Procedures For The Study Of Snow Avalanche Chronology Using Growth Layers Of Woody Plants

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PROCEDURES FOR THE STUDY OF SNOW AVALANCHE CHRONOLOGY USING GROWTH LAYERS OF WOODY PLANTS

by

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Cover: Unnamed snow avalanche path with many fallen trees brought down by an avalanche in February 1976, Rio de los Animas Perdidas, near Howardsville, Colorado, San Juan Mountains.

PREFACE

Throughout history, mountain-dwelling people in areas of heavy snow accumulation have reckoned with the fearsome phenomenon of the avalanche. Few of these encounters, however, have been accurately recorded or described in sufficient detail to benefit contemporary efforts in mountain land-use planning. Compared to the European Alpine countries, France, Austria and especially Switzerland, the pioneers in avalanche and snow mechanics research and their applications to land-use zoning policies, the mountainous regions of the North American West are virtually unknown.

Since the turn of the century, the Alps have experienced an accelerated growth in the tourist and recreation industries which has resulted in an enormous increase in man-made structures and year-round visitors. The avalanche hazard has grown accordingly, with a concomitant increase in related deaths, injuries and property damage, as well as capital outlay for defense structures. The development surge in the North American mountains has lagged some 15 years behind the European experience and is far less intense in terms of current population ratios. Nevertheless, the expansion of the ski industry, the spread of second homes, and the increased interest in winter back-country travel have made the avalanche hazard and land-use planning acute problems in Colorado and in many other western states.

In 1971, the University of Colorado Institute of Arctic and Alpine Research (INSTAAR) became involved in avalanche research in the San Juan Mountains through the award of contract no. 14-06-D-7155 from the Bureau of Reclamation. The original research objectives included the collection of environmental data for the development of an avalanche forecast model and the assessment of the potential impact of winter cloud seeding on avalanche activity. This resulted in establishment of INSTAAR's avalanche research office in Silverton and the development of a team of scientists and observers with Richard L. Armstrong as project leader. Important consultative assistance was provided by Drs. Edward LaChapelle, Malcolm Mellor and Wilford Weeks, internationally-recognized glaciologists. Other related research was built around the Bureau of Reclamation core project which concluded in the winter of 1975-76 with publication of the final report as INSTAAR Occasional Paper No. 19.

A major related step was the initiation in 1972 of a continuing research grant from the NASA Office of University Affairs (Grant Monitor Joseph Vitale) for application of remote sensing techniques to the solution of land-use problems in mountain Colorado (NASA-PY NGL-06-003-200). Much of this effort so far has been devoted to identification of areas subject to avalanche and other natural hazards in specific areas around Vail, Crested Butte, Telluride and Ophir. More recently, attention has been given to county-wide natural hazard mapping at a scale of 1:24,000 in San Juan, San Miguel, Ouray and Hinsdale counties, in relation to the requirements of Colorado State House Bill 1041. These studies were initiated by county request and conducted in collaboration with the Colorado Geological Survey. A related special project resulted in the publication of the San Juan County Avalanche Atlas as INSTAAR Occasional Paper No. 17.

Our basic research in snow mechanics forms the fundamentals for understanding of avalanche activity. But, to be of meaningful use to a decision-maker in mountain land management, specific studies on the magnitude of events and recurrence interval of a particular avalanche path are necessary. In the San Juan Mountains of southwestern Colorado we were fortunate to find a wealth of historical avalanche data from the early mining days which led to the publication of INSTAAR Occasional Paper No. 18 "A Century of Struggle Against Snow: A History of Avalanche Hazard in San Juan County" by Betsy Armstrong. However, such records date back a scant 100 years and are subject to human error. The population locations have also shifted since that time. It is here that tree-ring dating of avalanche activity can contribute valuable information on the magnitude and frequency of avalanche occurrence. This monograph by Colin and Vivian Burrows, compiled under support from NASA grant no. NGL-06-003-200 to Dr. Jack D. Ives, includes information on montane tree growth and development and the general effects of avalanches on vegetation. It is intended to serve as a field manual for the interpretation of tree-ring information in dating avalanche events and in defining the extent of runout zones. It should aid the local land-use planner in delineating the specific avalanche hazard. Accordingly, it is designated as a contribution to the United States UNESCO* Man and the Biosphere (MAB) Program Project 6A: study of the impact of human activities on mountain ecosystems.

Roger G. Barry
Acting Director, INSTAAR
December 1976

*United Nations Educational, Scientific and Cultural Organization

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1: INTRODUCTION

This handbook is a brief description of the background to and procedures for the use of annual growth layers (annual rings) of woody plants for dating snow avalanche events. Trees are most often used as subjects for study but there are some possibilities for using shrubs to date events over short intervals. The methodology of ring-dating is based on the growth behavior of woody plants in cold and temperate climates with marked differences between summer and winter temperature regimes. The winter conditions cause the plants to slow or stop their growth so that there is a discernible difference between the cell size and structure at the end of a growing season compared with that at the beginning of a new growing season. The numbers of rings in cross-sections of selected stems can provide a means of dating and reconstructing events of the past such as glacier fluctuations (Lawrence 1950, Sigafoos & Hendricks 1961), timberline changes (La Marche & Mooney 1972), lake level fluctuations (Cameron 1957, Lawrence 1972), landslides (Heath 1959, 1960), floods (Grant 1965, 1966), fires (Spurr 1954) and other natural and man-made changes. For the purposes of this handbook, the methodology will be referred to as tree-ring analysis, rather than dendrochronology. The latter term has come to be applied, more narrowly, to the somewhat more specialized methodology of use, for dating, cross-dating (to extend chronologies) and climatic analysis of sequences of wide and narrow growth layers in sensitive species in arid or cold climates (Glock 1937, Fritts 1966, 1969, Ferguson 1970, Suess 1970, La Marche & Fritts 1971, Fritts & Blasing 1974). Nevertheless, both methodologies make much the same use of knowledge of the characteristics of tree growth and wood structures. In certain rare circumstances, mentioned later, dendrochronological techniques might be applied to the dating of snow avalanches. Techniques most useful in tree ring analysis are described by Lawrence (1950), Potter (1969) and Stokes & Smiley (1968).

It must be stressed that the users of tree-ring analysis methods need to have a good understanding, not only of the principles of tree-ring methods, but also of the biology, anatomy, growth and ecological behavior of the plant species they are studying. They need to know details of seedling establishment, growth rates and responses of trees to the ecological factors affecting them. Gymnosperms differ from angiosperms in some respects and all woody plants differ from one another in some aspects of their ecology. Reference should be made to textbooks like Kozlowski (1962, 1971), Spurr (1964), and bibliographies like Roy (1953), Tackle & Crossley (1953), Agerter & Glock (1965), Ronco (1961), Christensen & Hunt (1965), Pronin & Vaughan (1968). Knowledge is also required of the nature of avalanches, especially as they affect trees. These effects are described in various publications (Krebs 1974, Armstrong 1973, 1974, Martinelli 1974).

It is most important to establish that the plants under study have annual growth and to understand the limiting factors for growth and the effects of various natural hazards, because growth checks at abnormal times may cause features in the wood which mimic annual rings. Abnormally bad growing seasons may cause partial or complete suppression of annual rings for that year. Some species do not produce clear rings, even although there is a marked seasonal periodicity in climate and growth. Although these are often avoided as subjects for study, some aids exist by which they may be studied.

This handbook is couched in simple terms which can be understood by non-biologists; references are given to fuller accounts of aspects of the subject and a glossary of terms is included at the end. The book is specifically relevant to the forests and mountains of Colorado, but it could be adapted for use in other areas.

2: TREE GROWTH AND DEVELOPMENT

Trees go through a sequence of more or less continuous developmental stages. For convenience they may be separated into seedling, sapling, pole, mature tree and senile tree phases (Fig. 1). There is great variety in the ecology of seed production and dispersal from species to species. Seedling growth and growth to maturity are described in Kozlowski (1971), Spurr (1964), Wilson (1970) and U.S. Department of Agriculture Forest Service (1965).

The young plants of some species of use in avalanche studies (*Pinus contorta*, lodgepole pine; *Populus tremuloides*, aspen) are almost obligatorily dependent on high light intensities for optimal growth and do not develop well in dense evergreen forest. Others have shade-tolerant youthful phases (Picea engelmannii, engelmann spruce; Abies lasiocarpa, subalpine fir), but their seedlings also thrive in well-lit conditions. Thus, these species are favored by the opening-up of forest, or the maintenance of clear avalanche tracks, despite the other disadvantages of such sites. Provided that there is no disturbance, there is an orderly sequence of growth to maturity, moderated by the limitations imposed by nutrient, water and light relationships and competition from neighbors. Time scales for maturation of some common species are given in Appendix I and rates of colonization of open areas in Appendix II. Mature trees continue to grow in height and diameter, usually at an increasingly slower rate until they can no longer cope with pathogens or physiological stresses, whereon their tops and main branches begin to die and eventually the whole tree dies, falls and decays. Maximum recorded ages for common species are given in Appendix I. Both height and diameter growth are dependent on local conditions of site quality and are highly variable from place to place, so the age of a tree may only be gauged roughly from its size.

Regeneration by vegetative means occurs in a number of species (more especially angiosperms) and is well known in aspen (Stoeckeler & Mason 1956, Graham, Harrison & Westell 1963, Larson 1959, Farmer 1962). Thus, when an aspen site is cleared (by an avalanche or otherwise) it may be expected that dense aspen stands will arise from root suckers. Since they are dioecious (trees either male or female), clones of aspens of either sex will indicate that this has occurred.

3: STEM ANATOMY AND WOOD GROWTH

Annual rings develop as layers within the xylem (wood), which forms the main cylinder of the stems of trees. The distribution of tissues in a representative tree is shown diagrammatically in Figure 2 in transverse section, radial longitudinal section and tangential longitudinal section. There is little basic difference in arrangement of tissues between gymnosperms and angiosperms. The xylem cells are differentiated towards the inside of the cambium, one of the main meristematic tissues.

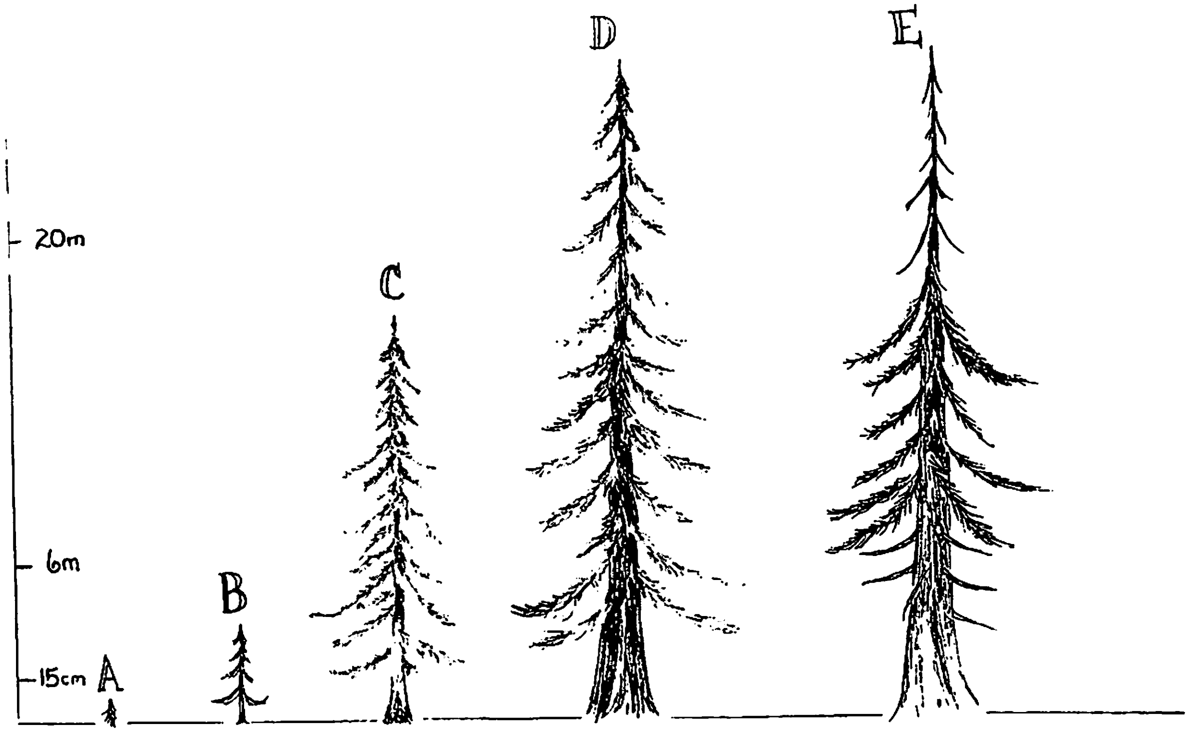

Fig. 1: Stature of the developmental classes of trees. A. seedling; B. sapling; C. pole; D. mature tree; E. senile tree.

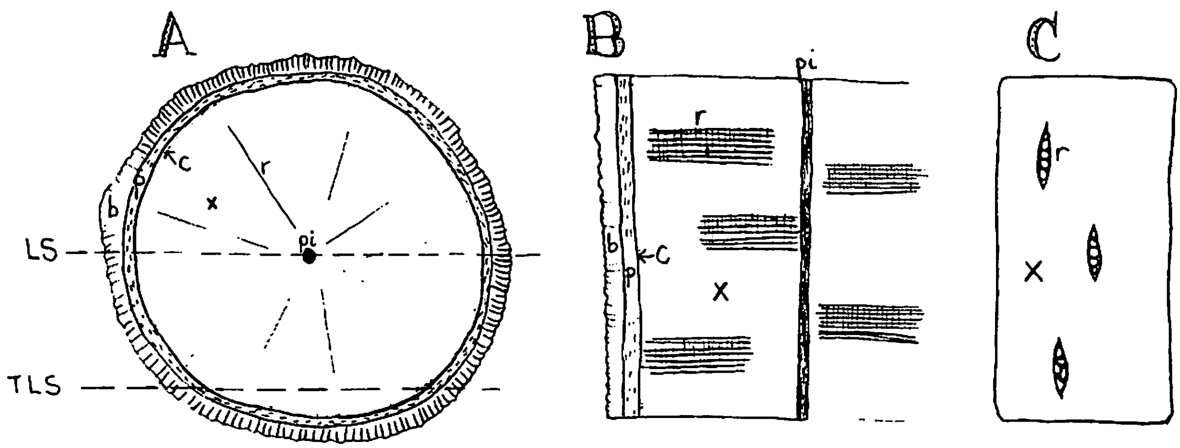

Fig. 2: Diagram of distribution of tissues in a tree-stem. A. transverse section; B. radial longitudinal section; C. tangential longitudinal section; pi-pith; x-xylem (wood); r-ray; c-cambium; p-phloem; b-bark.

In gymnosperms (douglas fir, *Pseudotsuga menziesii*; engelmann spruce; subalpine fir; lodgepole pine) xylem consists mainly of tracheids with their long axes longitudinally-arranged. Occasional rays, consisting of parenchyma cells and tracheids, extend transversely, radiating from the center of the cylinder. In angiosperms (aspen, willows (*Salix* spp.) birches (*Betula* spp.) longitudinally-arranged vessels, fibers and often parenchyma are also present in the wood. Their rays lack tracheids. As growth starts with the swelling of buds in spring the first-formed xylem cells are large and thin-walled, forming "early-wood". As successive layers of cells are differentiated through the growing season, physiological conditions within the tree gradually change so that the resulting xylem cells are smaller, with thicker walls. In the outer portion of the ring the cells formed at the end of the growing season in autumn (the "late-wood") are small and the wood appears to be dense and dark. This tissue forms a distinct boundary against the lighter early-wood of the next-formed ring.

Details of the structure and arrangements of the cells in transverse sections of stems of some tree species are shown in Figure 3 and the longitudinal arrangement of growth layers in a tree is shown in diagrammatic form in Figure 4.

The width of annual rings changes gradually with increasing age of the tree and may vary markedly from year to year, depending on variations in factors such as climate, nutrition, light conditions and attacks by pests, affecting the physiology of the tree prior to, or during the development of the cells forming the rings. Normally this need not be of concern in tree-ring analysis, unless there is so much interference with the growth of the tree that a false ring or partial ring (or no ring) is formed in a particular year. False rings mimic annual rings in that a band of smaller, denser cells than normal is laid down part way through the growing season. They are distinguished by the lack of a sharp boundary between the apparent late-wood and the successively-formed band of cells (Fig. 5). Glock (1937) and Krebs (1970) both give further discussion of this phenomenon. Partial rings (Fig. 6) result from the

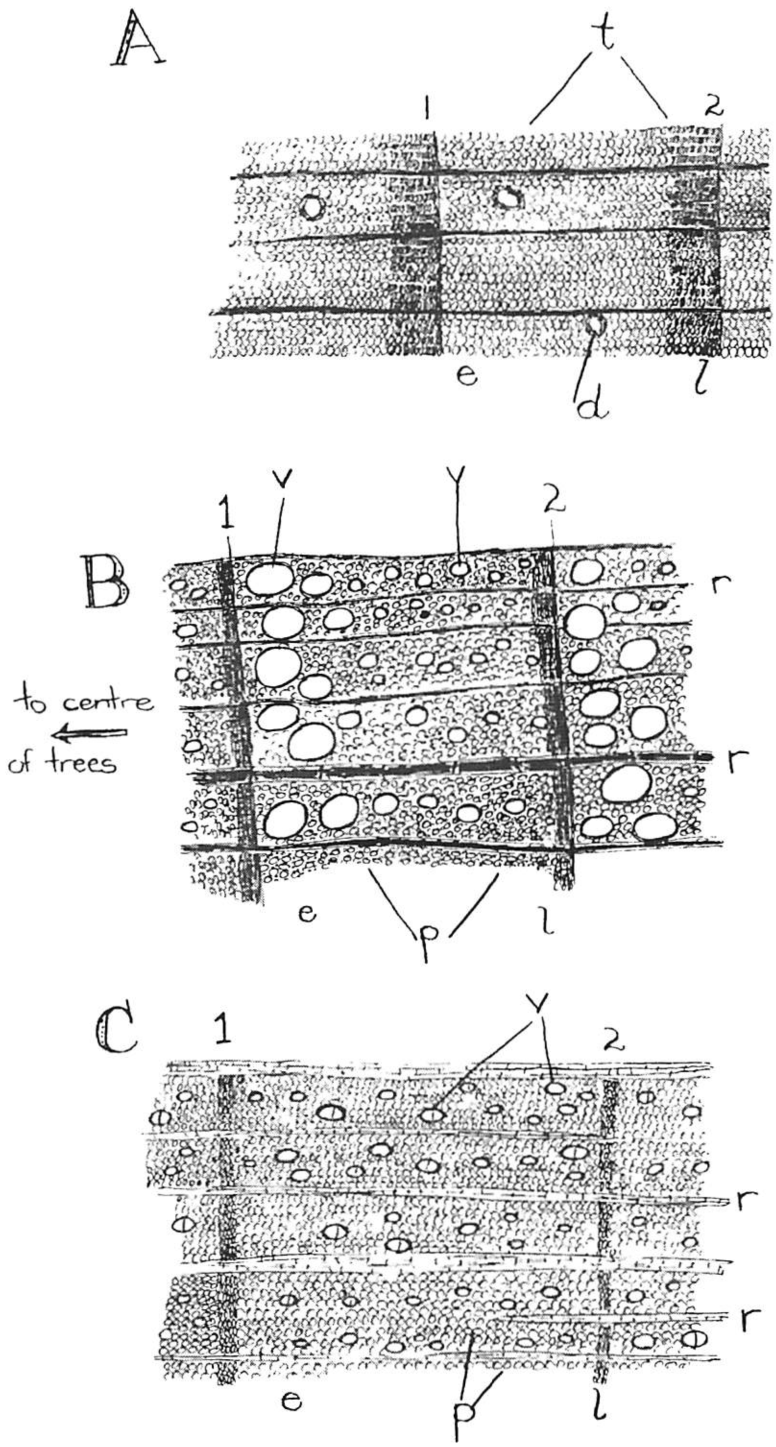

Fig. 3: Transverse sections of tree stems to show distribution of cells in annual growth layers. A. gymnosperm; B. angiosperm with ring-porous wood; C. angiosperm with diffuse-porous wood. 1 & 2-individual growth layers, number is at end of year's growth; e-early-wood; 1 & 2-late-wood: e-resin duct; r-ray; t-tracheids; v-vessels; p-wood parenchyma and fibers.

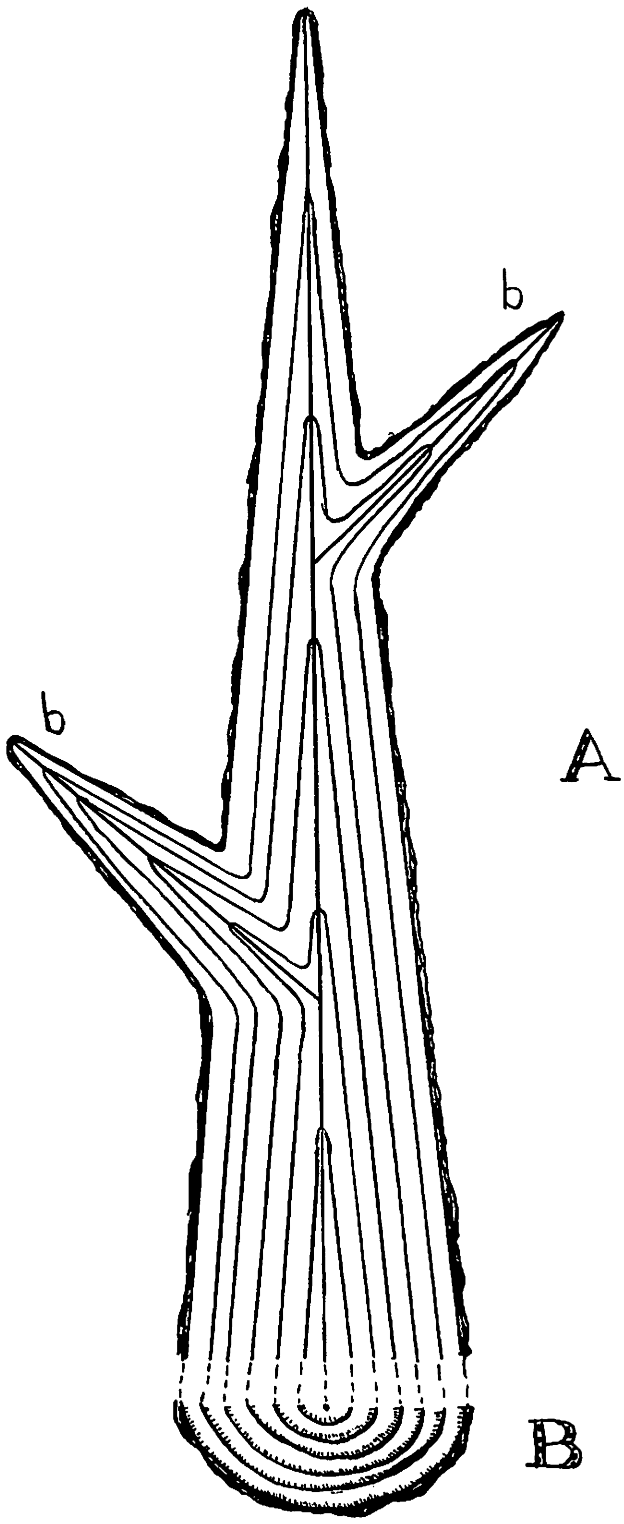

Fig. 4: A. Longitudinal section through a tree stem to show the relationship of growth layers to height growth, branching and to B, a transverse section at the base of the stem, b-branches.

inability of the tree to lay down a complete ring or a complete sequence of early- and late-wood cells. Absence of rings can only be detected by dendrochronological techniques (Glock 1937), but, provided that the trees being examined are not growing in extreme sites and that complete stem sections are being used, there should be little problem with partial or missing rings. Abrupt changes in patterns of ring-width may be useful in interpreting avalanche history, as is discussed later.

Verification of annual ring formation may need to be done if the species being studied are not well known. In numbers of species bark color differences and bud scars on a branch indicate each year's growth in length for several years, in which case growth ring production can be examined immediately. Another simple means of establishing whether annual rings are formed is to sample, for aging, a population of trees of known age. If either of these methods is not possible a longer term measurement must be done by marking one-year-old branches and sampling and sectioning them one, or more, years later to determine the increment.

4: TYPES OF WOOD: ILL-DEFINED RINGS

The types of wood so far mentioned have been those like engelmann spruce, subalpine fir, or oaks (*Quercus* spp.) which produce well-defined annual rings. Some angiosperm species such as aspen and maples (*Acer* spp.) have vessels of relatively small diameter, dispersed diffusely and uniformly through each annual ring. Species like oaks, on the other hand, have vessels of very large diameter in the early-wood and vessels of small diameter in the late-wood and are said to be ring-porous. The diffuse-porous species (aspen, maples) may have wood in which it is difficult to count annual rings and special techniques may be required (as discussed later).

5: THE FORM OF TREES, BRANCHING SYSTEMS, ROOT SYSTEMS

The stems and branches (and roots) of trees increase their diameter by the annual addition of wood. Increase in height of trees and length of branches and roots is accomplished by the laying down of cells from

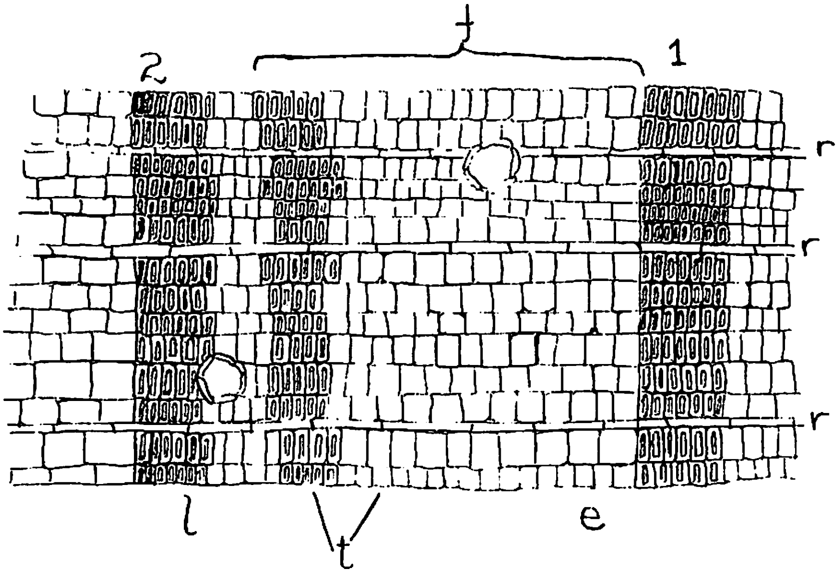

Fig. 5: False ring, f, in a transverse section of gymnosperm wood. e-early-wood 1-late-wood; r-resin canal; t-tracheids. Note that there is not an abrupt transition from the small cells of the false ring "late-wood" to the subsequent larger cells.

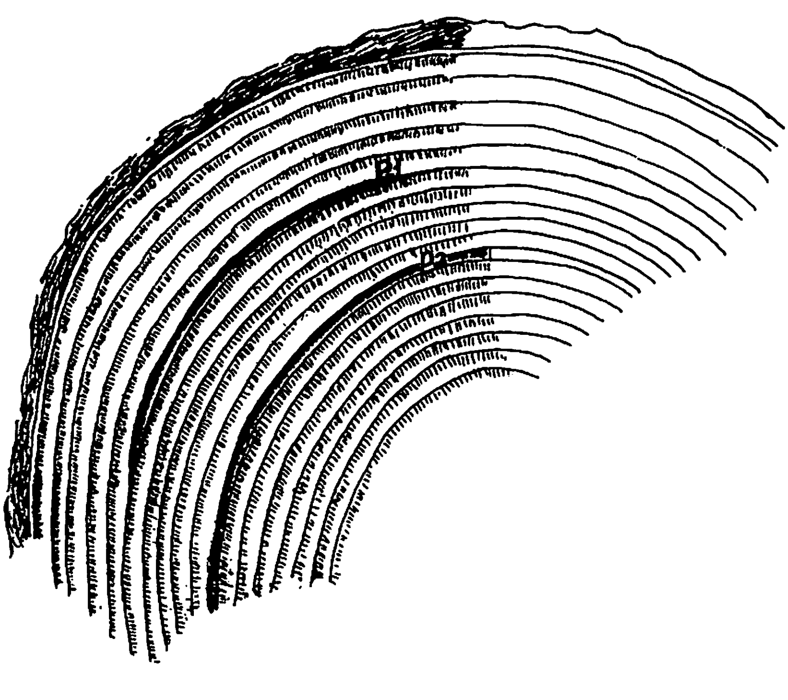

Fig. 6: Transverse section of a tree showing an incomplete, discontinuous partial ring, p1, and a ring, p2, which is incomplete, but continuous. This ring lacks most of the early-wood.

apical meristems present in growing tips. (In shoots these also give rise to leaves, flowers, etc.) Numbers of dormant meristems may occur in the stems and roots of trees. Behind the apical meristems the newly-produced cells elongate, thus increasing the length of the main stem, branches or roots (Fig. 7). Many tree species have strong apical dominance in their shoot systems so that the tip of the leading shoot extends most rapidly and further than lateral shoots. If it should be removed, however, one or more other shoots become dominant. Other tree species have less well-developed apical dominance so that their branching is diffuse, or they may have strong dominance for the early part of their life and diffuse shoot development later (Fig. 8). Dominance of a single shoot may be well-expressed when a species grows in a dense stand but it may have diffuse branching when grown in the open (Fig. 8).

Branches arise from meristems in buds behind the leading tip of main stems or larger branches. There are characteristic branching arrangements for each individual tree species. Branch wood may be detected in transverse or longitudinal sections by its relationship to the main stem wood arrangement. It is of no significance in ring counting except inasmuch as it may interfere with interpretation of the ring sequence. As discussed later, presence of broken branches, or broken leaders below which diffuse branching arises, is indicative of avalanche damage.

Epicormic branches are a form developed by growth from dormant meristems in tree stems, often as a result of damage (e.g., Stone 1953). Root suckers, as in aspen, have much the same origin.

Root systems are of little importance in avalanche studies except that weakly rooted individuals may be easily torn from the ground by avalanches. They need not be discussed further.

6: STRENGTH OF WOOD

Strength and/or resilience is imparted to wood by the properties of the walls of fibers and tracheids and by the arrangements of these cells in the stems and branches (Jane 1956). Each tree species has characteristic parameters of wood strength (Betts 1919, Forest Products Laboratory 1955). The strengths of woods have been used in the estimation, from broken trees, of the impact forces of avalanches (Mears 1975).

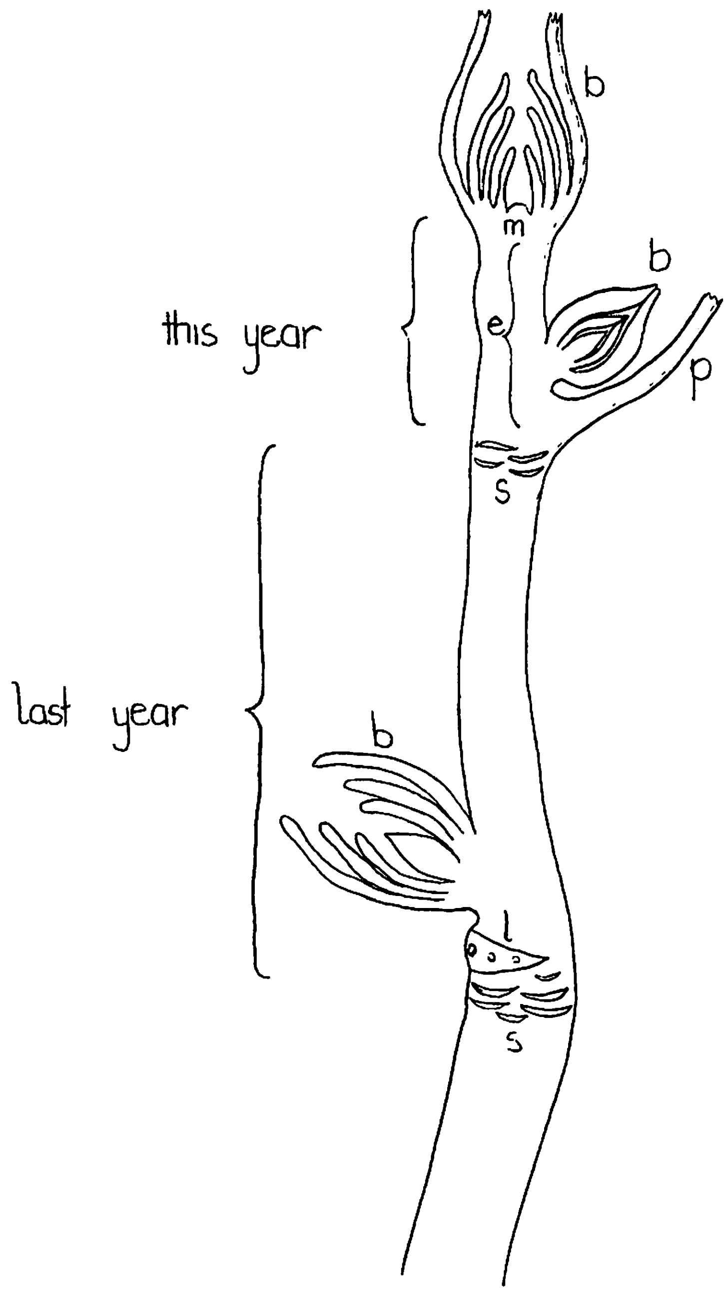

Fig. 7: Longitudinal diagram of branch tip of an angiosperm to show the position of the apical meristem (m). Other meristems are present in each other bud (b). The cambium is not shown. The region e represents the part of the stem laid down this year, which is still elongating. Last year a similar internode section was formed. These annual stem lengths can often be recognized by the bud scars (s) which are present at the nodes. p-petiole of a leaf; l-scar left by the shedding of a leaf.

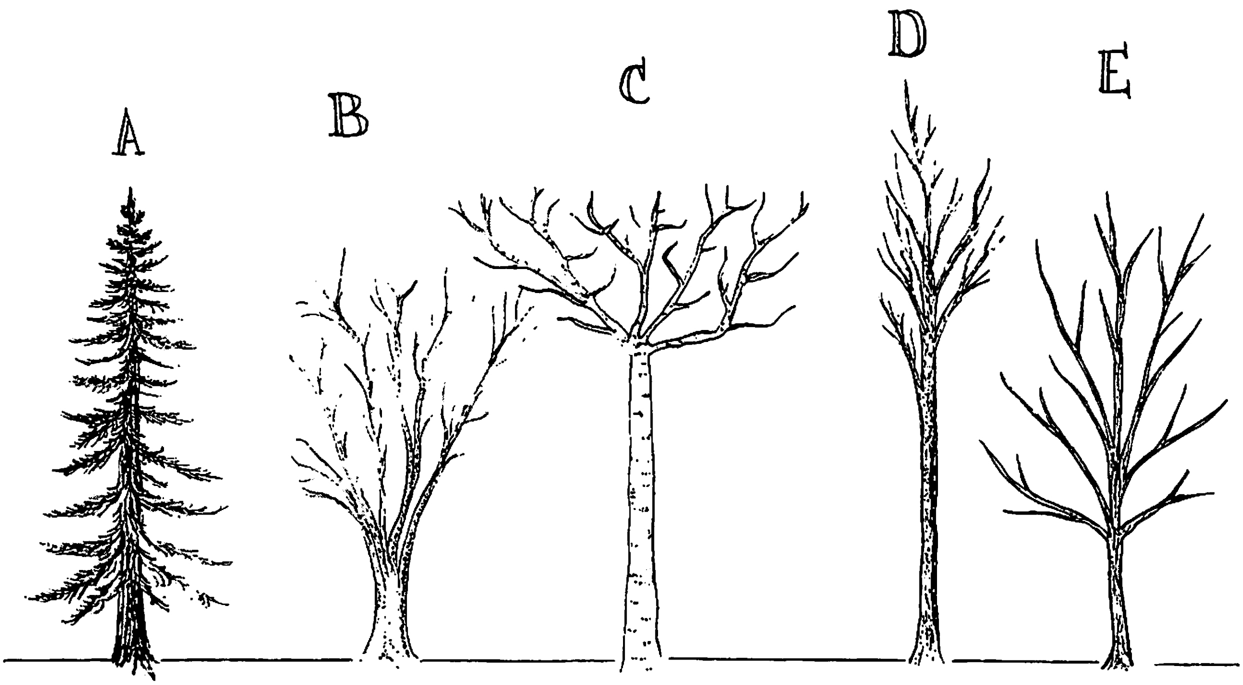

Fig. 8: Some different tree forms. A. strong apical dominance as in some gymnosperms; B. lack of dominance as in trees like Acer negundo (box elder) and many shrubs; C. early apical dominance then later lack of it, as may occur in Populus tremuloides (aspen); D. a tree such as an oak (Quercus sp.) or a cottonwood (Populus sp.) grown in a relatively closed stand; E. the same species grown in the open.

7: SHRUBS

Shrubs are relatively small woody plants which tend to lack apical dominance and have diffuse branching systems which either sprawl over the ground surface like juniper (*Juniperus communis*) or produce more or less upright stems like scrub birches and willows. Some of them have stems sufficiently tall and long-lived to be useful for dating, especially when scarring and breakage occurs. Many shrubs are small enough to lie beneath a protective snow cover or are so flexible that they are relatively little affected by the passage of avalanches. Little use has been made of shrubs for direct dating and checks may need to be made to determine that they produce annual growth layers. However, shrubs are often useful indicators of the frequency of avalanching or intensity of disturbance because they can grow in sites where trees cannot survive.

8: THE NATURE OF AVALANCHES AND THEIR GENERAL EFFECTS ON VEGETATION

Some knowledge of the nature of avalanches is needed before their effects on trees and other vegetation can be understood. Details of types of avalanches and their effects are described in Armstrong (1973, 1974), Potter (1969), Krebs (1974), and Ives et al. (1976). There are several ways of classifying avalanches.

(a) By size and velocity. Dependent on snow type, volume of snow released and slope.

(b) By type of path. Confined (or gully) paths are usually enclosed within depressions. They may be complex, with multiple upper paths channelled into one or more lower paths. Unconfined paths are present on broad slopes of generally even, steep (usually 30^{o}-45^{o}) gradient, often lacking forest vegetation (Fig. 9). Some unconfined avalanches occur in apparently unlikely places on quite well forested hillsides. These may be referred to as diffuse avalanches. Other geomorphic features such as the presence of large bowl-shaped snow-collecting basins or the occurrence of cliffs on the paths may be significant. Large avalanches down confined paths may be very destructive. Avalanching tends to happen less frequently on some unconfined paths, but they are destructive when they occur.

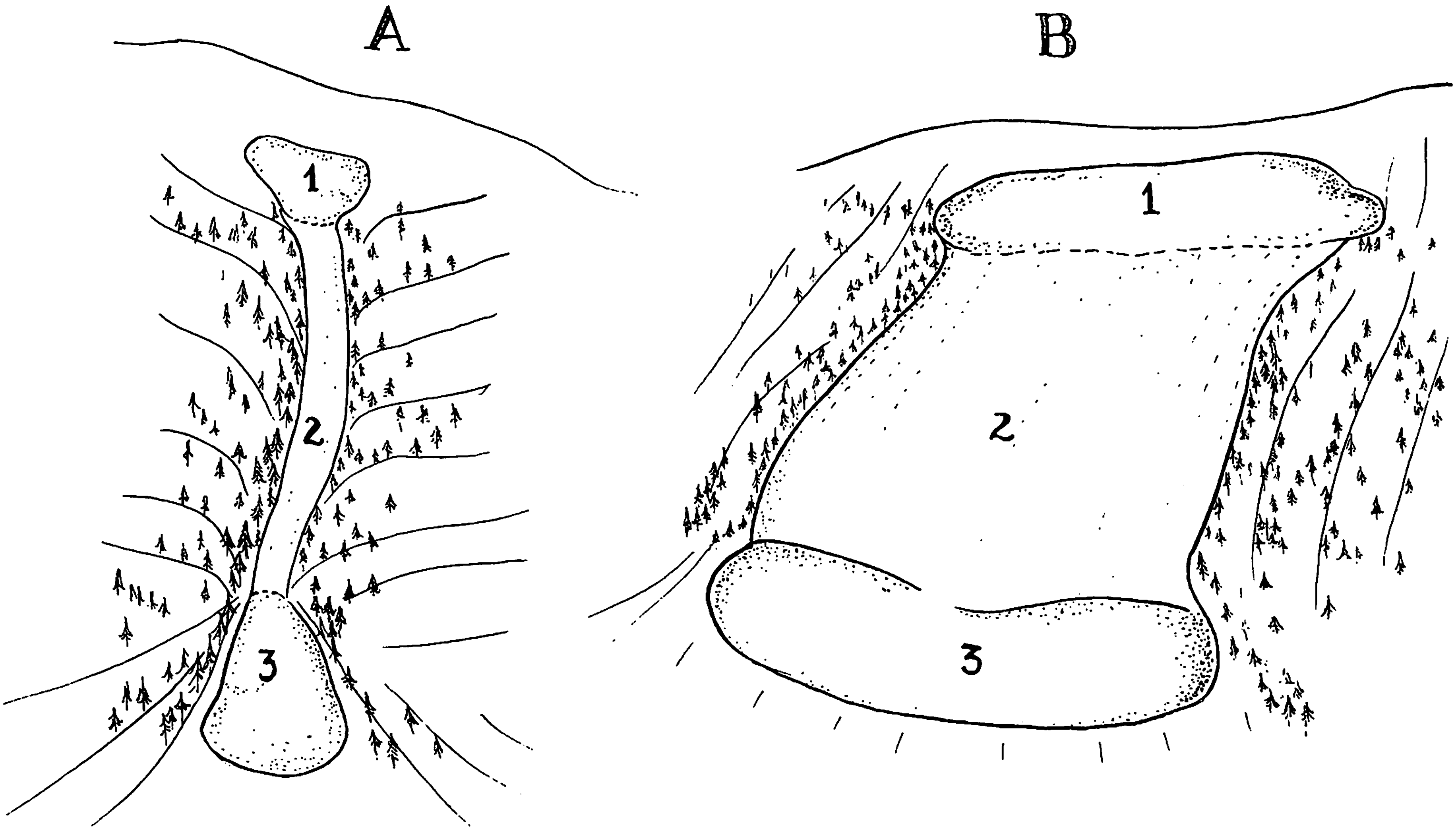

Fig. 9: Diagrams of the two common types of snow avalanche path. A. confined (or gully); B. unconfined. 1-starting zone; 2-track; 3-runout zone.

(c) By the type of snow. Loose snow avalanches, initiated by failure of a small amount of cohesionless snow, fall as a formless mass, of variable size. They may be formed of dry (winter) or wet (spring and summer) snow and some of the spring avalanches may be large. Wet snow avalanches flow close to the ground and travel at moderate velocities but may be destructive because of their density. Slab avalanches, starting when a cohesive snow layer slides from above another layer to which it is poorly bonded and falling in a dry, powdery mass, involve much larger areas and volumes of snow, achieve a higher velocity and are very destructive. They flow up to considerable heights above the ground. They may be accompanied by substantial wind blast of high velocity.

(d) According to whether the avalanche flows over a deep protective snowpack which prevents disturbance at ground level or whether the snow cover is thin and the sliding snow (and included debris) scours the ground surface.

(e) By frequency of occurrence.

Effects of avalanches on forest depend on the geomorphic situation, size of avalanche, type of snow and other factors. During an avalanche large enough to damage established trees, damage is caused not only by impact by the snow, but also by included debris such as broken trees and rocks from higher up the slope. Large, dry-powder avalanches cause damage such as breakage of tree stems and large branches near the boundaries of the path as much as 10 m or more above ground level. Damage may extend from starting zone to runout area. Wet snow avalanche damage may be more extensive and large trees are often uprooted. Smaller avalanches may merely tilt or break small trees and lateral branches along a trimline up to a few meters above ground level. However, they scour the bark, cause scarring and break branches on the uphill sides of larger trees standing in the avalanche track, up to the height of the top of the sliding snow. Undisturbed shrubs and tree branches up to a meter or so above ground level indicate that there has been protection in the form of a stable snowpack.

The plant species present on a site indicate the frequency of avalanching. Paths which avalanche annually have none or few large trees and these are usually badly damaged. Aspen is characteristically present on paths where avalanches are moderately frequent. Some large avalanches occur, infrequently but devastatingly, on slopes which, prior to the slide, were well clad in spruce-fir forest. There may be evidence of former avalanches, however, in the form of damaged or fallen trees or stands of forest younger than the mode for the area.

Certain small shrub and herb species are differentially distributed on paths subject to different amounts of disturbance. The nature of their ecology requires further study so that specific indicators can be identified. In some instances the plants of disturbed sites are not responding to disturbance, per se, but to enhanced light conditions or to enhanced fertility caused by the rejuvenating effects of avalanches on the soil (by provision of fresh, unweathered rock debris, soil and organic matter, or even to the activity of burrowing rodents which are common in such areas). Runout zones, depending on the frequency of avalanching and the length of time which the avalanche snow lies, have patterns of vegetation in which aspen and shrubs are often prominent. Where piles of snow lie late into the spring the cover may consist of herbaceous vegetation. A characteristic feature here and along the margins of paths is a jumbled mass of fallen trees brought down by the avalanches. The dates of avalanche episodes may be determined roughly, from these trees, if decay rates are known. Approximate decay rates of common trees are tabulated in Appendix III and data for the identification of woods in Appendix IV.

9: RESPONSE OF TREES TO TILTING, BREAKAGE AND SCARRING

Normally, the main stems of trees have more or less concentric growth rings (Fig. 10), but if tilting should occur they respond (especially those with strong apical dominance), by a curvature of the actively growing part of the stem which brings the long axis of the tree into a near-vertical position once more (Fig. 11). In the wood an often well-marked band of reaction wood (tension wood in angiosperms, compression wood

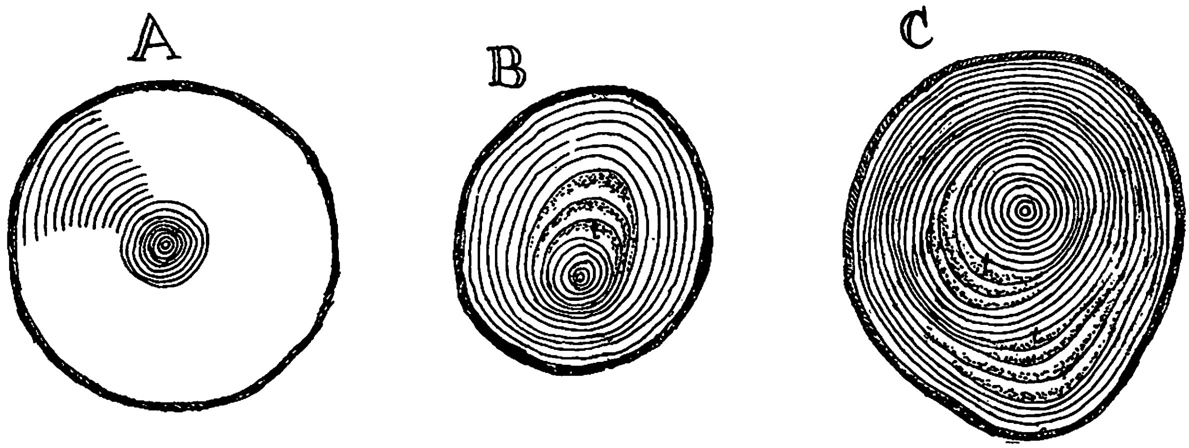

Fig. 10: Sections of tree stems showing A. concentric rings in a vertically-grown tree; B. reaction wood (t) formed in an angiosperm tilted in a direction toward the bottom of the page; C. reaction wood (t) formed in a gymnosperm after two episodes of tilting, more or less in the direction of the bottom of the page.

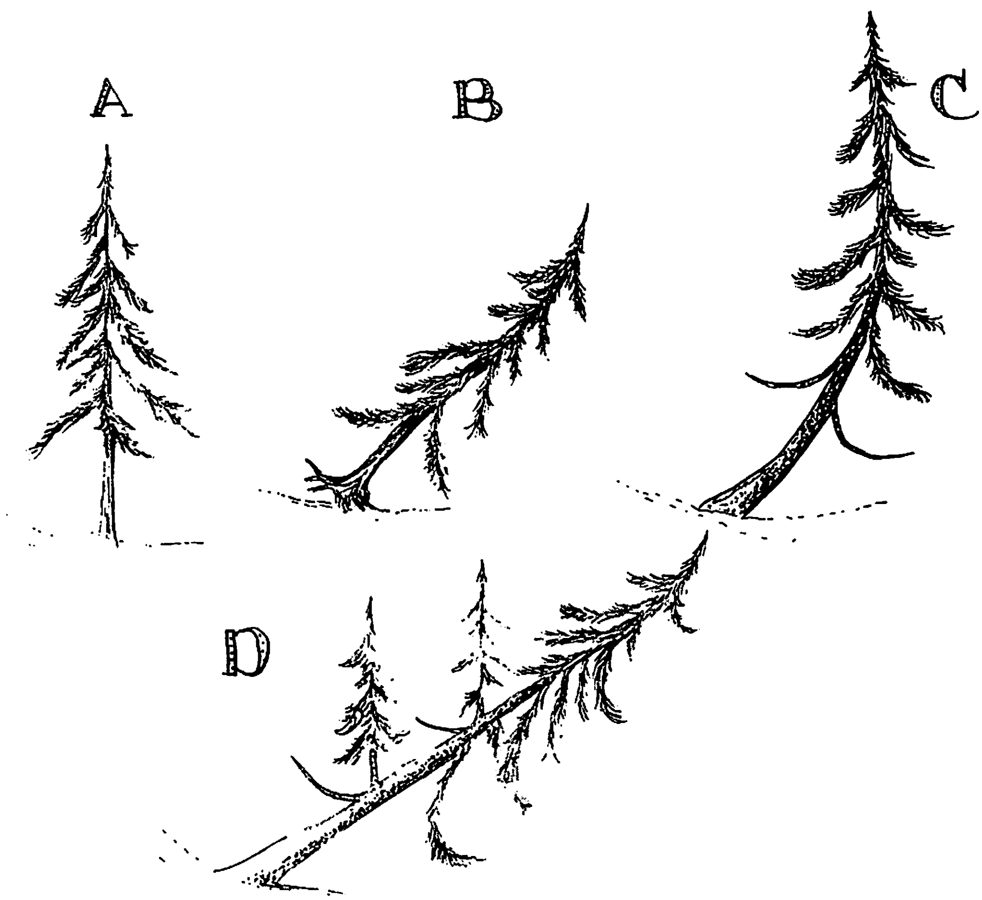

Fig. 11: A. an untilted tree; B. a young tree newly tilted; C. straightening of the same tree a few years later; C. production of new, vertically-aligned branches by a tilted tree.

in gymnosperms) and wider rings than normal are produced to one side, and the leaning tree acquires an eccentric cross section which contrasts with the earlier concentric rings (Pillow & Luxford, 1937, Lawrence, 1950, Dadswell, Wardrop & Watson, 1958, Esau, 1962). In gymnosperms the eccentricity is due to the formation of wider rings normally on the lower side of the stem, in angiosperms they are usually present on the upper side of the stem (Fig. 10). These phenomena permit precise dating of the tilting event (discussed later). Branches are not useful in this respect because their more or less horizontal position causes them to have eccentric growth throughout their life. Tilting, in some instances in the North American trees we have examined, does not result in curvature to a new vertical position. In these instances lateral branches may grow vertically and these can also be used to obtain a fairly precise date for the time of tilting (Fig. 11).

Tilting may occur in ways other than by avalanche effects. For example, strong winds may cause it and considerable amounts of tilting occur in some sites as a result of soil creep, snowpack creep and possibly as a result of snow loading in the upper branches. Aspen trees on slopes seem to be very commonly curved at their base, subsequent to tilting. Distinguishing whether tilting has resulted from avalanche effects (either direct impact or wind blast) requires a careful examination of the locality. Strong indications that tilting resulted from avalanches are that most trees are tilted in the direction of flow of the avalanche and that there are other signs of avalanche incidence such as stems broken near the impact level, and in the same direction, and scarring through the depth of the avalanche, on the uphill side of surviving trees. Large or small windthrows can simulate the pattern but breakage is less common and usually occurs high in the trees. There are usually no scars.

The most likely places for tilted trees to survive are along the margins of tracks and at the toe of runout areas. In some instances runout is uphill on the opposite side of a valley from the main avalanche tract so that trees tilted in an uphill direction, or in oblique or horizontal positions can occur, depending on the direction of the flow of snow during runout (Fig. 12).

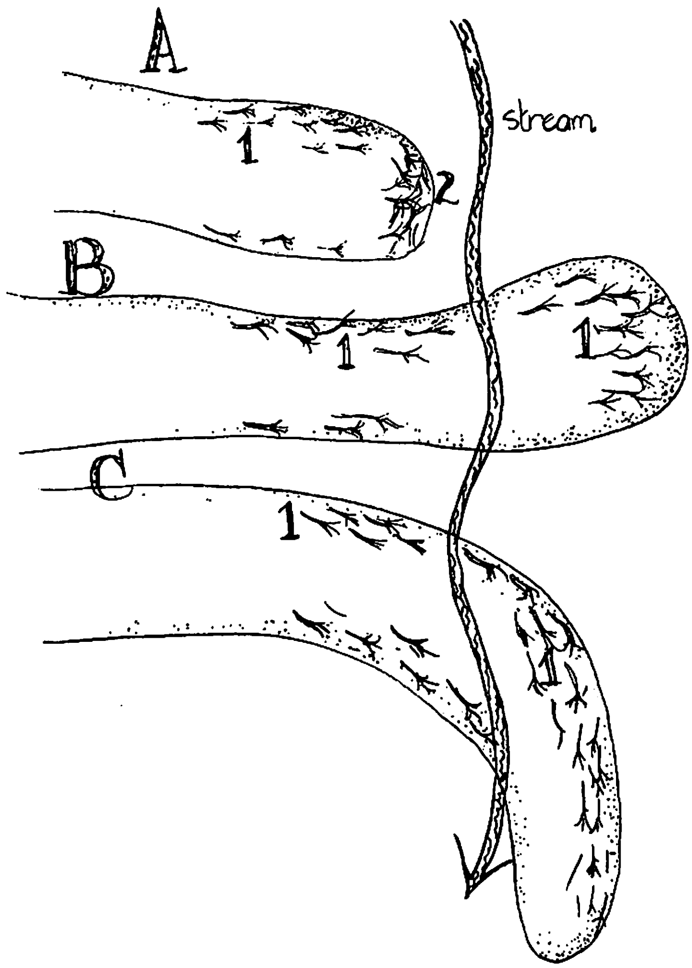

Fig. 12: Distribution of fallen tree stems on snow avalanche paths. A. a simple path descending to a valley floor; B. a path where avalanches cross a stream to mount a hillside opposite; C. a path where avalanches sweep down a hill, then downstream for some distance. 1 - fallen trees aligned in the direction the avalanches travel; 2 - jumble of trees in a runout zone.

Frequent avalanches down a track maintain clearly defined trimlines along forest edges (Fig. 13). Similar trimlines occur where an exceptional avalanche has cut a swath into well-established forest. Epicormic and scarred branches may be present along such trimlines and they may be used to date the occurrence of the avalanche. A useful situation is that where several stages of forest regrowth represent the cutting of several trimlines by successive avalanches at different times (Fig. 13).

Undamaged trees on or beside avalanche paths give minimal dates for the occurrence of the last major avalanche and they often occur in groves of different age which define, to some extent, the paths taken by particular avalanches. Their extent within their trimmed edges define regions on the tracks protected from particular avalanches (Fig. 14).

Breakage of stems of trees or branches may be used to define areas subject to avalanche and, in some circumstances, can provide dating tools. Dormant buds are sometimes stimulated to grow when branches or main stems are broken (Fig. 15) and counts of their growth rings give precise dates for the time of occurrence of the causative avalanche.

Scarring (Fig. 16) is also useful in dating. Trees and rocks carried by avalanches are hurled against the uphill side of standing trees, causing cuts in the stems. Wound healing begins and the scar eventually is grown over and may be difficult or impossible to detect some time after the event, although, if a section is cut, discoloration and healing tissue is usually evident. Multiple scarring may be evident in cross sections of stems (Fig. 16). There are other causes of scarring which may simulate avalanche effects, e.g., rockfall, sun-scald, frost damage and browsing by animals. Of these only scars caused by rockfall should be a confusing factor because none of the others will be distributed preferentially on the uphill side of trees. Normally, rockfall will be a less frequent cause of scarring than avalanche but it should be looked for when sites being studied lie beneath bluffs or screes with loose surface debris.

10: CHANGES IN RING WIDTHS

There may be two consequences of avalanche occurrence reflected in the patterns of ring width. Firstly, a swath may be cut in a dense stand

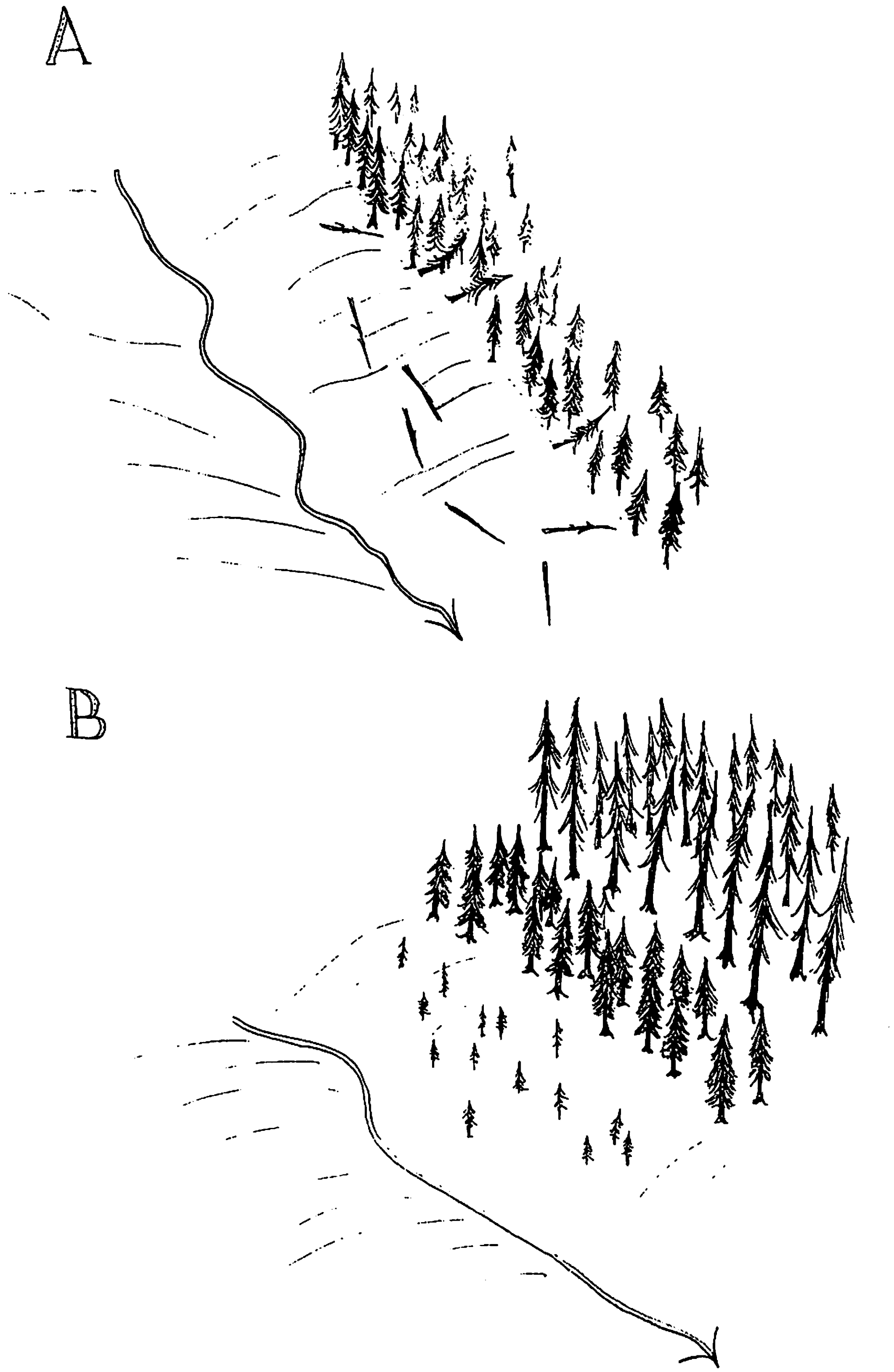

Fig. 13: Trimlines cut by snow avalanches. A. a clean trimline in mature forest, with a few tilted trees; B. closer view of a trimline showing two episodes of trimming, with trees of three age groups present.

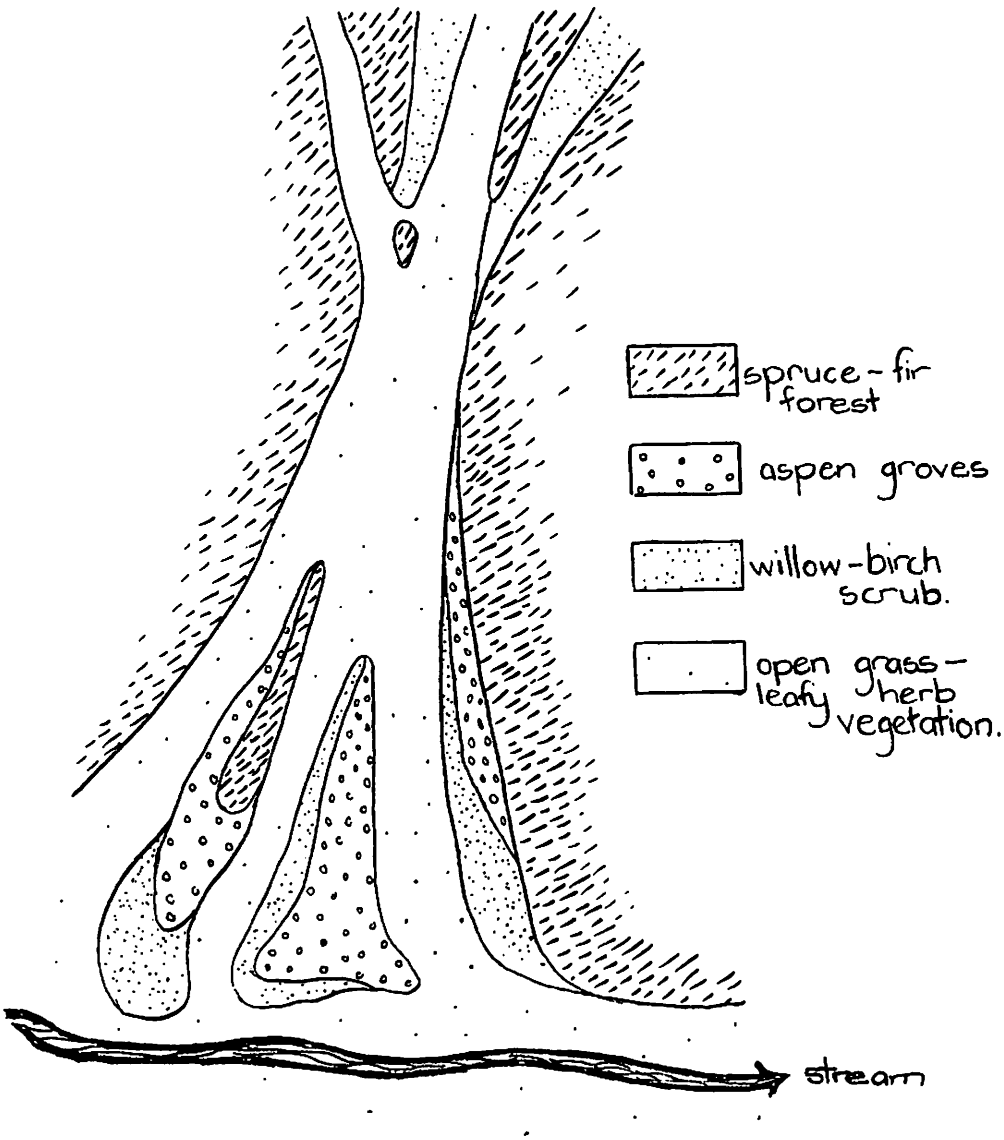

Fig. 14: Plan of a snow avalanche path with vegetation patterns reflecting a complex avalanche history. The grassy and scrub-covered areas experience frequent avalanches, and the aspen groves infrequent avalanches. The scrub areas are better-protected from scouring by avalanches than are the grass-covered areas.

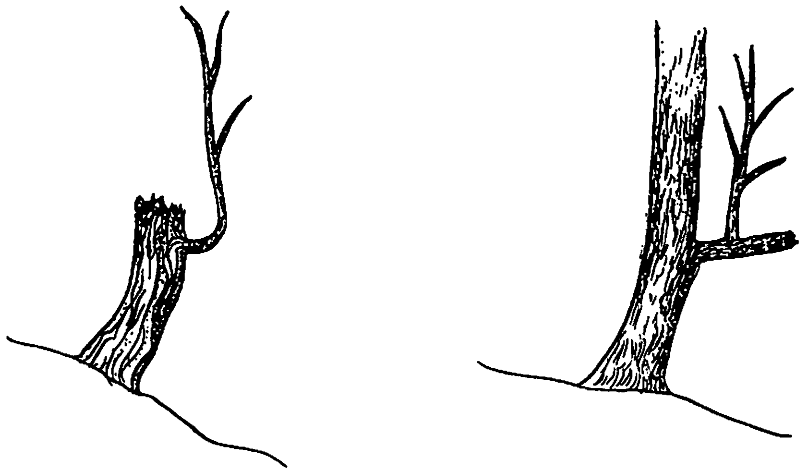

Fig. 15: Regrowth of branches from dormant buds after breakage by snow avalanche.

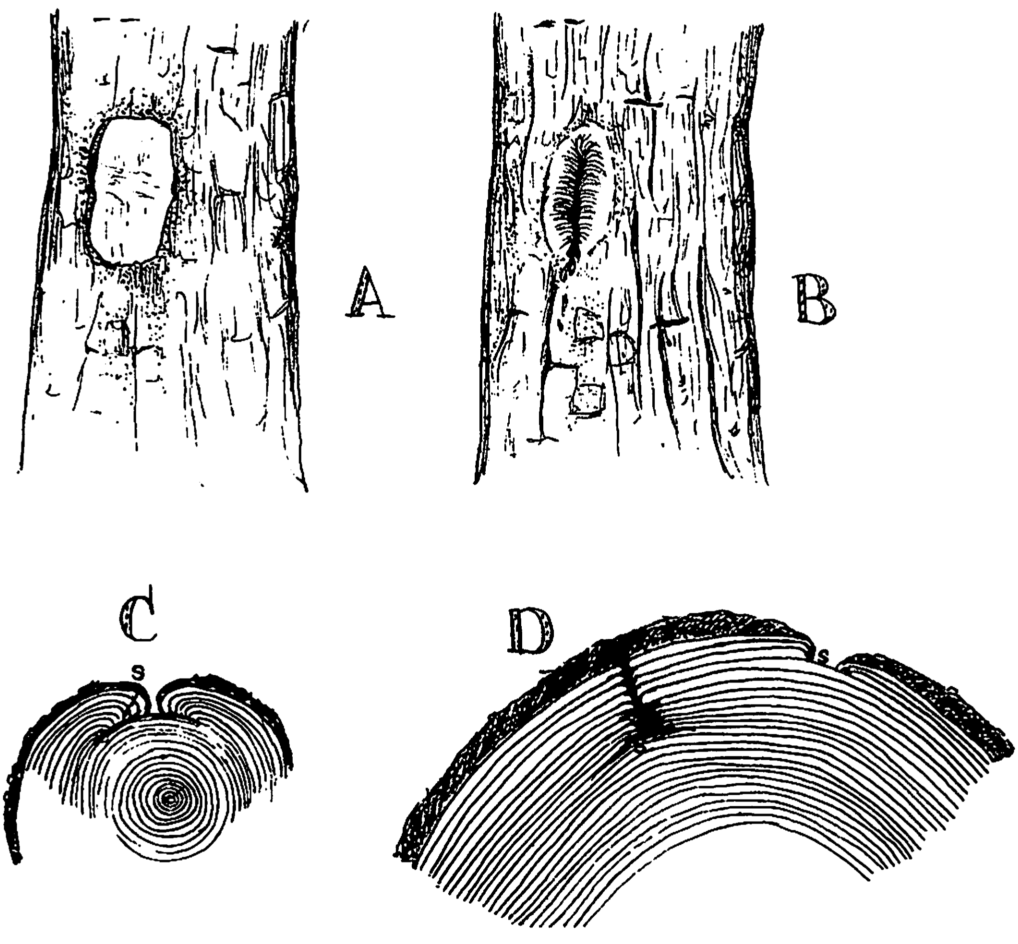

Fig. 16: Scar on tree (A) caused by a recent avalanche; B. healed scar some years after the damage occurred; C. transverse section of a stem with a partly healed scar (s) which occurred seven years ago; D. section with a recent scar and an older, completely healed scar which occurred eleven years ago.

of trees, or an avalanche may remove some trees and leave others unaffected. The trees along the margin of the new trimline or the undamaged survivors of the avalanche are released from root and shoot competition so that a consequence may be enhanced growth, reflected by the production of wider rings from the time of opening-up of the forest. Secondly, damage to trees by breakage or scarring, or disturbance of the root zone by scouring, may be so severe that a sequence of narrow rings is formed subsequent to an avalanche. Narrow rings also are formed after forest closure (and increased competition) or in old age. These changes should be more gradual than those caused by avalanche. Attacks by pathogens or damage by other hazards may also produce sudden sequences of narrow rings, however.

11: SEARCHING FOR SUITABLE SITES

There is usually no difficulty in finding sites for the study of avalanche chronologies in mountainous areas with heavy winter snowfall. Various pamphlets or papers describe many known avalanche paths in Colorado (Frutiger 1964, Martinelli 1974, Miller, Armstrong & Armstrong 1976) and others are well known to persons engaged in other aspects of avalanche research (personnel of the U.S.D.A. Forest Service, Forest and Range Experiment Station, Fort Collins, or INSTAAR). In areas where avalanches are common the clear tracks of many of them are easily visible on topographical maps or aerial photographs, contrasting with the relatively undisturbed forest. Scanning of oblique photographs, stereoscopic inspection of vertical air photographs and ground inspection in summer to ascertain the boundaries of avalanche paths (from the distribution of damaged trees) and to find stands of forest of different ages, is essential, however, in checking for evidence of older events. Scanning with binoculars from vantage points on opposite slopes may be useful. Otherwise, the places on avalanche tracks and runout areas which provide useful information will be obvious from the foregoing descriptions. In a search for older and perhaps massive events, unconfined paths or paths with infrequent avalanche events, well covered with mature trees, are likely to provide the most information; but in relatively unknown areas, information on frequency of avalanching may be obtained from confined paths where avalanches occur annually.

Care must be taken where there have been fires or where human disturbance such as mining or logging have interfered with the forests. Use of historical records and old dated photographs is obviously most important in assisting the study of avalanche chronologies as well as in the interpretation of other kinds of disturbances (Armstrong 1976).

It is desirable to prepare a reasonably large scale and detailed plan of each avalanche path being studied. Accurate maps can be prepared from air photographs by standard photogrammetic techniques (Spurr 1961) but working maps need not be so accurate. Sketching from vertical and/or oblique air photograph enlargements will be sufficiently accurate for many purposes. On these plans can be shown details of surface features, trimlines, positions of sampled trees and close-up photographs, positions of measured profiles and detailed vegetation studies. As well as field copies of the maps, master sheets are needed onto which final details can be transcribed.

In addition, careful records need to be kept of other details of the localities and characteristics of avalanche paths, wood samples and photographs taken. Code numbers and common names are already available for many avalanche paths in Colorado (Frutiger 1964, Martinelli 1974, Miller, Armstrong & Armstrong 1976) but map sheet grid references are also necessary. Prepared plot sheets (Appendix V) are useful for the documentation of information.

Levelling, using a surveyor's level and stadial rod, may be done to obtain profiles of the avalanche paths.

12: PROCEDURES FOR COLLECTING AND HANDLING SAMPLES FOR STUDY

The main kinds of samples to be collected are stem and branch sections and cores. Equipment and some advice for its use and care are listed in Appendix V1I.

Care is needed in the identification of the species and the characteristics of foliage, bark and wood of each species in the area should be learned (Harlow & Harrar 1937, Forest Products Laboratory 1955, Appendix IV).

Sections: These are much to be preferred because they provide more information and are easier to interpret than cores. Permission must be obtained from the authority controlling the forest (usually the U.S.D.A. Forest Service) before trees are cut. The trees need to be carefully selected, as those which will provide the most information and care must be taken to avoid unnecessary damage. Gnarled and broken trees can be cut with a clearer conscience than relatively undamaged trees.

Seedlings, saplings, small poles and branches can be cut with a sharp hand-saw. Larger trees require a chain saw and hard hats and eye shields should be worn. Considerable care is needed in the use and maintenance of chain saws and inexperienced persons should obtain advice from experts, not only for this but also for the rather dangerous business of tree-felling. If the tree is standing, a small wedge-shaped cut is made about one-third through the tree on the downhill side, lower than the main cut will be and in the direction in which it is desired to fell the tree (Fig. 17). It is not possible to change the direction of fall of a tree leaning more than 5^{o} from vertical. Wedges can be used when large trees are being cut. Avoid situations where the tree-top will become hung-up in the tops of other trees and watch for rolling butts. Always select safe positions into which you may retreat, if necessary. Once felled, cuts may be made in the tree wherever they are required. Already fallen trees, knocked over by recent avalanches, may provide a great deal of information and suitable specimens should be looked for before any standing trees are cut. Trees broken off or uprooted, but still more or less in situ are preferred because the positional data for them can be recorded. Nevertheless some of the freshly fallen trees in the jumble at the bottom of an avalanche path can provide useful information. Minimal dates for the length of time mature forest was undisturbed by avalanche can be obtained from the largest of these trees and, if it is certain that tilting or scarring resulted from avalanche, sections can be cut to date these.

There may be some problems in cutting leaning or fallen trees. Some, which are under tension, require care because cut stems may spring back and cuts in the wrong places can result in a pinched saw-blade

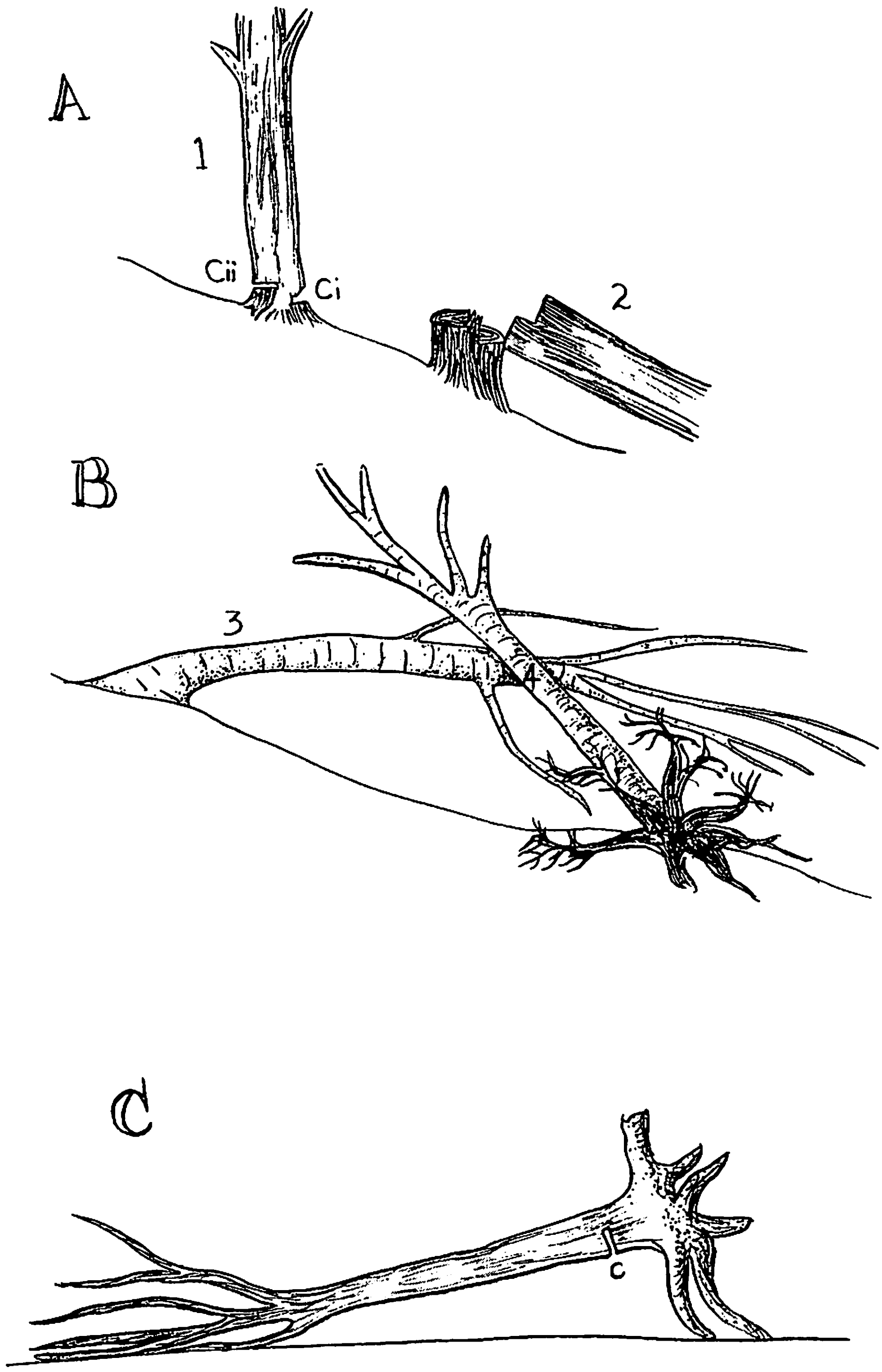

Fig. 17: A. cuts for felling a standing tree (1). ci-first cut; cii-second cut. 2. felled tree. B. tree 3 is under tension and care is needed in cutting it in case of spring-back of cut sections. Some undercutting may be needed. C. fallen tree - under-cut at c, then carefully cut from the top to avoid pinching of the saw.

(Fig. 17). Avoid situations where stones or soil may blunt or damage the saw teeth. Some excavation of soil and stones may be necessary.

Cuts are made, at right angles to the long axis of the stem or branch, in appropriate places (across scars, at the base of trees which have been tilted, at the base of branches which developed after breakage) (Fig. 18). Discs about 5 cm thick (or more) should be cut. If thinner sections are needed for microscopic examination, it is usually preferable to cut these with a band saw in a workshop. On the side of the disc, preferably in some cardinal direction, cut off the bark with a sharp knife and record with a marker pen a coded symbol for species, individual sampled and avalanche path. Mark north position and downhill position on the bottom of the disc. The individual number is marked in position on the field copy of the plan of the path. The diameter of the disc is marked on the plot sheet (two axes if eccentric). Discs may be stored, temporarily, in plastic bags but it is preferable that they should be dried to prevent them from becoming mouldy. Drying is done, slowly but steadily, to avoid excessive cracking. Keep them in a warm, dry place, but not in the sun.

Cores: These are taken mainly from large, old trees beyond the margins of avalanche trimlines, to obtain minimal ages for freedom of these sites from avalanche damage. They may also be taken from groves of younger, undamaged trees on avalanche paths for the same purpose. Cores are obtained with increment borers (Fig. 19). Choose a position as near the base of the tree as possible. If the trees have eccentric cross sections, look for the radii which are likely to have the widest rings. Clear the bark away with a knife and insert the borer carefully horizontally (turning clockwise) and aiming for the tree center. Do not exert lateral strain because this may break the borer. When it is felt that the center has been reached, insert the channeled extractor (always beneath the core), turn the borer half to one turn clockwise, then extract it by turning anticlockwise (Fig. 20). The marks of the extractor on the core will help to orient it for future examination. Examine the core to see whether the center of the tree has been hit. It is pointless to try to estimate the number of missing rings if the center has not been hit. Try again.

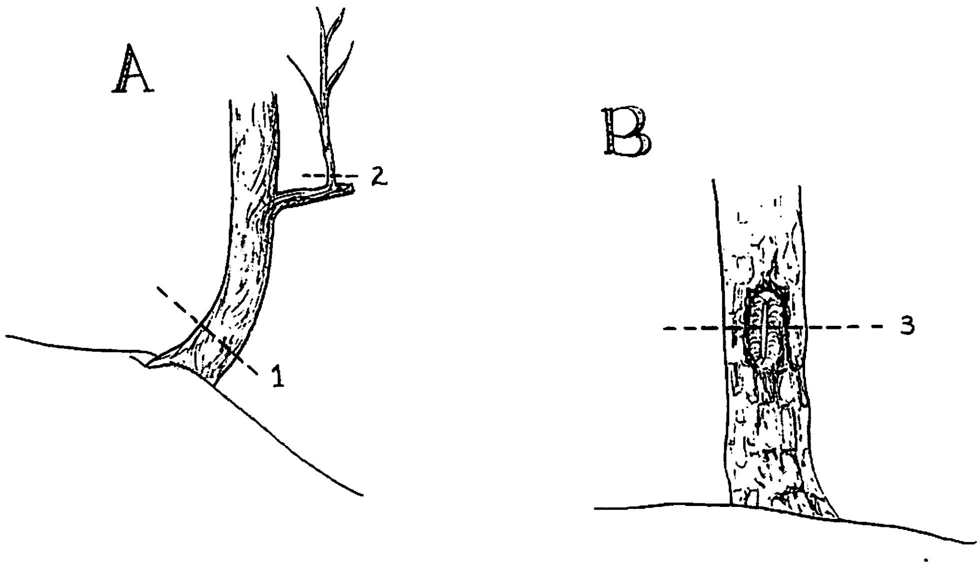

Fig. 18: Cuts to make for sections to age: 1. a period of tilting; 2. regrowth of branch from a dormant bud, after breakage; 3. a scarring event.

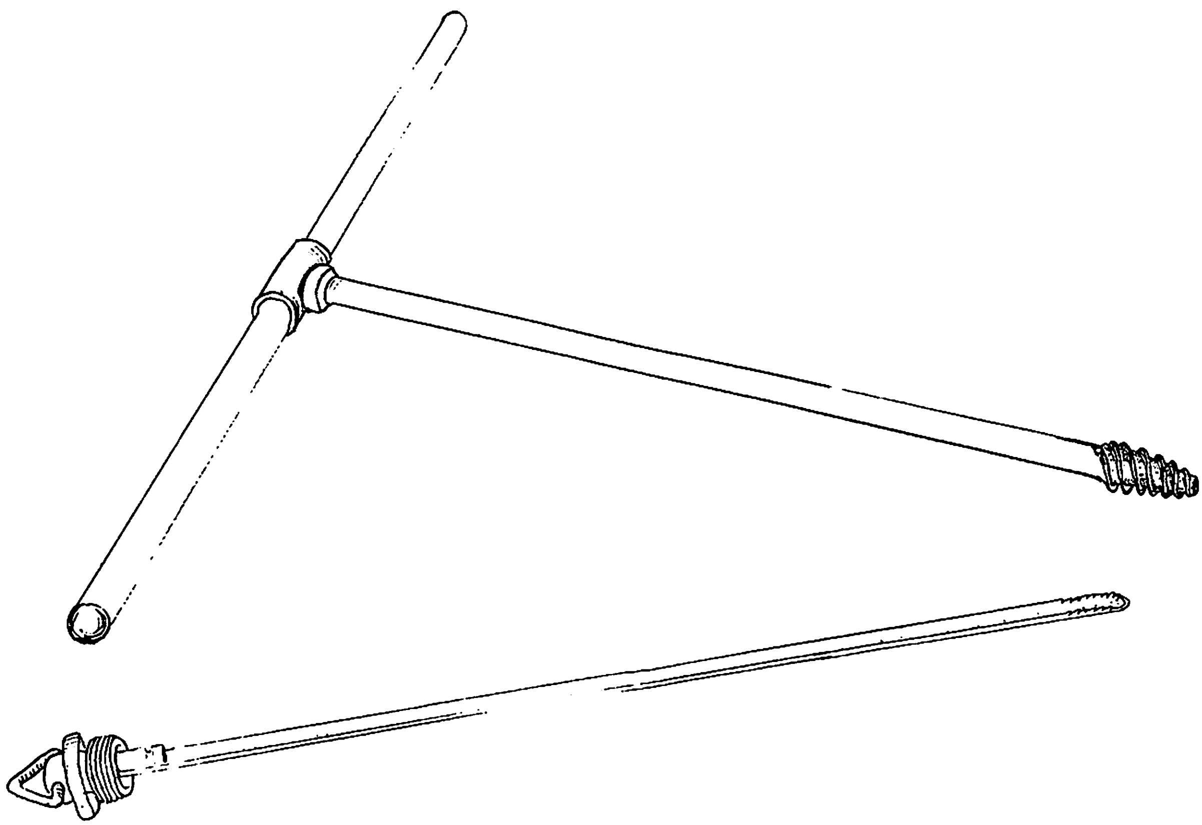

Fig. 19: Increment borer and channelled extractor.

It is preferable to obtain cores from at least two radii of each tree sampled. It may be desirable to plug all core holes with sections of dowel to prevent access by rot fungi; ask the local forest authority. Rotten hearts of trees may cause difficulties in extraction of the borer, so stop whenever lack of resistance is encountered during a boring operation.

Carefully slide the core into a plastic milk shake straw, label with a tag label and store the cores, for carrying, in a rigid box. A box with numbered positions, into each of which only one core will fit, is useful to ensure that there is no confusion. The cores of gymnosperms may be stored like this and usually dry out without difficulty. Aspen cores may require staining (cf. Appendix VI, Patterson 1959, Trujillo, 1975).

If a large number of core samples is to be taken a mechanical borer may be needed. These are usually in the form of electric drills (Stokes & Smiley 1968, p. 28, Yelf 1962, Bowers 1960, Stonecypher & Cech 1960).

Larger increment cores than normal may be required and special borers can be constructed for this (Transtrom 1952). Large wood samples can be extracted from living trees without causing excessive damage by methods like those described by Brown (1958).

Sample sizes: One tree may provide information about many avalanche events, and this may constitute a suitably-sized sample. However, it may be desired to obtain larger samples for statistical treatment. These, ordinarily, will need to be no bigger than five or six trees (e.g., to date a tilting event, or the event which caused scarring).

13: PREPARATION OF SECTIONS AND CORES FOR STUDY

Sections may need to be trimmed in a workshop with a band-saw (taking care to renew labelling if it is removed). For microscopic examination discs should be 4 to 5 cm in thickness. The next phase is polishing of the upper side of the disc. The first polish, to remove the rough saw cuts, is best done with a mechanical sander with coarse, then fine grades of paper. Then, if necessary, hand-sanding with finer and finer grades of sandpaper is done until the section has a smooth finish. Intransigent woods like aspen are smoothed and treated with chemicals or stains which

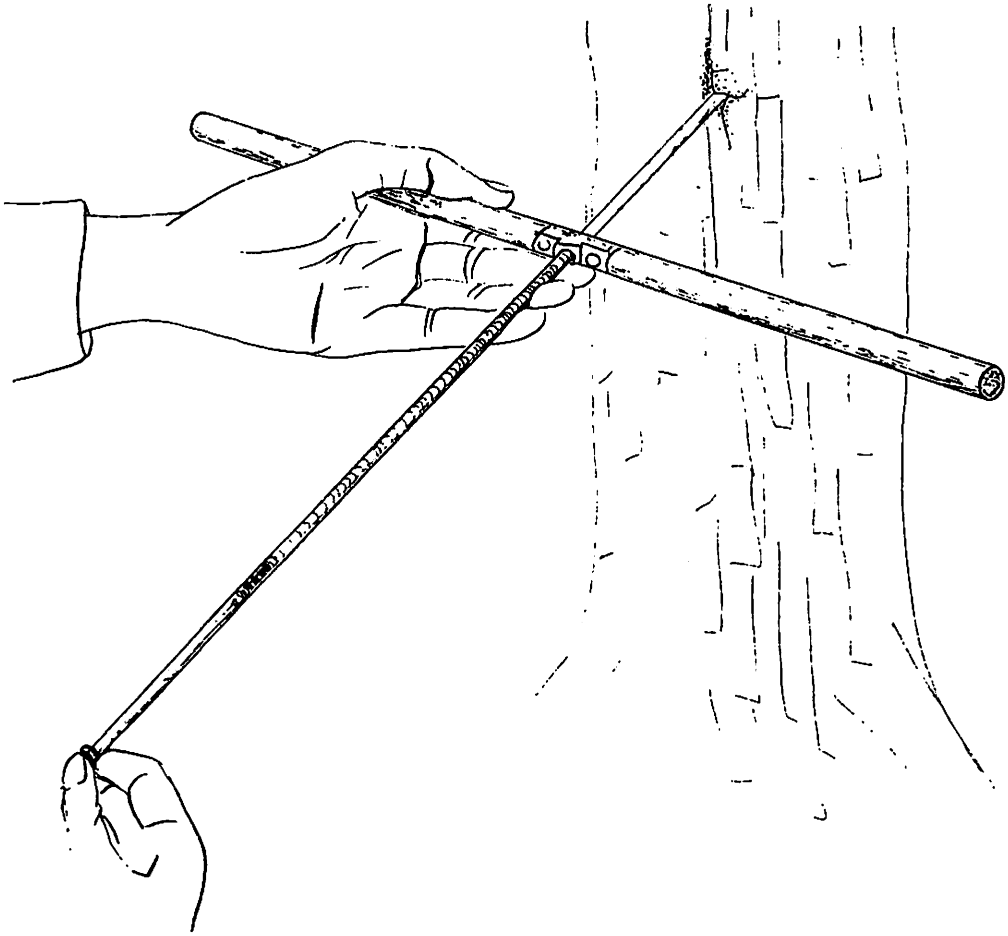

Fig. 20: Use of increment borer.

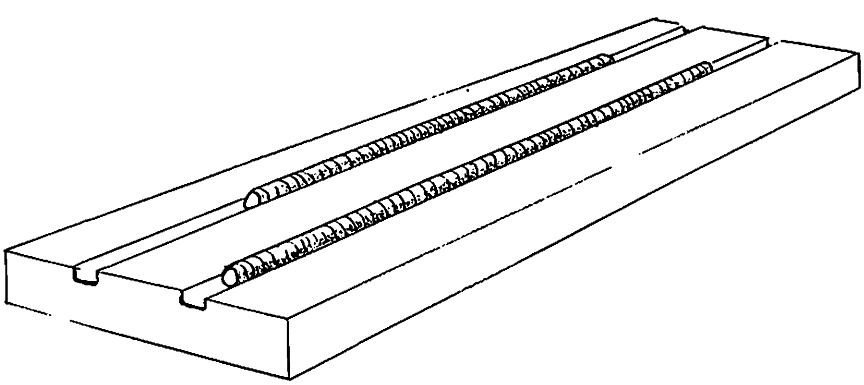

Fig. 21: Increment core in block ready to prepare for counting.

differentiate early and late wood. A range of stains and instructions for their use are noted in Appendix VI. One of the most useful for aspen is malachite green-methylene blue. Another method which we have found useful with some difficult woods is to cut a thin slice from the disc with a band-saw (3 to 5 mm thick) and examine it with transmitted light.

Cores are prepared, preferably when they are still wet, by jamming them, top uppermost, in blocks with grooves cut just wide enough to take the core (Fig. 21). The rough top of the core is sliced along, smoothly, with a sharp scalpel and, if necessary, polishing is done with very fine sandpaper. Aspen cores are treated as discussed by Trujillo (1975) or with one of the stains listed in Appendix VI.

14: COUNTING PROCEDURES AND RECORDS

Counting of rings, both in sections and cores, is done using a good stereomicroscope with wide field of vision, 2x or 5x eyepieces and 2x to about 10x objectives (or a zoom lens). Wetting with water, or more permanently with kerosene or diesel fuel often assists in making the rings stand out. Counting of growth layers is done systematically from the outside. Great care is needed in distinguishing narrow layers. Complete decades are marked with a pencil dot, half centuries with two dots, and centuries with three dots. Check counts should be made on the same and different radii. A code system may be used to indicate special features such as scarring, tilting, or false rings. In many instances the total number of rings after an event like scarring or tilting, or regrowth of a forest stand after a site has been cleared by an avalanche, is all that is needed. In other instances records similar to those given by Potter (1969) may be desired.

After counting is completed cores and sections should be permanently stored and labelled for future reference.

15: SUMMARY OF THE USE OF TREE RING INFORMATION FOR OBTAINING AGES OF AVALANCHE EVENTS

Minimal Dates: An approximate date for the last clearance of a site by avalanche is obtained by aging the oldest trees on the site. If the general rate of colonization of the site by the species concerned is known, then the chronology may be extended to be closer to the absolute date for the avalanche, by adding the number of years which elapse between an avalanche and establishment of young trees. Several years may need to be added to take into account the time taken for the young trees to grow to the height where the section or core was taken. This procedure only works where a devastating avalanche has cleared a swath through old forest, or where avalanches are infrequent; even then young trees may have survived the avalanche. Most avalanche tracks with frequent avalanching have small trees surviving on them in a more or less suppressed form, partially protected by the winter snowpack but damaged whenever they project above the snowpack. It is not known how long these stunted trees will persist, but some nearly 100 years old have been observed.

On sites which have been free from avalanching for a very long time, normally this procedure for obtaining minimal dates may only be applied within the lifetime of the oldest trees in the locality. In rare circumstances the root system of a mature tree may be found straddling an old, dead tree. In these circumstances, if the old tree is not too decayed, its age may be added to the age of the living tree.

Absolute Dates: Precise dates for avalanche events can be obtained where scarring, tilting and breakage of branches or main stems and regrowth of new branches has occurred. Care is needed to ensure that avalanche was the cause of the damage. Change in patterns of ring width resulting from opening up of forest (increase in width) or damage to trees (decrease in width) may be useful but the changes are less easily attributable to avalanche.

The kinds of interpretation which are made from tree ring data will depend on the purpose of the study and the results obtained during it. Perhaps the best way to exemplify the kind of things which may be discovered is to make reference to Potter's (1969) work in the Absaroka Mountains, Wyoming. Apart from observations on the importance of avalanches as geomorphic agents, Potter showed that large avalanches had occurred on one group of tracks in 1884, 1935, 1963 and 1965. He found little correspondence between this record and those on another group of tracks. He was able to define quite clearly and map the limits of the 1884, 1963 and 1965 events.

It is possible that other techniques may be useful for extending the chronology of avalanching beyond the age of the oldest trees in a locality. A dendrochronological study of old, dead wood, compared with the ring sequences in standing trees <u>might</u> be possible. A search in bogs lying beneath avalanche tracks for wood suitable for radiocarbon dating may offer the best opportunity for dating ancient avalanche episodes.

As a last word it remains to be said that there is a vast amount of chronological work to be done in areas subject to avalanche and it is likely that, when better chronologies are available, they will add appreciably to our understanding of the avalanche problem.

GLOSSARY

angiosperm: A member of the flowering plant group which includes hardwood trees such as oak and maple, plants such as grasses, other leafy herbs and many shrubs and herbs, all having the characteristic organs, flowers and seeds enclosed in ovaries.

annual growth layer: (Abbreviated to growth layer). A layer several to many cells thick in the wood of trees and shrubs, which is added to the cylinder of the stem, branch or root each year.
Synonymous with annual ring.

apical dominance: Situation in most trees and some herbs where the leading shoot grows further and more quickly than subsidiary shoots.

apical meristem: A tissue at the growing tip of stems, roots and branches which gives rise to new cells and thus permits their growth in length.

aspect: The direction in which a slope faces.

avalanche path: A general term; the whole or any part of the path of a snow avalanche.

avalanche track: A specific term; the part of the path of a snow avalanche which leads from the starting zone to the runout zone.

bark: The outer covering tissue of the stem, branches or roots of woody plants.

branch: A shoot of a plant which diverges from the main stem or another branch.

bud: An organ of a plant which contains a meristem and embryonic leaves (or other parts).

cambium: A thin layer of meristematic tissue in plant stems, branches and roots. It usually surrounds the stem, (etc.) just outside the wood and, by dividing off cells to the inside gives rise to new wood, thus increasing the diameter of the stem (etc.). It also divides off cells to the outside to form the phloem and other tissues and bark.

canopy: The top of the mature forest.

clone: A group of plants of uniform constitution formed by some method of vegetative reproduction such as root suckering.

closed: A forest where the trees are close together and the canopies touch.

deciduous: Losing its leaves during the winter season.

dendrochronology: The scientific study of unique sequences of wide and narrow growth layers (tree rings) in woody plants for the purposes of dating or climatic or other studies.

diffuse avalanche: An avalanche, on forested hillsides, which runs beneath the trees, causing relatively minor damage.

dioecious: Bearing male flowers on one individual plant and female flowers on another.

epicormic branch: A branch arising on the stem of a tree from a dormant bud.

evergreen: Retaining leaves during the winter season.

fiber: A long, very narrow and tough cell in wood, responsible for imparting strength and resilience.

fruit: A seed or group of seeds, together with the dry or fleshy tissues, derived from the ovary, which surrounds it or them.

gymnosperm: A member of the plant group which includes the conifers such as pines, firs and spruces and plants like junipers and yews which have more or less fleshy parts adjacent to their fruits. All have their seeds somewhat exposed on scale-like organs.

herb: Somewhat soft, non-woody plants, including grasses, sedges and plants with broader leaves. Some herbs have erect stems stiffened with fibrous tissue.

increment borer: A tubular boring instrument with a cutting edge with a smaller bore than the barrel, used to extract cores of wood from trees.

leader: The distal end of the main stem of a plant.

mature tree: One which has reached the potential full canopy height for the locality and which continues to be vigorous.

meristem: A tissue in plants capable of producing new cells. The main types of meristems are cambium, apical meristems, those giving rise to bark, those in buds and those at the base of leaves of grasses.

open:	A forest where the trees are relatively widely spaced and the canopies do not touch.
parenchyma:	Tissue formed of relatively undifferentiated and somewhat isodiametric cells.
phloem:	Tissue forming a narrow band or discrete bundles outside the xylem in stems, branches and roots in plants. It is responsible for the conduction of the products of photosynthesis.
population:	All the individuals of a class of things, such as trees.
pole tree:	A young tree which has not yet reached maturity, greater than 6 m high and less than full canopy height.
provenance:	The locality from which trees or seeds are derived.
ray:	A tissue in the wood, consisting of a lens of tracheids and parenchyma (gymnosperms) or vessels, fibers and parenchyma (angiosperms), which crosses the stem on a radius at right angles to the long axis.
reaction wood:	Specialized tissue with cells of different structure from normal, which is produced when a tree is tilted and assists in bringing the stem to an upright position. Synonymous with compression wood in gymnosperms and tension wood in angiosperms.
runout zone:	The part of an avalanche path where the debris comes to rest.
sample:	A number of individuals which is assumed to represent the whole population.
sapling:	A young tree from 15 cm to 6 m high.
seed:	A reproductive phase in plants, in the form of a small plant body (embryo), enclosed, together with food material, in seed coats and singly or in groups, surrounded by other dry or fleshy tissues to form fruits.
seedling:	Strictly a newly germinated plant, but here arbitrarily defined as a plant less than 15 cm tall.
senile tree:	A tree which is slowly dying of physiological disorders or attacks by pathogens.

shoot: Any above-ground stem or branch of a plant.

shrub: A woody plant less than 6 m tall usually with a diffuse branching system. Small shrubs may be only a few centimetres tall.

snow avalanche: A large mass of snow falling, sliding or flowing rapidly downhill.

snowpack: The permanent winter snow cover.

snow creep: Gradual downhill movement of the snowpack.

soil creep: Gradual downhill movement of the soil mantle.

starting zone: The region of snow accumulation where a snow avalanche begins.

stand: A group of plants of similar age, appearance, or near-uniform composition.

stem: The main axis of a plant. In trees, synonymous with trunk. In shrubs or trees lacking apical dominance, each main branch of equivalent size.

sucker: A stem which arises from a dormant bud at the base of a tree or on a root, often in response to damage.

tracheid: A narrow, long, relatively thick-walled cell, especially in the wood of gymnosperms. Responsible for conduction of water and dissolved nutrients and for imparting strength and resilience.

tree: A woody plant whose mature stage is at least 6 m tall.

tree-ring analysis: The use of tree-ring counts for dating.

trimline: A clearly marked edge in forest, scrub or other vegetation cleared or maintained by avalanche (or some other agency).

vegetation: The plant cover of a region. Arbitrarily classified, in terms of the stature and types of plants, into forest, scrub, grassland, etc.

vegetative reproduction: Reproduction by some method which does not involve seed, such as suckering, layering.

vessel: Part of the wood-tissue in angiosperms and consisting of a relatively wide tube formed from many cells end to end, with perforated plates between them. Responsible for conduction of water and dissolved nutrients.

windthrow: A tree or group of trees blown down by strong wind.

xylem: The tissue forming the great bulk of stems, branches and roots of trees and shrubs. Synonymous with wood.

17: ACKNOWLEDGMENTS

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APPENDIX I

GROWTH RATES AND MAXIMUM KNOWN AGES OF COMMON TREE SPECIES

The tree species listed are those most likely to occur on slopes subject to avalanching. The data are drawn mainly from Harlow, W.A., Harrar, E.S. 1937. Textbook of Dendrology, McGraw Hill, 527 pp; U.S. Dept. of Agriculture Forest Service 1965 Silvics of Forest Trees of the United States, U.S.D.A. Handbook No. 271, 762 pp.; field observations and information provided by Dr. P.V. Krebs. As far as possible they apply to Rocky Mountain provenances of the species.

	Dimensions of Mature Trees		Growth Rate	
	Height General Range (maximum)	Diameter 1.5m Above Ground General Range (maximum)	Time Taken to Reach Maturity (yr)	Maximum Age Observed* (yr)
Abies lasiocarpa	18-30 (40)m	45-60 (90)cm	150	ca 300
	60-100 (130)ft	1.5-2 (3)ft		
Picea engelmannii	30-36 (45)m	45-90 (100)cm	100	ca 500
	100-120 (150)ft	1.5-3 (4)ft		
Pinus contorta	15-24 (45)m	30-45 (60)cm	100	ca 350
	50-80 (150)ft	1-1.5 (2)ft		
Pseudotsuga menziesii	24-39 (45)m	45-90 (100)cm	100	ca [illegible]00
	80-130 (150)ft	1.5-3 (4)ft		
Populus tremuloides	15-18 (27)m	30-45 (60)cm	60	ca 200
	50-60 (190)ft	1-1.5 (2)ft		

*Many trees in a forest are affected by fungal rots or animal and plant parasites which curtail their lives. It should be stressed that maximum ages apply only to occasional individuals which may be growing in good quality sites or in some instances in poor sites where growth is very slow. The trees of hillsides subject to avalanching are often shorter-lived.

APPENDIX II

RATES OF ESTABLISHMENT OF COMMON TREE SPECIES IN OPEN AREAS

As well as rates of regrowth in open areas after snow avalanches or other disasters have destroyed forest, some other features are noted of the ecology of reproduction and regeneration influencing the establishment of forest tree species in open or closed stands. Textbook of Dendrology, McGraw Hill, 527 pp.: U.S. Dept. of Agriculture Forest Service 1965. Silvics of Forest Trees of the United States, U.S.D.A. Handbook No. 271, 762 pp., and field observations.

	Seedling					Establishment				
	Quantity	Age Seedling Begins	Periodicity	Dispersal	Viability	Time Taken* to Establish After Disturbance	Sites Favored	General Growth Rate	Shade Tolerance	Vegetative Reproduction
Abies lasiocarpa	abundant	ca. 20 yr.	ca. 3 yr. intervals	about 200m heavy winged seed	moderate	ca. 2-10 yr.	dry or wet mineral soil or deep moist humus	moderately slow, (very slow at advanced age)	very great but tolerates moderately wel-lit sites	layering, but seldom effective propagation
Picea engelmanni	abundant	ca. 20 yr.	2-6 yr. intervals	about 400m light winged seed	high	ca. 2-4 yr.	moist mineral soil, rotted logs, forest litter	slow at first then faster	great; may be suppressed 50-100 yr, but tolerates well-lit sites	occasional layering
Pinus contorta	abundant	ca. 10 yr.	heavy at 1-3 yr. intervals	about 60m, winged seed (not all shed annually, may be retained 15-20 yr. or more	high, retained in cone	ca. 1-3 yr.	moist to dry, but well-drained sandy or gravelly soil	moderately slow, very slow if in dense stand	none	none
Pseudotsuga menziesii	abundant	ca. 20 yr.	2-3 yr. intervals	about 200m light winged seed	high	ca. 1-3 yr.	moist humus & mineral soil; needs shade in open sites	moderately fast	moderately low, but requires some shading	none
Populus tremuloides	abudant	ca. 20 yr.	4-5 yr. intervals	long, distances, light down-covered seed	high, very short duration	ca. 1-3 yr. (from root suckers)	wide range of sites	fast at first, then slower	none	commonly by root suckers (believed uncommon to reproduce by seed)

*In all instances, (except perhaps Pinus contorta), after avalanche, it is usual for seedlings and young saplings which were present before the avalanche to have survived it.

APPENDIX III

RATES OF DECAY OF DEAD, FALLEN TIMBER OF COMMON TREE SPECIES

Decay rates of trees felled by snow avalanche are likely to be variable, depending on: (1) Species. The mature wood of engelmann spruce is more resistant to decay than subalpine fir, which is more resistant than aspen. (2) The part of the tree. Roots are often more resistant than stems. (3) The maturity of the tree and its size. Old seasoned heartwood (present in large, old trees) is more resistant than sapwood (abundant in younger trees). (4) The degree of decay before falling. Many fir trees appear to have heart rot before they reach full maturity. (5) The locality. Damp, shady sites are conducive to more rapid decay than drier open sites. (6) The intensity of activity of wood-eating invertebrates. This, and the effects of wood-decaying fungi probably depend to a large extent on the stage of maturity of the tree and the degree of dampness of the sites. Immature wood and damp sites will lead to greatest activity of organisms causing breakdown of the wood.

Thus it is not possible to give any absolute time scales which apply generally. The following account applies to the San Juan Mountains, near Silverton. It is based on observation of trees felled by snow avalanches over a range of known dates.

APPENDIX III - Continued

Locality	Date of Avalanche	Altitude (m)	Aspect	General Conditions	Presence of Bark	Outer Stem Color	Integrity and Condition of Wood	Other
1. Camp Bird	1974 (2 yr)	3000	W	Open area with tall herbs-shrub. Relatively moist but well-drained. Until 1974 a well-developed forest was present, post-dating the 1906 avalanche.	Present, almost unaltered on most logs.	Not visible on most logs. Yellowish-brown where bark removed.	Dried-out but otherwise unmodified except for some insect holes and some longitudinal cracking.	No aspen present.
2. Tronton Park	1957 (19 yr)	2930	E	Within opening in aspen-fir forest. Relatively moist, shady but well-drained slope.	Present, but cracking-off on fir, spruce. Absent on aspen except occasionally beneath stems	Grey in all three species	Aspen-some relatively unweathered but longitudinally cracked. Spruce, fir-most logs partially decayed, with many insect holes, but remain intact. Long logs can be broken fairly easily.	Spruce is scarce.
3. Sorges Slide	1944 (32 yr)	2830	W	Open rock-slide, relatively dry.	Absent on aspen. Absent on fir, spruce except occasionally where fragments occur beneath logs.	Grey in all three species	Aspen logs all well-rotted. Spruce and/or fir stems are cracked. Most are well-rotted and can be kicked apart. Many are broken to expose brown, blocky, rotten wood. Some have not rotted through. A few have rotted flat. Some roots have resisted decay.	Aspen is uncommon and in any case may date from a later event.
4. Jennie Parker	1927 (49 yr)	2830	E	Open grassy slope and rock-slide, relatively dry.	Absent	Grey in spruce (and fir)	A few cracked and weathered stems, often with attached roots, remain partly intact. Most logs have weathered flat, exposing brown, blocky rotten wood. Presumably smaller logs have completely disintegrated.	Aspen absent. Decay has proceeded further in grassy areas than on rock-slide.
5. Camp Bird	1906 (70 yr)	3000	W	As for 1.	Absent	Brownish	A few very large logs remain, presumed all to be spruce. Some appear intact but are quite rotten inside once the outer shell is broken. Other large logs present have weathered flat. Smaller logs have completely disintegrated.	Most logs have a mossy covering.

Older, decayed logs were seen at various places (specific ages unknown). On dry, exposed sites, such as mine tailings they were dark brown and heavily cracked. Mine effluent may have some preservative properties. On a relatively moist site at Camp Bird a large log more than 165 yr. old (a tree of this age straddled it) was brownish-yellow and rotted flat but still well-defined although the wood was reduced to a loose fibrous mass.

APPENDIX IV

THE IDENTIFICATION OF WOODS OF SOME COMMON TREE SPECIES

Wood in reasonably good condition often may be identified from macroscopic characters, including the type of bark, but if the wood is fragmentary or partially rotted it may be necessary to cut thin sections (by hand with a sharp razor-blade) and examine microscopic cellular characters. The table below deals with the wood of gymnosperms commonly found on snow avalanche paths. Angiosperms are distinguished from gymnosperms by possession of vessels in their wood. The only angiosperm tree likely to be found commonly on avalanche paths in Colorado is Populus tremuloides, though small-diameter wood of Sorbus scopulina, some of the taller Salix species, Betula glandulosa and some other shrubs may occur. Refer to the diagrams in Jane, F.W. 1956: The Structure of Wood, McMillan, New York, pp. 93-94, 278-310, for explanations of the terminology.

	Types of cross-field pits	Types of thickening in tracheids	Rays in tangential longitudinal section	Vertical resin canals	Transition early to late wood
Abies lasiocarpa	taxodioid	none	sometimes 30 or more cells high; uniseriate or biseriate in part.	none (but resin pockets present in bark)	gradual
Picea engelmannii	piceioid	none	uniseriate tails either side of a wider area containing resin canal. May be 20 or more cells high.	always present but sparser than pine, douglas fir	gradual
Pinus contorta	large window-like	dentate in ray tracheids	biseriate or multiseriate either side of wider resin canal area. Rarely more than 12 cells high.	always present	sudden
Pseudotsuga menziesii	piceioid	spiral in early wood	uniseriate or, if containing a resin canal multiseriate, short squat, about 8 cells high	always present	sudden

APPENDIX V

MODEL PLOT SHEET: SNOW AVALANCHE TREE RING SAMPLE

			Date: 23 June 1976
Locality: Silverton	Path: II Jennie Parker North	Air Photo: ENPQ/37,38 1964 U.S. Forest Service	Altit: 2980-3000 m
Map: SW/4 Silverton 15 Quadrangle 1955	Atlas Ref.: M A&A 1976, 152140	Ground Photos: B&W, color	Aspect: NE
Grid Ref.: 2645/41863	Path Subreg.: B/middle track		Slope: 25-30°

SITE CONDITIONS: Complex of paths subdivided into A(north), B,C(south). A is a complex marked by open aspen-spruce-fir poles and two aspen strips. B is more open, with bluffs in upper track and stands of pole and sapling aspen on S., scattered spruce and fir near margins and middle and much willow scrub; grassy area above road. Large rock-slide area below bluffs. It is separated from C by a tongue of old forest which has been swept by avalanche. C has sapling aspen, spruce and fir in the N and middle, then a strip of pole spruce and fir, then a tongue of old forest. Below the road except for a central area of aspen-conifer the path is grass and scrub-covered. Runout is into a carex-willow swamp. Charred wood is present over much of the path.

Tree Species/No.		Disc No.	Core No.	Positions on Path	Characteristics	Position on Tree
Picea	1	1 2 3 4 5 6		north of middle	old tree, broken(at 2m) at least twice & new branches grown, with erect leaders	base through main break area large branch upright on this branch large branch upright on this branch
Populus	2	1 2		near south margin, aspen stand	small pole, waved	base scar 1m
Populus	3	1 2		near south margin, aspen stand	small pole, broken top	base regrown branch 1.5m
Populus	4	1 2		aspen stand near pole spruce stand, south margin	tall pole, curved	base scar 1.5m
Picea	5	1 2		island of old conifers near N margin	old tree broken (at 1.5m) with 4 leaders	base, scar largest regrown leader
Abies	6		1 2 3	island of old conifers near N margin	leaning, submature tree	base, not to center (rotten) either side of scar at 2.5m
Abies	7		1	island of old conifers near north margin	mature tree 18mx80cm top broken	base, not to center (rotten)
Abies	8	1		beside rock-slide, north side	mature tree 15m, top broken, branches broken to 12m	scarred branches

APPENDIX VI

STAINS TO CLARIFY GROWTH LAYERS

Whenever it is difficult to distinguish growth layers clearly, the use of a stain may be worth considering. The following have been used successfully for woods with unclear growth layers or for other special purposes. Unless otherwise noted the methods are for use with polished thick sections, viewed with a stereomicroscope with normal lighting. Thin sections, cut by hand with a sharp razor-blade or with a wood microtome and viewed with a higher-magnification microscope may be needed in some cases. Refer to Johansen, D. 1940, Plant Microtechnique, McGraw Hill, New York and Gurr, E. 1966, Rational Uses of Dyes in Biology, Williams & Wilkins, Baltimore, for more details of staining systems and fine points of technique. Refer to Jane, F.W. 1956, The Structure of Wood, McMillan, New York, for explanations of cell and tissue terminology.

1. Aniline Sulphate: stains the lignified cells, (vessels, tracheids, fibers) yellow and leaves cellulose unstained. The greater the concentration of lignified tissue, the denser the color and late-wood tends to show up plainly.

   Schedule & Wood Treatment: Prepare a saturated aqueous solution of aniline sulphate. Brush on lightly or put on a little with a dropper. The color develops almost immediately. Variations are aniline sulphate-haematoxylin or aniline sulphate-methylene blue methods (Gurr 1966).

2. Fluorochrome Coriphosphine: A stain for reaction wood. Stains normal fibers yellow-green and gelatinous fibers orange-red. Thin sections are needed.

   S. & W. T.: 0.2% aqueous solution of fluorochrome coriphosphine is placed on the sections for five minutes, then wash with water. Examine with a fluorescence microscope.

3. Malachite Green-Methylene Blue: A good, quick general stain for differentiating early wood (bright green), late wood (light blue) and reaction wood (light blue-brown).

   S. & W. T.: Mixture of 0.1g malachite green, 0.1g methylene blue, 17ml absolute ethanol, 150ml water. Brush on. Can be applied in any dilution depending on the intensity of stain required. For very closely spaced rings apply excess-dilute stain to swell the early-wood cells. Examine with lateral lighting.

4. Pentachlorophenol: To differentiate rings in Populus tremuloides. (Used with cores by Tujillo (1975), but presumably also useful with sections).

   S. & W. T.: 4% solution of pentachlorophenol in kerosene. Shave freshly-obtained cores with a sharp scalpel or razor-blade. Oven-dry the cores at 100^{o} C until thoroughly dry. Moisten a cloth with the pentachlorophenol solution (Care, it is corrosive and should not be inhaled) and wipe on lightly. Oven-dry the cores at 100^{o}C for four hours.

5. Phloroglucinol: Especially useful for growth layers in diffuse-porous species. Stains lignin red, cellulose is unstained.

   S. & W. T.: 1% phloroglucinol solution in 95% ethanol. Brush on or soak increment cores or sections in this solution 1 minute, then in 50% hydrochloric acid 1 minute, then wash with water. The rings are most evident when dry and when examined in light from a fluorescent lamp. The color fades after a time.

6. Safranin-Fast Green: Has been used to recognize reaction wood. Stains normal fibers (lignin) bright red, gelatinous fibers (and cellulose) green.

   S. & W. T.: (A) 1% aqueous safranin O. Brush on then wash with water to remove excess stain. (B) 0.2% fast green FCF in 95% ethanol. Brush on a small amount. Probably best with thin sections.

APPENDIX VII

EQUIPMENT AND MATERIALS

abney level

adhesive tape

aneroid altimeter (in m to 4000 m, in feet to 15000 ft)

air photographs, vertical

axes (one large, one small)

ball points

calipers (one large, one small, precision scaled in mm, cm)

camera

chain saw (light, with spare chain and tools)

chemicals (stains, see Appendix VI)

chinagraph greasy pencils

chisels (one half-inch, one one-inch)

clip boards

compass, prismatic

core sample case

core sample blocks

dowel

drawing instruments

drawing paper

ear-muffs (soundproof)

envelopes

eye-shields (for chain-sawing and sanding)

file (document)

files (metal - work - flat and round, for chain saw)

film

first aid kit

flora

fuel can (for chain saw)

funnel (6 inch plastic)

hand saw (crosscut or rip saw)

hard hats

increment borers (one 22-cm, one 30-cm, one 40-cm)

index cards

insect repellent
labels, sticky
level (surveyor's)
light box, for mapping
maps, topographical
marking pens (indelible, different colors)
mattock (light)
measuring tapes (two x 3m, two x 10m, four x 20m)
microscope (stereo, 2 x to ca 40 x)
milk shake straws (plastic)
notebooks (two large hard-covered, four small hard-covered)
oil stone
oil for oil stone
oil for chain saw fuel mix
oil for chain saw bar
paper clips
pencils, lead
pencils, colored
plastic bags (heavy grade, six dozen 14 inch x 10 inch (approx.))
(one dozen 20 inch x 14 inch (approx.))
plastic tape (two-inch-wide, for marking trees, orange or red)
rubber bands
ruler (cm and mm, to 30cm)
sander (belt and sandpaper belts, various grades
sandpaper (large supply and range of grades)
scalpels (two, with detachable blades)
spade
stadial rod (surveyor's)
stereoscope
surform plane
tag labels (7.5cm x 5cm, twelve dozen)
tent (four-man, with floor, mosquito net and fly)
tracing paper
wedges (plastic)
wood plane
writing paper (lined)

INSTITUTE OF ARCTIC AND ALPINE RESEARCH
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7. *A Climatological Study of Strong Downslope Winds in the Boulder Area.* By W.A.R. Brinkmann. 1973. 228 pp. Order from the author, Institute for Environmental Studies, University of Wisconsin, 1225 West Dayton Street, Madison, Wisconsin 53706.

†8. *Environmental Inventory and Land Use Recommendations for Boulder County, Colorado.* Edited by R.F. Madole. 1973. 228 pp. 7 plates. $6.00.

†9. *Studies of Climate and Ice Conditions in Eastern Baffin Island.* 1971-73. By J.D. Jacobs, R.G. Barry, R.S. Bradley, and R.L. Weaver. 1974. 77 pp. $3.00.

†10. *Simulation of the Atmospheric Circulation Using the NCAR Global Circulation Model With Present Day and Glacial Period Boundary Conditions.* By J.H. Williams. 1974. 328 pp. $4.75.

11. *Solar and Atmospheric Radiation Data for Broughton Island, Eastern Baffin Island, Canada, 1971-73.* By J.D. Jacobs. 1974. 54 pp. (Out of print.) NTIS PB-248 955/7GA. Paper $4.50. Microfische $2.55.

12. *Deglacial Chronology and Uplift History: Northeastern Sector, Laurentide Ice Sheet.* By A.S. Dyke. 1974. 113 pp. (Out of print.)

†13. *Development of Methodology for Evaluation and Prediction of Avalanche Hazard in the San Juan Mountains of Southwestern Colorado.* By R.L. Armstrong, E.R. LaChapelle, M.J. Bovis, and J.D. Ives. 1975. 141 pp. $4.75.

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A stylized "ankh," the ancient
Egyptian sign for life, has been
incorporated into the symbol of
the Program on Man and the Biosphere (MAB).