71-25

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 71-25

DENDROCHRONOLOGICAL TECHNIQUES USED BY THE GEOLOGICAL SURVEY OF CANADA

M. L. Parker

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ABSTRACT

Dendrochronological studies have been conducted to build tree-ring width and density chronologies for coniferous tree sites in order to provide chronological and climatological information on postglacial events. The approach has been to use the well-developed methods in ring-width analysis (including computer data processing), and the newly devised techniques in tree-ring density analysis that employ X-ray and densitometric methods. New instruments and techniques developed are: the Geological Survey of Canada tree-ring scanning densitometer and data acquisition system, methods for producing X-ray negatives of tree-ring specimens, new specimen preparation techniques, a power-driven increment borer, a tree-ring dating computer program and other data processing programs. Tree-ring samples collected from 1,100 trees of 20 different species from 111 sites scattered throughout Canada indicate that many areas produce tree-ring series of datable quality, and that, in many cases, density measurements are more useful for cross-dating purposes than ring-width data.

RÉSUMÉ

Les régions couvertes de conifères ont fait l'objet d'études dendrochronologiques; il s'agit de mettre au point des chronologies fondées sur l'épaisseur et la densité des cercles d'aubier qui permettront de recueillir des renseignements chronologiques et climatologiques relatifs aux événements postglaciaires. Pour y parvenir, on a utilisé aussi bien les méthodes existantes d'analyse des cercles d'aubier (y compris le traitement des données à l'aide d'ordinateur), que les techniques nouvelles d'analyse de la densité des cercles d'aubier (rayons X et densimétrie). Entre autres instruments et techniques nouvellement mis au point, il faut relever: le densitomètre explorateur des cercles d'aubier et le système de recueil des données mis au point par la Commission géologique du Canada, les méthodes servant à réaliser les clichés aux rayons X des spécimens d'aubier, les nouvelles techniques employées pour préparer les spécimens, une tarière à moteur, un programme d'ordinateur pour la datation des cercles d'aubier et autres programmes de traitement des données. Les échantillons prélevés sur 1, 100 arbres, appartenant à 20 espèces différentes et provenant de 111 endroits répartis par tout le Canada, révèlent que plusieurs régions produisent des séries d'aubier dont la qualité est propice à la datation, et que, dans bien des cas, les mesures de densité servent mieux à la datation que les données sur l'épaisseur des cercles d'aubier.

Paper submitted to the Geological Survey of Canada in April 1970. It was presented at the Conference on Biology of Tree-Ring Formation in February 1970 and appeared, in its original form, in the Proceedings of the conference published by the University of British Columbia, Faculty of Forestry, Bulletin No. 7 in June 1970 on pages 55 to 66.

DENDROCHRONOLOGICAL TECHNIQUES USED BY THE GEOLOGICAL SURVEY OF CANADA

INTRODUCTION

A dendrochronological research project was initiated in the Division of Quaternary Research and Geomorphology of the Geological Survey of Canada in April 1968. The primary objective of this research has been to build and evaluate tree-ring chronologies for coniferous tree sites throughout Canada, thus providing chronological and climatological information on postglacial events. This paper reports on the techniques and instruments used or developed in carrying out this project. The geochronological and paleoecological information arising from the project is not presented here but will be the subject of future publications.

The approach taken involved the use of: (1) well-developed techniques in ring width analysis from the Laboratory of Tree-Ring Research, University of Arizona, Tucson, Arizona; (2) newly developed techniques in ring density analysis; and (3) some new techniques, tools, and instruments developed by the Geological Survey of Canada. Of particular value are the techniques of tree-ring crossdating, site and specimen selection, and data measuring, processing, and analyzing developed earlier in this century by Douglass (see references) and Schulman (1937, 1956). Methods in dendroclimatology and computer data processing developed by Fritts and others are also very useful (Fritts, 1963, 1965a, 1965b, 1966, 1969a, 1969b; Fritts *et al.*, 1965; Fritts *et al.*, 1969).

Perhaps the most important innovations in the field of dendrochronology in recent years have been the new techniques in tree-ring density measurement. If ring density information is used in conjunction with that of ring width, the amount of data that can be extracted from tree-ring series is more than doubled. This method is especially applicable to the numerous tree species that lack marked variability in ring width but are highly variable in ring density. Polge (1965a, 1965b, 1966) has developed the technique of obtaining density measurements by scanning X-ray negatives of tree-ring samples on a densitometer. A modified version of his technique is used by the Geological Survey.

New instruments and techniques developed at the Geological Survey of Canada are: (1) the G.S.C. tree-ring scanning densitometer and data acquisition system, (2) two techniques (stationary and moving carriage) for producing X-ray negatives of dendrochronological specimens, (3) a 3/4-inch power-driven increment borer, (4) new techniques for mounting 5-millimetre and 3/4-inch cores, (5) a method of X-raying charcoal, (6) methods of preparing wood cross-sections for X-ray analysis, (7) impregnating and encasing fragmentary specimens in plastic, (8) a tree-ring dating computer program, (9) a digital filter standardizing program, and (10) two line-printer plotting programs.

Sample Sites

Dendrochronological samples have been gathered from 1,100 trees of 20 different species from 111 sites scattered throughout all the provinces

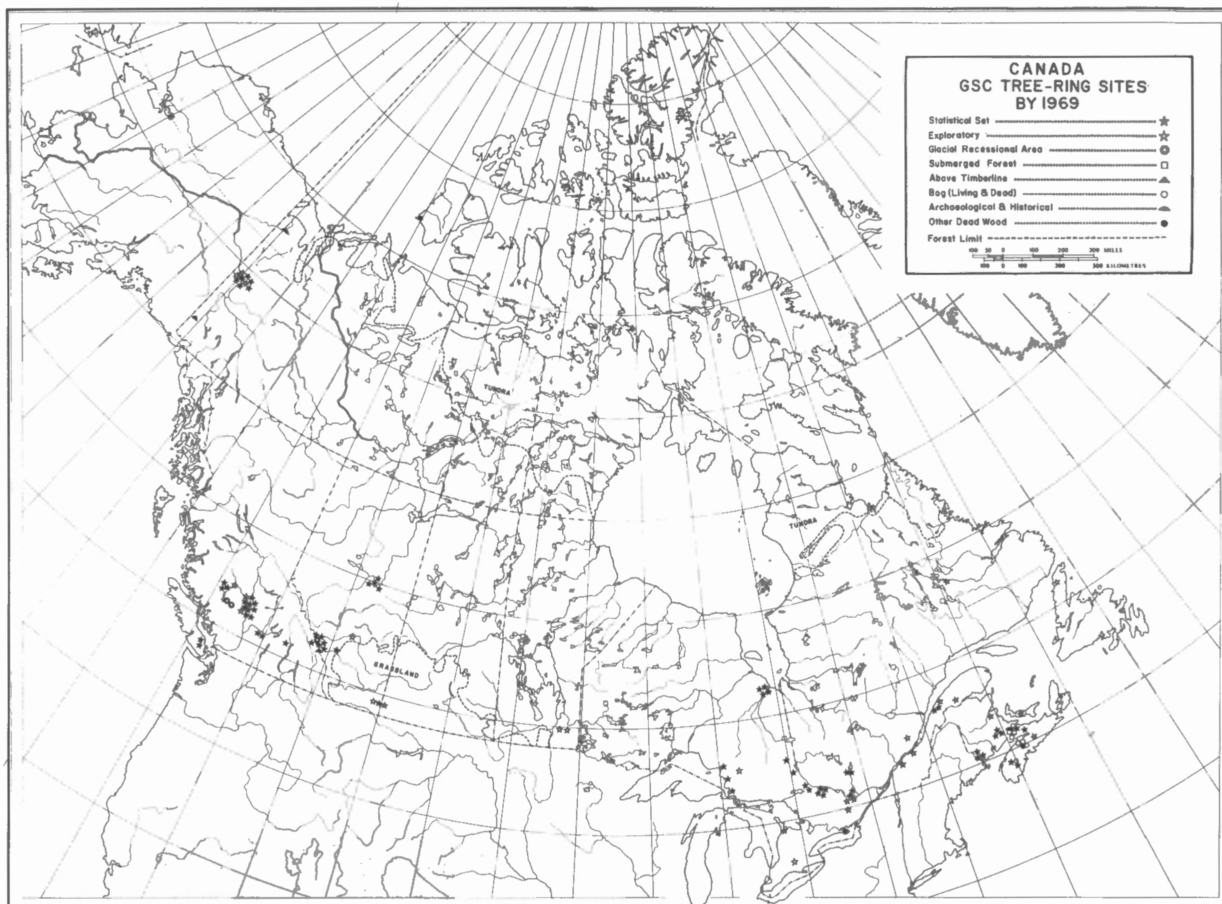

Figure 1. Index map of Geological Survey of Canada tree-ring sites at which samples were collected up to 1969. (G.S.C. photo 201408-G)

Figure 2. Taking 3/4-inch diameter cores with Geological Survey of Canada power-driven increment borer. (G.S.C. photo 201048-M)

and territories of Canada (Fig. 1)[1]. Specimens from these sites can be categorized as (1) statistical sets, generally consisting of two cores from each of 10 living trees, (2) exploratory cores (about three to ten cores taken to obtain limited information on age and sensitivity), (3) glacial recessional specimens (living and dead), (4) bog specimens (living and dead), and (5) dead wood

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[1] For the most part, the sites and dendrochronological samples bear upon current field research projects of the Division of Quaternary Research and Geomorphology. Samples have been provided by, or collected in conjunction with, the following officers of the Division: N.R. Gadd, D.R. Grant, J.A. Heginbottom, D. Hodgson, H.A. Lee, B.C. MacDonald, R.J. Mott, V. Rampton, S.H. Richard, D.A. St-Onge, and J. Terasmae as well as by W. Henoch of the Inland Waters Branch and K. Langmaid of the Canadian Department of Agriculture.

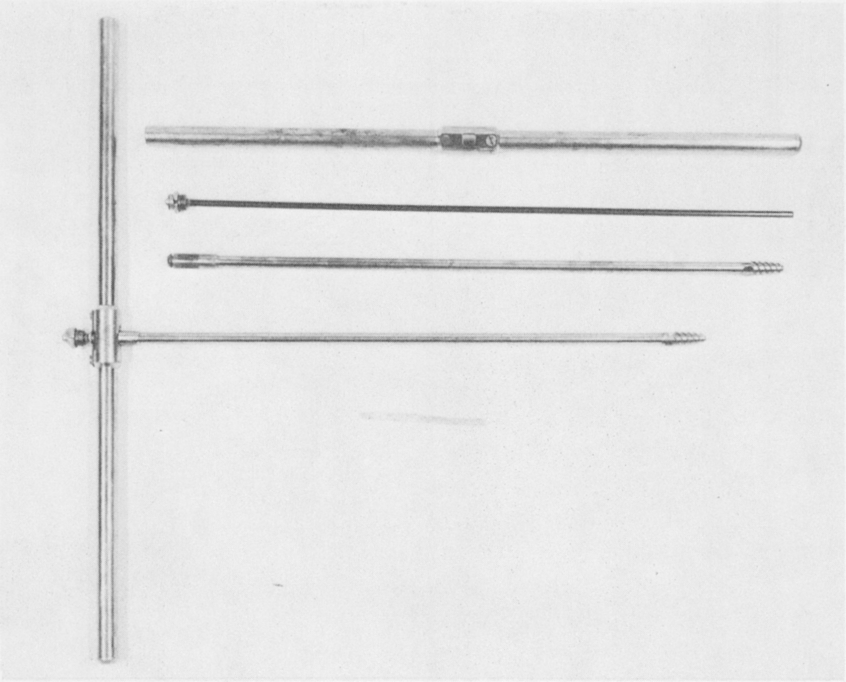


Figure 3. Swedish increment borer, assembled and in parts. (G.S.C. photo 201334-X)

samples, including submerged forest stumps and logs, historic and archaeological specimens, wood found above the timberline and interglacial samples. Master tree-ring width chronologies have been produced for 22 of the statistical set sites. All of the material has been examined either superficially in the field or more intensively in the laboratory for age and sensitivity.

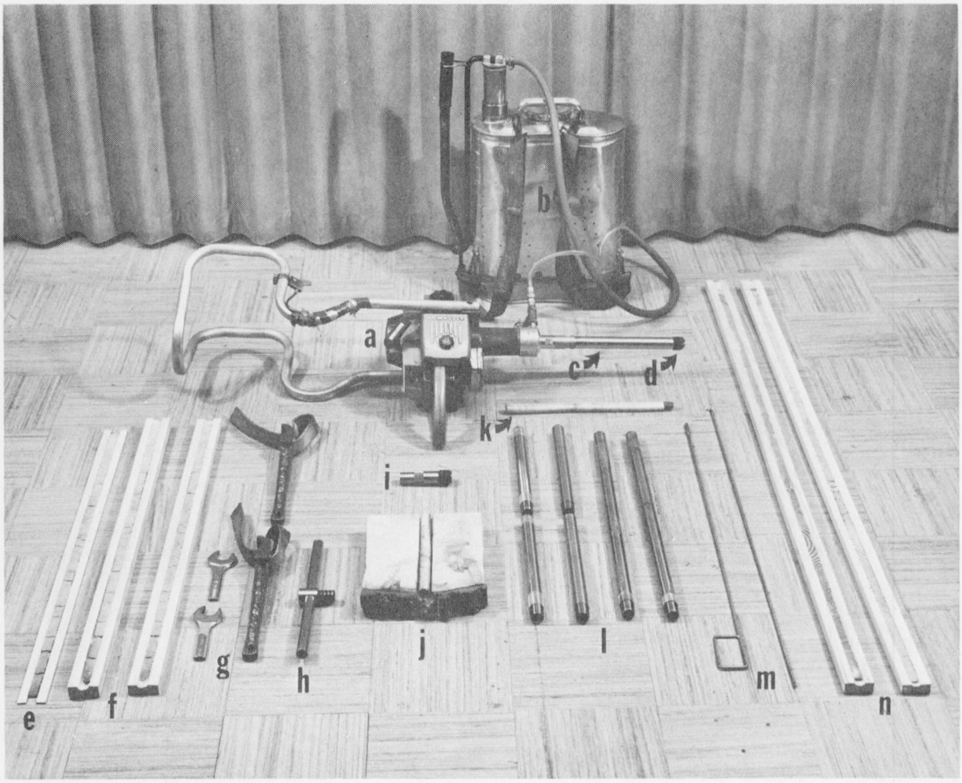
COLLECTING TECHNIQUES

The forms of specimens collected are 5-millimetre and 3/4-inch increment cores (Fig. 2), cross-sections (discs), stump V-cuts, entire wood fragments and entire small trees.

Collecting Tools

Most samples have been collected with Swedish increment borers that extract 4.5-millimetre or 5-millimetre diameter cores. The borers used range from 12 to 40 inches in length. This tool is light in weight, efficient to use, and can be used on most trees without causing permanent damage (Fig. 3).

A 3/4-inch diameter power-driven increment borer has been developed at the Geological Survey of Canada in collaboration with G.A. Meilleur (Fig. 4). A specially designed bit (Fig. 5) has been developed to convert a



a - drill motor with self-contained pump,
b - water tank (with pump for additional pressure when needed),
c - core barrel,
d - drill bit,
e - mounted core component for X-ray exposure,
f - mounted core components for dating and measuring with microscope,
g - wrenches for installing and removing core barrels, extensions, and bits,
h - handle for removing core barrel and bit assembly if jammed,
i - drill bit attached to auxiliary wood pulp impeller,
j - 3/4-inch core resting in cross-sectioned block from which it was extracted,
k - unmounted 3/4-inch core,
l - core barrel extensions (12 inches and 24 inches long),
m - core extractor,
n - mounted core components (57 inches long).

Figure 4. The Geological Survey's power-driven increment borer. (G.S.C. photo 201334-F)

portable rock-coring drill (Gaucher and Meilleur, 1965) into this wood-coring device. The bit revolves at a speed of 6,000 rpm cutting fine wood particles which are removed by a continuous flow of water from a self-contained pump. Additional water pressure is obtained, if needed, by a hand-operated pump on a five gallon water tank. Extensions can be added between the core barrel and bit for sampling large trees. Cores up to five feet in length have been

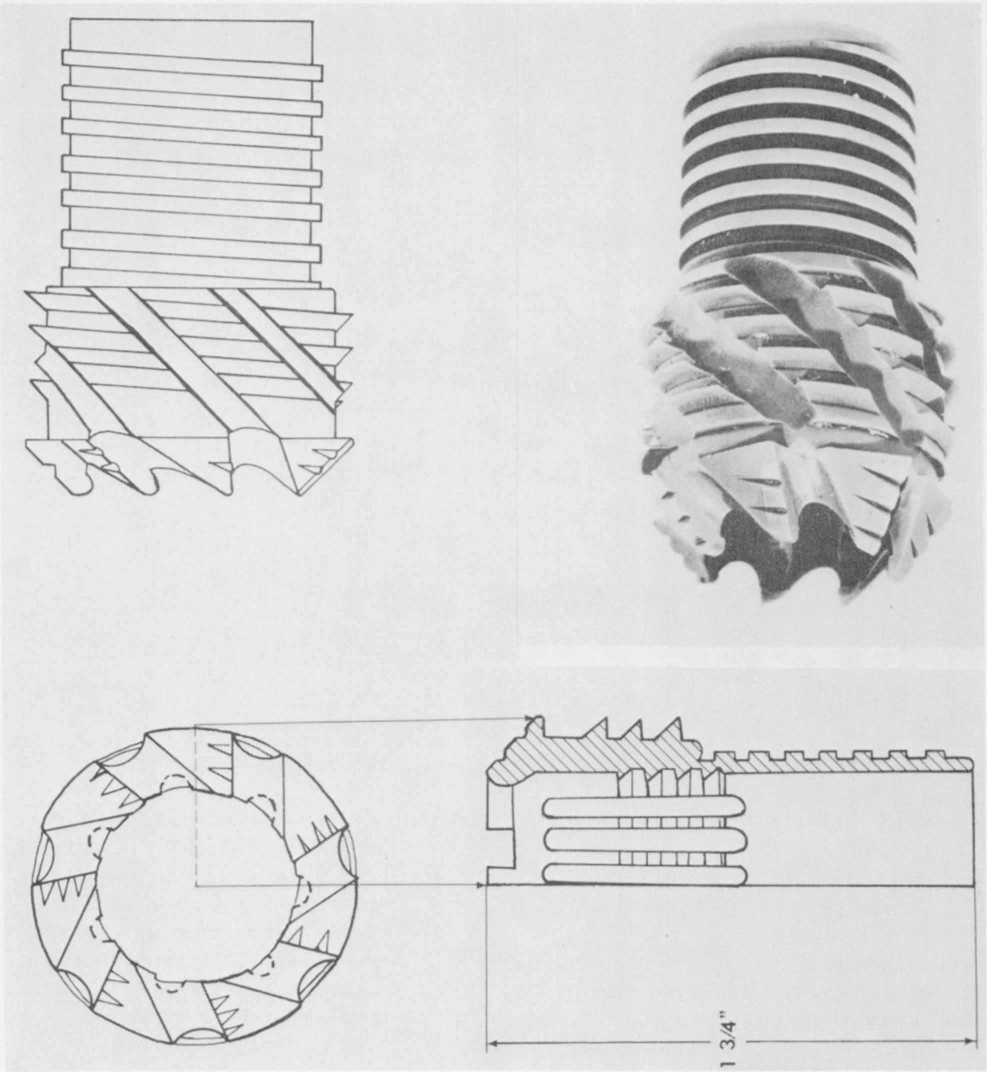


Figure 5. Wood coring bit developed at the Geological Survey of Canada. (G.S.C. photo 201408-K)

taken and we assume that much larger cores could be obtained without difficulty. The normal cutting speed is approximately six inches per minute. The drill is driven by a small gasoline chain-saw motor and the entire instrument weighs about 17.5 pounds, excluding the tank and water. This borer uses approximately one gallon of water for each foot of core extracted and is practical only where water is available.

The 3/4-inch power-driven borer has some advantages over the small increment borer. The 3/4-inch core is large enough for ring width, X-ray, radiocarbon, chemical, and fibre length analysis, and species identification. The large borer can be used to take samples from wood that is either very hard or quite decomposed and fragile. Longer cores can be obtained with this drill than with the 5-millimetre borer. The power-driven drill will take cores from hard, dead specimens without damaging the outermost rings.

Most of the cross-sections and stump V-cuts in the Geological Survey collection have been obtained with chain saws, but some were collected with hand bucksaws and cross-cut saws.

Site and Specimen Selection

Certain tree species growing on certain types of sites produce tree-ring chronologies that are more useful for dating purposes and climatic interpretation than other trees growing under different conditions. The principles of site and specimen selection were established by Douglass (1946a, 1946b) and Schulman (1937, 1956) and have been strengthened by more recent statistical studies by Fritts and others (Fritts et al., 1965). The oldest and most climatically sensitive conifers in western North America are those growing on dry sites where ground moisture is the most important factor limiting growth. Summer temperature is the major factor controlling radial tree growth along the northern limits of the boreal forest (Giddings, 1941, 1943; Schulman, 1944). Some tree-ring studies have been conducted in Canada (Giddings, 1947, 1954; Hustich, 1950, 1954, 1955, 1956; Lyon and Goldthwait, 1934; Marr, 1948; Mitchell, 1967; Polunin, 1955; Schulman, 1947, 1956) but many species and vast areas have not been investigated, and a great deal remains to be determined concerning the relationship between site conditions, climatic factors, and tree-ring growth. In the dendrochronological investigations conducted by the Geological Survey of Canada, attention has been given to finding and collecting samples from the oldest and most sensitive trees, but an effort also has been made to build a general inventory of the chronology characteristics of all coniferous species throughout Canada.

PREPARATION TECHNIQUES

The use of the newly developed tree-ring density analysis as well as the traditional tree-ring width studies has required the development of new methods of specimen preparation. Specimens are prepared in such a way that they can be viewed under the microscope for dating or measuring, or can be used to produce X-ray negatives for density studies.

Five-Millimetre Cores

The small increment cores are allowed to dry and are mounted with resin glue between two mounting sticks that are 1/2-inch wide and 3/32-inch thick. These mounting sticks are grooved on one edge to accommodate the cylindrically shaped core. A mounting jig (Fig. 6) has been designed to hold the cores and their mounting sticks in the proper position while the glue is drying. The cores are mounted with the long axis of the longitudinal tracheids in a vertical position. The rounded portions of the cores projecting above and below the core mounts are sanded with successively finer grits of sandpaper until this transverse cross-section of the core has a polished surface and is flush with the top and bottom surfaces of the core mounts. This technique

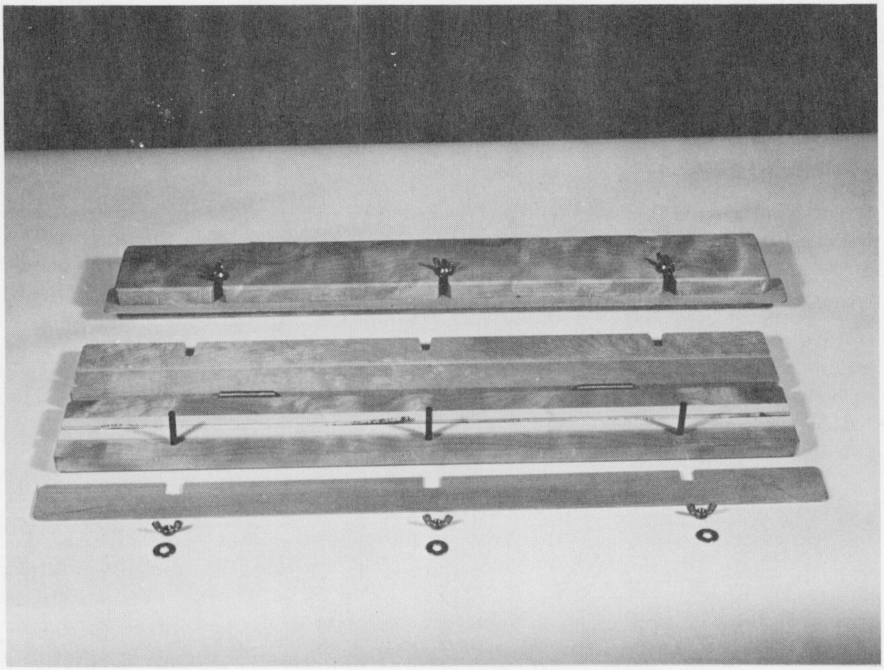


Figure 6. Small core mounting jigs (26 inches long). (G.S.C. photo 201334-H)

provides a core of uniform thickness with vertically oriented cells suitable for X-ray exposure, and with two sanded surfaces that may be examined under the microscope for dating and ring-width measurement. Fragmentary cores can be reconstructed and held together for X-ray processing by this core-mounting technique.

Three-Quarter-Inch Cores

The 3/4-inch cores are completely encased between two mounting sticks two inches wide and one inch thick (Fig. 7). Each mounting stick has a groove of the proper shape and depth to accommodate half of the core. Resin glue is used in the grooves around the core and between the seams formed where the mounts are in contact. The long axis of the longitudinal tracheids is aligned parallel to this seam. The core mounts are held together firmly with C-clamps until the glue is dry. The water used in the drilling process causes the cores to swell and they are allowed to dry thoroughly so that they will not crack in the core mount as they dry and shrink. A 3/32-inch-thick transverse cross-section of the core is produced by making two parallel saw cuts with a circular table saw or a band saw. These saw cuts are made along the longitudinal axis of the core mounts and perpendicular to the seams between the mounts. This technique produces three mounted core components, two of which can be sanded and examined under the microscope for dating and ring-width measurement (Fig. 8), and one with proper cell alignment and

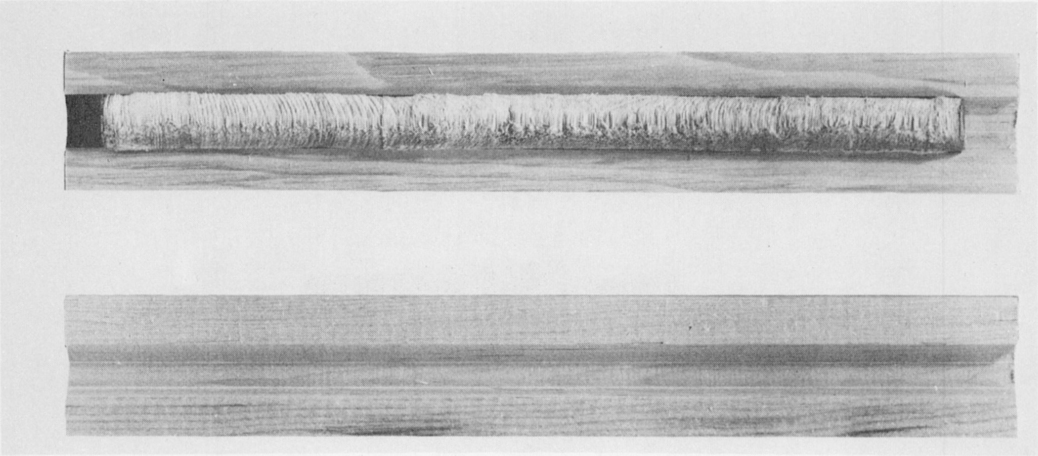


Figure 7. Three-quarter-inch diameter core and core mount. (G.S.C. photo 201034-B)

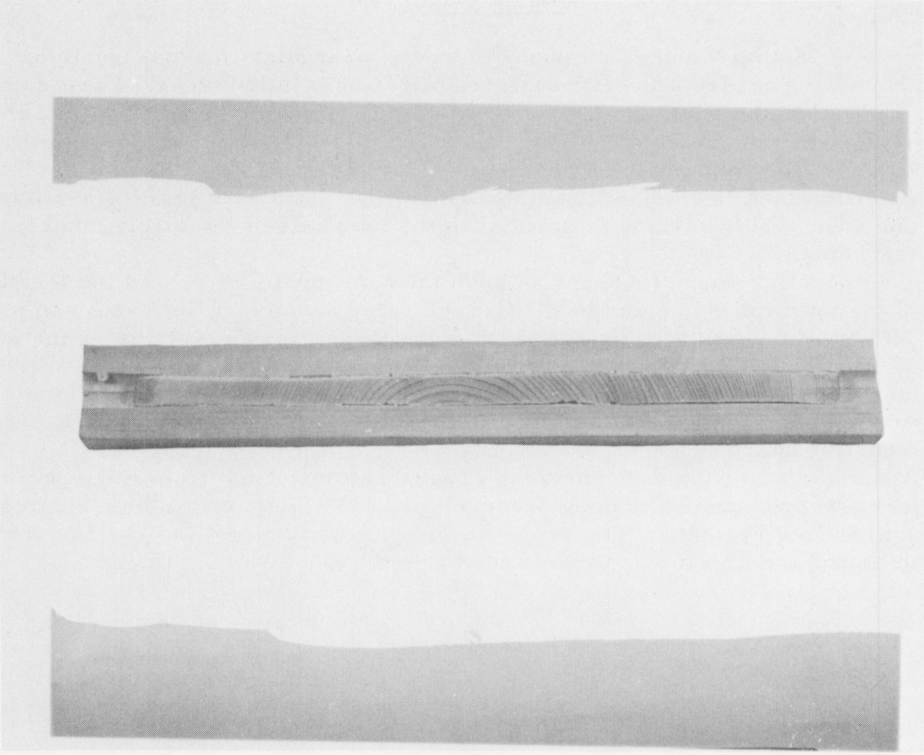


Figure 8. Three-quarter-inch diameter core, mounted and sanded. (G.S.C. photo 201334-O)

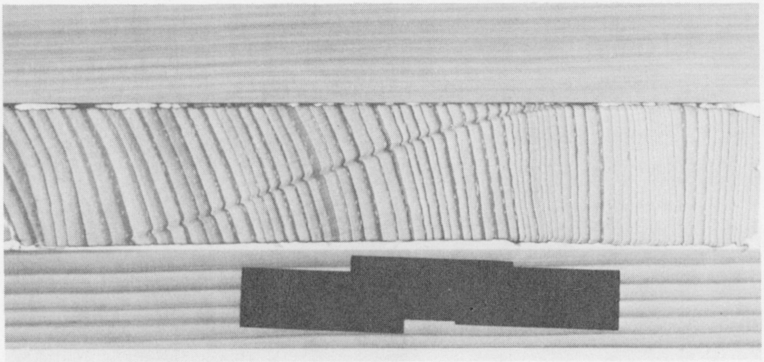


Figure 9. X-ray positive of portion of mounted 3/4-inch diameter core. (G.S.C. photo 201408-P)

thickness for X-ray exposure (Fig. 9). Each component has wood grain running in two different directions which prevents the mounted specimen from warping.

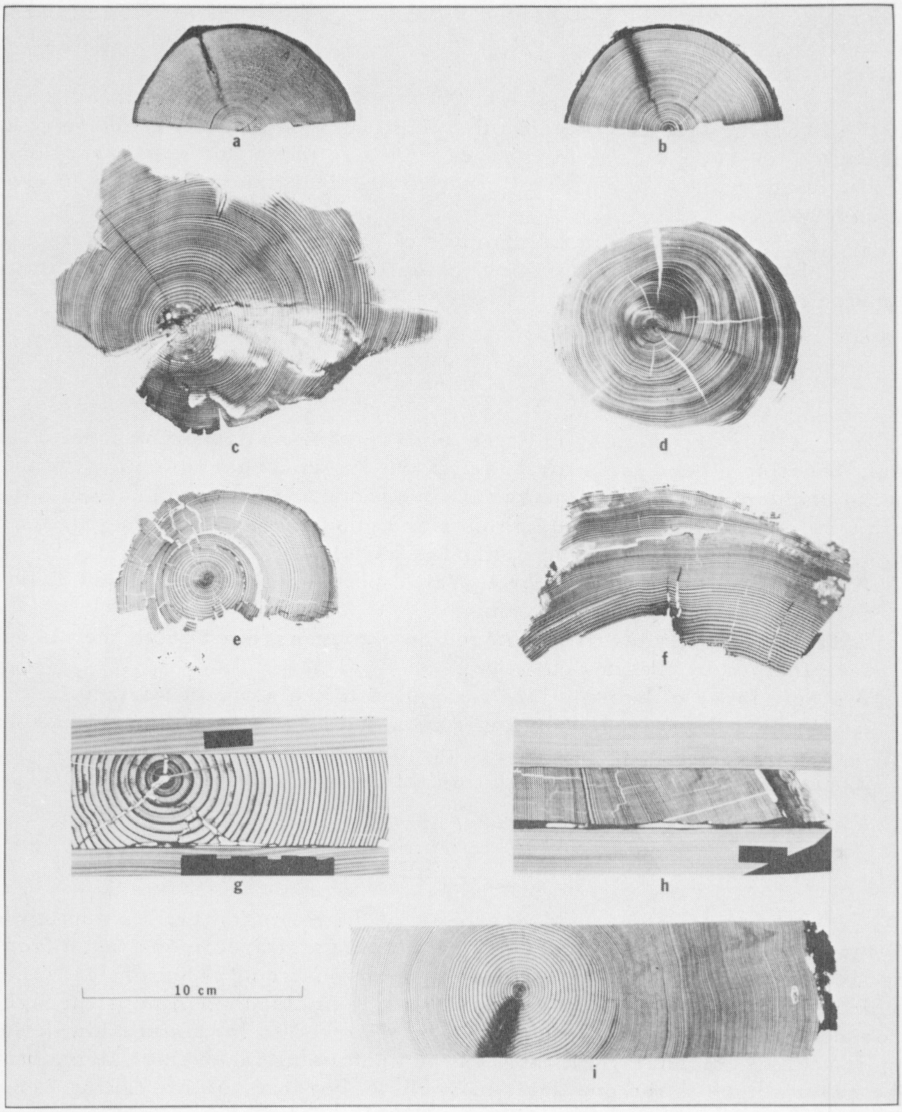
Stump V-cuts

"Stump V-cuts" are slabs of wood, triangular in cross-section, that have been cut from the flat surfaces of recently felled trees. These samples can be obtained by making two intersecting cuts with a chain saw into the top surface of the stump. The technique used to prepare stump V-cuts for X-ray and ring-width analysis at the Geological Survey is as follows:

1. A flat surface is chiseled from one end of the V-cut slab to the other along one edge. This surface is parallel to the long axis of the longitudinal tracheids.
2. The mounting board (perhaps 1/2 inch thick, 4 inches wide, and the length of the specimen) is glued to the flat, chiseled surface of the V-cut sample.
3. The specimen is "squared off" by making 90-degree saw cuts along the top of the slab, along the outer edge of the side opposite the first mounting board, and along the bottom of the specimen.
4. A second mounting board is glued to the plane surface opposite the first mounting board.
5. A number of mounted, transverse cross-sections of the tree-ring specimen are produced by making saw cuts along the long axis of the mounting boards (see Fig. 10). The cross-sections to be X-rayed are cut 3/32 inch thick and the specimens to be sanded are cut about 3/8 inch thick.

Cross-sections

"Tree-ring cross-sections" are made from discs of tree trunks and from transverse cross-sections of wood fragments (Fig. 10). These cross-sections are produced by two parallel saw cuts through the specimen perpendicular to the long axis of the longitudinal tracheid cells. Specimens to be sanded and examined under the microscope vary from 3/8 to 4 inches in



a – photograph of cross-section prepared for X-ray exposure,
b – X-ray positive of a (c through i are also X-ray positives),
c – archaeological specimen,
d – interglacial specimen (greater than 54,000 years old),
e and f – fragile submerged forest sections with backing tape,
g and h – V-cut stump sections with mounting boards,
i – section from block of manageable size from tree disc.

Figure 10. Cross-sections (all are 3/32 inch thick). (G.S.C. photo 201408-D)

thickness, depending on the diameter of the sample. These sections are surfaced with a 3-inch portable belt sander using 12 different grit sizes from coarse to very fine.

The cross-sections to be X-rayed are cut 3/32 inch thick. A single layer of backing tape is placed on the plane surface formed by the first saw cut before the second saw cut is made. Unless these thin cross-sections are thoroughly dry when they are cut, they are placed in a plant press to prevent warping.

In order to produce samples of manageable size from very large tree trunk discs, blocks containing the entire tree-ring series are cut and mounted in a manner similar to that described for the V-cut stumps.

Charcoal

Most archaeological tree-ring specimens are in the form of charcoal, creating a need for a method of X-raying charcoal if density measurements are desired. Experiments have been conducted on techniques of X-raying both coniferous and hardwood samples and good quality X-ray negatives have been produced (Fig. 11). The method is as follows:

1. A transverse cut is made through the specimen with a band saw in the area that contains the outermost rings.
2. Extraneous particles are removed by compressed air from the plane surface formed by the saw cut.
3. A single layer of backing tape is applied to the saw-cut surface.
4. A 3/32-inch-thick cross-section is obtained by making a second saw cut through the specimen parallel to the first cut.
5. X-ray film is exposed through this thin cross-section.

Dating

In the field of dendrochronology the term "dating" is applied to: (1) marking the calendar year dates on the rings of specimens taken from living trees, in which case the date of the outermost ring is known, and (2) establishing the correct date of the outermost ring on dead specimens through the crossdating process. The type of dating referred to in this section is the application of calendar year dates to the specimens taken from living trees. The system used is the one devised by the Laboratory of Tree-Ring Research, namely, a pin hole is made in the wood or the mount for each decade-year, two holes for each fifty year period, three holes for each century, and four holes for each millennium (Fig. 12). If pin holes are made in the wood prior to X-ray exposure, the dating will be automatically recorded on the X-ray negative, but the dates also can be placed on the X-ray negative after development by scratching marks in the film emulsion. In most cases, this type of dating requires not merely ring counting but the application of the crossdating technique to solve the problems created by absent rings, locally absent rings, false annual rings, faint rings, and the like.

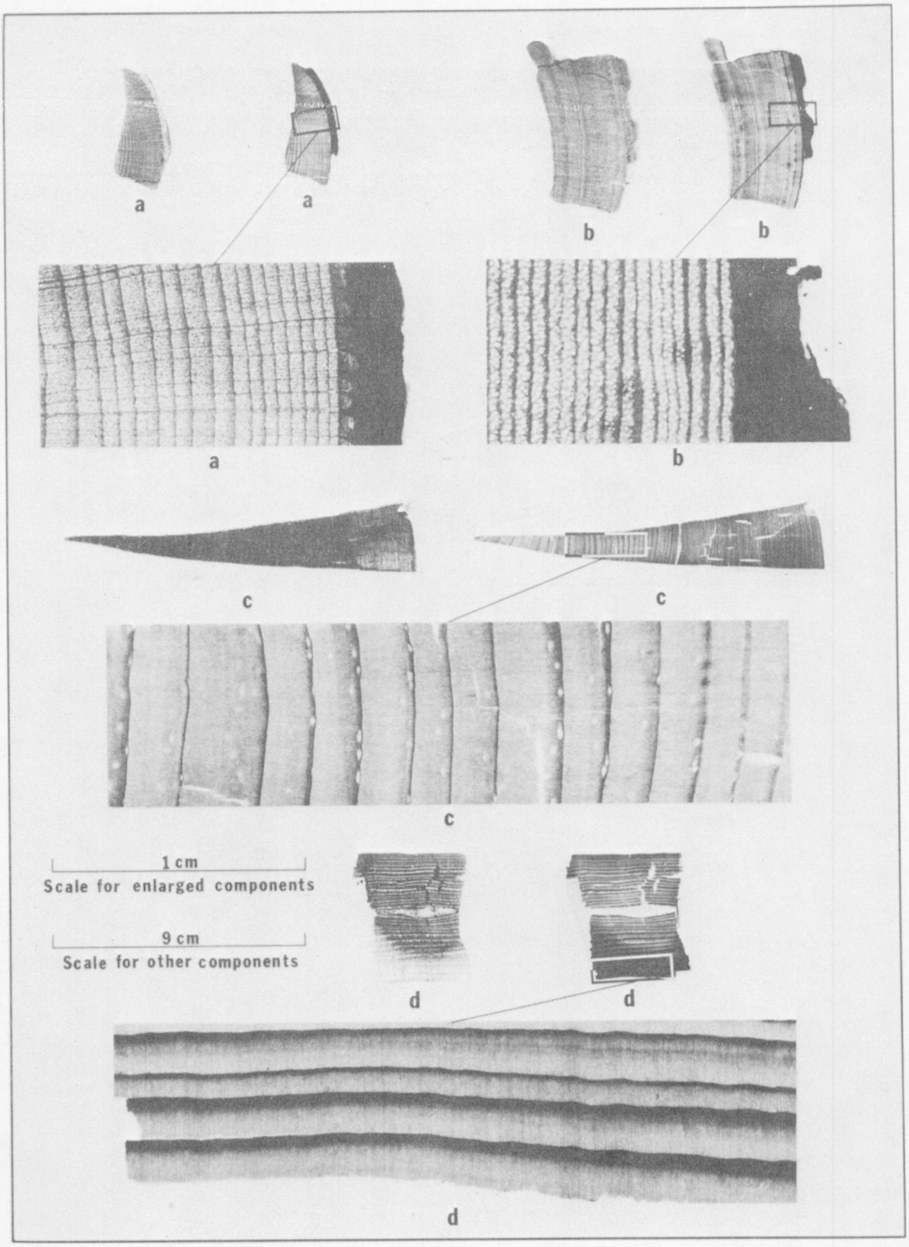


Figure 11. Charcoal cross-sections. a and b are sections from broad-leaved trees; c and d are sections from conifers. Each group of three components includes a photograph of a charcoal specimen (left), an X-ray positive of the same specimen (right), and an enlargement of a portion of the X-ray positive (below other two). (G.S.C. photo 201408-B)

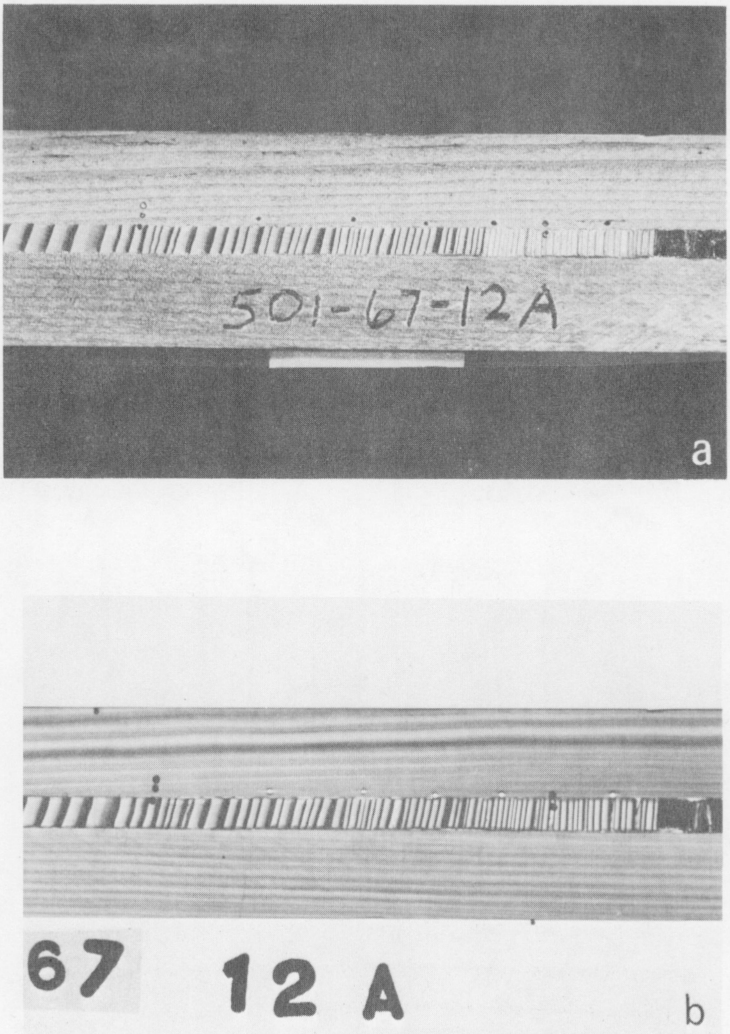
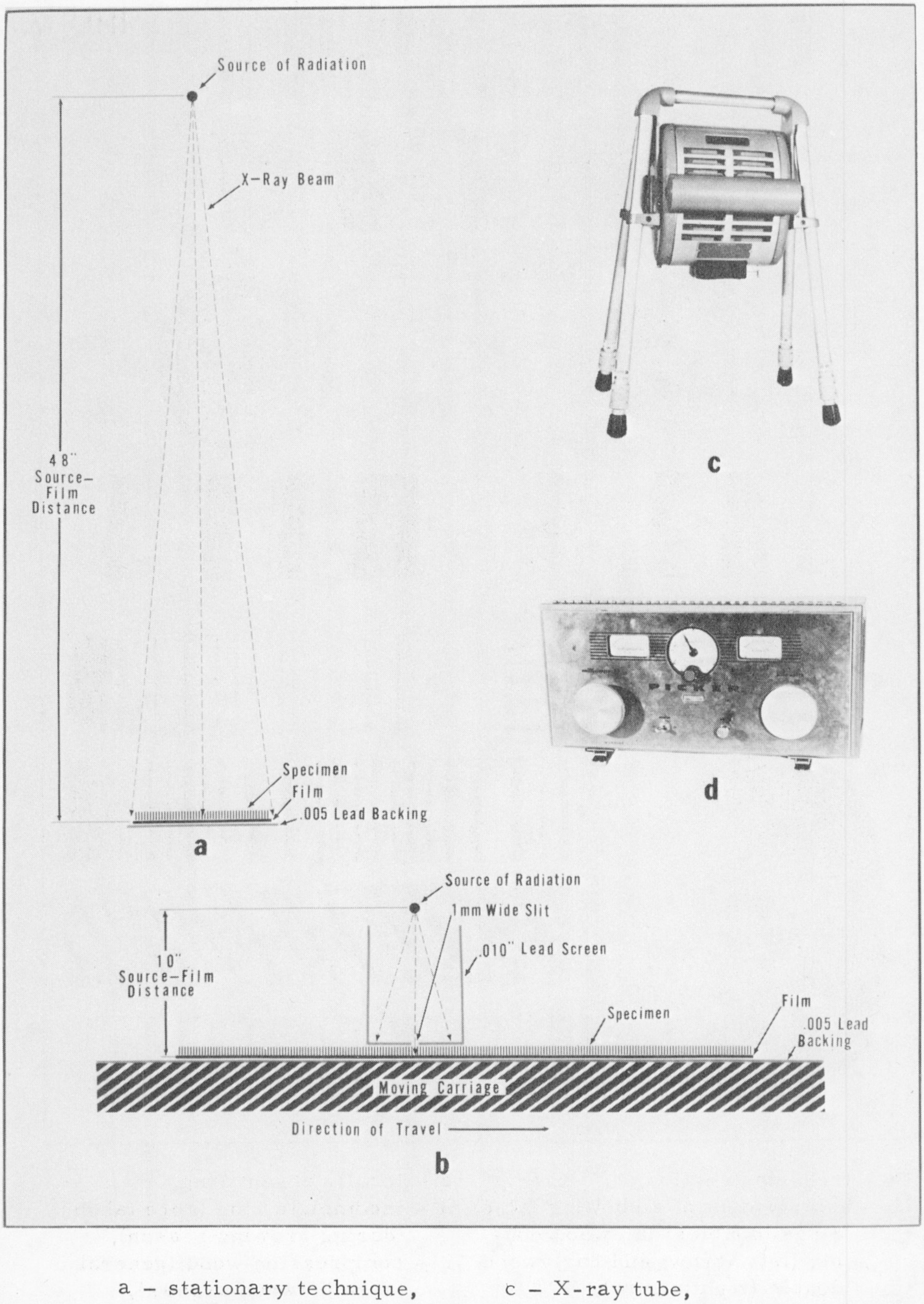


Figure 12. Portion of 5-millimetre diameter core (a), and its X-ray positive (b). (G.S.C. photo 201408-O)

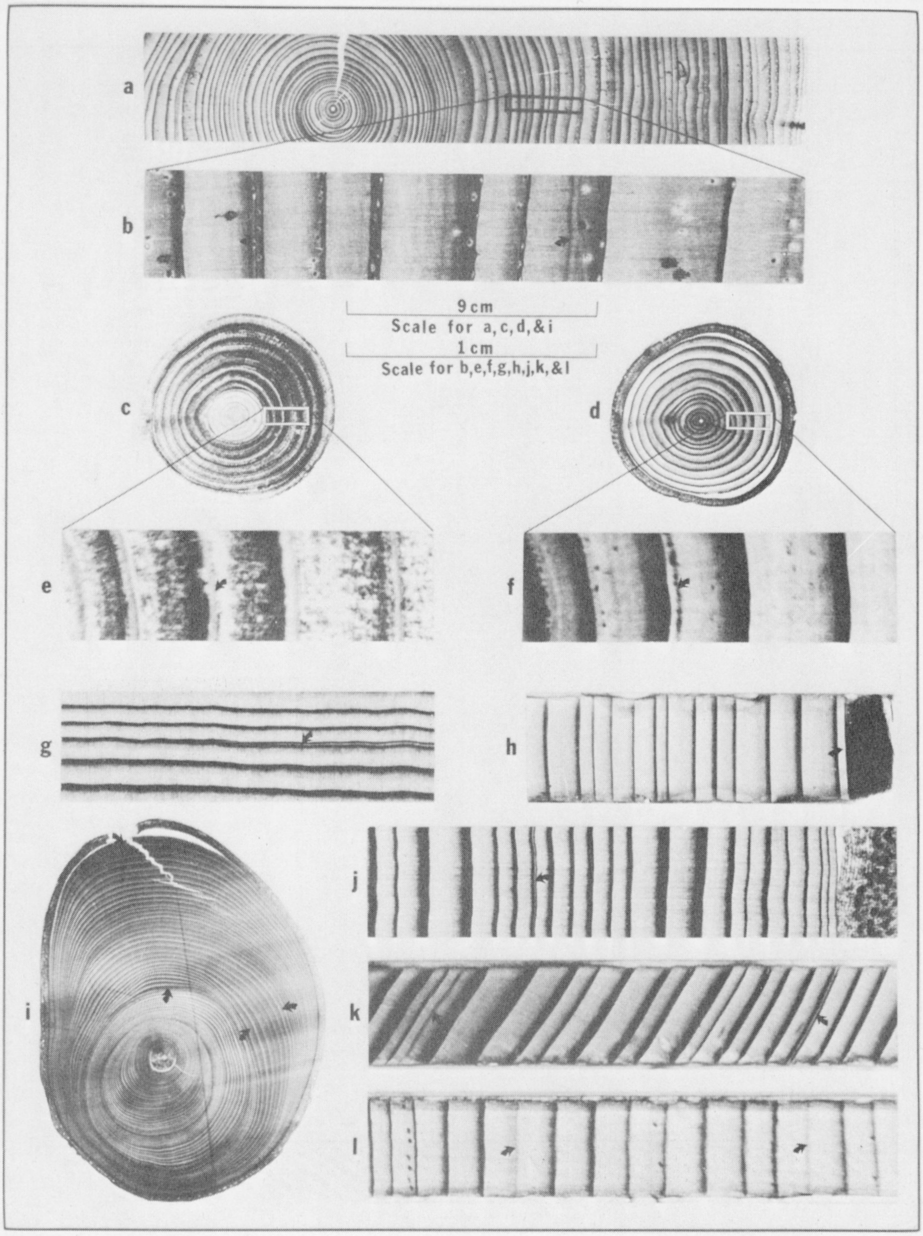
Plastic Impregnation and Encasing of Wood Samples

Experiments in impregnation and encasing of fragmentary wood samples with plastic have been conducted by C. R. McLeod, Geological Survey of Canada. The types of plastics that form a cast around the wood rather than impregnating it are more useful for dendrochronological preparation purposes. The impregnating plastics obscure the rings. The nonpenetrating types form a cast that gives the specimen the rigidity and strength required for X-ray and ring width processing, but do not interfere with the density and visibility of the rings.



a - stationary technique, c - X-ray tube,
b - in-motion technique, d - electronic controls.

Figure 13. X-ray techniques. (G. S. C. photo 201408-L)



a – tree-ring section,

b – enlargement of a showing false rings (doubles) latewood double (left arrow) and earlywood double (right arrow),

c and d – two forms of same cross-section (c, green state and d, dry state),

e and f – enlargements of c and d showing frost ring (arrows),

g – locally absent ring,

h – incomplete ring (core taken during growing season),

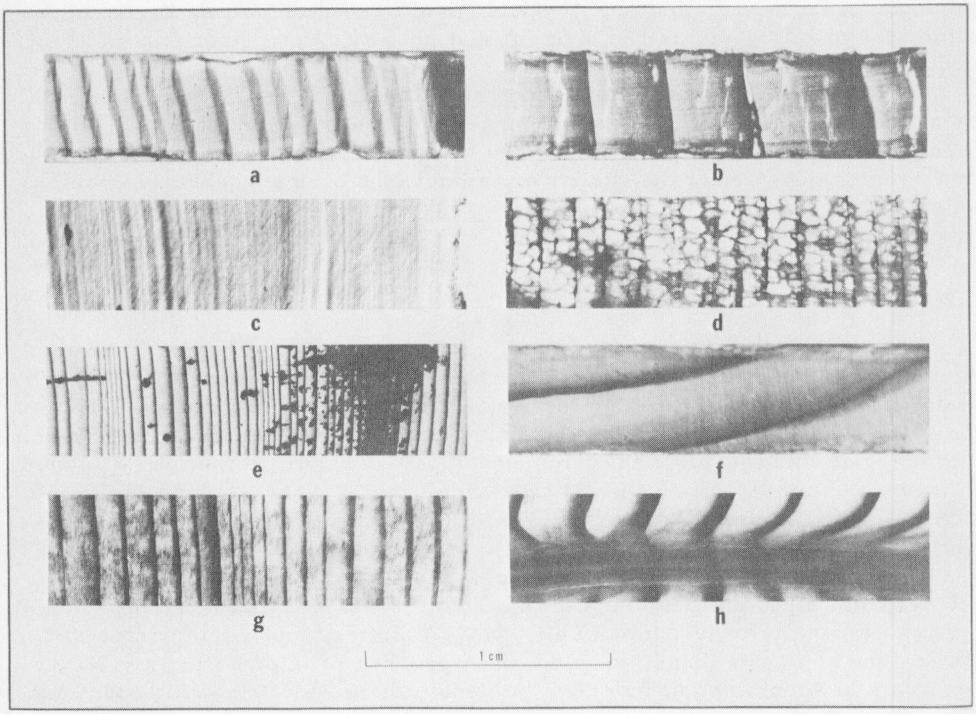
i – compression wood (general area between arrows),

j – microscopic ring,

k – false ring (left arrow) and microscopic ring (right arrow),

l – faint latewood (both arrows).

Figure 14. Tree-ring characteristics. All 12 components are X-ray positives. (G.S.C. photo 201408-E)



a – misaligned xylem cells (large rings),
b – cracks,
c – misaligned xylem cells (small rings),
d – rotten wood (ring-widths are discernible but density is distorted),
e – foreign matter (soil particles),
f – misaligned rings (core taken at incorrect radial direction),
g – foreign matter (polyethylene glycol preservative),
h – limb distortion.

Figure 15. Some factors affecting X-ray quality. All eight components are X-ray positives. (G.S.C. photo 201408-F)

X-ray Techniques

Two techniques of producing X-ray negatives of dendrochronological specimens have been developed in cooperation with K.R. Meleskie, Nondestructive Testing Laboratory, Mines Branch, Department of Energy, Mines and Resources (Fig. 13). The stationary technique is similar in principle to that reported by Polge (1965a, 1966). Soft radiation is emitted from a stationary source located 48 inches from the specimen and X-ray film, which is also held stationary during exposure. In the second technique, radiation passes through a narrow slit from a stationary source 10 inches from the tree-ring specimen and the X-ray film. The specimen and film are supported by a carriage moving at a slow and uniform speed beneath the slit. Long specimens can be exposed to radiation in their entire length at the desired perpendicular angle by this technique. The major reason for producing the X-ray negatives of tree-ring specimens is to provide a means of measuring relative density differences within and between the annual rings. These measurements are obtained by the Geological Survey of Canada scanning densitometer and data acquisition system that presents these data in both graphic and digital form.

The X-ray method provides an excellent means of examining and measuring the many complexities of tree-ring characteristics (Fig. 14); but techniques of specimen preparation and data analysis are complicated because many factors can affect the quality of radiographs of dendrochronological samples (Fig. 15).

MEASURING TECHNIQUES

Most of the tree-ring width measurements used by the Geological Survey to build chronologies have been obtained with a commercially available Swedish tree-ring width measuring instrument. Ring-width and ring-density measurements are now being produced by the G.S.C. tree-ring scanning densitometer and data acquisition system developed in cooperation with F.W. Jones. This instrument will produce: (1) tree-ring density plots, (2) ring-width measurements in printed and punch tape form, (3) maximum density bar graphs, and (4) ring-width bar graphs (Fig. 16).

The basic components of the system are: a scanning densitometer, a ring-width measuring table, a digital counter-scaler, an electronic control system, a remote hand-control unit, an X-Y plotter, and a teleprinter and paper-tape recorder (Figs. 17, 18). The sources of information are X-ray negatives of specimens scanned on the densitometer and tree-ring specimens viewed under a microscope on the ring-width measuring table. The digital counter-scaler, the electronic control system, and the remote hand-control unit are used by the operator to display the data in graphic form on the X-Y plotter and in digital form on the teleprinter and paper-tape recorder.

The tree-ring density plots (Fig. 19) are produced on the X-Y recorder from scans of X-ray negatives on the densitometer unit and are similar in form to those made by Polge (1965a, 1965b, 1966) from X-ray negatives and by Green (1964, 1965) from microtome thin sections of wood. Ring-width measurements can be obtained either from the wood specimens on the ring-width measuring table or from the X-ray negatives scanned on the densitometer unit. Maximum density and ring-width bar graphs are produced on the X-Y plotter and provide a convenient and rapid method of matching tree-ring series measurements.

A number of useful concepts and innovations have been incorporated into this system by Jones. A lightweight cylinder that encases the densitometer light source is used to transport the X-ray negative. The film transport on the densitometer and the specimen transport on the measuring table are driven by the same type of precision stepping motor, and electronic pulses used to operate these motors are used as the source of digitized output for the counter-scaler. These motors provide very accurate and controllable movement. The system is constructed mainly from commercially manufactured component parts that are relatively inexpensive and dependable. Electronic rather than mechanical components were used in the construction whenever possible because electronic units are generally more accurate, less expensive, more easily modified, and more easily controlled.

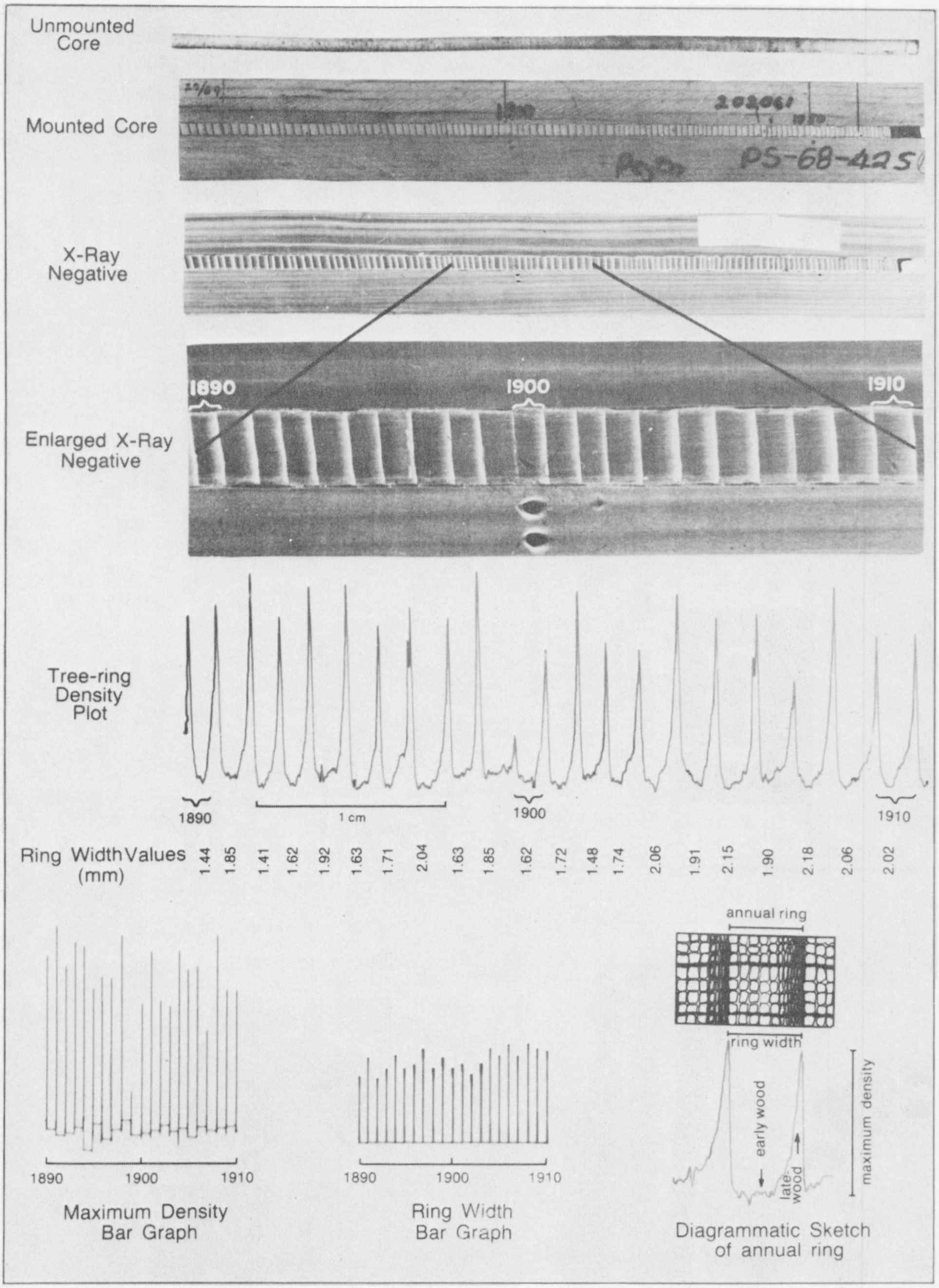


Figure 16. Tree-ring width and density data from X-ray of increment core. (G.S.C. photo 201408-M)

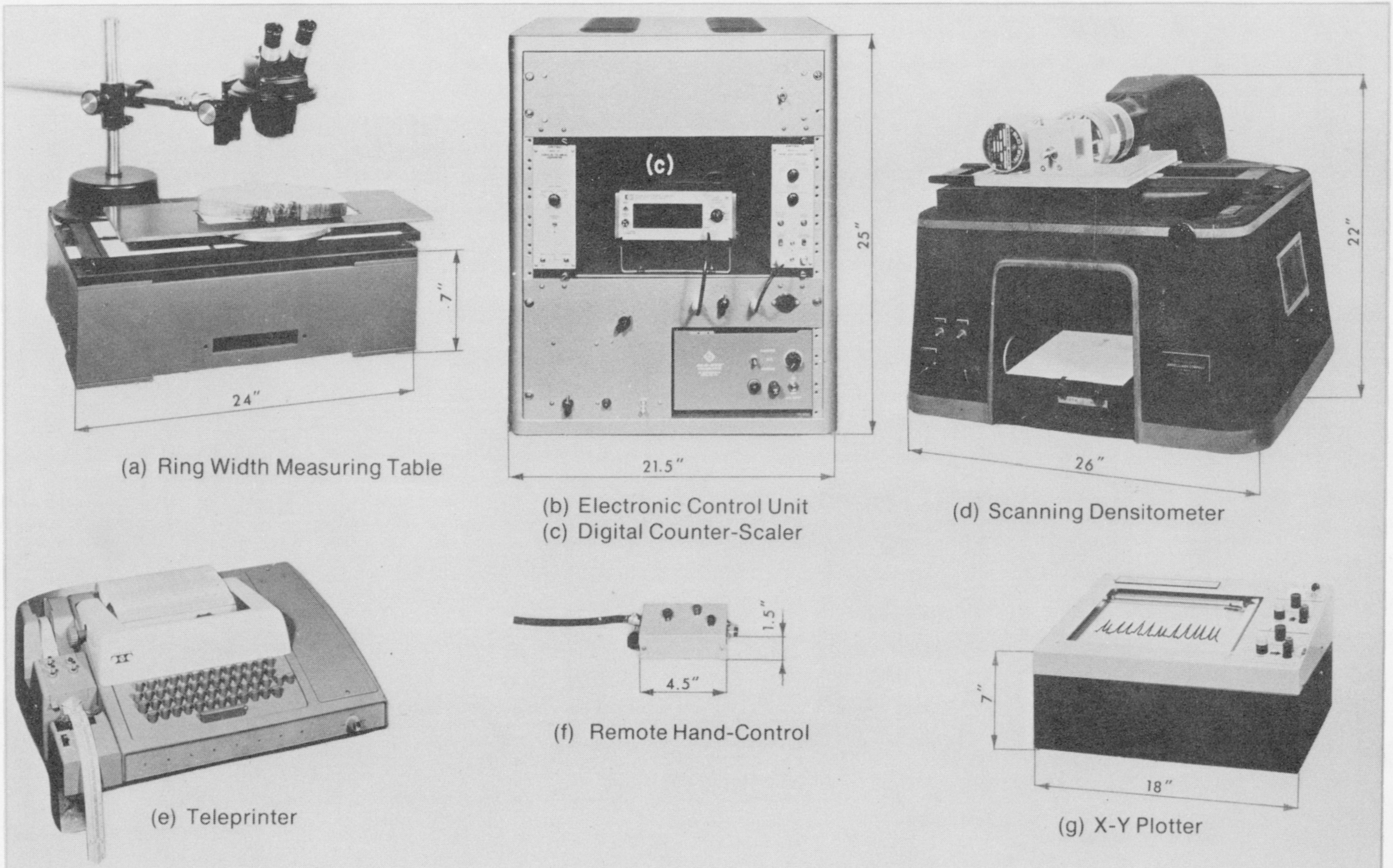


Figure 17. Basic units of Geological Survey of Canada scanning densitometer and data acquisition system. (G.S.C. photo 201408-I)

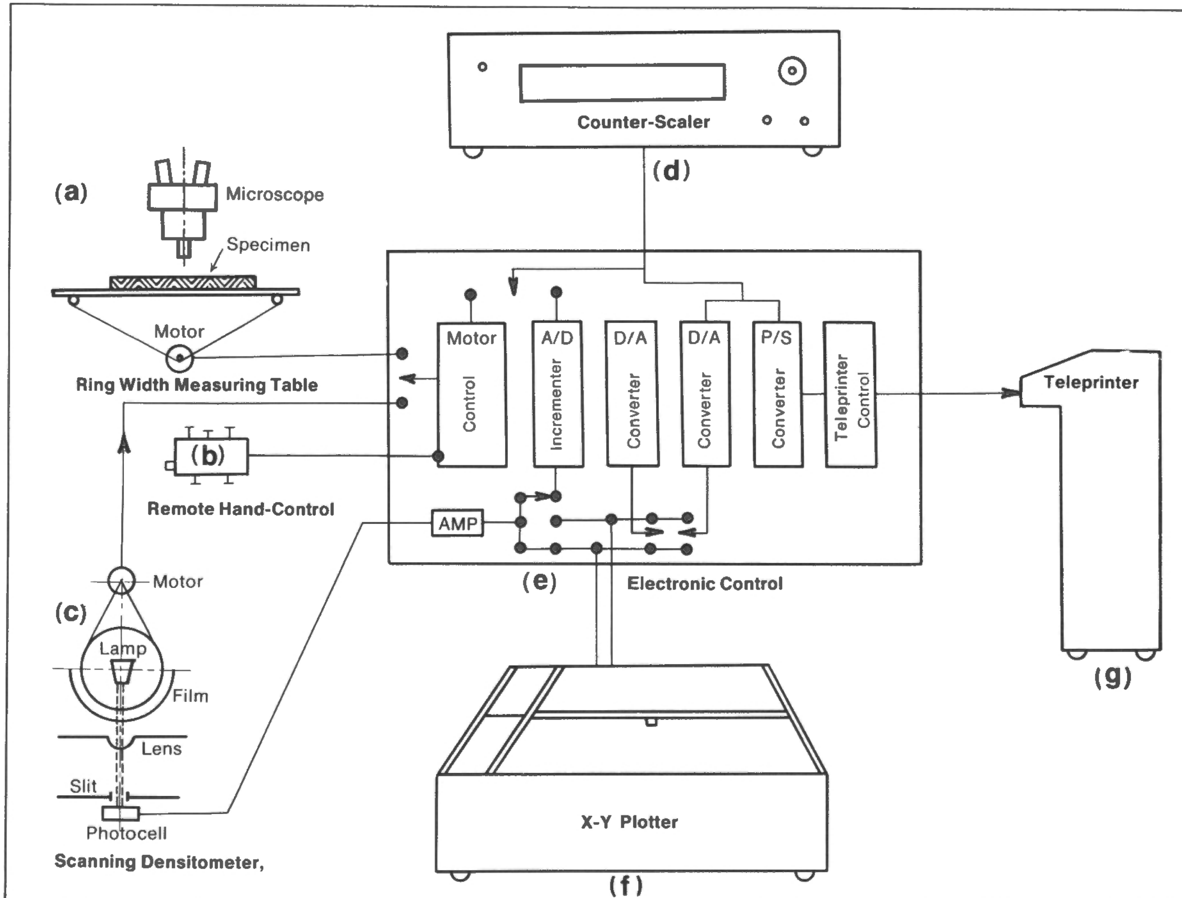


Figure 18. Schematic diagram of Geological Survey of Canada scanning densitometer and data acquisition system. (G.S.C. photo 201408-J)

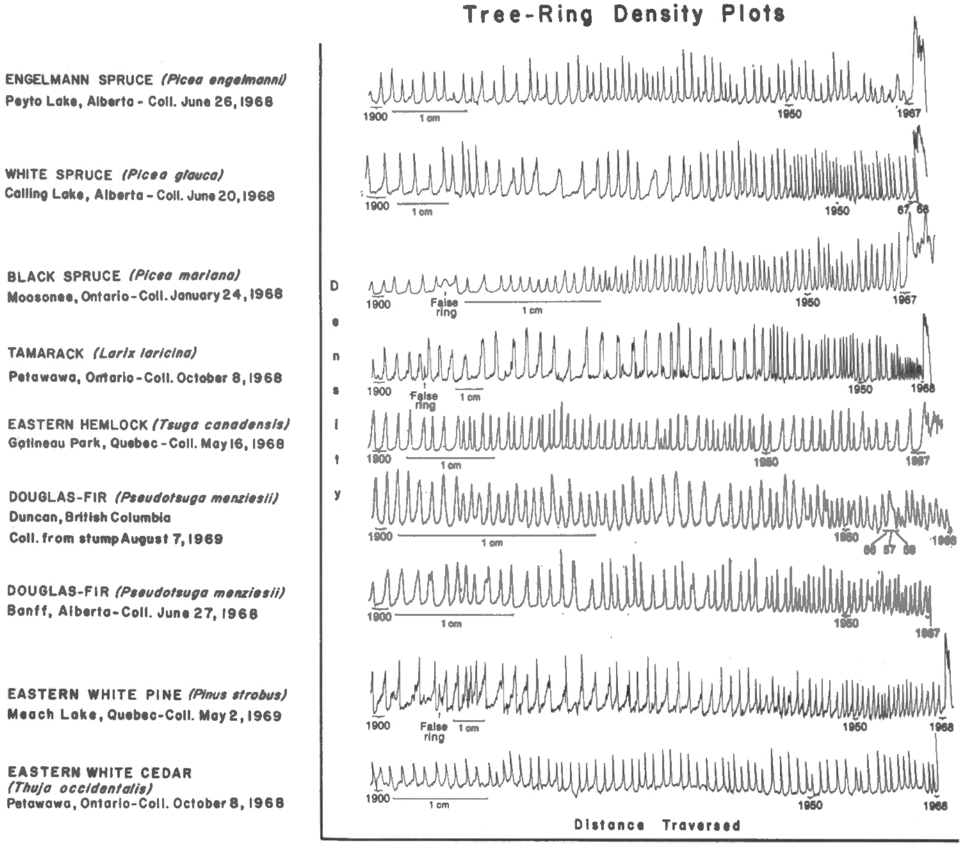


Figure 19. Tree-ring density plots. (G.S.C. photo 201408-A)

The use of tree-ring density measurements in dendrochronology is still in an incipient state of development. The amount of useful dendrochronological information to be obtained from tree-ring series is greatly enhanced by the use of density measurements. Maximum latewood density measurements can be processed with the same computer programs used to handle ring-width data and, in some cases, these density measurements are proving to be more useful for crossdating than ring-width measurements (Fig. 20). The Geological Survey of Canada scanning densitometer is designed to provide a means of investigating some of the uses of density measurements and, at the same time, produce tree-ring width measurements for traditional methods of analysis.

DATA PROCESSING

A number of tree-ring series averaged together provide a more useful chronology for crossdating and dendroclimatic interpretation than does a chronology consisting of values derived from a single specimen. In order to average several series, the growth trend must be removed from each series.

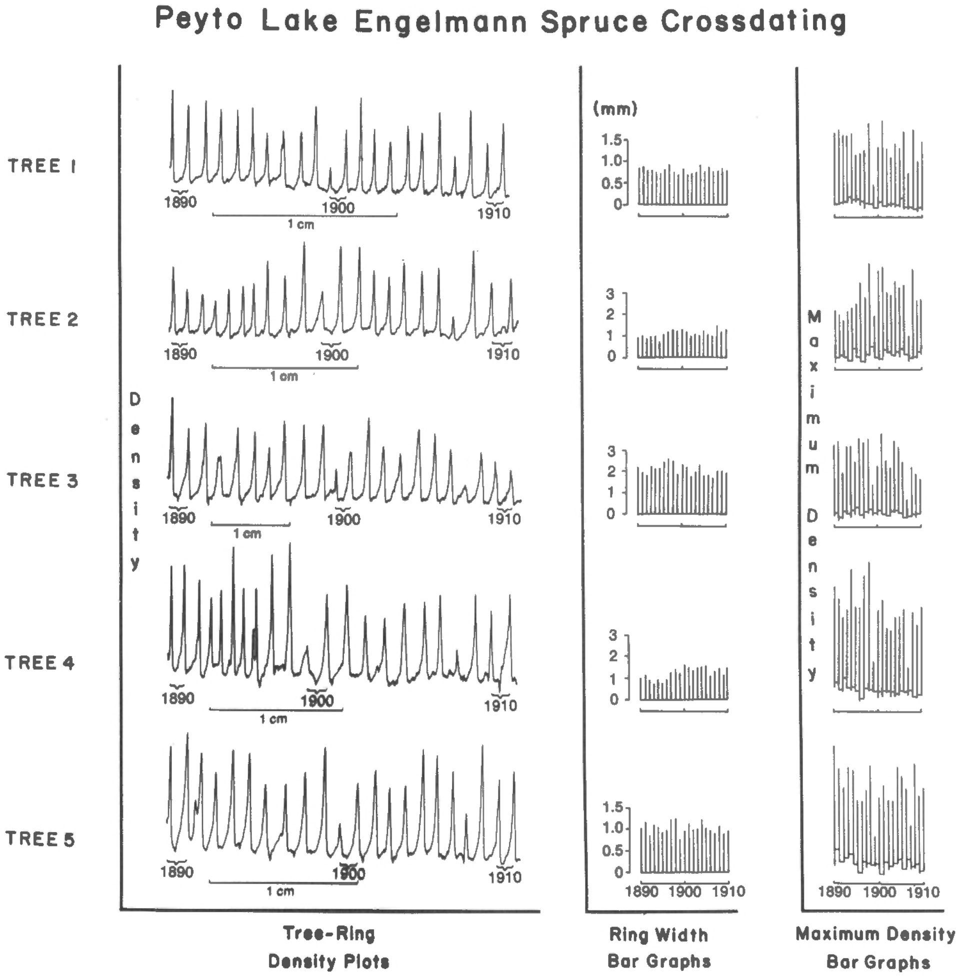


Figure 20. Ring-width and maximum density crossdating. (G.S.C. photo 201408-N)

Tree-ring values are converted to indices that can be averaged to form master tree-ring width index chronologies for each species at each site. Hundreds of thousands of calculations are involved in this process and the only practical way to handle this quantity of data is to use electronic computer techniques.

The tree-ring processing computer programs developed by Fritts and others (Fritts, 1963; Fritts, Mosimann and Bottorff, 1969) at the Laboratory of Tree-Ring Research have been made available to the Geological Survey. Six of the basic programs required for tree-ring processing have been converted for use on an available computer by K. Shimizu, Geological Survey of Canada, and J.A. MacFarlane, formerly with the Geological Survey. In addition to modifications on these programs, four new programs have been written.

The Laboratory of Tree-Ring Research Programs

The Ring-Width Listing Program prints ring-width values and calculates 20-year means, mean sensitivity (year-to-year variability), mean ring-width, and slope of the growth curve. The 20-year mean values are plotted in graph form on the computer printout sheets and an option has been added by the Geological Survey which also can be used to plot the yearly values. This program is used to check for errors in dating, measuring and card punching, and for selecting the specimens to be used in the site master chronology.

The Tree-Ring Index Program converts each ring-width series into tree-ring indices by removing the growth trend and then combines these index series into composite of "summary" chronologies by averaging them in any desired combination. Indices for individual specimens and for summary chronologies are printed in tabular form and punched on cards to be used as input for other computer processing programs. Statistics such as mean sensitivity, standard deviation, variance, serial correlation, and a number of other values are calculated by this program for the purpose of evaluating the tree-ring series and for input for other programs.

The Cross Correlation Program is used to determine the degree of similarity between tree-ring series and to calculate serial correlation within series. The results can be used to evaluate the suitability of specimens for crossdating within a site and determining summary chronologies between sites.

The Analysis of Variance Program is used to determine the percentage of variance in summary index chronologies due to several different factors such as differences within trees, differences between trees, and year-to-year differences. The degree to which the radial tree growth is responding to a common factor, such as climate, can be estimated and this is indicative of crossdating and dendroclimatic quality.

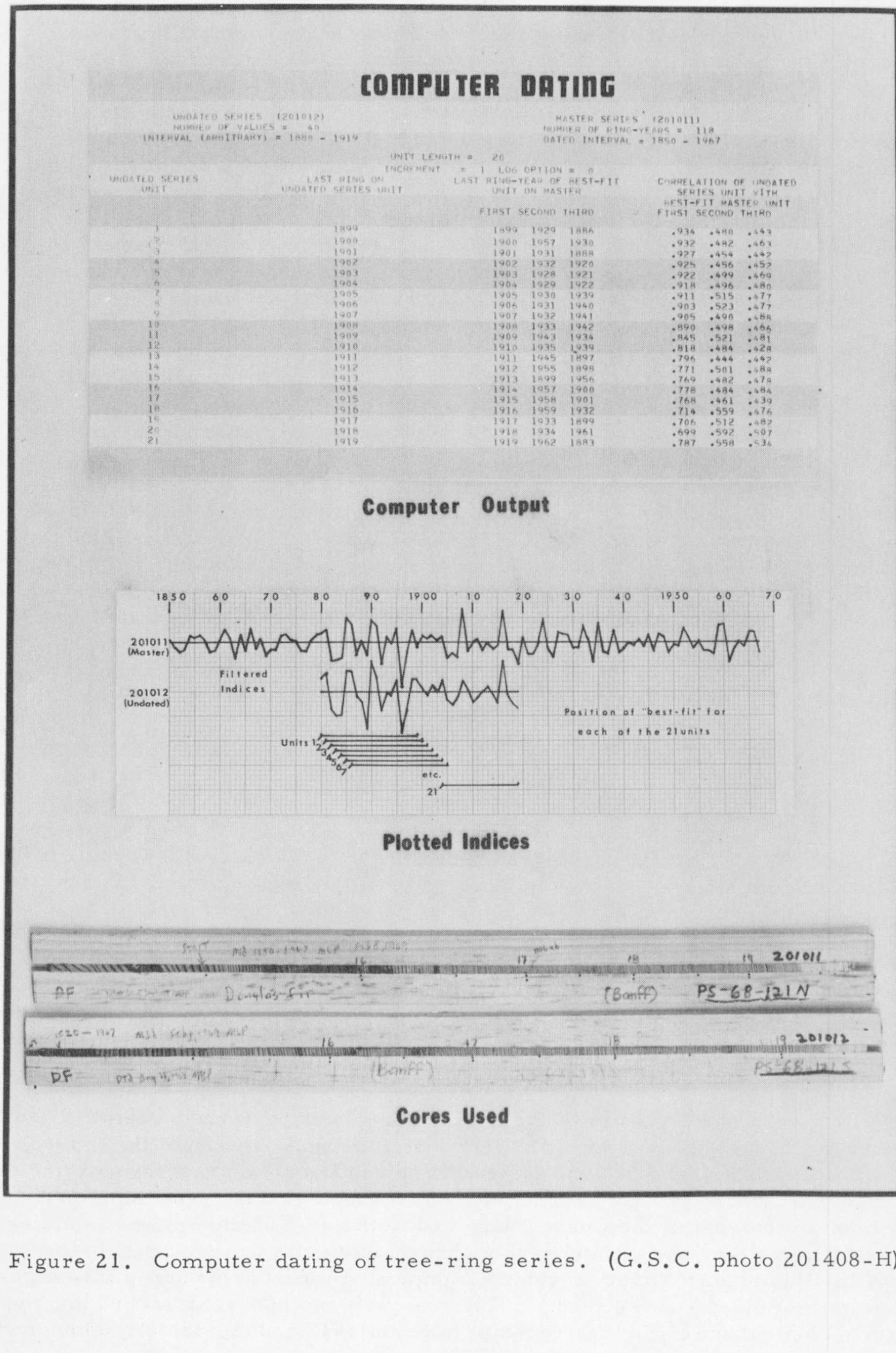
The Summing of Series Program is used to average several site or regional index chronologies.

The Compact Listing Program is used to print summary indices in compact table form. An option has been added by the Geological Survey which also will produce a line-printer plot of the indices.

The Geological Survey Programs

In addition to converting the Tucson programs for use on an available computer, several new programs have been written and program modifications have been made by Shimizu and MacFarlane.

Digital Filter Index Program. Some difficulties were encountered when the Laboratory of Tree-Ring Research Index Program was used to standardize ring series of tamarack (*Larix laricina*) and eastern hemlock (*Tsuga canadensis*) from eastern Canada. Many of the tamarack ring chronologies contain a very rapidly diminishing growth curve and the eastern hemlock series often have areas of aberrant ring suppression and release. The Index Program was designed to be used on ring series with less complex growth curves. The Digital Filter Program was written by Shimizu and MacFarlane, with advice from Fritts, to produce index chronologies that accentuate year-to-year variations and "filter out" fluctuations greater than 10 years. This program is useful for ring series with unusual growth curves and produces



COMPUTER DATING

UNDATED SERIES (201012)
NUMBER OF VALUES = 40
INTERVAL (ARBITRARY) = 1880 - 1919

MASTER SERIES (201011)
NUMBER OF RING-YEARS = 118
DATED INTERVAL = 1850 - 1967

UNIT LENGTH = 20
INCREMENT = 1 LOG OPTION = 0

UNDATED SERIES UNIT	LAST RING ON UNDATED SERIES UNIT	LAST RING-YEAR OF BEST-FIT UNIT ON MASTER			CORRELATION OF UNDATED SERIES UNIT WITH BEST-FIT MASTER UNIT		
		FIRST	SECOND	THIRD	FIRST	SECOND	THIRD
1	1899	1899	1929	1886	.934	.480	.443
2	1900	1900	1957	1930	.932	.482	.463
3	1901	1901	1931	1888	.927	.454	.442
4	1902	1902	1932	1920	.925	.456	.452
5	1903	1903	1928	1921	.922	.499	.469
6	1904	1904	1929	1922	.918	.496	.480
7	1905	1905	1930	1939	.911	.515	.477
8	1906	1906	1931	1940	.903	.523	.477
9	1907	1907	1932	1941	.905	.490	.488
10	1908	1908	1933	1942	.890	.498	.466
11	1909	1909	1943	1934	.845	.521	.481
12	1910	1910	1935	1939	.818	.484	.428
13	1911	1911	1945	1897	.796	.444	.442
14	1912	1912	1955	1898	.771	.501	.488
15	1913	1913	1899	1956	.769	.482	.478
16	1914	1914	1957	1900	.778	.484	.484
17	1915	1915	1958	1901	.768	.461	.439
18	1916	1916	1959	1932	.714	.559	.476
19	1917	1917	1933	1899	.706	.512	.482
20	1918	1918	1934	1961	.699	.592	.507
21	1919	1919	1962	1883	.787	.558	.534

Figure 21. Computer dating of tree-ring series. (G.S.C. photo 201408-H)

indices that are of good quality for crossdating purposes. The indices are derived by dividing the ring-width values into estimated values that are weighted running means.

Line-Printer Plotting Programs. Two line-printer plotting programs have been written, one for ring-widths and one for indices. The plots produced are not as precise and the scale is less flexible than are the plots produced by ink pen methods, but the line-printer plots are easily obtained and provide a rapid means of graphic examination of the data.

The Shifting Unit Dating Program was written several years ago with the advice of Dr. Fritts at the Laboratory of Tree-Ring Research (Parker, 1967) and additional modifications have been made by MacFarlane at the Geological Survey. The program is designed to detect crossdating between chronologies that is not apparent by visual comparison of plots. It can be used to date tree-ring series from which some rings may be absent.

The Shifting Unit Dating Program uses electronic computer techniques to crossdate tree-ring series. A portion (unit) of an undated tree-ring series is correlated with a dated master tree-ring series in all possible positions. The positions and correlations of the three best matches between the unit and the master series are recorded. Successive units (of designated length and increment) are correlated with the master at all possible locations until the entire undated series has been matched with the entire dated series. The validity of the crossdating is evaluated by the sequential placement of the units and the values of the correlation coefficients. This technique has successfully crossdated eastern hemlock chronologies from Ontario and Nova Scotia from sites which are over 600 miles apart.

The test example (Fig. 21) matches 40 ring-years ("undated series") of a Banff Douglas-fir increment core with 118 ring-years ("master series") of a core from the opposite side of the same tree. All units were matched correctly by the program.

FOUNDATIONS FOR ANALYSIS

The approach taken in dendrochronological investigations conducted by the Geological Survey has been to build a foundation for analysis by: (1) determining the species and site conditions that will produce high quality tree-ring chronologies, (2) collecting a sufficient number of specimens in a standard manner for statistical comparison, (3) using the X-ray technique and electro-mechanical measuring instruments to obtain ring-width and ring-density data, and (4) using computer techniques for processing. The purpose of these studies is to produce tree-ring chronologies that can be used for dating and comparison with weather records and to determine some of the relationships between site conditions, climatic zones, and tree-ring chronology characteristics.

To date, results of the studies have been very encouraging. The Geological Survey tree-ring collection contains specimens from living trees older than 1,200 years as well as preserved dead material that is interglacial in age (GSC-1236; greater than 54,000 radiocarbon years). The semi-arid regions to the east of the Coast Range and to the east of the Rocky Mountains produce sensitive, datable tree-ring chronologies of a quality equal to any that can be found in North America. Submerged forests now under investigation in the Bay of Fundy (Grant, 1970) may yield a 4,000-year record and the archaeological and historical tree-ring material in Canada is virtually untouched.

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REFERENCES

Douglass, A.E.

1919: Climatic cycles and tree-growth: A study of the annual rings of trees in relation to climate and solar activity; Carnegie Inst. Wash. Publ., vol. 1, No. 289, 127 pp.

1928: Climatic cycles and tree-growth: A study of the annual rings of trees in relation to climate and solar activity; Carnegie Inst. Wash. Publ., vol. 2, No. 289, 166 pp.

1929: The secret of the southwest solved by talkative tree rings; Natl. Geograph. Mag., vol. 56, No. 6, pp. 736-770.

1934: Accuracy in dating, I; Tree-Ring Bull., vol. 1, No. 2, pp. 10-11.

1937a: Tree-ring work, 1937; Tree-Ring Bull., vol. 4, No. 1, pp. 3-6.

1937b: Tree-rings and chronology; Univ. Ariz. Phys. Sci. Bull., No. 1, 36 pp.

1940: Notes on the technique of tree-ring analysis, I; Tree-Ring Bull., vol. 7, No. 1, pp. 2-8.

1941a: Notes on the technique of tree-ring analysis, II; Tree-Ring Bull., vol. 7, No. 4, pp. 28-34.

1941b: Notes on the technique of tree-ring analysis, III; Tree-Ring Bull., vol. 8, No. 2, pp. 10-16.

1943a: Notes on the technique of tree-ring analysis, IV: Practical instruments; Tree-Ring Bull., vol. 10, No. 1, pp. 2-8.

Douglass, A.E. (cont.)

1943b: Notes on the technique of tree-ring analysis, V: Practical instruments; Tree-Ring Bull., vol. 10, No. 2, pp. 10-16.

1946a: Precision of ring dating in tree-ring chronologies; Lab. of Tree-Ring Res. Bull., No. 3, 21 pp; Univ. Arizona Bull., vol. XVII, No. 3.

1946b: Researches in dendrochronology; Bull. Univ. Utah, vol. 37, No. 2, 19 pp.

Fritts, H.C.

1963: Computer programs for tree-ring research; Tree-Ring Bull., vol. 25, Nos. 3, 4, pp. 2-7.

1965a: Dendrochronology; in The Quaternary of the United States, A review volume for the VII Congress of the International Association for Quaternary Research, Wright, H.E. Jr. and Frey, D.G. (eds.), Princeton University Press, pp. 871-879.

1965b: Tree-ring evidence for climatic changes in Western North America; Monthly Weather Rev., vol. 93, No. 7, pp. 421-443.

1966: Growth-rings of trees: their correlation with climate; Science 154 (3752), pp. 973-979.

1969a: Tree-ring analysis: A tool for water resources research; Intern. Hydrol. Decade Bull., No. 1, National Academy of Sciences, pp. 22-29.

1969b: Bristlecone Pine in the White Mountains of California: growth and ring-width characteristics; Papers of the Lab. of Tree-Ring Res., No. 4, 44 pp.

Fritts, H.C., Mosimann, J.E., and Bottorff, C.P.

1969: A revised computer program for standardizing tree-ring series; Tree-Ring Bull., vol. 29, Nos. 1, 2, pp. 15-20.

Fritts, H.C., Smith, D.G., Cardis, J.W., and Budelsky, C.A.

1965: Tree-ring characteristics along a vegetation gradient in northern Arizona; Ecology, vol. 46, No. 4, pp. 393-401.

Gaucher, E.H., and Meilleur, G.A.

1965: Foreuse portative pour l'échantillonnage en surface; in Report of Activities, Pt. II; Geol. Surv. Can., Paper 65-2, pp. 12-17.

Giddings, J.L. Jr.

1941: Dendrochronology in northern Alaska; Lab. of Tree-Ring Res. Bull., No. 1; Univ. Arizona Bull., vol. 12, No. 4, 108 pp.

1943: Some climatic aspects of tree growth in Alaska; Tree-Ring Bull., vol. 9, No. 4, pp. 26-32.

Giddings, J.L. Jr. (cont.)

1947: Mackenzie River Delta chronology; Tree-Ring Bull., vol. 13, No. 4, pp. 26-29.

1954: Tree-ring dating in the American Arctic; Tree-Ring Bull., vol. 20, Nos. 3, 4, pp. 23-25.

Grant, D.R.

1970: Recent coastal submergence of the Maritime Provinces, Canada; Can. J. Earth Sci., vol. 7, No. 2, pp. 676-689.

Green, H.V.

1965: Wood characteristics, IV: The study of wood characteristics by means of a photometric technique; Woodlands Res. Index, No. 167, Pulp and Paper Research Institute of Canada.

Green, H.V., and Worrall, J.

1964: Wood quality studies, I: A scanning microphotometer for automatically measuring and recording certain wood characteristics; Tech. Assoc. of the Pulp and Paper Ind., vol. 47, No. 7, pp. 419-427.

Hustich, I.

1950: Notes on the forests on the east coast of Hudson Bay and James Bay; Acta Geograph., vol. 11, No. 1, 83 pp., Helsinki.

1954: On forests and tree growth in the Knob Lake area, Quebec-Labrador Peninsula; Acta Geograph., vol. 13, No. 1, 60 pp., Helsinki.

1955: Forest-botanical notes from the Moose River area, Ontario, Canada; Acta Geograph., vol. 13, No. 2, 50 pp., Helsinki.

1956: Correlation of tree-ring chronologies of Alaska, Labrador, and Northern Europe; Acta Geograph., vol. 15, No. 3, 26 pp., Helsinki.

Lyon, C.J., and Goldthwait, J.W.

1934: An attempt to cross-date trees in drowned forests; Geograph. Rev., vol. 24, pp. 605-614.

Marr, J.W.

1948: Ecology of the forest-tundra ecotone on the east coast of Hudson Bay; Ecol. Monographs, vol. 18, No. 1, pp. 117-144.

Mitchell, V.L.

1967: An investigation of certain aspects of tree growth rates in relation to climate in Central Canadian boreal forests; Technical Report, No. 33; Univ. Wisconsin, 62 pp.

Parker, M.L.

1967: Dendrochronology of point of pines; M.A., master's thesis, Univ. Arizona.

Polge, H.

1965a: Study of wood density variations by densitometric analysis of X-ray negatives of samples taken with a Pressler Auger; paper presented to a meeting of the International Union of Forest Research Organizations (Section 41) in Melbourne.

1965b: The use of curves of density variation for the study of environmental factors and in particular of climatic factors; paper presented to a meeting of the International Union of Forest Research Organizations (Section 41) in Melbourne. Copies of the paper are available from the author.

1966: Etablissement des courbes de variation de la densité du bois par exploration densitométrique de radiographies d'échantillons prélevés à la tarière sur des arbres vivants; Ann. des Sciences Forestières, XXIII, Fas. 1, 1017 pp.

Polunin, N.

1955: Attempted dendrochronological dating of ice island T-3; Science, vol. 122, No. 3181, pp. 1184-1186.

Schulman, E.

1937: Selection of trees for climatic study; Tree-Ring Bull., vol. 3, No. 3, pp. 22-23.

1944: Tree-ring work in Scandinavia; Tree-Ring Bull., vol. 11, No. 1, pp. 2-6.

1947: Dendrochronologies in southwestern Canada; Tree-Ring Bull., vol. 13, No. 2-3, pp. 10-24.

1956: Dendroclimatic changes in semi arid America; Univ. Arizona Press, 142 pp.