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THE USE OF X-RAY DENSITOMETRIC METHODS IN DENDROCHRONOLOGY

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INTRODUCTION

Dendrochronologists have traditionally relied primarily on the variations of ring-width in tree-ring sequences for purposes of crossdating and for paleoclimatic analysis. However, recent advances in techniques for measurement of wood density variations now provide a complementary method of tree-ring study.

Wood density is an integrated measure of several variable wood properties, including cell-wall thickness, lumen diameter, size and density of vessels or ducts, proportion of fibers, etc. It is possible to obtain continuous records of wood density by several non-mechanical methods. Photometry (Green and Worral 1964; Elliott and Brook 1967) and β-ray absorpiton (Phillips 1960) techniques are used with microscopic sections. Densitometric scanning of X-ray negatives (Polge 1966) offers the advantage that increment cores from living trees can be used with little further preparation.

This last method is also quick and sufficiently accurate to permit the critical evaluation of ring-density variations in a large number of samples in any particular study.

Several types of data can be obtained from the X-ray negatives. Of special interest are the maximum and minimum densities within each annual ring, and the rate of change of density between the earlywood and the latewood components. Density fluctuations within annual increments, such as those associated with intra-annual bands or "false" rings, can also be easily evaluated.

METHODOLOGY

The methodology may be summarized as follows:

Cores are taken with very well sharpened and cleaned borers, so that they are not distorted or damaged and so that the diameter is strictly uniform.

Cores which have not been extracted exactly following a perpendicular to the grain direction are propped adequately by gluing a piece of cardboard to obtain a clear image in spite of this obliquity.

Several cores (in general from 10 to 20) are X-rayed together using a tube with Beryllium-target and a low voltage both giving soft rays and therefore images with high contrast.

Now, in order that the optical density of the radiograph of a specimen can be used to study its wood density, it is necessary that there should be no other cause for changes in the optical density than the changes that actually occur in the wood density. This implies that the incident radiation should be uniform over the area containing the film, and that a given amount of radiation causes a given amount of film blackening.

Concerning the first requirement, a quite unusual source-film distance of 2.50m. is necessary to obtain a good uniformity of X-ray dose on all the film area since the corners of the film are further from the target than the centre, and since the intensity of the rays is inversely related to the third power of the distance from the source. In addition, we can have a clear image of all the rings (which are parallel to each other) only by using an approximately parallel X-ray beam obtained at the distance of 2.50 m.

The uniformity of blackening for a given dose received is only a problem of film development but it needs a meticulous care and particularly a continuous agitation of the developer.

The recording of optical density variations is made with a microdensitometer providing a high resolution and allowing an increase of the magnification of ring-width up to 50 times and also to change, when necessary, the scale of optical density.

When certain conditions are fulfilled (which cannot be detailed here) the optical density of the X-ray negatives is linearly and inversely related to wood density, so that microdensitometric records may be calibrated directly in wood density.

Applications

Former Results

In work previously reported (Polge 1966), it was shown that certain wood density parameters can be more characteristic of rings fromed in a given year than are the ring-widths themselves. In this work, samples from European plantations of *Abies grandis* and *Pseudotsuga menziesii* were studied. Each sample included 50 trees, and two 5 mm. increment cores (north and south sides respectively) from each tree. A total of 11 rings (representing the period 1953 - 1963) was analyzed from each radius. The results of a statistical analysis reproduced in Table 1 show that both the maximum latewood density and the difference between maximum density for one year and the minimum density for the following year are superior to the ring-width as a determinant of the year of formation of the annual ring.

Furthermore, a comparison with climatic records suggests that maximum density may be a sensitive indication of seasonal weather conditions. For the 11-year period of analysis, a coefficient of – 0.89 was obtained for the correlation of peak latewood density of *Pseudotsuga menziesii* with total precipitation for August, September and October. For the same period, peak density in *Abies grandis* gives a correlation of + 0.81 with the total duration of sunlight in July, August, and September.

First Dating Work Using Densitometric Parameters

In another study, the results of which are summarized here, wood-density variations served as the primary tool for crossdating of increment cores. This work, performed at the request of Th. Keller of the Federal Institute for Forest Research of Zurich (Birmensdorf), was concerned with the evaluation of damage to a stand of Norway spruce

Table 1. Variance Analysis

Characteristics	"F" test	
	Pseudotsuga menziesii	*Abies grandis*
Maximum annual density	79.07	71.83
Maximum density year n less minimum density year n + 1	57.13	80.76
Ringwidth	38.03	39.58
Minimum annual density	28.67	21.87
Percentage of latewood	16.36	13.51
Width of latewood	11.80	10.65

caused by heavy emission of industrial smoke during the last war. It was clear that a major effect of the smoke had been to reduce the width of several annual rings, and that in some cases the rings for the critical years were absent from the samples. The initial problem was thus to identify each of the annual rings in the samples from the damaged stand.

The approach which we followed was to analyze the density and ring-width characteristics from 25 trees in each of three stands: one heavily damaged (plot 1), one somewhat affected (plot 2), and another, unfortunately younger, which was unaffected and served as the control sample (plot 3). The period of analysis began in 1935, so that data were available for several years prior to the period of maximum industrial activity.

Results

Shape Of Densitometric Records

The shape of the densitometric curve proved to be highly characteristic of rings formed in certain years, and provided a powerful dating tool. Examples are shown in Figure 1. The curves for 1935 typically show a rapid increase in density at the earlywood – latewood boundary, and often a bifurcated latewood peak. The 1939 and 1940 rings generally have very similar records. The ring for 1943 is one of the most characteristic rings for the plots 1 and 2, with a high minimum density and low maximum density. However, it is frequently absent, indicating the beginning of injury due to smoke. Yet it is quite normal from densitometric point of view for the plot 3. The ring for 1947 is also typified by high earlywood density followed by a low latewood density. However, it shows a more rapid density increase at the transition than does the 1943 ring and also the densitometric characteristics are the same for the plots 1 and 2 and for the plot 3. For 1960, the density maximum shows a double peak in most cases, of which the higher is often lower than the maximum densities in 1959 and 1961.

Characteristics Years

The years, called "characteristics years", for which either the ring-width, or the maximum annual density or the minimum annual density have varied in the same direction (by comparison with the preceeding year) for at least 80 % of the total number

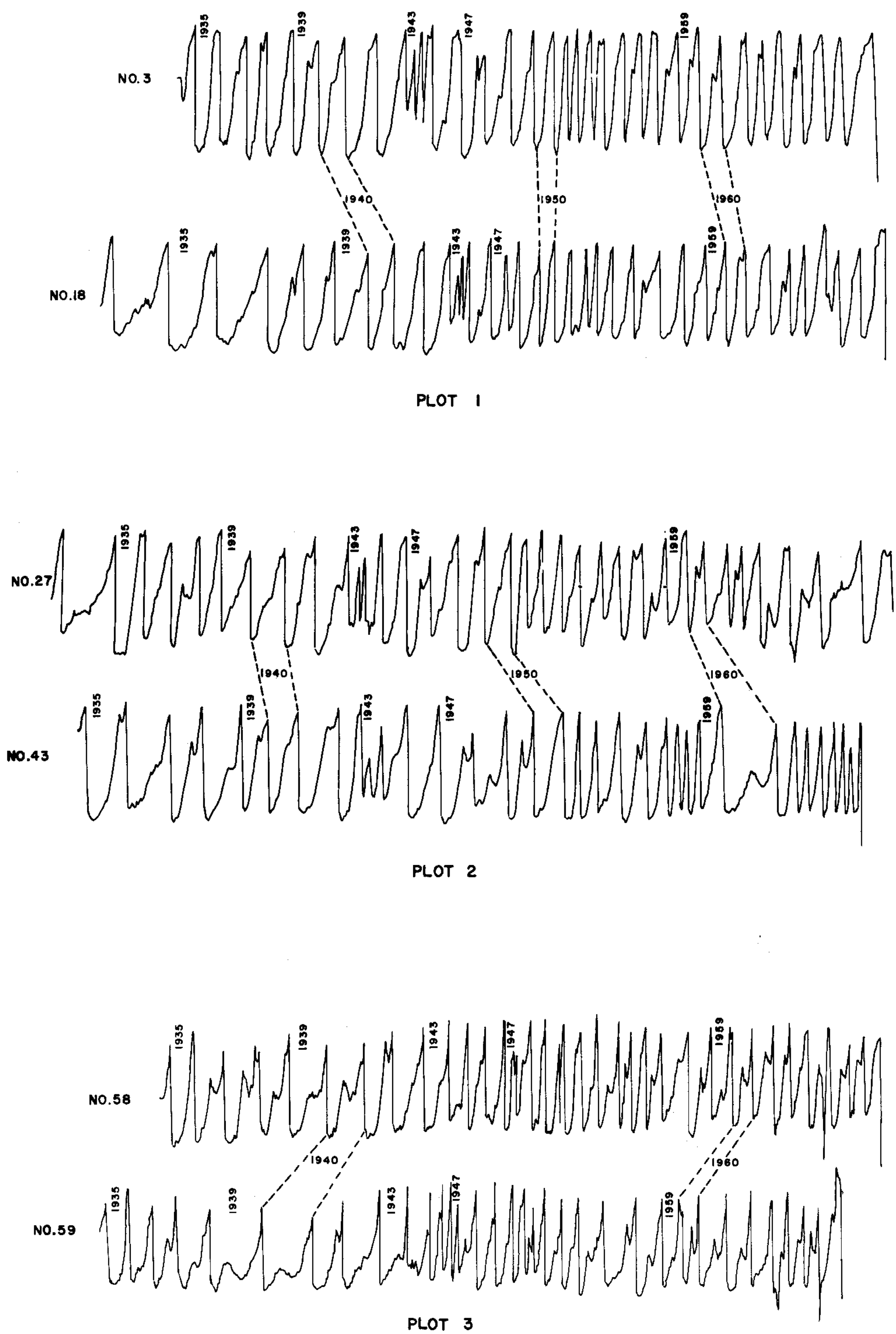

Fig. 1. Examples of Densitometric Records

Table 2. Number of Characteristic Years

	Plot 1	Plot 2	Plot 3	Total
Ringwidth	9	13	12	4
Maximum density	16	15	18	12
Minimum density	16	17	22	16

of trees, have been determined from densitometric records. The numbers of characteristic years are given in Table 2 for each plot separately and for the 75 trees of the 3 plots together.

We see that the homogeneity of results is very good for densitometric parameters, particularly when all the trees are considered together. In this case the number of "characteristic years" is three times higher for maximum density than for ring-width and four times higher for minimum density.

MEAN VALUES PER PLOT

The mean values of maximum density, minimum density and ring-width are shown in the Figure 2.

All the characteristics are similar between plots 1 and 2, but differ between both of them and plot 3. Ring-widths exhibit the greatest differences while the minimum densities exhibit the smallest differences.

The influence of the age of trees is very clear in plot 3 which has larger rings and lower maximum densities until about 1941. Then the stand apparently passed from the juvenile state to the adult one. After that the radial growth remains greater in plot 3 than in others plots, but the differences in maximum and minimum densities are very small.

There is a complete opposition between the curves of plots 1 and 2 and that of the plot 3 for ring 1943, with a larger ring a lower maximum density and a higher minimum density in the stand 3 than in the others. In 1947 the rings in all plots are similar. Thus the very low maximum density of 1943 is apparently due to the damages by industrial smoke, while that of 1947 is only related to climatic factors.

The variation coefficients (standard deviation reported to the mean values) are given in Table 3 for the 33 years of record. They confirm the larger variability of ring-width not only during the juvenile period but also for the rings near the bark.

CORRELATIONS BETWEEN THE MEAN VALUES OF THE PLOTS

Correlations between mean value of plots are given on the Table 4.

The correlation between the plots 1 and 2 is higher for the three criteria, leading to the conclusion that the both stands have been subjected to the same damages. Elsewhere in each comparison the density data show somewhat better mutual agreement than do the ring-width data.

The minimum density in particular appears as an excellent criterion for dating. It gives the highest correlation twice, and the coefficient for the third comparison is not very much lower than that of the maximum density. Thus it appears to be sensitive to climatic factors and not very sensitive to other causes of wood structure variation.

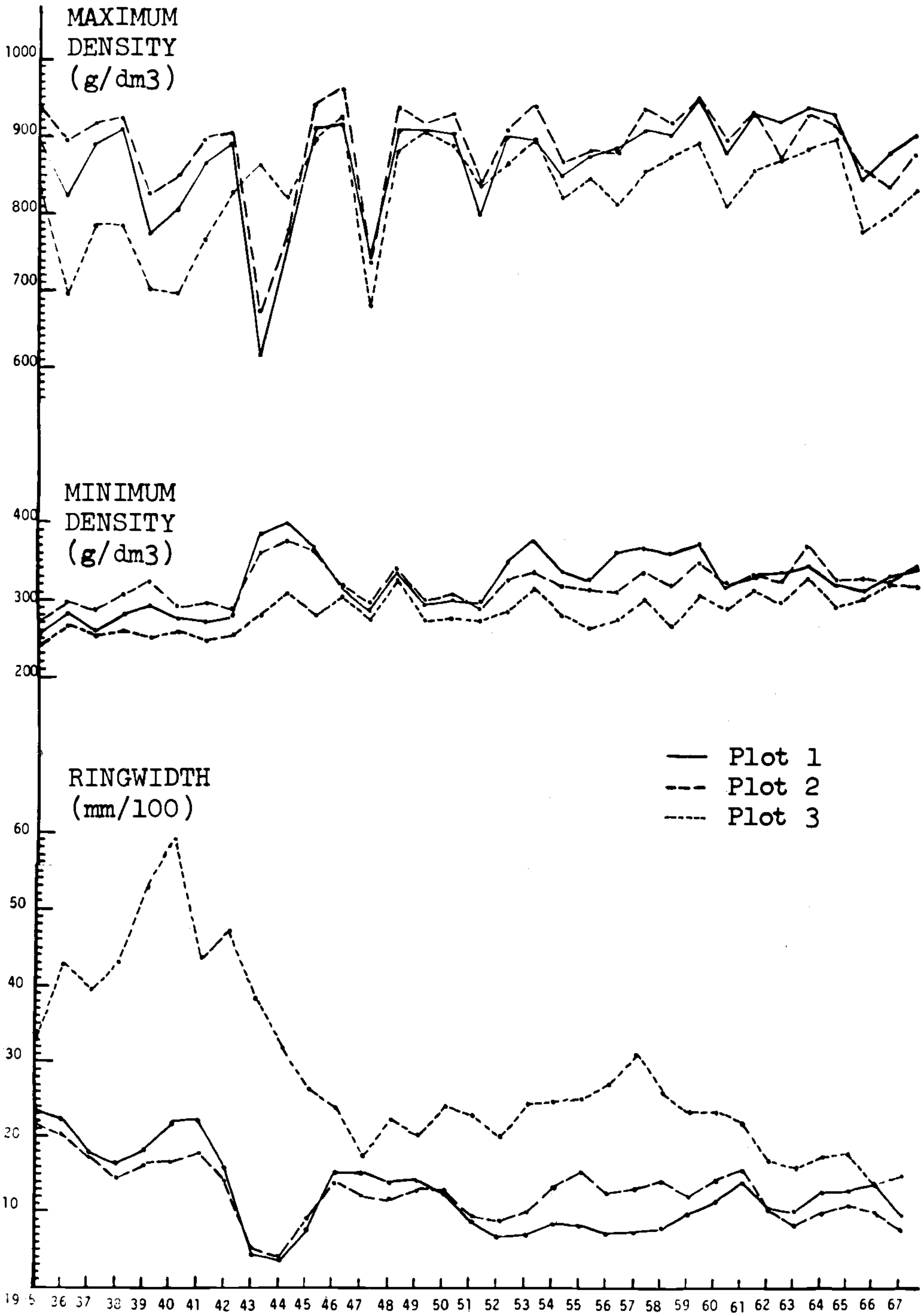

Fig. 2. Mean Annual Values per Plot

Table 3. Coefficient of Variation Between the Mean Values of the Plots

Years	Ringwidths	Maximum densities	Minimum densities
1935	23.07	5.99	6.06
1936	43.77	12.70	5.13
1937	51.12	7.98	7.25
1938	64.12	8.73	8.35
1939	69.84	8.19	12.70
1940	70.71	9.98	5.86
1941	48.33	7.99	8.92
1942	70.91	4.67	6.34
1943	117.38	18.05	15.90
1944	119.39	3.75	13.20
1945	69.94	2.59	15.37
1946	28.39	2.51	1.96
1947	16.16	4.95	4.23
1948	34.08	3.20	1.86
1949	24.14	0.73	4.69
1950	38.72	2.37	5.74
1951	54.91	3.02	4.21
1952	55.96	0.39	10.62
1953	63.49	2.86	9.28
1954	50.79	2.64	9.61
1955	49.96	2.24	11.60
1956	62.15	4.74	14.43
1957	68.12	4.69	11.05
1958	54.36	2.48	15.94
1959	45.96	3.63	10.35
1960	36.31	5.12	5.45
1961	22.65	4.87	3.76
1962	27.56	3.19	6.49
1963	32.79	3.33	6.66
1964	26.50	1.87	6.00
1965	24.10	5.41	4.39
1966	16.31	4.84	1.42
1967	33.00	4.25	4.56
Total	1614.99	163.95	259.38

Correlations Between Characteristics

The correlation between ring-width, maximum density and minimum density are shown in Table 5.

The minimum density and ring-width are inversely correlated in all three cases. The maximum and minimum density are sometimes positively correlated. The maximum density and ring-width can be either positively or negatively correlated. Although the present data are inconclusive, it may develop that the time series of two or more ring-width or density parameters will commonly be found to be somewhat independant. This could provide a much stronger statistical basis for numerical cross-identification that is provided by ring-width data alone.

Table 4. Coefficients of Correlation Between the Mean Values of the Plots

	Ringwidths	Maximum densities	Minimum densities
Between plots 1 and 2	0.78**	0.91**	0.82**
Between plots 1 and 3	0.36NS	0.49*	0.60**
Between plots 2 and 3	0.45*	0.46*	0.69**

* – Significant
** – Highly significant

Synthetic Xylochronologic Profiles

Synthetic Xylochronologic profiles (from the greek ξυλον = wood) are diagrams that record, for each year, in abcissa, the mean ring-width, and in ordinates, the mean maximum and minimum wood densities, and on which these extreme values of density are joined together by segments of straight lines.

Thus, details in the shape of densitometric records are not utilized. Yet these profiles make the work of wood dating very easy because they summarize the annual variations of two criteria instead of one in the usual ring-width chronology.

When some difficult problems of dating occur for a particular tree, a simple visual comparison of its synthetic profile with the mean profile of the correspounding plot generally allows a solution.

Example Of Synchronization

The densitometric record of tree 58 (see Fig. 1) shows eight apparent rings after the ring for 1960. Yet the sample had been gathered before the growing season of 1968. The dating up to 1960 was probably good because of the very characteristic shape of numerous rings. So a verification was necessary. We have compared the synthetic profile of this tree with the mean profile of the plot 3(Fig. 3).

On the mean profile of the plot the characteristic years for maximum and minimum densities (the definition of which is given above) are marked by a line slanting up or down as the correspounding parameter is significantly higher or lower than for the preceeding year.

On the profile of the tree 58 the same line is drawn when the parameter varies in the same direction as for the mean profile of the plot. A "O" means that the parameter varies in an opposite direction. We obtain a coincidence for 17 rings out of 18 from the point of view of maximum density, and 15 out of 18 for minumum density. Thus the dating seems right, since no change of the origin could give so much similarities of results.

Looking more carefully at the last rings, it appears that the dating of the rings 1962 and 1963 on the one hand and 1965 on the other hand are probably true, for it gives the same characteristic variations as the mean profile. This leads to the conclusion that the ring 1964 is represented on the densitometric record by something like two rings. In fact a more attentive examination of the radiography and of the sample itself reveals a very thin internal split in this ring, which gave an abnormal peak toward the low densities inside the latewood. Thus the appearance of an additional ring is explained.

Table 5. Coefficients of Correlation Between Characteristics

	Plot 1	Plot 2	Plot 3	Total
Between maximum density and minimum density	- 0.02	- 0.11	0.43*	0.22*
Between maximum density and ringwidth	0.09	0.40*	- 0.54**	- 0.36**
Between minimum density and ringwidth	- 0.87**	- 0.72**	- 0.64**	- 0.74**

* – Significant
** – Highly significant

CONCLUSION

The densitometric records provide a way to measure objectively parameters other than ring-width and are not very closely related to ring-width. They can give additonal tool for wood dating.

Elsewhere these measures of density change less markedly with changes in tree age than do the ring-width. So there is often no need to remove growth functions when using density measurements.

Thus, together with ring-width, the densitometric parameters make cross-identification easier, quicker, and more accurate.

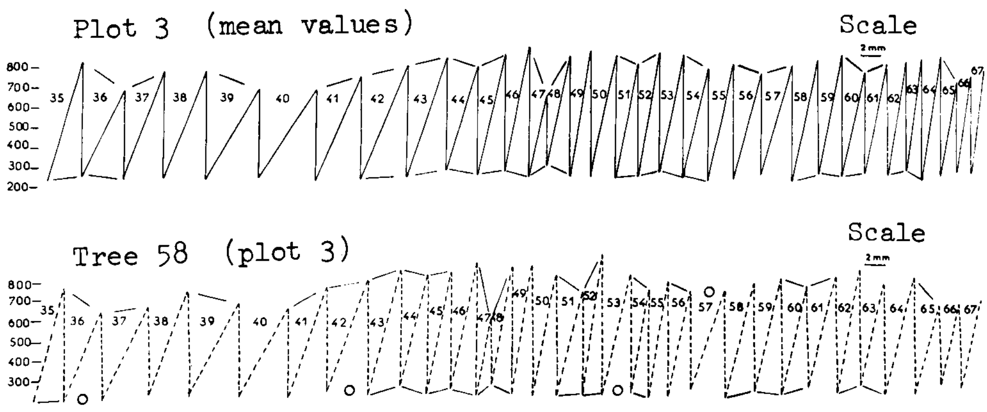

Fig. 3. Synthetic Xylochronologic Profiles

REFERENCES

Elliott, G. K., and S. E. G. Brook
1967 A microphotometric technique for growth-ring analysis. *Journal of the Instutute of Wood Science*, No. 18.

Green, H. V., and J. Worrall
1964 Wood quality studies. I – A scanning microphotometer for automatically measuring and recording certain wood characteristics. *Tappi*, Vol. 47, No. 7, pp. 419-427.

Phillips, E. W. J.
1960 The beta ray method of determing the density of wood and the proportion of summer wood. *Journal of the Institute of Wood Science*, Nos. 5-8.

Polge, H.
1966 Etablissement des carbes de variation de la densité du bois par exploration densitométrique de rediographies d'échantillons prélevés à la tariére sur des arbres vivants. Applications dans les domaines technologique et physiologique. Thèse Docteur ès-Sciences, Faculté des Sciences de Nancy (Ann. Sci. For., Vol. XXIII, No. 1, 1966).

PREPARATION OF X-RAY NEGATIVES OF TREE-RING SPECIMENS FOR DENDROCHRONOLOGICAL ANALYSIS

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ABSTRACT

Techniques for producing X-ray negatives of dendrochronological specimens have been developed at the Geological Survey of Canada and the Nondestructive Testing Laboratory, Mines Branch, The radiographs are produced to provide tree-ring density data to supplement ring-width measurements for dating and climatic studies. New specimen preparation techniques and X-ray methods are discussed. The quality and quantity of tree-ring information is enhanced by the use of X-ray analysis.

INTRODUCTION

The usefulness of tree-ring density analysis for evaluating the commercial quality of wood and for dendroclimatic interpretation has been demonstrated in recent years by Polge (1965a, 1965b, 1966), Green and Worrall (1964), Green (1965), and Harris (1969). One of the best techniques for obtaining graphic and quantitative tree-ring density data is to scan X-ray negatives of dendrochronological specimens on a densitometer (Polge 1966; Jones and Parker 1970). The purpose of this paper is to describe the technique used at the Geological Survey of Canada to prepare X-ray negatives of tree-ring samples for dendrochronological analysis. Particular attention is given to the production of radiographs that can be used for the two traditional foci of dendrochronology: (1) the dating of tree-ring specimens, and (2) the relating of tree-ring data to climatic factors.

Accurate crossdating of the annual rings in tree-ring series and the assigning of correct calendar year dates to each ring in tree-ring chronologies is essential for both dendrochronological dating and dendroclimatic analysis. Tree-ring density measurements obtained from X-ray negatives can be used to supplement ring-width measurements for crossdating purposes (Jones and Parker 1970). Tree-ring chronology characteristics such as false annual rings, locally absent rings, rings with very faint latewood, and microscopic rings are important considerations in crossdating ring widths. These same characteristics need to be considered in tree-ring density studies and X-ray examples of these features are presented.

Techniques in field collection and specimen preparation used at the Geological Survey of Canada are designed to accommodate both tree-ring density and tree-ring width analysis. Preparation requirements are more stringent for density studies and new specimen preparation methods have been devised. Specimen preparation and X-ray exposure procedures are designed to accommodate large quantities of material.

Two techniques for producing the X-ray negatives have been developed. In one method the X-ray film, the tree-ring specimen, and the X-ray source are held stationary during exposure. This technique is similar to that used by Polge (1966) in his tree-ring density studies. In the other method the X-ray source is held stationary and emits radiation through a narrow slit onto a moving carriage supporting the tree-ring specimen and film.

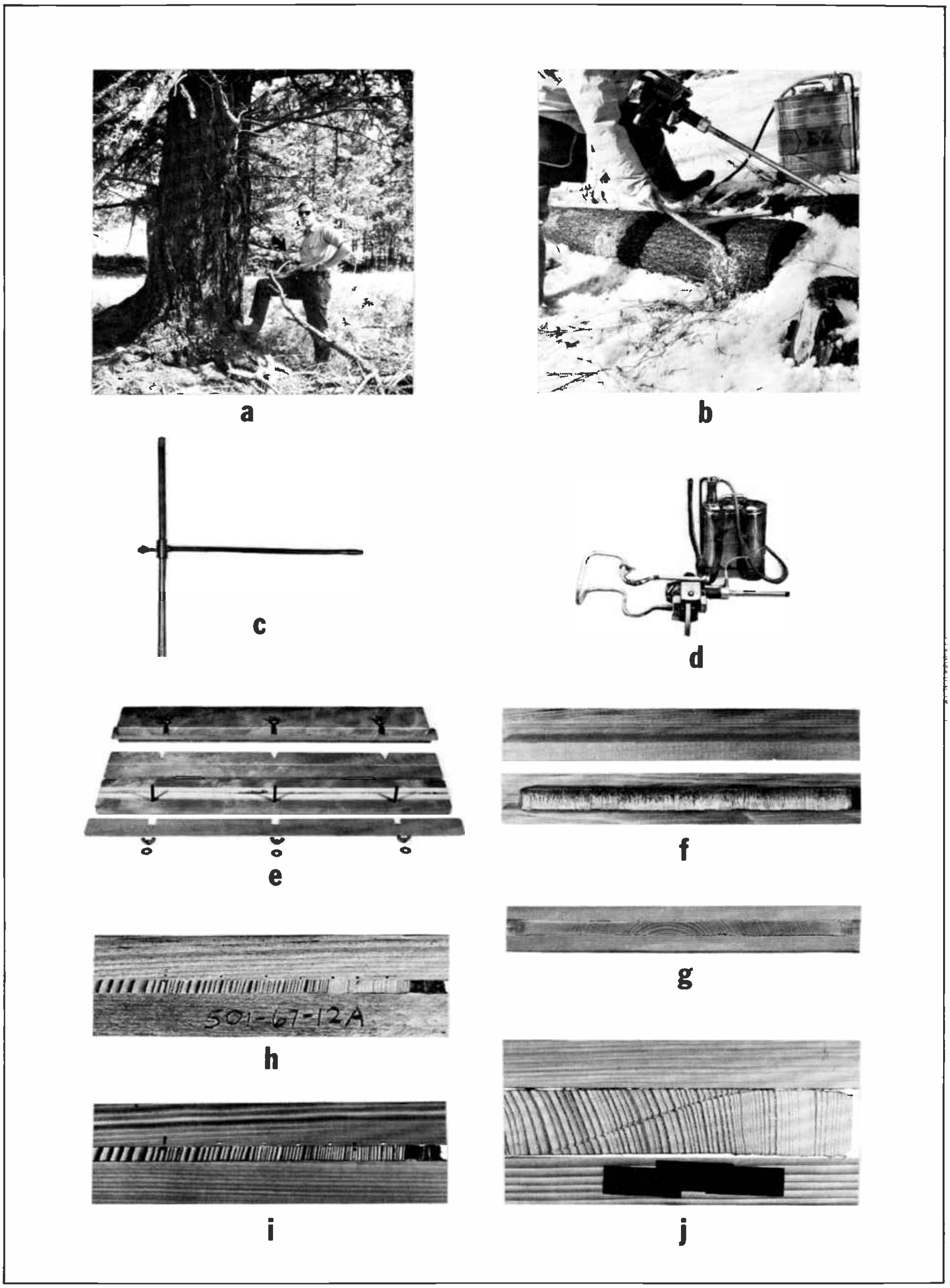

Fig. 1. Increment cores. *a*, extracting 5 mm diameter core with 40 inch increment borer (arrow); *b* taking 3/4 inch diameter cores with G. S. C. power-driven increment borer; *c*, Swedish increment borer (handle 18 inches long); *d*, G. S. C. power-driven increment borer (overall length 48 inches as shown); *e*, small core mounting jogs (26 inches long); *f*, 3/4 inch diameter core and core mount; *g*, mounted and sanded 3/4 inch core; *h*, photograph of portion of 5 mm diameter core; *i*, X-ray positive of same 5 mm core; *j*, X-ray positive of portion of mounted 3/4 inch diameter core.

Many factors can affect the quality of the radiographs from field sampling and specimen preparation to X-ray exposure and film development. The problems encountered in producing X-ray negatives of dendrochronological specimens are discussed and conclusions concerning some of the advantages of the X-ray technique are presented.

SPECIMEN PREPARATION AND X-RAY EXAMPLES

PREPARATION OF INCREMENT CORES

Two types of increment cores are used for tree-ring studies at the Geological Survey of Canada (Fig. 1). The small cores (4.5 or 5 mm. diameter) are extracted with Swedish increment borers, ranging from 12 to 40 inches in length. The large cores (5/8 or 3/4 inch diameter) are taken with a powerdriven increment borer developed at the Geological Survey with the help of G. A. Meilleur.

The small increment cores are allowed to dry and 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 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 provides a core of uniform thickness and 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 mounting technique.

The large cores are completely incased between two mounting sticks two inches wide and one inch thick. Each mounting stick has a groove of the proper shape and depth to accommodate one half of the core. Resin glue is used in the grooves (around the core) and between the seams fromed 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. 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, and one with proper cell alignment and thickness for X-ray exposure. Each component has wood grain running in two different directions which prevents the mounted specimen from warping.

PREPARATION OF WOOD CROSS SECTIONS

Transverse cross sections of tree trunks or wood fragments (Fig. 2) are prepared for X-ray exposure by making two parallel saw cuts through the specimen perpendicular to the long axis of the longitudinal tracheid cells. These sections are cut 3/32 inch thick. If the sample is fragile, a single layer of backing tape is placed on the plane surface formed by the first saw cut before the second cut is made. The backing tape is retained during X-ray exposure. No surface preparation, other than the rough saw cut, is required.

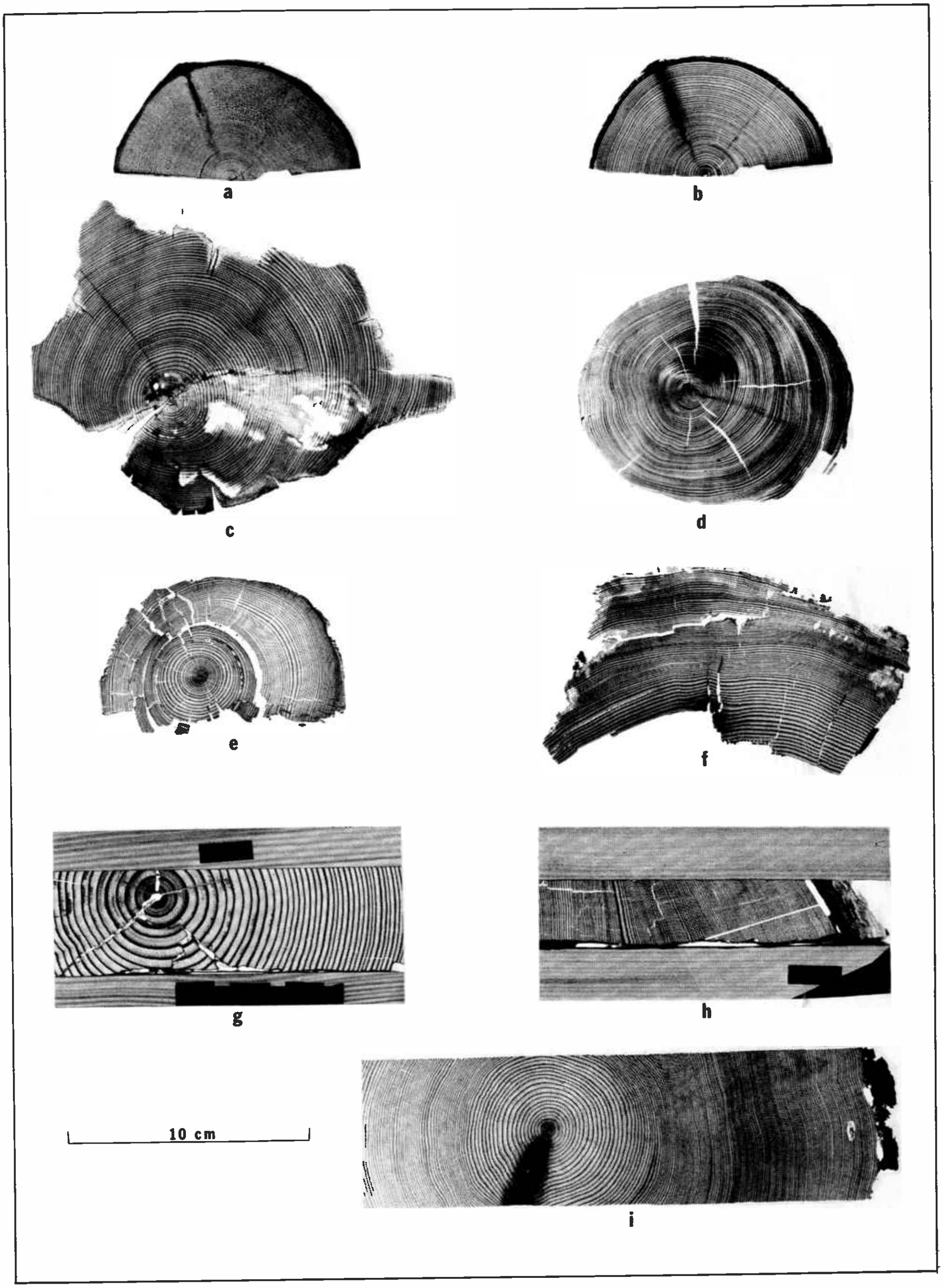

Fig. 2. Cross sections. *a*, photograph of cross section prepared for X-ray exposure; *b*, X-ray positive of *a* (*c* through *i* are also X-ray positives); *c*, archaeological specimen; *d*, interglacial specimen (greater than 54,000 years old); *e* and *f*, fragile submerged forest sections with backing tape; *g* and *h*, V-cut stump sections with mounting boards; *i*, section from block of manageable size from tree disc. All sections are 3/32 inch thick.

Wedge-shaped slabs of wood cut from the flat surface of tree stumps ("stump V-cuts") are prepared for X-ray exposure in the following manner: (1) a flat surface, parallel to the long axis of the longitudinal tracheids, is chiseled along one edge of the V-cut slab, (2) a 1/2 inch thick mounting board is glued to this chiseled surface, (3) the specimen is "squared off" by making 90° 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, and (5) 3/32 inch thick transverse cross sections of the tree-ring specimen are produced by making saw cuts along the long axis of the mounting boards.

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 stump samples.

Charcoal

Many archaeological tree-ring specimens are in the form of charcoal, creating a need for a method of X-raying charcoal if density measurements are required. Experiments have been conducted on techniques of X-raying both coniferous and hardwood samples, and good quality X-ray negatives have been produced (Fig. 3). 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 with compressed air from the plane surface formed by the saw cut, (3) a single layer of backing tape is applied to this 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.

Tree-Ring Characteristics

The amount of information to be obtained from tree-ring series is greatly increased if intra-annual ring density data are used to supplement tree-ring width data. However, new problems are introduced regarding methods of preparation and analysis. Tree-ring characteristics such as false rings, frost rings, faint latewood, microscopic rings, locally absent rings, partially formed rings, and compression wood can be presented graphically and quantitatively by X-ray and densitometric techniques. Radiographs of some of these tree-ring characteristics (Fig. 4) demonstrate the quality of information that can be obtained by the X-ray technique, and suggest the added complexities this method may introduce.

X-Ray Technique

Techniques for producing the X-ray negatives of tree-ring samples have been developed at the Nondestructive Testing Laboratory, Mines Branch (Fig. 5). Research by Polge (1965a, 1965b, 1966) has been a useful guide.

X-Ray Apparatus

The X-ray apparatus used is a Picker portable instrument with a 50 kilovolt (maximum) capacity, 1.5 mm focal spot, .5 mm thick beryllium window, and self-rectifying circuit. It operates on a 110 volt, 60 cycle power source, and has an air-cooled oil circulation system. The duty cycle at 50 kilovolts is 50 percent at 10 milliamperes and 100 percent at 7 milliamperes. Soft X-rays are produced by this machine.

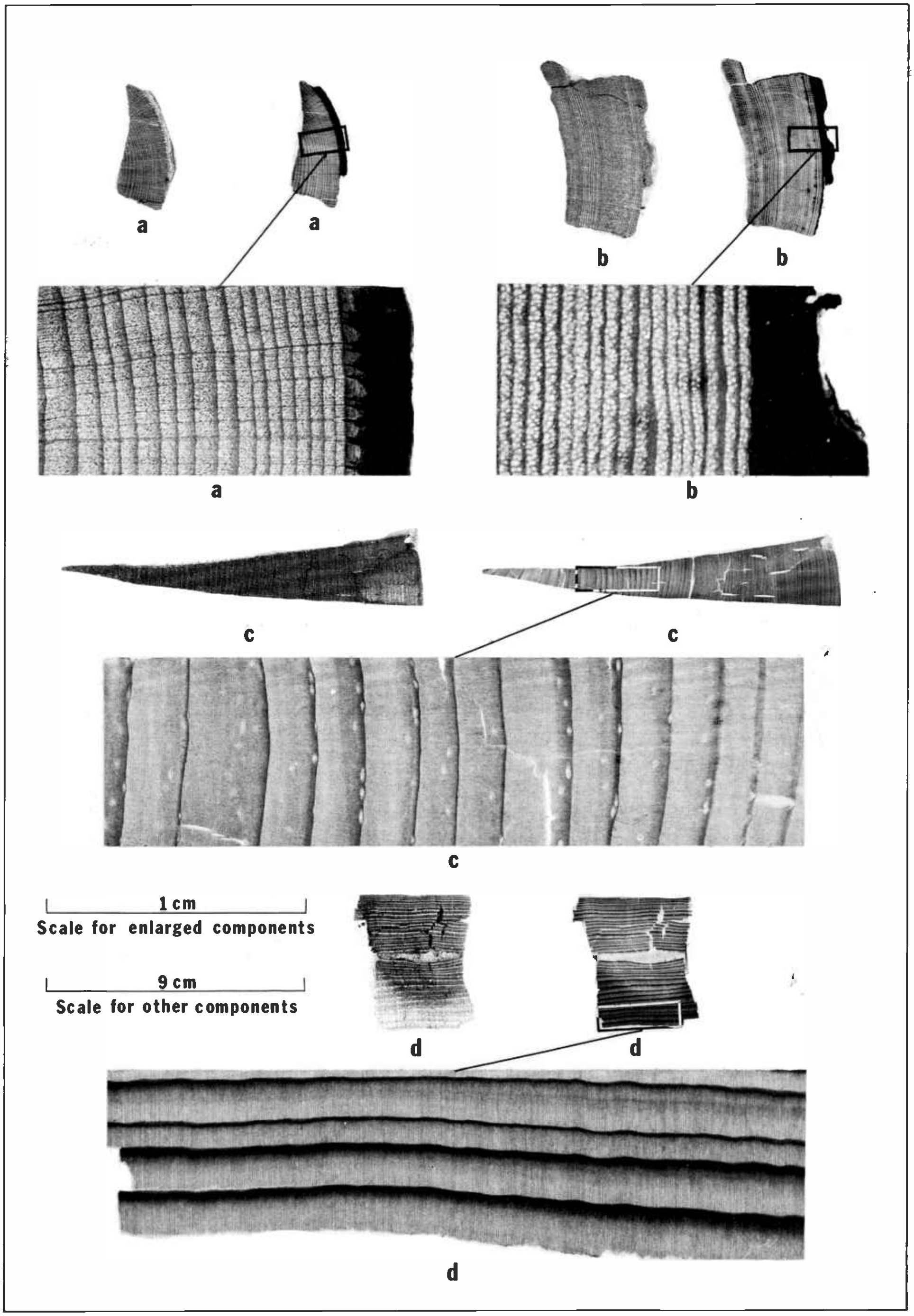

Fig. 3. Charcoal cross sections *a* and *b* are sections from broad-leaved trees; *c* and *d* are sections from conifers. Each group of three components includes a photograph of a charcoal specimen (left), and X-ray positive of the same specimen (right), and an enlargement of a portion of the X-ray positive (below other two).

Stationary Technique

One method for producing the radiographs is to hold the X-ray source, tree-ring specimen, and film stationary during exposure. The wood sample is placed on single emulsion radiographic film and subjected to X-radiation from a distance of 48 inches and an angle of 90°. Under normal conditions the exposure is for 2 minutes at 22 kilovolts and 5 milliamperes.

In-Motion Technique

Proper definition of annual ring density is obtained only if the X-rays penetrate the sample at an angle parallel to the long axis of the longitudinal tracheids. A technique has been devised to expose long tree-ring samples at the desired angle by in-motion radiography. X-radiation is transmitted through a 1 mm wide slit from a stationary source 10 inches from the tree-ring specimen positioned on the film. The specimen and film are supported by a carriage moving at a slow and uniform speed 3/8 inch beneath the slit. Successful experiments have been conducted using a carriage speed of 2 inches per minute with the X-ray machine set for 22 kilovolts and 6.5 milliamperes.

Film

Experiments have been conducted using double emulsion radiographic film, single emulsion radiographic film, and photographic film. If the double emulsion film is exposed at an angle other than 90° a double image will result from thy parallax effect, limiting the use of this type of film for some purposes. A fine grain photographic film was used with good results. Photographic film can be purchased in continuous rolls in bulk quantities.

The film selected for standard use is a single emulsion radiographic film with very high contrast and very fine grain (Kodak X-Ray Film, Type R). Tests were conducted by varying the kilovoltage and milliamperage until the desired contrast was obtained by using 22 kilovolts and 5 milliamperes. All exposures have been made on film in sealed, opaque, paper envelopes. Kodak liquid developer and replenisher for industrial radiography has been used at the recommended development time of 8 minutes at 68°F.

Discussion

The concept of using X-ray and densitometric techniques in tree-ring studies is relatively new. A great deal remains to be determined concerning the most useful methods of preparation and the many applications of the principle. The objective of our investigations, to this point, has been to make a general evaluation of the advantages of the X-ray technique and to examine the factors affecting the quality of X-ray negatives to be used for crossdating and for climatic compairsons. *Optical density* measurements of the X-ray negatives have been used, but techniques to use *wood density* measurements are now being investigated.

Advantages of the X-ray Technique

In terms of dendrochronological requirements, the technique of producing X-ray negatives of tree-ring samples has certain advantages over the use of sanded wood surfaces, microtome thin sections, or photographs of the specimens. The X-ray technique is nondestructive and produces a permanent and exact scale record of ring density. Both ring-width and ring-density data can be extracted from radiographs. This information can

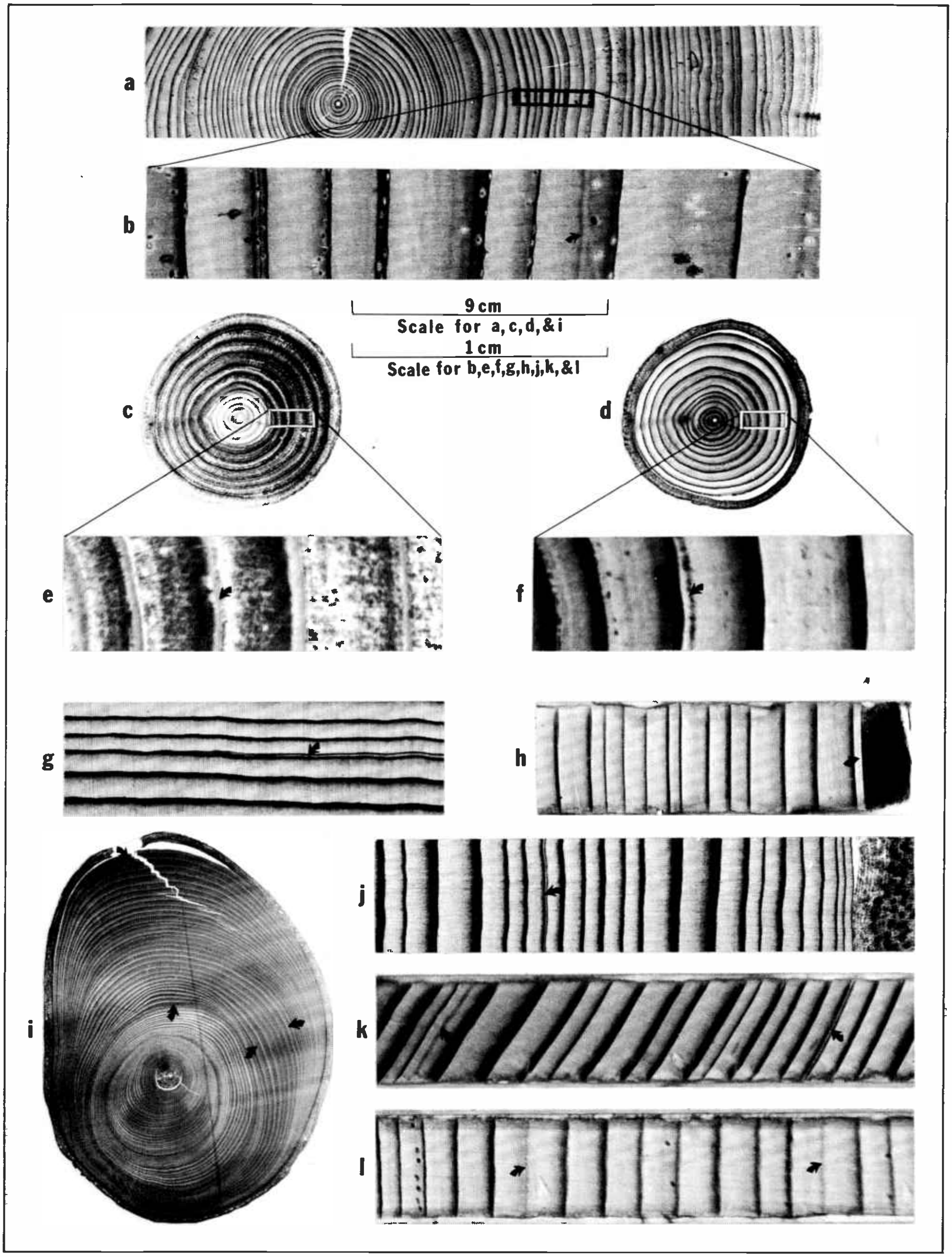

Fig. 4. Tree-ring characteristics. All 12 components are X-ray positives. *a*, tree-ring section; *b*, enlargement of *a* showing false rings (doubles): latewood double (left arrow) and earlywood double (right arrow); *c* and *d*, two forms of same cross section (*c*, green state and *d* dry state); *e* and *f*, enlargements of *c* and *d* showing frost ring (arrows); *g*, locally absent ring; *h*, incompete 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).

be quantitatively measured and presented graphically in the form of density plots (Jones and Parker 1970) and as photographic prints made from the X-ray negatives. Quantitative measurements of a number of intra-ring features such as frost rings, false annual rings, and latewood density can be made. Relatively little time is required to prepare the sample for X-raying and to make the radiograph. Much longer tree-ring series can be recorded on a single X-ray negative than can be prepared on a single microtome thin section. Well defined ring series can be produced by X-raying charcoal, and radiographs of very rotten wood will produce images sufficient for ring-width measurement. Color distortions such as stains and heartwood and sapwood differences do not affect the radiograph as they do photographic negatives or other media using reflected light. Intense and easily controlled transmitted light can be projected through the radiograph on a densitometer to record the density information.

In a few ways, however, the X-ray technique is less useful for tree-ring analysis than the others mentioned, and should supplement rather than replace these other methods. Some aspects of wood cell structure can be observed from good quality radiographs but microtome thin sections are much more useful for examination of microscopic features. Very small rings can be observed more accurately for ring-width measurement on finely sanded surfaces of tree-ring samples than on radiographs, *unless* the angle of X-radiation exposure is exactly parallel to the long axis of the longitudinal trachieds. If the angle is correct, however, very fine ring definition is obtained by the X-ray technique. Photographs also have certain advantages over radiographs for illustrative purposes or for color differentiation.

Factors Affecting X-Ray Quality

The quality of X-ray negatives to be used for dendrochronological purposes can be affected by a large number of factors (Fig. 6). These factors are related to the condition of the specimens, methods of specimen preparation, and X-ray and film developing techniques. One of the most important considerations is the alignment of the xylem cells within the specimen to be X-rayed. Increment cores should be taken at an angle perpendicular to the longitudinal tracheids if density studies are to be made. If X-ray negatives are produced by radiation penetrating the specimen at some angle other than parallel to the long axis of the longitudinal tracheids, the ring boundaries are poorly defined and the density measurements are distorted. The angle of X-ray exposure of the core can be changed by tipping the X-ray apparatus or the core and film to compensate for this condition, but this procedure is time consuming and usually can be avoided if the cores are correctly extracted.

There are other factors related to the condition of the specimen and preparation techniques that will affect quality such as the presence of foreign matter (preservatives, glue, sand, etc.), root flare, branch distortion, cracks, state of preservation (rotten wood), inherent dendrochronological quality of the species, moisture content (green or dry state), size of rings, thickness of specimen, variations in thickness, and ring boundary alignment.

Many factors related to X-ray and film development also can affect quality. Contrast and optical resolution are affected by kilovoltage, milliamperage, slit size, X-ray window (filter), source to film distance, source to specimen distance, specimen to film distance, type of film, development of film, and exposure time.

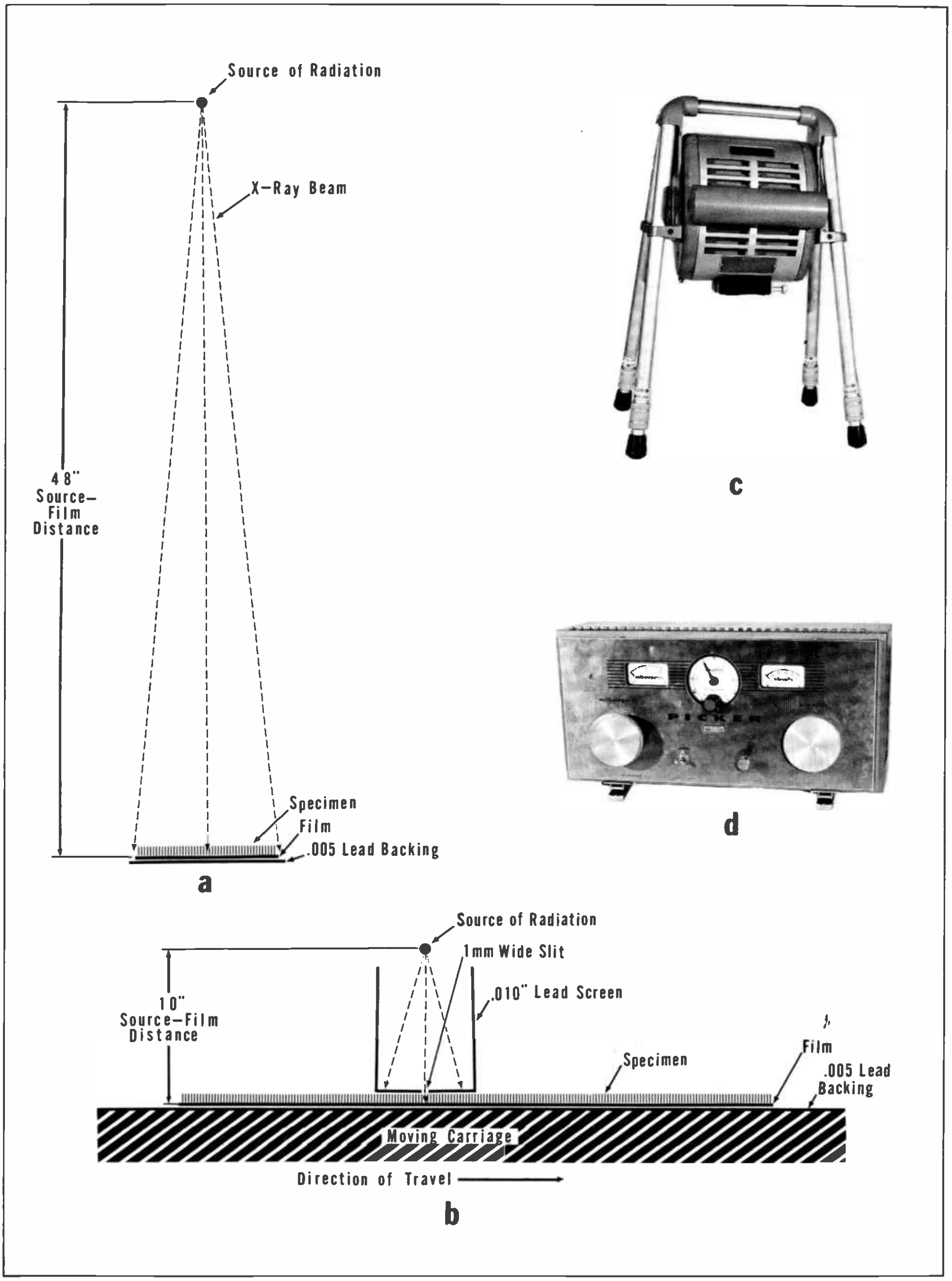

Fig. 5. X-ray techniques *a*, stationary technique; *b*, in-motion technique; *c* X-ray tube; *d*, electronic controls.

Conclusion

The potential for using the X-ray technique for dendrochronological analysis has just begun to be investigated. Many technical problems remain to be resolved, but the quantity and quality of information to be obtained from density studies makes this new approach to tree-ring studies well worth while.

Acknowledgements

We wish to acknowledge the help of A. Marleau in the development of X-ray methods, D. E. Field and E. Fitzpatrick for assistance in specimen preparation techniques, F. J. Cooke for the photography, and J. A. Heginbottom for editorial suggestions. Advice from H. Polge and H. V. Green also has been most useful. We also acknowledge the Nondestructive Testing Section, Physical Metallurgy Division, Mines Branch for the radiography of the specimens.

REFERENCES

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

Green, H. V., and J. Worrall
1964 Wood quality studies, I. A scanning microphotometer for automatically measuring and recording certain wood characteristics. *TAPPI*, Vol. 47, No. 7, pp. 419-427.

Harris, J. M.
1969 The use of beta rays in determining wood properties. *New Zealand Journal of Science*, Vol. 12, No. 2, pp. 395-451.

Jones, F. W., and M. L. Parker
1970 G. S. C. tree-ring scanning densitometer and data acquisition system. *Tree-Ring Bulletin*, Vol. 30 Nos. 1–4.

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 I.U.F.R.O. (Section 41), Melbourne, 1965.

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 I.U.F.R.O. (Section 41), Melbourne, 1965.

1966 Etablissement des courbes de variation de la densité du bois par exploration densitométrique de radiographies d'échantillons prélevés à la tariére sur des arbres vivants. *Ann. des Sciences Forestiére*, XXIII, Fas. 1.

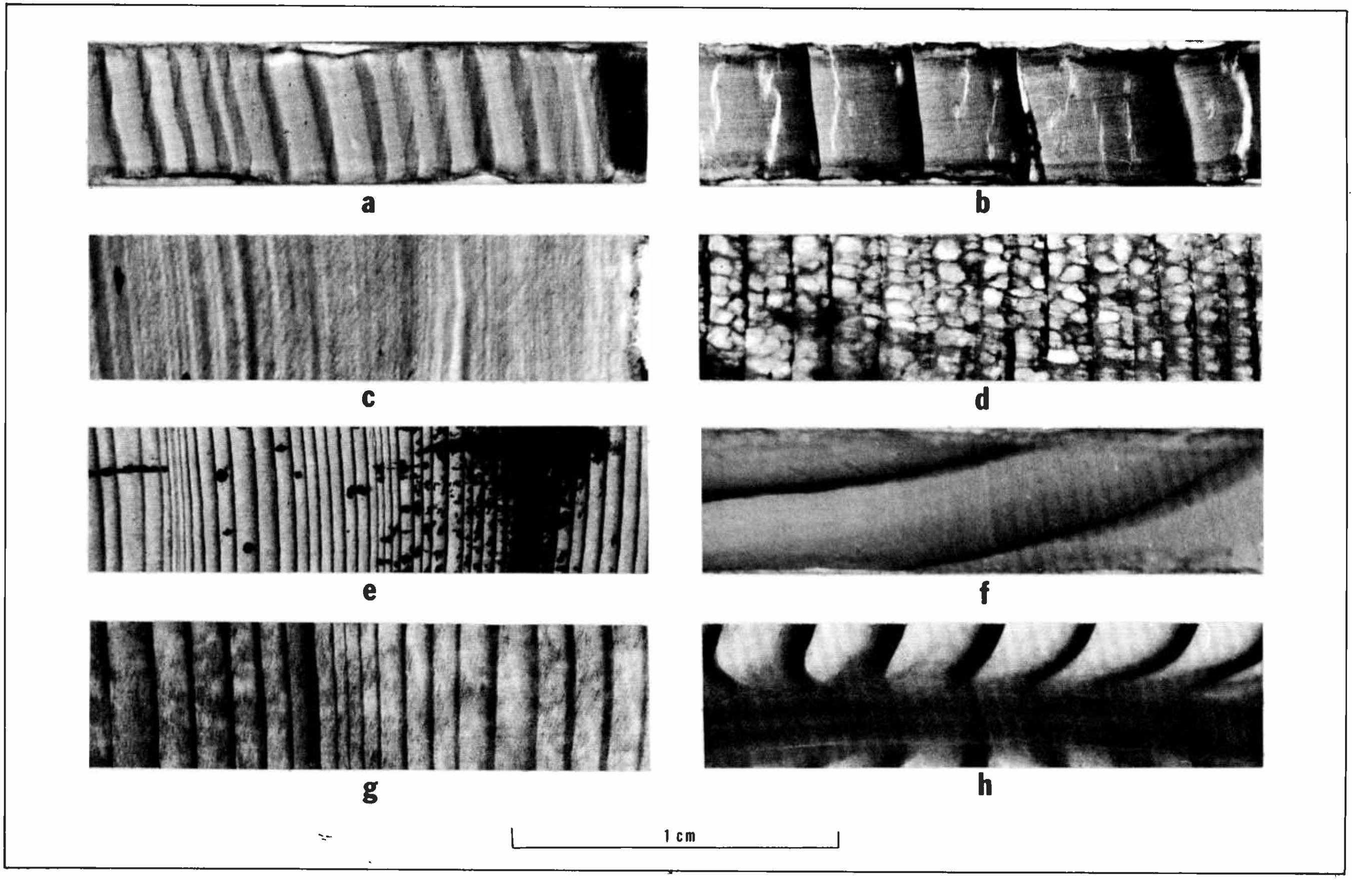

Fig. 6. Some factors affecting X-ray quality. All eight components are X-ray positives. *a*, misaligned xylem cells (large rings); *b*, cracks; *c* missaligned xylem cells (small rings); *d*, rotten wood (ring widths are discernible but density is distorted); *e*, foreign matter (soil particles); *f*, misaligned rings (core taken at incorrect radial direction); *g*, foreign matter (polyethylene glycol preservative); *h*, limb distortion.

G. S. C. TREE-RING SCANNING DENSITOMETER AND DATA ACQUISITION SYSTEM

F. W. JONES AND M. L. PARKER

ABSTRACT

A tree-ring scanning densitometer and data acquisition system has been built by the Geological Survey of Canada to extract tree-ring density and tree-ring width data from dendrochronological specimens and X-ray negatives of specimens. The system produces tree-ring density plots, ring density and ring-width bar graphs, and printed and punch tape digital data. This prototype was built primarily from commercial pre-constructed electronic components, but a modified densitometer and other original-design units also were used in the construction.

INTRODUCTION

Climatically controlled annual ring-width variation has been the basis for tree-ring studies since the development of dendrochronology early in this century. These unique patterns of ring-widths have made possible the accurate dating of thousands of archaeological tree-ring specimens in the Southwestern United States and elsewhere. These patterns also have been fundamental to studies in dendroclimatology relating annual radial tree growth to climatic parameters. Although *ring-width* variation is the basis for dendrochronology, other features, such as false annual rings, percentage of latewood, transition of earlywood to latewood, and maximum density of latewood are useful for crossdating and climatic comparison. Only recently, however, have techniques of *tree-ring density* analysis been developed that present these characteristics in parctical graphic and quantitative form. Of particular value is the technique of using X-ray negatives of increment borings to produce densitometric plots of tree-ring series (Polge 1965a, 1965b, 1966) and the method of measuring wood density on a scanning microphotometer and automatically recording data on punched tape for computer analysis (Green and Worrall 1964; Green 1965).

This paper reports on the construction and use of the tree-ring scanning densitometer and data acquisition system developed at the Geological Survey of Canada to use this new and promising technique of density analysis. This prototype will record *both ring-width and ring density* data and present them in graphic and digital form. Density and ring-width values are obtained from X-ray negatives, and ring-width measurements can also be taken directly from the tree-ring specimens.

FORM OF THE DATA

The G. S. C. tree-ring scanning densitometer is designed to produce: (1) density plots, (2) ring-width measurements, (3) maximum density bar graphs, and (4) ring-width bar graphs (Fig. 1). The density plots presented in this paper are from X-ray negatives (Parker and Meleskie 1970) plotted by an X-Y recorder and are similar to those produced by Green and Worrall (1964) from radial scans of transverse microtome thin sections of wood samples and by Polge (1966) from scans of X-ray negatives. Radial distance is measured in .01 mm increments by a scan of the X-ray film from pith area toward the bark and recorded on the X-axis in an expanded scale. Film density

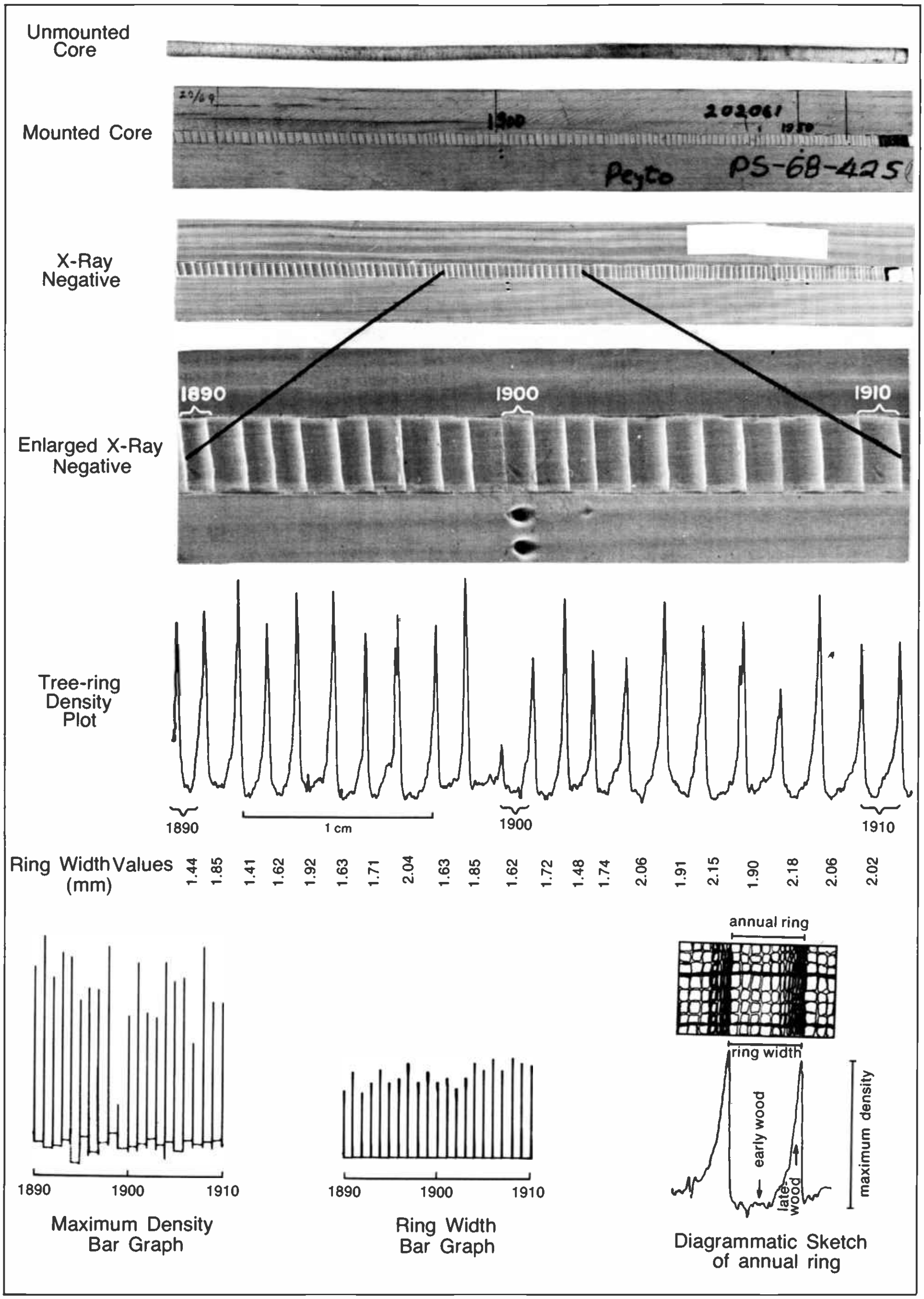

Fig. 1. Tree-Ring Width and Density Data from X-Ray of Increment Core

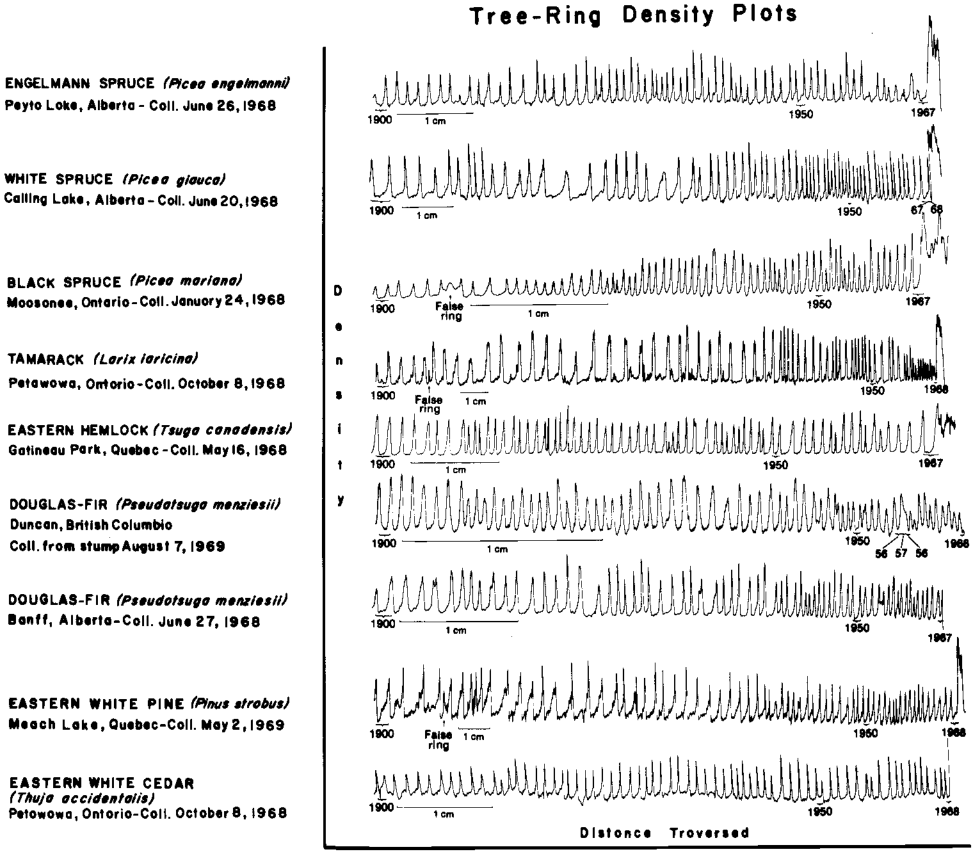

Fig. 2. Tree-Ring Density Plots

(representing wood density) is plotted as relative values on the Y-axis. Maximum plot amplitude indicates maximum wood density.

Annual ring-widths are measured between points of maximum density change on the X-ray negative. Ring-width measurements also are obtained from tree-ring specimens mounted on a carriage and viewed through a microscope with cross hair. Ring boundary positions are determined by the operator and the ring-width data are recorded automatically in printed form and on punched tape.

On the maximum density bar graph, the maximum annual latewood density is plotted on the Y-axis relative to fixed equal year increments on the X-axis. The X-axis is similarly plotted in equal year increments on the ring-width bar graph, but the Y-axis records annual ring-width values.

A number of density plots of tree-ring series of different species are presented to show the form of the data (Fig. 2). Some species exhibit much variation in latewood density and others are more variable in width of the rings. Crossdating between Engelmann spruce trees from the Peyto Lake area in Alberta is illustrated in three different ways: (1) by tree-ring density plots, (2) by ring-width bar graphs, and (3) by maximum density bar graphs (Fig. 3).

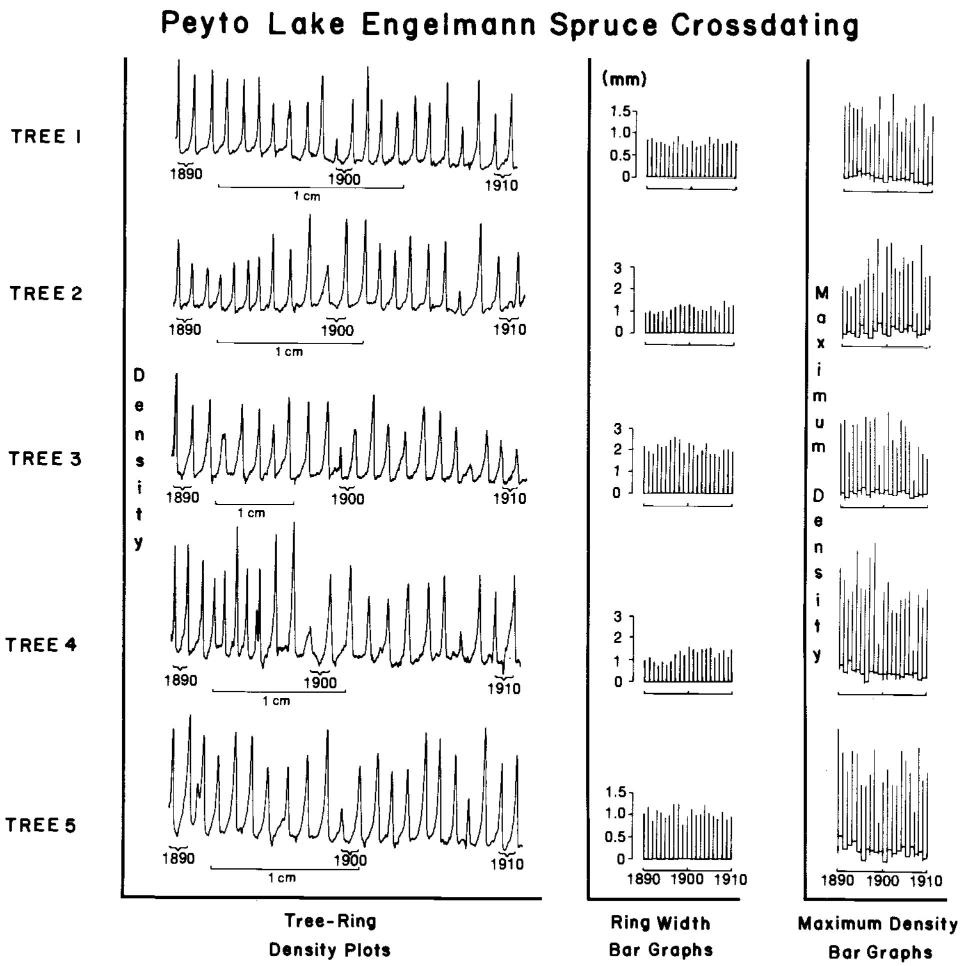

Fig. 3. Ring-Width and Density Crossdating

DESIGN AND CONSTRUCTION

APPROACH AND OBJECTIVES

It is not economical to construct a complex electro-mechanical system in a small laboratory if comparable apparatus is available from a commercial firm with production line facilities. There is, however, a sound basis for building a system with modern electronic data handling units that can be tied into an existing instrument, such as a densitometer. This is especially true if a new form of data is discovered or developed, a form that cannot be handled by existing commercial instruments. The system to be described is based on these considerations and on the judgement that there are definite advantages in using X-ray negatives of tree-ring specimens for evaluation of annual rings and variations within seasonal growth (Parker and Meleskie 1970).

The negatives produced by X-ray techniques are similar to spectrographic films and can be viewed on most densitometers but need some instrument modification if graphs and digital data are required. Some form of digitized output for computer use is almost essential because of the quantity of data required for building tree-ring chronologies. A precision stepping motor can be used as a source of digitized output. This type of motor, with pulse synchronized to an electronic system, is more advanced and less costly than any comparable mechanical instrument with related gears and shaft-type translators. Modern data acquisition systems, whether computer based or made from separate modules, are reliable, compact, and easily modified to keep pace with future developments. Many manufacturers offer suitable equipment and will usually advise on interconnection between in-going and out-going signal devices.

Basic Units and Operation

Although all components of the system are interrelated, seven basic units are designated for simplicity in explaining its operation: (1) the scanning densitometer, (2) the ring-width measuring table, (3) the digital counter-scaler, (4) the electronic control system, (5) the remote hand-control unit, (6) the X-Y plotter, and (7) the teleprinter and paper tape recorder (Fig. 4). X-ray negatives scanned on the densitometer unit will produce density plots, density bar graphs, and ring-width bar graphs on the X-Y plotter, and ring-width values to be printed and punched by the teleprinter. The functions of start, stop, print, motor speed control, and year increment are controlled by the operator with the remote hand-control unit. Ring-width values are obtained from tree-ring specimens on the ring-width measuring table, also operated by the remote hand-control unit, and recorded on the teleprinter in digital form and as ring-width bar graphs on the X-Y plotter. Radial distances traversed, i. e., values in .01 mm units representing actual distance traversed on the X-ray film or tree-ring specimen, are displayed on the digital counter-scaler. The electronic control system integrates and converts data carrying signals and control signals between all components of the system.

The system, as a whole, permits a great deal of latitude in X-axis and Y-axis plotting scale and scanning speed. At the same time, it is very accurate and responds immediately to control commands.

The Modified Jarrell-Ash Densitometer

A Jarrell-Ash[1] densitometer, now out of production in its original form, has been partially dismantled and modified in the construction of the scanning densitometer and ring measuring table. A new film transport is used, consisting of a pulsed stepping motor with planetary reduction gear and belt drive to a transparent plastic cylinder, around which the X-ray negative is wrapped (Fig. 4*d*; Fig. 5*c*). The transparent cylinder encases the existing light projection arm of the densitometer, permitting the image on the film to be projected onto the original slit table with photoelectric cell beneath. The top part of the original instrument is removed for use as the specimen carriage on the ring-width measuring table, and is driven by the same type of pulsed motor (Fig. 4*a*; Fig. 5*a*).

The pulsed motor (several makes of which are available), driven by a translator unit, permits direct conversion of angular rotation into displayed digits on the electronic scaler-counter, which in turn, provides a binary coded decimal signal to perform any function that is associated with coded data acquisition. The motor has a 200 step function for 360 degrees of rotation, and the shaft to cylinder ratio plus a selected planetary gear provide suitable amount of film advance for one electrical pulse. This is the counting pulse of the scaler and in this system is designated for one hundredth part of a

[1] Brand names are given for information only, with no intention of endorsing any particular product.

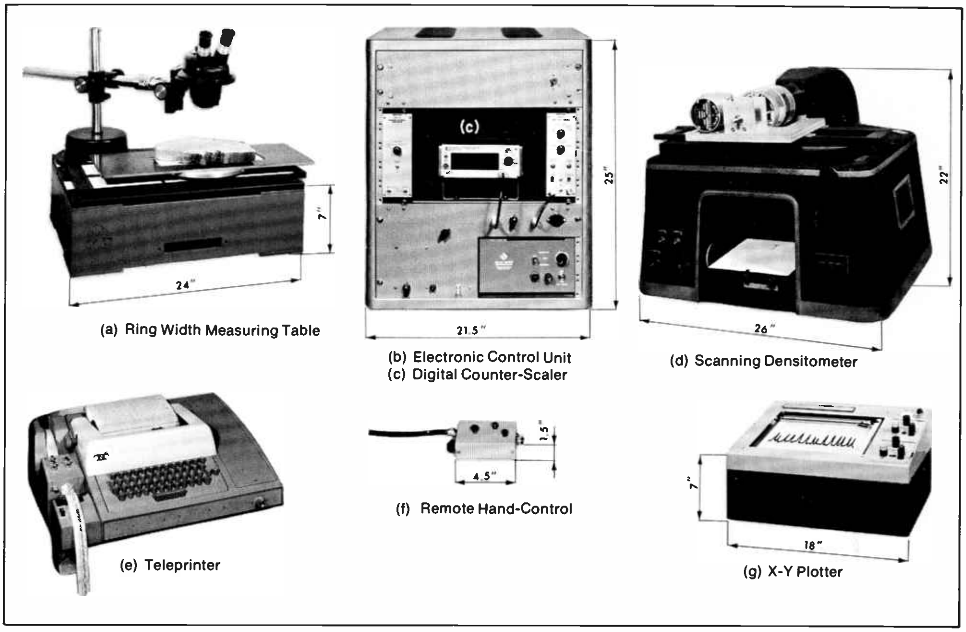

Fig. 4. Basic Units of the System

millimeter, i. e., actual film movement for one digit count. This is well within specification limits of the motor without requiring the use of a high precision unit. Reproducibility is excellent and a distance of 10 cm may be scanned with ±.02 mm. With a suitable belt drive between motor and cylinder, no backlash is present.

The rotating cylinder has the advantage over horizontal table drive in that the overall inertia of the drive system is minimized, permitting the full precision capability of the motor to be used. A table using the heavy steel castings of the original densitometer top has been made for use with heavy wood sections viewed under the microscope. It is working satisfactorily but would be improved by lighter construction to reduce momentum when stopped from fast traverse speeds.

The Electronic System For Control and Data Acquisition

There are two forms of signal information from the X-ray negative that the electronic system can use to transmit data: (1) the distance between chosen points on the line scan of the film surface, and (2) the variation in density within the thickness of the emulsion. The radial distance scanned is a direct function of the stepping motor and is predetermined by the gear ratio selected for one digit displayed by the counter. The only variable is time per step and this is controlled by the motor speed adjustment from approximately 4 to 300 steps per second. The signal is an electrical pulse.

A number of variables can affect the stability of the density information signal, for example the lamp source, the optical system, and the slit control, and these aspects of the basic densitometer design must be considered. In addition, the choice of film emulsion characteristics and the selection of the photosensitive device and its attendant amplifier are important. The density signal is in analog form.

The component parts of the electronic system are: (1) the stepping motors and translator drive (motor control) unit, (2) the logic circuits for digital and analog conversion, (3) the X-Y recorder, (4) the teleprinter and paper tape recorder with control units, (5) the D. C. power supply, and (6) the basic control units and cabinetry for the whole system (Fig. 5). All units can be purchased in complete form except the basic control, and this component can be constructed at moderate cost by one who is versed in logic control methods.

The stepping motors and translator have been described in the preceding section.

The digital counter-scaler has five digit capability plus an outlet in 8421 binary coded decimal (BCD) form to supply the conversion modules. It has an up-down count function to permit decrease in reading for reversal of film direction. This unit is provided with stop, start, and reset output facilities for remote control.

The digital and analog conversion modules are used to perform several functions. The distance-traversed signal, in digital form, from the stepping motor and translator drive unit is converted to an analog signal for X-Y recorder operation by way of the BCD of the scaler. The density signal, of analog origin, is fed directly to the X-Y plotter and may be converted into digital form if needed as output to the teleprinter. Preconstructed module boards that perform these functions are mounted in the basic control unit.

A simple X-Y recorder that plots on 8½ x 11 inch sheets is used in this system. The bar graphs are made using a digital to analog incrementer in the basic control unit. Any standard recorder of this type will accept the analog signals carrying distance and density information, but more elaborate instruments may be worth consideration. The use of

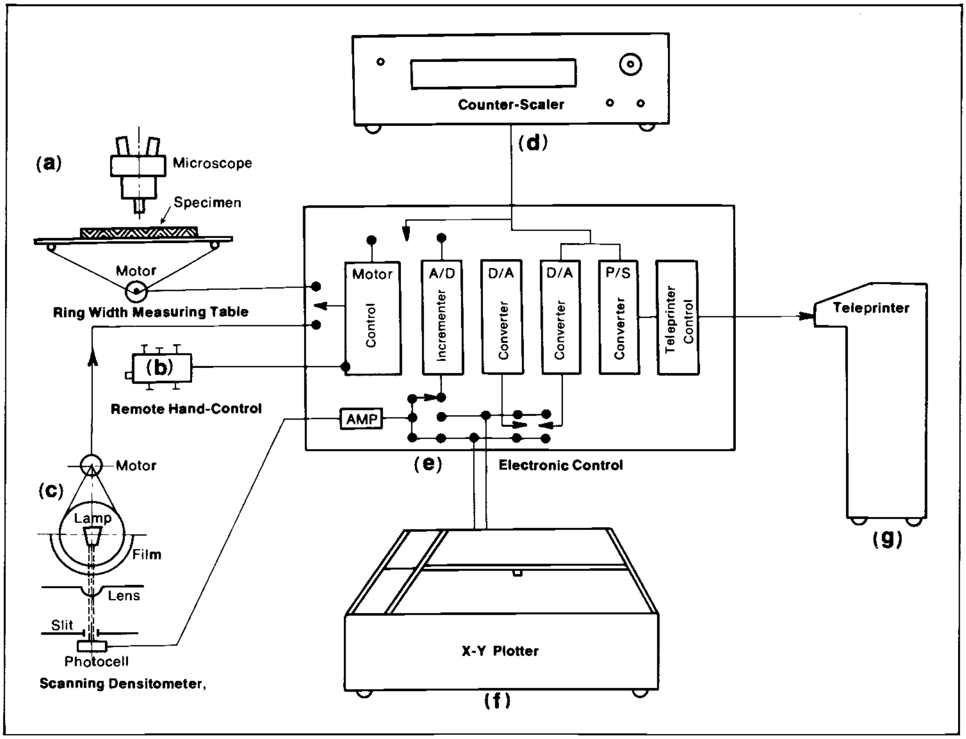

Fig. 5. Schematic Diagram of the System

Z-folded or continuous-roll paper would facilitate the production of the density and bar graph plots; plug-in time-base facilities also would be useful for bar graph plotting; and there are X-Y recorders that interface with computers for in-out signal transfer, making possible the plotting of computer processed data.

The teleprinter and paper tape recorder is a standard ASR 33 Teletype machine and is probably the least expensive recorder on the market for the facilities it offers. An external control is used that includes parallel to series conversion (for the BCD signal from the scaler) and a means for regulating character and line space. Several suppliers offer control units for Teletype machines.

The D. C. power supply is an independent unit, well regulated and with low ripple in order to supply the converters and operational amplifiers needed in the basic control unit.

The basic control unit receives the two information signals (density and distance-traversed) directly for processing by digital or analog conversion modules before being switched to read-out instruments. X-axis or Y-axis amplifiers may be selected for either signal, or one signal only may be selected for one axis while the other axis is fed incremental signals to produce bar graphs. The BCD information is fed into this unit from the scaler and out to the teleprinter and X-Y recorder. The control pulses for start, stop, print, reset, etc., are handled by this unit and cable access is provided for the remote hand-control unit permitting the operator to countermand the panel controls while viewing either the projected image on the scanning densitometer or the tree-ring specimen under the microscope on the ring-width measuring table. The main A. C. supply with fuse and bussed outlets for other units is included in this basic control unit and all of these components are mounted in a standard 19 inch rack-type cabinet (Fig. 4*b*; Fig 5*e*).

SUGGESTED MODIFICATIONS

The system, as described, has cost approximately $7,000 for all component parts except the original densitometer which was available at no cost. This figure does not include the labor involved in design and assembly. The present system is to be considered a prototype and anyone wishing to duplicate it may alternatively consider the use of a small digital control type computer, of which there are now many on the market for about $8,000 including teleprinter in-out control. A universal type interface board could be inserted into the computer to receive the information signals, and a pulsing motor drive board also could be incorporated. The only additional components needed would be the scanning densitometer, the ring-width measuring table, and the X-Y plotter. It would be relatively easy to program in machine language for all of the functions described in this paper.

A great deal could be done to improve the present densitometer aspect of the system by building a completely new optical system with balanced photocell light source designed to maintain constant light level. The slit and projection image could have a finer position indicator line to establish peak locations and also could have better shielding from extraneous light. The transparent cylinder could be mounted vertically for better access, and if it were made of glass it would not be as easily scratched as the plastic cylinder. A rotable slit holder would permit better alignment with the ring boundaries and the angle of rotation could be used to calculate the divergence of the actual scan from a desired scan that is perpendicular to the ring boundaries.

CONCLUSION

Use of tree-ring density information more than doubles the data that can be extracted from tree-ring series by techniques utilizing ring-widths alone. It has been demonstrated that ring density data relate to climatic factors (Polge 1965*b*), and therefore, can be used to supplement ring-width indices for dating and dendroclimatic analysis. The tree-ring scanning densitometer and data acquisition system built by the Geological Survey of Canada extracts width and density data from dendrochronological specimens and X-ray negatives of specimens, and converts these data into useful graphic and digital form. The system was built primarily from pre-constructed modules, and electronic rather than mechanical components were used whenever possible. The overall objective has been to develop a system that will extract both tree-ring width data, for which methods of analysis are well developed, and tree-ring density information, for which methods of analysis have not been developed, but may prove to be at least as important as ring-width data in the future development of dendrochronology.

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REFERENCES

Green, H. V., and J. Worrall
1964 Wood quality studies, I. A scanning microphotometer for automatically measuring and recording certain wood characterisitcs. *TAPPI*, Vol. 47, No. 7, pp. 419-427.

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

Parker, M. L., and K. R. Meleskie
1970 Preparation of X-ray negatives of tree-ring specimens for dendrochronological analysis. *Tree-Ring Bulletin*, Vol. 30, Nos. 1–4.

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 I.U.F.R.O. (Section 41), Melbourne, 1965.

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 I.U.F.R.O. (Section 41), Melbourne, 1965.

1966 Establissement des courbes de variation de la densité du bois par exploration densitométrique de raradiographies d'échantillons prélevés à la tarière sur des arbres vivants. *Ann. des Sciences Forestières*, XXIII, Fas. 1.