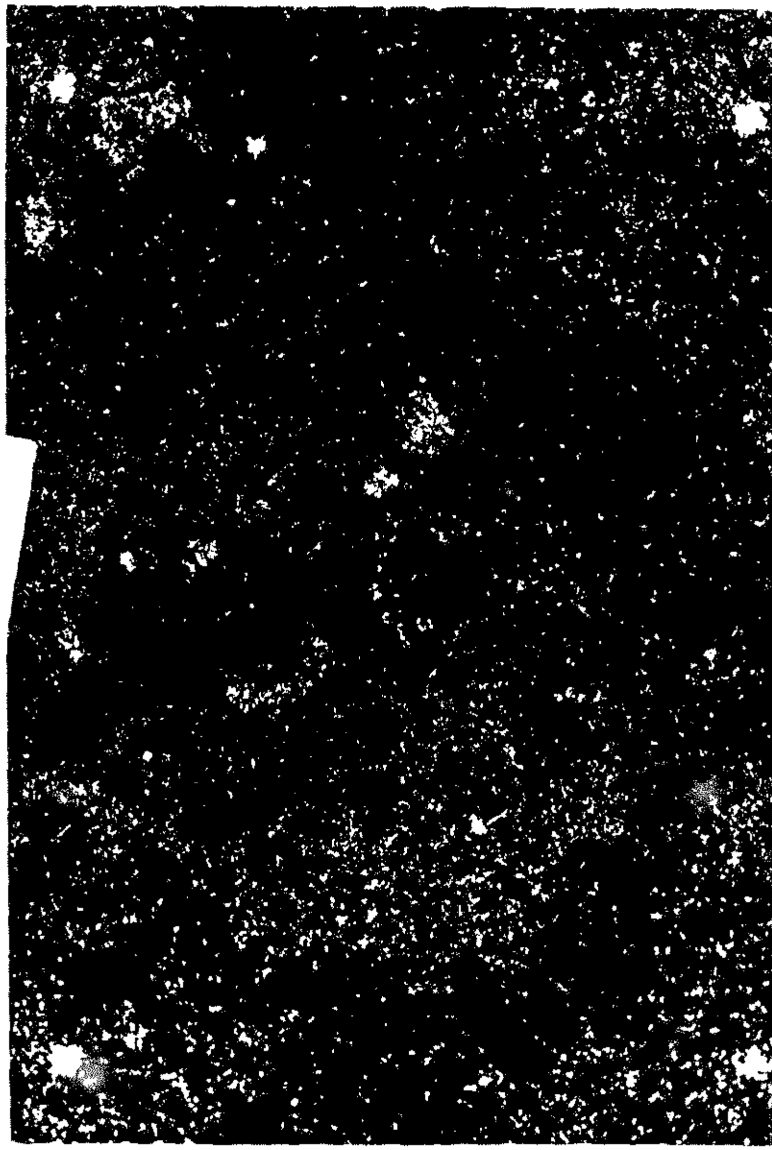
Site 204 - 1988

Site 205 - 1992

Site 205 - 1988



Site 206 - 1992



Site 206 - 1988