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Biophysical, Morphological, Canopy Optical Property, and Productivity Data From the Superior National Forest

F.G. Hall
NASA Goddard Space Flight Center
Greenbelt, Maryland

K.F. Huemmrich
Hughes STX Corporation
Lanham, Maryland

D.E. Strebel
VERSAR, Inc.
Columbia, Maryland

S.J. Goetz and J.E. Nickeson
Hughes STX Corporation
Lanham, Maryland

K.D. Woods
University of California, Santa Barbara
Santa Barbara, California

NASA

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

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Acknowledgements

This experiment was conceived in 1982 by Daniel B. Botkin, University of California Santa Barbara (UCSB), and Robert B. MacDonald, Johnson Space Center (JSC) in Houston, Texas. A group of scientists at UCSB and JSC, including the Principal Investigators and Drs. Forrest Hall, Gautam Badhwar, Jack Estes, Alan Fieveson, Mark Wilson, Keith Henderson, Jack Paris, David Pitts and David Thompson, developed and submitted a proposal entitled "Habitability of the Earth: Assessing Key Vegetation Characteristics" to NASA Headquarters, Land Processes Branch, on November 1, 1982. The objective of the proposal was "... to investigate the use of satellite remote sensing to estimate leaf area index, biomass and net primary productivity..." . The proposal was funded and two field seasons were conducted in the summers of 1983 and 1984 over a test site near Ely, Minnesota.

Dr. Kerry Woods, then at UCSB (now at Bennington College), along with Daniel Botkin, Robert MacDonald, Forrest Hall, and David Pitts, designed a detailed ground-data collection scheme and, along with Laurie Schmidt and a field crew of approximately 12, acquired the ground data throughout the summers of 1983 and 1984. A NASA Bell Jet-Ranger helicopter, piloted by Mr. Jim Adamson (now a Shuttle astronaut) and Mr. Steve Feaster of Johnson Space Center acquired spectral data over approximately 60-30 meter-diameter sites. The NASA C-130, managed by NASA Ames Research Center acquired Thematic Mapper Simulator spectral image data and color infrared photography. The U.S. Forest Service also supported the experiment by providing access, detailed maps of the area, and laboratory space and support in Ely.

As the second year of data collection was nearing completion, the satellite remote sensing program was eliminated at JSC. As a consequence, Dr. Forrest Hall moved to the Goddard Space Flight Center (GSFC) and, supported by Dr. Donald Strebel now of VERSAR Inc., transported the dataset to the GSFC. NASA Headquarters continued support for the transfer and analysis of the data.

Badhwar et al. (1986, 1986a), Pitts et al.(1988), and Shen et al. (1985) at JSC have published analysis results on the relationship of spectral data to biophysical parameters. Botkin et al. (1984), and Woods et al. (1991) have published analysis results on the biometry and ecology of the study. Hall et al. (1987, 1991) have published results on the use of satellite data to study the large-scale successional dynamics of the boreal forest.

Mr. K. Huemmrich of ST Systems Corp. organized the biophysical and leaf optical data, and wrote and edited this document. He worked with Mr. S. Goetz, and Ms. J. Nickeson of ST Systems Corp., who organized the helicopter, aircraft, and satellite data and wrote chapters 6, 7 and 8 documenting these data. Parts of chapter 3 were taken from the work of K. Woods (Woods et al. 1991). Ms. A. Montoro and Mr. E. Russell assisted by entering and formatting datasets.

Contents

1.0 Introduction

During the summers of 1983 and 1984, NASA conducted an intensive experiment in a portion of the Superior National Forest (SNF) near Ely, Minnesota. The purpose of this experiment was to investigate the ability of remote sensing to provide estimates of biophysical properties of ecosystems, such as leaf area index (LAI), biomass and net primary productivity (NPP). The SNF is mostly covered by boreal forest. Boreal forests were chosen for this experiment because of their relative taxonomic simplicity, their great extent and their potential sensitivity to climatic change. Satellite, aircraft, helicopter and ground observations were obtained for the study area. These data comprise a unique dataset for the investigation of the relationships between the radiometric and biophysical properties of vegetated canopies. This is perhaps the most complete dataset of its type ever collected over a forested region. This report contains a compilation of data collected in this experiment.

Detailed vegetation data were collected on the ground for about 100 sampled sites. These sites represent a range of stand density and age for spruce and aspen and also include jackpine and mixed stands. At each site, five circular subplots of 16 meters in diameter were sampled within a large plot of 60-meters in diameter. Within the subplots, all woody stems over 2 meters tall were tallied by species, diameter and height. Within each subplot, coverage by vegetation was determined for the canopy, subcanopy and understory. Thirty each of black spruce and aspen trees from outside of the plots were sacrificed, and dimensional analysis relations developed between diameter at breast height, biomass and leaf area index. Also, above-ground net primary productivity was estimated for each test site. For the aspen sites, bark area and understory leaf area indexes were found. During the spring, measurements of understory leaf extension and canopy coverage were made on several days to describe the phenology of an aspen stand.

Measurements of the optical properties of canopy components were made for wavelengths between 0.35 and 2.1 micrometers. Reflectance and transmittance properties of leaves and needles of eight major overstory tree species and three understory shrubs were measured. Multiple measurements of aspen and spruce allow an investigation of the variability of optical properties within a species. Also, reflectance measurements were made for the bark of several tree species, sphagnum moss and leaf litter.

Above-canopy reflectance was observed by a helicopter-mounted Barnes Modular Multiband Radiometer (MMR). The helicopter MMR data have a spatial resolution of approximately 32 meters. In 1983, 10 days of data were collected between May and October, with a total of 105 sites observed. In 1984, 8 days of data were collected between May and September, with a total of 29 sites observed. Several sites have multiple observations, to allow studies of seasonal variation.

Thematic Mapper Simulator (TMS) data were collected from the NASA C-130 flying over the SNF. The flights were in a "criss-cross" pattern to allow observation of the same location with multiple sun and view angles. The TMS scans out to 50 degrees off nadir; in flights at 5000 feet above ground level, a nadir pixel covers 3.81 meters along the scan. Three days of TMS data are presented; these data have been geometrically corrected, registered, atmospherically corrected and calibrated to determine surface reflectance.

A key goal of the experiment was to use the aircraft measurements to scale up to satellite observations for the remote sensing of biophysical parameters. Landsat and SPOT data were collected and examined. A listing of scenes that were aquired and comments on their quality are provided.

The data collected in the SNF are reported here to provide the research community with access to this valuable dataset.

2.0 Ecological Setting

The experiment took place in the Superior National Forest (SNF) in northeastern Minnesota, north of the town of Ely. The study area was centered at approximately 48 degrees North latitude and 92 degrees West longitude. The SNF is primarily boreal forest. Boreal forests were chosen for this study because of their relative taxonomic simplicity, great extent, and potential sensitivity to climatic change. Boreal forests cover approximately 9 million km^2 with eight species dominating in North America. The SNF is located near the southern edge of the North American boreal forest. This area may be particularly sensitive to climate change.

While several dozen tree species occur in the SNF, a few species dominate the landscape. Early successional stands on uplands are dominated by aspens (Populus tremuloides and P. grandidentata) or jack pines (Pinus banksiana). Jack pine, an evergreen conifer, generally dominates sites with shallow, dry soils, while the broadleaf deciduous aspens occur on mesic sites. Later in the succession, upland stands tend towards dominance by conifers: spruce (Picea mariana and P. glauca) and balsam fir (Abies balsamea). White and red pine (P. strobus and P. resinosa) are frequent and locally dominant, but constitute a small proportion of the total landscape cover. Extensive acidic peatlands often support sparse to dense stands of black spruce (P. mariana), mixed with open stands of tamarack (Larix laricina). Unforested areas occur on uplands in early succession or on rocky outcrops and in peatlands of perennially high water tables or extremely low nutrient availability.

Table 2.1 contains a list of the plant species encountered in the SNF with their scientific names and abbreviations used in this report.

Study sites were chosen in areas where the cover type was uniform. The sites in which biophysical measurements were made were, as much as possible, pure stands of aspen or spruce. The dominant species in each stand constituted over 80 percent, and usually over 95 percent, of the total tree density and basal area. Aspen stands were selected to be evenly distributed over the full range of age and stem density for stands that were essentially pure aspen, of nearly complete canopy closure, and greater than 2 meters in height. Spruce stands ranged from very sparse stands on wet, nutrient-poor bog sites to dense, closed stands on more productive peatlands. The sites were sampled to represent a variety of stand densities and leaf area indexes. Also, the sites needed to be accessible by investigators. Table 2.2 provides a list of the site locations and descriptions.

Table 2.1 - SNF Plant Species

This table contains the abbreviation, common and scientific names of plant species found in the SNF. The abbreviations are used to identify species in Tables 3.1, 3.2 and 3.3.

Abbr	Common Name	Scientific Name
ABBA	Fir, Balsam	Abies balsamea
ACRU	Maple, Red	Acer rubrum
ACSP	Maple, Mountain	Acer spicatum
ACTA	Baneberry	Actaea spp.
ALCR	Alder, Green	Alnus crispa
ALRU	Alder, Speckled	Alnus rubra
AMEL	Juneberry	Amelanchier spp.
ANGL	Bog Rosemary	Andromeda glaucophylla
ANQU	Wood Anemone	Anemone quinquefolia
ARNU	Wild Sarsaparilla	Aralia nudicaulis
ASCA	Wild Ginger	Asarum canadense
ASMA	Big-leaved Aster	Aster macrophyllus
ATFE	Lady Fern	Athyrium felix-femina
BEPA	Birch, Paper	Betula papyrifera
BLIT	Brown Litter	
BLWT	Bellwort	
CHCA	Leatherleaf	Chamaedaphne calyculata
CLBO	Blue-bead Lily	Clintonia borealis
COAM	Hazelnut, American	Corylus americana
COCA	Bunchberry	Cornus canadensis
COCO	Hazelnut, Beaked	Corylus cornuta
COGR	Gold-thread	Coptis groenlandica
COMP	Composites	(Unidentified)
COST	Red-osier Dogwood	Cornus stolonifera
DILO	Bush Honeysuckle	Diervilla lonicera
DRYO	Shield Fern	Dryopteris spp.
EQUI	Horsetail	Equisetum spp.
ERIO	Cotton Grass	Eriophorum spp.
FRVE	Wood Strawberry	Fragaria vesea
FUNG	Fungi	
GACI	Bedstraw (Wide Leaves)	Galium circaezans
GAHI	Creeping Snowberry	Gaultheria hispidula
GAPR	WinterGreen	Gaultheria procumbens
GATR	Bedstraw (Narrow Leaves)	Galium triflorum

Abbr	Common Name	Scientific Name
GLIT	Green Litter	
GORE	Rattlesnake Plantain	Goodyera repens
GRAS	Grasses (Unidentified)	
IMBI	Touch-me-not/Jewelweed	Impatiens biflora
KAPO	Bog Laurel	Kalmia polifolia
LALA	Tamarack (Larch)	Larix laricina
LAOC	Yellow Vetchling	Lathyrus ochrobucus
LAVE	Veiny (Purple) Vetch	Lathyrus venosus
LEGR	Labrador Tea	Ledum groenlandicum
LIBO	Twinflower	Linnaea borealis
LICH	Lichens	
LOCA	Honeysuckle	Lonicera canadensis
LYAN	Running Club Moss	Lycopodium annotinum
LYCL	Hairy Club Moss	Lycopodium claratum
LYCO	Ground Cedar	Lycopodium complanatum
LYOB	Ground Pine	Lycopodium obscurum
MACA	Canadian Mayflower	Maianthemum canadense
MINT	Mint (Unidentified)	
MOSS	Mosses (Non-Sphagnum)	
OSCI	Cinnamon Fern	Osmunda cinnamomea
OSCL	Interrupted Fern	Osmunda claytoniana
PEPA	Early Sweet Coltsfoot	Pestasites palmata
PIBA	Pine, Jack	Pinus banksiana
PIGL	Spruce, White	Picea glauca
PIMA	Spruce, Black	Picea mariana
PIRE	Pine, Red	Pinus resinosa
PIST	Pine, White	Pinus strobus
POBA	Balsam Poplar	Populus balsamifera
POGR	Aspen, Big-Tooth	Populus gradidentata
POPE	May-Apple (Mandrake)	Podophyllum pletatum
POPU	Solomon Seal	Polygonatum pubescens
POTR	Aspen, Trembling	Populus tremuloides
POVU	Polypody Fern	Polypodium vulgare
PRPE	Cherry, Pin	Prunus pennsylvanica
PRVE	Cherry, Choke	Prunus virginiana
PTAQ	Bracken Fern	Pteridium aquilinum
PYEL	Shinleaf	Pyrola elliptica
QUBO	Oak, Northern Red	Quercus borealis
QUPA	Oak, Pin	Quercus palustris

Abbr	Common Name	Scientific Name
RIBE	Gooseberry/Currant	Ribes spp.
ROCK	Rocks	
ROSA	Roses	Rosa spp.
RUBU	Brier	Rubus spp.
SALX	Willows	Salix spp.
SAMA	Black Snakeroot	Sanicula marilandica
SAPU	Pitcher Plant	Sarracenia purpurea
SEDG	Sedges (Unidentified)	
SMTR	Bog False Solomon Seal	Smilacina trifoliata
SOAM	Mountain Ash	Sorbus americana
SOLI	Goldenrod	Solidago spp.
SPHA	Sphagnum Moss	Sphagnum spp.
STRO	Twisted Stalk	Streptopus roseus
TRBO	Starflower	Trientalis borealis
TRCE	Noffing Trillium	Trillium cernuum
VAAN	Lowbush Blueberry	Vaccinium angustifolium
VAMA	Large Cranberry	Vaccinium macrocarpon
VAOX	Small Cranberry	Vaccinium oxycoccus
VIOL	Violet	Viola spp.
VIRE	Arrowood	Viburnum recognitum
VITR	Highbush Cranberry	Viburnum trilobum
VTCH	Vetch	

Table 2.2 - SNF Study Site Locations

This table contains the locations of the study sites in the SNF experiment. The first column is the identification number assigned to the site. The location is given in north latitude and west longitude in the form degrees, minutes, seconds. The elevation is in feet above sea level. Tree height is an estimate of the average canopy height in feet.

Site	Latitude	Longitude	Elev.	Tree Ht	Description
1	48 6 46	92 20 28	1380	80	high-density red pine
2	48 8 7	92 18 21	1360	50	dense, mature black spruce
3	48 7 55	92 15 15	1380	80	medium-density mature aspen
4	48 8 30	92 12 1	1440		medium-density red pine
5	48 6 15	92 9 9	1460		
6	48 8 4	92 15 7	1380		
8	48 6 13	92 4 4	1370	60	medium-density jack pine over black spruce
10	48 6 7	92 3 50	1370	70	mature jack pine over mixed species
12	48 4 42	91 57 36	1430	20	sparse, low black spruce
13	48 4 40	91 57 16	1480		medium-density red pine
14	48 8 10	92 18 24	1360	60	dense, mature black spruce
15	48 8 14	92 18 27	1360	60	dense, mature black spruce
16	48 7 55	92 15 3	1380	60	medium--density mature aspen
17					
18	48 4 45	91 57 36	1430	25	sparse, low black spruce
19	48 4 49	91 57 36	1430	25	sparse, low black spruce
20	48 6 18	92 2 34	1420	45	medium-density aspen, mixed
21	48 5 59	92 0 59	1440	65	medium-to high-density aspen
22	48 5 56	92 0 59	1440	50	high-density aspen
23	48 8 15	92 17 15	1360		water site, Lake Jeanette
24	48 8 15	92 8 0	1380		water site, Meander Lake
25	48 5 0	92 0 0	1410		water site, Big Lake
26	48 4 30	91 56 45	1460		water site, Ed Shave Lake
27			1370		water site
28			1390		water site
30	48 4 22	92 7 45	1420		medium-density red pine
36	47 59 33	91 54 35	1500		medium-density aspen, mixed
37	48 6 52	92 9 30	1410		medium-density aspen
38	48 7 21	92 9 54	1440	30	low-to medium-density black spruce
39	47 59 52	91 55 13	1440	20	low-to medium-density black spruce
40					
41	48 0 25	91 55 46	1400	60	high-density black spruce
42	48 0 25	91 55 42	1400	60	medium-density black spruce
43	48 1 17	91 55 8	1440	60	medium-density black spruce
45	48 0 40	91 50 18	1360	40	medium-density black spruce
46	48 0 40	91 50 13	1360	40	medium-density black spruce
47	48 1 1	91 53 2	1500	35	medium-density black spruce
48	48 1 2	91 53 29	1520	50	medium-density black spruce
49	48 1 5	91 53 26	1500	35	medium-density black spruce
50	48 0 50	91 53 45	1480	35	low-density black spruce
51	47 59 57	91 55 21	1440	25	low-density black spruce
52	48 0 0	91 55 19	1440	60	low-density black spruce
53	48 0 14	91 55 3	1450		medium-density red pine
54	48 0 19	91 55 3	1450	35	low-density black spruce
55	48 0 13	91 55 19	1450	40	medium-density black spruce

Site	Latitude	Longitude	Elev.	Tree Ht	Description
56	48 2 18	91 55 23	1430		medium-density black spruce
57	48 7 44	92 18 15	1360		high-density black spruce
58	48 7 60	92 19 18	1360	40	low-density tamarack and black spruce
59	48 7 54	92 19 14	1360	45	low-density black spruce
60	48 7 40	92 15 5	1360		low-density black spruce
61	48 7 50	92 2 38	1400		low-density, young jack pine
62	48 4 56	91 57 52	1430	35	low-density black spruce
63	48 5 3	91 57 35			low-density black spruce
64	48 5 50	91 58 26	1430	35	small growth, low-density black spruce
65	48 6 15	92 1 34	1430	35	medium-density red pine
66	48 6 18	92 1 44	1450	35	medium-density red pine
67	48 6 12	92 1 34	1430	30	medium-density red pine
68	48 6 9	92 1 20	1425	45	high-density black spruce
69	48 6 41	92 8 50	1430	20	high-density, young aspen
70	48 6 37	92 8 48		20	high-density, young aspen
71	48 6 24	92 8 53	1450	25	high-density, young aspen
72	48 10 7	92 29 59	1300	80	high-density, large aspen
73	48 10 11	92 30 5	1250	80	high-density, large aspen
74	48 10 3	92 30 15	1325	80	high-density, large aspen
75	48 9 53	92 30 21	1300	80	medium-density, large aspen
76	48 9 55	92 30 8	1250	60	medium-density aspen
77	48 9 9	92 26 17	1320	80	high-density, large aspen
78	48 9 7	92 26 24	1280	80	high-density aspen
79	47 58 23	91 46 7	1400	85	medium-density, large aspen, some birch
80	47 58 20	91 46 7	1400	80	medium-density aspen, birch
81	47 58 43	91 48 50	1400	85	high-density, large aspen
82	47 58 39	91 48 53	1410	85	high-density, large aspen
83	47 58 36	91 48 56	1410	85	high-density, large aspen
84	48 6 51	92 7 35	1500	15	high-density, small aspen
85	48 6 52	92 7 38	1510	65	medium-density, medium size aspen
86	47 59 1	91 53 7	1520	15	low-density aspen
87	48 7 42	92 7 26	1380	20	low-density aspen
88	48 6 11	92 9 9	1465	25	low-density, young aspen
89	48 7 5	92 9 19	1450	20	low-density aspen,with maple,oak,birch
90	48 9 28	92 22 10	1380	80	medium-density aspen
91	48 9 8	92 21 55	1380	80	high-density aspen
92	48 9 33	92 26 46	1260	85	high-density aspen
93	48 9 35	92 26 43	1285	90	high density aspen
94	48 0 41	91 50 45	1400	15	low-density, young aspen
95	48 0 22	91 50 52	1395	15	low-density aspen
96	47 58 15	91 46 0	1400	80	medium-density aspen
97	47 58 20	91 45 57	1410	80	medium-density aspen, open understory
98	48 0 23	91 50 59	1390	70	medium-density aspen
99	48 0 45	91 50 26	1440	20	low-density, young aspen, dense understory
100	48 0 10	91 49 60	1360		high-density black spruce
101	48 0 34	91 50 7	1380		high-density black spruce
102	48 6 9	92 1 14	1430	50	high-density black spruce
103	48 5 51	91 58 28	1450	45	low-density black spruce
104	48 5 56	91 58 28	1440	30	low-density black spruce
105	48 4 38	92 4 17	1375	50	high-density black spruce
106	48 0 54	91 53 34	1520	60	high-density jack pine and aspen mix
107	48 0 50	91 53 37	1520	60	high-density jack pine and aspen mix
108	48 0 22	91 52 58	1530	60	high-density jack pine and aspen mix

Site	Latitude	Longitude	Elev.	Tree Ht	Description
109			1520	60	high-density jack pine and aspen mix
110			1500	60	high-density jack pine and aspen mix
111	48 0 57	91 52 49	1500	60	high-density jack pine and aspen mix
112	48 0 56	91 52 35	1500	60	high-density jack pine and aspen mix
113	48 0 59	91 52 13	1440	60	high-density jack pine and aspen mix
114	48 0 59	91 52 15	1460	60	high-density jack pine and aspen mix
115	48 0 50	91 52 16	1440	60	high-density jack pine and aspen mix
116	47 44 50	91 58 12	1480	60	high-density jack pine
117	47 42 57	91 59 23	1460	60	high-density jack pine
118	47 42 58	91 59 25	1460	60	high-density jack pine
119	47 40 49	91 50 28	1530	60	high-density jack pine
120	47 40 45	91 50 24	1530	60	high-density jack pine
121	47 40 47	91 50 20	1530	60	high-density jack pine
122	47 40 49	91 50 25	1530	60	high-density jack pine
123	47 40 44	91 50 28	1540	60	high-density jack pine
124	47 39 27	91 47 41	1640	15	low-density jack pine
125	47 39 45	91 47 32	1610	15	low-density jack pine

3.0 Biophysical Data

3.1 Introduction

The purpose of the SNF study was to improve our understanding of the relationship between remotely sensed observations and important biophysical parameters in the boreal forest. A key element of the experiment was the development of methodologies to measure forest stand characteristics to determine values of importance to both remote sensing and ecology. Parameters studied were biomass, leaf area index, above-ground net primary productivity, bark area index and ground coverage by vegetation. Thirty-two quaking aspen and thirty-one black spruce sites were studied.

3.2 Site Measurements

Sites were chosen in uniform stands of aspen or spruce. The dominant species in each site constituted over 80 percent, and usually over 95 percent, of the total tree density and basal area. Aspen stands were chosen to represent the full range of age and stem density of essentially pure aspen, of nearly complete canopy closure, and of greater than 2 meters in height. Spruce stands ranged from very sparse stands on bog sites to dense, closed stands on more productive peatlands.

In each stand a uniform site 60 meters in diameter was laid out. Within this site, five circular plots, 16 meters in diameter, were positioned. One plot was at the center of the site and four were tangent to the center plot, one each in the cardinal directions. In very dense stands, plot radii were decreased so that stem count for the five plots remained around 200 stems. Use of multiple plots within each site allowed estimation of the importance of spatial variation in stand parameters.

Within each plot, all woody stems greater than 2 meters in height were recorded by species and relevant dimensions were measured. Diameter breast height (dbh) was measured directly. Height of the tree and height of the first live branch were determined by triangulation. The difference between these two heights was used as the depth of crown. The distances between trees and observer were such that no angle exceeded 65 degrees. Most plots were level, small slopes were ignored in calculating heights. Similar measurements were made for shrubs between 1 and 2 meters tall in the aspen sites. Table 3.1 has the species counts of the trees over 2 meters, and Table 3.2 has the species counts for the subcanopy trees between 1 and 2 meters tall.

For each plot, a 2-meter-diameter subplot was defined at the center of each plot. Within this subplot, the percent of ground coverage by plants under 1 meter in height was determined by species. These data, averaged for the five plots in each site, are presented in Table 3.3. Also, in each plot for the aspen sites, a visual estimation of the percent coverages of the canopy, subcanopy and understory vegetation was made. Table 3.4 contains the site averages of these coverage estimates.

3.3 Sacrificed Trees

Dimension analysis of sampled trees was used to develop equations linking the convenience measurements taken at each site and the biophysical characteristics of interest (for example, LAI or biomass). To develop these relations, 32 aspen and 31 spruce trees were sacrificed. The trees were randomly sampled, with stratification by diameter, from stands similar and near to the study sites.

Fifteen mountain maple and fifteen beaked hazelnut trees were also sampled and leaf areas were determined. These data were used to determine understory leaf area.

For each sampled tree, diameter at breast height, height to first live branch and total height were measured before and after felling. Measurements of all branches included: height of attachment on bole, diameter, length to first secondary branch and total length. Crowns were vertically stratified into three equal sections and six branches were randomly sampled from each stratum. For each sampled branch, all leaves and wood were weighted green and the current year's woody growth was measured. A sample of 200 leaves from each stratum had leaf area measured with a Licor leaf area meter and were dried and weighed. Subsamples from each sampled branch were dried and weighed.

Removal of green spruce needles from branches proved impractical, so needle-bearing parts of sampled branches were cut off, separated between current year and older classes, and dried. A sample of 21 needles each from the new and older growth were randomly selected from each canopy stratum. The sampled needles were photographed and green and dry weights were measured. Projected area was determined from the digitized photographs.

Boles were sectioned and weighed green. Four sections, 5 to 20 centimeters long were cut from: the base of the bole; halfway between the base and first live branch; just below the first live branch; and halfway between the first live branch and the tree top. Each section was measured, then dried and weighed.

3.4 Parameter Estimation from Sampled Trees

For each of the sacrificed trees, the total above-ground biomass was estimated as the sum of the branch and bole biomass. Branch biomass was estimated by finding the dry-to-green weight ratios for leaves, twigs and wood and using the ratios to convert the green-to-dry weights for the sampled branches. A regression of branch biomass on branch dimensions was done independently for each tree and used to determine biomass for the unsampled branches. Total branch biomass was the sum of the estimated biomass of the sampled and unsampled branches. Bole biomass was estimated by finding the dry-to-green weight ratios for each section, converting the green weights and summing. Total biomass is the sum of the branch and bole biomass.

Methods for estimating leaf area were parallel to those for estimating branch biomass. Leaf weights for unsampled branches were estimated using tree-specific, linear regressions on branch dimensions fit with data from sampled branches. For spruce, separate regressions were done for current-year and older needles. Measured and estimated foliage weights were summed within strata and, for spruce, age class. The foliage weights were converted to leaf areas using ratios determined from sampled leaves, then totaled for trees. The sacrificed tree statistics for aspen and spruce are in Tables 3.5 and 3.6.

Bark area in aspen was determined using similar techniques to those for leaf area. Sampled branches were divided into segments, each segment was assumed to be a cylinder and the surface area was calculated. Total branch surface area was the sum of the surface areas of the segments. A regression was developed to determine branch area for the unsampled branches. The sum of the estimated branch areas for the sampled and unsampled branches is the total bark area.

Net primary productivity was estimated from the average radial growth over 5 years measured from the segments cut from the boles and the terminal growth measured as the height increase of the tree. Allometric equations were used to find the height and radial increment as a function of crown height and diameter at breast height. Spruce used an additional parameter of stem density. The models were used to back project 5 years and determine biomass at that time. The change in biomass over that time was used to determine the productivity.

Measurements of the sacrificed trees were used to develop relationships between the biophysical parameters (biomass, leaf area index, bark area index and net primary productivity) and the measurements made at each site (diameter at breast height, tree height, crown depth and stem density). These relationships were then used to estimate biophysical characteristics for the aspen and spruce study sites as shown in Tables 3.7 and 3.8, respectively.

3.5 Stand Characteristics

Aspen is an early successional, shade intolerant species. Aspen stands are essentially even aged, and stand age appears to be the most significant difference among sites in determining stand density, average diameter, and biomass density. Biomass density was highest in stands of older, larger trees and decreased in younger stands with smaller, denser stems. Since all aspen stands had closed canopies, the inverse relationship between biomass density and stem density suggests a series of stands in various stages of self thinning. Aspen trees do not survive suppression, so that bole diameters tend to be relatively uniform and age-determined and biomass increases with age and diameter while density declines. LAI, however, remains relatively constant once a full canopy is established with aspen's shade intolerance generally preventing development of LAI greater than two to three.

Biomass density and projected LAI were much more variable for spruce than for aspen. Spruce LAI and biomass density have a tight, nearly linear relationship. Stand attributes are often determined by site characteristics. Wet, ombrotrophic sites support open, low-biomass, mixed-age stands. Spruce stands with LAI below about two and biomass densities below about 5 kg/m^2 appear to be limited by site characteristics such as nutrient poverty and wetness. Stand quality improves with site richness until canopy closure brings on self thinning. Closed canopies attain maximum LAI at around four, higher than aspen, perhaps because spruce is more shade tolerant (it is often observed growing beneath closed aspen stands in the study area). However, differences between maximum LAI for aspen and spruce also may be related to differences in the leaf distribution within the canopy.

3.6 Phenology

Deciduous vegetation undergoes dramatic changes over the seasonal cycle. The varying amount of green foliage in the canopy effects the transpiration and productivity of the forest. Measurements of changes in the canopy and subcanopy green foliage amount over the spring of 1984 have been made. From above the subcanopy, photographs of the aspen canopy were taken, pointing vertically up. The photographs were taken at two locations in sites 16 and 93 on several different days. Foliage coverage was determined by overlaying grids with 200 points onto the photos of the canopy. The number of points obscured by vegetation were counted. These counts were adjusted for the area of the branches, which had been determined by photos taken before leaf out. The number of foliage points were then scaled between zero, for no leaves, to one, for maximum coverage. These values are presented in Table 3.9.

Subcanopy leaf extension was measured for beaked hazelnut and mountain maple, the two most common understory shrubs. For selected branches on trees in sites 16 and 93, the length and width of all leaves were measured on several days. These measurements were used to calculate a total leaf area which was scaled between 0 and 1 as with the aspen. These data are in Table 3.10.

These measurements of leaf out show that the subcanopy leaf expansion lags behind that of the canopy (see Figures 3.1 and 3.2). Subcanopy leaf expansion only begins in earnest after the canopy has reached nearly full coverage.

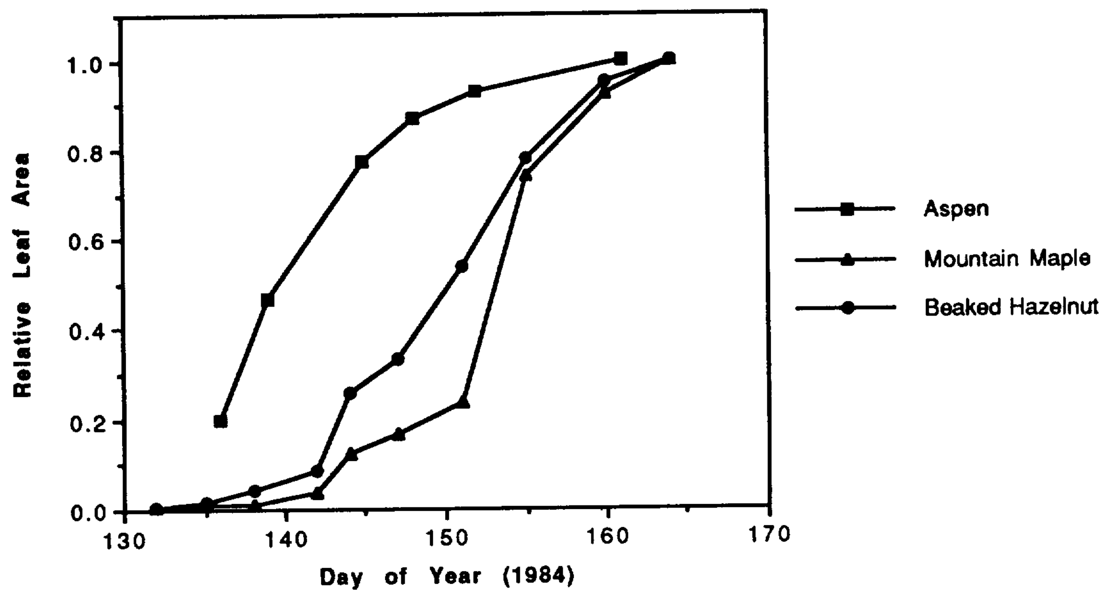

Figure 3.1 Relative canopy coverage of aspen overstory and relative leaf extension of understory trees, mountain maple and beaked hazelnut, during the spring of 1984 at site 16.

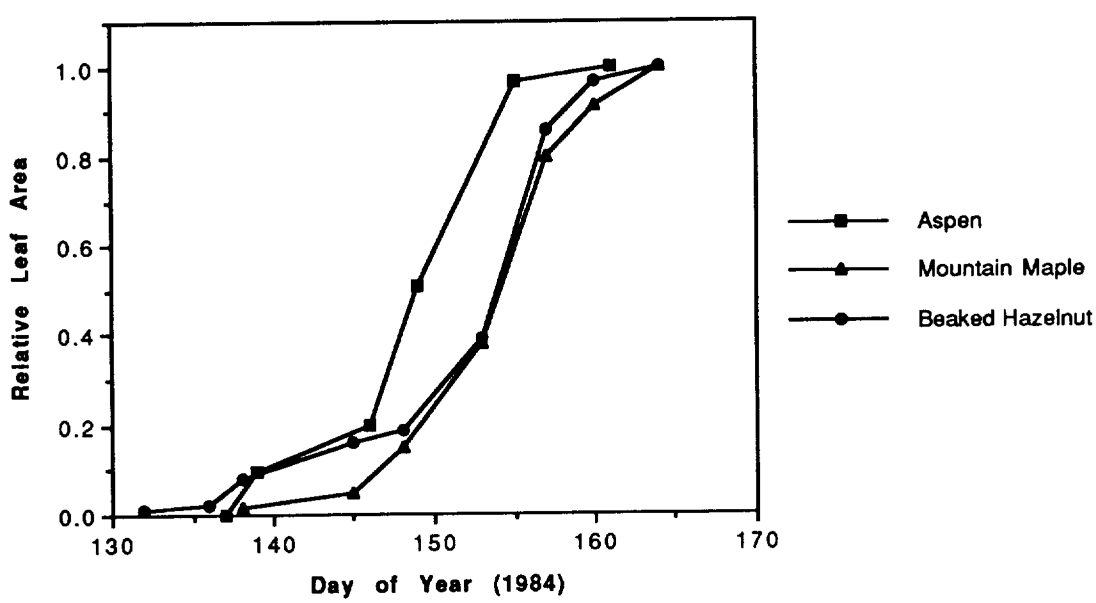

Figure 3.2 Relative canopy coverage of aspen overstory and relative leaf extension of understory trees, mountain maple and beaked hazelnut, during the spring of 1984 at site 93.

Table 3.1 - Canopy Species

This table provides a count of the number of trees over 2 meters broken down by species. The first column contains the site numbers, the other columns are the population of each species of tree at each site. The site locations are given in Table 2.2 and the species codes used for the column headings are described in Table 2.1.

Site	ABBA	ACRU	ACSP	ALCR	ALRU	AMEL	BEPA	LALA	PIBA	PIGL	PIMA	PIRE	PIST	POBA	POGR	POTR	PRPE	QUBO	SALX	Total
2	0	0	0	0	0	0	0	0	0	0	221	0	0	0	0	0	0	0	0	221
3	0	0	16	0	2	6	5	0	0	0	0	0	0	18	0	67	0	0	2	117
8	2	0	0	0	0	0	30	0	88	0	69	0	0	0	0	1	0	0	0	190
10	7	0	0	0	0	0	3	0	70	0	15	2	2	0	0	0	0	0	0	99
12	0	0	0	0	0	0	0	27	0	0	202	0	0	0	0	0	0	0	0	229
14	0	0	0	0	0	0	0	0	0	0	302	0	0	0	0	0	0	0	0	302
15	0	0	0	0	0	0	0	0	0	0	252	0	0	0	0	0	0	0	0	252
16	2	0	12	2	0	0	6	0	1	0	1	0	0	2	1	88	4	0	0	119
18	0	0	0	0	0	0	0	17	0	0	273	0	0	0	0	0	0	0	0	290
19	0	0	0	0	0	0	0	6	0	0	263	0	0	0	0	0	0	0	0	269
20	4	118	0	0	0	0	44	0	0	0	1	0	0	0	0	80	0	0	0	247
21	1	35	0	0	0	6	20	0	0	2	2	2	0	0	13	81	0	1	0	162
36	83	15	0	0	0	0	96	0	0	0	0	0	0	0	0	98	0	0	0	292
38	0	0	0	0	1	0	0	3	23	0	500	0	0	0	0	0	0	0	0	527
39	0	0	0	0	0	0	0	6	6	0	393	0	0	0	0	0	0	0	0	405
41	0	0	0	0	0	0	0	0	0	0	209	0	0	0	0	0	0	0	0	209
42	5	0	0	0	0	0	1	0	0	0	258	0	1	0	0	0	0	0	0	265
43	0	0	0	0	0	0	0	1	0	0	295	0	2	0	0	0	0	0	0	298
49	0	0	0	0	0	0	0	1	35	0	394	1	0	0	0	0	0	0	0	431
50	0	0	0	0	0	0	0	0	1	0	353	0	0	0	0	0	0	0	0	354
51	0	0	0	0	0	0	0	21	0	0	397	0	0	0	0	0	0	0	0	418
52	0	0	0	0	0	0	0	1	0	0	460	0	0	0	0	0	0	0	0	461
55	0	0	0	0	0	0	0	0	0	0	362	0	0	0	0	0	0	0	0	362
62	0	0	0	0	0	0	0	49	0	0	184	0	0	0	0	0	0	0	0	233
63	0	0	0	0	0	0	0	42	0	0	294	1	0	0	0	0	0	0	0	337
69	0	32	0	0	0	0	4	0	2	0	0	0	0	0	0	374	0	0	0	412
71	0	12	0	0	0	0	1	0	0	0	0	0	0	0	16	509	31	0	0	569
72	22	0	0	0	0	0	3	0	0	0	0	0	0	0	0	190	0	0	0	215
73	4	15	0	0	0	0	3	0	0	0	0	0	0	0	0	108	0	0	0	130
74	8	52	0	0	0	0	5	0	0	0	0	0	0	0	0	112	0	0	0	177
75	11	7	0	0	0	3	21	0	0	0	0	0	0	0	0	173	0	0	0	215
77	43	0	0	0	0	0	2	0	0	0	0	0	0	0	0	89	0	0	0	134
79	10	8	0	0	0	0	46	0	0	0	0	0	0	0	0	271	0	0	0	335
80	13	2	0	0	0	0	74	0	1	0	0	0	0	0	0	295	0	0	0	385
81	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	150	0	0	0	174
82	3	20	0	0	0	0	43	0	0	0	0	0	0	0	0	171	0	0	0	237
83	1	9	0	0	0	0	49	0	0	0	0	0	0	0	4	132	0	0	0	195
85	0	103	0	0	0	0	11	0	0	0	0	0	0	0	0	146	0	0	0	260
86	0	2	0	0	0	0	0	0	0	0	0	0	0	0	50	250	0	0	0	302
87	1	74	0	0	0	0	0	0	0	0	0	0	0	0	0	131	0	6	0	212

Site	ABBA	ACRU	ACSP	ALCR	ALRU	AMEL	BEPA	LALA	PIBA	PIGL	PIMA	PIRE	PIST	POBA	POGR	POTR	PRPE	QUBO	SALX	Total
88	5	71	0	0	0	0	19	0	0	0	0	0	0	0	0	306	0	0	0	401
89	0	79	0	0	0	0	58	0	0	0	0	1	0	0	24	154	0	3	1	320
90	3	63	0	0	0	0	40	0	1	1	0	0	0	0	0	112	0	1	0	221
92	13	8	0	0	0	0	4	0	0	1	0	0	0	0	0	103	0	0	0	129
93	10	4	0	0	0	0	5	0	0	0	0	0	0	0	0	79	0	0	0	98
94	0	3	0	0	0	0	5	0	0	0	0	0	0	0	6	445	0	0	1	460
95	0	1	0	0	0	0	29	0	0	0	0	0	0	0	0	539	0	0	7	576
96	24	31	0	0	0	0	49	0	1	0	0	0	0	0	0	119	0	0	0	224
97	23	0	0	0	0	0	57	0	0	2	3	0	0	0	0	144	0	0	0	229
98	9	0	0	0	0	0	48	0	6	3	0	0	3	0	2	209	0	0	0	280
99	0	14	0	0	0	0	28	0	0	0	0	0	0	0	19	259	0	0	0	320
117	13	0	0	0	0	0	1	0	122	0	1	0	0	0	0	0	0	0	0	137

Table 3.2 - Subcanopy Species

This table provides a count of the number of trees between 1 and 2 meters tall, broken down by species. The first column contains the site numbers, the other columns are the population of each tree at each site. The site locations are given in Table 2.2 and the species codes used for the column headings are described in Table 2.1.

Site	ABBA	ACRU	ACSP	ALRU	AMEL	BEPA	COCO	COST	LOCA	POTR	PRPE	OTHER	Total
3	0	0	6	3	3	0	13	1	0	1	0	0	27
16	0	13	45	6	0	0	88	0	0	2	0	0	154
20	0	7	1	0	0	0	62	0	0	6	0	0	76
21	0	6	0	1	2	0	32	0	0	5	0	4	50
36	5	0	0	0	0	0	0	0	0	11	0	0	16
69	0	3	0	0	0	0	35	0	0	0	9	0	47
71	0	4	0	0	2	0	9	0	0	2	14	0	31
72	0	0	6	0	2	0	31	0	13	0	0	0	52
73	1	0	33	0	0	0	42	0	0	0	0	0	76
74	0	0	18	1	0	0	35	2	0	2	0	0	58
75	1	0	51	0	4	0	61	0	0	0	0	0	117
77	0	0	44	0	0	0	37	0	1	0	0	0	82
79	0	10	46	0	5	0	5	0	0	29	0	0	95
80	0	0	1	0	0	0	37	1	0	28	0	0	67
81	0	0	59	0	7	0	32	30	0	20	0	0	148
82	0	2	45	0	0	0	2	1	0	21	0	0	71
83	0	0	54	0	2	0	45	0	0	21	0	0	122
84	0	7	9	0	0	0	24	0	0	36	0	0	76
85	0	1	11	0	0	3	58	4	0	4	0	0	81
86	0	2	20	12	0	0	39	0	0	32	0	2	107
87	0	0	6	0	0	0	188	0	0	0	0	0	194
88	0	9	7	0	0	3	14	0	0	1	0	0	34
89	0	4	12	0	0	4	31	0	0	2	0	0	53
90	1	6	1	6	0	0	142	0	0	3	0	4	163
92	1	1	3	0	5	0	143	0	0	2	0	4	159
93	2	1	23	0	8	0	143	0	0	0	0	0	177
94	0	4	0	0	0	0	200	0	0	85	2	0	291
95	0	0	0	8	0	3	24	0	0	43	0	0	78
96	0	2	0	0	0	0	3	0	0	3	0	0	8
97	0	0	0	0	0	0	3	0	0	0	0	2	5
98	4	0	0	0	6	1	25	0	0	5	0	1	42
99	0	0	0	57	0	1	305	0	0	34	1	2	400

Table 3.3 - Understory Composition

This table provides a measurement of the percent ground coverage provided by each species. The percentages are the average of five 2-meter-diameter subsamples in each site. Each column is a study site with a row for each species. Species codes are described in Table 2.1, site locations are listed in Table 2.2.

	2	3	12	14	15	16	18	19	20	21	36	38	39	41	42	43	45	47
ABBA	0	0	0	0	0	0	0	0	3	2	6	0	0	0	1	0	0	0
ACRU	0	2	0	0	0	10	0	0	1	5	6	0	0	0	0	0	0	0
ACSP	0	2	0	0	0	17	0	0	1	1	0	0	0	0	0	0	0	0
ALRU	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
AMEL	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
ANGL	0	0	4	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0
ANQU	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
ARNU	0	7	0	0	0	2	0	0	0	10	0	0	0	0	0	0	0	0
ASMA	0	18	0	0	0	14	0	0	8	26	38	0	0	0	0	0	0	0
ASCA	0	3	0	0	0	6	0	0	0	1	0	0	0	0	0	0	0	0
ATFE	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BEPA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BLIT	14	6	1	14	7	14	7	5	5	16	25	10	3	17	14	13	25	8
CHCA	5	0	9	1	8	0	12	28	0	0	0	12	0	0	1	3	4	8
CLBO	0	1	0	0	0	3	0	0	3	2	6	2	0	0	0	0	0	0
COCA	0	0	0	0	0	0	0	0	10	6	7	0	1	0	4	0	0	0
COCO	0	1	0	0	0	6	0	0	8	5	3	0	0	0	0	0	0	0
COGR	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0
COMP	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COST	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DILO	0	3	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0
EQUI	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
ERIO	0	0	3	0	0	0	11	10	0	0	0	0	0	0	0	0	0	0
FRVE	0	5	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
FUNG	1	1	4	0	4	1	1	0	0	0	0	1	0	0	0	0	0	3
GACI	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
GAHI	28	0	2	7	13	0	0	0	0	0	0	2	4	6	8	5	3	4
GAPR	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
GATR	0	4	0	0	0	2	0	0	0	0	3	0	0	0	0	0	0	0
GLIT	2	1	0	0	0	2	0	0	0	0	0	3	1	3	8	2	5	3
GRAS	5	5	12	2	4	2	4	1	4	1	5	8	5	3	0	0	0	1
IMBI	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
KAPO	0	0	3	1	0	0	2	5	0	0	0	1	1	0	0	0	1	1
LALA	0	0	0	0	0	0	2	3	0	0	0	0	0	0	0	0	0	0
LAOC	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
LEGR	33	0	5	14	27	0	6	6	0	0	0	24	24	6	15	28	7	9
LIBO	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0
LICH	0	0	0	0	0	0	2	3	0	0	0	0	0	0	2	2	3	2
LOCA	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
LYAN	0	0	0	0	0	0	0	0	0	0	1	6	5	0	0	0	0	8
LYCL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LYCO	0	0	0	0	0	0	0	0	0	1	11	0	0	0	0	0	0	0
LYOB	0	0	0	0	0	1	0	0	6	11	0	0	1	1	1	0	0	0
MACA	0	2	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0
MINT	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MOSS	3	2	0	72	30	3	3	0	14	5	3	10	34	4	36	34	8	5
OSCI	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0
OSCL	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
PEPA	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Table 3.3 cont. - Sites 2 through 47

	2	3	12	14	15	16	18	19	20	21	36	38	39	41	42	43	45	47
PIMA	1	0	3	2	3	0	13	15	0	0	0	2	6	1	4	2	0	2
PIST	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
POTR	0	1	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0
POPU	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
PTAQ	0	2	0	0	0	1	0	0	14	18	6	0	0	0	0	0	0	0
RIBE	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
ROSA	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
ROCK	0	0	0	0	0	0	0	0	17	2	10	0	0	0	0	0	0	0
RUBU	0	6	0	0	0	1	0	0	0	3	1	0	0	0	0	0	0	0
SALX	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
SAMA	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
SAPU	0	1	3	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0
SEDG	0	0	1	0	0	0	0	0	6	0	3	0	0	0	5	0	10	32
SMTR	14	0	14	13	12	0	0	0	0	0	0	6	9	5	6	6	4	20
SOLI	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
SPHA	68	0	60	16	68	0	62	62	0	0	0	82	60	72	34	32	55	64
STRO	0	1	0	0	0	4	0	0	0	0	3	0	0	0	0	0	0	0
TRBO	0	2	0	0	0	1	0	0	1	4	4	0	0	0	1	0	0	0
TRCE	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
VAAN	4	0	0	5	5	0	0	0	3	10	0	4	5	5	9	5	5	5
VAMA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
VAOX	6	0	4	1	3	0	5	5	0	0	0	1	4	0	2	1	2	5
VIOL	0	0	0	0	0	1	0	0	0	0	3	0	0	0	0	0	0	0
VIRE	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VITR	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	48	49	50	51	52	54	55	56	57	62	63	64	68	69	71	72	73	74
ABBA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1
ACRU	0	0	1	0	0	0	0	0	0	0	0	0	0	1	2	2	4	2
ACSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	4
ACTA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0
ALRU	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AMEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
ANGL	0	0	0	1	1	0	0	2	0	0	2	5	0	0	0	0	0	0
ANQU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
ARNU	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	5	6	7
ASMA	0	0	0	0	0	0	0	0	0	0	0	0	0	11	16	14	21	4
ASCA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
ATFE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
BEPA	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
BLIT	12	5	18	3	3	16	30	13	5	1	8	0	8	15	20	32	34	24
CHCA	0	0	0	17	9	10	2	5	20	20	12	24	5	0	0	0	0	0
CLBO	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5	3	2	2
COCA	0	1	2	0	0	0	0	0	0	0	0	0	0	17	5	4	3	4
COCO	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2	2	5
COGR	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
COMP	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	2	1
COST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
DILO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	1	2
EQUI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	1
ERIO	0	0	0	8	0	0	0	0	0	0	24	0	0	0	0	0	0	0
FRVE	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	4	1
FUNG	3	0	0	0	1	0	0	4	3	0	0	0	2	0	0	0	0	0
GAHI	1	2	3	0	4	3	6	3	4	0	0	0	5	1	0	0	0	0

Table 3.3 cont. - Sites 48 through 74

	48	49	50	51	52	54	55	56	57	62	63	64	68	69	71	72	73	74
GAPR	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
GATR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	4	1
GLIT	4	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0
GRAS	10	5	2	1	17	5	0	0	0	17	6	0	1	2	2	1	4	5
KAPO	0	0	0	5	0	0	0	2	2	1	8	4	2	0	0	0	0	0
LALA	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LEGR	6	1	11	34	36	22	4	34	17	7	12	6	4	0	0	0	0	0
LICH	1	1	0	0	1	0	1	2	0	0	1	1	0	0	1	0	0	0
LOCA	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	2	1	0
LYCL	0	7	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
LYCO	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LYOB	7	0	0	0	0	0	0	0	0	0	0	0	0	3	2	5	4	3
MAAP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	4
MACA	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	4	4	3
MOSS	13	6	38	2	5	0	18	6	4	12	1	6	9	5	5	4	5	2
OSCI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
OSCL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	5
PIBA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
PIMA	1	0	0	6	1	1	4	6	3	4	8	7	1	0	0	0	0	0
PIST	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
POTR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
POPU	0	0	0	0	4	5	0	0	0	0	0	0	0	0	0	0	0	0
PRPE	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
PRVE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
PTAQ	0	0	0	0	0	1	0	0	0	0	0	0	0	2	4	0	1	3
QUBO	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
RIBE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
ROSA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
ROCK	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0
RUBU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	2	4
SAPU	0	0	0	0	0	0	0	2	2	3	1	7	0	0	0	0	0	1
SEDG	2	14	6	0	1	0	2	5	14	6	0	34	10	0	2	0	0	0
SMTR	10	5	4	2	0	7	6	2	0	0	0	0	1	0	0	0	0	0
SPHA	64	48	38	74	86	62	38	68	72	66	56	56	62	1	1	0	0	0
STRO	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	5	4	4
TRBO	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	5	4	4
VAAN	0	2	0	0	0	4	5	2	0	0	0	0	0	7	3	0	1	1
VAMA	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
VAOX	0	1	1	3	2	2	2	4	4	4	3	4	5	0	0	0	0	0
VIOL	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	3	3

	75	77	79	80	81	82	83	84	85	86	87	88	89	90	92	93	94	95
ABBA	3	1	3	0	2	0	1	0	0	0	0	0	0	1	1	1	0	0
ACRU	5	2	3	2	3	1	4	5	4	0	0	2	1	5	1	2	1	0
ACSP	7	4	9	2	8	12	3	1	2	0	0	1	1	0	2	4	0	0
ACTA	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
AMEL	1	0	2	0	2	0	0	0	0	0	0	0	0	0	1	1	0	0
ANQU	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
ARNU	4	4	14	7	6	8	6	8	0	0	0	4	0	0	5	3	6	2
ASMA	14	2	14	18	31	48	22	23	30	10	7	12	3	13	10	12	36	26
ASCA	0	0	2	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0
ATFE	1	5	2	10	0	0	0	0	0	0	0	1	0	0	0	6	0	0
BEPA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
BLIT	20	46	14	6	32	18	24	22	24	22	30	42	24	24	32	26	10	16

Table 3.3 cont. - Sites 75 through 95

	75	77	79	80	81	82	83	84	85	86	87	88	89	90	92	93	94	95
CLBO	2	5	3	1	0	1	0	0	1	0	2	4	4	2	6	4	1	0
COCA	4	4	8	0	0	2	0	1	2	6	0	4	8	4	4	3	4	3
COCO	2	0	1	1	0	0	2	1	0	2	3	3	1	3	7	6	5	9
COGR	2	3	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
COMP	1	0	3	5	1	0	0	1	1	0	0	1	0	0	0	2	4	1
COST	0	0	2	4	3	0	0	0	0	0	0	0	0	0	0	0	0	1
DILO	2	0	8	3	2	3	3	0	1	1	1	1	2	0	1	1	1	1
DRYO	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EQUI	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRVE	4	0	5	5	1	3	1	0	0	0	0	0	0	1	0	0	1	2
FUNG	0	0	0	1	0	0	0	1	1	1	3	3	1	2	0	1	0	0
GACI	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GAPR	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
GATR	2	2	4	4	3	4	4	0	0	0	0	0	0	0	0	4	1	2
GLIT	0	6	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GRAS	6	2	3	5	4	5	5	1	4	5	3	2	1	5	5	4	4	7
IMBI	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAOC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
LAVE	0	0	0	0	1	6	2	0	0	0	0	0	0	0	0	0	0	0
LEGR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
LIBO	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0
LICH	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
LOCA	0	1	4	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
LYAN	0	5	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0
LYCL	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
LYOB	0	2	2	0	0	0	0	3	4	4	3	6	6	6	8	6	5	0
MAAP	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
MACA	5	3	3	2	4	3	3	2	0	0	0	2	0	0	4	4	0	1
MINT	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
MOSS	6	7	7	2	5	6	6	4	11	4	5	4	17	6	3	1	0	2
OSCI	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OSCL	1	1	1	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0
PEPA	0	0	1	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0
PIBA	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
PIRE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
POTR	0	1	2	1	5	1	3	4	0	0	0	0	0	0	3	1	1	1
PTAQ	0	0	7	2	0	1	2	20	7	4	0	0	0	0	1	3	4	3
PYEL	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
QUBO	0	2	0	0	0	0	0	0	1	0	0	0	0	4	0	0	0	0
RIBE	0	0	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
ROSA	0	0	0	1	3	1	0	1	0	0	0	0	0	0	1	0	3	0
ROCK	1	2	0	0	4	1	2	3	7	18	1	3	8	1	0	0	0	0
RUBU	5	3	7	6	0	4	5	0	0	4	1	2	1	1	1	3	3	8
SAMA	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0
SAPU	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SEDG	1	1	1	0	0	0	1	1	0	0	0	1	0	1	0	0	0	0
SPHA	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
STRO	4	3	5	1	2	3	4	1	0	0	0	1	0	0	5	5	1	0
TRBO	5	4	5	2	0	2	1	3	4	0	2	3	0	2	4	4	0	1
VAAN	1	0	2	0	0	0	0	3	5	5	0	2	3	2	0	2	0	6
VIOL	5	4	3	0	1	3	0	3	0	0	0	1	1	0	2	2	1	1
VIRE	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VITR	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VTCH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2

Table 3.3 cont.

	96	97	98	99	100	101	102	103	105
ABBA	5	4	5	0	0	0	0	0	0
ACRU	6	3	0	0	0	0	0	0	0
ACSP	1	0	0	0	0	0	0	0	0
AMEL	0	0	1	0	0	0	0	0	0
ANGL	0	0	0	0	0	0	0	5	1
ARNU	2	2	0	0	0	0	0	0	0
ASMA	17	36	38	20	0	0	0	0	0
BLIT	31	11	14	42	17	35	8	2	9
CHCA	0	0	0	0	0	0	4	15	0
CLBO	1	2	0	0	0	0	0	0	0
COCA	8	4	0	4	0	0	0	0	0
COCO	1	1	3	3	0	0	0	0	0
COGR	1	2	0	0	0	0	0	0	0
COMP	2	1	1	0	0	0	0	0	0
DILO	2	8	1	1	0	0	0	0	0
EQUI	1	0	0	0	0	0	0	0	0
FRVE	4	4	1	1	0	0	0	0	0
FUNG	0	0	0	0	5	2	3	3	5
GACI	0	1	0	0	0	0	0	0	0
GAHI	0	0	0	0	2	1	4	1	3
GATR	2	1	1	0	0	0	0	0	0
GRAS	4	3	3	5	0	0	6	0	2
KAPO	0	0	0	0	0	0	1	5	0
LAOC	0	0	2	0	0	0	0	0	0
LAVE	0	1	0	0	0	0	0	0	0
LEGR	0	0	0	0	0	0	8	10	6
LIBO	0	0	1	0	0	0	0	0	0
LICH	0	0	0	0	0	0	0	1	0
LOCA	0	0	1	0	0	0	0	0	0
LYAN	2	0	9	1	0	0	0	0	0
LYCL	0	0	1	0	0	0	0	0	0
LYCO	0	0	0	1	0	0	0	0	0
LYOB	3	3	6	1	0	0	0	0	0
MACA	6	5	3	0	0	0	0	0	0
MOSS	3	2	3	4	10	10	10	9	16
PIMA	0	0	0	0	0	0	3	8	3
POTR	1	0	3	0	0	0	0	0	0
PTAQ	6	18	7	9	0	0	0	0	0
ROSA	1	0	2	1	0	0	0	0	0
RUBU	4	3	2	5	0	0	0	0	0
SAPU	0	0	0	0	0	0	0	4	0
SEDG	1	2	0	1	20	1	6	26	11
SMTR	0	0	0	0	2	0	2	1	3
SPHA	0	0	0	0	60	36	50	60	70
STRO	1	2	1	1	0	0	0	0	0
TRBO	5	2	2	0	0	0	0	0	0
VAAN	2	1	2	5	1	0	0	0	0
VAOX	0	0	0	0	1	2	4	5	5
VIOL	1	2	1	0	0	0	0	0	0

Table 3.4 - Cover by Stratum and Plot for Aspen Sites

Average percent coverage and standard deviation from the five subplots at each aspen site. Site is the site identification number, Canopy is coverage of trees over 2 meters tall, Subcanopy is the percent coverage of trees and shrubs between 1 and 2 meters tall, Understory is coverage of plants under 1 meter, and Dead Canopy is the amount of coverage by dead limbs or trees.

	Canopy		Subcanopy		Understory		Dead Canopy	
Site	Avg	Std	Avg	Std	Avg	Std	Avg	Std
3	56.7	25.2	66.7	15.3	65.0	39.7	3.3	2.9
16	58.0	8.4	60.0	23.5	38.0	11.0	4.0	2.2
20	62.0	11.0	36.0	21.9	64.0	16.7	5.0	0.0
21	44.0	11.4	44.0	20.7	70.0	15.8	2.0	2.7
36	46.0	5.5	15.0	7.1	76.0	20.7	7.0	7.6
69	68.0	4.5	7.0	2.7	70.0	7.1	4.0	2.2
71	68.0	8.4	11.0	11.4	68.0	14.8	5.0	0.0
72	60.0	14.1	20.0	0.0	50.0	0.0	5.0	0.0
73	66.0	5.5	34.0	15.2	66.0	21.9	5.0	0.0
74	60.0	7.1	20.0	17.3	64.0	11.4	5.0	0.0
75	66.0	5.5	34.0	16.7	68.0	8.4	5.0	0.0
77	56.0	5.5	32.0	25.9	52.0	13.0	5.0	0.0
79	72.0	4.5	26.0	8.9	82.0	11.0	2.0	2.7
80	70.0	7.1	16.0	8.9	80.0	10.0	4.0	2.2
81	66.0	8.9	54.0	23.0	48.0	20.5	5.0	0.0
82	62.0	4.5	24.0	13.4	68.0	4.5	5.0	0.0
83	62.0	4.5	27.0	14.8	70.0	14.1	5.0	0.0
84	70.0	7.1	13.0	11.5	60.0	15.8	1.0	2.2
85	62.0	8.4	17.0	14.0	48.0	16.4	16.0	24.6
86	50.0	18.7	24.0	13.4	56.0	13.4	0.0	0.0
87	56.0	15.2	34.0	20.7	38.0	13.0	12.0	10.4
88	66.0	11.4	14.0	10.8	54.0	8.9	6.0	4.2
89	60.0	14.1	28.0	8.4	36.0	5.5	5.0	0.0
90	50.0	7.1	48.0	17.9	38.0	8.4	5.0	0.0
92	56.0	8.9	37.0	27.3	52.0	19.2	6.0	2.2
93	58.0	4.5	74.0	8.9	66.0	8.9	5.0	0.0
94	50.0	0.0	68.0	19.2	74.0	20.7	0.0	0.0
95	52.0	8.4	17.0	24.1	80.0	18.7	2.0	2.7
96	70.0	7.1	3.0	2.7	64.0	13.4	5.0	0.0
97	62.0	8.4	4.0	4.2	83.0	14.0	4.0	2.2
98	56.0	5.5	18.0	16.0	88.0	7.6	5.0	0.0
99	50.0	18.7	66.0	8.9	46.0	8.9	3.0	2.7

Table 3.5 - Statistics for Sacrificed Aspen Trees

Values from aspen trees cut near to the study sites. Dbh is diameter breast height in centimeters; height is total height of tree in meters; doc is the depth of the crown, i.e., the height from the first leaf-bearing branches to the top of the tree in meters; leaf area is the total area of the leaves on the tree calculated from sampled branches with the standard error in square centimeters; and the tree biomass is calculated from sampled branches, with the standard error in grams.

dbh (cm)	height (m)	doc (m)	leaf area (cm^2)	SE (la)	biomass (g)	SE (bm)
0.9	2.20	1.78	1280.16	0.00	112.58	2.10
1.2	2.80	1.77	1766.12	165.46	168.70	24.25
1.4	3.43	2.14	3677.92	290.14	256.28	8.83
1.8	3.78	2.62	9708.01	1685.75	598.47	70.36
2.0	4.60	2.40	9043.15	814.04	567.40	19.03
2.2	3.10	1.80	11658.80	1771.70	606.54	16.69
3.4	5.70	4.43	20256.21	853.54	1909.26	37.94
3.4	5.35	4.05	32123.67	3891.72	1936.82	59.93
3.5	5.35	4.15	14072.01	818.25	1532.02	29.73
7.3	9.20	4.90	102891.09	19216.20	14346.30	621.48
9.1	9.40	4.42	83769.87	9591.30	11250.38	313.15
10.5	11.50	5.30	148084.39	11454.91	29413.23	966.04
13.0	16.10	5.05	109339.86	12714.04	54486.61	1178.68
13.7	15.90	4.65	108924.04	8857.67	60834.46	1118.45
15.1	16.70	6.95	91855.49	4814.76	67338.04	1262.27
15.4	17.40	7.10	138091.91	8771.01	80391.10	1515.08
15.8	15.60	5.40	193240.13	8073.15	71016.01	1280.61
17.3	15.50	8.40	218524.41	6802.89	73012.54	1162.92
19.4	23.00	10.30	312907.63	10882.57	171922.24	2513.05
19.5	19.35	7.40	175246.08	10190.74	107218.69	1803.00
21.5	23.10	5.75	182521.34	19549.84	177285.82	2196.16
22.5	22.50	7.25	500455.06	41004.35	238477.34	3218.93
22.6	18.10	7.40	287153.53	11609.84	191767.73	2248.49
22.8	22.40	6.60	422196.53	23861.99	233177.57	2992.33
23.0	22.50	8.70	382654.50	12988.99	237964.00	3036.38
25.1	23.80	8.85	273654.69	23332.50	274651.80	3343.34
25.2	22.50	8.80	241456.02	49253.56	270825.85	3766.19
27.8	23.50	16.25	745781.00	73361.20	448440.07	6264.33
30.2	23.50	10.05	743229.75	71937.20	437031.91	5502.92
32.1	23.80	8.90	531668.81	71937.81	456140.40	4753.74
32.4	23.50	12.80	1017735.38	91915.13	533887.77	5360.41
35.4	22.50	11.50	1228601.50	112045.76	559046.90	5050.19

Table 3.6 - Statistics for Sacrificed Spruce Trees

Values from spruce trees cut near to the study sites. Dbh is diameter breast height in centimeters; height is total height of tree in meters; doc is the depth of the crown, i.e., the height from the first leaf-bearing branches to the top of the tree in meters; leaf area is the total area of the leaves on the tree calculated from sampled branches with the standard error in square centimeters; and the tree biomass is calculated from sampled branches with the standard error in grams.

dbh (cm)	height (m)	doc (m)	leaf area (cm^2)	SE (la)	biomass (g)	SE (bm)
2.9	2.90	1.66	8303.50	1307.83	957.73	59.84
4.1	3.70	3.60	28230.51	5520.61	3541.01	230.67
4.1	4.37	4.24	42984.57	18818.73	5251.89	445.79
4.4	4.20	2.61	19539.94	2915.01	3286.88	152.28
4.9	5.60	2.15	13361.46	2415.06	3720.22	320.19
5.1	4.15	1.90	18259.08	1675.77	4389.37	105.35
5.5	8.55	5.00	37405.26	4111.27	6242.02	260.35
5.7	6.00	3.10	46803.37	2895.23	6177.99	376.14
6.9	6.90	5.12	46080.43	6772.37	8869.33	233.97
8.2	9.35	3.55	34179.43	5821.31	14609.92	377.44
9.1	10.56	4.82	57286.88	7504.30	16967.75	622.87
9.2	11.70	3.40	50016.85	6077.54	19912.67	411.31
11.0	12.86	5.11	115016.66	12092.50	35581.93	581.85
11.0	10.90	7.50	115095.30	18986.75	31188.50	716.32
11.5	12.60	7.55	160659.06	15806.49	43375.69	942.15
12.1	11.00	4.00	93923.11	14070.42	32544.85	876.03
12.7	14.70	7.70	77944.05	17154.32	45656.59	1637.72
14.1	11.94	9.38	165289.27	27741.48	53860.68	2846.02
14.3	13.90	7.80	335712.03	29299.56	60976.55	1218.13
14.4	13.10	7.50	119594.65	21101.48	52109.21	1331.45
15.6	14.40	8.00	66331.88	6845.71	59780.82	917.52
15.6	13.10	8.15	115336.13	22047.93	62144.07	1152.50
16.4	11.80	8.50	438570.81	73382.71	70466.63	1878.40
18.1	19.90	8.65	214715.11	36310.12	133180.07	2484.47
18.9	18.80	8.43	241654.33	34868.48	128709.13	2019.30
19.0	14.15	12.43	450936.09	69085.73	114136.00	2979.51
19.6	14.70	10.47	298449.13	45453.35	114821.05	3087.88
20.2	14.60	12.40	243767.86	27349.37	128890.17	3164.18
20.8	15.30	7.27	146029.06	24910.89	104981.92	2439.91
22.8	17.50	10.10	239635.28	37735.02	137075.67	2088.36
23.0	19.95	12.49	492978.78	60853.75	204608.74	6718.30

Table 3.7 - Aspen Biophysical Parameters

This table contains data on the biophysical characteristics of the aspen sites. The Site column contains the site number, NT is the number of trees on the site, Area is the site area in square meters, Avg DBH and SD DBH are the average and standard deviation of the tree diameter at breast height in cm, Stems per m^2 is the number of trees per square meter on the site, Basal Fraction is the ratio of bole area to surface area, BMI and SD BMI are the biomass index and its standard deviation in kg/m^2, NPP is the net primary production in $kg/m^2/year$, LAI and SD LAI are the one-sided leaf area index and its standard deviation, BAI and SD BAI are the bark area index and its standard deviation. The bark area is the entire surface area of the boles and branches. Sub LAI is the subcanopy leaf area index.

Site	NT	Area	Avg DBH	SD DBH	Stems per m^2	Basal Fraction	BMI	SD BMI	NPP	LAI	SD LAI	BAI	SD BAI	Sub LAI
3	95	1005	15.22	9.56	0.09450	0.00239	13.705	1.388	0.563	2.524	0.253	1.286	0.353	0.201
16	100	1005	16.42	8.87	0.09947	0.00272	13.433	1.034	0.667	2.427	0.235	1.498	0.278	1.080
20	231	1005	8.48	7.16	0.22978	0.00222	10.340	1.698	0.736	2.464	0.436	1.144	0.466	0.500
21	144	1005	10.11	8.48	0.14324	0.00195	11.122	1.842	0.590	3.118	0.789	1.096	0.336	1.393
36	236	1005	6.36	6.85	0.23475	0.00161	8.106	0.980	0.538	2.056	0.236	1.020	0.221	0.193
69	377	251	2.75	1.40	1.50004	0.00112	2.697	0.438	0.855	2.793	0.436	0.568	0.141	0.264
71	498	251	2.36	1.19	1.98148	0.00109	2.250	0.270	0.786	2.849	0.391	0.914	0.474	0.210
72	167	1005	16.07	4.83	0.16612	0.00367	18.164	0.933	0.922	3.039	0.345	2.026	0.281	0.315
73	107	1005	19.31	7.19	0.10643	0.00354	20.210	0.886	0.812	3.233	0.236	1.920	0.218	0.655
74	142	1005	17.05	7.34	0.14125	0.00382	21.881	1.173	0.947	3.265	0.273	2.136	0.289	0.417
75	161	1005	15.92	4.83	0.16015	0.00348	17.648	1.090	0.882	2.935	0.326	1.992	0.350	1.324
77	105	1005	20.51	6.29	0.10445	0.00377	22.159	1.000	0.853	3.523	0.281	2.098	0.285	0.987
79	283	1005	8.81	9.26	0.28151	0.00361	20.543	1.110	0.881	3.971	0.307	2.066	0.285	0.936
80	369	1005	4.89	7.54	0.36705	0.00232	11.804	1.025	0.624	2.473	0.254	1.412	0.057	0.550
81	145	1005	13.18	10.05	0.14423	0.00310	17.820	0.722	0.702	2.965	0.241	1.752	0.174	1.218
82	202	1005	10.32	9.28	0.20093	0.00303	16.171	1.087	0.711	2.708	0.269	1.726	0.091	0.645
83	175	1005	10.11	10.27	0.17408	0.00283	15.674	1.415	0.682	2.742	0.317	1.562	0.356	1.026
84	644	207	1.74	0.73	3.10593	0.00087	1.279	0.211	0.529	2.757	0.465	0.510	0.185	2.378
85	230	1005	12.35	6.78	0.22879	0.00356	15.657	1.052	0.985	2.847	0.336	1.956	0.313	0.578
86	301	192	1.85	0.69	1.57068	0.00048	0.812	0.162	0.308	1.607	0.324	0.268	0.086	0.799
87	194	185	3.42	1.58	1.04665	0.00117	3.128	0.618	0.999	2.626	0.466	0.668	0.276	3.055
88	370	229	3.00	1.64	1.61335	0.00148	3.860	0.663	1.199	3.390	0.568	1.884	1.402	0.297
89	297	214	2.63	1.38	1.39027	0.00096	2.299	0.686	0.887	2.465	0.611	0.690	0.167	0.571
90	186	1005	12.63	8.67	0.18502	0.00341	18.350	0.871	0.864	3.195	0.279	1.886	0.133	1.180
92	108	1005	19.92	6.25	0.10743	0.00368	20.941	0.894	0.825	3.086	0.265	2.062	0.237	1.169
93	86	1005	19.48	7.85	0.08555	0.00296	16.888	1.256	0.686	2.562	0.259	1.618	0.237	1.818
94	458	251	1.64	0.61	1.82232	0.00044	0.726	0.109	0.213	1.652	0.243	0.218	0.043	1.990
95	569	251	1.58	0.67	2.26398	0.00052	0.959	0.226	0.258	2.070	0.455	0.262	0.118	0.599
96	173	1005	13.27	7.79	0.17209	0.00319	16.887	0.767	0.860	3.044	0.285	1.782	0.098	-
97	167	1005	15.31	5.65	0.16612	0.00347	18.785	0.953	0.896	3.322	0.384	1.936	0.091	-
98	262	1005	8.13	10.17	0.26062	0.00346	19.455	2.349	0.811	3.050	0.406	1.912	0.536	-
99	319	251	1.74	0.71	1.26926	0.00035	0.622	0.109	0.190	1.294	0.205	0.174	0.049	-

Table 3.8 - Spruce Biophysical Parameters

This table contains data on the biophysical characteristics of the spruce sites. The Site column contains the site number, NT is the number of trees on the site, Area is the site area in square meters, Avg DBH and SD DBH are the average and standard deviation of the tree diameter at breast height in cm, Stems per m^2 is the number of trees per square meter on the site, Basal Fraction is the ratio of bole area to surface area, BMI and SD BMI are the biomass index and its standard deviation in kg/m^2, NPP and SD NPP are the net primary production and its standard deviation in $kg/m^2/year$, LAI and SD LAI are the leaf area index and its standard deviation. Spruce leaf area is the projected area of the needles.

Site	NT	Area	Avg DBH	SD DBH	Stems per m^2	Basal Fraction	BMI	SD BMI	NPP	SD NPP	LAI	SD LAI
2	176	1005	14.52	4.43	0.17507	0.00317	12.378	0.830	0.3248	0.0412	2.884	0.340
12	165	1005	4.54	2.11	0.16413	0.00032	0.678	0.127	0.0394	0.0123	0.484	0.181
14	248	1005	13.22	4.13	0.24669	0.00372	13.643	0.587	0.4323	0.0351	3.266	0.427
15	225	1005	12.21	3.83	0.22381	0.00288	10.680	0.675	0.3476	0.0546	2.692	0.383
18	262	1005	4.24	2.06	0.26062	0.00046	1.093	0.192	0.0632	0.0061	0.739	0.254
19	257	1005	4.05	1.98	0.25564	0.00041	1.032	0.200	0.0582	0.0141	0.692	0.242
38	472	1005	7.33	3.35	0.46951	0.00240	6.790	0.600	0.2951	0.0281	2.691	0.644
39	379	1005	5.15	2.50	0.37700	0.00097	2.373	0.421	0.1176	0.0381	1.319	0.455
41	184	1005	13.49	5.73	0.18303	0.00308	11.135	0.517	0.3492	0.0301	2.842	0.313
42	260	1005	8.60	5.80	0.25863	0.00218	7.314	0.455	0.2584	0.0311	2.279	0.283
43	284	782	8.44	4.79	0.36305	0.00268	8.696	0.716	0.3303	0.0457	2.791	0.476
45	265	496	7.28	3.65	0.53387	0.00278	8.446	1.253	0.3575	0.1002	3.085	0.761
47	269	462	5.29	2.50	0.58249	0.00156	3.527	0.465	0.1799	0.0464	1.996	0.757
48	224	660	9.83	3.19	0.33953	0.00285	9.149	1.665	0.4044	0.1327	2.700	0.795
49	304	427	7.38	3.18	0.71152	0.00360	10.088	0.821	0.4097	0.0510	3.736	1.114
50	289	427	7.61	3.41	0.67641	0.00369	10.363	1.746	0.4324	0.1144	3.730	1.109
51	380	1005	5.92	3.04	0.37799	0.00131	3.620	0.501	0.1739	0.0361	1.685	0.454
52	341	958	9.92	3.91	0.35588	0.00318	10.036	0.574	0.3747	0.0520	3.034	0.588
54	409	741	5.71	3.46	0.55165	0.00193	5.565	0.869	0.2665	0.0618	2.444	0.625
55	321	606	7.56	3.44	0.52942	0.00287	8.578	0.818	0.3603	0.0560	3.091	0.785
56	245	958	8.09	4.29	0.25569	0.00168	5.280	0.345	0.2152	0.0304	1.834	0.329
57	287	911	9.52	3.89	0.31502	0.00262	8.293	0.539	0.3191	0.0395	2.595	0.495
62	197	1005	4.52	2.15	0.19596	0.00039	0.894	0.175	0.0505	0.0177	0.592	0.211
63	321	1005	3.94	2.16	0.31930	0.00051	1.274	0.232	0.0706	0.0142	0.842	0.290
64	149	1005	5.09	2.06	0.14821	0.00035	0.877	0.209	0.0488	0.0229	0.521	0.186
68	282	427	7.40	2.83	0.66002	0.00325	8.719	0.515	0.3822	0.0350	3.475	1.042
100	210	462	10.98	2.66	0.45473	0.00455	15.046	1.046	0.5375	0.0634	4.001	0.931
101	270	251	7.22	2.37	1.07430	0.00487	13.500	0.871	0.5718	0.0592	5.423	1.689
102	340	371	5.92	2.34	0.91716	0.00292	7.246	0.736	0.3456	0.0431	3.670	1.228
103	201	1005	4.86	2.88	0.19994	0.00050	1.349	0.283	0.0663	0.0281	0.709	0.222
105	228	496	10.48	3.77	0.45933	0.00447	15.136	0.892	0.5378	0.0666	4.260	0.761

Table 3.9 - Aspen Canopy Phenology

This table contains measurements of the green leaf coverage during the spring of 1984 for two aspen sites. The canopy was photographed from below at two locations at each site on several days during the spring. Coverage was determined from the photographs and scaled such that 0 is no leaves and 1 is the maximum leaf coverage.

Site is the site number, Day is the day of the year the photos were taken, View is the position of the camera at the site, Cover is the scaled coverage, and GDD is the number of growing degree days (difference between daily average temperature and 40 degrees Farenheit, when positive, summed for the year to that day).

Site	Day	View	Cover	GDD
16	136	1	0.304	188
16	136	2	0.090	188
16	139	1	0.554	231
16	139	2	0.382	231
16	145	1	0.739	300
16	145	2	0.809	300
16	148	1	0.891	306
16	148	2	0.843	306
16	152	1	0.967	376
16	152	2	0.888	376
16	161	1	1.000	554
16	161	2	1.000	554
93	137	1	0.000	208
93	137	2	0.000	208
93	139	1	0.123	231
93	139	2	0.068	231
93	146	1	0.189	302
93	146	2	0.205	302
93	149	1	0.557	308
93	149	2	0.466	308
93	155	1	0.962	436
93	155	2	0.966	436
93	161	1	1.000	554
93	161	2	1.000	554

Table 3.10 - Subcanopy Phenology

This table contains data on leaf expansion for the two major understory species in the SNF, mountain maple and beaked hazel. The size of all the leaves on selected twigs was determined for several days in the spring of 1984. A relative area was determined, by scaling the leaf areas between 0 for no leaves to 1 for maximum leaf extension.

Site is the study site number, Day is the day of the year, Rel Area is the relative leaf extension, and GDD is the number of growing degree days (difference between daily average temperature and 40 degrees Farenheit, when positive, summed for the year to that day).

Mountain Maple

Site	Day	Rel Area	GDD
16	132	0.008	153
16	135	0.010	177
16	138	0.011	223
16	142	0.039	272
16	144	0.122	299
16	147	0.167	306
16	151	0.238	355
16	155	0.742	436
16	160	0.923	544
16	164	1.000	606
93	138	0.015	223
93	145	0.046	300
93	148	0.152	306
93	153	0.381	394
93	157	0.799	486
93	160	0.910	544
93	164	1.000	606

Beaked Hazelnut

Site	Day	Rel Area	GDD
16	132	0.008	153
16	135	0.014	177
16	138	0.042	223
16	142	0.086	272
16	144	0.259	299
16	147	0.330	306
16	151	0.539	355
16	155	0.777	436
16	160	0.950	544
16	164	1.000	606

Beaked Hazelnut (cont.)

Site	Day	Rel Area	GDD
93	132	0.009	153
93	136	0.020	188
93	138	0.079	223
93	145	0.160	300
93	148	0.186	306
93	153	0.393	394
93	157	0.860	486
93	160	0.964	544
93	164	1.000	606

4.0 Climate

Northern Minnesota has a humid continental climate with cold winters, cool summers, and precipitation scattered throughout the year. Continental climates characteristically have a great range in temperatures between the winter and summer. The average temperature is below freezing for 5 months of the year and extreme cold is frequent in the winter. The coldest temperature recorded for this region is -59 degrees F (-51° C). In the summer, hot periods occur with temperatures in the 90s. Although the summers are generally mild, midsummer frosts may also occur. Most of the precipitation falls during the 5 months from May to September. Often the precipitation during this time of year comes as thunderstorms. These storms may be quite powerful, producing strong winds called downbursts, which may be very destructive. In 1976, a downburst storm in the SNF destroyed forests in an area one fourth of a mile wide and 10 miles long. In the winter, almost all of the precipitation which falls comes as snow. Most of the snowfall occurs in the early months of the winter before the freezing of the lakes shuts off the major source of moisture to the atmosphere.

Table 4.1 - Monthly Climatological Data

The climatological data presented in the following table was collected by the National Weather Service in International Falls, Minnesota. International Falls is about 80 miles from the SNF, but the weather data is representative of the area. Total solar insolation measurements were made at Fall Lake Dam in Winton, Minn. by Prof. Donald Baker of the Department of Soil Science at the University of Minnesota, St. Paul. Insolation values were measured using a Yellow Springs solar cell calibrated against an Eppley Pyranometer. The data presented here are monthly summary values. The temperature columns contain the monthly averages of the daily minimum (Min), maximum (Max), and average (Avg) temperatures. All temperatures are in Fahrenheit degrees. The precipitation column contains the water equivalent of the total monthly precipitation in inches. The insolation column contains the monthly average of the daily values in Langleys. There are gaps in the insolation data (but not in the Weather Service data) and the Days column contains the number of days of insolation data available in each month.

	Temperature (°F)					
Date	Min	Max	Avg	Precip (in)	Insolation	Days
JAN 76	-12.1	12.7	-0.3	0.99	121.7	31
FEB 76	3.0	26.1	14.6	0.46	207.5	29
MAR 76	7.3	30.9	19.3	1.82	280.1	31
APR 76	31.1	54.5	43.1	1.02	438.3	30
MAY 76	37.2	69.8	53.4	0.12	582.7	31
JUN 76	52.0	76.7	64.8	7.01	529.5	30
JUL 76	52.5	77.5	66.0	5.70	548.8	31
AUG 76	50.9	76.8	65.1	1.85	466.1	28
SEP 76	39.2	67.6	54.7	1.19	337.1	30
OCT 76	26.2	44.5	35.6	0.84	187.6	31
NOV 76	7.7	24.2	16.1	0.19	130.1	30
DEC 76	-14.4	8.0	-3.1	0.59	109.9	30
JAN 77	-15.6	4.1	-5.8	0.66	132.4	31
FEB 77	3.3	22.0	12.8	1.01	210.4	28
MAR 77	19.5	39.7	29.9	1.89	289.7	31
APR 77	30.0	55.6	43.1	1.01	424.5	30
MAY 77	47.3	73.7	61.2	5.81	483.0	31
JUN 77	50.9	72.5	62.1	4.20	468.5	30
JUL 77	54.5	78.7	66.9	2.16	462.9	31
AUG 77	45.0	69.0	57.1	3.01	399.7	31
SEP 77	44.0	61.0	52.8	6.81	240.1	10
OCT 77	32.6	53.9	43.5	0.80		
NOV 77	14.0	31.1	22.8	3.49	105.5	23
DEC 77	-4.8	11.8	3.5	0.98	86.3	31

Table 4.1 cont.

Date	Temperature (°F) Min	Max	Avg	Precip (in)	Insolation	Days
JAN 78	-13.1	6.2	-3.4	0.78	149.2	31
FEB 78	-9.2	14.4	2.7	0.27	244.3	28
MAR 78	6.3	30.6	18.7	0.41	362.1	31
APR 78	26.6	47.4	37.3	1.12	429.4	30
MAY 78	42.2	68.7	55.7	3.86	460.0	31
JUN 78	46.7	72.4	59.9	2.89	483.2	30
JUL 78	53.2	73.8	63.8	6.29	423.5	31
AUG 78	52.5	73.3	63.2	2.96	413.9	31
SEP 78	46.2	65.8	56.2	3.62		
OCT 78	33.7	53.7	43.7	0.39	225.5	24
NOV 78	10.8	30.2	20.7	1.60	130.7	18
DEC 78	-10.8	12.2	0.7	0.93		
JAN 79	-19.0	2.0	-8.6	0.58	139.0	12
FEB 79	-11.1	10.0	-0.6	1.03	188.8	15
MAR 79	10.1	29.2	19.8	1.66	249.3	31
APR 79	24.5	43.5	34.2	2.70	352.6	25
MAY 79	36.2	55.8	46.1	1.73	407.4	31
JUN 79	47.6	71.0	59.7	4.06	467.0	30
JUL 79	54.4	78.4	67.4	1.08	481.2	27
AUG 79	48.2	72.0	60.4	1.68	398.3	31
SEP 79	42.2	64.6	53.7	2.12	296.8	30
OCT 79	28.2	46.1	37.3	1.55	159.9	24
NOV 79	15.9	30.9	23.7	3.08	112.8	16
DEC 79	4.6	24.7	14.9	0.42		
JAN 80	-8.8	12.9	2.1	0.92		
FEB 80	-2.1	18.2	8.2	0.55	184.7	28
MAR 80	3.5	30.0	17.0	0.90	341.6	31
APR 80	30.9	57.6	44.5	0.45	421.5	30
MAY 80	44.3	73.2	58.9	0.83	464.3	31
JUN 80	50.3	74.3	62.6	1.70	521.3	30
JUL 80	55.0	82.0	69.0	2.23	461.7	31
AUG 80	54.3	75.5	65.2	4.03	345.0	31
SEP 80	42.8	62.7	53.0	4.08	274.1	30
OCT 80	30.2	47.5	38.7	1.81	196.3	31
NOV 80	18.2	33.9	26.3	1.62	92.1	30
DEC 80	-5.5	14.5	4.6	0.56	78.9	30

Table 4.1 cont.

Date	Temperature (°F) Min	Max	Avg	Precip (in)	Insolation	Days
JAN 81	-5.1	17.5	6.4	0.26	159.6	25
FEB 81	5.1	23.8	14.6	0.22	177.1	28
MAR 81	19.1	38.1	28.9	1.18	309.2	31
APR 81	29.9	51.9	41.1	1.49	361.5	30
MAY 81	40.6	66.0	53.6	2.47	475.3	31
JUN 81	50.6	72.4	61.7	3.71	409.7	30
JUL 81	55.7	81.5	68.8	2.33	490.5	31
AUG 81	56.9	78.7	68.1	2.03	384.1	31
SEP 81	43.4	64.6	54.3	4.12	306.7	30
OCT 81	31.5	48.6	40.4	2.86	168.9	31
NOV 81	27.0	42.8	35.2	0.67	113.7	30
DEC 81	3.0	18.0	10.6	0.76	77.9	31
JAN 82	-22.8	1.8	-10.6	1.24	127.5	31
FEB 82	-3.8	16.8	6.2	0.51	208.6	28
MAR 82	10.5	30.4	20.6	1.85	270.4	31
APR 82	24.8	50.3	37.8	0.56	446.2	30
MAY 82	43.6	66.6	55.4	3.58	381.6	5
JUN 82	45.6	69.3	57.7	2.69	469.9	15
JUL 82	56.0	78.5	67.6	3.05	417.9	31
AUG 82	48.6	72.7	60.9	2.74	367.2	31
SEP 82	42.7	63.0	53.5	4.00	266.4	30
OCT 82	36.8	52.2	44.8	2.76	151.5	31
NOV 82	16.4	29.5	21.7	1.45	110.5	30
DEC 82	6.2	23.6	15.1	0.28	72.2	31
JAN 83	2.6	19.8	11.3	0.36	93.8	31
FEB 83	7.7	25.4	16.7	0.98	125.1	28
MAR 83	20.7	34.9	28.1	0.72	265.9	31
APR 83	27.6	48.8	38.4	0.62	384.4	30
MAY 83	36.4	61.9	49.2	1.21	488.2	31
JUN 83	50.3	73.5	62.1	5.02	457.9	30
JUL 83	58.7	80.5	69.9	2.98	453.4	31
AUG 83	56.6	80.5	68.8	3.66	404.2	25
SEP 83	45.6	64.6	55.3	4.23	269.9	30
OCT 83	33.3	50.1	41.9	2.58	170.5	31
NOV 83	22.7	32.6	27.8	1.95	83.4	30
DEC 83	-13.5	4.9	-4.3	0.66	98.0	26

Table 4.1 cont.

	Temperature (°F)					
Date	Min	Max	Avg	Precip (in)	Insolation	Days
JAN 84	-9.7	11.2	0.6	0.29	128.8	31
FEB 84	12.2	29.2	21.0	0.76	184.8	29
MAR 84	6.7	28.3	17.6	0.22	329.7	31
APR 84	31.7	56.3	44.3	0.89	409.8	30
MAY 84	36.0	60.9	49.2	1.77	394.8	25
JUN 84	50.8	72.2	61.8	6.50	417.2	30
JUL 84	53.0	77.2	65.4	2.14	480.6	31
AUG 84	55.6	79.7	67.9	1.30	399.4	31
SEP 84	38.2	59.7	49.2	1.14	262.1	30
OCT 84	36.9	52.2	44.8	4.11	145.3	31
NOV 84	17.3	33.8	25.8	0.91	112.9	30
DEC 84	-6.8	13.5	3.5	1.27	87.7	30
JAN 85	-10.9	10.8	0.0	0.38	113.1	31
FEB 85	-5.9	15.2	4.8	0.70	203.4	28
MAR 85	16.9	36.4	26.9	0.72	316.8	31
APR 85	30.8	52.8	42.2	3.17	377.3	30
MAY 85	42.4	66.1	54.5	6.31	548.2	3
JUN 85	43.7	64.7	54.5	6.51		
JUL 85	51.7	75.6	64.0	1.21	586.0	9
AUG 85	49.9	70.3	60.4	3.33	425.2	31
SEP 85	42.2	61.6	52.1	3.76	334.9	30
OCT 85	31.9	52.1	42.1	2.12	260.9	31
NOV 85	6.7	25.3	16.2	1.53	126.7	30
DEC 85	-8.9	8.5	-0.2	0.55	91.8	31
JAN 86	-2.2	17.5	7.8	0.61	150.4	31
FEB 86	-0.1	18.8	9.6	0.95	192.2	28
MAR 86	16.5	38.7	27.8	0.26	351.9	25
APR 86	32.7	53.7	43.5	3.33	443.9	30
MAY 86	43.2	68.7	56.4	0.50	559.4	31
JUN 86	47.9	72.9	60.7	3.67	625.3	30
JUL 86	55.9	77.4	67.0	2.59	498.0	31
AUG 86	48.8	73.5	61.4	1.52	472.9	31
SEP 86	43.0	61.9	52.8	2.42	304.8	30
OCT 86	31.6	51.2	41.7	0.64	197.5	31
NOV 86	11.3	28.5	20.1	1.27	154.3	30
DEC 86	6.1	25.6	16.1	0.35	129.5	31

5.0 Leaf Optical Properties

5.1 Introduction

Knowledge of the optical properties of the components of the forest canopy is important to the understanding of how plants interact with their environment and how this information may be used to determine vegetation characteristics using remote sensing.

During the summers of 1983 and 1984, samples of the major components of the boreal forest canopy (needles, leaves, branches, moss, litter) were collected in the Superior National Forest (SNF) of Minnesota and sent to the Johnson Space Center (JSC). At JSC, the spectral reflectance and transmittance characteristics of the samples were determined for wavelengths between .35 and 2.1 μm using the Cary-14 radiometer. This report presents plots of these data as well as averages to the Thematic Mapper Simulator (TMS) bands.

There were two main thrusts to the SNF optical properties study. The first was to collect the optical properties of many of the components of the boreal forest canopy. The reflectance and transmittance properties of the leaves and needles of eight major overstory tree species and three understory shrubs were measured. Also, reflectance measurements were made for the bark of several tree species, sphagnum moss and leaf litter. The second goal of the study was to investigate the variability of optical properties within a species. Measurements of reflectance and transmittance of quaking aspen leaves and black spruce needles were made at three levels in the canopy and for three stand densities. The results of these studies allow a comparison of the optical properties of a variety of different species and a measure of the variability within species. These data provide basic information necessary to model canopy reflectance patterns.

5.2 Methodology

The vegetation samples were collected in the SNF and placed in zip-lock plastic bags. These bags were packed in cardboard boxes and sent to JSC by priority mail. Samples were collected from late August through September in 1983. In 1984, samples were collected on May 23, June 25 and August 14 and mailed the same day. It took between 3 and 6 days for the samples to reach JSC.

The handling of the samples at JSC evolved over time. In 1983 and early 1984, the samples were stored in plastic bags and refrigerated at JSC. Later, due to problems with too much wetness on the leaves, the branches were not refrigerated and their ends were put in water to keep the leaves alive.

The optical properties were measured using the Cary-14 system at JSC. The Cary-14 has a wavelength range between 0.35 and 2.1 μm. The sampling interval varies between 0.002 and 0.01 micrometer, depending on the rate of change between the values in each sample interval. Each measurement samples at approximately 250 different wavelengths.

Optical-property measurements were made for both the tops and bottoms of leaves. When leaf top or bottom is referred to in these observations it indicates the side of the leaf which is illuminated by the Cary-14. For observing broad leaves, a sample of the leaf without holes or visible defects was used; however, for needle leaves, either a collection of individual needles was aligned in the instrument holder or a section of twig with needles attached was used. Each of the spectra reported represents a single measurement of an individual leaf, needle, or bark sample.

The optical properties measured by the Cary-14 are displayed in Figures 5.1 through 5.41. An inventory of the data is presented in tabular form in Table 5.1. In Figures 5.19 through 5.23 and 5.32 through 5.35, averages and standard deviations of sets of data are plotted. Since the Cary-14 does not sample in exactly the same wavelengths in each measurement, the data were resampled using a one-dimensional, quasi-cubic hermite interpolation before averaging. Table 5.2 lists the Cary-14 reflectance and transmittance values averaged to Thematic Mapper Simulator wavelength bands.

5.3 Results

Three species of broad leafed deciduous trees were sampled: paper birch (Betula papyrifera), red maple (Acer rubum) and quaking aspen (Populus tremuloides). Figures 5.1 through 5.4 show the optical properties of the birch and maple. These plots are representative of the spectral pattern of green leaves. In the visible region (0.4 to 0.7 μm), most of the radiation is absorbed by the leaf and little is reflected or transmitted. Reflectance and transmittance minima occur at approximately 0.45 and 0.65 μm due to chlorophyll absorption. The near-infrared region (0.7 to 1.3 μm) is characterized by very high reflectance and transmittance and low absorptance. The internal structure of the leaf determines the optical properties in this region. The middle infrared (1.3 to 3.0 μm) is dominated by strong water-absorption bands at approximately 1.4 and 1.9 μm. Reflectance and transmittance in the mid-infrared is related to the amount of water in the leaf.

All the birch and maple leaves were collected on the same day and received the same treatment. The leaf-top reflectance and transmittance are very close for all four samples in all wavelengths measured. However, there is a great deal of variation in the leaf-bottom transmittance. The differences in leaf optical properties for these four samples do not seem to be related to the differences in species or canopy height.

Quaking aspen leaves were sampled for three canopy heights and three stand densities. Aspen optical properties are plotted in Figures 5.5 through 5.23. A striking feature in these graphs is the differences between the optical properties of healthy and diseased leaves. For example, in Figure 5.5 the diseased leaf (line 7) has a much lower reflectance in both the near-and mid-infrared regions. This effect occurs even when the leaf appears green. In Figure 5.10, the leaf sample used for line 4 is described as being "most uniform in color and clean," but, once more, in the near and mid-infrared, the reflectance is much lower than for the healthy leaves. The diseased leaves also have a much higher transmittance in all wavelength bands.

The leaf-top reflectance for aspen (Figures 5.5, 5.10, 5.15 and 5.19) show that in the visible region, the high-density stand has a lower reflectance. In the infrared regions, the reflectances do not distinguish between stand density or crown height. The mid-infrared wavelengths show the most separability between the different samples. The variability between different aspen leaves is greater than the variability between the birch and maple samples. The leaf-top reflectances of the birch and maple match up well with aspen from the high-density stand in the visible. However, aspen has a much higher reflectance in the near infrared. In the mid-infrared, the birch and maple reflectances fall within the range of the aspen, but the aspen tends to have a slightly higher reflectance.

The aspen leaf-bottom reflectances (Figures 5.6, 5.11, 5.16 and 5.20) tend to be higher than the leaf-top reflectances in all wavelengths. In the visible, this is readily seen in the light color of the aspen leaf bottoms. The aspen leaf-bottom reflectances do not show any pattern based on canopy height or stand density. The leaf-bottom reflectance is similar between aspen, birch and maple in the visible, but in the infrared the aspen has the higher leaf-bottom reflectance.

Aspen leaf transmittance (Figures 5.7, 5.8, 5.12, 5.13, 5.17, 5.18, 5.21 and 5.22) is slightly greater in the infrared for high density stands versus low-density stands. The maple and birch leaf transmittances tend to be greater in all wavelengths than the aspen transmittances.

Bark reflectance for aspen (Figures 5.9, 5.14 and 5.23) varies greatly in all wavelengths. There are two spectral reflectance patterns for the bark. The first pattern has a steep jump in reflectance at 0.7 μm and high near-infrared reflectance values. The second bark reflectance pattern does not have the jump at 0.7 μm and increases monotonically through the visible and near infrared. Both bark types have similar patterns in the mid-infrared. The first type of bark tends to be found in the upper crown of the aspen. The second type of bark is found low in the aspen canopy, suggesting that it is older bark.

Five species of needle-leafed trees were sampled in this study: jack pine (Pinus banksiana), red pine (Pinus resinosa), larch (Larix laricina), balsam fir (Abies balsamea) and black spruce (Picea glauca). Figure 5.24 shows the needle-top reflectance for the larch, fir, jack and red pines. While the reflectance pattern is similar to broad leaves, the reflectance of the needles is much more variable in all wavelengths. The variability in needle reflectance is not just a function of species since jack pine has both high and low reflectance values. In the visible region, the red pine and larch reflectances are similar to broad-leaf reflectance, but fir and the low value for jack pine are much less. In the near-infrared plateau, there are two depressions occurring around 1.0 and 1.2 μm. These depressions are also present in broad leaves but are less pronounced. Broad-leaf reflectance in the near infrared falls in the middle of the range of needle near-infrared reflectances. In the mid-infrared region, broad-leaf reflectance is much higher than that of needles. The needle-bottom reflectance (Figure 5.25) has similar characteristics to the needle-top reflectance. In the visible region, fir has a greater bottom reflectance than top reflectance.

Needle transmittance (Figure 5.26) is much lower in all wavelengths than that of broad leaves.

While the reflectance of the bark of needle-leafed trees (Figure 5.27) shows a great deal of variability, the pattern of the reflectance is the same as that of aspen bark from the lower canopy. The needle-leaved tree bark does not show a jump at the visible near-infrared boundary as does some of the aspen bark.

Several samples of black spruce needles were measured to look at the variability of optical properties within a conifer species. In Figure 5.28, spruce needle-top reflectance is plotted. Spruce needle-top reflectance falls mid-range with other needle reflectances. Within spruce, needles from high-density stands have the highest reflectance in near and mid-infrared. Needles from a middle-density stand have lower reflectance in the near and mid-infrared, with reflectances of needles from a low-density stand being lowest in the near infrared and about the same as the mid-density needles in the mid-infrared. Spruce-needle reflectance data taken in 1983 were of a combination of both the tops and bottoms of the needles (Figures 5.30 and 5.34). The results are comparable with the 1984 data in the near and mid-infrared, however the 1983 visible reflectances are much higher than the 1984 data. This is not due to the effects of needle-bottom reflectance in 1983 samples since the 1984 needle-bottom reflectances (Figures 5.29 and 5.33) in the visible are not much different than those of the needle tops, and are much lower than the 1983 visible reflectances. Spruce-needle reflectance (Figure 5.32) in comparison with aspen leaf reflectance (Figure 5.19) is a little lower in the visible, much lower in the near infrared, and greatly lower in the mid-infrared.

Spruce-needle transmittance (Figures 5.31 and 5.35) is slightly higher than other needle transmittance in the visible and near-infrared regions. In comparison with aspen leaf transmittance (Figure 5.21), they are nearly equal in the visible, spruce is slightly lower in the near infrared, and much lower in the mid-infrared.

Three species of understory shrubs were sampled: beaked hazel (Corylus cornuta), labrador tea (Ledum groenlandicum) and leatherleaf (Chamaedaphne calyculata) (Figures 5.36 through 5.39). Only leaf-top reflectance was determined for labrador tea and leatherleaf. The labrador tea and leatherleaf have very high reflectances in the near infrared compared to other leaves or needles sampled. The hazel has much lower reflectance in the near infrared. The water absorption bands at 1.4 and 1.9 μm are not very deep for the hazel.

Sphagnum moss (Sphagnum spp.) reflectance (Figure 5.40) is extremely variable in all bands. The difference between samples may be caused by differences in location, moisture or type of sphagnum. Background reflectance can have a significant effect on the total canopy reflectance. If sphagnum is the background, the reflectance may vary with place and time. This variable background can be an important complication in the understanding of reflectance images of the boreal forest regions. In contrast to the sphagnum reflectance is the reflectance of aspen leaf litter (Figure 5.41). The leaf litter reflectance is much different than that of the sphagnum and appears to be more like the needle-leafed tree bark (Figure 5.27).

Table 5.1 - Optical Properties Data Availability

This table provides an inventory of the Cary-14 spectrometer measurements of the optical properties of canopy components. The numbers refer to the number of samples measured, where each measurement is a single scan by the Cary-14. The values in the N/A column for the Reflectance and Transmittance refer to measurements of entire shoots.

Species	Plant Part	Reflectance Top	Reflectance Bottom	Reflectance N/A	Transmittance Top	Transmittance Bottom	Transmittance N/A
Jack Pine (Pinus banksiana)	Needle	2	1		1		
	Bark	1					
Red Pine (Pinus resinosa)	Needle	1			1		
	Bark						
Larch (Larix laricina)	Needle	2	2				
	Bark	1					
Balsam Fir (Abies balsamea)	Needle	1	1				
	Bark	1					
Black Spruce (Picea glauca)	Needle	5	5	5			4
	Bark	2					
Red Maple (Acer rubum)	Leaf	2	2		2	2	
	Bark						
Paper Birch (Betula papyrifera)	Leaf	2	2		2	2	
	Bark						
Quaking Aspen (Populus tremuloides)	Leaf	17	17		17	17	
	Bark	10					
Beaked Hazel (Corylus cornuta)	Leaf	1	1		1	1	
	Bark						
Labrador Tea (Ledum groenlandicum)	Leaf	1					
	Bark						
Leatherleaf (Chamaedaphne calyculata)	Leaf	1					
	Bark						
Sphagnum Moss (Sphagnum spp)		4					
Leaf Litter		1					

Table 5.2 - TM Band Averages

This table lists the Cary-14 reflectance and transmittance values averaged to Thematic Mapper Simulator wavelength bands. The Thematic Mapper Simulator bands are:

TM 1	0.45 - 0.52 μm
TM 2	0.52 - 0.60 μm
TM 3	0.63 - 0.69 μm
TM 4	0.76 - 0.90 μm
TM 5	1.00 - 1.30 μm
TM 6	1.55 - 1.75 μm
TM 7	2.08 - 2.35 μm

A weighted average is calculated based on the width of the sampling interval for the Cary-14 measurements in each TMS band.

The file name is the unique name given to each sample measured. The Fig column refers to the figure number in this report with the plot of the Cary-14 data. The Line column gives the line type in the figure. The line types and numbers are displayed on each plot.

Jack Pine (Pinus banksiana)

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Needle Reflectance/Top:									
PB0N2T1R	5.24	2	3.261	6.231	3.830	37.215	33.575	12.418	1.817
PBLR	5.24	3	6.201	12.710	6.237	54.317	49.179	23.199	7.830
Needle Reflectance/Bottom:									
PB0N2B1R	5.25	2	3.191	6.071	3.231	34.890	31.508	11.904	1.542
Needle Transmittance:									
PBLT	5.26	1	0.416	1.956	0.581	33.547	30.364	10.354	0.806
Bark Reflectance:									
PB0B201R	5.27	2	6.774	7.985	8.863	14.106	33.267	40.477	27.730

Red Pine (Pinus resinosa)

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Needle Reflectance:									
PRLR	5.24	6	6.189	11.258	6.025	49.165	45.819	24.076	9.174

Red Pine (Pinus resinosa) cont.

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Needle Transmittance:									
PRLT	5.26	2	1.451	4.902	1.523	36.916	34.441	14.639	3.245

Larch (Larix laricina)

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Needle Reflectance/Top:									
LL0N2T1R	5.24	4	5.841	12.712	6.478	48.436	46.656	23.054	3.597
LL0N7T1R	5.24	5	4.497	12.139	5.711	53.489	51.759	24.722	6.789
Needle Reflectance/Bottom:									
LL0N2B1R	5.25	3	6.418	13.850	9.090	48.913	48.979	26.742	9.573
LL0N7B1R	5.25	4	6.171	12.815	8.231	42.973	42.162	23.388	7.635
Bark Reflectance:									
LL0B201R	5.27	3	8.753	10.275	12.029	18.185	32.206	45.939	22.064

Balsam Fir (Abies balsamea)

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Needle Reflectance/Top:									
AB0N2T1R	5.24	1	2.636	5.526	3.537	29.542	29.545	14.661	5.038
Needle Reflectance/Bottom:									
AB0N2B1R	5.25	1	9.758	16.270	8.973	53.960	51.091	25.496	10.067
Bark Reflectance:									
AB0B201R	5.27	1	18.815	21.984	24.135	34.443	42.720	33.693	18.179

Black Spruce (Picea glauca)

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Needle Reflectance/Top:									
PM3N2T1R	5.28	1	4.248	9.433	4.307	50.277	47.278	19.773	6.062
PM2N2T1R	5.28	2	4.411	9.267	4.806	40.813	38.529	15.887	4.010
PM1N2T1R	5.28	3	4.429	9.044	4.144	37.707	35.588	15.862	4.737
PM0N7T1R	5.28	4	5.137	11.312	5.602	45.205	38.574	12.928	1.347
PM6N7T1R	5.28	5	4.417	8.463	4.290	38.930	36.316	14.818	3.514
Needle Reflectance/Bottom:									
PM3N2B1R	5.29	1	4.708	8.642	4.614	42.400	39.919	18.027	4.607
PM2N2B1R	5.29	2	5.143	10.212	5.410	40.585	37.482	16.625	5.362
PM1N2B1R	5.29	3	5.051	9.259	5.179	35.166	33.418	15.752	5.961
PM0N7B1R	5.29	4	8.208	15.885	10.946	52.556	43.850	17.227	2.910
PM6N7B1R	5.29	5	4.294	8.182	5.342	34.705	36.008	17.259	6.543
Needle Reflectance (1983):									
S60H01R	5.30	1	11.907	20.376	11.859	53.258	48.137	22.995	8.285
S60H02R	5.30	2	13.288	20.848	12.678	50.085	44.803	20.115	7.420
S60H03R	5.30	3	7.499	12.840	8.284	40.393	37.999	18.210	6.924
SY2R	5.30	4	6.702	12.421	7.508	44.566	40.602	19.296	8.027
SYYR	5.30	5	8.284	15.906	8.811	45.943	42.093	20.875	8.153
Needle Transmittance (1983):									
S60H01T	5.31	1	2.835	8.409	3.767	39.514	37.835	17.428	4.871
S60H02T	5.31	2	0.630	4.793	1.477	35.871	34.129	12.364	1.994
SY2T	5.31	3	2.272	4.825	2.444	39.123	38.014	15.689	2.014
SYYT	5.31	4	1.076	5.372	1.591	40.391	38.172	14.677	2.078
Bark Reflectance:									
PM0B201R	5.27	4	2.571	3.038	3.744	9.428	24.091	20.944	5.704

Red Maple (Acer rubum)

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Leaf Reflectance/Top:									
AR0L3T1R	5.1	3	5.065	10.526	5.240	45.877	44.065	30.479	11.234
AR0L3T2R	5.1	4	4.902	9.980	4.941	43.194	41.663	32.143	12.507

Red Maple (Acer rubum) cont.

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Leaf Reflectance/Bottom:									
AR0L3B1R	5.2	3	18.105	24.817	17.170	44.201	43.466	31.703	14.862
AR0L3B2R	5.2	4	13.010	19.677	12.437	39.091	37.504	29.823	12.551
Leaf Transmittance/Top:									
AR0L3T1T	5.3	3	1.965	11.072	2.976	44.660	46.654	38.835	19.600
AR0L3T2T	5.3	4	3.641	14.068	4.620	48.453	49.356	45.262	16.978
Leaf Transmittance/Bottom:									
AR0L3B1T	5.4	3	1.556	7.752	2.123	34.481	36.248	29.149	12.075
AR0L3B2T	5.4	4	4.328	15.339	5.306	51.469	53.185	49.676	29.916

Paper Birch (Betula papyrifera)

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Leaf Reflectance/Top:									
BP0L3T1R	5.1	1	5.698	11.945	5.526	44.065	42.892	32.234	15.287
BP0L3T2R	5.1	2	5.036	10.802	4.939	43.751	42.322	32.768	15.537
Leaf Reflectance/Bottom:									
BP0L3B1R	5.2	1	11.976	19.835	13.014	38.042	37.694	29.428	14.430
BP0L3B2R	5.2	2	10.833	17.416	10.135	37.106	36.519	29.534	15.528
Leaf Transmittance/Top:									
BP0L3T1T	5.3	1	4.603	16.026	6.311	46.241	47.886	41.519	18.895
BP0L3T2T	5.3	2	4.180	15.826	5.344	50.251	50.987	43.720	23.663
Leaf Transmittance/Bottom:									
BP0L3B1T	5.4	1	4.481	15.937	6.042	48.297	49.809	43.198	14.323
BP0L3B2T	5.4	2	4.940	17.912	6.341	54.888	55.588	49.488	31.447

Quaking Aspen (Populus tremuloides)

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Leaf Reflectance/Top:									
A25H29RF	5.5	1	6.286	11.048	6.628	46.087	44.808	32.821	16.418
A26H21RF	5.5	2	6.626	11.321	7.425	50.530	49.552	35.794	18.491
A25M11RF	5.5	3	6.740	10.625	6.706	50.905	48.220	33.521	15.653
A26M11RF	5.5	4	6.117	9.699	6.870	50.762	48.392	34.765	16.447
A25L01RF	5.5	5	7.199	11.630	7.572	52.586	50.049	35.325	18.650
A26L01RF	5.5	6	7.384	11.607	7.451	52.068	49.925	36.866	19.107
PT3L2T1R	5.5	7	4.682	9.687	5.430	34.898	37.204	25.443	8.187
A27H21RF	5.10	1	7.774	13.218	7.861	52.664	49.637	34.669	15.785
A27M19RF	5.10	2	7.142	11.557	6.982	48.907	46.066	31.351	14.177
A27L01RF	5.10	3	6.723	10.468	7.119	52.056	49.194	33.069	14.544
PT2L2T1R	5.10	4	5.920	16.397	6.731	40.667	37.789	25.318	8.916
AXXH21RF	5.15	1	5.697	10.167	6.433	52.569	50.130	34.881	16.238
AXXM19RF	5.15	2	7.345	10.628	7.350	45.557	52.027	38.874	20.528
AXXL01RF	5.15	3	7.185	14.658	7.652	50.274	48.838	36.350	18.848
PT1L2T1R	5.15	4	5.790	15.112	6.080	36.246	33.319	22.306	8.616
PT1L3T1R	5.15	5	5.416	11.072	4.700	51.850	49.305	31.874	9.766
PT1L3T2R	5.15	6	7.391	13.098	6.948	51.826	50.402	38.561	18.028
Leaf Reflectance/Bottom:									
A25H29RB	5.6	1	13.065	21.033	14.371	49.432	47.594	36.615	21.961
A26H21RB	5.6	2	12.209	19.212	13.101	53.250	50.967	38.358	22.873
A25M11RB	5.6	3	12.621	19.810	13.200	51.435	48.445	35.759	20.035
A26M11RB	5.6	4	11.752	18.817	12.589	51.623	49.000	37.069	20.753
A25L01RB	5.6	5	12.851	20.194	12.922	53.351	50.427	37.747	22.273
A26L01RB	5.6	6	11.731	19.211	12.567	53.115	50.681	38.983	22.845
PT3L2B1R	5.6	7	8.793	15.232	10.083	35.258	36.472	26.835	6.623
A27H21RB	5.11	1	13.841	23.272	15.126	54.215	51.292	38.205	21.493
A27M19RB	5.11	2	12.723	20.796	12.771	50.322	47.157	34.769	19.481
A27L01RB	5.11	3	13.639	22.536	14.776	52.789	49.731	36.609	20.624
PT2L2B1R	5.11	4	12.206	22.486	12.993	39.849	37.615	26.032	9.974
AXXH21RB	5.16	1	15.445	22.128	15.586	52.702	49.749	36.684	21.009
AXXM19RB	5.16	2	12.780	16.490	14.272	46.593	51.832	40.139	23.586
AXXL01RB	5.16	3	14.690	24.913	15.818	51.698	49.343	37.785	21.829
PT1L2B1R	5.16	4	8.666	17.639	9.382	33.788	32.604	22.825	11.263
PT1L3B1R	5.16	5	14.154	24.093	13.889	51.052	47.107	33.342	15.696
PT1L3B2R	5.16	6	12.363	20.792	12.134	50.091	47.482	38.427	19.638

Quaking Aspen (Populus tremuloides)

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Leaf Transmittance/Top:									
A25H29TF	5.7	1	2.408	7.910	4.155	43.467	46.150	39.131	25.560
A26H21TF	5.7	2	1.475	4.916	2.808	41.232	43.716	36.259	22.073
A25M11TF	5.7	3	1.977	7.014	3.039	45.225	46.025	36.747	20.452
A26M11TF	5.7	4	1.679	6.140	2.868	46.152	47.286	40.024	24.415
A25L01TF	5.7	5	1.756	5.785	3.127	42.998	44.107	35.721	20.019
A26L01TF	5.7	6	1.712	5.302	2.765	40.383	43.008	36.339	22.341
PT3L2T1T	5.7	7	3.690	14.945	7.960	45.549	53.544	46.854	29.613
A27H21TF	5.12	1	2.053	8.196	3.791	47.764	43.470	35.750	22.140
A27M19TF	5.12	2	2.751	9.488	4.740	47.151	48.051	39.272	23.178
A27L01TF	5.12	3	1.526	6.185	3.189	41.046	41.741	33.446	19.033
PT2L2T1T	5.12	4	9.036	27.819	13.240	54.989	55.142	47.803	15.873
AXXH21TF	5.17	1	1.402	4.405	2.261	39.264	40.675	32.204	17.723
AXXM19TF	5.17	2	0.764	1.877	1.841	26.546	38.363	32.403	20.100
AXXL01TF	5.17	3	2.787	9.853	4.523	39.572	41.515	34.369	19.971
PT1L2T1T	5.17	4	9.109	28.886	14.053	54.971	58.744	52.361	34.680
PT1L3T1T	5.17	5	1.589	7.270	2.738	41.284	42.481	31.634	7.153
PT1L3T2T	5.17	6	1.777	6.635	2.591	40.231	41.544	37.129	19.402
Leaf Transmittance/Bottom:									
A25H29TB	5.8	1	2.118	7.480	4.112	43.016	46.553	40.279	26.810
A26H21TB	5.8	2	1.580	6.704	3.031	46.368	47.341	37.903	20.532
A25M11TB	5.8	3	2.079	6.269	3.398	44.772	45.885	37.254	21.039
A26M11TB	5.8	4	1.573	5.426	2.660	44.821	46.243	39.359	25.159
A25L01TB	5.8	5	1.433	4.949	2.665	42.880	44.614	37.187	21.962
A26L01TB	5.8	6	1.594	5.445	2.972	43.132	46.087	37.834	22.224
A27H21TB	5.13	1	2.003	7.704	3.898	42.813	43.679	36.065	23.005
A27M19TB	5.13	2	2.420	8.363	4.343	46.232	47.712	39.830	24.094
A27L01TB	5.13	3	1.511	5.662	2.802	40.290	41.741	34.137	19.435
PT2L2B1T	5.13	4	8.680	27.590	12.075	56.943	57.613	48.410	15.542
AXXH21TB	5.18	1	1.480	4.760	2.785	41.611	43.161	33.169	17.479
AXXM19TB	5.18	2	0.926	2.515	2.014	26.733	37.334	31.944	19.958
AXXL01TB	5.18	3	2.711	9.881	4.378	42.189	43.975	36.798	21.875
PT1L2B1T	5.18	4	9.271	30.111	14.499	57.417	59.522	51.976	26.441
PT1L3B1T	5.18	5	1.532	6.527	2.265	39.082	39.450	29.472	10.807
PT1L3B2T	5.18	6	1.863	6.911	2.535	39.794	41.765	37.070	20.683

Quaking Aspen (Populus tremuloides) cont.

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Bark Reflectance:									
A25HB1RF	5.9	1	16.203	21.441	21.738	71.859	66.736	37.195	21.683
A26HB1RF	5.9	2	25.821	32.494	36.779	71.587	66.835	41.696	28.893
A25MB1RF	5.9	3	16.136	19.960	19.534	62.522	58.079	35.439	23.267
A26MB1RF	5.9	4	16.975	22.435	24.790	67.643	64.433	39.141	25.323
A25LB1RF	5.9	5	18.073	19.878	22.479	31.104	38.871	43.223	37.276
A26LB1RF	5.9	6	21.154	24.083	27.413	39.297	52.271	48.308	36.854
A27HB1RF	5.14	1	12.422	17.312	18.337	62.955	59.913	30.887	18.303
A27MB1RF	5.14	2	14.346	17.549	19.611	26.897	48.769	32.898	20.681
A27LB1RF	5.14	3	13.710	17.930	18.975	56.822	55.245	33.141	20.449
PT0B200R	5.14	4	7.065	9.503	10.426	29.684	41.565	24.356	4.835

Beaked Hazel (Corylus cornuta)

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Leaf Reflectance/Top:									
CC0L3T1R	5.36	1	5.032	10.189	5.046	43.927	42.907	36.844	24.451
Leaf Reflectance/Bottom:									
CC0L3B1R	5.37	1	12.259	16.695	11.223	36.818	35.989	30.609	16.675
Leaf Transmittance/Top:									
CC0L3T1T	5.38	1	2.905	11.394	3.991	43.216	46.199	43.754	31.136
Leaf Transmittance/Bottom:									
CC0L3B1T	5.39	1	3.359	10.560	3.951	40.782	43.871	40.115	31.177

Labrador Tea (Ledum groenlandicum)

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Leaf Reflectance/Top:									
LG0L7T1R	5.36	2	5.835	15.080	6.289	63.527	64.294	41.256	18.050

Leatherleaf (Chamaedaphne calyculata)

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Leaf Reflectance/Top:									
CH0L7T1R	5.36	3	5.760	13.149	6.325	66.766	63.900	38.129	12.713

Sphagnum Moss (Sphagnum spp)

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Plant Reflectance/Top:									
SM00201R	5.40	1	6.172	11.838	14.263	27.062	29.836	12.181	1.579
SM607T1R	5.40	2	15.608	29.521	24.383	61.302	65.386	51.722	17.664
SM707T1R	5.40	3	4.806	11.209	7.445	32.156	26.639	6.244	0.835
SM807T1R	5.40	4	5.266	11.393	12.794	48.649	49.280	22.533	4.016

Leaf Litter

File	Fig.	Line	TM 1	TM 2	TM 3	TM 4	TM 5	TM 6	TM 7
Reflectance/Top:									
BL00201R	5.41	1	6.078	8.687	13.104	23.040	33.820	35.820	9.864

Table 5.3 - Figure Captions

Figures 5.1 through 5.4: Broad-leaf trees

Line	Description
1	Paper birch leaf from lower canopy, collected June 1984
2	Paper birch leaf from upper canopy, collected June 1984
3	Red maple leaf from lower canopy, collected June 1984
4	Red maple leaf from upper canopy, collected June 1984

Figures 5.5 through 5.8: Aspen leaves from high-density stand

Line	Description
1	Leaf from upper canopy of tree 25, collected 1983
2	Leaf from upper canopy of tree 26, collected 1983
3	Leaf from middle canopy of tree 25, collected 1983
4	Leaf from middle canopy of tree 26, collected 1983
5	Leaf from lower canopy of tree 25, collected 1983
6	Leaf from lower canopy of tree 26, collected 1983
7	Leaf described as "very mottled and probably diseased," collected May 1984

Figure 5.9: Aspen bark reflectance from high-density stand

Line	Description
1	Bark from upper canopy of tree 25, collected 1983
2	Bark from upper canopy of tree 26, collected 1983
3	Bark from middle canopy of tree 25, collected 1983
4	Bark from middle canopy of tree 26, collected 1983
5	Bark from lower canopy of tree 25, collected 1983
6	Bark from lower canopy of tree 26, collected 1983

Figures 5.10 through 5.13: Aspen leaves from middle-density stand

Line	Description
1	Leaf from upper canopy of tree 27, collected 1983
2	Leaf from middle canopy of tree 27, collected 1983
3	Leaf from lower canopy of tree 27, collected 1983
4	Leaf described as "most uniform in color and clean" of mottled leaves sent, collected May 1984

Figure 5.14: Aspen bark reflectance from middle-density stand

Line	Description
1	Bark from upper canopy of tree 27, collected 1983
2	Bark from middle canopy of tree 27, collected 1983
3	Bark from lower canopy of tree 27, collected 1983
4	Bark collected May 1984, stand density or canopy height unknown

Figures 5.15 through 5.18: Aspen leaves from low-density stand

Line	Description
1	Leaf from upper canopy of tree XX, collected 1983
2	Leaf from middle canopy of tree XX, collected 1983
3	Leaf from lower canopy of tree XX, collected 1983
4	Leaf with dark spots, collected May 1984
5	Leaf from lower canopy, collected June 1984
6	Leaf from lower canopy, collected June 1984

Figure 5.19: Average and plus-and-minus one standard deviation aspen leaf-top reflectance from all stand densities and canopy heights, not including diseased leaves, 14 samples used

Figure 5.20: Average and plus-and-minus one standard deviation aspen leaf-bottom reflectance from all stand densities and canopy heights, not including diseased leaves, 14 samples used

Figure 5.21: Average and plus-and-minus one standard deviation aspen leaf-top transmittance from all stand densities and canopy heights, not including diseased leaves, 14 samples used

Figure 5.22: Average and plus-and-minus one standard deviation aspen leaf-bottom transmittance from all stand densities and canopy heights, not including diseased leaves, 14 samples used

Figure 5.23: Average and plus-and-minus one standard deviation aspen bark reflectance from all stand densities and canopy heights, 10 samples used

Figure 5.24: Needle leaf-top reflectance

Line	Description
1	Balsam fir, collected May 1984
2	Jack pine, collected May 1984
3	Jack pine, mixed tops and bottoms of needles, collected 1983
4	Larch, collected May 1984
5	Larch, collected August 1984

Figure 5.24 cont.

Line	Description
6	Red pine, mixed tops and bottoms of needles, collected 1983

Figure 5.25: Needle leaf-bottom reflectance

Line	Description
1	Balsam fir, collected May 1984
2	Jack pine, collected May 1984
3	Larch, collected May 1984
4	Larch, collected August 1984

Figure 5.26: Needle leaf transmittance

Line	Description
1	Jack pine, mixed tops and bottoms of needles, collected 1983
2	Red pine, mixed tops and bottoms of needles, collected 1983

Figure 5.27: Needle-leafed tree bark reflectance

Line	Description
1	Balsam fir, bark air dried, includes some white patches, collected May 1984
2	Jack pine, bark damp, measurement taken on driest piece, collected May 1984
3	Larch, collected May 1984
4	Spruce, collected August 1984

Figures 5.28 and 5.29: Spruce needle reflectance

Line	Description
1	Needles from high-density stand, collected May 1984
2	Needles from middle-density stand, collected May 1984
3	Needles from low-density stand, collected May 1984
4	Collected August 1984
5	Collected August 1984

Figure 5.30: Spruce needle reflectance, mixed tops and bottoms of needles, collected 1983

Line	Description
1	Needles from tree 60
2	Needles from tree 60
3	Needles from tree 60
4	Needles without tree identifier

Figure 5.30 cont.

Line	Description
5	Needles without tree identifier

Figure 5.31: Spruce needle transmittance, mixed tops and bottoms of needles, collected 1983

Line	Description
1	Needles from tree 60
2	Needles from tree 60
3	Needles without tree identifier
4	Needles without tree identifier

Figure 5.32: Average and plus-and-minus one standard deviation spruce needle-top reflectance from 1984 data, five samples used

Figure 5.33: Average and plus-and-minus one standard deviation spruce needle-bottom reflectance from 1984 data, five samples used

Figure 5.34: Average and plus-and-minus one standard deviation spruce needle reflectance, mixed tops and bottoms of needles, from 1983 data, five samples used

Figure 5.35: Average and plus-and-minus one standard deviation spruce needle transmittance, mixed tops and bottoms of needles, from 1983 data, four samples used

Figures 5.36 through 5.39: Shrub leaves

Line	Description
1	Beaked hazel, collected June 1984
2	Labrador tea, collected August 1984
3	Leatherleaf, collected August 1984

Figure 5.40: Sphagnum moss reflectance

Line	Description
1	Collected May 1984
2	Dry sphagnum moss, collected August 1984
3	Collected August 1984
4	Sphagnum moss from hummock, collected August 1984

Figure 41: Aspen leaf-litter reflectance

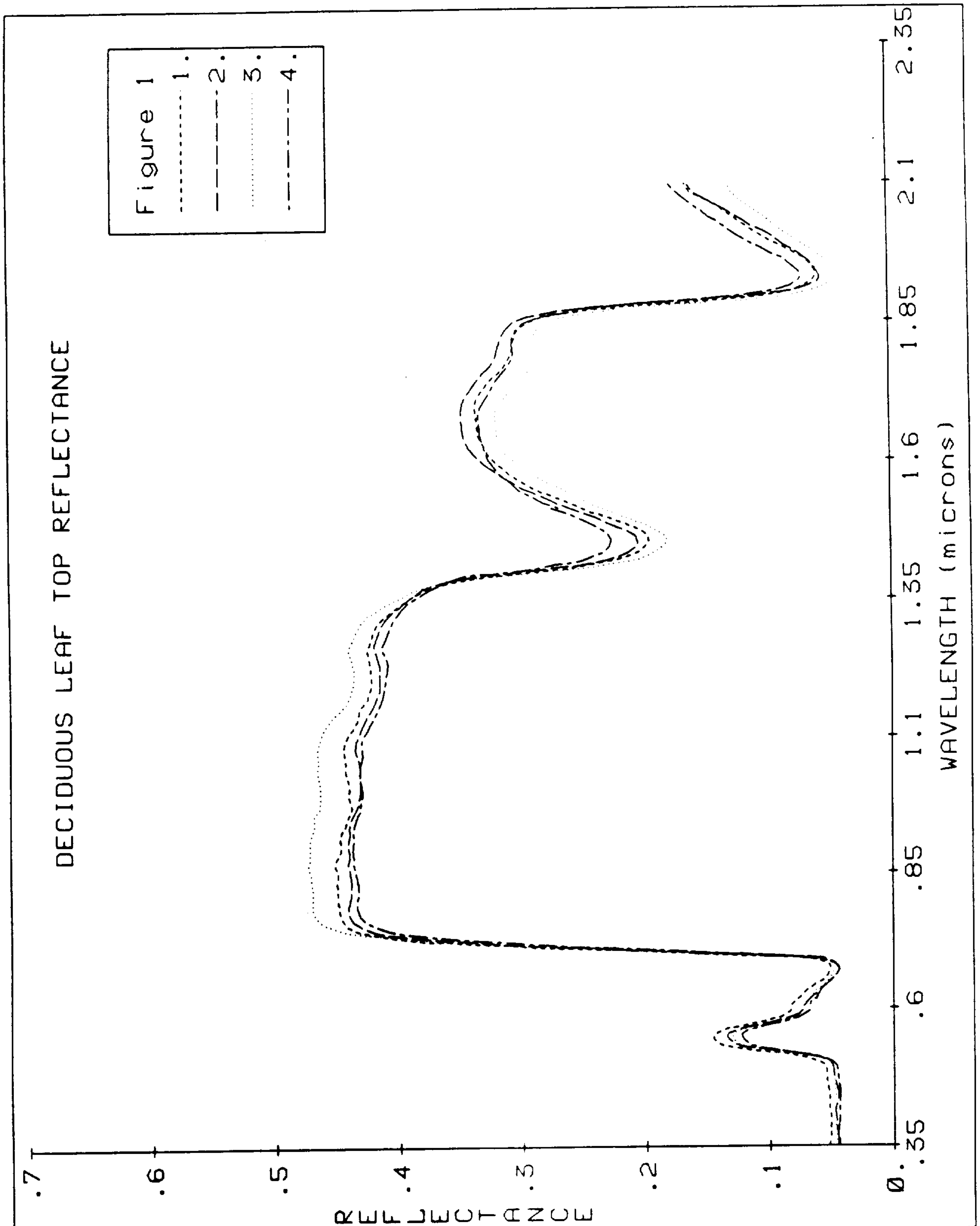

Figure 5.1 See Table 5.3 for description of line numbers.

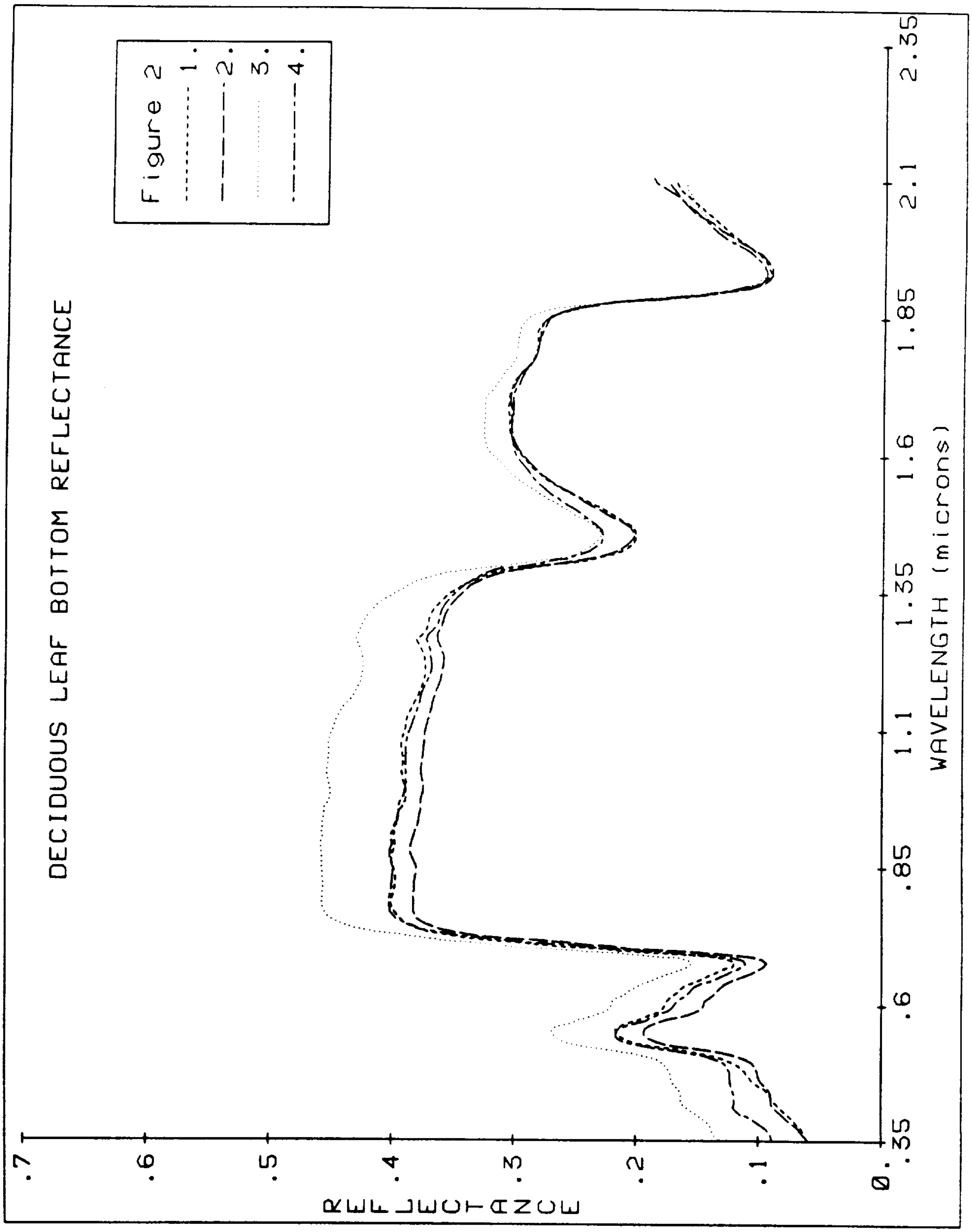

Figure 5.2 See Table 5.3 for description of line numbers.

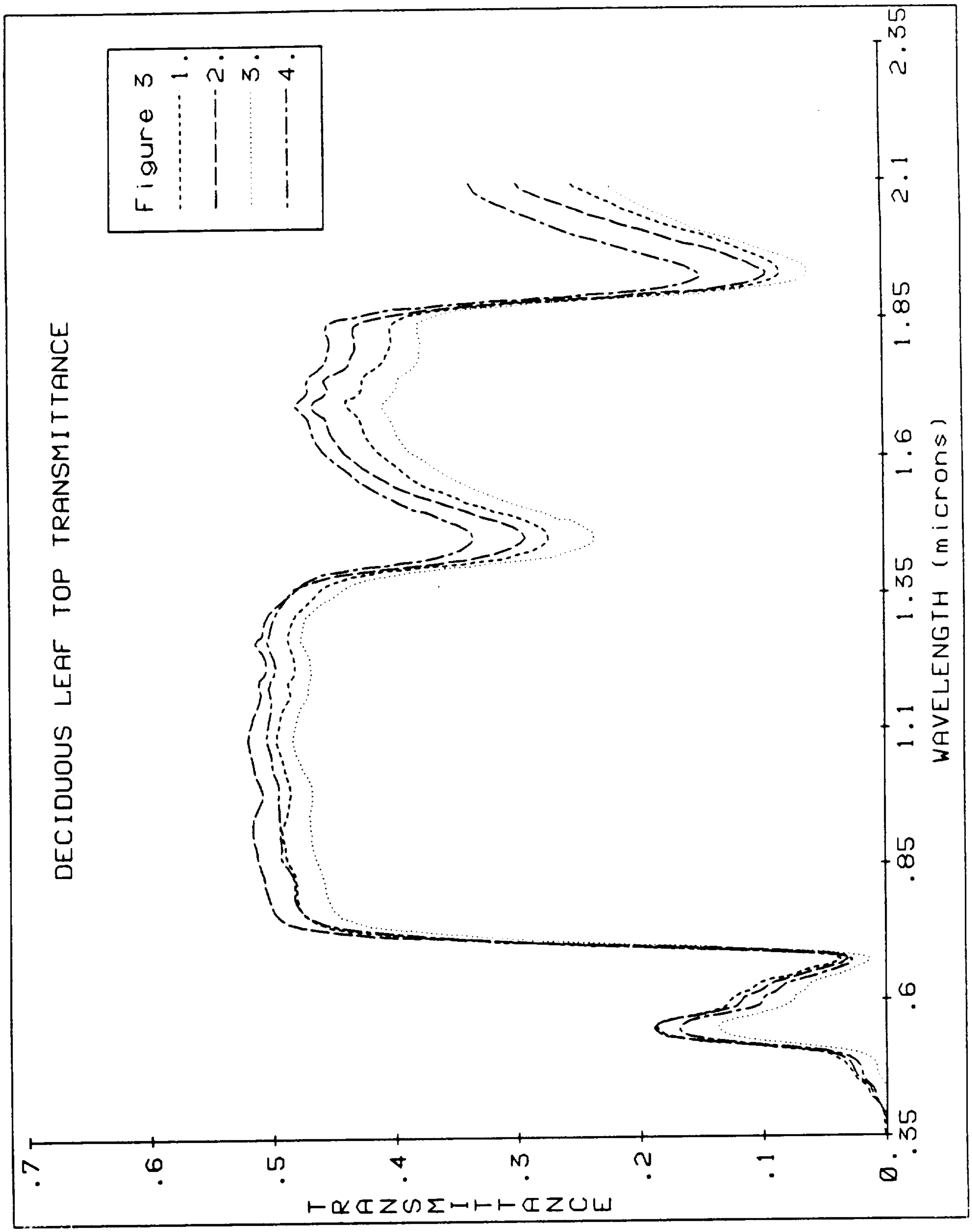

Figure 5.3 See Table 5.3 for description of line numbers.

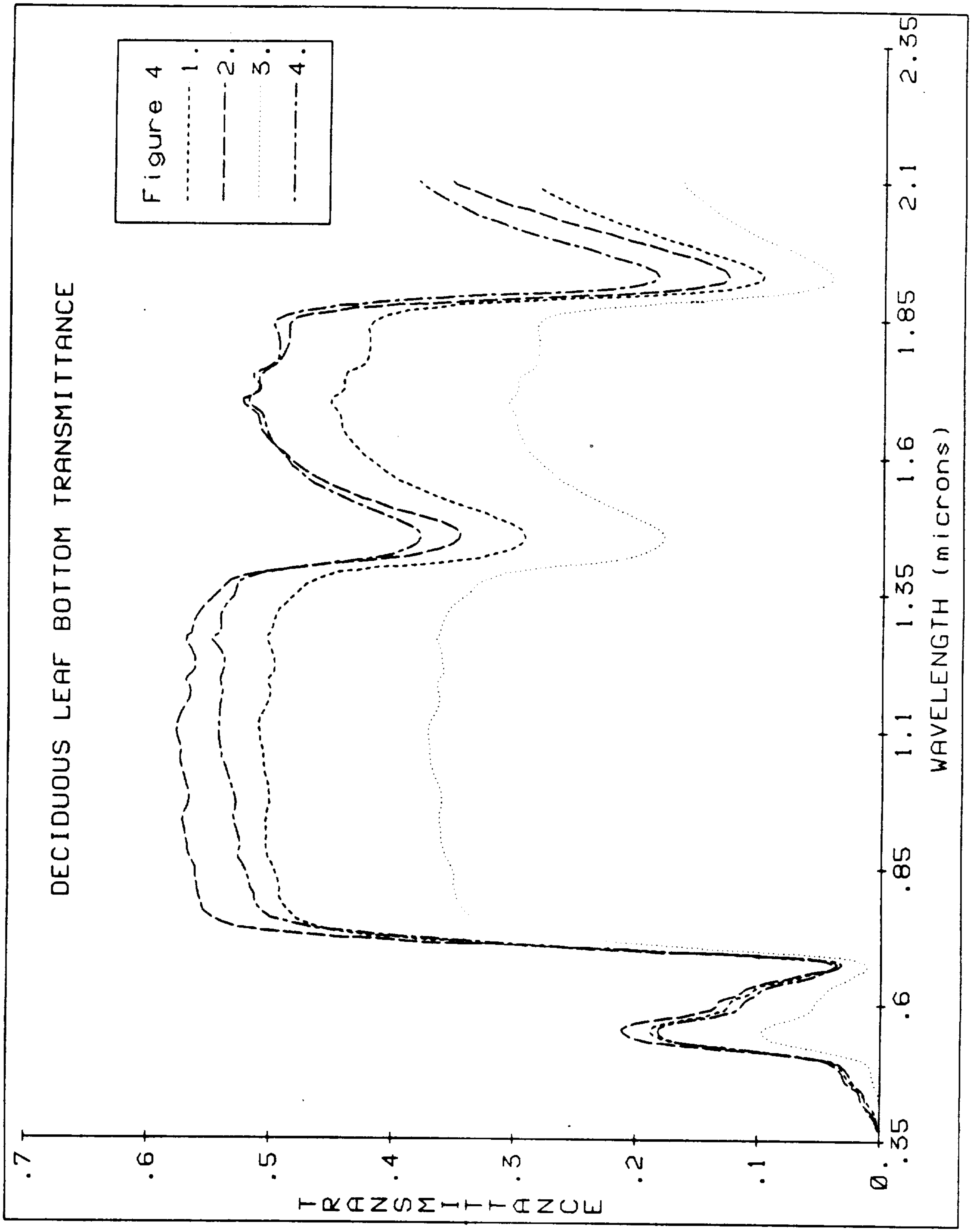

Figure 5.4 See Table 5.3 for description of line numbers.

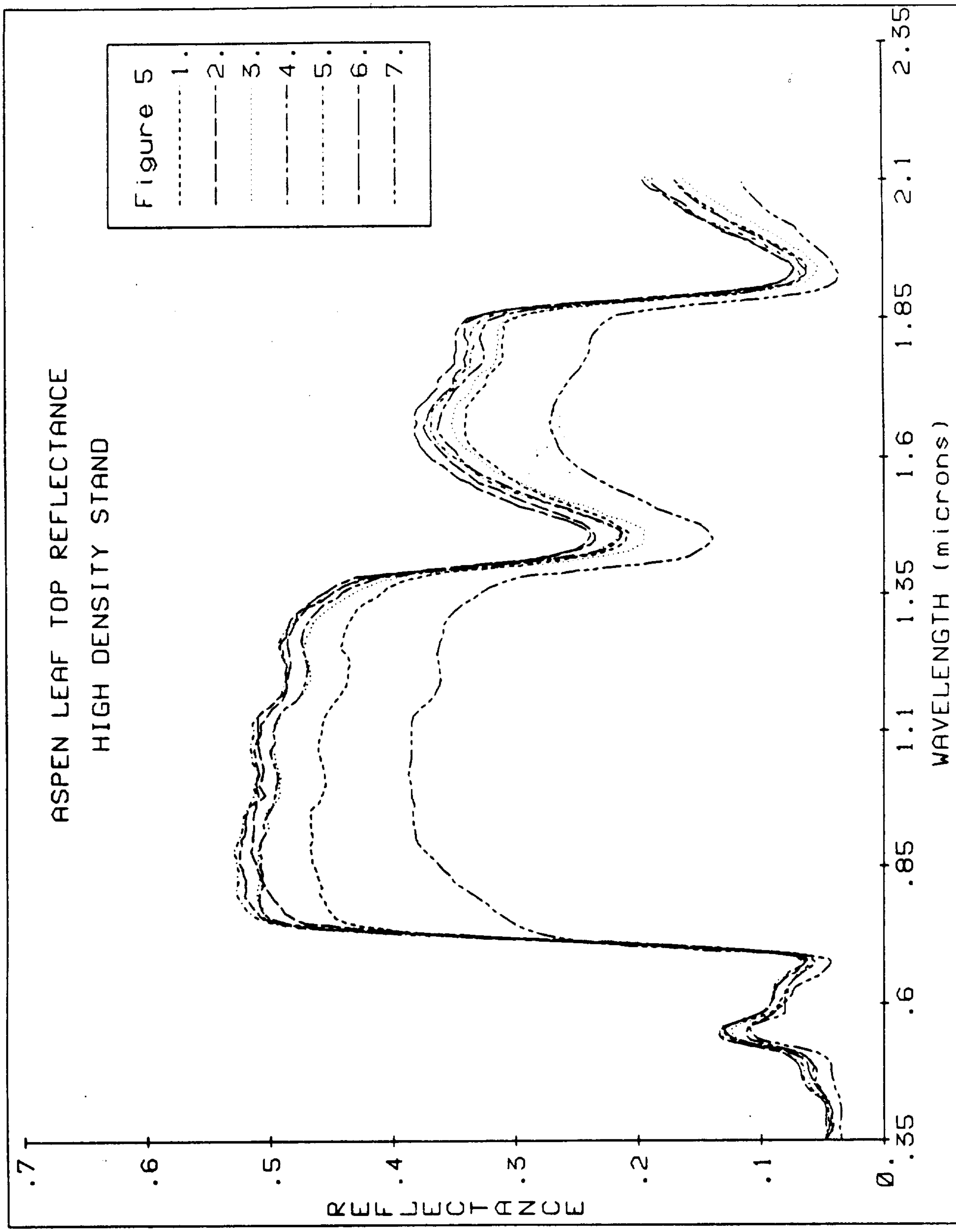

Figure 5.5 See Table 5.3 for description of line numbers.

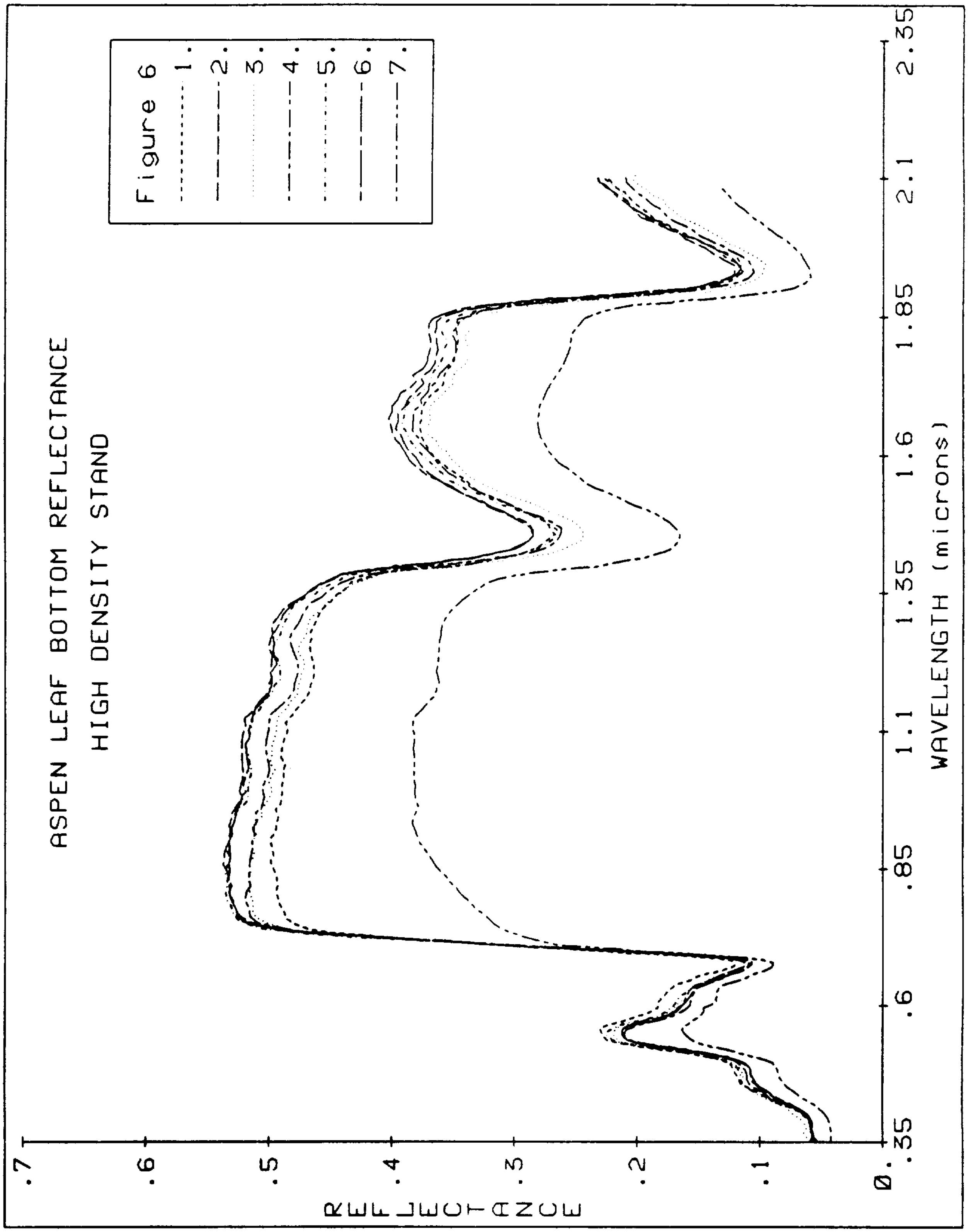

Figure 5.6 See Table 5.3 for description of line numbers.

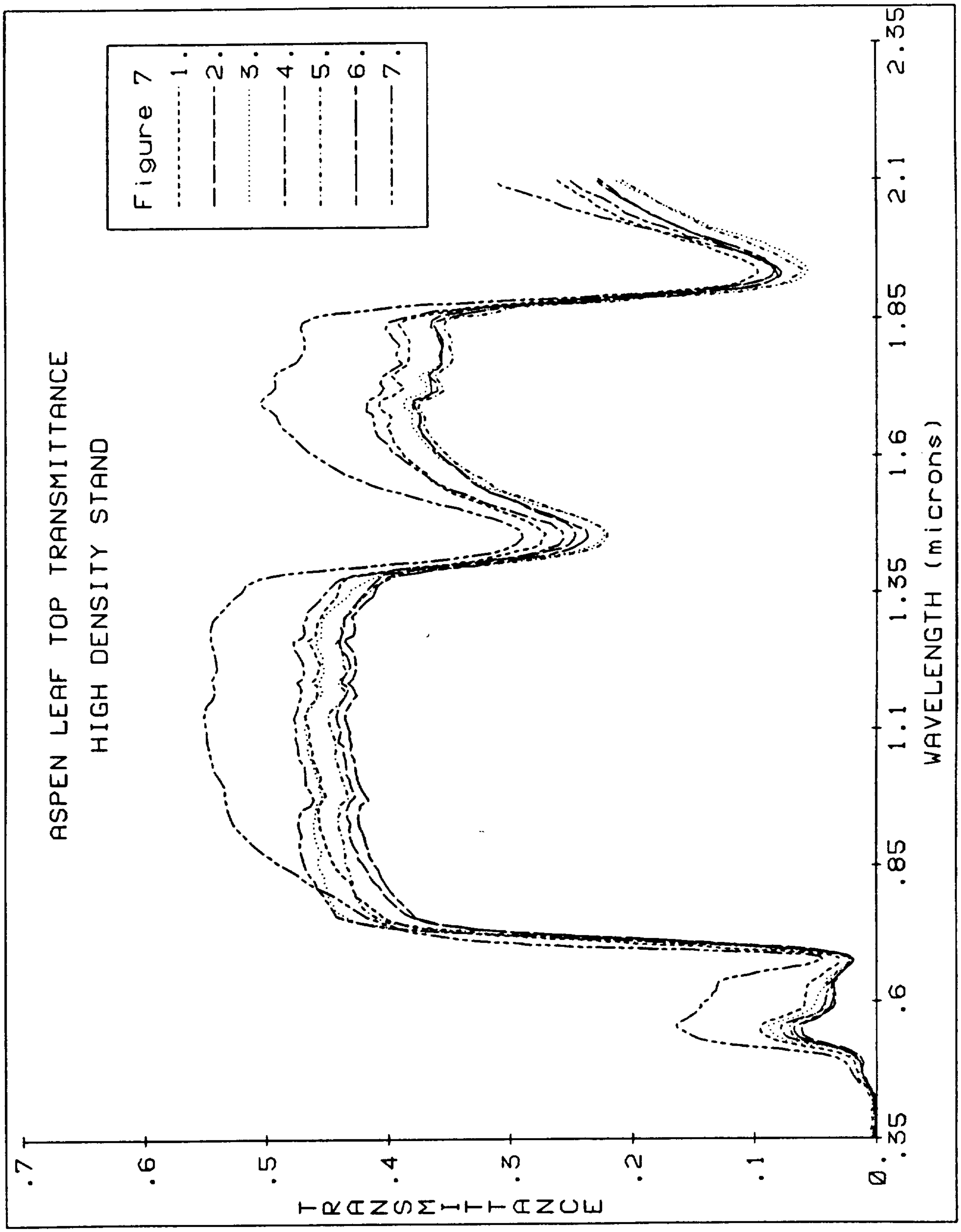

Figure 5.7 See Table 5.3 for description of line numbers.

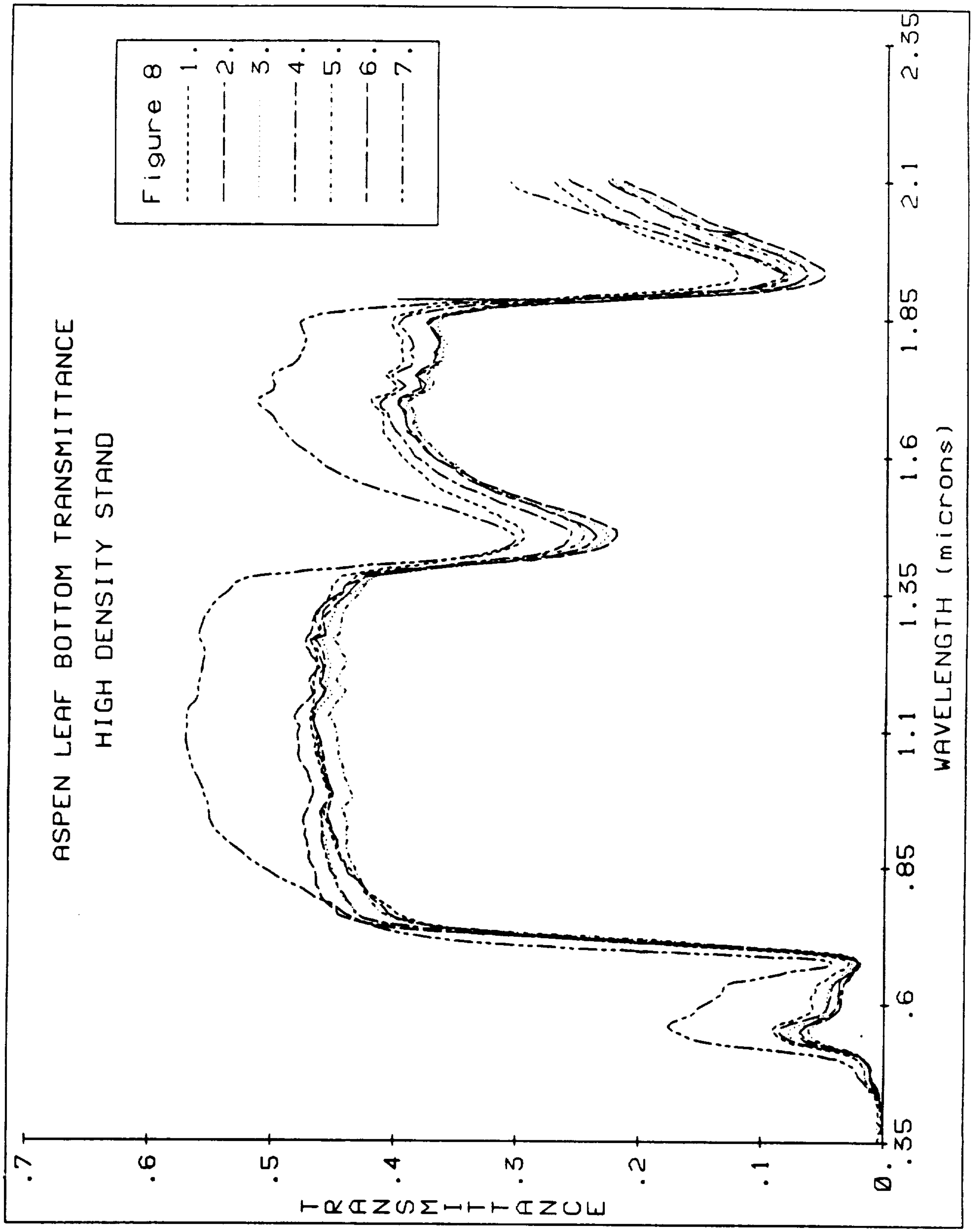

Figure 5.8 See Table 5.3 for description of line numbers.

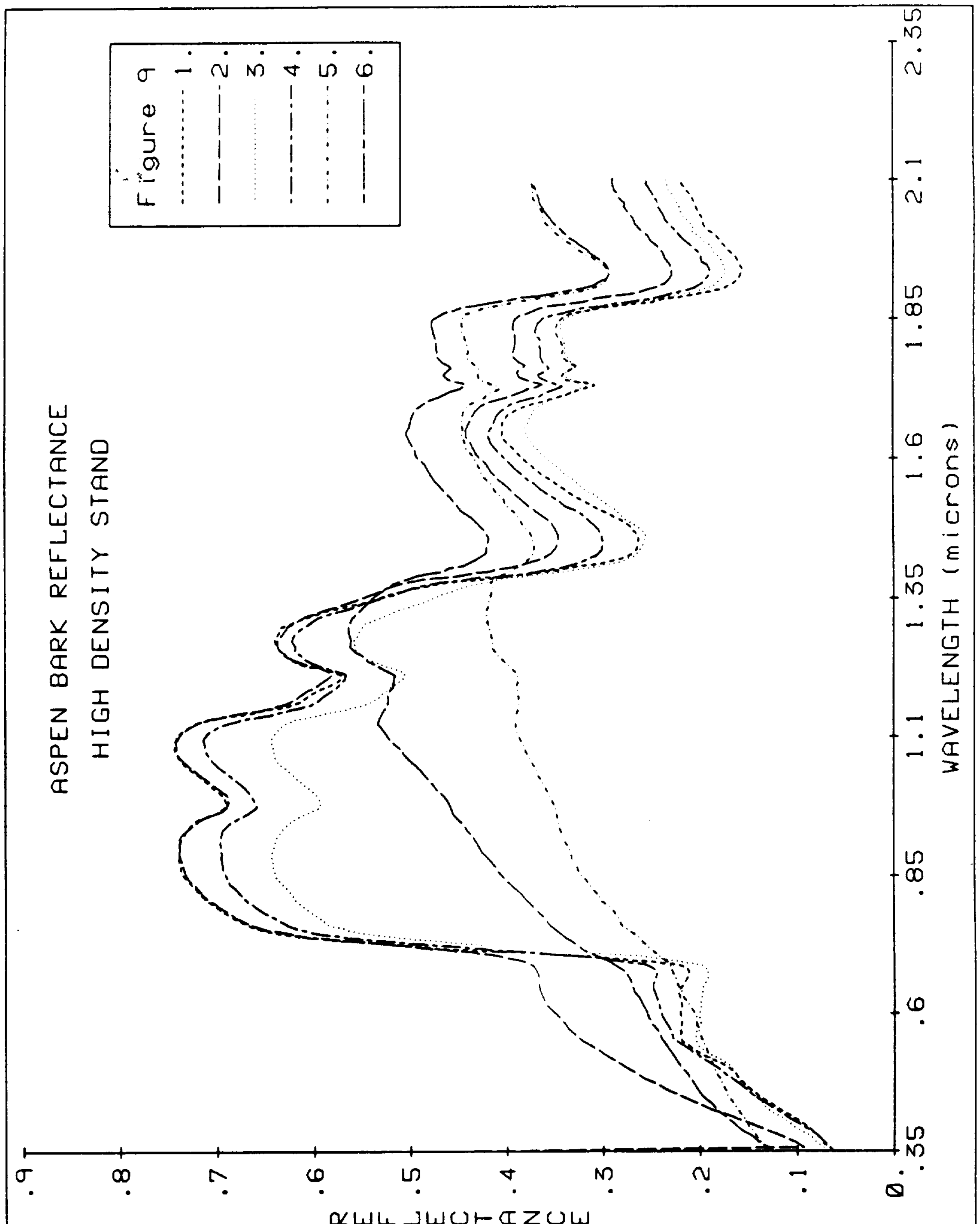

Figure 5.9 See Table 5.3 for description of line numbers.

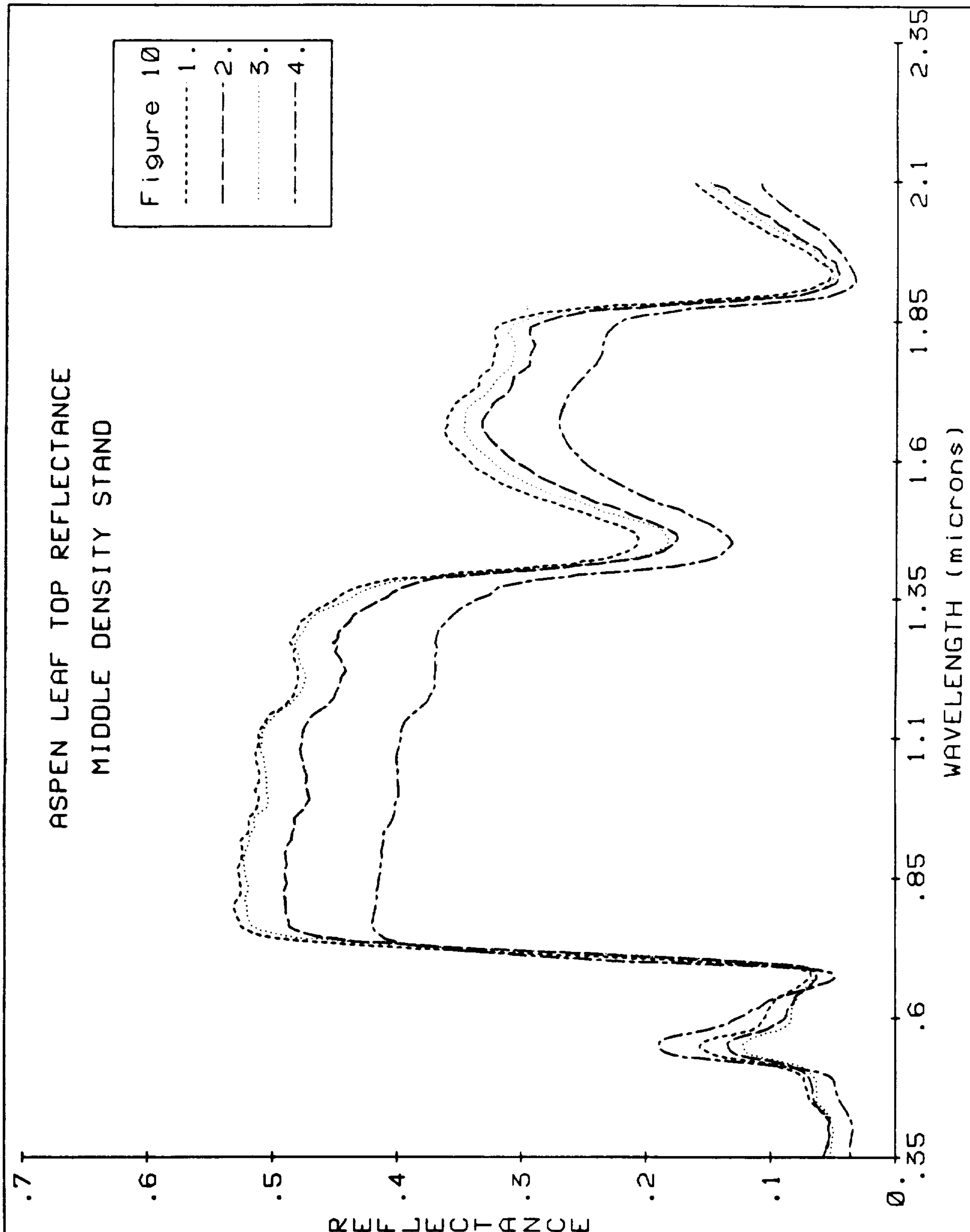

Figure 5.10 See Table 5.3 for description of line numbers.

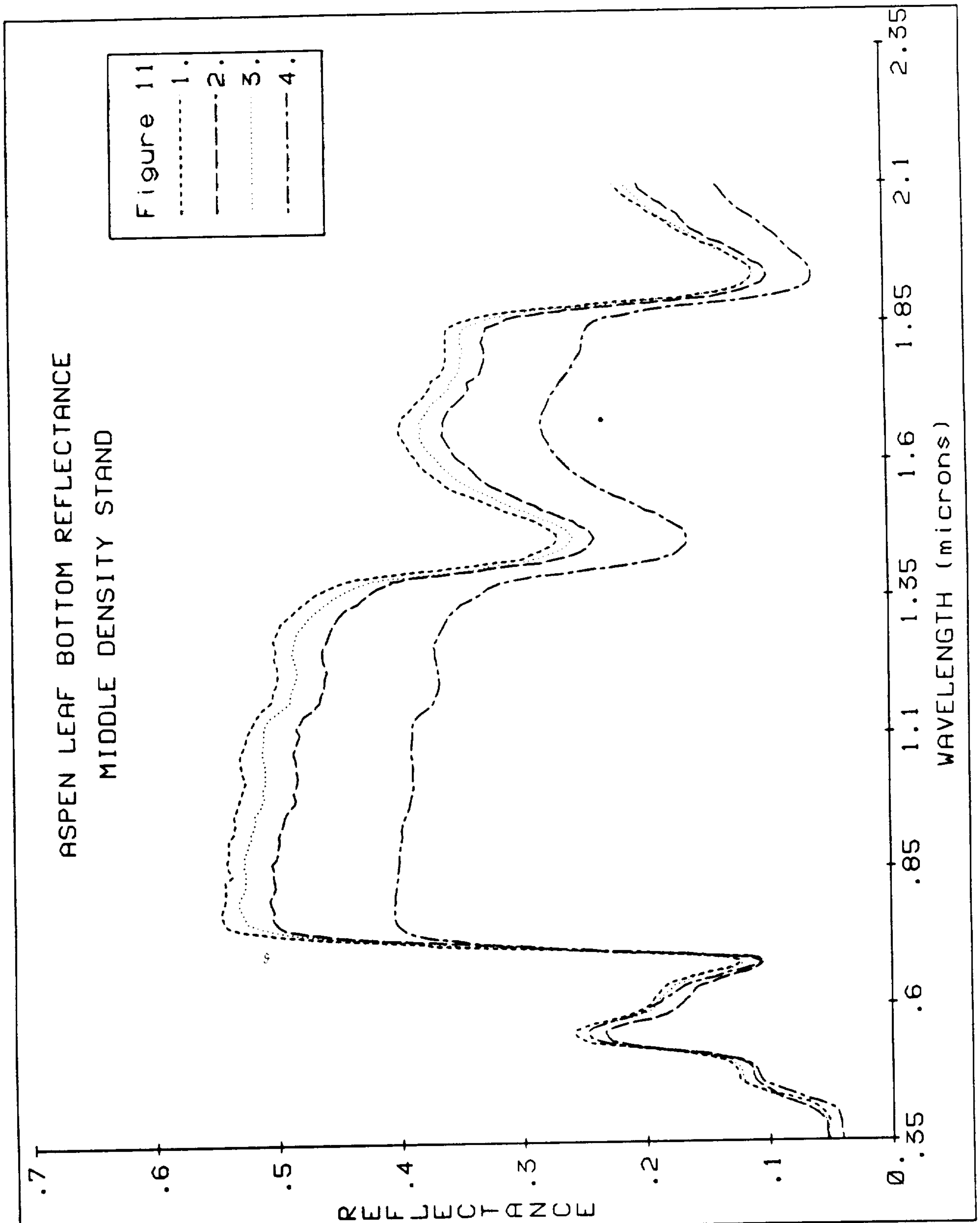

Figure 5.11 See Table 5.3 for description of line numbers.

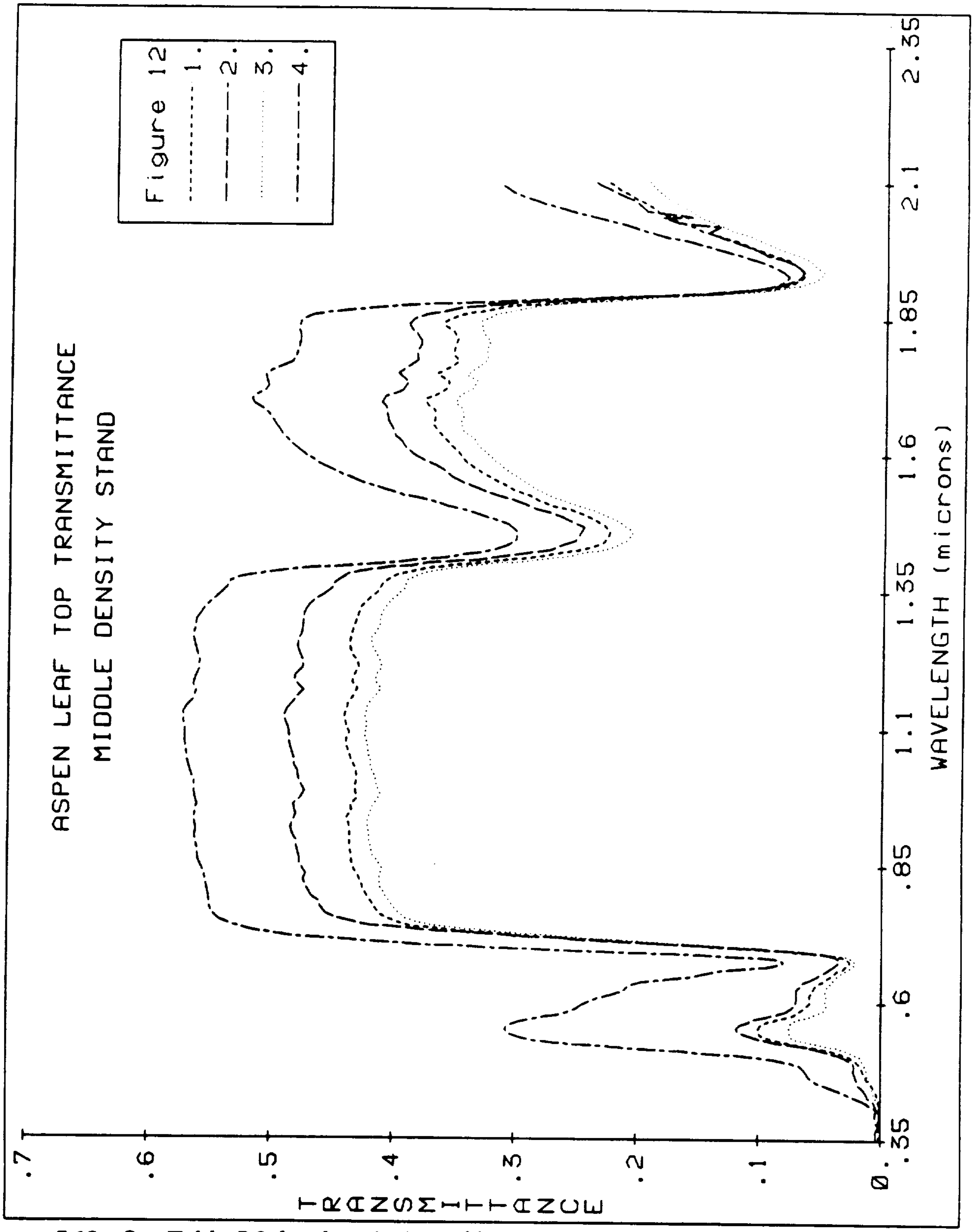

Figure 5.12 See Table 5.3 for description of line numbers.

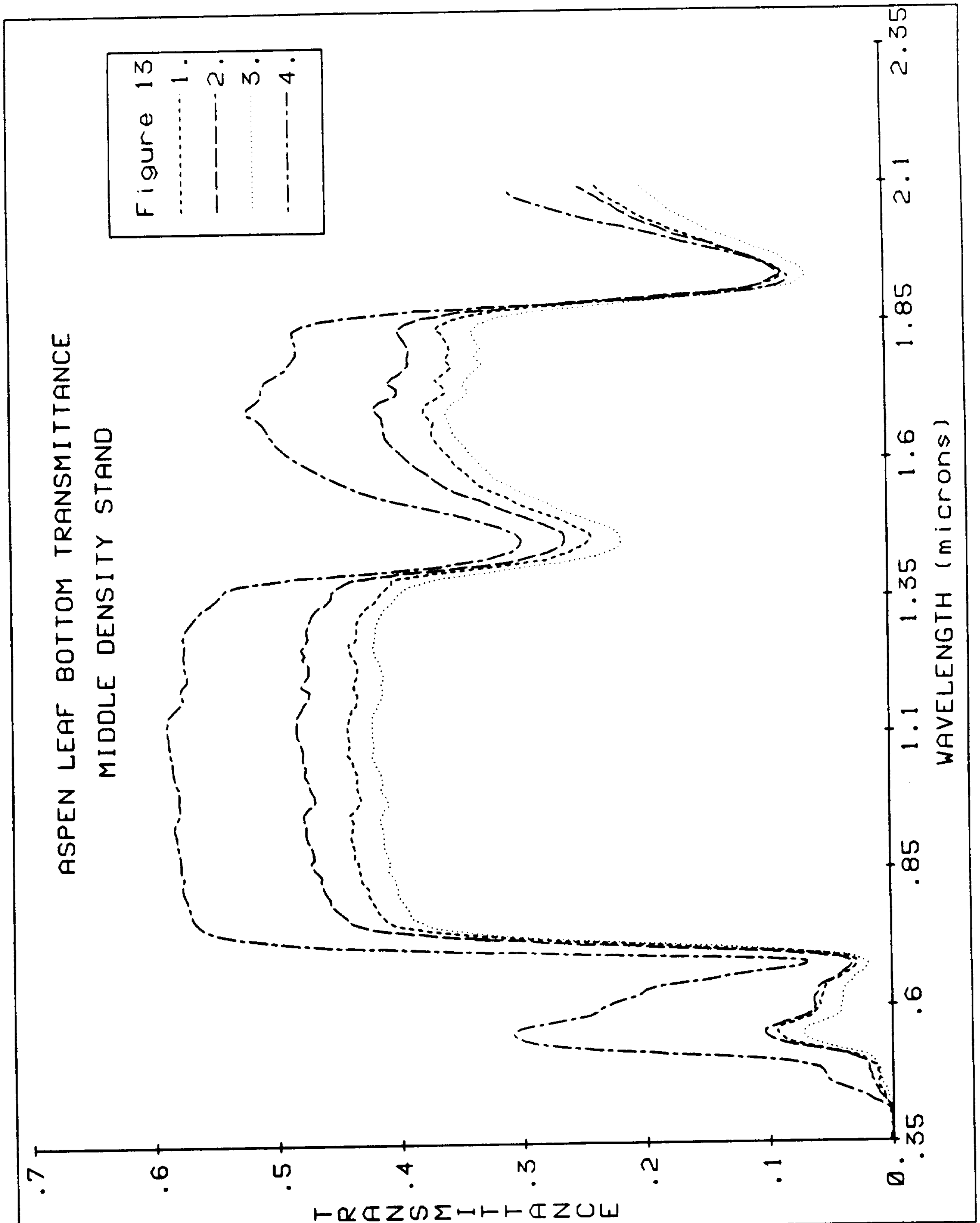

Figure 5.13 See Table 5.3 for description of line numbers.

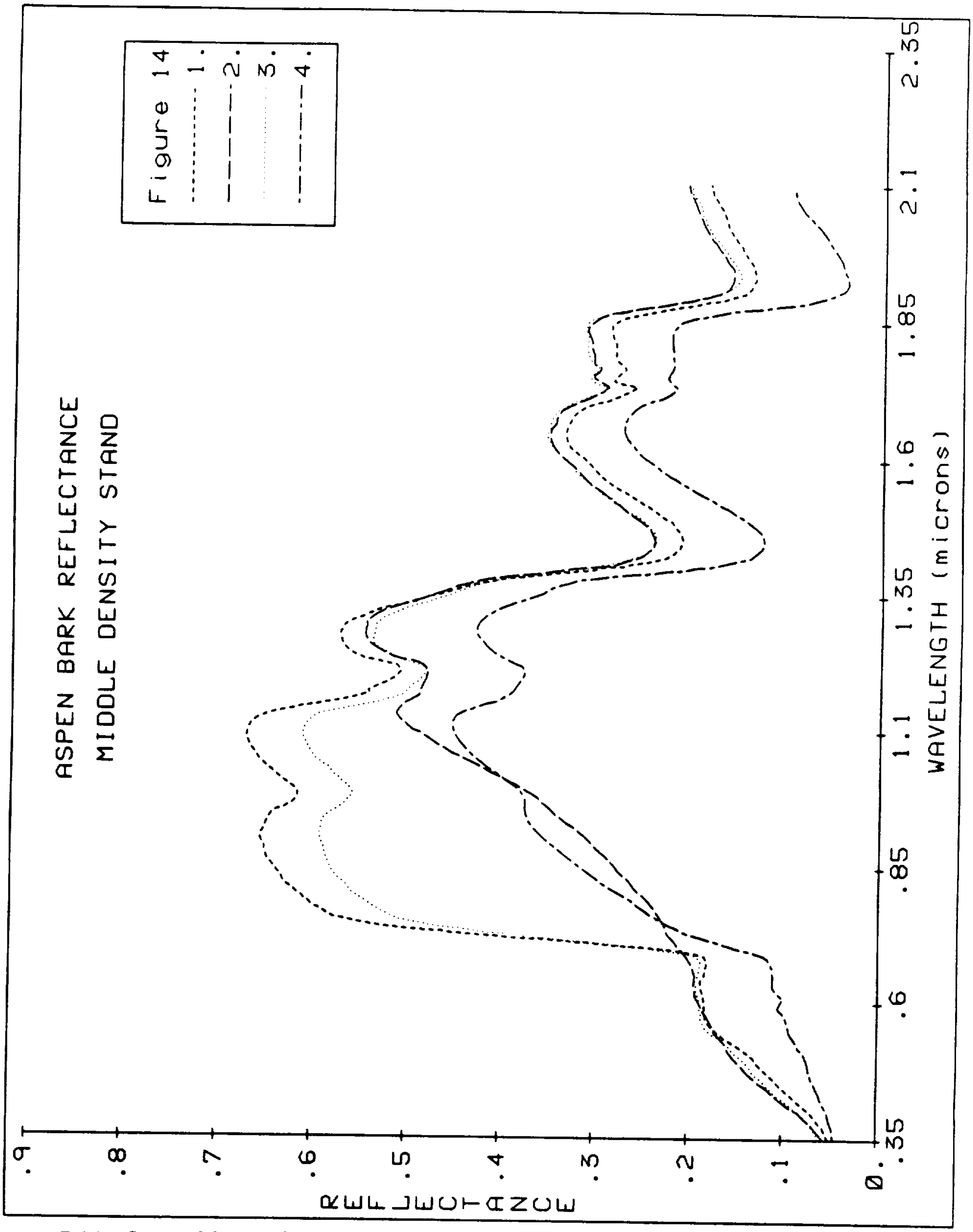

Figure 5.14 See Table 5.3 for description of line numbers.

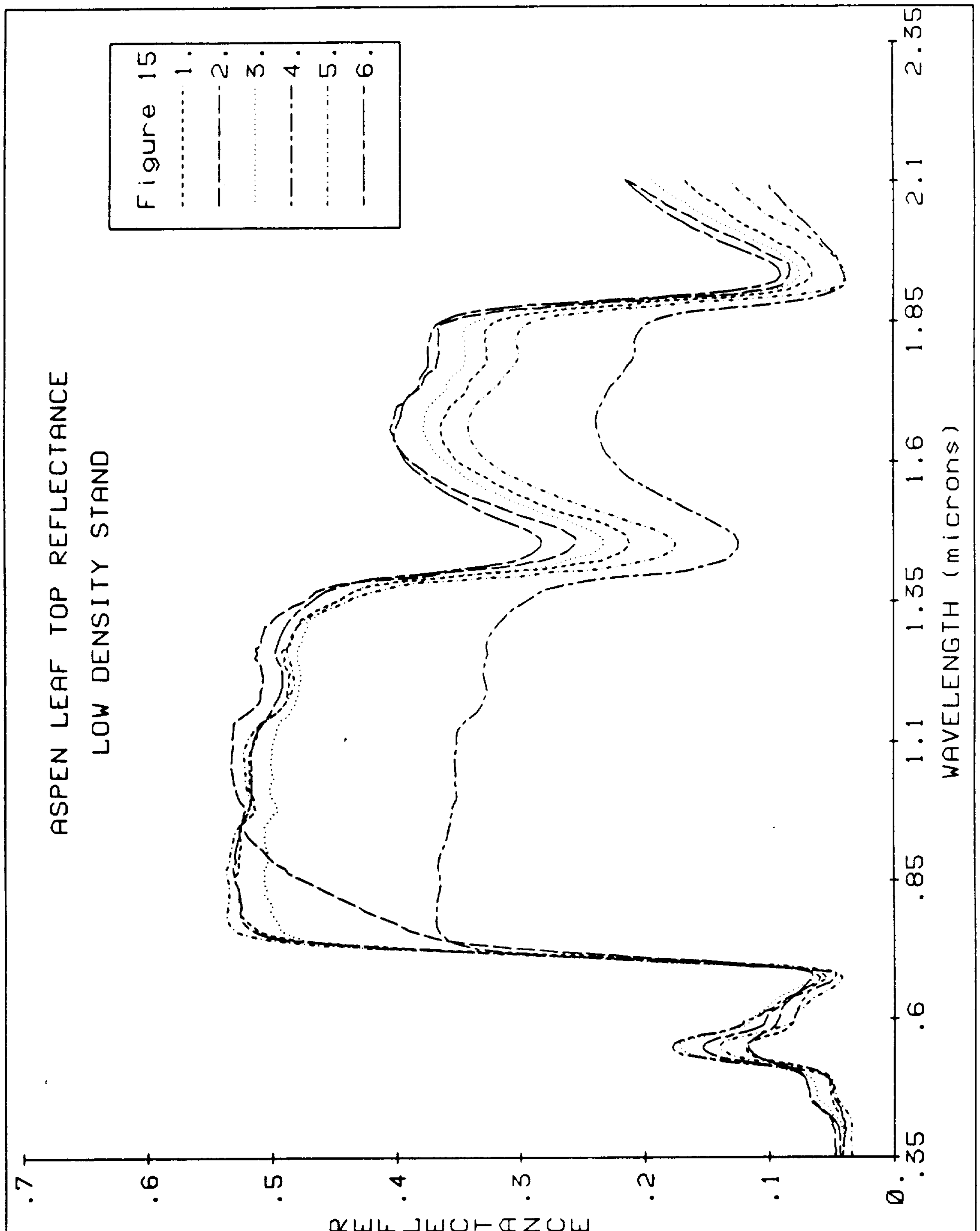

Figure 5.15 See Table 5.3 for description of line numbers.

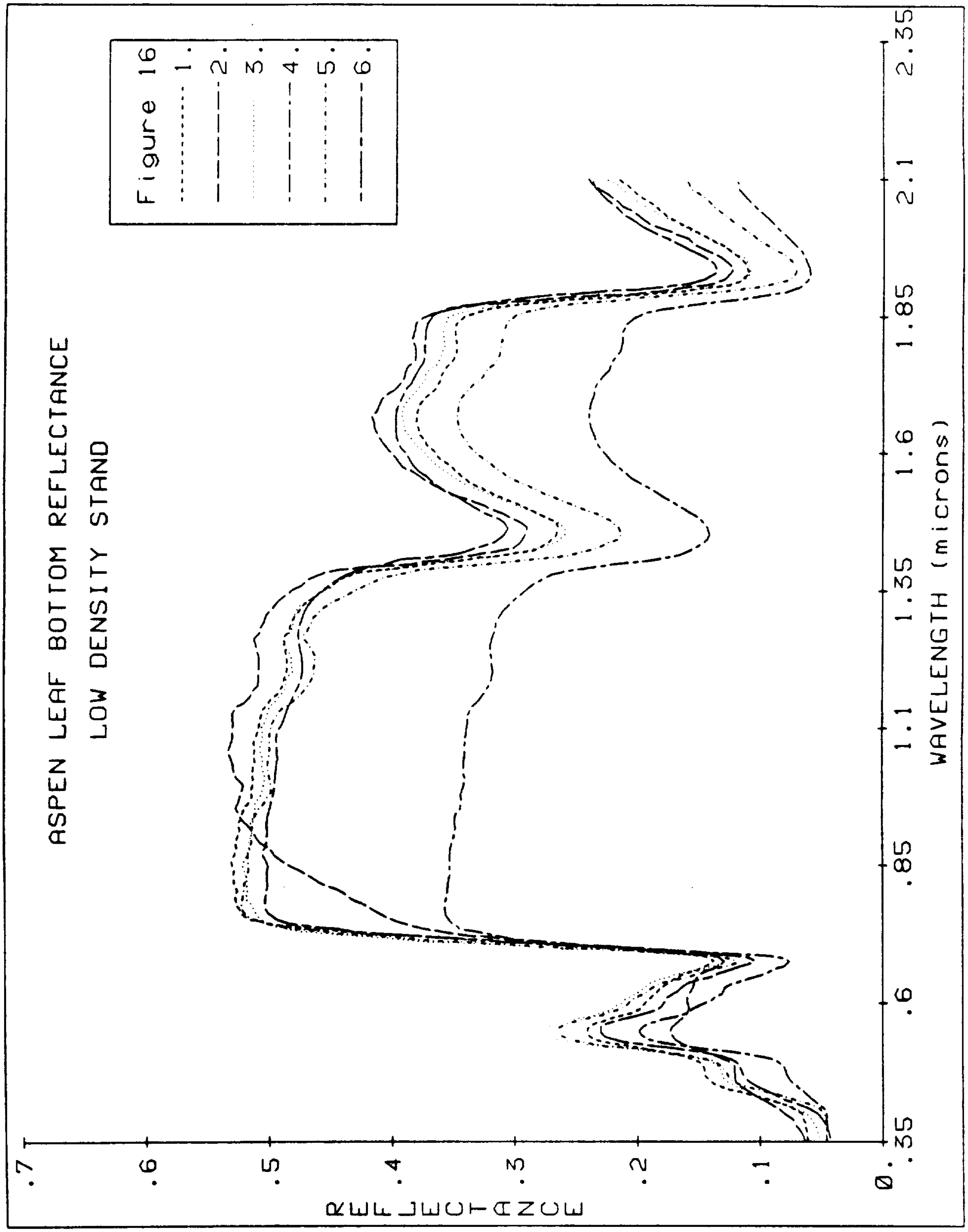

Figure 5.16 See Table 5.3 for description of line numbers.

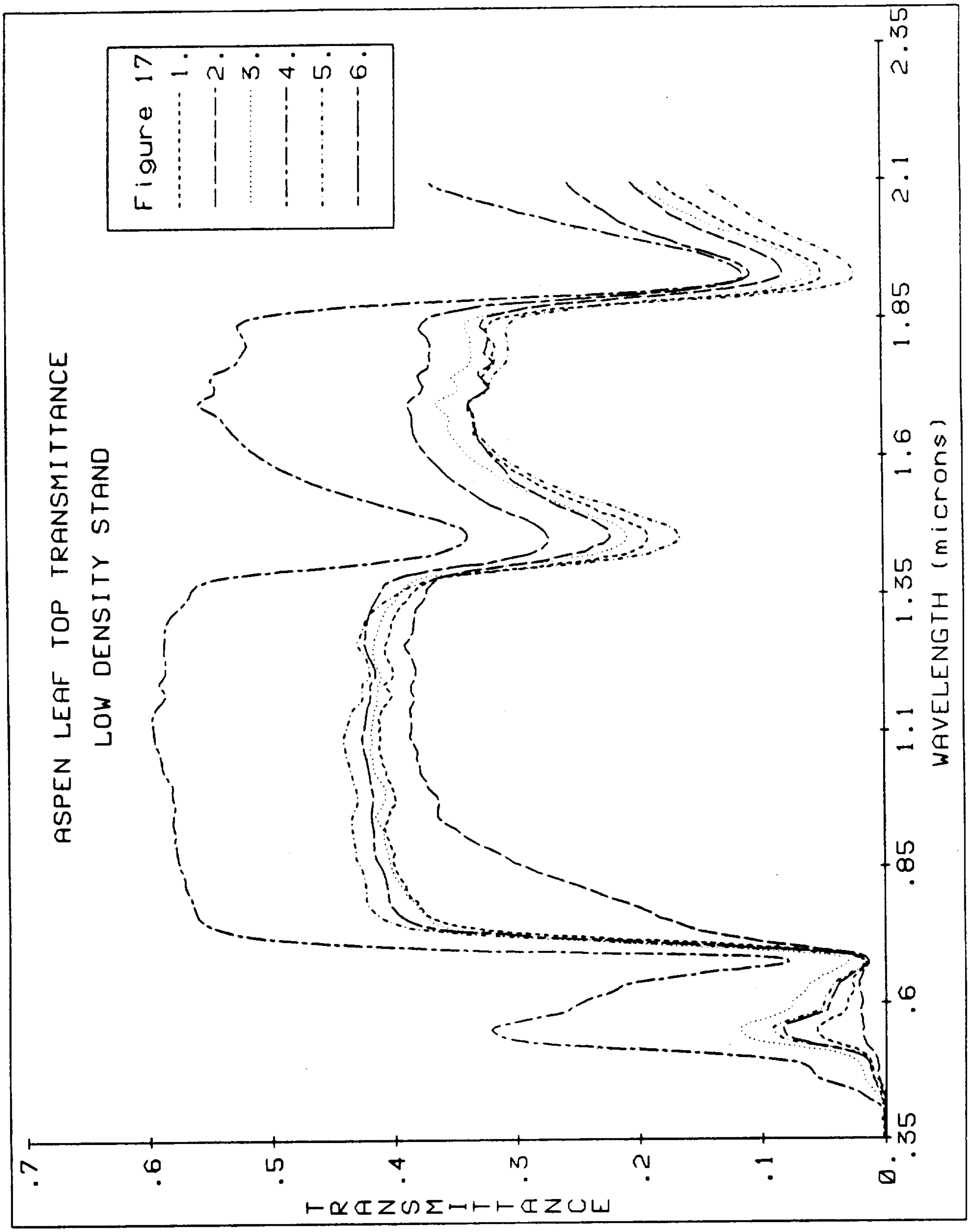

Figure 5.17 See Table 5.3 for description of line numbers.

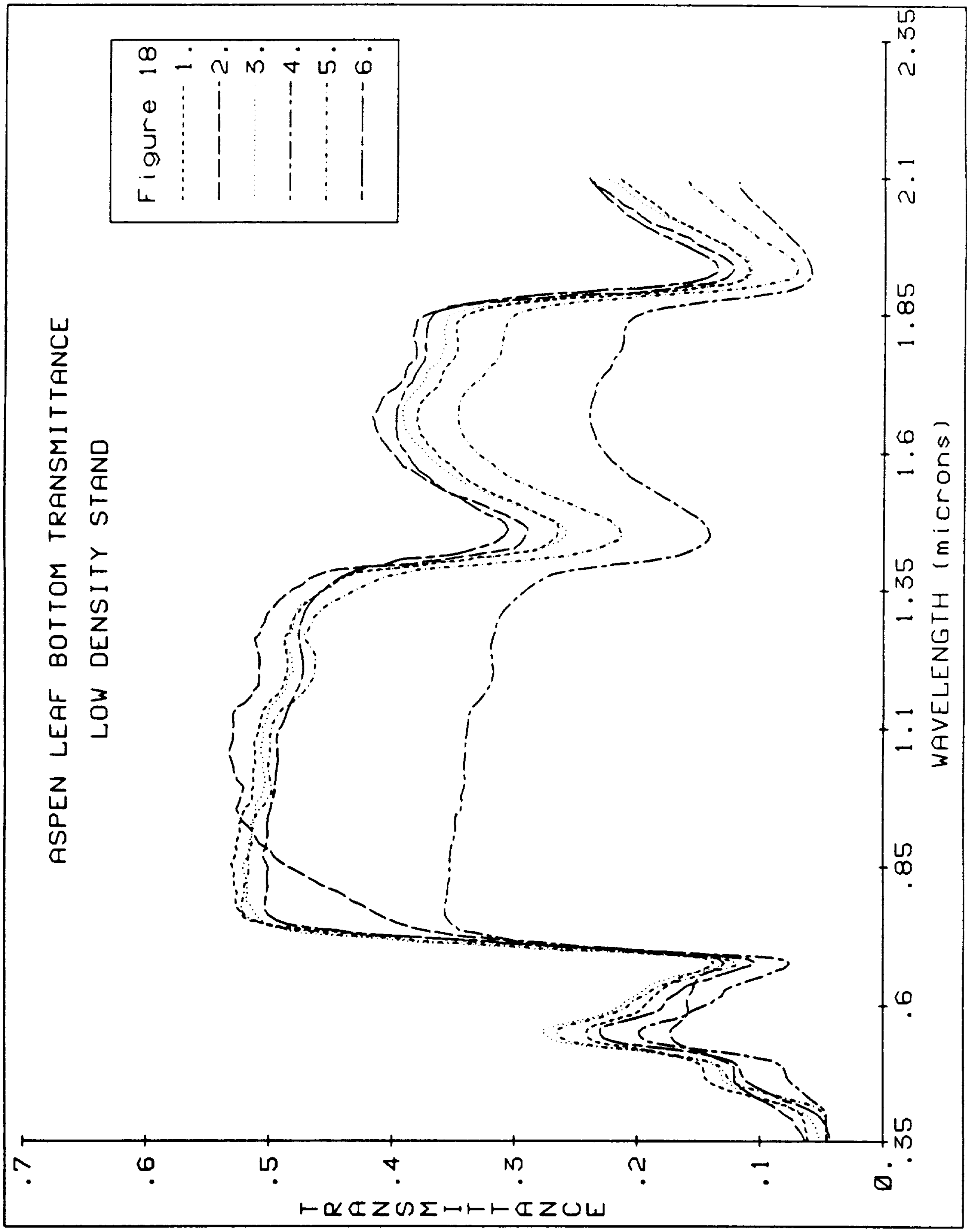

Figure 5.18 See Table 5.3 for description of line numbers.

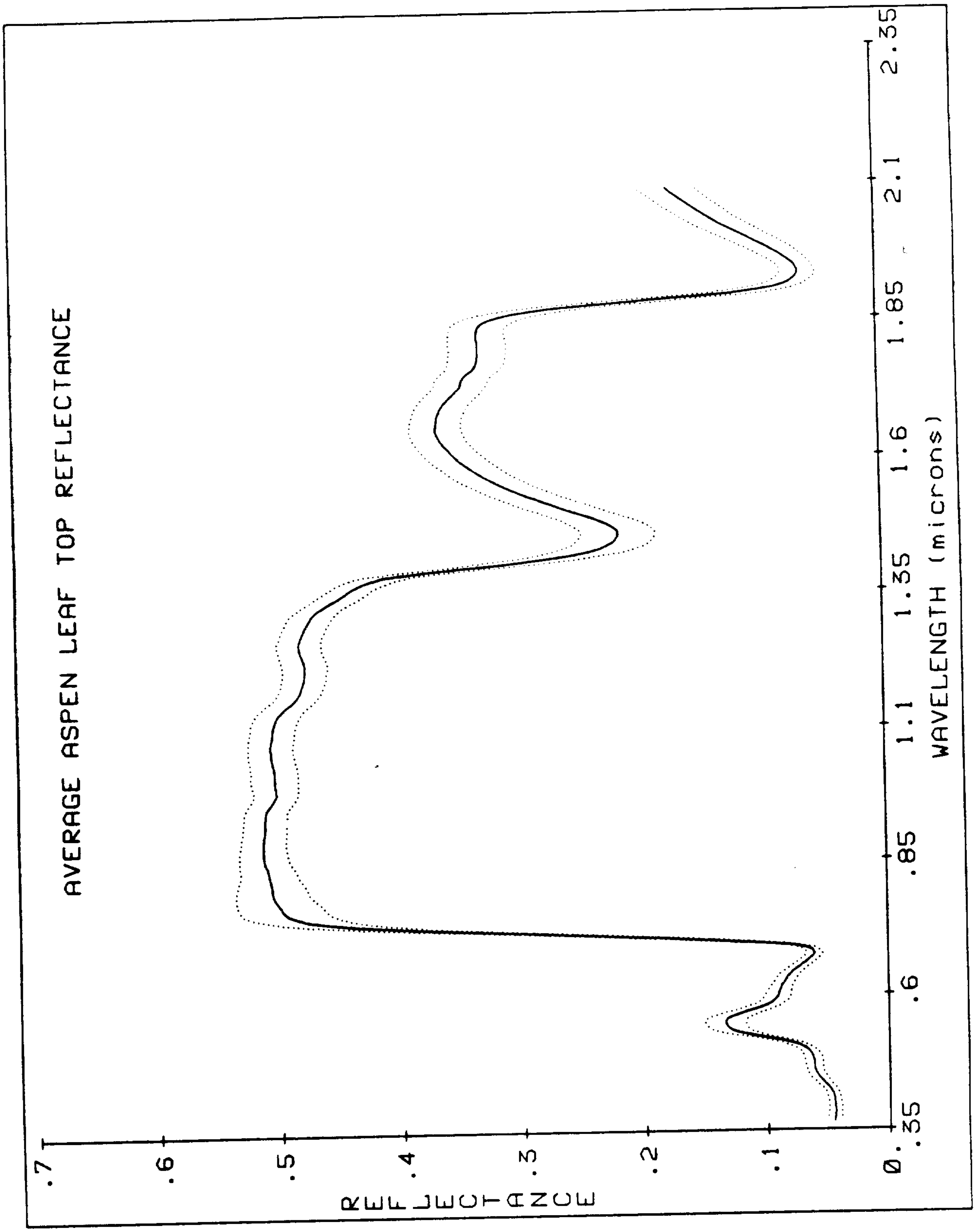

Figure 5.19 See Table 5.3 for plot description.

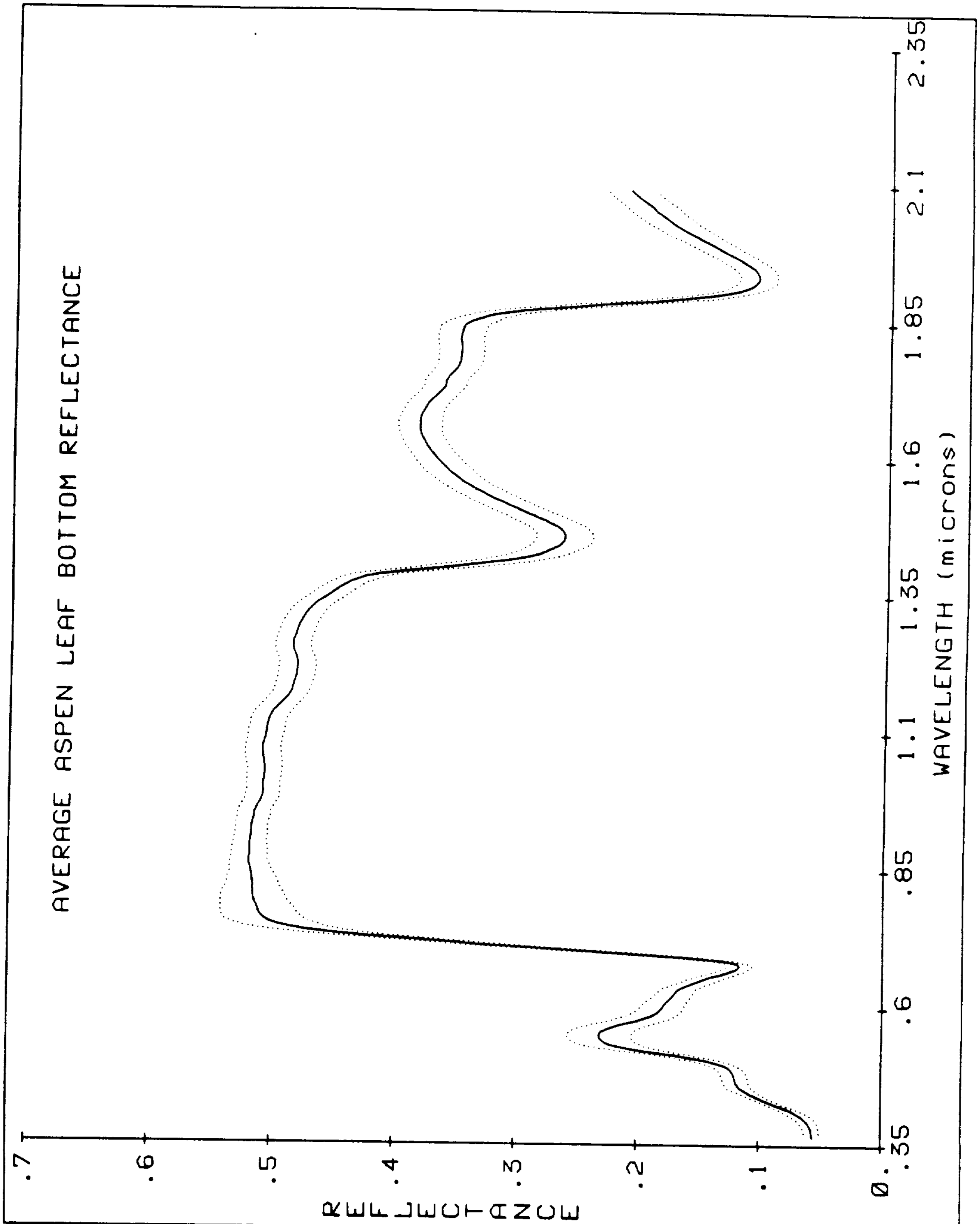

Figure 5.20 See Table 5.3 for plot description.

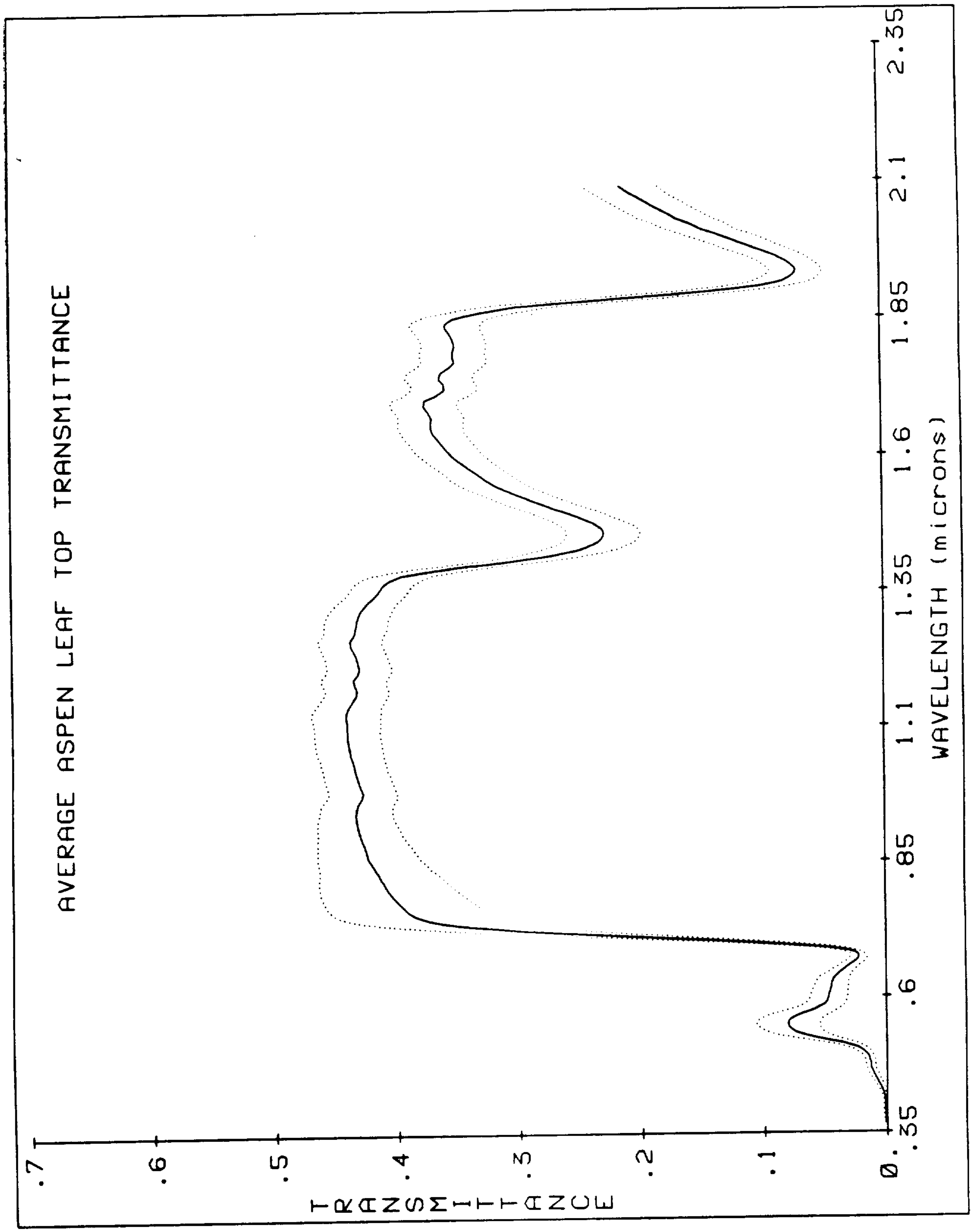

Figure 5.21 See Table 5.3 for plot description.

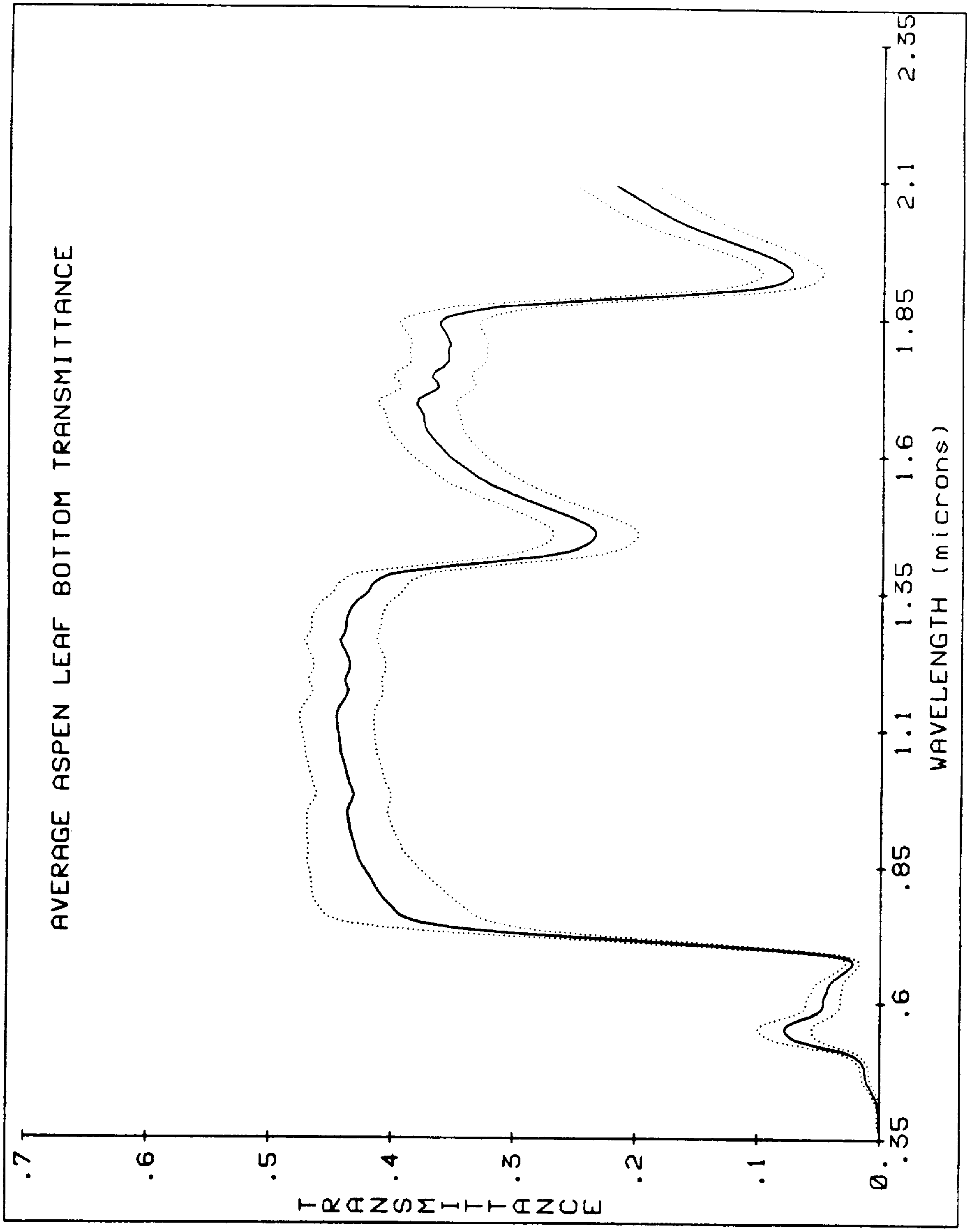

Figure 5.22 See Table 5.3 for plot description.

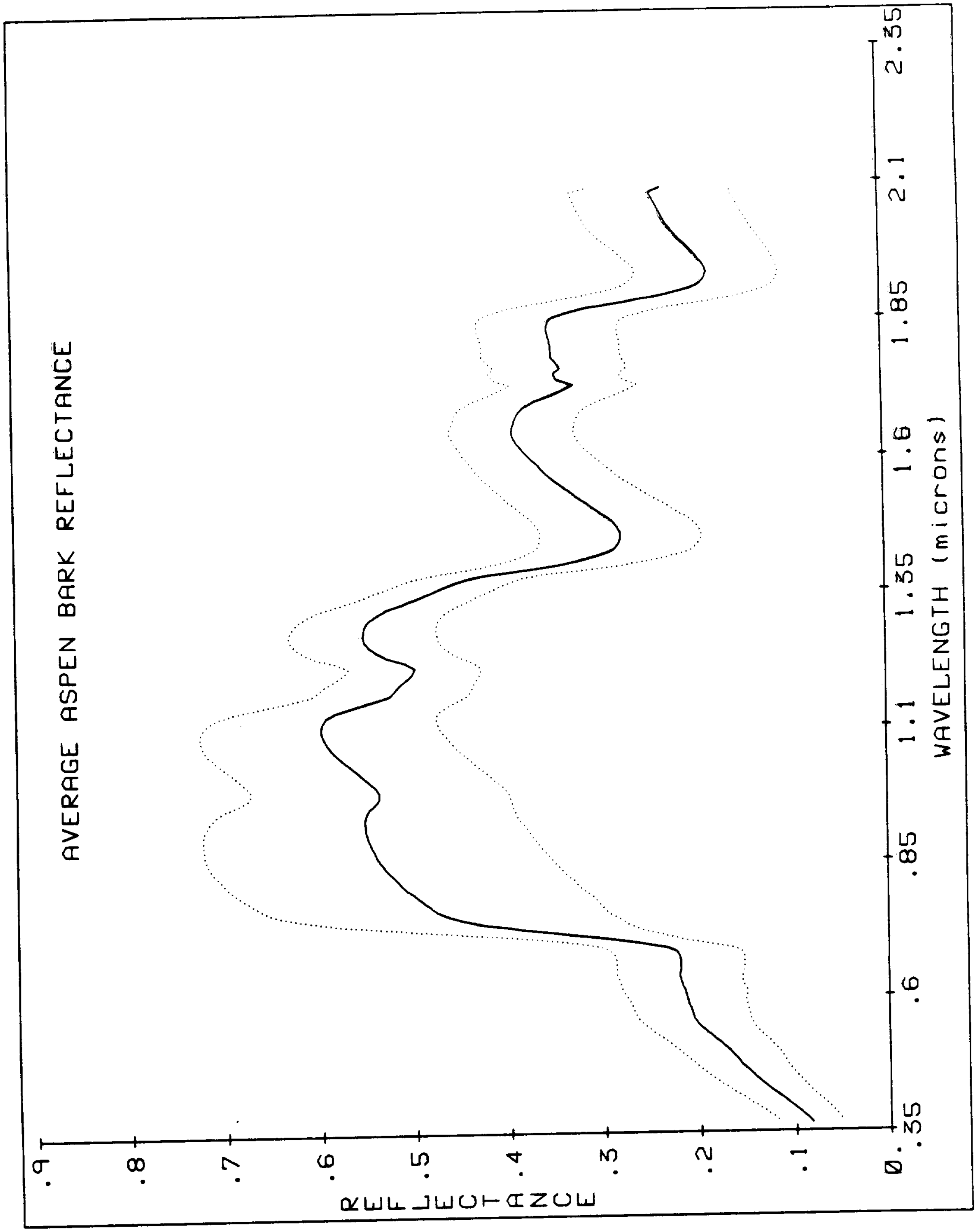

Figure 5.23 See Table 5.3 for plot description.

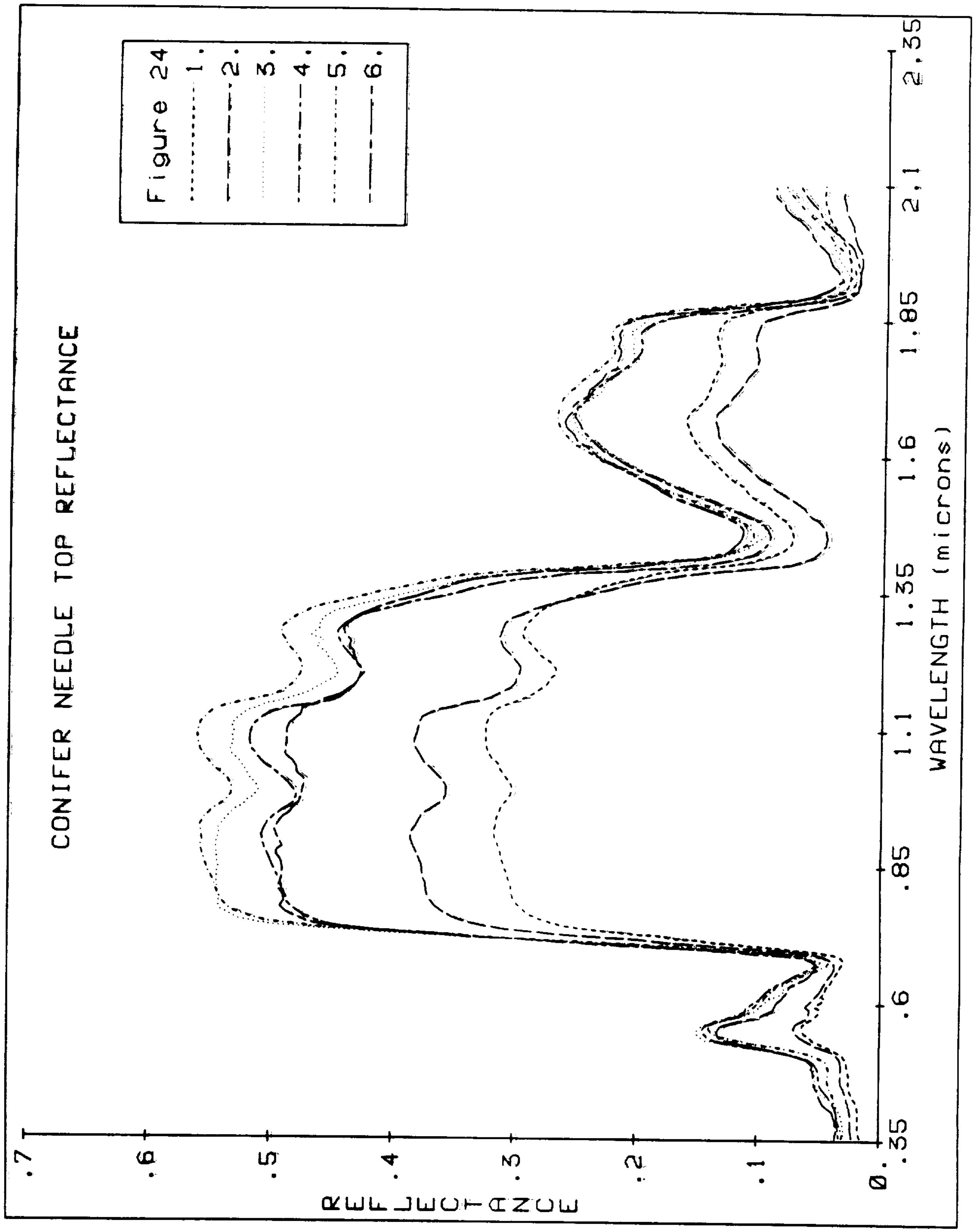

Figure 5.24 See Table 5.3 for description of line numbers.

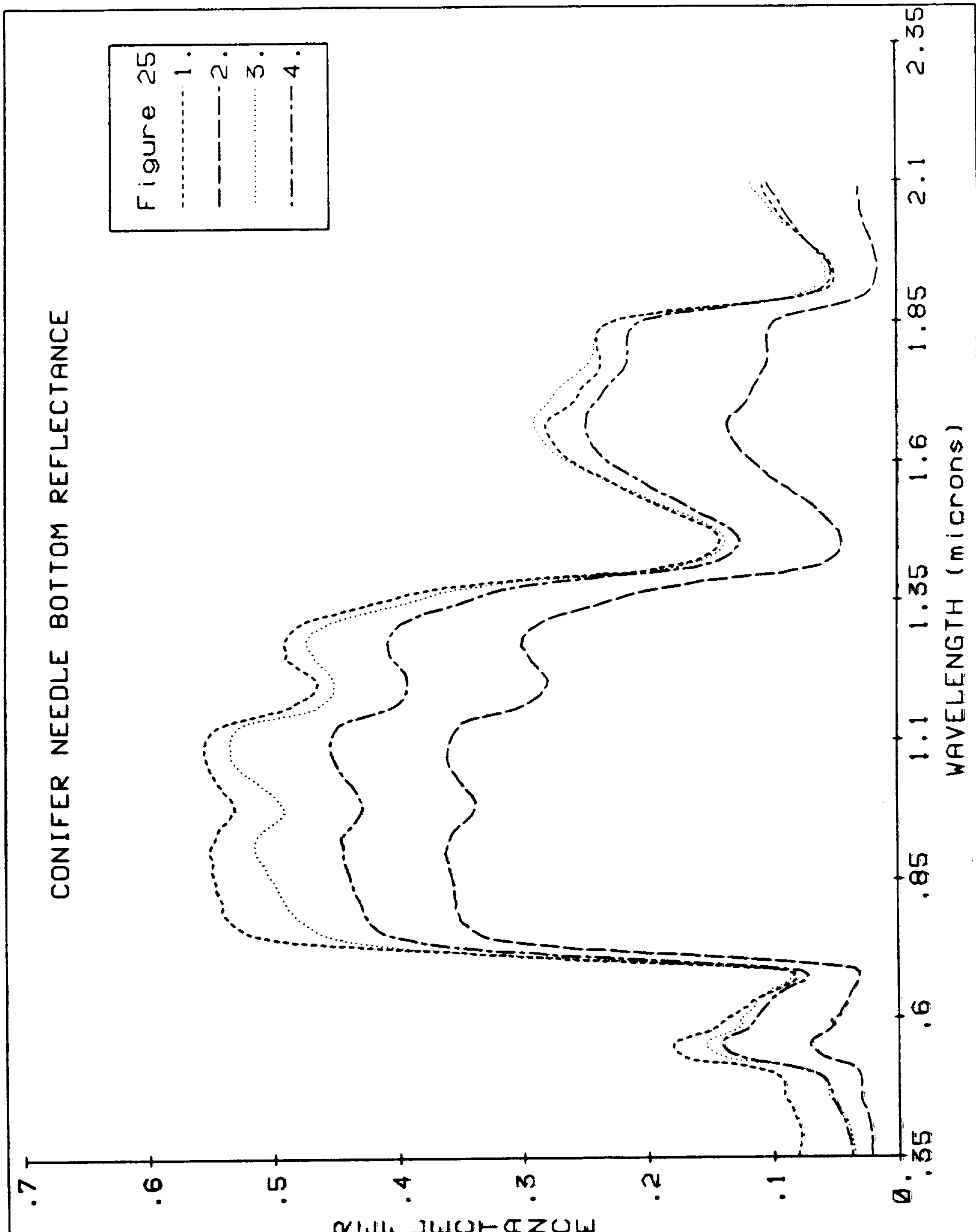

Figure 5.25 See Table 5.3 for description of line numbers.

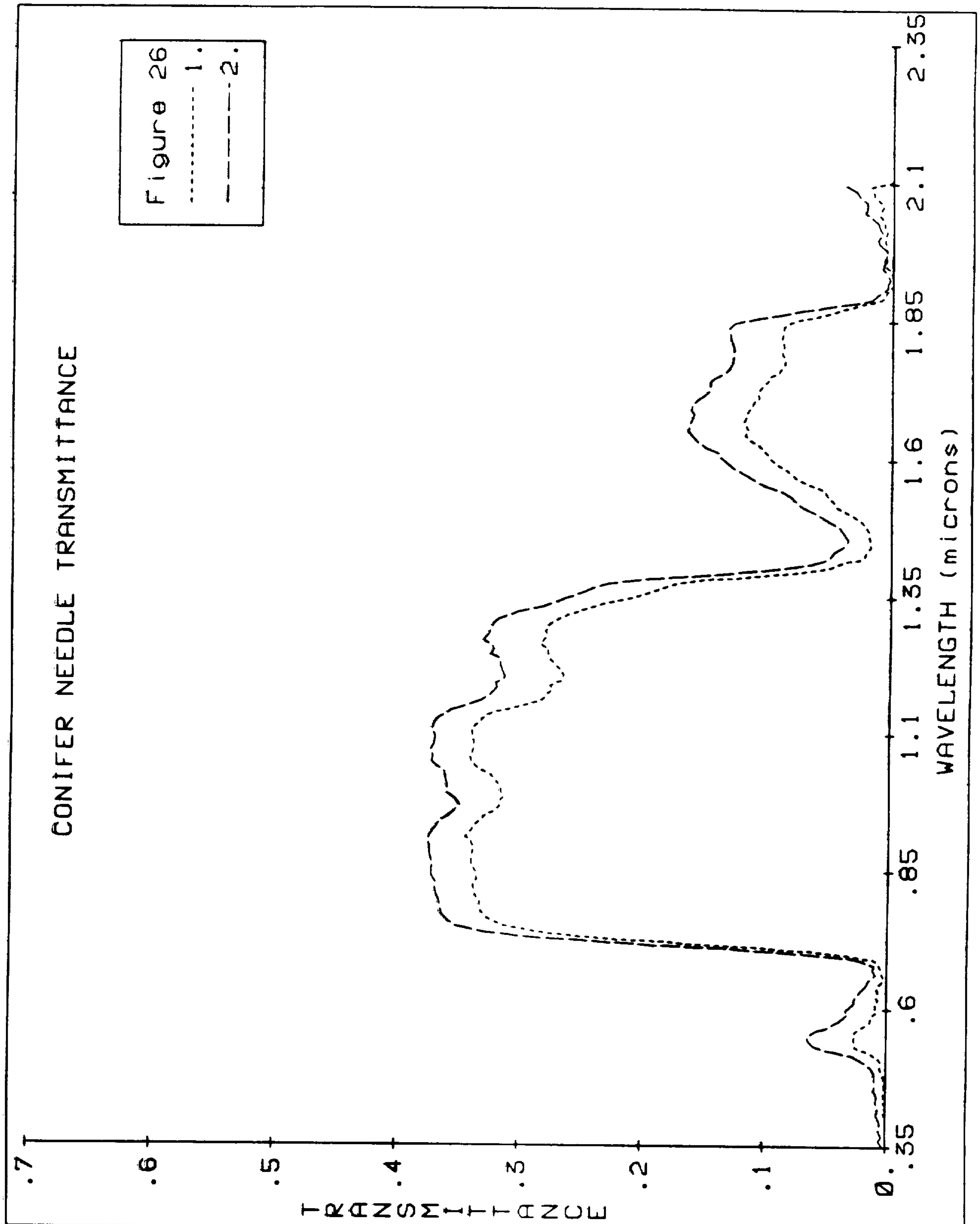

Figure 5.26 See Table 5.3 for description of line numbers.

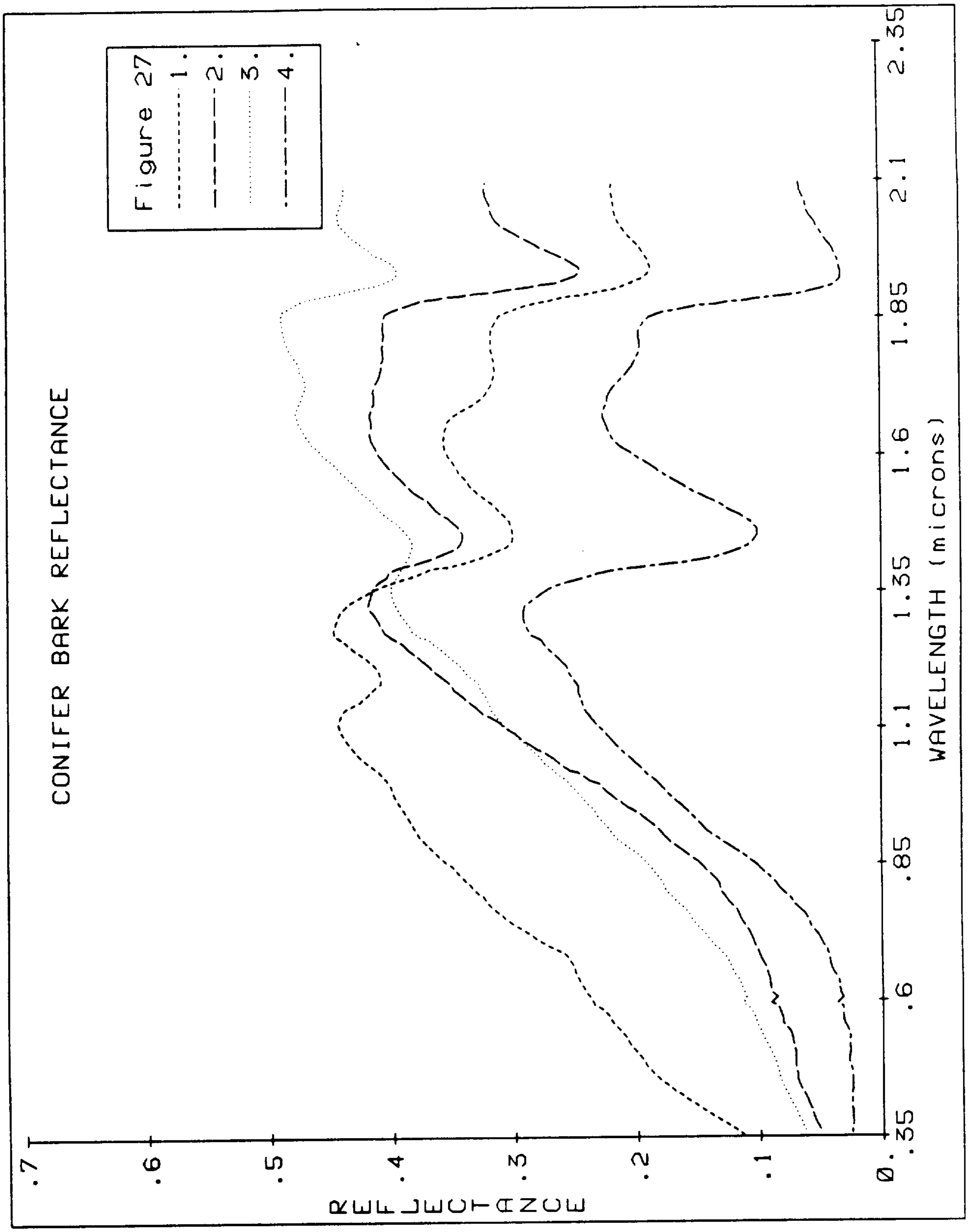

Figure 5.27 See Table 5.3 for description of line numbers.

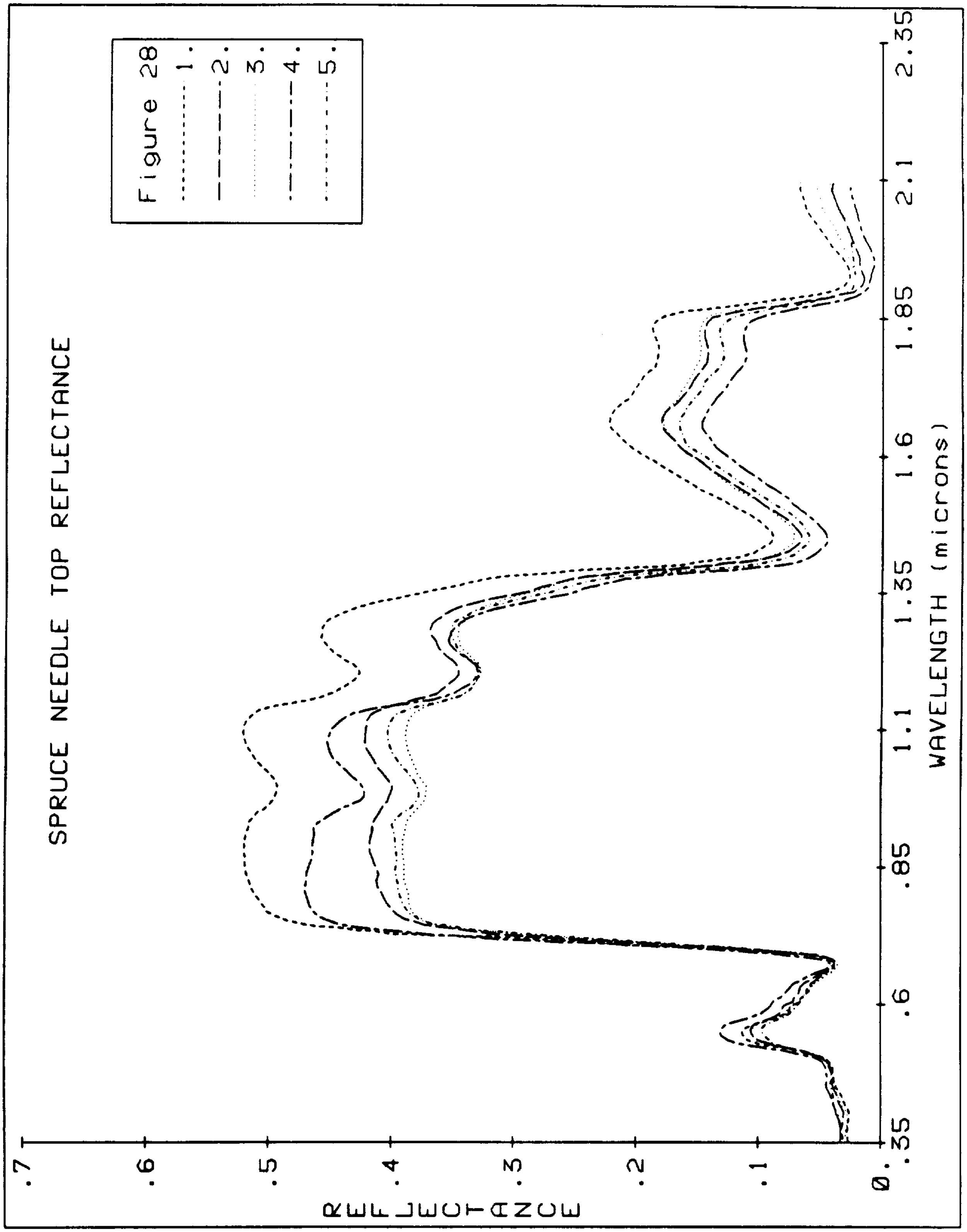

Figure 5.28 See Table 5.3 for description of line numbers.

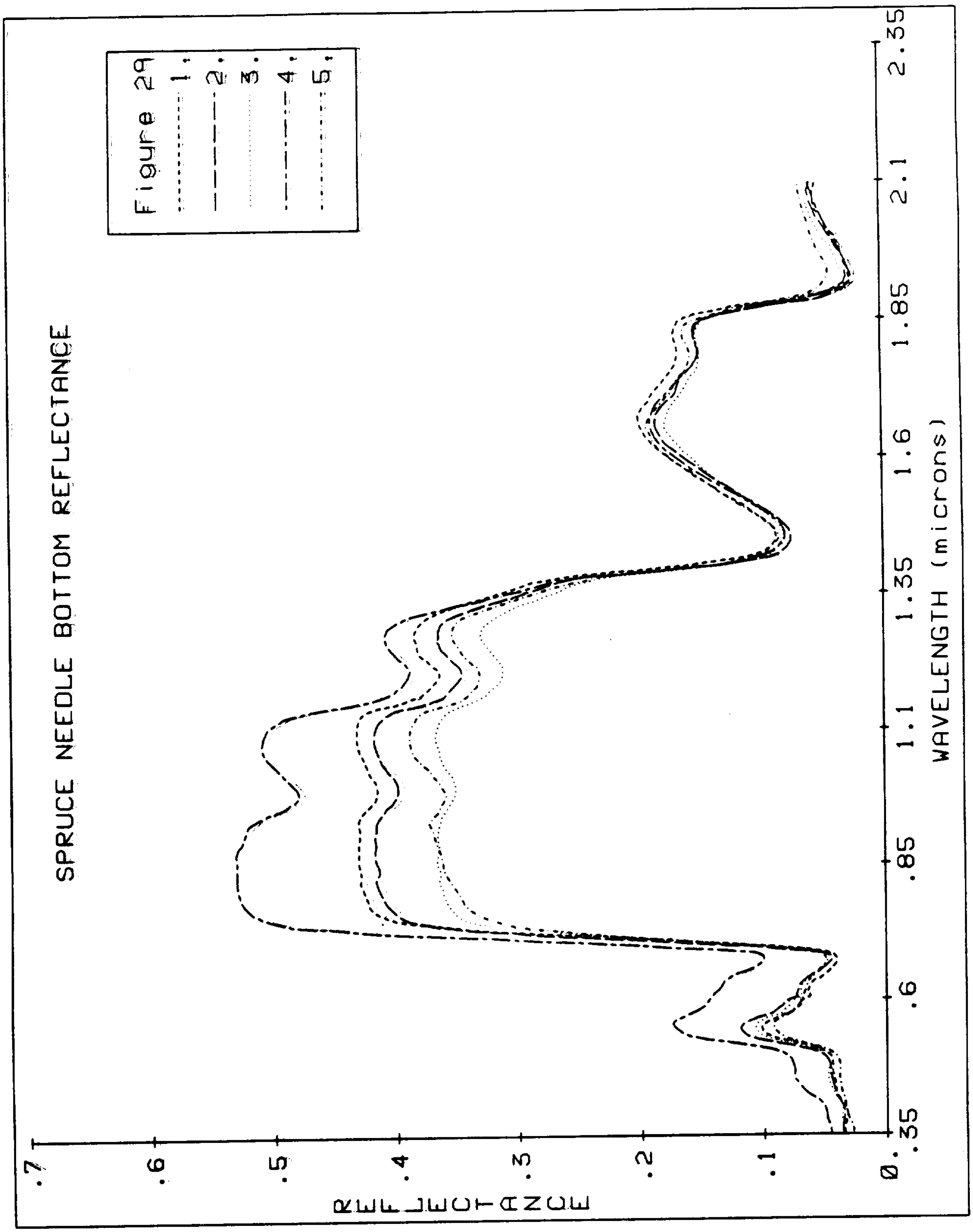

Figure 5.29 See Table 5.3 for description of line numbers.

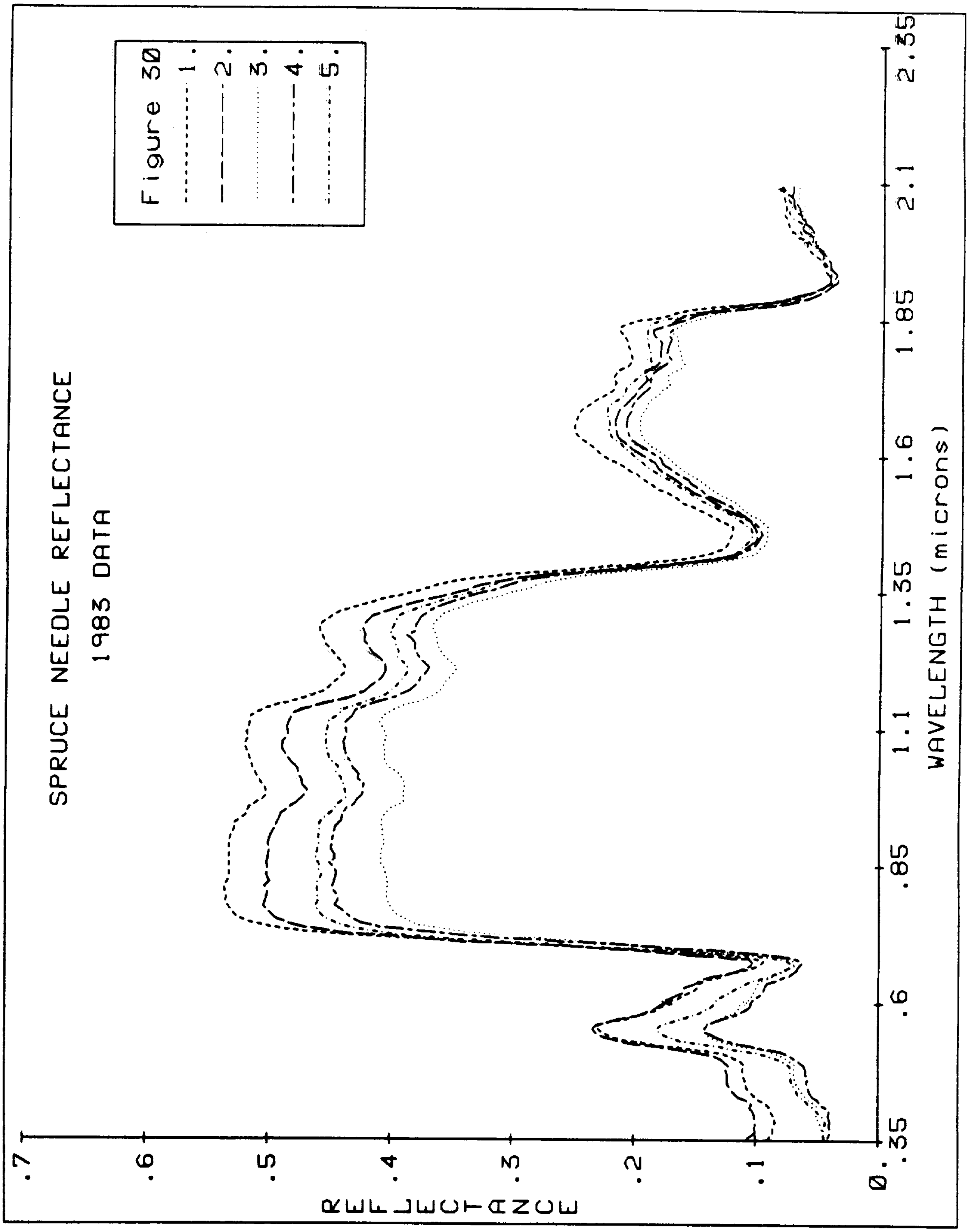

Figure 5.30 See Table 5.3 for description of line numbers.

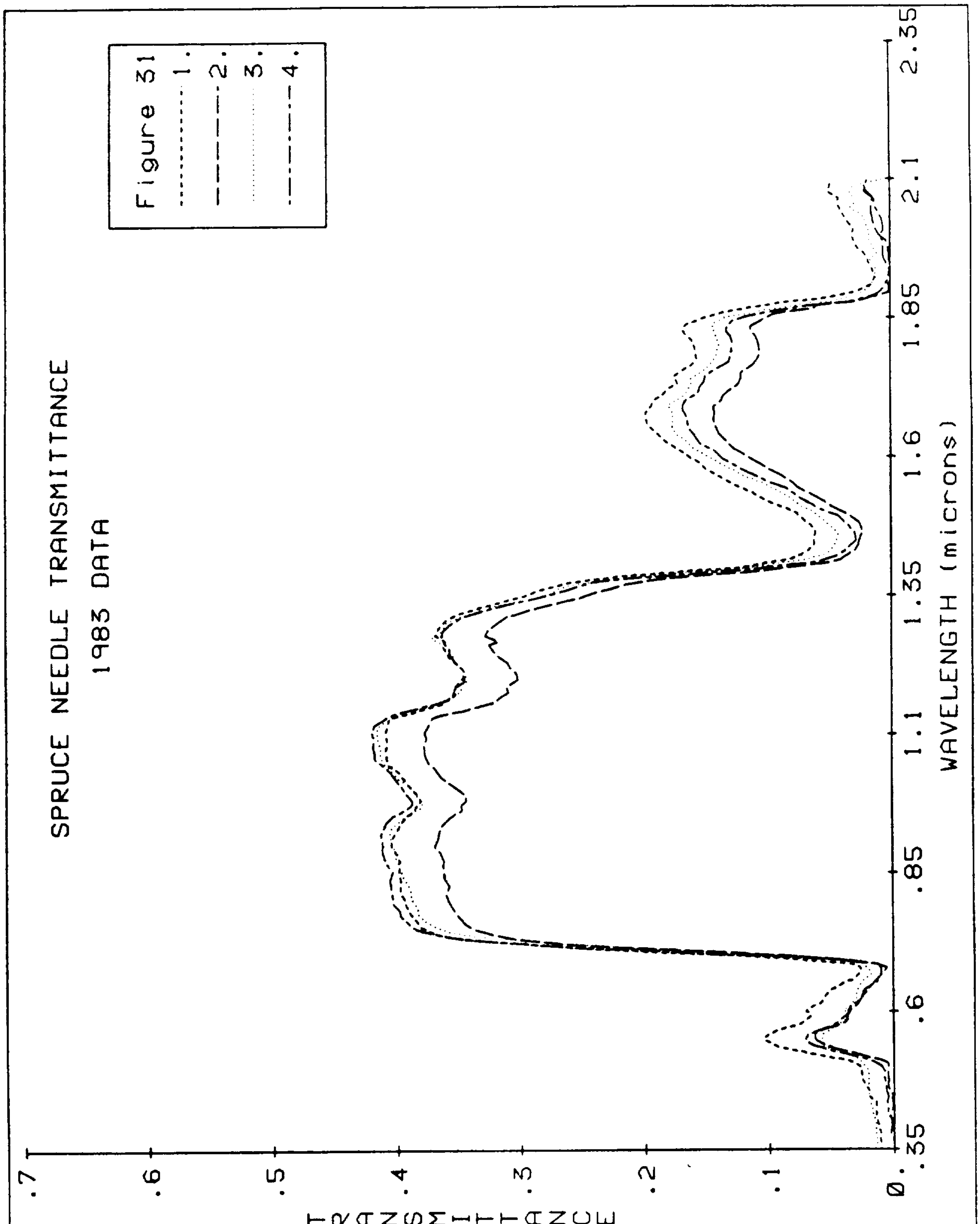

Figure 5.31 See Table 5.3 for description of line numbers.

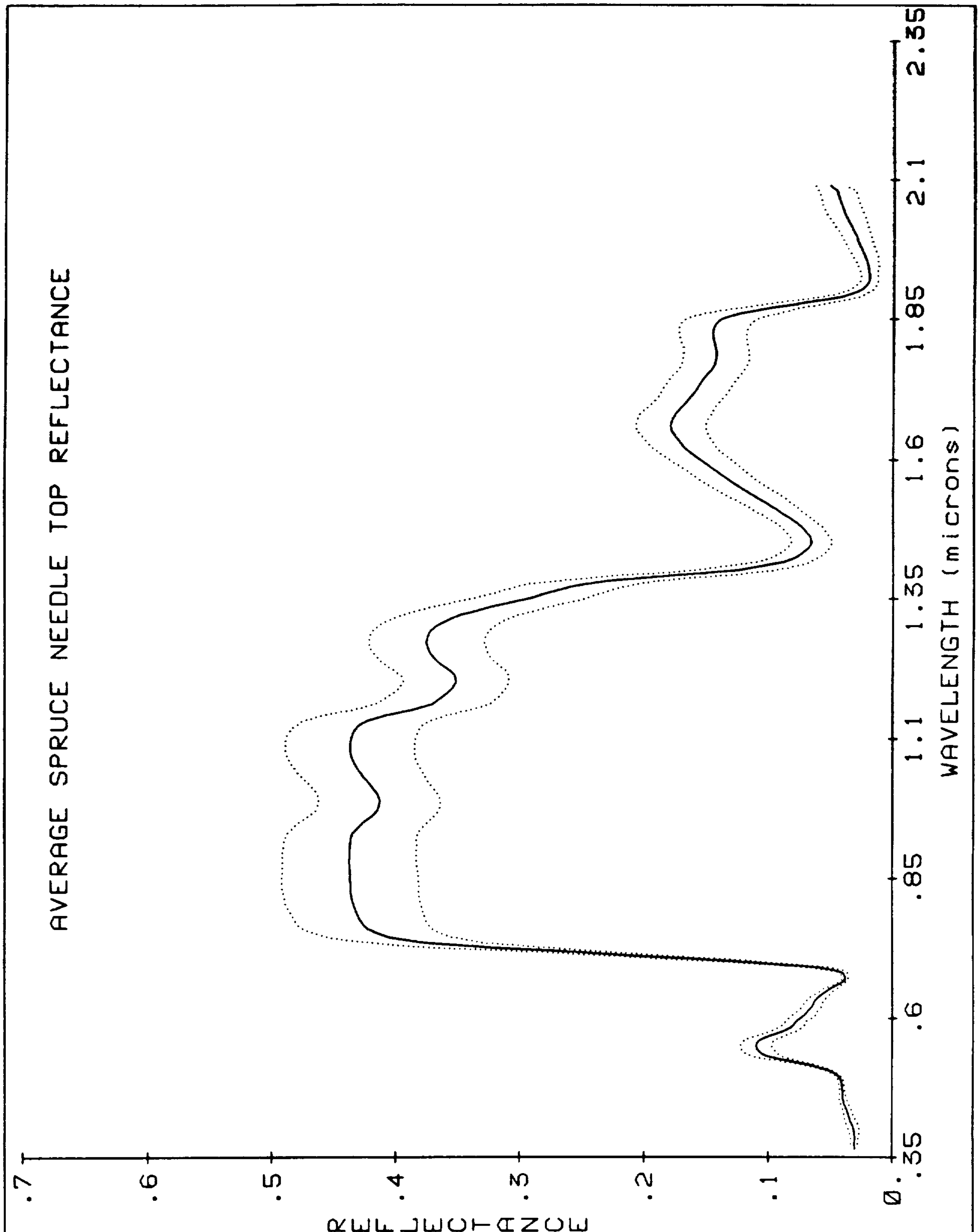

Figure 5.32 See Table 5.3 for plot description.

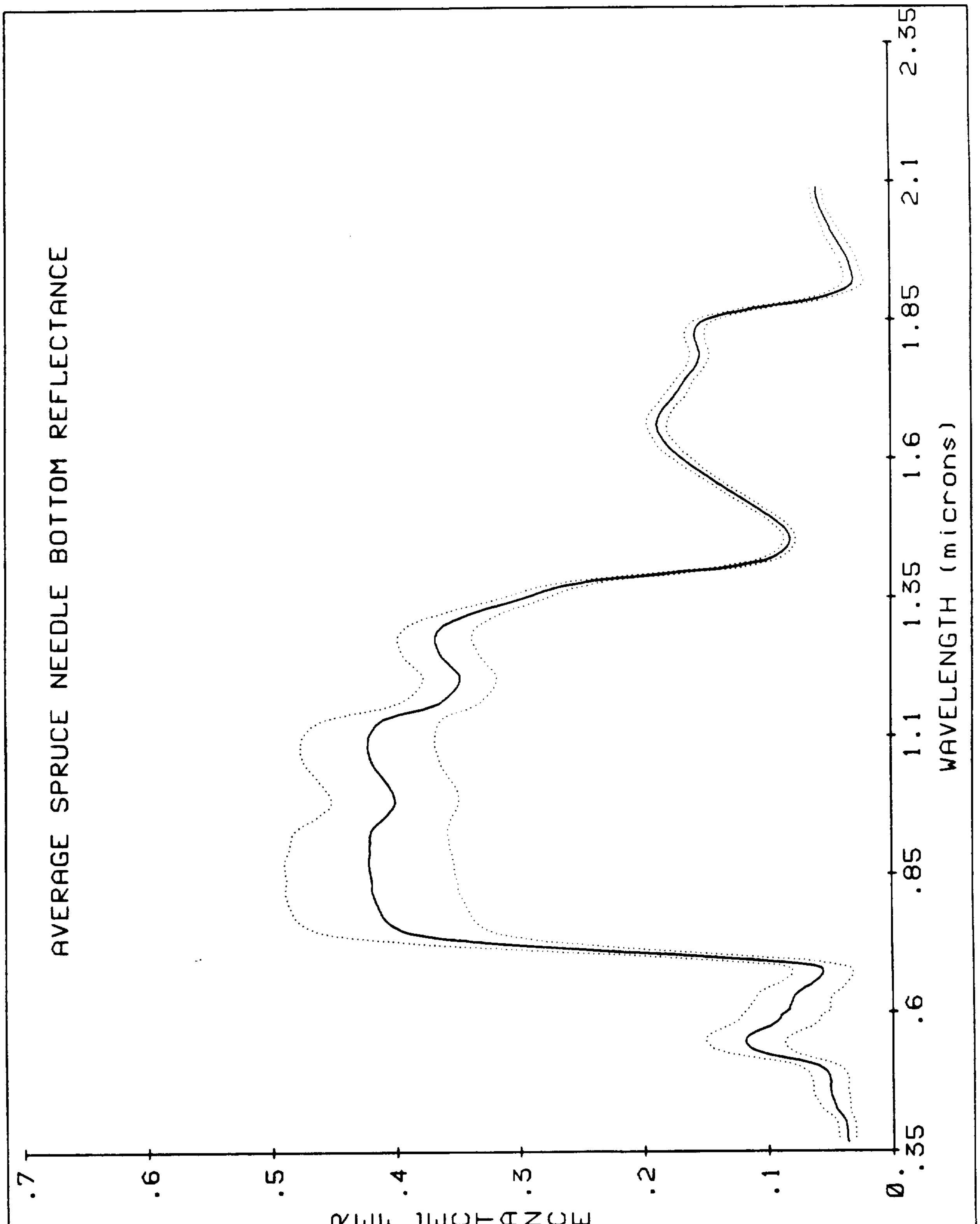

Figure 5.33 See Table 5.3 for plot description.

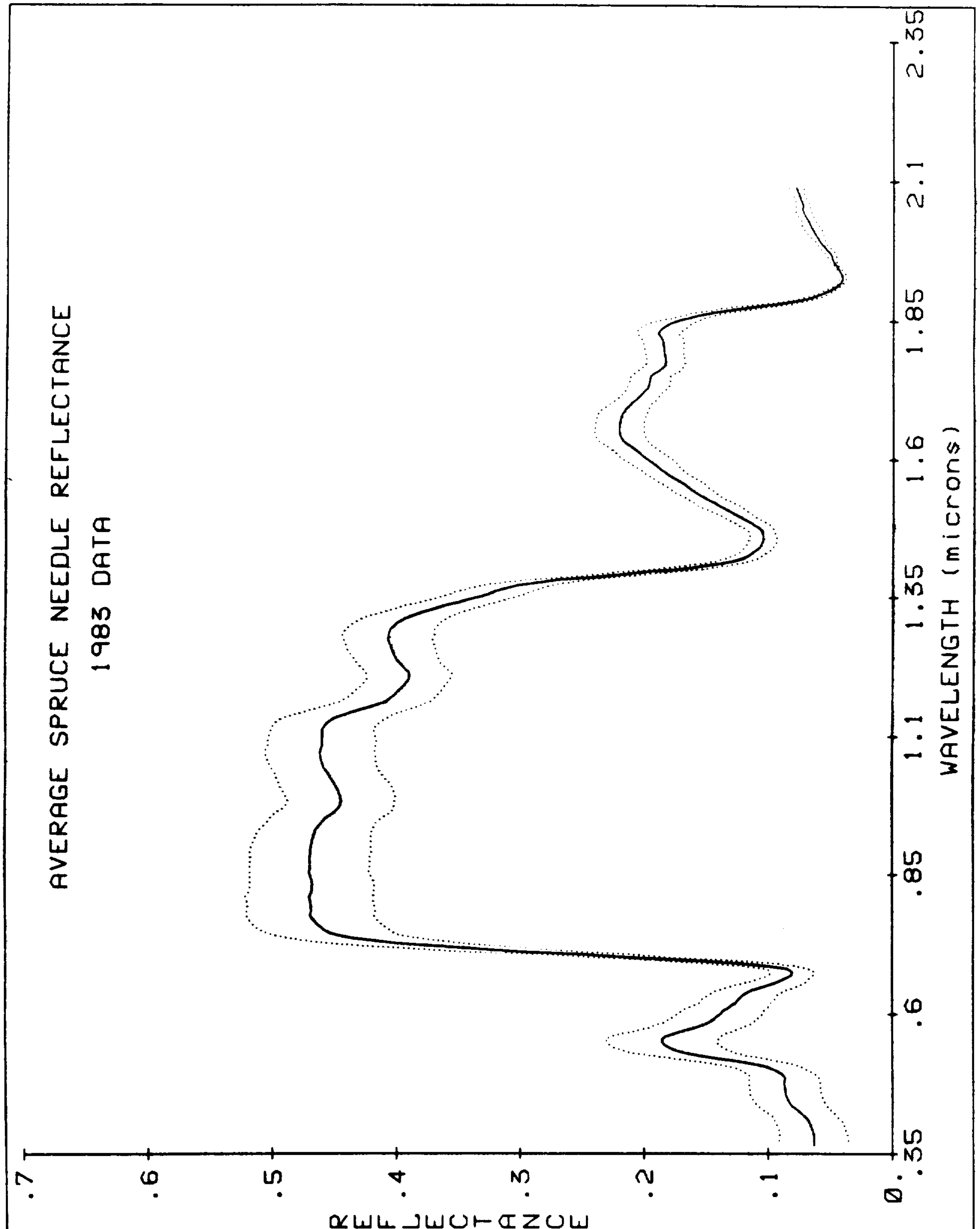

Figure 5.34 See Table 5.3 for plot description.

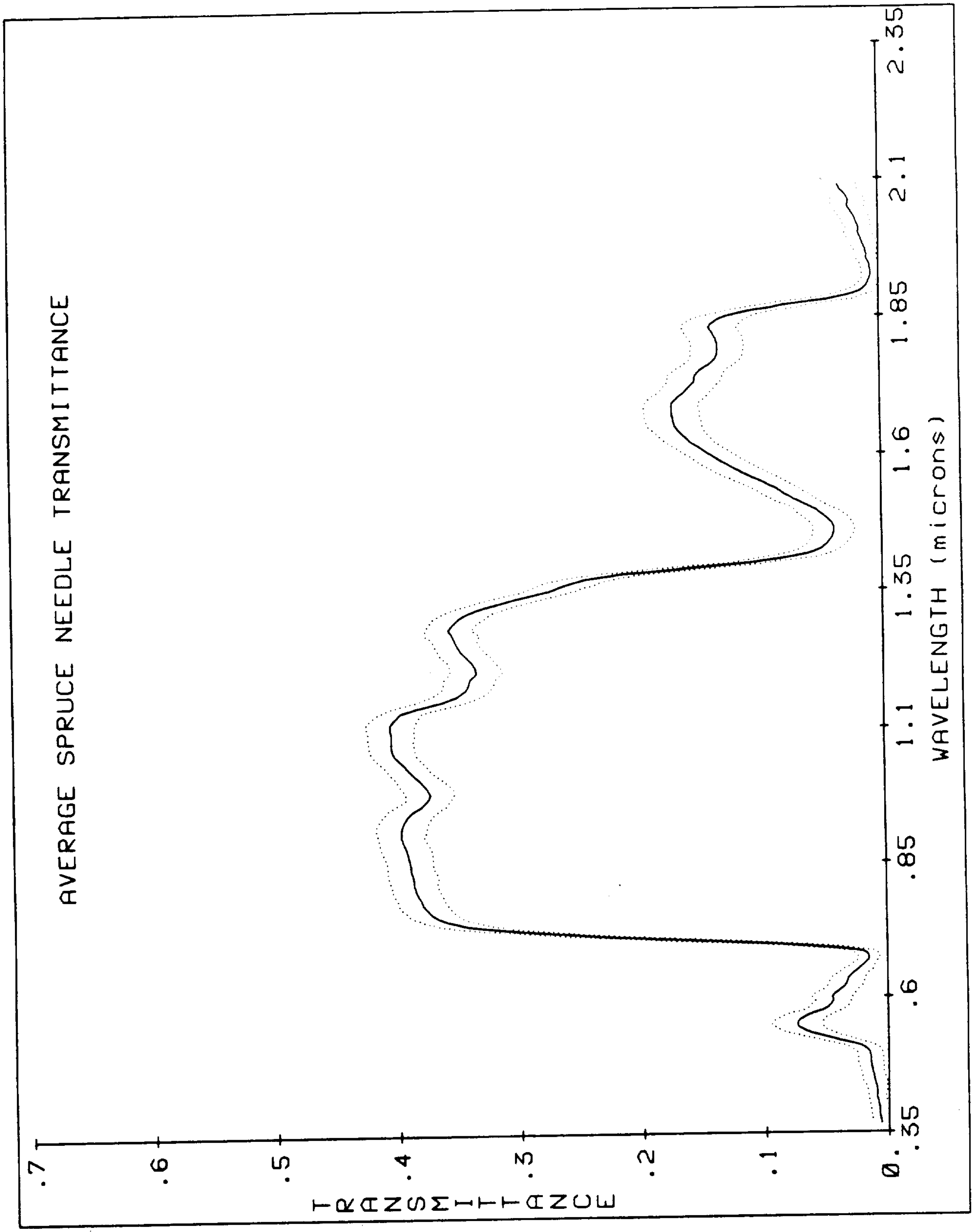

Figure 5.35 See Table 5.3 for plot description.

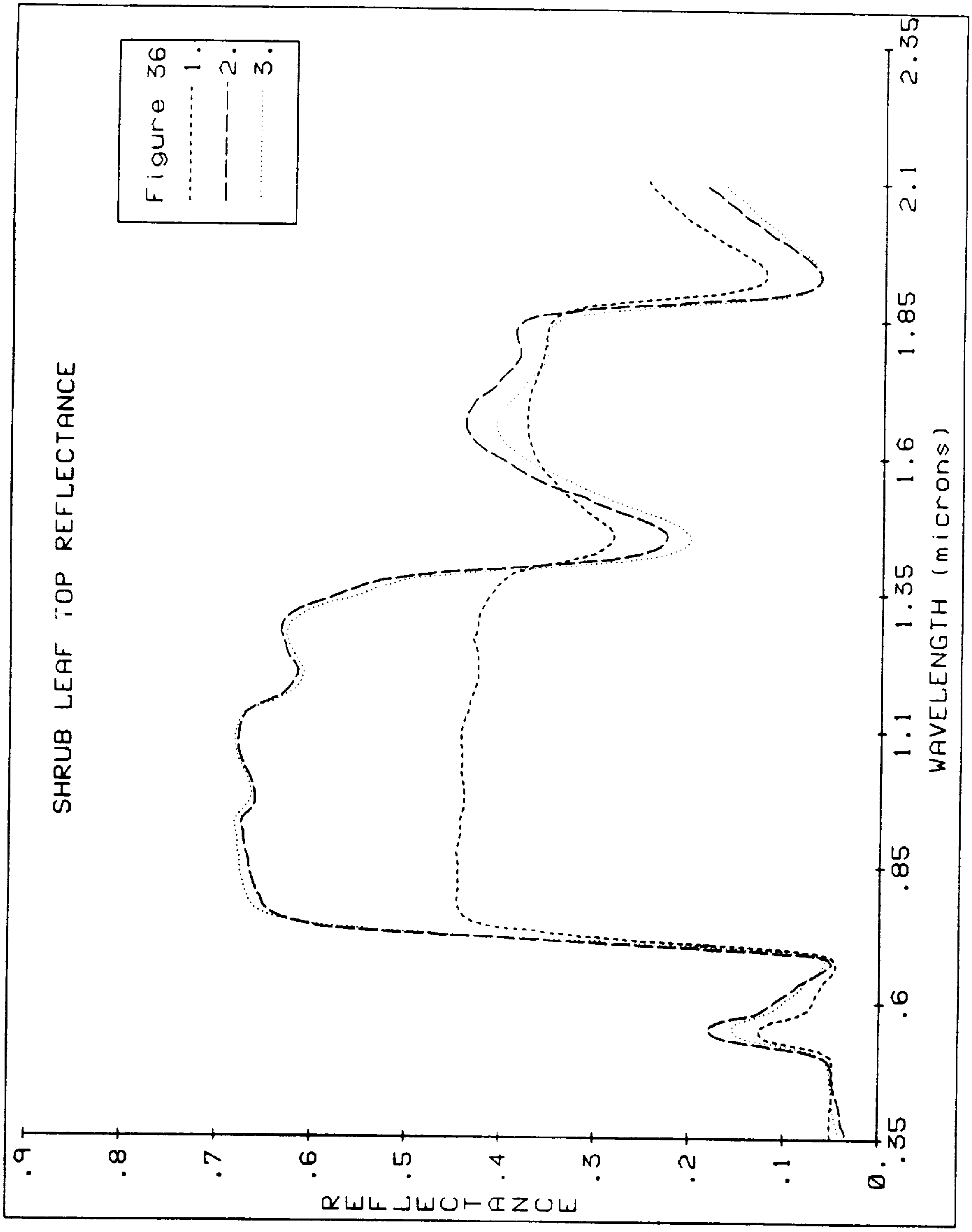

Figure 5.36 See Table 5.3 for description of line numbers.

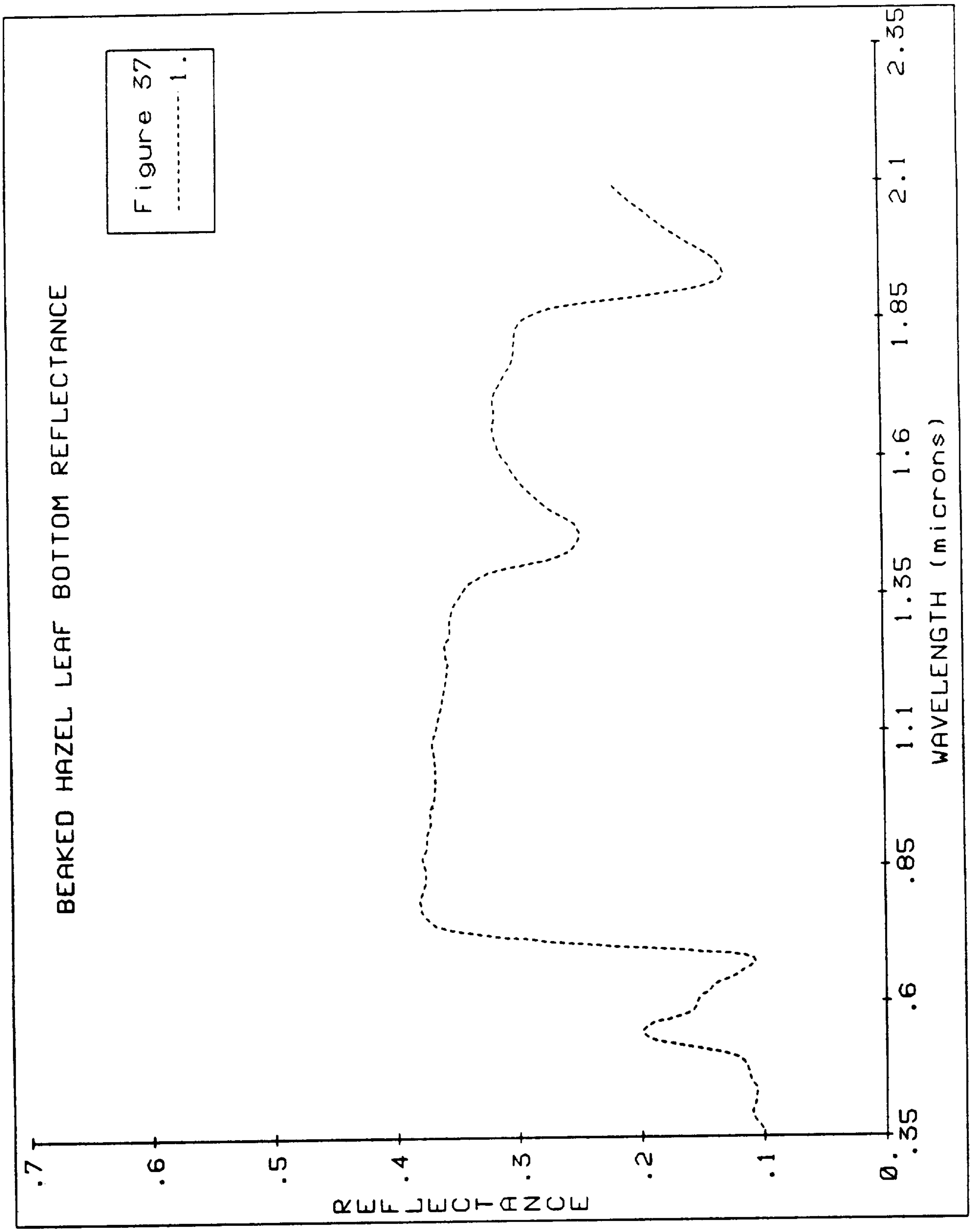

Figure 5.37 See Table 5.3 for description of line numbers.

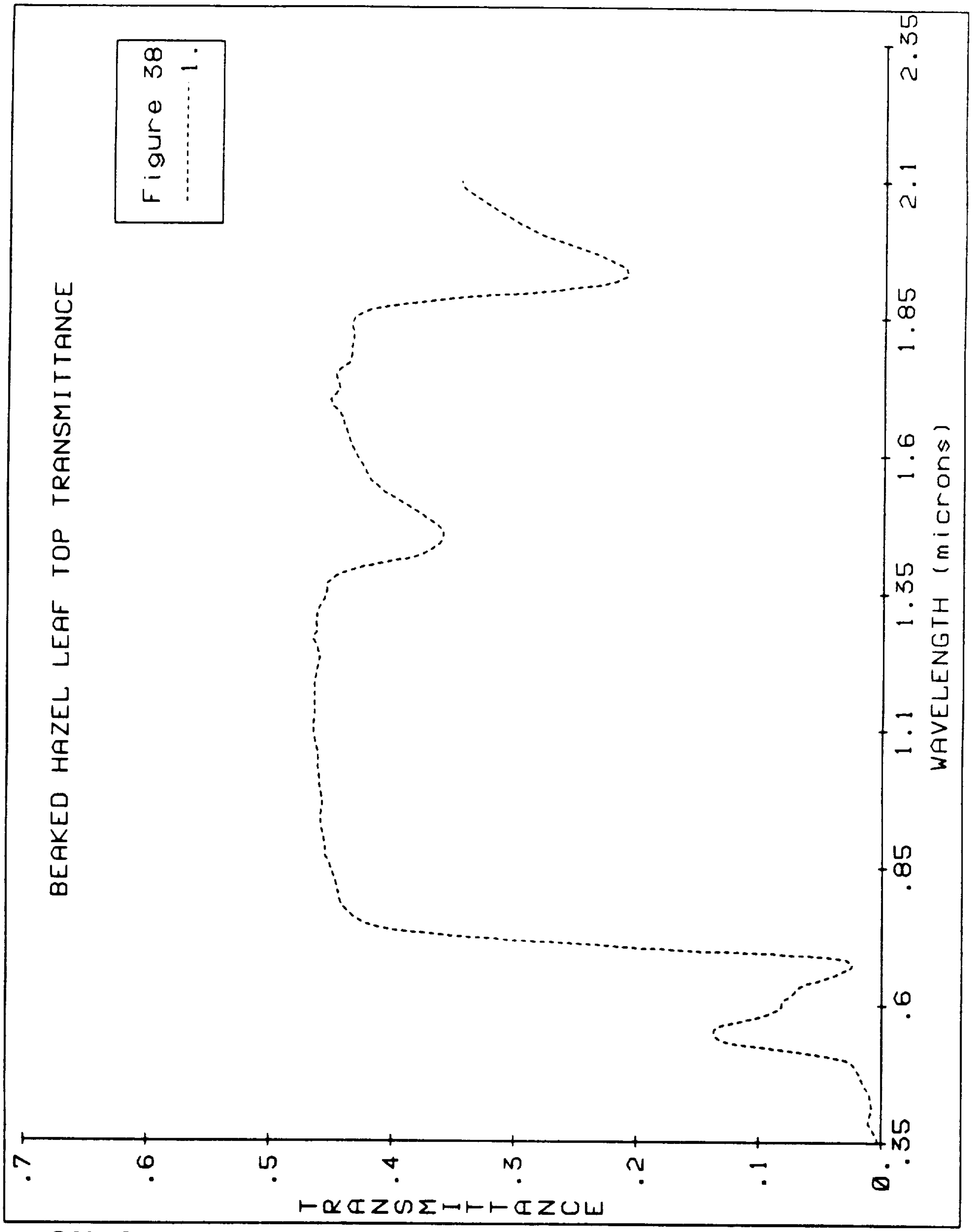

Figure 5.38 See Table 5.3 for description of line numbers.

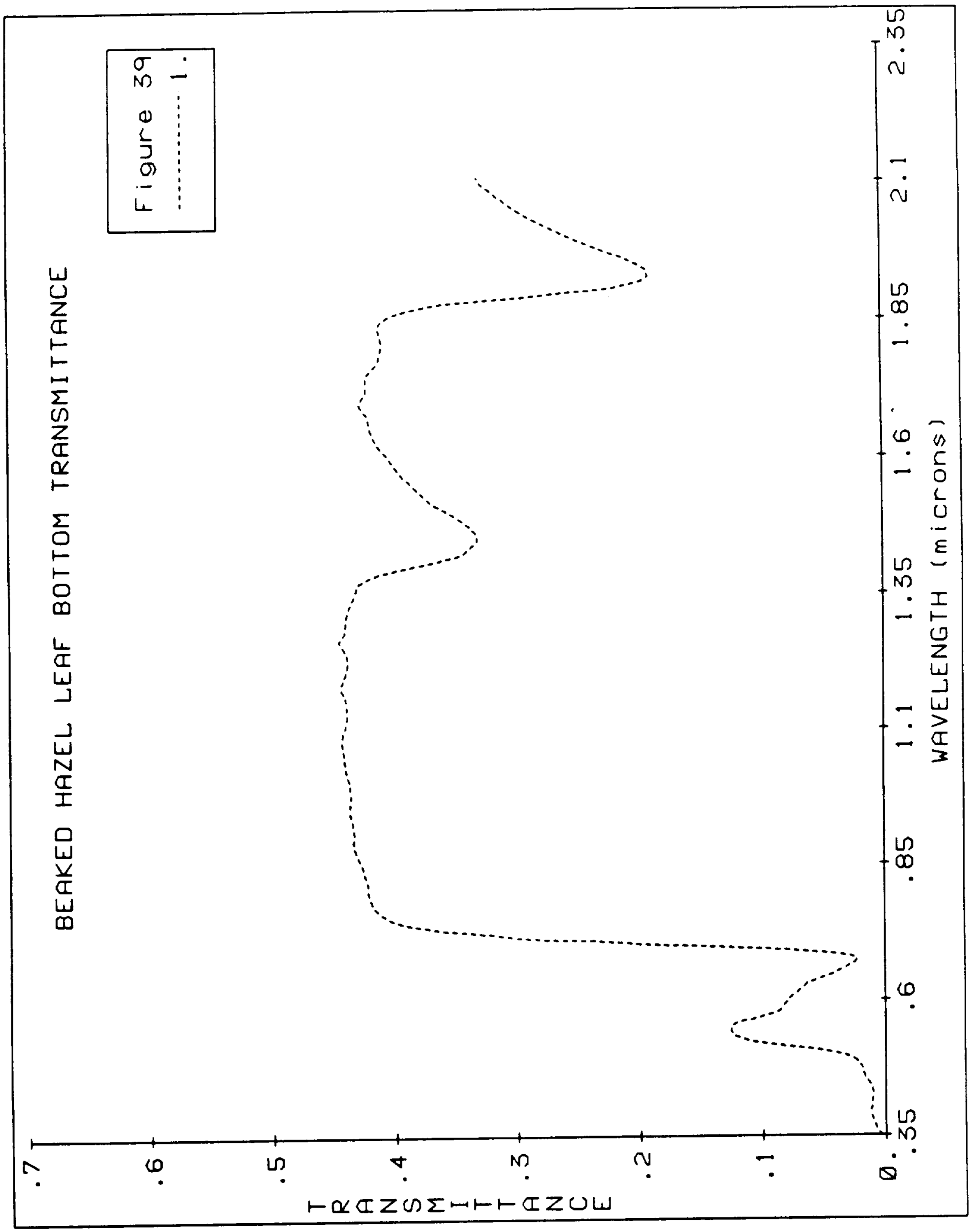

Figure 5.39 See Table 5.3 for description of line numbers.

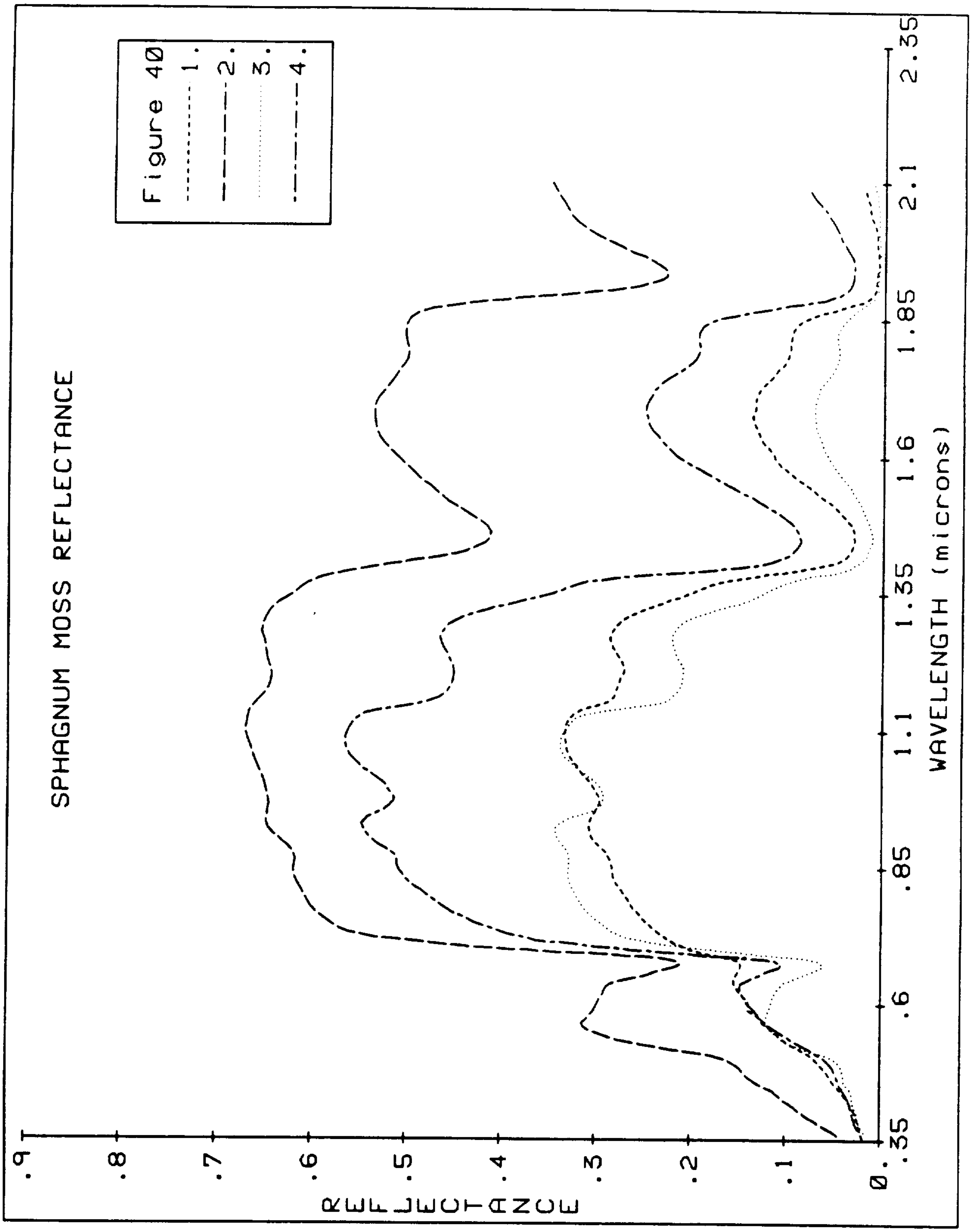

Figure 5.40 See Table 5.3 for description of line numbers.

C-2

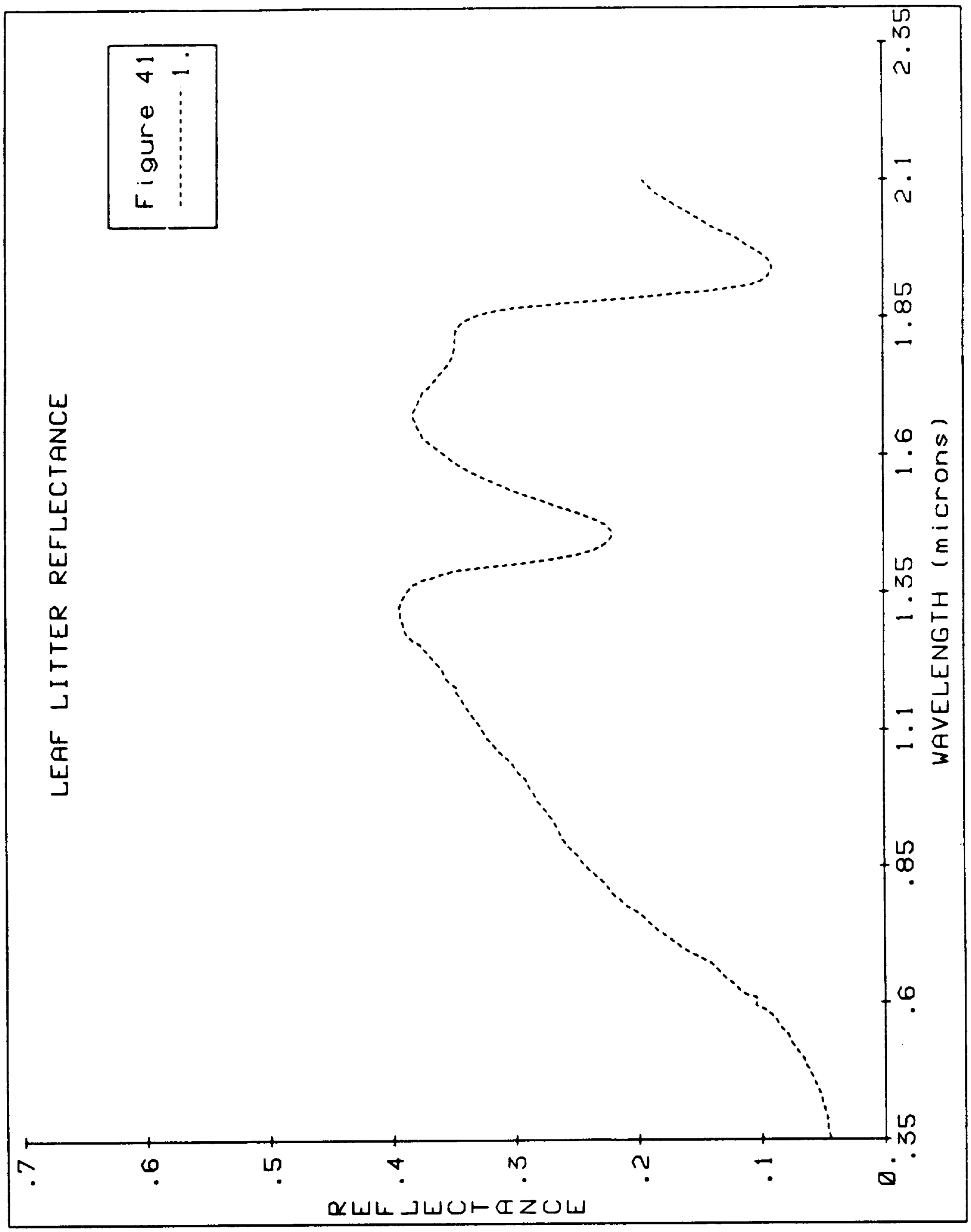

Figure 5.41 See Table 5.3 for description of line numbers.

6.0 Helicopter MMR Data

6.1 Introduction

A major aspect of the ground data collection effort in the SNF during the summers of 1983 and 1984 was the acquisition of helicopter canopy reflectance measurements. Canopy measurements were made at numerous sites with a helicopter-mounted Barnes Modular Multiband radiometer (MMR). The MMR measures on the same wavelength bands as the Thematic Mapper Simulator (see Table 5.2). MMR data were collected on ten dates in 1983 and eight dates in 1984. An additional Barnes radiometer was used to make simultaneous reference panel measurements. The canopy reflectance was derived from the canopy and reference panel measurements. All canopy and reference panel measurements were made under clear sky conditions. A majority of the helicopter measurements were taken at nadir view, although some off-nadir view angle measurements were taken primarily over black spruce and aspen sites. The acquisition dates in 1983 were: May 5 and 16, June 9, July 12 and 13, August 12 and 14, and October 6, 26 and 27. The 1984 acquisition dates were: May 18 and 28, June 3, August 2, 3 and 16, and September 16 and 23.

6.2 Methodology

Reference panel measurements were used to convert voltages measured by the canopy instrument to reflectance factors. The reference panel was a surface painted with barium sulfate. The reflectance factor is the ratio of radiant flux of the canopy measurement to that of the reference or calibration panel under the same illumination and viewing conditions. Another component to be considered is atmospheric scatter, especially for aircraft measurements taken at higher altitudes. The amount of atmospheric scattering can be determined by using reflectance measurements of water targets. Assuming the reflectance of water is zero, reflectance measured at these targets is a measure of the amount of atmospheric scatter. Reflectance measurements over water targets are included for all acquisitions in 1983. However, no water target measurements were taken during the 1984 field campaign.

During the 1983 field campaign, the helicopter measurements were usually taken at an altitude of 122 meters (400 feet), with a few observations at 61 and 91.5 meters (200 and 300 feet). At an altitude of 122 meters and a radiometer field of view of 15 degrees, the canopy area being sensed is approximately 32 meters (105 feet) in diameter. In 1984, most measurements were taken at an altitude of 183 meters (600 feet). To measure the same canopy area at this altitude, the field of view was reduced to 10 degrees, although on two dates this was reduced further to 6 degrees. At 183 meters, the reduction of the field of view from 10 to 6 degrees reduces the canopy area being sensed from 32 to 19.2 meters (105 to 63 feet) in diameter.

6.3 Results

There are approximately 317 observations made over 105 different sites in 1983 and about 160 observations made over 29 sites in 1984. Tables 6.1 and 6.2 are a summary of the sites observed and the dates of observation for the 1983 and 1984 datasets, respectively. Each set of reflectance values for a site is actually the mean of observations taken over a given time interval and generally averaged between 16 and 20 separate measurements.

The summarized MMR data listed in Tables 6.3 and 6.4 includes: site number, number of observations averaged, code for altitude of instrument above the canopy (in hundreds of feet), the time (GMT) at which observations begin, the time at which observations end (each a six-digit number: the first two correspond to hours, the second and third two correspond to minutes and seconds, respectively), solar zenith angle, solar azimuth angle, and reflectance for each of the bands with standard deviations. Values of -1.0 signify missing data. All measurements were taken at nadir, except where otherwise indicated.

Figures 6.1 through 6.3 are reflectance plots for a sample set of black spruce and aspen sites. The black spruce sites, 14 and 15, are located within the same bog, and the aspen sites, 3 and 16, are located only about 80 meters apart. These sample plots were produced to note the differences in MMR band reflectance for aspen and black spruce at the beginning, middle, and end of the growing season. These plots show the consistency of the spectral reflectance of the spruce sites in comparison with the seasonal changes in the aspen. Another comparison between aspen and spruce sites may be seen in Figure 6.4, where values for the Normalized Difference Vegetation Index (NDVI) are plotted throughout 1983 for an aspen site (site 16) and a spruce site (site 14). NDVI is the difference between the reflectance in MMR bands four and three divided by their sum, and is related to the amount of green foliage present in the canopy. Figure 6.4 shows the aspen stand "greening up" in the spring and becoming senescent in the autumn, while NDVI in the evergreen spruce stand does not show a seasonal variation.

In 1984, MMR data were collected using off-nadir view angles to measure the bidirectional reflectance characteristics of the forests. Figure 6.5 shows the reflectances for three different view angles for a spruce and aspen site. In the backward scattering direction (view azimuth=0) both the spruce and aspen stands have higher reflectances in all channels because more of the illuminated foliage is seen. There is little difference between the nadir (view zenith=0) and forward scattering (view azimuth=180) views within each stand.

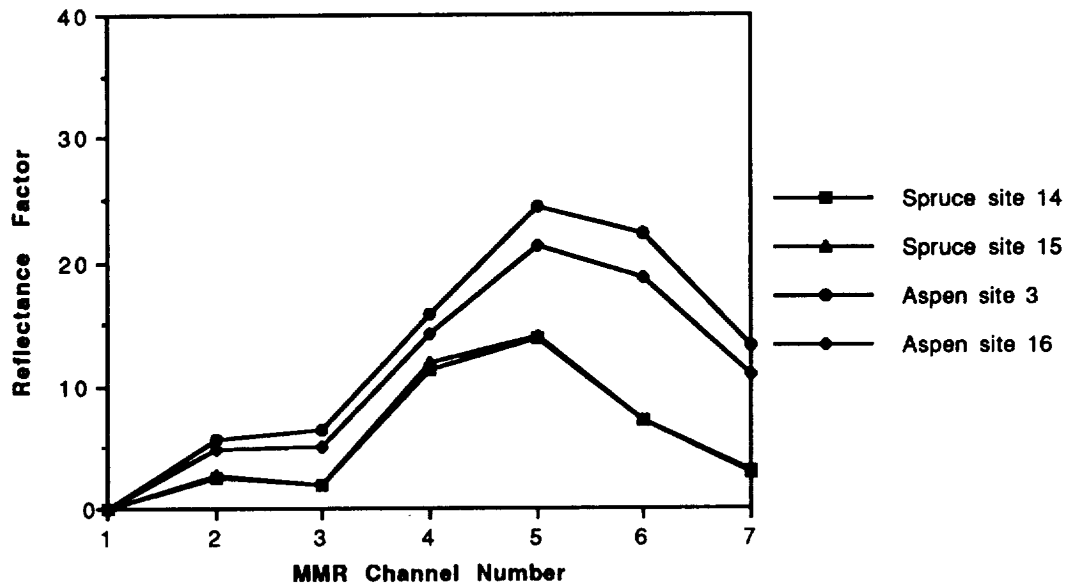

Figure 6.1 Spectral reflectance in each MMR band collected from the helicopter for two spruce and two aspen sites on May 15, 1983.

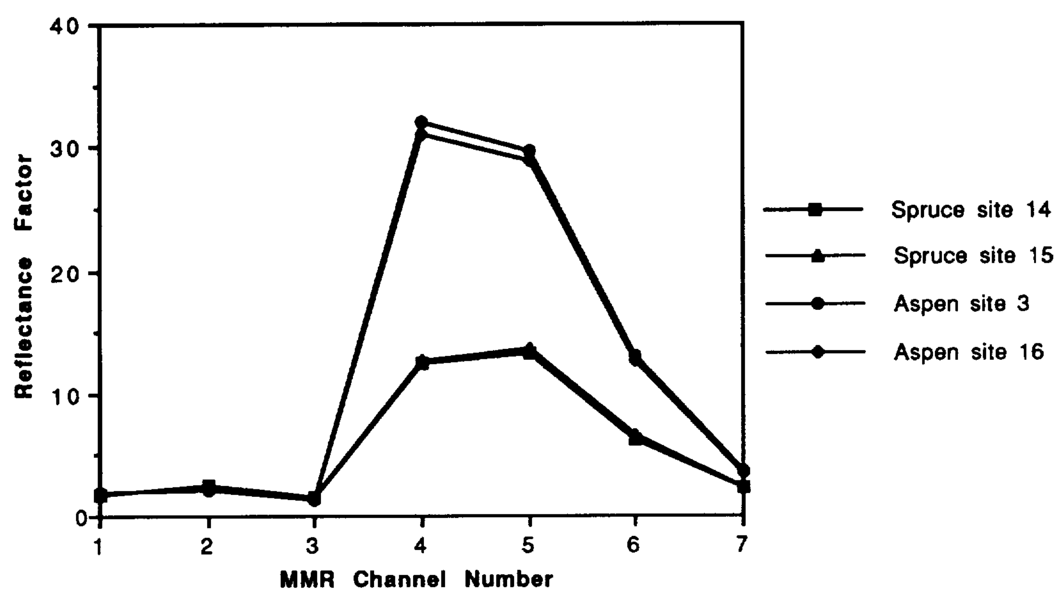

Figure 6.2 Spectral reflectance in each MMR band collected from the helicopter for two spruce and two aspen sites on July 12, 1983.

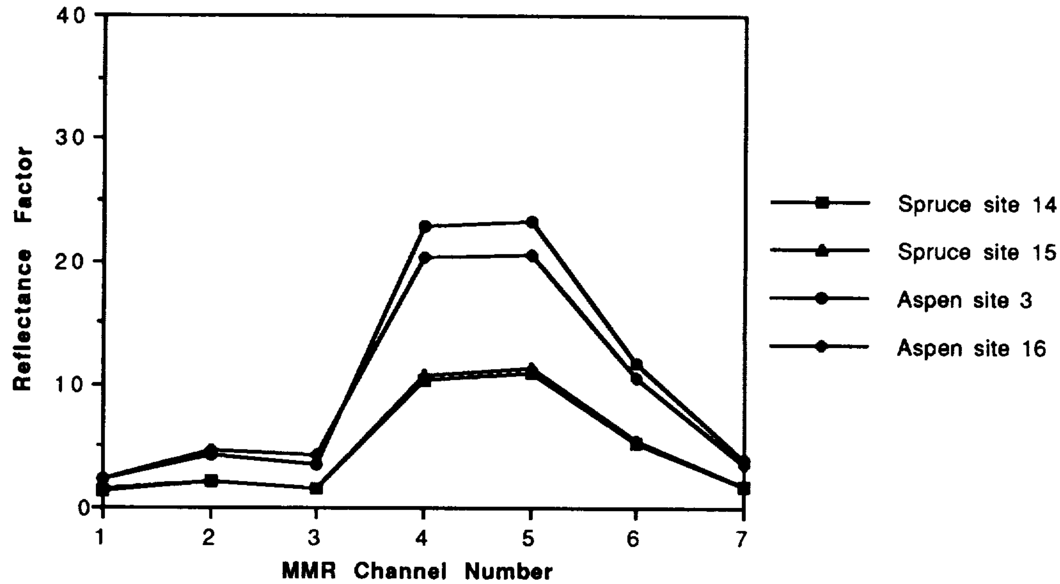

Figure 6.3 Spectral reflectance in each MMR band collected from the helicopter for two spruce and two aspen sites on October 6, 1983.

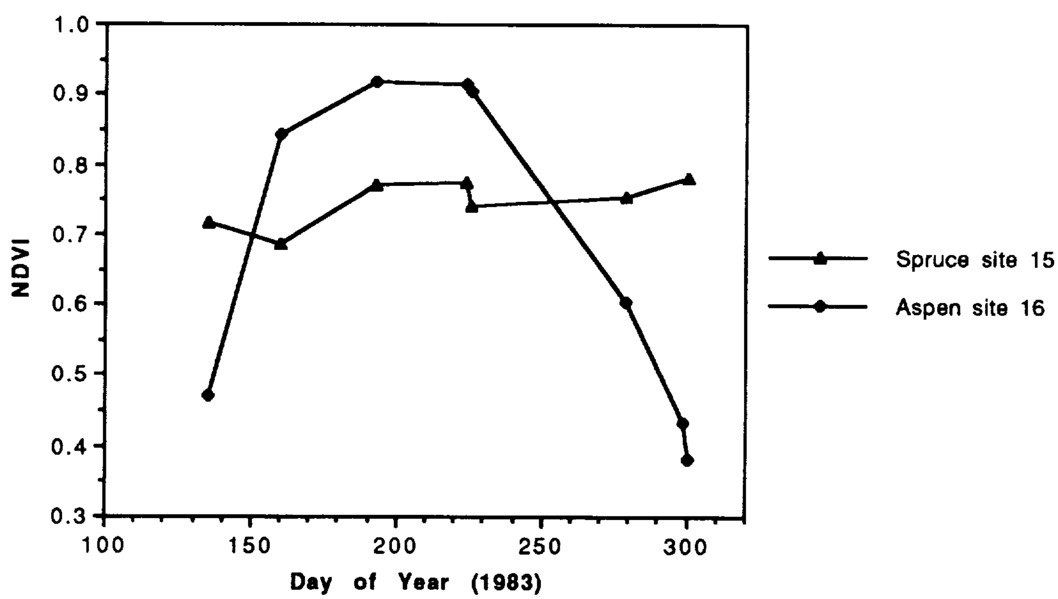

Figure 6.4 Normalized Difference Vegetation Index (NDVI) from helicopter MMR throughout 1983.

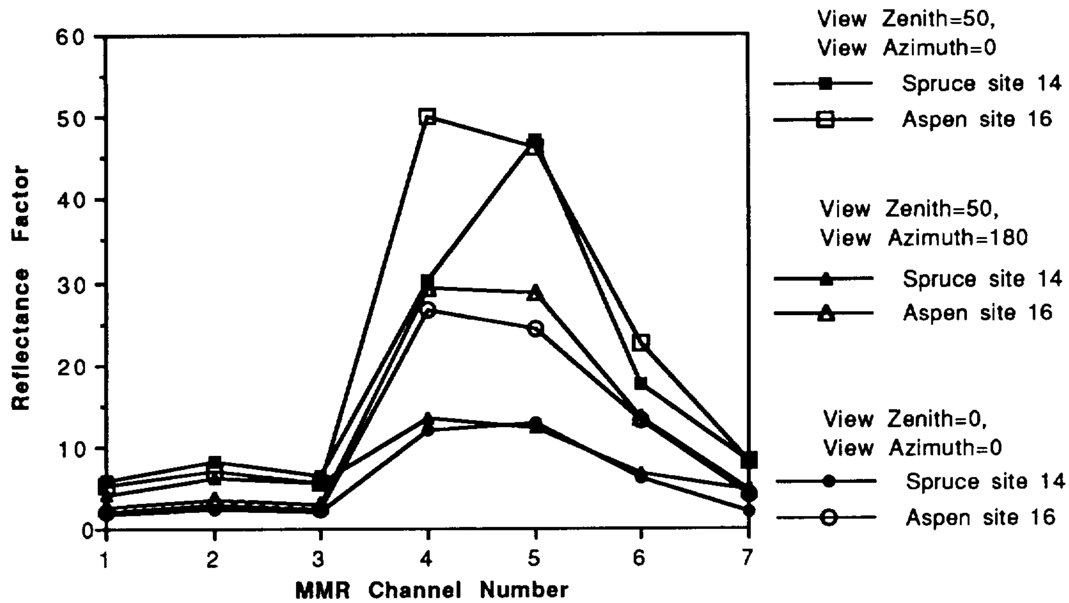

Figure 6.5 Spectral reflectance in each MMR band at three different view and zenith angles collected from the helicopter for spruce and aspen sites on September 16, 1984.

Table 6.1 - Helicopter MMR Availability 1983

Number of observations aquired for each site and date. Each row is for a given site and each column is a seperate date given by month and day.

	Acquisition Dates 1983										
Site	05/15	05/16	06/09	07/12	07/13	08/12	08/14	10/06	10/26	10/27	12/03
1	1		1			1					
2	1		1	1		1	1	1		1	1
3	3		1	1		1	1	1	1		1
4	1		1							1	
5	1										
6	1		1								
8	1		1							1	
10	1		1							1	
12	1		1		1	1	1	1	1		1
13	1		1			1					
14	1	2	1	1		1	1	1		1	1
15	3		1	1		1		1		1	1
16	1		1	1		1	1	2	1	2	2
17	1		1								
18	1		1		1	1	1	1	1		
19	1	3	1		1	1	1	1	1		
20	1		1		1					1	
21	1		1		1	1	1	1	1		
22	1	2	1		1	1	1			1	
23	1		1	1	1	1	1	1		1	1
24	1		1	1							
25	1	1	1		1	1	1	1	1		
26	1										
28					1	1	1				
38					1						
39					1						
40							1				
41					1	1	1			1	
42					1		1			1	
43			1		1	1					
45					1	2	1			1	
46					1	1					
47					1	1					
48					1	1					
49					1	1					
50					1	1					
51					1	1	1			1	
52					1						1
53							1				
54					1	1					
55					1	1					
56					1	4	3				
57					1	1					

	Acquisition Dates 1983										
Site	05/15	05/16	06/09	07/12	07/13	08/12	08/14	10/06	10/26	10/27	12/03
58							1				
59							1				
60					1	1					
61							1				
62					1	1					
63					1	1					
64					1	1					
65						1	1			1	
66						1	1			1	
67						1	1			1	
68					1	1	1	1	1		
69				1		1	1	1	1		
70				1							
71				1		1	1	1	1		
72					1	1		1		1	1
73				1		2		1		1	1
74					1	1					
75					1	1					
76					1	1					
77				1		1					
78					1	1					
79					1	1				1	
80					1	1	1			1	
81					1						
82					1						
83					1	1					
84					1	2	1			1	
85					1		1			1	
86					1						
87					1						
88					1					1	
89					1					1	
90					1	1				1	
91					1	1		1		1	
92					1	1		1		1	
93					1	1					
94						1					
95						1					
96						1					1
97						1				1	
98						1					
99			1			1					
100						1					
101						1					
102						1	1	2	1	2	
103						1	1				
104						1	1				
105									1		
106								1	1		
107								1	1		

	Acquisition Dates 1983										
Site	05/15	05/16	06/09	07/12	07/13	08/12	08/14	10/06	10/26	10/27	12/03
108								1	1		
111								1	1		
112								1	1		
113									1		
114									1		
115									1		
116										1	
117										1	
118										1	
119										1	
120										1	
121										1	
122										1	
124										1	
125										1	
999										1	

Table 6.2 - Helicopter MMR Availability 1984

Number of observations acquired for each site and date. Each row is for a given site and each column is a separate date given by month and day.

	Acquisition Dates 1984							
Site	05/18	05/28	06/03	08/02	08/03	08/16	09/16	09/23
2	1	1	1		3	2	4	1
3	1	1	1	1	3	2	3	
10							1	1
12	1	1	1	2	3	2	2	1
14	1		1		3	2	3	1
16	1	1	1	1	3	2	3	
18	1						1	1
19	1		1				1	1
21	1						1	
39								1
42			1					1
48			1					1
52	1	1	1	2	2	1	2	1
61							3	1
70	1	1	1				1	
73	1	1	1	1			1	
75	1	1	1	1			1	
84			1					
87		1						
88	1	1	1	1	3	2	3	
89				1	3	2	3	
92	1	1	1		3	1	4	
93	1	1	1		3	1	3	
102	1						3	1
119								1
121								1
122								1
124								1
125								1

Table 6.3 - 1983 Helicopter MMR Data

Reflectance data collected from the helicopter-mounted MMR in 1983. Each table has data collected from a single day. Site is the site location; Obs. is the number of observations averaged; Hgt. is the altitude of the helicopter in hundreds of feet; start and end times are in GMT in the form HHMMSS; Sol Zen and Sol Az are the solar zenith and azimuth angles; Rfl 1 through 7 are the average percent reflectance measured by the MMR. Std 1 through 7 are the standard deviations of the reflectance measurements. Unless otherwise noted, all observations are nadir views. Reflectances of -1.00 are missing values.

May 15, 1983

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
1	16	1	193624	193740	35.00	220.50	0.00	0.00	3.07	0.08	2.65	0.15	17.21	1.02	18.37	0.49	8.94	0.25	3.91	0.31
2	16	1	194212	194408	35.50	222.50	0.00	0.00	2.52	0.07	1.87	0.05	11.08	0.26	13.56	0.32	7.04	0.27	3.02	0.14
14	16	1	194528	194610	36.00	223.31	0.00	0.00	2.63	0.08	1.94	0.07	11.37	0.17	13.84	0.24	7.28	0.18	3.16	0.11
15	16	2	194918	195002	36.00	225.00	0.00	0.00	2.66	0.04	1.97	0.03	11.89	0.16	14.09	0.14	7.15	0.12	2.96	0.07
15	16	3	195122	195159	36.00	225.00	0.00	0.00	2.53	0.06	1.85	0.05	11.14	0.12	13.29	0.16	6.72	0.16	2.81	0.10
15	16	4	195238	195325	37.00	226.00	0.00	0.00	2.46	0.07	1.79	0.05	10.98	0.30	12.96	0.30	6.52	0.16	2.69	0.07
23	16	1	195511	195545	37.00	227.00	0.00	0.00	0.57	0.03	0.48	0.02	0.30	0.03	0.16	0.02	0.07	0.02	0.03	0.01
3	16	3	200013	200058	38.00	229.00	0.00	0.00	5.63	0.22	6.40	0.26	15.86	0.67	24.45	0.68	22.17	0.65	13.30	0.45
16	16	1	200511	200546	38.00	230.00	0.00	0.00	4.82	0.09	5.17	0.17	14.33	0.23	21.21	0.33	18.71	0.57	10.99	0.43
3	16	2	200800	200836	39.00	231.00	0.00	0.00	5.90	0.09	6.64	0.09	16.86	0.23	25.38	0.34	22.62	0.15	13.38	0.10
3	16	4	200939	201014	39.00	231.44	0.00	0.00	5.58	0.13	6.43	0.18	15.30	0.29	24.00	0.52	21.64	0.77	13.03	0.52
4	16	1	201517	201610	40.00	233.25	0.00	0.00	3.15	0.18	2.51	0.23	19.37	0.48	19.20	0.77	8.88	0.83	3.52	0.54
6	16	1	202129	202205	40.00	235.00	0.00	0.00	6.25	0.24	8.02	0.30	14.24	0.23	25.08	0.36	25.11	0.30	15.63	0.18
17	16	1	202747	202825	41.00	237.00	0.00	0.00	5.66	0.17	6.97	0.18	14.76	0.32	25.87	0.24	24.60	0.52	15.10	0.41
5	16	1	203115	203152	42.00	238.00	0.00	0.00	4.62	0.18	5.14	0.30	14.54	0.28	22.64	0.39	18.46	0.46	10.67	0.45
24	16	1	203416	203450	42.00	239.00	0.00	0.00	0.62	0.01	0.39	0.01	0.20	0.01	0.10	0.02	0.03	0.01	0.01	0.01
26	12	1	211923	211947	49.00	250.00	0.00	0.00	0.76	0.03	0.47	0.03	0.23	0.03	0.11	0.03	0.03	0.01	0.01	0.01
13	12	1	212355	212420	50.00	251.75	0.00	0.00	2.47	0.11	2.01	0.08	14.74	0.71	15.83	0.48	7.78	0.22	3.01	0.15
12	12	1	213005	213033	51.00	253.00	0.00	0.00	4.14	0.22	4.58	0.36	14.74	0.57	19.39	0.82	11.50	0.62	5.79	0.42
18	12	1	213242	213307	51.00	253.33	0.00	0.00	4.60	0.94	5.20	0.08	16.72	0.21	20.81	0.16	12.77	0.11	6.32	0.07
19	12	1	213438	213503	51.00	254.00	0.00	0.00	4.05	0.09	4.18	0.12	15.08	0.22	19.94	0.34	12.04	0.28	5.62	0.17
25	12	1	213642	213707	52.00	254.33	0.00	0.00	0.67	0.05	0.49	0.05	0.29	0.06	0.20	0.04	0.08	0.04	0.04	0.03
22	12	1	213949	214013	52.00	255.00	0.00	0.00	5.03	0.13	6.34	0.20	12.39	0.30	21.07	0.61	20.57	0.64	12.54	0.36
21	12	1	214115	214139	52.00	255.00	0.00	0.00	5.08	0.10	5.61	0.14	14.28	0.29	21.43	0.28	19.05	0.46	10.91	0.35
20	10	1	214505	214532	53.00	256.00	0.00	0.00	4.18	0.29	4.81	0.33	12.50	0.93	19.49	1.04	16.67	1.06	9.50	0.77
10	12	1	214902	214929	54.00	257.00	0.00	0.00	2.72	0.04	2.37	0.04	12.48	0.14	15.58	0.10	9.75	0.07	4.44	0.06
8	12	1	215026	215051	54.00	257.00	0.00	0.00	1.91	0.11	1.44	0.08	10.48	0.68	11.28	0.61	5.86	0.33	2.37	0.13

May 16, 1983

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
14	16	3	194707	194748	36.00	224.00	0.00	0.00	2.96	0.17	2.17	0.13	12.42	0.53	14.14	0.59	7.56	0.40	3.37	0.20
14	36	4	194932	195356	36.00	225.44	0.00	0.00	2.92	0.23	2.15	0.17	12.22	0.73	14.00	0.75	7.52	0.47	3.33	0.23
22	16	3	202225	202259	40.00	236.00	0.00	0.00	5.52	0.23	7.13	0.32	13.74	0.30	24.03	0.56	24.19	0.70	15.60	0.54
22	32	4	202501	202747	41.00	237.00	0.00	0.00	5.65	0.21	7.09	0.48	14.20	0.25	24.06	0.89	23.78	1.49	15.07	1.18
25	16	1	202912	202948	41.00	238.00	0.00	0.00	0.59	0.03	0.43	0.03	0.23	0.03	0.14	0.03	0.05	0.02	0.02	0.00
19	16	2	203702	203735	42.00	240.00	0.00	0.00	4.97	0.07	5.38	0.10	17.01	0.14	23.12	0.18	14.84	0.23	7.56	0.16
19	16	3	203823	203904	42.19	240.19	0.00	0.00	4.75	0.07	5.01	0.06	16.62	0.25	22.22	0.16	13.79	0.12	6.91	0.06
19	32	4	203948	204122	43.00	241.00	0.00	0.00	4.72	0.16	4.92	0.19	16.51	0.44	21.91	0.42	13.43	0.33	6.71	0.20

June 9, 1983

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
1	16	4	190837	190951	28.00	211.00	2.38	0.07	3.58	0.06	2.71	0.09	20.38	0.30	20.79	0.32	10.51	0.18	4.27	0.10
2	16	4	192555	192648	30.00	218.81	2.12	0.05	3.28	0.09	2.49	0.07	13.34	0.22	15.81	0.28	8.79	0.20	3.89	0.11
14	16	4	192814	192903	30.00	220.00	2.17	0.15	3.39	0.22	2.52	0.18	13.41	0.62	15.82	0.70	8.77	0.45	3.90	0.24
15	16	4	194804	194850	32.00	227.00	2.10	0.08	3.32	0.12	2.46	0.10	13.25	0.29	15.77	0.38	8.84	0.30	3.91	0.16
23	16	4	195142	195221	33.00	228.50	0.81	0.05	0.82	0.05	0.70	0.05	0.52	0.04	0.35	0.06	0.25	0.08	0.16	0.06
3	16	4	195938	200031	34.00	231.50	2.26	0.06	3.53	0.11	2.29	0.07	27.23	0.99	26.63	0.97	14.32	0.65	5.28	0.26
16	16	4	200212	200306	34.00	232.25	2.16	0.15	3.39	0.23	2.20	0.20	25.65	0.92	25.14	1.16	13.39	1.03	4.97	0.51
4	16	4	200605	200801	34.75	234.00	2.43	0.21	3.82	0.36	2.93	0.35	20.73	1.16	21.46	1.57	11.13	1.49	4.75	0.85
6	16	4	201056	201138	35.00	235.00	3.40	0.28	5.11	0.27	4.51	0.48	24.25	0.49	28.56	0.08	19.34	0.55	9.35	0.69
17	20	4	201613	201658	36.00	237.00	2.79	0.12	4.67	0.12	3.55	0.25	25.58	0.77	29.55	0.27	18.87	0.40	8.36	0.45
24	16	4	202608	202648	37.00	240.00	0.75	0.02	0.82	0.02	0.52	0.02	0.29	0.03	0.17	0.03	0.11	0.02	0.03	0.01
8	32	4	203154	203759	38.88	242.66	1.70	0.14	2.67	0.21	2.07	0.21	12.24	0.96	13.99	1.38	8.07	0.97	3.55	0.51
10	16	4	204122	204159	39.00	244.00	2.15	0.03	3.39	0.04	2.79	0.02	14.81	0.22	18.12	0.16	11.46	0.10	5.21	0.05
20	20	4	204950	205049	41.00	246.80	2.44	0.09	4.30	0.09	2.95	0.15	23.12	0.78	25.25	0.72	15.45	0.38	6.24	0.17
21	16	4	215402	215501	51.00	261.06	3.16	0.19	4.66	0.23	4.01	0.30	20.57	0.81	23.87	0.66	16.01	0.59	7.52	0.42
22	16	4	220140	220214	52.00	263.00	2.21	0.05	3.76	0.09	2.30	0.08	24.68	0.68	24.62	0.53	13.19	0.34	4.81	0.17
25	16	4	220407	220443	53.00	263.00	0.53	0.01	0.51	0.01	0.33	0.01	0.15	0.02	0.04	0.02	0.01	0.01	0.00	0.00
12	16	4	220732	220814	53.00	264.00	3.11	0.15	4.76	0.26	4.65	0.27	17.75	0.96	20.19	0.63	11.54	0.46	5.88	0.31
18	16	4	220925	221001	54.00	264.06	3.23	0.10	5.04	0.15	4.91	0.16	17.37	0.46	21.02	0.36	12.65	0.23	6.23	0.16
19	16	4	221037	221111	54.00	265.00	2.96	0.06	4.68	0.09	4.40	0.09	16.53	0.27	21.00	0.32	12.64	0.25	6.01	0.13
99	20	4	221312	221401	54.00	265.00	3.10	0.60	4.97	0.82	4.63	1.10	18.68	3.28	21.09	2.58	12.37	2.23	5.99	1.59
13	20	4	221655	221739	55.00	266.00	1.69	0.09	2.60	0.13	1.76	0.12	16.31	1.01	16.30	0.87	7.61	0.30	2.74	0.11
43	20	4	222246	222331	56.00	267.00	1.78	0.05	2.78	0.07	1.94	0.05	12.98	0.60	14.75	0.73	7.71	0.49	3.04	0.16

July 12, 1983

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
73	16	4	143647	143721	50.00	101.00	2.00	0.02	2.29	0.05	1.40	0.03	35.12	0.38	33.61	0.31	14.34	0.18	3.81	0.06
77	16	4	144432	144507	49.00	103.00	1.79	0.05	2.18	0.06	1.41	0.04	25.94	0.77	25.67	0.66	12.11	0.33	3.65	0.11

July 12, 1983 (continued)

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
2	16	4	145111	145146	48.00	104.00	1.55	0.05	2.31	0.07	1.46	0.05	11.67	0.23	12.53	0.22	5.87	0.13	2.06	0.08
14	16	4	145358	145435	47.00	105.00	1.69	0.08	2.53	0.12	1.60	0.09	12.44	0.37	13.22	0.41	6.26	0.25	2.27	0.12
15	16	4	145825	145902	47.00	106.00	1.71	0.07	2.59	0.09	1.65	0.06	12.72	0.34	13.70	0.28	6.54	0.16	2.36	0.09
23	16	4	150044	150118	46.00	107.00	0.52	0.02	0.58	0.01	0.57	0.01	0.21	0.01	0.05	0.00	0.01	0.00	0.00	0.01
3	16	4	150519	150552	46.00	108.00	1.95	0.04	2.20	0.06	1.42	0.03	31.96	0.90	29.70	0.66	13.15	0.27	3.69	0.12
16	16	4	151002	151044	45.00	109.00	1.87	0.06	2.16	0.06	1.35	0.04	31.03	1.05	28.82	0.90	12.63	0.41	3.54	0.14
24	16	4	151537	151615	44.00	110.00	0.55	0.03	0.54	0.02	0.35	0.03	0.17	0.03	0.07	0.03	0.04	0.03	0.03	0.01
69	16	4	152009	152050	43.00	111.00	2.29	0.03	3.16	0.08	1.89	0.05	34.78	0.52	35.19	0.46	17.16	0.28	5.29	0.11
70	16	4	152156	152235	43.00	112.00	2.22	0.03	3.00	0.05	1.78	0.04	34.85	0.35	34.95	0.35	17.14	0.28	5.36	0.12
71	16	4	152710	152750	42.00	113.00	2.48	0.02	3.45	0.03	1.94	0.02	40.59	0.22	38.16	0.18	17.53	0.13	5.19	0.06

July 13, 1983

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
68	16	4	134812	134847	58.00	92.00	1.73	0.05	2.64	0.09	1.57	0.06	13.21	0.27	11.92	0.29	4.98	0.20	1.65	0.10
21	16	4	135116	135149	58.00	92.00	2.25	0.04	2.76	0.07	1.77	0.04	32.70	0.44	29.89	0.37	13.53	0.20	4.14	0.08
22	16	4	135301	135349	57.00	93.00	2.65	0.05	3.38	0.07	2.15	0.05	41.32	0.45	38.06	0.71	18.13	0.53	5.76	0.24
25	16	4	135547	135632	57.00	93.00	0.55	0.02	0.55	0.02	0.39	0.02	0.14	0.02	0.00	0.01	-0.44	0.50	0.00	0.00
12	20	4	135959	140056	56.00	94.00	2.84	0.04	4.62	0.07	3.68	0.06	25.00	0.37	23.56	0.37	11.75	0.24	4.86	0.13
18	16	4	140242	140316	56.00	94.50	3.05	0.06	4.80	0.08	4.29	0.09	19.73	0.27	22.37	0.43	12.36	0.28	5.54	0.14
19	16	4	140512	140557	55.00	95.00	2.78	0.04	4.38	0.07	3.80	0.07	18.31	0.28	21.68	0.33	11.96	0.22	5.21	0.12
45	16	4	141146	141223	54.00	96.00	2.18	0.04	3.35	0.06	2.03	0.05	16.74	0.18	15.23	0.17	6.38	0.14	2.02	0.07
42	16	4	141656	141734	54.00	97.00	1.71	0.07	2.54	0.11	1.56	0.09	13.12	0.41	12.30	0.41	5.27	0.28	1.73	0.12
41	16	4	141843	141917	53.00	98.00	1.64	0.03	2.45	0.05	1.47	0.04	12.51	0.19	11.45	0.15	4.78	0.10	1.50	0.04
51	16	4	142200	142241	53.00	98.00	2.23	0.07	3.54	0.12	2.41	0.08	16.66	0.36	18.15	0.26	9.16	0.18	3.64	0.11
79	16	4	142940	143029	51.50	100.00	2.08	0.02	2.51	0.04	1.59	0.02	33.84	0.30	29.50	0.26	12.66	0.13	3.52	0.04
80	16	4	143309	143349	51.00	101.00	1.89	0.11	2.37	0.14	1.51	0.12	28.86	0.96	26.15	0.70	11.44	0.42	3.36	0.20
28	16	4	143643	143717	50.00	101.50	0.45	0.01	0.55	0.01	0.30	0.00	0.10	0.01	0.00	0.00	-0.75	0.43	0.00	0.00
81	16	4	151736	151811	44.00	111.00	2.44	0.03	2.94	0.04	1.83	0.04	39.51	0.96	35.35	0.84	15.79	0.35	4.51	0.08
82	16	4	151905	151938	43.00	111.00	2.45	0.03	3.25	0.07	2.00	0.05	37.48	0.90	33.54	0.63	15.05	0.23	4.49	0.07
83	16	4	152149	152231	43.00	112.00	2.12	0.08	2.84	0.10	1.65	0.07	35.15	0.95	31.82	0.70	14.17	0.34	4.11	0.09
86	16	4	152817	152855	42.00	114.00	2.76	0.08	3.97	0.15	2.40	0.13	37.17	0.53	36.34	0.50	18.04	0.42	5.91	0.27
84	16	4	153101	153136	42.00	114.00	2.62	0.03	3.72	0.06	2.06	0.04	44.28	0.37	40.44	0.41	18.41	0.26	5.36	0.11
85	16	4	153232	153305	41.00	115.00	2.20	0.06	2.97	0.10	1.86	0.08	33.13	0.84	30.68	0.60	14.18	0.35	4.34	0.18
38	16	4	153635	153721	41.00	116.00	2.36	0.09	3.57	0.14	2.42	0.13	18.48	1.64	20.64	1.92	11.42	1.35	4.70	0.53
39	16	4	153944	154021	40.00	116.56	2.39	0.05	3.77	0.08	2.46	0.06	16.31	0.42	17.07	0.67	8.36	0.36	3.24	0.15
52	16	4	154415	154449	40.00	118.00	2.06	0.07	3.23	0.09	2.13	0.08	14.04	0.30	14.65	0.33	7.28	0.26	2.90	0.19
46	16	4	155050	155126	39.00	120.00	2.72	0.09	4.16	0.13	2.67	0.10	18.76	0.37	18.31	0.37	8.46	0.30	3.01	0.19
88	16	4	170656	170731	29.00	147.00	2.67	0.06	3.69	0.12	2.32	0.09	36.45	0.83	35.94	0.72	17.50	0.61	5.53	0.33
89	16	4	171234	171314	29.00	149.31	2.71	0.09	3.92	0.24	2.38	0.15	38.65	0.63	38.81	0.82	19.57	0.79	6.36	0.50

July 13, 1983 (continued)

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
60	16	4	172033	172106	28.00	153.00	2.94	0.14	4.76	0.23	3.21	0.17	22.87	0.64	24.33	0.54	13.19	0.37	5.35	0.22
57	16	4	172354	172427	28.00	154.75	2.84	0.22	4.39	0.34	3.05	0.29	18.38	0.92	20.06	1.23	10.99	0.95	4.68	0.55
91	16	4	173408	173442	27.00	159.00	2.36	0.08	3.37	0.12	1.98	0.08	33.52	0.81	32.99	0.64	16.98	0.33	5.57	0.14
50	16	4	184746	184821	27.00	197.56	2.37	0.09	3.71	0.13	2.34	0.09	17.00	0.57	16.50	0.32	8.01	0.20	2.85	0.11
47	16	4	185036	185110	27.00	199.00	2.19	0.83	3.84	0.11	2.77	0.11	15.43	0.41	17.40	0.31	10.52	0.27	4.91	0.18
49	15	4	185249	185326	27.00	200.00	2.32	0.10	3.52	0.14	2.34	0.11	16.11	0.67	15.95	0.63	8.23	0.38	3.19	0.18
48	16	4	185406	185439	27.00	201.00	2.16	0.08	3.28	0.13	2.18	0.09	15.50	0.54	15.44	0.25	7.88	0.13	3.04	0.06
55	16	4	185800	185835	28.00	202.00	2.23	0.16	3.04	1.06	2.16	0.17	15.24	0.88	14.10	3.99	7.29	0.45	2.37	0.89
54	16	4	190035	190108	28.00	203.25	2.01	0.79	3.37	0.24	1.77	1.07	18.21	0.95	18.44	1.37	9.02	0.92	3.25	0.41
43	16	4	190411	190447	28.00	205.00	2.06	0.06	2.74	0.97	1.85	0.74	14.03	0.31	14.98	0.42	7.77	0.26	2.97	0.11
56	16	4	190721	190755	28.00	207.00	1.97	0.77	3.43	0.08	2.27	0.05	17.50	0.61	18.62	0.67	9.88	1.03	3.56	0.18
62	16	4	191129	191203	29.00	209.00	4.18	0.10	6.76	0.13	6.33	0.15	26.84	0.38	30.61	0.57	18.58	0.40	8.67	0.23
63	16	4	191402	191439	29.00	210.00	3.60	0.10	5.71	0.15	4.90	0.74	22.37	0.39	26.92	0.55	16.46	0.47	7.45	0.23
64	16	4	191742	191817	29.00	211.50	3.77	1.24	6.19	0.20	5.67	0.29	25.33	0.39	31.20	0.69	19.48	0.66	8.90	0.39
20	16	4	192450	192527	30.00	214.75	2.21	0.06	2.88	1.01	1.97	0.09	31.11	0.77	30.60	0.53	15.51	0.25	5.02	0.15
87	16	4	193023	193057	30.00	217.00	2.45	0.09	3.33	0.13	1.94	0.49	34.74	0.56	33.29	0.60	16.33	0.53	5.08	0.27
90	15	4	194312	194353	32.00	222.00	2.15	0.07	2.87	0.11	1.82	0.10	30.94	0.89	29.19	0.42	14.25	0.18	4.42	0.09
78	15	4	194734	194808	32.00	224.00	2.10	0.06	2.70	0.09	1.78	0.09	28.55	0.61	27.32	0.46	13.89	0.21	4.47	0.10
92	15	4	195133	195210	33.00	225.00	2.22	0.07	2.94	0.11	1.79	0.75	27.96	0.50	27.06	0.54	14.00	0.29	4.33	1.43
93	16	4	195511	195545	33.00	227.00	1.90	0.75	2.67	0.09	1.71	0.05	28.55	0.42	27.18	0.32	13.79	0.23	4.31	0.13
75	16	4	195916	195953	34.00	228.00	2.09	0.06	2.57	0.06	1.64	0.06	31.45	0.59	28.41	0.48	13.41	0.23	3.89	0.06
74	20	4	200202	200257	34.00	229.00	1.93	0.05	2.41	0.07	1.54	0.07	29.35	0.64	26.51	0.56	12.83	0.36	3.87	0.19
72	19	4	200535	200652	34.00	230.00	2.05	0.10	2.72	0.16	1.69	0.12	27.93	0.75	25.22	0.70	12.30	0.49	3.48	1.07
76	15	4	200855	200936	35.00	231.00	1.94	0.79	2.85	0.06	1.76	0.07	32.46	0.57	30.47	0.91	15.71	0.15	4.96	0.08
23	16	4	201549	201623	36.00	233.69	1.62	0.70	1.79	0.76	1.74	0.75	1.34	0.72	1.14	0.76	1.33	1.23	0.83	0.62

August 12, 1983

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
56	16	4	140241	140334	61.00	100.00	1.38	0.07	2.01	0.13	1.28	0.09	11.02	0.66	11.36	0.72	4.97	0.35	1.72	0.12
73	16	4	142126	142201	57.94	104.00	2.18	0.04	2.51	0.05	1.62	0.03	35.63	0.72	32.51	0.55	13.57	0.22	3.54	0.07
78	15	4	143801	143838	55.00	108.00	1.90	0.06	2.38	0.09	1.59	0.05	25.30	0.50	24.75	0.48	11.68	0.26	3.46	0.09
2	23	4	144611	145210	53.65	109.70	1.43	0.11	2.01	0.17	1.31	0.11	10.81	0.73	11.24	0.64	5.00	0.34	1.67	0.14
14	16	4	145735	145811	52.00	112.00	1.57	0.07	2.22	0.11	1.47	0.09	11.65	0.36	11.99	0.34	5.35	0.22	1.85	0.11
15	16	4	145942	150020	51.50	112.50	1.63	0.05	2.35	0.06	1.57	0.04	12.30	0.24	12.86	0.22	5.86	0.15	2.05	0.07
23	16	4	150135	150210	51.00	113.00	0.72	0.02	0.91	0.02	0.87	0.02	0.34	0.02	-0.04	0.25	-0.94	0.25	-0.94	0.25
3	24	4	150757	151007	50.04	114.83	1.90	0.08	2.16	0.10	1.49	0.06	29.12	1.53	27.10	1.90	12.01	0.44	3.27	0.51
16	16	4	151127	151201	50.56	114.25	1.91	0.03	2.17	0.03	1.43	0.03	32.07	0.38	28.91	0.46	12.31	0.19	3.36	0.05
69	16	4	151732	151812	49.00	117.00	2.34	0.05	3.12	0.05	1.96	0.03	35.96	0.87	35.05	0.61	16.80	0.27	5.01	0.09
71	16	4	152020	152101	48.00	118.00	2.37	0.05	3.12	0.06	1.90	0.04	36.72	0.94	33.95	0.62	15.10	0.29	4.26	0.09

August 12, 1983 (continued)

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
68	20	4	152733	152824	47.00	119.55	1.86	0.08	2.70	0.11	1.78	0.09	13.64	0.46	13.70	0.44	6.21	0.23	2.18	0.11
21	16	4	153016	153053	47.00	120.00	2.44	0.07	3.18	0.10	2.17	0.10	32.10	0.85	32.03	0.56	15.58	0.31	5.03	0.22
25	20	4	153253	153347	47.00	121.00	0.62	0.02	0.71	0.01	0.52	0.02	0.16	0.01	-0.02	0.23	-0.95	0.22	-1.00	0.00
56	15	4	153816	153852	46.00	122.00	1.94	0.04	2.96	0.05	2.02	0.05	15.13	0.31	15.96	0.26	7.77	0.16	2.97	0.10
12	16	4	154415	154454	45.00	124.00	3.15	0.07	5.08	0.09	4.28	0.09	27.51	0.27	28.96	0.25	14.73	0.30	6.00	0.20
18	16	4	154615	154655	45.00	125.00	3.32	0.10	5.23	0.14	4.81	0.16	22.36	0.40	26.37	0.53	14.60	0.40	6.43	0.21
19	16	4	154913	154950	44.00	125.00	3.16	0.03	4.87	0.04	4.43	0.05	20.96	0.15	26.15	0.23	14.81	0.18	6.46	0.07
41	20	4	155524	155612	43.00	127.00	2.03	0.11	2.87	0.17	1.95	0.13	14.91	0.69	15.29	0.73	7.09	0.46	2.55	0.20
42	16	4	155709	155748	43.00	128.00	1.97	0.10	2.79	0.13	1.88	0.09	13.59	0.44	14.11	0.39	6.49	0.21	2.30	0.08
51	20	4	160345	160434	42.00	130.00	2.40	0.07	3.76	0.10	2.64	0.07	19.02	0.48	21.03	0.50	10.69	0.27	4.20	0.13
84	20	4	165441	165537	37.00	147.00	2.03	0.08	2.94	0.20	1.81	0.11	29.24	1.17	30.94	0.91	15.01	0.74	4.82	0.41
83	12	4	165613	165654	37.00	147.00	2.12	0.06	3.04	0.20	1.88	0.09	30.41	0.89	31.73	0.75	15.26	0.67	4.87	0.39
84	16	4	165817	165858	36.00	148.00	2.52	0.05	3.55	0.15	2.19	0.08	38.70	0.29	41.33	0.50	19.75	0.38	6.02	0.22
45	16	4	170545	170622	36.00	151.00	2.26	0.03	3.18	0.05	2.15	0.03	16.73	0.36	17.67	0.50	8.20	0.25	2.85	0.10
46	28	4	170753	171022	35.57	152.29	2.24	0.08	3.22	0.13	2.14	0.09	16.63	0.25	17.27	0.27	7.77	0.16	2.64	0.08
79	20	4	171629	172019	35.00	156.60	2.15	0.04	2.69	0.06	1.82	0.03	31.91	0.75	31.72	0.66	14.63	0.25	4.36	0.07
80	16	4	172132	172208	35.00	157.25	2.22	0.08	2.79	0.10	2.05	0.10	28.69	1.89	29.63	1.54	14.39	0.59	4.71	0.15
96	16	4	172432	172511	34.00	159.00	2.28	0.06	2.83	0.10	1.88	0.07	30.16	0.71	29.24	0.78	13.77	0.48	4.14	0.21
97	20	4	172642	172733	34.00	159.65	2.10	0.06	2.62	0.07	1.80	0.03	31.10	1.24	30.39	0.99	14.22	0.48	4.31	0.14
28	16	4	172824	172901	34.00	160.06	1.08	0.09	1.30	0.09	0.89	0.10	0.54	0.09	0.40	0.09	0.35	0.09	0.27	0.07
47	16	4	173551	173628	34.00	163.75	2.09	0.06	3.19	0.08	2.39	0.08	13.10	0.28	15.93	0.33	9.71	0.25	4.73	0.15
50	16	4	173930	174008	34.00	165.00	1.96	0.07	2.88	0.09	1.93	0.07	14.85	0.48	15.20	0.35	6.99	0.17	2.43	0.08
49	16	4	174310	174346	33.00	167.00	2.02	0.08	2.95	0.13	2.05	0.08	14.69	0.54	15.48	0.47	7.54	0.20	2.85	0.09
48	12	4	174430	174501	33.00	167.00	1.86	0.09	2.72	0.13	1.86	0.08	13.88	0.67	14.43	0.54	6.92	0.23	2.51	0.09
54	16	4	175016	175054	33.00	170.00	1.89	0.13	2.84	0.19	1.92	0.15	16.50	0.90	17.66	1.10	8.41	0.68	2.97	0.27
53	16	4	175146	175223	33.00	170.63	1.64	0.08	2.45	0.12	1.58	0.07	17.67	0.50	16.93	0.48	7.27	0.30	2.35	0.12
55	16	4	175359	175443	33.00	171.00	1.99	0.11	2.78	0.14	1.94	0.12	14.06	0.46	14.96	0.53	7.01	0.34	2.43	0.15
43	16	4	175851	175936	33.00	173.75	1.72	0.09	2.42	0.13	1.71	0.10	12.06	0.55	13.54	0.55	6.75	0.32	2.55	0.15
56	16	4	180157	180238	33.00	174.88	2.22	0.11	3.42	0.15	2.40	0.11	17.83	1.01	19.66	1.01	9.96	0.57	3.81	0.24
13	16	4	180634	180711	33.00	177.00	2.16	0.15	3.26	0.25	2.21	0.18	21.95	1.03	23.38	0.65	11.44	0.31	4.07	0.15
63	16	4	180912	180953	33.00	178.00	3.38	0.09	5.36	0.16	4.78	0.19	22.28	0.66	27.25	0.65	15.95	0.45	7.10	0.24
62	16	4	181150	181223	33.00	179.00	4.07	0.07	6.52	0.09	6.16	0.13	26.29	0.34	31.91	0.33	19.03	0.32	8.82	0.19
64	16	4	181704	181742	33.00	182.00	3.72	0.13	5.73	0.20	5.14	0.30	23.77	0.39	30.48	1.02	18.31	0.90	8.27	0.53
104	16	4	181917	181954	33.00	182.00	2.80	0.06	4.42	0.11	3.63	0.07	21.88	0.72	24.68	0.74	13.19	0.38	5.51	0.14
103	16	4	190333	190417	34.00	201.44	3.28	0.17	5.28	0.28	4.42	0.31	25.28	1.12	28.59	1.54	15.55	1.01	6.67	0.49
22	20	4	190830	190931	35.00	204.00	2.23	0.12	3.09	0.19	2.11	0.20	30.26	1.09	31.53	0.97	15.90	0.57	5.28	0.23
102	16	4	191526	191604	35.00	206.19	1.80	0.06	2.71	0.12	1.80	0.07	13.37	0.52	13.48	0.38	6.37	0.13	2.28	0.03
66	16	4	191820	191856	35.00	208.00	1.79	0.06	2.60	0.10	1.63	0.05	20.91	1.20	20.02	0.87	8.86	0.35	2.91	0.13
65	28	4	192150	192353	36.00	209.00	1.93	0.16	2.82	0.28	1.97	0.24	21.55	1.03	21.12	1.41	9.90	1.17	3.45	0.56

August 12, 1983 (continued)

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
67	16	4	192503	192540	36.00	210.00	1.52	0.17	2.19	0.26	1.38	0.18	19.01	1.83	18.19	1.21	7.91	0.66	2.59	0.27
73	16	4	193838	193919	37.00	215.00	2.00	0.02	2.39	0.02	1.57	0.02	30.04	0.17	29.02	0.17	13.39	0.12	3.81	0.05
72	16	4	194112	194158	37.00	216.00	1.88	0.06	2.60	0.04	1.66	0.02	26.19	0.28	26.30	0.22	12.93	0.12	3.79	0.53
74	16	4	194500	194534	38.00	218.00	1.86	0.06	2.36	0.08	1.62	0.08	26.78	0.67	26.81	0.55	13.16	0.33	4.09	0.16
75	20	4	194656	194756	38.00	218.00	2.05	0.06	2.54	0.08	1.74	0.06	29.67	1.29	28.97	1.14	13.61	0.54	4.02	0.13
76	19	4	194937	195123	38.37	219.37	2.04	0.05	2.66	0.06	1.75	0.06	29.88	0.54	30.98	0.42	15.84	0.27	4.99	0.11
93	16	4	195548	195640	39.00	221.00	1.89	0.06	2.44	0.09	1.68	0.06	23.12	0.74	24.40	0.77	13.15	0.48	4.35	0.18
92	16	4	195735	195821	39.00	222.00	1.93	0.05	2.53	0.08	1.84	0.06	22.85	0.45	23.70	0.49	12.53	0.34	4.34	0.18
77	16	4	200509	200553	40.00	224.00	1.90	0.09	2.45	0.10	1.72	0.09	23.38	1.31	23.77	1.00	12.64	0.36	4.26	0.14
91	16	4	200943	201025	41.00	226.00	2.00	0.06	2.75	0.09	1.72	0.06	28.76	0.67	28.93	0.58	14.39	0.23	4.51	0.07
90	16	4	201640	201724	41.50	228.00	2.08	0.05	2.70	0.05	1.80	0.05	30.09	1.01	28.75	0.72	13.38	0.26	3.98	0.11
1	16	4	202332	202410	42.00	230.00	1.79	0.08	2.52	0.12	1.65	0.10	21.25	0.57	18.50	0.40	7.45	0.21	2.25	0.09
59	16	4	202732	202808	43.00	231.25	2.28	0.15	3.41	0.19	2.55	0.16	16.05	0.45	19.21	0.53	11.41	0.47	5.16	0.31
58	16	4	202911	202945	43.00	232.00	2.26	0.09	3.39	0.13	2.56	0.10	15.27	0.52	17.61	0.55	10.43	0.31	4.84	0.14
57	16	4	203154	203243	43.00	233.00	1.73	0.13	2.59	0.17	1.78	0.14	12.49	0.62	13.23	0.57	6.77	0.37	2.64	0.20
60	16	4	203729	203804	44.00	234.19	2.23	0.13	3.47	0.18	2.41	0.16	16.41	0.68	17.51	0.81	9.43	0.56	3.86	0.28
61	16	4	204157	204234	45.00	235.88	1.61	0.06	2.45	0.12	1.62	0.12	18.42	0.52	18.73	0.59	9.06	0.63	3.18	0.33
100	20	4	212412	212521	51.00	247.00	1.55	0.13	2.15	0.18	1.47	0.14	12.20	0.71	12.28	0.73	5.59	0.42	1.99	0.22
101	20	4	212722	212823	51.40	247.40	2.02	0.08	2.82	0.12	1.78	0.08	17.62	0.62	15.45	0.55	5.93	0.27	1.65	0.12
45	16	4	213119	213159	52.00	248.00	1.19	0.09	1.68	0.11	1.05	0.08	10.35	0.83	9.52	0.63	3.67	0.20	1.01	0.05
95	16	4	213504	213548	53.00	249.00	2.33	0.06	3.43	0.11	2.23	0.08	31.00	0.95	33.44	0.68	16.74	0.29	5.40	0.15
98	20	4	213753	213841	53.00	250.00	2.21	0.14	3.10	0.21	2.03	0.16	29.74	1.70	28.05	1.41	12.90	0.62	3.92	0.19
94	16	4	214113	214152	54.00	251.00	2.43	0.07	3.50	0.13	2.27	0.09	30.71	0.64	34.73	0.67	17.43	0.40	5.60	0.16
99	16	4	214254	214328	54.00	251.00	2.16	0.02	3.25	0.04	1.96	0.03	30.61	0.64	32.41	0.40	15.79	0.13	4.91	0.05
56	20	4	214649	214800	54.80	252.00	1.43	0.12	2.10	0.16	1.39	0.12	11.64	0.75	12.46	0.74	5.94	0.48	2.12	0.24

August 14, 1983

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
56	16	4	144339	144414	54.00	109.44	1.54	0.09	2.22	0.15	1.45	0.11	11.72	0.58	11.56	0.56	5.24	0.33	1.94	0.15
104	16	4	145226	145302	53.00	111.13	2.36	0.04	3.53	0.08	2.65	0.05	19.11	0.30	19.58	0.24	9.77	0.14	3.88	0.08
103	16	4	145529	145603	52.88	112.00	2.80	0.05	4.31	0.06	3.42	0.09	23.30	0.36	23.75	0.56	11.82	0.31	4.59	0.12
25	16	4	145717	145752	52.00	113.00	0.61	0.02	0.63	0.00	0.44	0.00	0.16	0.02	0.03	0.00	0.00	0.00	0.00	0.00
22	20	4	150620	150708	51.00	115.00	2.46	0.05	3.14	0.08	2.13	0.07	33.86	0.71	33.59	0.71	16.20	0.44	5.15	0.18
102	16	4	150948	151027	50.00	115.75	1.85	0.06	2.59	0.08	1.69	0.06	13.71	0.35	13.27	0.33	5.84	0.18	1.99	0.08
65	16	4	151240	151321	50.00	116.00	1.49	0.03	2.00	0.06	1.25	0.04	18.00	0.18	15.30	0.16	5.78	0.08	1.67	0.04
67	16	4	151409	151448	50.00	117.00	1.72	0.07	2.40	0.10	1.50	0.06	20.99	0.73	18.87	0.63	7.78	0.34	2.49	0.14
66	16	4	151634	151710	49.00	117.00	1.84	0.04	2.57	0.06	1.59	0.04	22.32	0.44	19.87	0.37	7.56	1.44	2.47	0.08
56	16	4	152228	152311	48.69	119.00	1.83	0.13	2.71	0.21	1.84	0.17	13.87	0.85	14.48	0.94	6.99	0.59	2.73	0.29
41	16	4	152612	152654	48.00	120.00	1.76	0.04	2.44	0.08	1.64	0.06	13.61	0.30	13.59	0.29	6.10	0.18	2.11	0.10

August 14, 1983 (continued)

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
42	16	4	152754	152829	48.00	120.00	1.72	0.05	2.33	0.08	1.54	0.05	12.42	0.22	12.03	0.24	5.18	0.13	1.71	0.06
84	16	4	153208	153250	47.00	121.00	2.57	0.06	3.52	0.11	2.17	0.06	39.89	0.65	39.59	0.88	18.57	0.56	5.56	0.24
85	16	4	153502	153543	47.00	122.00	2.18	0.04	2.85	0.08	1.79	0.06	32.28	0.93	29.99	0.62	13.68	0.19	4.05	0.08
51	20	4	153927	154024	46.00	123.40	2.24	0.07	3.42	0.11	2.38	0.10	18.21	0.46	19.48	0.56	9.62	0.34	3.70	0.17
80	20	4	154936	155035	45.00	126.00	2.16	0.16	2.69	0.21	1.82	0.19	29.76	1.15	28.96	1.00	13.35	0.64	4.14	0.27
28	16	4	155121	155156	44.00	127.00	0.73	0.01	0.91	0.01	0.49	0.01	0.17	0.00	0.02	0.00	0.01	0.01	0.00	0.00
45	16	4	155641	155719	44.00	128.00	1.98	0.07	2.73	0.09	1.80	0.07	15.56	0.48	14.80	0.57	6.24	0.32	2.00	0.13
56	16	4	160123	160213	43.00	130.00	1.84	0.14	2.78	0.21	1.88	0.16	14.46	0.86	15.67	0.78	7.75	0.40	3.02	0.19
19	16	4	160806	160853	42.00	132.00	2.96	0.11	4.55	0.17	4.10	0.16	20.39	0.49	25.04	0.70	13.78	0.52	5.95	0.25
18	16	4	160951	161046	42.00	132.00	3.16	0.09	4.90	0.16	4.42	0.16	21.82	0.37	25.66	0.67	14.03	0.52	6.10	0.29
12	16	4	161203	161242	42.00	133.00	3.09	0.05	4.93	0.05	4.12	0.04	26.71	0.66	28.24	0.33	14.35	0.13	5.87	0.12
68	16	4	162410	162504	40.00	137.00	2.03	0.12	3.13	0.80	1.97	0.11	14.44	0.56	14.34	0.50	6.77	0.26	2.49	0.12
21	16	4	163224	163312	39.00	139.38	2.38	0.07	3.07	0.12	1.88	0.75	31.27	1.10	31.70	1.03	15.82	0.56	5.09	0.64
69	16	4	163851	163939	39.00	141.75	2.42	0.04	3.27	0.05	2.10	0.03	34.70	1.15	35.41	0.55	17.85	0.33	5.76	0.13
71	20	4	164147	164255	38.20	143.00	2.40	0.05	3.33	0.09	1.97	0.05	36.55	1.00	35.59	0.95	16.73	0.62	5.12	0.25
16	16	4	164717	164802	38.00	145.00	2.01	0.05	2.31	0.06	1.54	0.04	30.90	0.89	29.54	0.71	13.56	0.39	4.05	0.13
3	16	4	164903	164937	38.00	145.00	2.17	0.03	2.55	0.07	1.75	0.04	31.67	0.65	30.94	0.32	14.58	0.20	4.45	0.13
15	16	4	173735	173813	34.00	164.44	2.06	0.11	2.94	0.15	2.07	0.12	13.91	0.48	16.68	0.55	8.39	0.33	3.38	0.18
14	16	4	174119	174157	34.00	166.00	2.12	0.07	2.99	0.09	2.11	0.08	13.83	0.34	16.03	0.39	8.07	0.26	3.25	0.14
2	20	4	174921	175010	34.00	169.25	2.07	0.07	2.96	0.10	2.10	0.09	13.82	0.26	16.03	0.28	8.34	0.22	3.42	0.12
23	16	4	175127	175205	34.00	170.25	0.89	0.03	1.19	0.05	1.13	0.04	0.48	0.03	0.08	0.02	0.04	0.01	0.01	0.01

October 6, 1983

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
16	16	4	145221	145311	66.00	129.00	2.30	0.06	4.63	0.16	4.25	0.15	20.23	0.42	20.49	0.29	10.46	0.24	3.58	0.08
3	16	4	145821	145900	65.94	130.00	2.39	0.12	4.25	0.33	3.44	0.32	22.92	1.36	23.17	1.23	11.65	0.73	3.82	0.25
69	20	4	150422	150511	65.00	131.20	2.91	0.11	3.97	0.23	4.81	0.26	11.44	0.76	17.09	0.83	13.86	0.52	7.26	0.21
71	16	4	150917	151004	64.00	133.00	3.14	0.12	6.39	0.46	7.07	0.52	21.75	1.55	25.62	1.37	15.47	0.66	6.03	0.23
102	16	4	151557	151636	63.13	134.00	1.46	0.05	2.14	0.06	1.47	0.06	10.88	0.29	10.65	0.28	4.73	0.14	1.50	0.06
68	16	4	152014	152051	63.00	135.00	1.46	0.04	2.15	0.06	1.47	0.05	10.77	0.29	10.53	0.24	4.71	0.11	1.51	0.04
21	16	4	152750	152828	62.00	137.00	2.79	0.09	5.82	0.18	5.53	0.22	22.40	0.53	25.11	0.48	14.09	0.29	5.19	0.15
25	16	4	153016	153051	62.00	138.00	0.68	0.03	0.69	0.03	0.48	0.04	0.23	0.03	0.11	0.03	0.09	0.04	-0.04	0.25
19	16	4	153340	153416	61.00	138.50	2.06	0.07	3.16	0.10	2.99	0.10	15.07	0.32	17.00	0.48	9.22	0.31	3.64	0.14
18	16	4	153541	153615	61.00	139.00	2.18	0.05	3.38	0.06	3.16	0.06	16.10	0.33	17.40	0.26	9.63	0.17	3.88	0.09
12	16	4	153746	153819	61.00	140.00	2.30	0.05	3.60	0.06	3.68	0.07	18.81	0.16	18.96	0.12	10.27	0.17	4.15	0.12
107	16	4	154618	154659	60.00	142.00	1.52	0.13	2.57	0.32	2.20	0.25	13.86	1.44	14.27	1.32	7.17	0.70	2.42	0.18
106	20	4	154740	154830	60.00	142.00	1.54	0.08	2.94	0.29	2.58	0.34	13.65	0.42	13.82	0.48	6.85	0.34	2.33	0.19
111	20	4	160241	160342	58.00	146.00	1.68	0.15	2.96	0.35	2.89	0.47	13.13	0.72	14.37	0.76	7.93	0.57	3.13	0.31
112	16	4	160711	160801	58.00	147.06	1.96	0.27	3.85	0.71	3.67	0.75	16.50	2.49	17.25	2.40	9.41	1.46	3.45	0.50

October 6, 1983 (continued)

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
108	20	4	161013	161109	58.00	148.20	2.09	0.21	3.42	0.42	2.70	0.24	19.08	2.23	19.31	1.97	10.30	0.98	3.61	0.23
72	16	4	163138	163222	56.00	154.00	2.36	0.12	3.92	0.36	4.04	0.23	12.50	1.03	15.35	1.03	11.23	0.58	5.60	0.14
73	20	4	163548	163632	56.00	155.70	3.32	0.03	6.84	0.12	6.88	0.11	23.45	0.46	27.98	0.39	17.57	0.20	7.05	0.14
93	16	4	164901	164947	55.00	159.00	2.56	0.14	3.77	0.30	4.44	0.40	10.27	0.72	15.31	0.97	13.70	0.73	8.00	0.30
92	16	4	165155	165241	55.00	160.00	2.96	0.11	4.10	0.19	4.70	0.25	11.48	0.61	16.72	1.04	14.78	0.96	8.45	0.45
2	20	4	165728	165834	54.00	162.00	1.43	0.08	2.02	0.11	1.44	0.10	10.04	0.33	10.80	0.32	5.28	0.24	1.82	0.12
14	16	4	165950	170025	54.00	162.75	1.44	0.07	2.08	0.09	1.47	0.08	10.35	0.31	10.86	0.34	5.18	0.23	1.72	0.10
15	16	4	170110	170148	54.00	163.00	1.48	0.05	2.16	0.08	1.51	0.05	10.77	0.38	11.37	0.33	5.40	0.17	1.79	0.06
23	16	4	170242	170319	54.00	163.50	0.75	0.04	1.03	0.03	1.00	0.03	0.37	0.03	0.05	0.03	0.06	0.03	-0.23	0.44
16	20	4	170951	171040	54.00	165.80	2.68	0.10	5.12	0.19	5.02	0.26	20.43	0.49	24.13	0.75	14.44	0.65	5.52	0.33
102	20	4	171745	171831	54.00	168.00	1.69	0.11	2.49	0.16	1.78	0.14	12.09	0.51	12.55	0.57	6.06	0.41	2.02	0.20

October 26, 1983

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
16	16	4	152503	152540	68.00	141.00	3.00	0.07	3.75	0.10	4.44	0.14	11.18	0.37	15.51	0.51	11.64	0.42	6.38	0.25
3	16	4	152814	152854	68.00	142.00	3.37	0.12	4.47	0.15	5.42	0.20	13.83	0.65	19.18	0.76	14.36	0.48	7.62	0.23
69	16	4	153430	153506	67.75	143.25	2.83	0.04	3.44	0.05	4.26	0.06	9.93	0.18	16.52	0.26	14.68	0.21	8.21	0.12
71	24	4	153657	153808	67.00	144.00	2.87	0.07	3.70	0.10	4.88	0.11	11.91	0.26	19.53	0.37	15.31	0.38	7.79	0.22
102	16	4	154306	154348	67.00	145.00	1.47	0.02	2.13	0.03	1.50	0.02	11.19	0.13	10.96	0.10	4.78	0.08	1.48	0.04
68	16	4	154723	154759	66.00	146.00	1.47	0.03	2.16	0.04	1.49	0.03	11.38	0.32	11.00	0.29	4.78	0.12	1.46	0.03
21	20	4	155023	155115	66.00	147.00	3.38	0.07	4.27	0.08	5.22	0.10	12.65	0.42	19.29	0.36	15.00	0.28	7.97	0.13
25	12	4	155326	155353	66.00	148.00	0.52	0.01	0.50	0.01	0.29	0.01	0.11	0.02	0.02	0.01	0.00	0.01	-0.17	0.37
12	16	4	155654	155729	65.00	149.00	2.39	0.04	3.46	0.05	3.88	0.09	16.97	0.22	16.78	4.59	10.14	0.20	4.46	0.14
18	20	4	155848	155940	65.00	149.00	2.14	0.02	3.14	0.02	3.19	0.06	14.55	0.08	14.66	5.22	8.72	2.23	3.90	0.07
19	20	4	160036	160143	65.00	150.00	2.01	0.04	2.90	0.05	2.89	0.05	13.92	0.20	16.57	0.29	9.20	0.22	3.75	0.11
107	16	4	160806	160855	64.00	152.00	1.32	0.05	1.93	0.03	1.63	0.05	10.83	0.13	11.60	0.13	6.05	0.13	2.30	0.07
106	16	4	161051	161134	64.00	152.00	1.38	0.08	1.98	0.08	1.73	0.12	10.88	0.16	11.95	0.23	6.34	0.23	2.42	0.15
111	16	4	161345	161421	64.00	153.00	1.62	0.09	2.32	0.11	2.11	0.13	12.18	0.31	13.76	0.45	7.88	0.38	3.17	0.21
112	16	4	161621	161704	64.00	154.00	2.12	0.13	3.01	0.19	3.27	0.28	13.36	0.80	15.61	0.88	9.91	0.59	4.47	0.29
113	16	4	162527	162609	63.00	156.00	1.84	0.11	2.72	0.12	2.56	0.21	13.71	0.31	16.81	0.76	10.82	0.88	4.59	0.47
114	16	4	162733	162819	63.00	157.00	1.69	0.13	2.35	0.15	2.21	0.19	10.76	0.44	12.81	0.30	7.97	0.22	3.53	0.18
115	16	4	163055	163132	63.00	157.81	2.12	0.08	2.74	0.10	2.75	0.12	10.10	0.21	12.80	0.28	8.69	0.27	4.26	0.17
108	16	4	163454	163536	63.00	159.00	1.98	0.16	2.97	0.26	3.34	0.46	14.65	0.89	16.91	1.15	10.31	0.84	4.07	0.39
105	16	4	164432	164520	62.00	161.00	1.50	0.05	2.17	0.07	1.53	0.07	11.79	0.43	11.75	0.36	5.21	0.19	1.58	0.07

October 27, 1983

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
102	20	4	142741	142833	75.00	128.60	1.44	0.07	2.08	0.10	1.43	0.09	11.41	0.57	10.19	0.54	3.91	0.21	1.18	0.08
20	16	4	143253	143327	75.00	130.00	2.52	0.09	3.01	0.12	3.41	0.14	8.16	0.47	11.48	0.56	8.37	0.44	4.78	0.25

October 27, 1983 (continued)

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
2	16	4	144450	144530	73.00	132.00	1.22	0.03	1.70	0.04	1.16	0.03	9.14	0.18	8.79	0.15	3.65	0.12	1.10	0.05
14	16	4	144648	144727	73.00	133.00	1.26	0.04	1.74	0.04	1.19	0.02	9.53	0.23	8.96	0.21	3.71	0.11	1.13	0.04
15	16	4	144833	144908	73.00	133.00	1.27	0.03	1.80	0.05	1.23	0.04	10.04	0.19	9.58	0.19	3.88	0.11	1.16	0.04
23	12	4	145036	145101	73.00	133.00	0.69	0.03	0.64	0.00	0.56	0.02	0.26	0.02	0.03	0.01	0.01	0.01	0.02	0.02
92	16	4	145649	145724	72.00	135.00	2.63	0.06	3.20	0.06	3.60	0.09	7.77	0.14	10.65	0.20	10.63	0.30	7.25	0.22
93	16	4	145934	150023	71.50	136.00	2.15	0.07	2.56	0.08	2.91	0.11	5.92	0.17	8.47	0.16	9.15	0.18	6.72	0.13
72	16	4	150320	150355	71.00	136.00	2.12	0.07	2.55	0.08	2.80	0.10	7.43	0.27	9.24	0.21	8.19	0.13	5.39	0.14
73	20	4	150552	150648	71.00	137.00	3.73	0.07	4.91	0.08	6.12	0.08	13.87	0.17	19.74	0.24	17.16	0.27	10.02	0.17
999	32	4	151022	151235	70.00	138.00	2.44	0.38	3.04	0.50	3.63	0.56	9.79	1.32	14.33	1.94	10.93	1.35	5.90	0.91
90	20	4	151836	151925	69.00	140.00	3.40	0.07	4.28	0.10	5.38	0.11	12.58	0.39	17.83	0.22	14.55	0.11	8.31	0.08
91	16	4	152113	152147	69.00	141.00	2.72	0.05	3.46	0.06	4.50	0.06	10.16	0.10	15.27	0.19	12.96	0.22	7.49	0.17
42	16	4	153858	153954	67.00	145.00	1.32	0.06	1.90	0.07	1.36	0.05	10.88	0.36	10.90	0.28	4.69	0.17	1.45	0.08
41	16	4	154124	154201	67.00	145.00	1.24	0.05	1.69	0.07	1.17	0.06	9.82	0.32	9.31	0.27	3.83	0.13	1.09	0.06
51	16	4	154515	154554	67.00	146.00	1.53	0.06	2.26	0.11	1.85	0.09	11.26	0.37	12.12	0.49	6.28	0.34	2.47	0.17
84	16	4	154924	154958	66.00	147.00	3.24	0.09	4.14	0.14	5.74	0.24	11.76	0.49	20.84	0.82	20.05	0.79	11.60	0.45
85	16	4	155114	155155	66.00	148.00	4.01	0.11	5.30	0.15	6.85	0.26	15.19	0.51	20.62	0.89	16.44	0.84	8.93	0.46
45	16	4	155510	155549	66.00	149.00	1.61	0.07	2.31	0.09	1.63	0.08	14.40	0.75	13.34	0.69	5.42	0.32	1.51	0.10
79	16	4	160102	160141	65.00	150.00	3.26	0.06	4.27	0.10	5.06	0.12	13.71	0.39	18.07	0.60	13.49	0.47	7.12	0.21
80	16	4	160328	160415	65.00	151.00	2.92	0.26	3.65	0.31	4.05	0.40	11.60	0.52	15.61	0.67	11.45	0.77	6.08	0.56
97	12	4	160631	160658	65.00	152.00	3.09	0.05	3.93	0.08	4.76	0.08	12.85	0.17	17.76	0.22	13.78	0.18	7.38	0.11
96	16	4	160805	160841	65.00	152.00	2.79	0.04	3.43	0.05	3.78	0.08	12.54	0.30	15.83	0.15	10.87	0.17	5.50	0.14
116	12	4	163114	163141	63.00	158.00	1.25	0.05	1.85	0.06	1.63	0.04	11.17	0.36	12.33	0.27	6.69	0.15	2.64	0.09
118	16	4	163401	163445	63.00	159.00	1.02	0.03	1.51	0.05	1.26	0.05	9.48	0.24	10.23	0.14	5.42	0.13	2.08	0.10
117	16	4	163529	163604	63.00	159.00	1.24	0.02	1.90	0.02	1.62	0.03	11.08	0.28	12.04	0.19	6.71	0.10	2.69	0.05
123	16	4	164149	164231	62.25	161.00	1.12	0.04	1.71	0.07	1.43	0.06	11.17	0.43	11.69	0.38	5.85	0.19	2.16	0.08
119	16	4	164358	164432	62.00	161.75	1.17	0.03	1.84	0.04	1.51	0.04	12.04	0.21	12.46	0.15	6.21	0.12	2.27	0.06
120	20	4	164540	164627	62.00	162.00	1.13	0.04	1.73	0.06	1.36	0.06	11.44	0.33	11.69	0.29	5.74	0.17	2.04	0.09
122	16	4	164736	164812	62.00	162.25	1.09	0.06	1.68	0.14	1.35	0.08	11.26	0.77	11.63	0.61	5.71	0.26	2.03	0.11
121	16	4	164915	164952	62.00	163.00	1.14	0.02	1.74	0.03	1.44	0.03	11.10	0.21	11.70	0.17	6.17	0.07	2.35	0.04
125	16	4	165340	165419	62.00	164.00	1.42	0.06	2.26	0.09	1.62	0.07	19.15	0.72	17.38	0.47	6.95	0.21	1.90	0.06
124	16	4	165543	165622	62.00	165.00	1.24	0.04	1.95	0.06	1.37	0.04	16.65	0.70	14.87	0.59	5.95	0.27	1.60	0.07
16	16	4	175510	175555	61.00	181.00	3.54	0.05	4.45	0.07	5.74	0.10	12.85	0.20	20.01	0.31	25.24	0.43	10.15	0.20
4	16	4	180000	180039	61.00	182.81	1.64	0.12	2.35	0.15	1.72	0.17	17.52	0.66	15.46	0.67	6.58	0.52	1.99	0.26
88	16	4	180419	180457	61.00	184.00	2.97	0.07	3.55	0.08	4.44	0.10	9.78	0.17	15.89	0.30	15.37	0.33	8.64	0.17
10	16	4	180851	180935	61.00	185.00	1.64	0.04	2.48	0.05	2.33	0.06	12.78	0.30	15.15	0.43	9.49	0.35	3.84	0.14
8	16	4	181053	181130	61.00	185.69	1.46	0.06	2.14	0.07	1.87	0.11	11.90	0.29	12.98	0.30	7.43	0.38	2.87	0.23
102	16	4	181412	181454	61.00	187.00	1.48	0.10	2.15	0.14	1.52	0.12	11.13	0.57	10.94	0.58	5.22	0.35	1.66	0.14
67	16	4	181559	181636	61.00	187.00	1.49	0.05	2.10	0.08	1.83	0.04	15.71	0.88	15.14	0.52	7.10	0.14	2.34	0.03
65	20	4	181811	181905	61.00	188.00	1.44	0.07	2.09	0.09	1.69	0.08	16.59	0.65	15.14	0.43	6.47	0.23	1.89	0.09
66	16	4	182001	182038	61.00	188.00	1.58	0.07	2.27	0.13	1.97	0.11	16.27	0.79	15.82	0.71	7.58	0.35	2.56	0.12
22	16	4	182219	182258	61.00	189.00	3.50	0.10	4.42	0.12	5.78	0.18	12.66	0.31	22.87	0.44	20.77	0.47	11.23	0.27

Table 6.4 - 1984 Helicopter MMR Data

Reflectance data collected from the helicopter-mounted MMR in 1984. Each table has data collected from a single day or view angle. Site is the site location; Obs is the number of observations averaged; Hgt is the altitude of the helicopter in hundreds of feet; start and end times are in GMT in the form HHMMSS; Sol Zen and Sol Az are the solar zenith and azimuth angles; Rfl 1 through 7 are the average percent reflectance measured by the MMR in bands 1 through 7. Std 1 through 7 are the standard deviations of the reflectance measurements. Unless otherwise noted, all observations are nadir views. Reflectances equal to -1.00 are missing values.

May 18, 1984

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
75	12	6	161133	161153	37.00	123.17	2.80	0.06	4.71	0.10	3.70	0.10	23.04	0.55	25.85	0.40	17.75	0.33	8.11	0.22
73	12	6	161415	161435	37.00	124.08	2.58	0.08	4.16	0.15	3.32	0.12	19.02	1.05	22.08	1.09	15.50	0.84	7.18	0.36
93	12	6	161859	161919	36.00	125.83	3.11	0.07	4.12	0.14	4.60	0.09	11.79	0.54	18.74	0.54	19.08	0.30	12.16	0.23
92	12	6	162201	162221	36.00	126.75	3.15	0.23	4.69	0.31	4.52	0.47	15.47	0.41	20.99	0.80	18.17	1.48	10.45	1.13
14	12	6	162815	162835	35.00	128.50	1.84	0.09	2.77	0.14	2.16	0.11	12.20	0.51	14.16	0.51	7.97	0.30	3.30	0.15
2	12	6	163105	163125	34.00	129.33	1.94	0.14	2.86	0.21	2.32	0.15	12.41	0.66	14.61	0.72	8.41	0.49	3.58	0.27
3	12	6	163501	163521	34.00	131.17	3.16	0.29	4.75	0.28	4.61	0.50	18.65	0.49	24.48	0.72	19.42	1.22	10.11	0.96
16	12	6	163715	163735	34.00	131.17	2.92	0.18	4.45	0.22	4.17	0.26	17.89	0.53	23.10	0.66	18.23	0.64	9.41	0.42
70	12	6	164512	164532	33.00	134.75	4.02	0.18	6.06	0.14	6.46	0.31	21.31	0.25	30.40	0.44	24.99	0.63	13.38	0.53
88	12	6	164730	164750	33.00	134.75	3.90	0.29	5.33	0.22	5.82	0.53	16.69	0.65	25.52	0.61	23.30	1.45	13.44	1.30
102	12	6	165317	165336	32.00	137.42	2.14	0.14	3.32	0.21	2.53	0.17	14.23	0.51	15.69	0.64	8.28	0.49	3.31	0.28
21	12	6	165528	165548	32.00	138.33	3.56	0.08	5.20	0.04	5.39	0.11	18.21	0.23	26.12	0.28	22.32	0.34	12.14	0.23
19	12	6	170038	170057	31.00	140.08	3.17	0.10	4.77	0.14	4.86	0.15	18.76	0.28	23.37	0.64	14.10	0.53	6.66	0.26
18	12	6	170124	170143	31.00	140.08	3.41	0.10	5.16	0.15	5.23	0.16	19.91	0.46	23.12	0.52	13.70	0.50	6.57	0.28
12	12	6	170210	170229	31.00	141.00	2.96	0.20	4.35	0.34	4.32	0.35	18.30	1.56	21.65	0.94	11.64	0.60	5.34	0.31
52	12	6	170851	170911	31.00	143.42	1.93	0.09	3.01	0.14	2.41	0.14	12.95	0.54	14.70	0.63	7.95	0.50	3.29	0.27

May 28, 1984

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
52	36	6	144510	144924	47.67	104.72	1.52	0.13	2.35	0.18	1.98	0.17	11.35	0.72	15.29	1.38	7.12	0.76	2.95	0.36
12	12	6	145718	145738	46.00	102.83	2.56	0.05	3.86	0.04	3.72	0.05	17.30	0.21	24.43	0.22	12.25	0.21	5.68	0.17
70	12	6	150823	150842	44.00	105.42	2.10	0.03	3.77	0.03	2.47	0.07	27.32	0.83	34.16	0.33	18.08	0.33	6.67	0.28
88	12	6	151247	151307	44.00	106.33	2.11	0.09	3.93	0.10	2.52	0.14	25.28	0.45	31.07	0.48	17.08	0.62	6.50	0.41
87	12	6	151756	151816	43.00	108.00	2.32	0.05	3.76	0.11	2.57	0.10	29.66	0.42	34.94	0.20	18.09	0.24	6.53	0.17
16	12	6	152310	152330	42.00	108.92	1.99	0.07	3.09	0.11	2.22	0.10	22.05	0.42	26.36	0.57	13.75	0.48	5.23	0.27

May 28, 1984 (continued)

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
3	24	6	152739	152832	41.00	112.88	2.03	0.06	3.16	0.14	2.27	0.15	23.68	1.13	28.70	0.79	15.28	0.73	5.86	0.46
2	12	6	153237	153257	41.00	110.67	1.44	0.04	2.08	0.07	1.66	0.04	10.16	0.25	14.28	0.25	7.20	0.18	2.94	0.08
93	12	6	154126	154146	40.00	113.33	2.01	0.04	3.80	0.04	2.61	0.04	17.42	0.33	24.38	0.33	16.26	0.14	7.50	0.06
92	12	6	154446	154505	39.00	113.58	1.89	0.01	3.41	0.02	2.19	0.02	22.67	0.34	28.07	0.25	15.87	0.09	6.21	0.03
75	12	6	154835	154855	39.00	114.17	1.97	0.04	3.25	0.06	2.08	0.05	24.30	0.31	29.08	0.39	14.92	0.21	5.34	0.11
73	12	6	155048	155108	38.00	115.00	1.99	0.03	3.25	0.06	1.96	0.03	29.17	0.28	33.17	0.40	15.95	0.27	5.30	0.12

June 3, 1984

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
73	12	6	154004	154024	39.00	111.42	2.13	0.06	2.90	0.09	1.73	0.06	34.71	0.46	32.62	0.44	14.93	0.33	4.40	0.13
75	12	6	154238	154258	39.00	112.33	2.10	0.06	2.95	0.10	1.87	0.06	29.26	0.55	28.60	0.55	14.08	0.37	4.49	0.15
93	12	6	154626	154645	38.00	113.17	1.89	0.02	3.26	0.05	1.77	0.02	25.85	0.46	25.81	0.33	13.85	0.17	4.84	0.06
92	12	6	154908	154927	38.00	114.08	2.07	0.08	3.21	0.10	2.01	0.06	28.40	1.46	28.64	1.21	15.27	0.58	5.26	0.15
2	12	6	155540	155559	37.00	115.83	1.79	0.09	2.61	0.10	2.15	0.10	11.97	0.28	14.96	0.40	8.31	0.31	3.40	0.18
14	12	6	155654	155713	37.00	115.83	1.88	0.11	2.76	0.17	2.25	0.14	12.43	0.54	15.39	0.65	8.54	0.44	3.50	0.23
16	12	6	160137	160157	36.00	117.58	2.20	0.13	3.02	0.21	2.06	0.13	28.27	1.11	28.42	1.38	14.68	0.98	4.86	0.41
3	12	6	160421	160441	36.00	118.50	2.25	0.07	3.27	0.13	2.27	0.13	28.39	0.96	29.84	0.92	16.42	0.72	5.77	0.38
70	12	6	160910	160930	35.00	119.33	2.53	0.04	4.16	0.08	2.26	0.05	37.88	0.38	36.89	0.44	18.77	0.39	5.92	0.16
88	24	6	161026	161226	34.50	124.13	2.36	0.14	3.87	0.25	2.21	0.15	34.06	0.90	33.44	0.91	17.38	0.54	5.55	0.25
12	24	6	163711	164026	31.00	134.04	3.43	0.29	5.30	0.47	4.87	0.60	21.72	0.77	24.09	0.83	13.81	0.90	6.25	0.49
19	12	6	164148	164208	31.00	130.42	3.39	0.11	5.26	0.15	4.96	0.11	20.63	0.29	25.23	0.59	15.31	0.57	6.93	0.33
52	24	6	164725	164947	30.00	137.33	2.24	0.15	3.38	0.21	2.66	0.22	14.20	0.73	16.21	0.84	9.09	0.59	3.77	0.31
42	12	6	165430	165450	29.00	135.33	2.22	0.21	3.21	0.29	2.66	0.27	14.26	0.99	16.80	1.07	9.71	0.74	4.03	0.37
84	12	6	165823	165843	29.00	136.25	2.62	0.08	4.40	0.17	2.34	0.0	42.08	0.88	38.57	0.89	19.65	0.61	5.97	0.23
48	12	6	170230	170250	29.00	138.08	2.29	0.10	3.47	0.14	2.68	0.12	15.62	0.57	17.00	0.62	9.26	0.44	3.77	0.20

August 2, 1984

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
52	12	6	144216	144236	52.00	101.50	1.07	0.10	2.12	0.14	-1.00	0.00	11.88	0.69	12.50	0.80	5.26	0.45	1.52	0.22
12	12	6	144728	144748	52.00	102.42	2.27	0.07	4.27	0.06	-1.00	0.00	24.98	0.21	28.18	0.29	13.75	0.23	5.00	0.15
88	12	6	145502	145522	50.00	104.08	1.69	0.12	2.51	0.11	-1.00	0.00	30.80	0.84	31.09	0.78	14.16	0.44	3.61	0.14
89	12	6	145739	145759	50.00	105.00	2.27	0.07	3.16	0.12	-1.00	0.00	40.86	0.56	41.14	0.46	18.93	0.49	5.04	0.22
3	12	6	150228	150248	49.00	105.83	1.70	0.12	2.20	0.10	-1.00	0.00	29.06	1.77	31.77	1.40	15.48	0.96	4.56	0.34
16	12	6	150504	150524	49.00	105.83	1.72	0.07	2.19	0.16	-1.00	0.00	31.95	1.10	32.60	1.31	14.41	1.00	3.59	0.45
73	12	6	165104	165124	35.00	134.00	1.86	0.05	2.45	0.08	-1.00	0.00	32.67	0.40	33.63	0.37	15.64	0.19	4.21	0.06
75	12	6	165314	165334	35.00	134.92	1.84	0.04	2.45	0.05	-1.00	0.00	28.38	0.52	29.92	0.46	14.02	0.25	3.94	0.09
52	12	6	171925	171945	32.00	144.75	1.42	0.06	2.49	0.09	-1.00	0.00	12.74	0.41	14.65	0.35	6.74	0.25	2.22	0.13
12	24	6	172624	172727	32.00	152.75	2.77	0.08	5.03	0.16	-1.00	0.00	26.93	0.61	32.33	0.76	16.37	0.63	6.30	0.34

August 3, 1984

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
52	12	6	124401	124421	72.00	82.08	0.62	0.08	1.54	0.10	-1.00	0.00	10.89	0.72	9.44	0.78	2.95	0.30	-0.10	0.65
12	12	6	124958	125018	71.00	83.83	1.68	0.18	3.37	0.14	-1.00	0.00	20.96	0.43	19.67	0.50	8.70	0.40	2.67	0.19
88	12	6	125902	125921	70.00	84.67	1.37	0.11	2.25	0.12	-1.00	0.00	28.08	1.18	23.25	1.14	9.55	0.71	2.14	0.24
89	12	6	130149	130208	69.00	85.00	2.43	0.07	3.39	0.12	-1.00	0.00	46.78	1.31	39.72	0.90	16.95	0.46	4.39	0.21
16	12	6	130641	130700	68.92	85.50	1.35	0.23	1.81	0.21	-1.00	0.00	28.79	2.40	23.13	1.73	8.91	0.95	1.82	0.35
3	12	6	130858	130918	68.00	86.33	1.49	0.12	1.92	0.15	-1.00	0.00	30.63	1.94	24.72	1.20	9.89	0.50	2.22	0.16
14	12	6	131417	131437	67.00	87.17	0.66	0.08	1.34	0.08	-1.00	0.00	10.21	0.49	8.64	0.37	2.77	0.16	0.19	0.36
2	12	6	131637	131657	67.00	87.17	0.65	0.11	1.31	0.08	-1.00	0.00	9.74	0.21	8.56	0.16	2.91	0.10	0.36	0.06
92	12	6	132659	132719	65.00	88.83	1.47	0.08	2.14	0.10	-1.00	0.00	26.89	1.42	23.88	1.31	10.42	0.63	2.58	0.32
93	12	6	132949	133009	65.00	89.33	1.18	0.11	1.63	0.14	-1.00	0.00	26.33	1.18	22.23	0.86	9.45	0.37	2.14	0.15
52	12	6	145603	145622	50.00	105.00	1.22	0.08	2.18	0.11	-1.00	0.00	12.43	0.63	11.91	0.79	5.17	0.50	1.43	0.23
12	12	6	150244	150304	49.00	105.83	2.52	0.08	4.55	0.11	-1.00	0.00	25.01	0.74	26.17	0.71	12.67	0.43	4.65	0.17
88	12	6	151012	151032	48.00	107.58	1.71	0.12	2.60	0.17	-1.00	0.00	30.19	0.30	28.66	0.48	13.17	0.50	3.51	0.21
89	12	6	151309	151329	48.00	108.50	2.24	0.03	2.97	0.07	-1.00	0.00	39.89	1.21	37.30	0.81	17.12	0.29	4.44	0.09
16	12	6	151742	151802	47.00	109.33	1.74	0.07	2.18	0.05	-1.00	0.00	30.27	1.02	28.07	0.70	12.37	0.31	3.09	0.09
3	12	6	151936	151955	47.00	109.33	1.81	0.08	2.34	0.11	-1.00	0.00	29.03	1.43	29.24	1.01	14.68	0.58	4.38	0.33
2	12	6	152326	152346	46.00	110.17	1.18	0.05	1.96	0.07	-1.00	0.00	11.33	0.29	11.86	0.31	5.39	0.23	1.60	0.10
14	12	6	152717	152737	46.00	111.08	1.32	0.08	2.20	0.07	-1.00	0.00	12.09	0.28	12.68	0.18	5.75	0.10	1.77	0.07
92	12	6	153258	153318	45.00	111.92	1.65	0.06	2.39	0.06	-1.00	0.00	25.40	0.31	25.78	0.38	12.94	0.33	3.92	0.18
93	12	6	153444	153504	45.00	112.83	1.52	0.07	2.20	0.12	-1.00	0.00	27.58	0.55	26.93	0.41	12.79	0.33	3.46	0.10

August 3, 1984
View zenith 50 degrees, view azimuth 0 degrees

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
92	12	6	133813	133833	63.00	90.50	4.67	0.10	6.72	0.07	-1.00	0.00	56.20	0.99	49.57	0.53	26.00	0.24	8.73	0.11
93	12	6	133907	133927	63.00	90.50	3.64	0.15	5.19	0.28	-1.00	0.00	46.31	1.04	40.71	0.76	20.69	0.45	6.55	0.17
2	24	6	134722	134822	62.00	93.63	4.80	0.59	7.01	0.65	-1.00	0.00	29.40	1.81	29.28	1.94	16.07	1.48	6.97	0.82
14	12	6	134926	134946	62.00	92.25	5.36	0.15	7.81	0.22	-1.00	0.00	31.31	0.66	30.75	0.74	16.23	0.54	6.93	0.33
16	12	6	135445	135505	60.75	93.33	4.92	0.23	6.28	0.28	-1.00	0.00	55.34	1.24	48.90	1.17	24.38	0.86	7.82	0.43
3	12	6	135544	135604	60.00	93.92	4.46	0.19	5.89	0.28	-1.00	0.00	52.31	1.46	46.90	1.23	23.82	0.73	7.82	0.34
89	24	6	140121	140217	59.00	96.38	4.86	0.28	7.07	0.51	-1.00	0.00	62.75	2.08	56.85	1.59	28.74	1.30	9.30	0.88
88	12	6	140612	140632	59.00	95.67	5.56	0.73	8.95	1.15	-1.00	0.00	58.65	2.00	53.26	2.20	28.32	1.86	10.25	1.22
12	12	6	143957	144016	53.00	101.58	8.25	0.65	12.86	0.85	-1.00	0.00	48.11	2.70	51.53	2.20	33.62	1.19	16.69	1.12
52	12	6	144641	144701	52.00	102.50	5.55	0.23	8.04	0.31	-1.00	0.00	27.77	0.95	30.14	0.95	18.07	0.60	8.71	0.32
93	24	6	154143	154356	44.00	117.79	2.80	1.13	3.91	1.65	-1.00	0.00	35.70	9.21	34.34	9.26	17.66	6.21	5.56	2.40

August 16, 1984

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
52	12	6	224309	224329	65.00	246.50	0.57	0.07	-1.00	0.00	-1.00	0.00	10.87	0.56	9.26	0.91	-1.00	0.00	-1.00	0.00
12	12	6	225023	225042	66.00	247.50	1.45	0.10	-1.00	0.00	-1.00	0.00	17.92	1.21	19.74	1.32	-1.00	0.00	-1.00	0.00
89	12	6	225802	225822	67.00	248.50	0.87	0.13	-1.00	0.00	-1.00	0.00	19.97	1.13	18.01	0.78	-1.00	0.00	-1.00	0.00

August 16, 1984 (continued)

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
88	12	6	230102	230121	68.00	249.50	1.83	0.08	-1.00	0.00	-1.00	0.00	35.85	0.69	34.04	0.69	-1.00	0.00	-1.00	0.00
3	12	6	230622	230642	69.00	250.50	1.08	0.21	-1.00	0.00	-1.00	0.00	24.30	2.55	24.36	1.87	-1.00	0.00	-1.00	0.00
16	12	6	230853	230912	69.00	250.50	1.14	0.15	-1.00	0.00	-1.00	0.00	28.49	1.89	26.13	1.78	-1.00	0.00	-1.00	0.00
14	24	6	231220	231432	70.00	259.75	0.24	0.27	-1.00	0.00	-1.00	0.00	11.33	0.32	7.97	0.56	-1.00	0.00	-1.00	0.00
2	12	6	231608	231628	70.00	252.42	-0.16	0.59	-1.00	0.00	-1.00	0.00	11.37	0.16	7.94	0.33	-1.00	0.00	-1.00	0.00

August 16, 1984
View zenith 50 degrees, view azimuth 0 degrees

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
93	12	6	213411	213431	54.00	231.83	1.83	0.04	2.60	0.07	-1.00	0.00	30.72	0.94	28.52	0.75	11.77	0.24	3.50	0.07
92	24	6	213529	220333	56.00	242.92	2.56	0.39	3.53	0.50	-1.00	0.00	36.90	3.73	34.57	3.15	15.71	1.81	4.85	0.61
14	24	6	220903	221013	59.00	247.79	1.08	0.06	1.66	0.05	-1.00	0.00	12.21	0.26	12.04	0.27	4.76	0.17	1.12	0.10
2	12	6	221102	221122	60.00	239.67	1.18	0.06	1.82	0.06	-1.00	0.00	12.89	0.35	13.62	0.45	5.98	0.33	1.64	0.12
3	12	6	221422	221442	60.00	240.58	2.35	0.08	2.85	0.12	-1.00	0.00	35.46	3.04	33.44	2.46	15.02	1.08	4.05	0.34
16	12	6	221532	221552	60.00	240.58	3.05	0.25	3.78	0.21	-1.00	0.00	38.99	3.58	36.38	2.10	16.74	0.73	4.86	0.24
89	12	6	222004	222024	61.00	241.58	2.25	0.18	3.36	0.27	-1.00	0.00	31.93	1.47	31.14	1.15	14.96	0.69	4.57	0.31
88	12	6	222230	222249	61.00	241.58	2.76	0.11	4.15	0.14	-1.00	0.00	42.29	0.95	41.02	0.79	19.43	0.30	5.54	0.15
12	12	6	222949	223009	63.00	243.58	2.87	0.16	5.05	0.32	-1.00	0.00	29.37	3.11	34.94	3.46	18.68	1.79	7.10	0.52
52	12	6	223509	223529	64.00	244.58	1.16	0.12	1.87	0.17	-1.00	0.00	12.95	0.86	13.22	1.13	5.63	0.53	1.49	0.25

September 16, 1984

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
93	12	6	162505	162525	50.00	138.92	1.87	0.05	2.83	0.09	2.06	0.12	25.97	0.17	22.61	0.17	12.57	0.13	3.91	0.07
92	12	6	163116	163136	50.00	140.75	2.16	0.07	3.34	0.08	2.54	0.06	25.63	0.96	23.80	0.85	14.04	0.56	4.86	0.21
2	12	6	163815	163835	49.00	142.50	1.44	0.07	2.22	0.08	1.83	0.03	10.78	0.47	11.54	0.39	5.66	0.21	2.04	0.11
14	12	6	164055	164115	49.00	143.42	1.66	0.09	2.48	0.12	1.99	0.07	11.99	0.40	12.74	0.45	6.09	0.33	2.18	0.17
16	12	6	164537	164556	49.00	144.33	2.15	0.08	3.03	0.09	2.40	0.08	26.77	1.00	24.41	1.07	13.25	0.69	4.23	0.27
3	12	6	164707	164727	48.00	145.17	2.10	0.11	2.96	0.11	2.47	0.13	24.29	0.93	23.50	0.62	13.77	0.39	4.85	0.22
61	24	6	165048	165242	48.00	151.25	1.50	0.08	2.58	0.10	2.01	0.08	16.15	0.65	15.00	0.64	7.95	0.46	2.80	0.17
89	12	6	165728	165747	48.00	147.92	2.58	0.01	4.29	0.11	3.16	0.11	29.49	0.81	27.77	0.60	16.48	0.46	5.67	0.27
88	12	6	170158	170218	47.00	149.67	2.24	0.05	3.85	0.05	2.80	0.06	26.40	1.09	24.35	0.78	14.00	0.36	4.76	0.17
102	12	6	170727	170747	47.00	151.50	1.85	0.10	2.78	0.14	2.05	0.10	13.77	0.46	12.22	0.47	6.35	0.32	2.18	0.15
12	12	6	171211	171230	47.00	153.33	3.00	0.05	4.77	0.04	4.69	0.04	21.77	0.31	24.03	0.24	14.42	0.24	6.14	0.18
52	24	6	171953	172233	46.00	160.54	1.65	0.05	2.57	0.07	1.97	0.06	12.14	1.50	11.16	2.28	6.33	0.17	2.35	0.08

September 16, 1984
View zenith 50 degrees, view azimuth 0 degrees

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
52	12	6	134428	134447	71.00	104.92	6.20	0.10	8.99	0.14	7.50	0.14	29.37	0.37	28.09	0.30	18.43	0.29	10.37	0.23
12	12	6	135329	135349	70.00	105.75	5.66	0.21	8.74	0.17	8.19	0.18	31.79	1.16	32.96	1.07	22.50	0.44	12.51	0.40
102	12	6	140016	140036	69.00	107.50	6.35	0.50	9.15	0.66	7.23	0.59	34.30	2.29	29.80	1.93	17.23	1.21	8.17	0.57

September 16, 1984 (continued)
View zenith 50 degrees, view azimuth 0 degrees

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
88	12	6	141126	141146	67.00	109.17	5.61	0.12	9.26	0.21	6.65	0.21	48.47	0.86	43.03	2.14	22.83	0.47	9.00	0.25
89	36	6	141600	141722	66.00	112.67	6.85	0.30	10.92	0.43	8.58	0.59	59.23	0.79	56.01	7.53	31.30	1.26	12.91	0.95
16	12	6	142608	142628	65.00	111.75	5.17	0.18	6.91	0.26	5.47	0.21	49.97	1.65	46.38	1.83	22.40	1.11	8.13	0.51
3	12	6	143342	143401	64.00	113.50	6.22	0.22	8.53	0.33	6.86	0.30	52.02	0.39	50.32	0.47	26.87	0.64	10.94	0.53
61	12	6	143756	143816	63.00	114.33	4.26	0.33	7.11	0.43	5.32	0.50	35.07	1.06	33.08	1.98	17.10	1.63	7.14	0.93
2	12	6	144715	144735	62.00	116.08	5.16	0.23	6.98	0.31	5.61	0.28	26.81	1.11	44.31	1.13	15.88	0.72	7.44	0.42
14	12	6	144825	144844	62.00	116.08	6.00	0.58	8.06	0.77	6.55	0.69	30.05	2.19	47.10	2.53	17.50	1.67	8.12	0.94
92	12	6	145909	145929	60.00	118.67	6.32	0.41	9.49	0.54	6.95	0.57	56.35	1.61	51.16	1.33	30.32	1.21	11.78	0.78
93	12	6	150017	150036	60.00	118.67	5.65	0.31	8.53	0.44	6.06	0.39	51.38	1.81	47.58	1.69	27.92	1.09	10.61	0.53
75	12	6	205422	205442	58.00	217.50	2.64	0.19	3.84	0.31	2.78	0.15	28.86	1.08	25.38	1.75	12.98	0.51	4.47	0.24
93	12	6	205811	205831	59.00	218.50	2.41	0.03	3.64	0.05	2.52	0.02	29.05	1.01	28.15	5.84	13.97	0.42	4.82	0.12
92	24	6	205947	210113	59.00	226.71	2.70	0.36	4.11	0.46	2.88	0.37	30.44	1.68	29.57	2.13	15.43	1.28	5.61	0.71
102	12	6	213746	213805	64.33	228.08	1.80	0.04	2.57	0.03	2.49	0.02	14.37	0.21	12.58	0.14	5.98	0.10	1.97	0.04
21	12	6	214057	214116	65.00	229.08	2.73	0.09	4.18	0.15	3.18	0.08	29.44	0.69	26.28	0.64	15.11	0.56	5.44	0.18
19	12	6	214500	214519	66.00	230.08	2.55	0.04	3.82	0.05	3.26	0.04	18.41	0.15	18.66	0.13	10.94	0.08	4.38	0.04
18	10	6	214603	214619	66.00	227.10	2.56	0.03	3.84	0.03	3.31	0.03	18.79	0.41	18.82	0.32	11.20	0.18	4.56	0.08

September 16, 1984
View zenith 50 degrees, view azimuth 180 degrees

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
52	12	6	134724	134744	71.00	104.92	2.17	0.25	3.70	0.22	2.79	0.18	13.91	1.34	12.76	1.34	6.19	0.82	2.39	0.36
12	12	6	135544	135603	69.75	106.67	2.82	0.11	4.59	0.18	3.93	0.16	21.35	1.17	21.22	0.92	12.07	0.55	5.19	0.27
102	12	6	140239	140259	69.00	107.50	2.09	0.09	3.12	0.06	2.40	0.05	14.39	0.17	11.69	0.13	4.98	0.07	1.73	0.04
88	12	6	141327	141347	67.00	110.08	3.22	0.14	5.49	0.19	3.51	0.14	31.35	0.73	36.58	3.94	14.96	0.44	6.06	0.29
89	24	6	141930	142031	66.00	112.96	3.91	0.11	6.26	0.16	4.36	0.18	41.76	0.86	37.93	0.94	19.48	0.43	7.62	0.23
16	12	6	143103	143122	64.00	112.58	2.70	0.07	3.60	0.07	2.69	0.06	28.29	1.73	27.07	1.28	11.81	0.49	4.17	0.11
3	12	6	143536	143556	64.00	113.50	2.72	0.05	3.62	0.05	2.67	0.04	29.43	0.28	28.30	0.36	14.15	0.62	4.41	0.09
61	24	6	144020	144116	63.00	117.63	1.88	0.23	2.93	0.27	2.17	0.23	19.87	0.81	24.83	1.91	7.00	0.83	2.19	0.45
14	12	6	145028	145048	62.00	117.00	3.97	0.37	6.02	0.57	5.55	0.56	13.37	0.32	12.40	0.84	6.70	0.71	4.76	0.54
2	12	6	145129	145149	61.00	116.92	4.59	2.26	6.38	2.57	6.08	3.24	13.63	2.17	17.16	6.79	11.65	6.96	7.88	5.24
93	12	6	150628	150648	59.00	119.50	2.26	0.07	3.29	0.13	2.18	0.07	28.49	0.36	25.67	0.31	13.07	0.16	4.42	0.08
92	12	6	150744	150803	59.00	120.42	2.63	0.08	4.04	0.10	2.65	0.09	34.26	0.72	30.76	0.61	16.16	0.38	5.61	0.18
73	12	6	205156	205216	58.00	217.50	2.60	0.07	3.80	0.11	2.69	0.08	31.39	0.33	33.29	3.71	13.47	0.40	4.38	0.12
14	12	6	210644	210703	60.00	220.67	1.46	0.05	1.92	0.06	2.04	0.02	10.28	0.10	17.42	2.53	5.64	0.84	1.40	0.06
2	12	6	210809	210829	60.00	221.33	1.53	0.11	2.00	0.13	2.13	0.06	10.03	0.85	16.55	2.57	4.82	0.59	1.69	0.27
3	12	6	211219	211239	61.00	222.33	2.68	0.02	3.48	0.03	2.74	0.04	30.59	0.80	39.33	3.02	14.13	0.17	4.77	0.06
16	12	6	211351	211411	61.00	222.33	2.67	0.06	3.48	0.08	2.82	0.05	29.16	0.59	28.71	2.95	13.59	0.22	4.72	0.11
61	12	6	211620	211639	61.00	223.25	1.99	0.05	3.03	0.06	2.41	0.03	21.64	0.40	23.50	2.61	8.26	0.23	2.28	0.04

September 16, 1984 (continued)
View zenith 50 degrees, view azimuth 180 degrees

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
89	12	6	212132	212151	62.00	224.25	3.04	0.12	4.94	0.19	3.64	0.21	31.66	0.65	30.08	0.40	16.49	0.43	6.18	0.26
70	12	6	212418	212438	63.00	225.25	3.14	0.07	5.14	0.12	3.45	0.07	35.30	0.64	33.30	0.74	19.11	1.01	6.36	0.26
88	12	6	212604	212624	63.00	225.25	3.55	0.24	6.17	0.50	4.03	0.23	37.01	2.83	37.84	2.36	20.60	1.43	7.83	0.50
10	12	6	213428	213448	64.00	227.17	1.95	0.10	2.68	0.11	2.55	0.05	15.95	0.83	18.87	1.37	8.86	0.50	3.28	0.19

September 23, 1984

Site	Obs.	Hgt.	St Time	End Time	Sol Zen	Sol Az	Rfl 1	Std1	Rfl2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl6	Std 6	Rfl 7	Std 7
2	12	6	140346	140406	70.00	110.33	1.10	0.07	1.96	0.06	2.11	0.10	10.90	0.13	10.47	0.12	4.38	0.07	1.34	0.04
14	24	6	140738	140828	69.50	112.67	1.18	0.06	2.09	0.08	2.10	0.06	11.20	0.28	9.90	0.28	4.22	0.18	1.25	0.09
61	12	6	141140	141200	69.00	111.25	1.23	0.05	2.54	0.06	2.27	0.08	16.51	0.44	14.12	0.39	5.84	0.20	1.80	0.09
10	12	6	142051	142110	67.42	113.50	1.37	0.05	2.45	0.07	2.36	0.08	12.87	0.27	13.02	0.29	6.93	0.18	2.75	0.12
102	12	6	142528	142548	67.00	114.67	1.42	0.08	2.37	0.12	1.90	0.07	12.93	0.54	11.03	0.46	4.73	0.28	1.42	0.12
12	12	6	143042	143102	66.00	115.50	2.34	0.06	3.98	0.06	3.97	0.08	19.18	0.21	20.61	0.24	10.98	0.31	4.63	0.22
19	12	6	143350	143409	65.50	116.00	1.95	0.07	3.27	0.13	2.93	0.10	17.22	0.47	17.20	0.67	8.95	0.42	3.51	0.21
18	36	6	143544	143712	65.00	119.44	2.00	0.07	3.46	0.11	3.10	0.11	18.20	0.81	17.81	0.51	9.27	0.27	3.66	0.12
42	12	6	144126	144146	64.00	117.17	1.21	0.10	2.04	0.12	1.74	0.07	10.85	0.83	9.71	0.70	4.35	0.38	1.36	0.17
52	48	6	144420	144625	64.00	121.77	1.43	0.31	2.46	0.42	2.04	0.36	12.35	2.98	11.74	3.09	5.75	1.67	2.17	0.72
39	12	6	144800	144819	63.00	118.92	1.38	0.07	2.29	0.09	1.85	0.06	11.56	0.57	10.18	0.49	4.66	0.27	1.51	0.11
48	36	6	145133	145305	63.00	123.28	1.32	0.08	2.26	0.11	1.78	0.07	12.84	0.75	11.19	0.68	4.96	0.42	1.59	0.24
124	12	6	152447	152507	58.00	125.83	1.80	0.03	3.25	0.06	2.72	0.06	23.09	0.39	19.14	0.33	8.27	0.17	2.59	0.06
125	24	6	152643	152740	57.42	129.88	1.50	0.06	2.59	0.13	2.08	0.11	19.47	0.93	15.93	0.91	6.62	0.43	1.98	0.16
122	12	6	153125	153145	57.00	127.58	1.35	0.04	2.37	0.07	2.14	0.06	13.51	0.45	12.70	0.43	6.50	0.20	2.46	0.09
121	24	6	153231	153330	57.00	130.79	1.44	0.05	2.55	0.09	2.36	0.08	13.65	0.39	13.17	0.29	7.00	0.21	2.72	0.12
119	24	6	153426	153515	57.00	131.75	1.53	0.05	2.62	0.07	2.46	0.07	14.04	0.26	13.65	0.24	7.28	0.17	2.87	0.10

7.0 Thematic Mapper Simulator Data

7.1 Introduction

The NS001 Thematic Mapper Simulator (TMS) was flown on the NASA C-130 aircraft over the SNF study area. The TMS was a scanning radiometer with eight wavelength bands (see Table 5.2). Band 8 was a thermal band and not processed in this study. The C-130 flew a "crisscross" pattern over the SNF, which provided a variety of sun and view angles. The TMS data were processed to provide reflectance values of study sites. These data are useful in the analysis of the bidirectional reflectance function of forest canopies. TMS data were collected and processed for three days: July 13 and August 6, 1983; and June 28, 1984.

7.2 Data Processing

Several processing steps were required to turn raw TMS data into physically meaningful numbers for the test sites.

The TMS scanner sweeps through view angles of plus or minus 50 degrees. This introduces both geometric distortions and varying atmospheric path lengths across the scan line. At extreme scan angles, a pixel covers an area on the ground several times larger than at nadir. At the nominal 1524 meter (5,000-foot) altitude flown, a nadir pixel covers 3.81 meters along the scan, expanding to 9.22 meters at 50 degrees off nadir. To compensate for this distortion, the data were linearly resampled to a constant pixel size, the same size as the nadir pixel. The scan-angle-corrected images from different flight lines were then registered to a common image. The registration algorithm used control points to remove distortions locally rather than globally, and was effective in correcting for perturbations introduced by variations in aircraft motion. Sites were located in the imagery using photographs, descriptions of site locations, first hand knowledge and maps. Digital count values for areas four by four pixels, approximately 16 by 16 meters, were extracted from each flight line. Using the calibration data provided for each scan line, these values were converted to radiance values by subtracting the low blackbody radiance count and multiplying by the radiance calibration factor.

The TMS radiance values were converted to reflectances using values for insolation, atmospheric transmittance, and path-scattered radiance for the appropriate solar and view angles. No measurement of these values was made, so the LOWTRAN6 atmosphere model was used to generate them. Scattering contributions calculated from the path between the canopy and the sensor were subtracted from the sensor-detected radiances and divided by the incident flux to generate reflectance factors.

7.3 Results

Corrected canopy reflectance values for 3 days are presented in Table 7.1. The sun and view angles are referenced to the same coordinate system centered on the observation point. Standard spherical polar coordinates, with zero-degree azimuth due north, are given. Note that the sensor and the Sun are in line when they have the same coordinates, i.e. the sensor looks at its shadow. Errors in the determination of these angles are possible due to the lack of precise aircraft position. The sensor zenith angles were determined from the sensor scan angle and should be accurate to within a degree. The sensor azimuth angles were determined from plotting the center points of a nadir view camera on an air photo of the area and connecting them to determine the aircraft heading. Because of the errors in this method, view azimuth accuracy is probably no more than 2 to 3 degrees. Solar zenith and azimuth were determined computationally from the time at the beginning of each flight line and should be within a degree. Sites referred to as 0 and 999 in the tables are observations of water.

Table 7.1 - Thematic Mapper Simulator Data

Canopy reflectance values were determined for 3 days from TMS. The NASA C130 flew several flight lines over the SNF to collect data at several view and solar angles for each site. The view and solar angles are in the same coordinate system with zero-degree azimuth being due north. Reflectance values were determined for sets of four-by-four pixels at each site and are reported as average precent reflectance and standard deviation for each TMS band. Sites 0 and 99 are water sites.

July 13, 1983

Site	Fight	Sol Zen	Sol Az	View Zen	View Az	Rfl 1	Std 1	Rfl 2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl 6	Std 6	Rfl 7	Std 7
2	1	56.16	94.33	3.00	90.00	3.97	0.26	4.47	0.36	2.31	0.28	14.34	1.74	16.95	1.70	4.57	0.45	-	-
2	2	53.84	97.10	33.70	88.00	2.54	0.18	3.00	0.28	1.33	0.20	13.77	1.13	16.61	1.02	4.34	0.29	0.25	0.27
2	3	51.53	99.97	20.86	268.00	6.33	0.36	7.82	0.68	4.70	0.39	21.21	1.75	25.94	1.82	8.21	0.73	1.97	0.56
2	4	49.40	102.75	17.71	50.00	3.91	0.21	4.75	0.41	2.68	0.25	15.04	1.15	18.40	1.33	5.03	0.42	0.59	0.26
2	5	47.46	105.41	19.57	233.00	4.71	0.21	6.17	0.35	3.70	0.31	18.14	1.64	22.81	1.54	6.95	0.55	1.83	0.43
2	6	44.13	110.37	23.29	320.00	6.01	0.33	8.42	0.61	5.48	0.40	23.42	2.40	29.13	2.36	10.26	1.01	4.24	0.76
14	1	56.16	94.33	1.14	90.00	3.92	0.22	4.37	0.46	2.33	0.37	13.72	1.70	16.44	1.69	4.46	0.56	-	-
14	2	53.84	97.10	33.14	88.00	2.46	0.10	2.90	0.32	1.44	0.17	12.29	1.14	15.61	1.06	4.63	0.26	0.50	0.21
14	3	51.53	99.97	22.28	268.00	6.39	0.21	8.01	0.35	4.84	0.45	20.76	0.96	25.79	1.14	8.50	0.67	2.47	0.61
14	4	49.40	102.75	17.71	50.00	3.80	0.23	4.53	0.51	2.48	0.28	13.85	1.76	17.35	2.06	4.94	0.51	0.54	0.50
14	5	47.46	105.41	19.29	233.00	4.71	0.36	6.32	0.70	3.84	0.47	18.60	2.20	23.62	2.52	7.29	0.64	1.91	0.43
14	6	44.13	110.37	25.57	320.00	6.40	0.14	8.92	0.30	5.83	0.34	24.30	0.87	29.46	1.02	9.74	0.51	3.76	0.59
15	1	56.16	94.33	1.43	90.00	4.08	0.19	4.70	0.46	2.44	0.32	15.12	1.49	17.77	1.47	4.63	0.37	-	-
15	2	53.84	97.10	32.57	88.00	2.32	0.21	2.94	0.20	1.44	0.19	13.12	0.69	16.19	0.74	4.27	0.18	0.40	0.25
15	3	51.53	99.97	23.28	268.00	6.57	0.33	8.33	0.58	5.00	0.45	21.69	1.11	26.93	1.38	8.81	0.78	2.59	0.59
15	4	49.41	102.75	18.14	50.00	3.94	0.14	4.85	0.41	2.83	0.30	15.58	1.39	19.32	1.44	5.28	0.58	1.35	0.46
15	5	47.46	105.41	19.00	233.00	4.72	0.31	6.57	0.78	3.93	0.51	19.59	2.23	24.48	2.65	7.35	0.86	2.05	0.66
15	6	44.13	110.37	29.43	320.00	6.43	0.43	8.86	0.86	5.82	0.52	22.83	2.63	28.99	2.77	10.51	1.14	3.86	0.71
57	1	56.16	94.33	7.29	90.00	3.38	0.31	3.88	0.57	1.99	0.28	12.02	1.67	14.82	1.87	4.18	0.71	-	-
57	2	53.84	97.10	38.00	88.00	1.94	0.13	2.62	0.26	1.16	0.16	11.30	0.59	14.60	0.51	4.37	0.32	0.33	0.28
57	3	51.53	99.97	16.29	268.00	5.92	0.19	7.61	0.56	4.69	0.29	19.71	1.62	25.62	2.06	8.78	0.81	2.94	0.52
57	4	49.40	102.74	9.71	50.00	4.01	0.27	5.15	0.60	3.07	0.37	15.76	1.55	20.11	1.89	6.13	0.68	1.09	0.33
57	5	47.46	105.41	27.57	233.00	5.54	0.46	7.43	0.93	4.75	0.67	19.49	2.32	25.81	2.87	9.17	1.14	3.35	0.79
57	6	44.13	110.37	3.00	320.00	3.69	0.24	5.31	0.56	3.23	0.43	16.78	1.88	21.34	2.00	6.42	0.81	1.82	0.59

July 13, 1983 (continued)

Site	Fight	Sol Zen	Sol Az	View Zen	View Az	Rfl 1	Std 1	Rfl 2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl 6	Std 6	Rfl 7	Std 7
58	1	56.17	94.31	34.57	270.00	9.73	0.33	11.49	0.60	7.62	0.41	30.26	2.08	39.38	2.18	16.79	0.91	-	-
58	2	53.85	97.08	2.29	268.00	4.52	0.23	5.73	0.50	3.31	0.39	22.45	2.40	28.20	3.07	9.10	1.26	2.50	0.61
58	3	51.54	99.96	48.00	268.00	13.52	0.19	16.10	0.32	11.03	0.26	39.26	1.20	51.43	1.49	22.87	0.41	11.30	0.59
58	4	49.41	102.73	18.71	230.00	5.03	0.33	6.80	0.61	4.13	0.42	23.50	2.10	31.57	2.52	11.27	1.09	4.31	0.69
58	5	47.47	105.40	45.57	233.00	7.26	0.14	8.87	0.36	5.72	0.25	28.63	1.62	38.98	1.96	14.93	1.72	6.23	0.52
58	6	44.14	110.35	39.00	320.00	8.06	0.30	10.78	0.44	7.04	0.36	35.56	1.99	46.09	2.71	18.16	1.14	8.06	0.57
59	1	56.17	94.31	31.00	270.00	9.69	0.41	11.85	0.81	8.23	0.61	27.65	2.59	37.17	3.20	16.23	1.10	-	-
59	2	53.85	97.08	4.29	268.00	4.34	0.19	5.78	0.44	3.54	0.34	18.85	2.54	25.28	3.14	8.45	0.99	2.34	0.49
59	3	51.54	99.96	46.00	268.00	13.56	0.33	16.68	0.33	12.09	0.63	33.40	1.01	45.02	1.02	21.24	1.08	11.10	1.10
59	4	49.41	102.73	19.00	230.00	5.73	0.27	8.29	0.62	5.62	0.43	25.06	2.07	34.32	2.61	12.87	0.92	5.53	0.50
59	5	47.47	105.40	45.43	233.00	7.38	0.36	9.18	0.70	6.24	0.59	22.98	1.64	32.10	2.28	13.12	1.00	6.25	0.91
59	6	44.14	110.35	33.29	320.00	8.19	0.27	11.16	0.59	8.23	0.55	28.39	1.80	37.23	2.28	14.84	0.75	7.31	0.57
99	1	56.16	94.33	12.00	90.00	2.73	0.17	1.71	0.29	1.02	0.10	0.14	0.00	0.73	0.10	0.24	0.29	-	-
99	2	53.84	97.10	40.57	88.00	6.83	0.78	6.70	1.25	6.13	1.24	4.25	0.99	5.36	1.15	3.74	0.92	3.00	1.02
99	3	51.53	99.97	11.43	268.00	2.78	0.11	1.83	0.18	1.26	0.14	0.17	0.17	0.70	0.09	0.25	0.21	-1.30	0.30
99	4	49.40	102.75	17.43	50.00	2.66	0.13	1.93	0.14	1.40	0.12	0.24	0.20	0.69	0.12	0.24	0.25	-1.30	0.36
99	5	47.46	105.41	19.29	233.00	2.33	0.10	1.59	0.14	1.12	0.16	0.09	0.13	0.63	0.11	0.28	0.17	-1.30	0.29
99	6	44.13	110.37	8.57	320.00	1.80	0.09	1.31	0.13	1.00	0.00	0.28	0.17	0.46	0.09	0.12	0.15	-1.50	0.24

August 6, 1983

Site	Fight	Sol Zen	Sol Az	View Zen	View Az	Rfl 1	Std 1	Rfl 2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl 6	Std 6	Rfl 7	Std 7
0	1	48.96	113.47	44.89	313.50	2.58	0.08	1.76	0.14	1.27	0.00	0.52	0.00	0.46	0.27	0.22	0.16	-0.96	0.23
0	2	45.82	118.80	1.25	313.00	3.01	0.13	1.98	0.10	1.24	0.15	0.22	0.16	0.28	0.00	0.10	0.14	-1.17	0.21
0	3	38.50	135.18	1.69	270.00	2.48	0.07	1.87	0.13	1.43	0.09	0.32	0.00	0.50	0.22	0.40	0.12	-0.92	0.17
0	4	37.03	139.86	7.03	36.00	2.43	0.10	1.80	0.11	1.35	0.08	0.46	0.00	0.41	0.22	0.28	0.14	-1.02	0.14
0	5	35.70	144.41	46.52	40.50	1.64	0.09	1.36	0.12	1.04	0.13	0.14	0.00	0.22	0.22	0.11	0.10	-0.79	0.15
0	6	41.76	126.96	33.57	262.50	2.55	0.15	1.84	0.20	1.39	0.13	0.36	0.00	0.44	0.24	0.13	0.17	-1.26	0.22
0	7	44.38	121.50	17.40	266.50	2.65	0.10	2.03	0.16	1.51	0.00	0.29	0.00	0.45	0.00	0.03	0.16	-0.58	0.28
72	1	48.96	113.47	37.88	313.50	3.46	0.15	4.56	0.33	2.54	0.17	39.99	1.99	45.44	2.13	11.69	0.52	2.47	0.19
72	2	45.82	118.80	11.56	133.00	4.59	0.53	5.74	0.78	3.34	0.59	42.05	4.34	52.31	4.66	15.77	1.30	4.42	0.61
72	3	38.50	135.18	0.93	90.00	4.11	0.23	5.45	0.49	3.27	0.33	39.73	3.33	49.15	3.26	14.93	1.04	3.62	0.47
72	4	37.03	139.66	5.08	216.00	3.92	0.26	5.31	0.45	3.33	0.35	39.61	3.20	48.30	3.58	14.29	1.15	3.47	0.37
72	5	35.70	144.41	39.41	40.50	3.81	0.19	5.18	0.25	3.06	0.23	38.48	2.32	47.33	2.37	13.61	0.54	3.35	0.34
72	6	41.76	126.95	33.37	262.50	3.59	0.20	4.59	0.34	2.83	0.25	37.79	2.51	44.14	2.65	12.13	0.72	2.46	0.25
72	7	44.38	121.50	18.08	266.50	4.11	0.17	5.14	0.32	3.14	0.23	39.20	2.73	47.41	3.09	13.21	0.99	3.54	0.43

August 6, 1983 (continued)

Site	Fight	Sol Zen	Sol Az	View Zen	View Az	Rfl 1	Std 1	Rfl 2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl 6	Std 6	Rfl 7	Std 7
73	1	48.96	113.47	33.64	313.50	2.98	0.14	4.13	0.29	2.30	0.17	37.35	2.50	42.20	2.41	10.41	0.48	2.21	0.19
73	2	45.82	118.80	18.01	133.00	4.65	0.22	5.91	0.31	3.45	0.21	42.40	2.36	50.66	2.48	13.96	0.86	3.54	0.42
73	3	38.50	135.18	6.49	90.00	3.79	0.19	5.25	0.23	3.07	0.20	37.97	1.51	45.68	1.56	12.89	0.77	2.83	0.40
73	4	37.03	139.66	4.97	216.00	3.67	0.15	5.28	0.26	3.13	0.15	39.31	1.83	46.47	2.27	13.20	0.95	3.14	0.51
73	5	35.70	144.41	39.54	40.50	3.37	0.20	4.73	0.24	2.81	0.17	37.04	1.81	44.26	1.92	11.63	0.50	2.66	0.26
73	6	41.76	126.95	29.96	262.50	3.24	0.18	4.41	0.35	2.57	0.16	34.66	2.66	40.39	2.50	10.61	0.56	2.14	0.27
73	7	44.38	121.50	13.66	266.50	3.63	0.15	4.94	0.34	2.86	0.18	36.96	2.84	43.99	3.00	11.48	0.96	2.84	0.44
74	1	48.96	113.47	34.87	313.50	2.91	0.22	4.16	0.23	2.16	0.13	41.03	2.46	47.42	1.92	12.14	0.50	2.93	0.40
74	2	45.82	118.80	16.49	133.00	4.36	0.14	5.63	0.23	3.21	0.22	43.66	2.37	52.93	2.31	15.26	0.57	3.96	0.31
44	3	38.50	135.18	12.43	90.00	3.91	0.11	5.29	0.16	3.12	0.11	41.78	1.27	51.04	1.35	15.47	0.48	3.91	0.29
74	4	37.03	139.66	6.54	36.00	3.37	0.12	4.63	0.25	2.71	0.17	39.37	1.82	48.20	2.07	14.53	0.73	3.50	0.38
74	5	35.70	144.41	46.34	40.50	3.38	0.23	4.97	0.25	2.86	0.14	40.02	1.44	48.54	1.71	13.90	0.51	3.42	0.24
74	6	41.76	126.96	24.41	262.50	3.41	0.34	4.46	0.70	2.65	0.43	38.42	4.91	46.11	5.27	13.13	1.61	2.92	0.62
74	7	44.38	121.64	5.77	266.50	3.60	0.19	4.72	0.35	2.75	0.28	39.08	2.55	47.34	2.69	13.32	0.88	3.47	0.50
75	1	48.96	113.47	37.96	313.50	2.96	0.11	3.55	0.17	1.92	0.17	37.32	1.10	41.71	1.20	9.77	0.37	2.14	0.16
75	2	45.82	118.80	11.72	133.00	4.20	0.11	5.15	0.21	3.08	0.19	42.17	1.93	49.98	2.08	13.33	0.46	3.11	0.27
75	3	38.50	136.18	14.37	90.00	4.13	0.12	5.38	0.17	3.37	0.17	40.93	4.52	48.75	1.86	13.86	0.51	3.26	0.24
75	4	37.03	139.66	15.54	36.00	3.45	0.12	4.51	0.17	2.74	0.12	38.88	1.54	46.34	1.62	12.84	0.47	2.84	0.28
75	5	35.70	144.41	50.81	40.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-
75	6	41.76	126.95	21.62	262.50	3.27	0.18	4.09	0.20	2.47	0.23	36.46	2.19	42.54	2.34	10.92	0.49	2.20	0.25
75	7	44.38	121.50	1.58	86.50	3.92	0.08	4.89	0.19	2.87	0.15	39.67	1.68	47.04	1.84	12.38	0.54	2.95	0.20

June 28, 1984

Site	Fight	Sol Zen	Sol Az	View Zen	View Az	Rfl 1	Std 1	Rfl 2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl 6	Std 6	Rfl 7	Std 7
3	1	42.39	110.16	0.99	328.00	2.49	0.44	3.53	0.53	1.71	0.41	45.24	5.92	52.92	5.97	11.20	1.74	2.60	0.84
3	2	43.65	108.20	11.21	144.00	4.60	0.27	6.04	0.61	3.37	0.40	55.30	5.97	65.60	6.40	15.89	1.81	4.79	0.90
3	3	41.00	112.45	9.63	90.00	3.36	0.31	4.50	0.86	2.61	0.59	42.26	8.04	53.01	8.70	12.73	2.08	3.90	1.05
3	4	39.62	114.84	39.88	89.00	3.30	0.36	4.75	0.65	2.69	0.58	36.02	4.81	45.03	5.20	12.09	1.47	4.00	0.62
3	5	37.97	117.90	19.22	233.00	2.52	0.41	3.68	0.58	2.04	0.49	36.69	6.20	46.44	6.07	10.44	1.53	2.79	0.65
3	6	35.67	122.68	27.14	48.00	3.44	0.31	4.10	0.59	2.45	0.38	32.11	5.21	39.22	5.43	10.03	1.35	3.02	0.49
3	7	33.36	128.23	2.93	14.00	2.45	0.29	3.55	0.43	2.00	0.29	35.77	6.33	44.65	6.31	10.51	1.05	2.60	0.52
3	1	42.39	110.16	1.18	328.00	2.49	0.75	3.46	1.30	1.74	0.82	34.34	10.57	43.27	11.65	9.63	2.43	2.09	0.90
3	2	43.65	108.20	11.22	144.00	4.90	0.32	5.94	0.84	3.87	0.57	46.76	7.58	56.43	7.84	13.95	1.83	4.43	0.90
3	3	41.00	112.45	11.24	90.00	3.30	0.40	3.86	0.76	2.24	0.56	35.41	5.95	44.36	6.52	10.02	1.51	2.85	0.91
3	4	39.62	114.84	38.57	89.00	3.54	0.26	4.48	0.38	2.80	0.24	34.03	2.69	41.86	3.45	10.41	0.98	3.13	0.49

June 28, 1984 (continued)

Site	Fight	Sol Zen	Sol Az	View Zen	View Az	Rfl 1	Std 1	Rfl 2	Std 2	Rfl 3	Std 3	Rfl 4	Std 4	Rfl 5	Std 5	Rfl 6	Std 6	Rfl 7	Std 7
3	5	37.97	117.90	21.36	233.00	2.43	0.32	3.24	0.44	2.02	0.49	30.22	4.33	38.74	4.68	8.93	1.15	2.43	0.72
3	6	35.67	122.68	25.65	48.00	3.12	0.20	4.06	0.54	2.30	0.31	36.06	5.09	42.79	5.21	10.05	1.09	2.82	0.53
3	7	33.36	128.23	1.22	14.00	2.59	0.39	3.74	0.75	2.36	0.71	35.39	5.74	44.29	6.28	10.77	1.44	2.84	0.50
3	1	42.39	110.16	10.90	328.00	2.46	0.57	4.17	1.11	2.46	0.81	17.12	3.77	23.53	4.97	6.59	1.73	1.88	1.23
3	2	43.65	108.20	0.66	144.00	5.13	0.48	8.40	1.48	5.36	1.36	27.23	5.82	35.59	8.00	10.60	2.47	4.58	1.42
3	3	41.00	112.45	13.10	270.00	3.40	0.25	4.97	0.70	2.80	0.58	17.77	2.89	23.48	3.18	6.15	0.99	1.97	0.46
3	4	39.62	114.84	37.03	89.00	5.37	0.22	7.88	0.65	5.45	0.33	20.83	3.99	28.80	4.95	10.12	0.95	4.87	0.55
3	5	37.97	117.90	14.64	233.00	3.25	0.23	5.28	0.98	3.11	0.91	18.55	3.53	24.94	4.52	6.77	1.43	2.52	0.90
3	6	35.67	122.68	29.82	48.00	4.01	0.28	5.45	0.54	3.52	0.46	15.58	1.23	20.65	1.54	6.74	0.71	2.88	0.41
3	7	33.36	128.23	13.70	14.00	2.69	0.20	4.75	0.61	2.92	0.35	18.80	3.72	25.41	4.03	7.36	0.90	2.51	0.46
3	1	42.39	110.16	13.81	328.00	1.51	0.21	3.21	0.43	2.04	0.41	21.12	1.62	28.08	1.89	6.56	0.96	2.02	0.45
3	2	43.65	108.20	3.24	144.00	2.71	0.33	4.97	0.80	3.06	0.55	24.83	3.87	32.69	4.60	8.30	1.39	3.11	0.85
3	3	41.00	112.45	26.84	270.00	1.76	0.19	3.04	0.50	1.80	0.28	17.10	2.51	23.36	2.99	5.65	0.84	1.87	0.49
3	4	39.62	114.84	21.61	89.00	2.96	0.20	5.91	0.72	3.64	0.56	25.61	3.26	35.03	4.17	9.74	1.64	3.63	0.80
3	5	37.97	117.90	30.76	233.00	1.53	0.27	3.18	0.54	1.92	0.30	17.27	1.98	24.09	2.60	5.81	0.86	1.78	0.44
3	6	35.67	122.68	17.61	48.00	2.76	0.21	5.04	0.67	3.24	0.49	23.89	2.43	31.90	3.15	8.43	1.18	3.00	0.59
3	7	33.36	128.23	3.36	14.00	1.88	0.21	3.99	0.64	2.46	0.52	21.30	2.52	29.34	3.27	7.74	1.22	2.38	0.63

8.0 Satellite Data Availability

The purpose of the SNF study was to develop the techniques to make the link from biophysical measurements made on the ground to aircraft radiometric measurements and then to scale up to satellite observations. Therefore, satellite image data were acquired for the Superior National Forest study site. These data were selected from all the scenes available from Landsat 1 through 5 and SPOT platforms. Image data substantially contaminated by cloud cover or of poor radiometric quality were not acquired. Of the Landsat scenes, only one Thematic Mapper (TM) scene was acquired; the remainder are Multispectral Scanner (MSS) images. Table 8.1 contains a listing of the scenes which passed inspection and were acquired and archived by Goddard Space Flight Center. Some of the acquired image data have cloud cover in portions of the scene or other problems with the data. These problems and other comments about the images are summarized in Table 8.2.

TABLE 8.1 Satellite Image Data Acquired for the SNF Study Area

This table contains a listing of the satellite image data acquired for the SNF study area in Minnesota. The first column is the date of the satellite overpass; Plat is the platform with Landsat abbreviated LS; Inst is the instrument the data were collected with, MSS is the Multi-Spectral Scanner, TM is the Thematic Mapper and HRV1 and 2 are High-Resolution Visible sensors on SPOT; Sol Zen for solar zenith angle (degrees); Sol Az for solar azimuth angle (degrees); View Zen for view zenith angle (degrees); View Az for view azimuth angle (degrees); Pixels for the number of pixels in a record; Recs for number of image records (or lines); GMT for Greenwich Mean Time when the image was collected.

Date	Plat	Inst	Sol Zen	Sol Az	View Zen	View Az	Pixels	Recs	GMT
03-JUL-73	LS-1	MSS	32	132	0	0	3264	2983	1628
23-JUN-75	LS-1	MSS	35	125	0	0	3264	2983	1609
21-MAY-76	LS-2	MSS	36	131	0	0	3264	2983	1614
05-JUL-76	LS-1	MSS	40	117	0	0	3264	2983	1544
01-AUG-76	LS-2	MSS	39	130	0	0	3264	2983	1612
06-SEP-76	LS-2	MSS	49	139	0	0	3264	2983	1611
24-SEP-76	LS-2	MSS	54	144	0	0	3264	2983	1610
21-JUN-77	LS-2	MSS	36	122	0	0	3264	2983	1559
11-JUN-79	LS-2	MSS	35	127	0	0	3264	2983	1612
05-JUN-82	LS-3	MSS	34	133	0	0	3264	2983	1628
01-MAY-83	LS-4	MSS	38	141	0	0	3264	2983	1628
18-JUN-83	LS-4	MSS	32	133	0	0	3264	2983	1628
25-APR-84	LS-5	TM	40	139	0	0	6967	5965	1628
28-JUN-84	LS-5	MSS	32	129	0	0	3264	2983	1628
21-AUG-86	LS-5	MSS	43	136	0	0	3264	2983	1628
22-JAN-87	SPOT	HRV2	69	165	2.3	103.4	3000	3000	1719
25-APR-87	SPOT	HRV2	36	164	17.2	105.3	3000	3000	1730
05-MAY-87	SPOT	HRV2	33	168	27.6	106.8	3000	3000	1738
31-MAY-87	SPOT	HRV2	27	165	26.2	106.6	3000	3000	1738
28-JUL-87	SPOT	HRV1	31	155	7.3	104.0	3000	3000	1723
08-AUG-87	LS-5	MSS	40	134	0	0	3264	2983	1628
13-AUG-87	SPOT	HRV1	35	155	3.6	102.6	3000	3000	1715
14-SEP-87	SPOT	HRV1	46	157	24.1	100.0	3000	3000	1700
24-SEP-87	SPOT	HRV1	50	162	13.8	101.4	3000	3000	1708
04-OCT-87	SPOT	HRV2	53	167	3.3	102.7	3000	3000	1715
23-JUL-90	LS-4	MSS	36	131	0	0	3264	2983	1628
31-JUL-90	LS-5	MSS	38	130	0	0	3264	2983	1628
16-AUG-90	LS-5	MSS	42	134	0	0	3264	2983	1628

Table 8.2 Comments on Satellite Image Data Acquired for the SNF Study Area

This table contains brief descriptions of the quality of the satellite image data described in Table 8.1.

Date	Comments
03-JUL-73	Band 1 and 2 data striped, scattered cumulus in SNF.
23-JUN-75	Band 1 and 2 data striped, SNF clear of cloud cover.
21-MAY-76	Band 1 and 2 data striped, SNF clear of cloud cover.
05-JUL-76	Band 1 and 2 data striped, few cumulus.
01-AUG-76	Band 1 and 2 data striped, few cumulus.
06-SEP-76	Band 1 and 2 data striped, SNF clear of cloud cover.
24-SEP-76	Band 1 and 2 data striped, SNF clear of cloud cover.
21-JUN-77	Band 1 and 2 data striped, SNF clear, SNF cut off to East of Big Lake.
11-JUN-79	Band 1 and 2 data striped, SNF at bottom of scene.
05-JUN-82	Line start error North and West of Ely, SNF cut off to East of Big Moose Lake.
01-MAY-83	SNF clear of cloud cover.
18-JUN-83	SNF clear of cloud cover, image used as reference for GSFC work.
25-APR-84	SNF clear of cloud cover.
28-JUN-84	SNF clear of cloud cover, possible calibration problems.
22-JAN-87	Snow covered, SNF has some cirrus.
25-APR-87	Heavy cirrus cloud cover in northern SNF.
05-MAY-87	Cirrus cloud cover in Western portion of SNF.
31-MAY-87	Heavy cumulus cloud cover throughout SNF.
28-JUL-87	SNF clear of cloud cover.
08-AUG-87	SNF clear of cloud cover.
13-AUG-87	Few scattered cumulus.
14-SEP-87	SNF clear of cloud cover.
24-SEP-87	SNF clear of cloud cover.
04-OCT-87	Some cirrus cloud cover in Eastern SNF.
23-JUL-90	Band 1 and 2 data striped, some cumulus outside SNF.
31-JUL-90	Band 1 and 2 data striped, SNF clear of cloud cover.
16-AUG-90	Band 1 and 2 data striped, some cirrus cloud cover in SNF.

9.0 Superior National Forest Related Publications

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Hall, F. G., S. J. Goetz and J. E. Nickeson (1992), Seasonal and interannual variability in photosynthetic activity in the boreal forest of northeast Minnesota: a remote sensing based model, In: *Proceedings of the Seventh Annual Landscape Ecology Symposium*, Corvallis, Oregon.

Hall, F. G., D. E. Strebel, J. E. Nickeson and S. J. Goetz (in preparation), Boreal forest seasonal dynamics derived from satellite remote sensing.

Hall, F. G., K. F. Huemmrich, S. J. Goetz, J. E. Nickeson and D. E. Strebel (in preparation), Remote sensing and canopy modeling of phenological development in a boreal forest.

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Woods, K. D., A. H. Fieveson and D. B. Botkin (1991), Statistical error analysis for biomass density and leaf area index estimation, *Can J For Res* 21:974-989.

Appendix 1 - SNF Data Disk Documentation

In order for the SNF data to be useful to investigators, a floppy disk has been created that contains the data presented in this document. This disk can be ordered from the Pilot Land Data System (PLDS) at Goddard Space Flight Center by contacting:

PLDS User Support Office
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

Phone: (301) 286-9761
E-mail: pldsuso@pldsg3.gsfc.nasa.gov

All data tables in this document are on the disk. Tables that have been left out are ones which provide inventory information. Data tables are stored as ASCII files with the columns of the data separated by tabs. Each file begins with a description of the data. The files are named for the table number as they appear in this document.

There are two subdirectories on the disk. They contain additional data which was not included in the text document. The directory WEATHER contains daily weather data from International Falls; a full description of the data is in the file WEATHER.TXT. The directory SPECTRA contains leaf and bark spectral reflectance and transmittance data.

Disk contents:

README.TXT - Appendix 1, SNF data disk description
TABLE2.1 - SNF plant species names and abbreviations
TABLE2.2 - SNF study site locations and description
TABLE3.1 - Canopy species
TABLE3.2 - Subcanopy species
TABLE3.3 - Understory composition
TABLE3.4 - Cover by stratum and plot for aspen sites
TABLE3.5 - Statistics for sacrificed aspen trees
TABLE3.6 - Statistics for sacrificed spruce trees
TABLE3.7 - Aspen biophysical parameters
TABLE3.8 - Spruce biophysical parameters
TABLE3.9 - Aspen canopy phenology
TABLE3.10 - Subcanopy phenology
TABLE4.1 - Monthly climatological data
TABLE5.2 - TMS band averages of leaf and bark optical properties
TABLE6.3 - Helicopter MMR data, both 1983 and 1984
TABLE7.1 - Thematic Mapper Simulator data
TABLE8.1 - Satellite image data acquired for the SNF

SPECTRA.DIR - This directory contains in numerical form the spectral reflectance and transmittance data displayed graphically in Section 5. The file SPECTRA.TXT provides a description of the contents of each file. Files in SPECTRA:

A25H29RB.DAT	A25H29RF.DAT	A25H29TB.DAT	A25H29TF.DAT
A25HB1RF.DAT	A25L01RB.DAT	A25L01RF.DAT	A25L01TB.DAT
A25L01TF.DAT	A25LB1RF.DAT	A25M11RB.DAT	A25M11RF.DAT
A25M11TB.DAT	A25M11TF.DAT	A25MB1RF.DAT	A26H21RB.DAT
A26H21RF.DAT	A26H21TB.DAT	A26H21TF.DAT	A26HB1RF.DAT
A26L01RB.DAT	A26L01RF.DAT	A26L01TB.DAT	A26L01TF.DAT
A26LB1RF.DAT	A26M11RB.DAT	A26M11RF.DAT	A26M11TB.DAT
A26M11TF.DAT	A26MB1RF.DAT	A27H21RB.DAT	A27H21RF.DAT
A27H21TB.DAT	A27H21TF.DAT	A27HB1RF.DAT	A27L01RB.DAT
A27L01RF.DAT	A27L01TB.DAT	A27L01TF.DAT	A27LB1RF.DAT
A27M19RB.DAT	A27M19RF.DAT	A27M19TB.DAT	A27M19TF.DAT
A27MB1RF.DAT	AB0B201R.DAT	AB0N2B1R.DAT	AB0N2T1R.DAT
AR0L3B1R.DAT	AR0L3B1T.DAT	AR0L3B2R.DAT	AR0L3B2T.DAT
AR0L3T1R.DAT	AR0L3T1T.DAT	AR0L3T2R.DAT	AR0L3T2T.DAT
AXXH21RB.DAT	AXXH21RF.DAT	AXXH21TB.DAT	AXXH21TF.DAT
AXXL01RB.DAT	AXXL01RF.DAT	AXXL01TB.DAT	AXXL01TF.DAT
AXXM19RB.DAT	AXXM19RF.DAT	AXXM19TB.DAT	AXXM19TF.DAT
BL00201R.DAT	BP0L3B1R.DAT	BP0L3B1T.DAT	BP0L3B2R.DAT
BP0L3B2T.DAT	BP0L3T1R.DAT	BP0L3T1T.DAT	BP0L3T2R.DAT
BP0L3T2T.DAT	CC0L3B1R.DAT	CC0L3B1T.DAT	CC0L3T1R.DAT
CC0L3T1T.DAT	CH0L7T1R.DAT	FH0B201R.DAT	LG0L7T1R.DAT
LL0B201R.DAT	LL0N2B1R.DAT	LL0N2T1R.DAT	LL0N7B1R.DAT
LL0N7T1R.DAT	PB0N2B1R.DAT	PB0N2T1R.DAT	PBLR.DAT
PBLT.DAT	PM0B201R.DAT	PM0N7B1R.DAT	PM0N7T1R.DAT
PM1N2B1R.DAT	PM1N2T1R.DAT	PM2N2B1R.DAT	PM2N2T1R.DAT
PM3N2B1R.DAT	PM3N2T1R.DAT	PM6N7B1R.DAT	PM6N7T1R.DAT
PRLR.DAT	PRLT.DAT	PT0B200R.DAT	PT1L2B1R.DAT
PT1L2B1T.DAT	PT1L2T1R.DAT	PT1L2T1T.DAT	PT1L3B1R.DAT
PT1L3B1T.DAT	PT1L3B2R.DAT	PT1L3B2T.DAT	PT1L3T1R.DAT
PT1L3T1T.DAT	PT1L3T2R.DAT	PT1L3T2T.DAT	PT2L2B1R.DAT
PT2L2B1T.DAT	PT2L2T1R.DAT	PT2L2T1T.DAT	PT3L2B1R.DAT
PT3L2B1T.DAT	PT3L2T1R.DAT	PT3L2T1T.DAT	S60H01R.DAT
S60H01T.DAT	S60H02R.DAT	S60H02T.DAT	S60H03R.DAT
SM00201R.DAT	SM607T1R.DAT	SM707T1R.DAT	SM807T1R.DAT
SPECTRA.TXT	SY2R.DAT	SY2T.DAT	SYYR.DAT
SYYT.DAT			

WEATHER.DIR - This directory contains daily weather data from International Falls, MN for the years 1976 through 1986. The file WEATHER.TXT provides a description of the data files. Files in WEATHER:

MET76.DAT	MET77.DAT	MET78.DAT	MET79.DAT
MET80.TXT	MET81.DAT	MET82.DAT	MET83.DAT
MET84.DAT	MET85.DAT	MET86.DAT	WEATHER.TXT

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This report describes the results of a NASA field experiment conducted in the Superior National Forest near Ely, Minnesota, during the summers of 1983 and 1984. The purpose of the experiment was to examine the use of remote sensing to provide measurements of biophysical parameters in the boreal forests. Leaf area index, biomass, net primary productivity, canopy coverage, overstory and understory species composition data are reported for about 60 sites, representing a range of stand density and age for aspen and spruce. Leaf, needle, and bark high-resolution spectral reflectance and transmittance data are reported for the major boreal forest species. Canopy bidirectional reflectance measurements are provided from a helicopter-mounted Barnes Multiband Modular Radiometer (MMR) and the Thematic Mapper Simulator (TMS) on the NASA C-130 aircraft.

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