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THE GEOLOGY AND DATING OF SUNSET CRATER, FLAGSTAFF, ARIZONA*

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The small, colorful cinder cone near Flagstaff, Arizona, called Sunset Crater, probably erupted during the latter part of A.D. 1064 and, or, the early part of 1065. The dating of this eruption is based on the interpretation of known evidence, and is the result of research in the fields of archaeology, dendrochronology, geology, paleobotany, and volcanology. A brief resume of the geology and the dating of this phenomenon follows.

INTRODUCTION

The San Francisco Mountains volcanic field of north-central Arizona contains approximately 2,200 square miles of lava flows and other manifestations of volcanism. The volcanic activity occurred during three major periods (Robinson, 1913). About 400 extinct volcanoes are located in the field, six of which are of considerable size (Colton, 1937, p. 5). These six are called, Kendrick Peak, Bill Williams Mountain, O'Leary Peak, Sitgreaves Peak, Mormon Mountain, and, the largest of all, the San Francisco Peaks (fig. 1). The San Francisco Peaks dominate the area and are about 5,000 feet above their base (12,794 feet above sea-level). They serve as a prominent landmark for many miles in all directions. Sunset Crater is the most recent manifestation of volcanic activity known in the entire field. It lies at the base of the east slope of the San Francisco Peaks. Two lava flows are associated with the formation of this cinder cone; one to the northeast called the Kana-a flow (largely buried under ash) and the other to the northwest called the Bonito flow (partly buried under ash) (fig. 2).

The general appearance of the crater, the ash, and the sharpness of the exposed portion of the flows give an indication of recent volcanic activity. The first comprehensive study of the general area, including the Sunset Crater, was made in 1901-3 by H. H. Robinson (1913). He recognized the recency of Sunset Crater activity and, with regard to the flows, he stated "They are probably not less than 300 years old, as judged from the pine trees that grow along the border of the Bonito flow, and they may be (in round numbers) 1,000 years old."

Precise dating of the eruption became possible in 1930 when archaeological excavations uncovered two pithouses buried under ash ejected during the formation of the crater. Many pithouses such as these were found to contain remains of beams which could be dated by the tree-ring method. Surface houses constructed on the ash also yielded remains of beams. Thus, if houses buried under the ash could be found and dated, a bracket of time during which the eruption took place could be determined. The entire question seemed rather clear and precise in 1931 and 1932 when this problem was first attacked. As the study progressed, other problems were discovered and complications in interpretation were encountered. Several different "dates" on the eruption were published which were later found to be erroneous.

The volcano Paricutin, in Mexico, began erupting on February 20, 1943 (Foshag and Gonzales, 1950). Numerous specialists made visits to the area to study the activity and its effects on the flora and fauna of the region. Paricutin is, for all practical purposes, a "geologic twin" of Sunset Crater. The difference is not geological but, rather, it is climatological. Sunset Crater is located in a semiarid area wherein rainfall is now approximately 16 inches annually. Paricutin is in a more humid area and the rainfall averages about 75 inches. This difference in rainfall has had considerable effect on the rate of plant recovery.

Published results of the studies conducted at Paricutin were used to reinterpret evidence of apparent similar phenomena found at Sunset Crater. The eruption date given here is, therefore, based on a restudy of all evidence found at Sunset Crater thus far.

GEOLOGY

Numerous lava flows and cinder cones indicate that the area to the east and north of the San Francisco Peaks has been recently disturbed by volcanic activity (older volcanism has also disturbed the area but is not discussed in this short report). In the immediate area around Sunset Crater, craters are so numerous that in several cases older ones were disturbed during the formation of younger ones (see fig. 2). The geology of the crater is known only through observations made on surface conditions and exposed material. No detailed subsurface study has been conducted and no profiles have been exposed. From the studies that have been made, a possible sequence of events has been determined.

A northwest-southeast trending fissure opened in the surface extending from Janus Crater to Yaponcha Crater (Colton, 1937, p. 33). A vent was formed in a structurally weak spot in the fissure and Sunset Crater grew around this vent.

Early in the period of activity, two separate lava flows were extruded. Lavas in one of the flows moved northeast down a small wash toward the Little Colorado River (the Kana-a flow). Lavas in the other flows moved northwest into a basin nearby (the Bonito flow). It has not been determined whether or not these flows were extruded before or after any major cineritic activity. Considerable ash was ejected subsequent to the flows however, because both were buried under ejectamenta.

The complete story of cineritic activity is not known. One specific example indicates that there were at least two major periods. A pithouse located about six miles northwest of the crater (site number NA:1920B), was completely buried under the ash. Two distinct layers of ash were deposited in the depression when the roof collapsed. These two layers were separated by a layer of wind-blown material (Colton, 1949, p. 11). No estimate of elapsed time separating the two deposits can be given.

Fumeroles and spatter cones were formed along the entire fissure. Ash which had fallen along the fissure was oxidized to a red color by the hot steam escaping from openings.

Following the virtual cessation of the cineritic phase, lava was extruded again in the Bonito flow area causing considerable fracturing of old material, some of which was floated on the new. In places the new lava hardened and became semi-solid and was then forced through fissures as

*A full length report of this research is being prepared for publication.

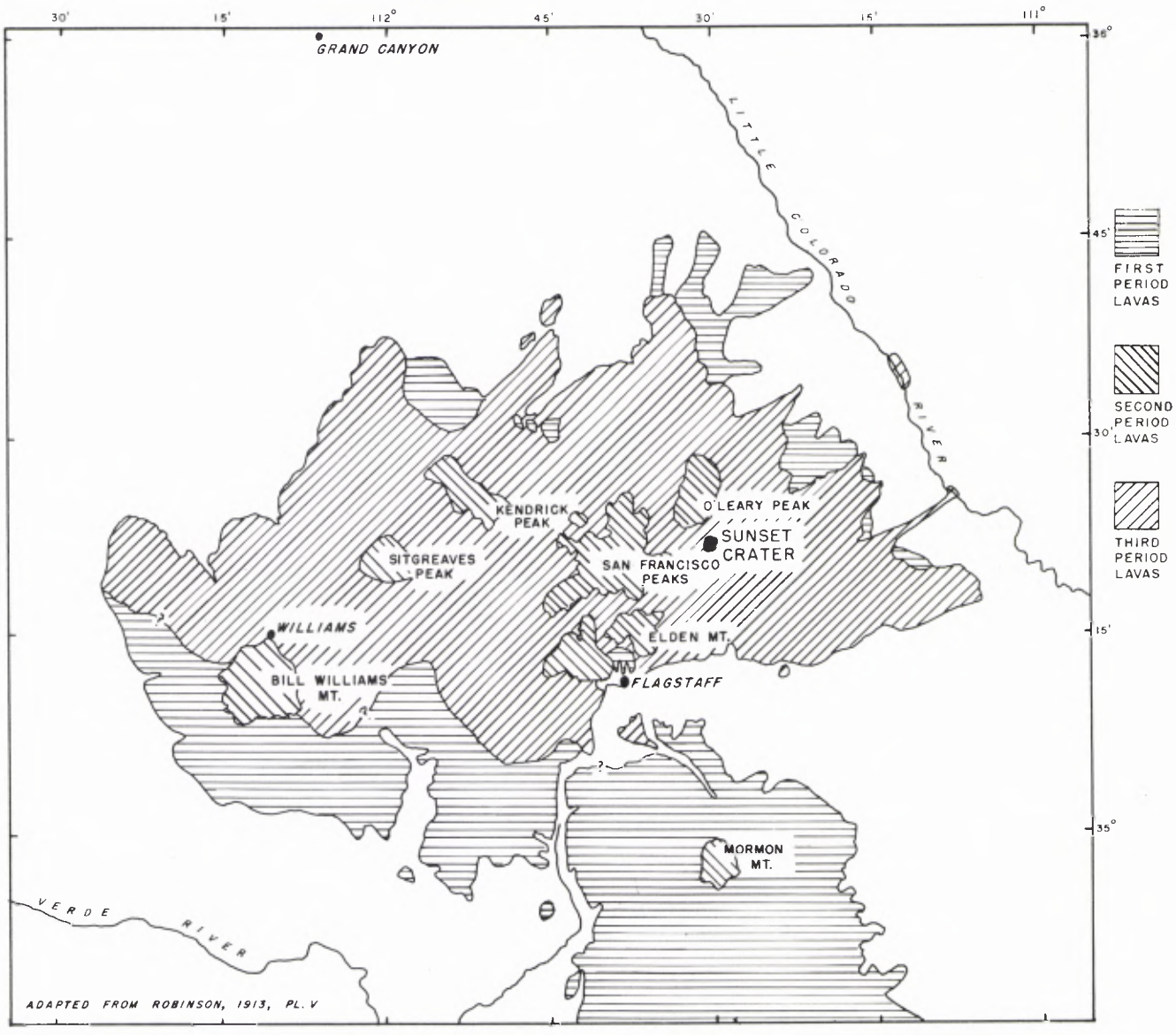


FIGURE 1. The San Francisco Mountains volcanic field, Flagstaff, Arizona.

thin vertical sheets, later cooling and solidifying. These vertical sheets contain grooves which conform to the walls of the fissures through which they were forced. These are called "squeeze-ups," or ansoma, and are common in the Bonito flow area (Colton and Park, 1930, p. 579).

Sometime, either immediately preceding this extrusion or early in the activity, a small satellite cone was formed in the central part of the Bonito flow. This satellite, called Yaponcha, was partly disturbed by subsequent movement of the lavas. Very little, if any, cineritic activity followed the extrusion of these late lavas and the formation of the satellite — at least they are free of ash except of minute amounts apparently blown in by the wind.

Hot gases continued to escape from the main crater for a considerable length of time. Deposits of gypsum, sulfur, and limonite were crystallized out of steam coming from the vent. These vari-colored materials give the crater the appearance of always being in the light of a perpetually setting sun — hence the name.

Colton (1945, p. 8) studied the size of the lava flows, the extent of the ash fall, and the dimensions of the crater to obtain an estimate of the amount of material ejected during the activity. He arrived at the amounts of about a million tons of material in the lava flows, about a half-billion tons in the ash, and another half-billion tons in the cone proper. This billion or more tons of material would comprise about ten percent of a cubic mile.

DATING THE ERUPTION

The archaeological staff of the Museum of Northern Arizona, Flagstaff, has for many years been engaged in survey and excavation studies in the northern Arizona area. The location of each site discovered was plotted on a large

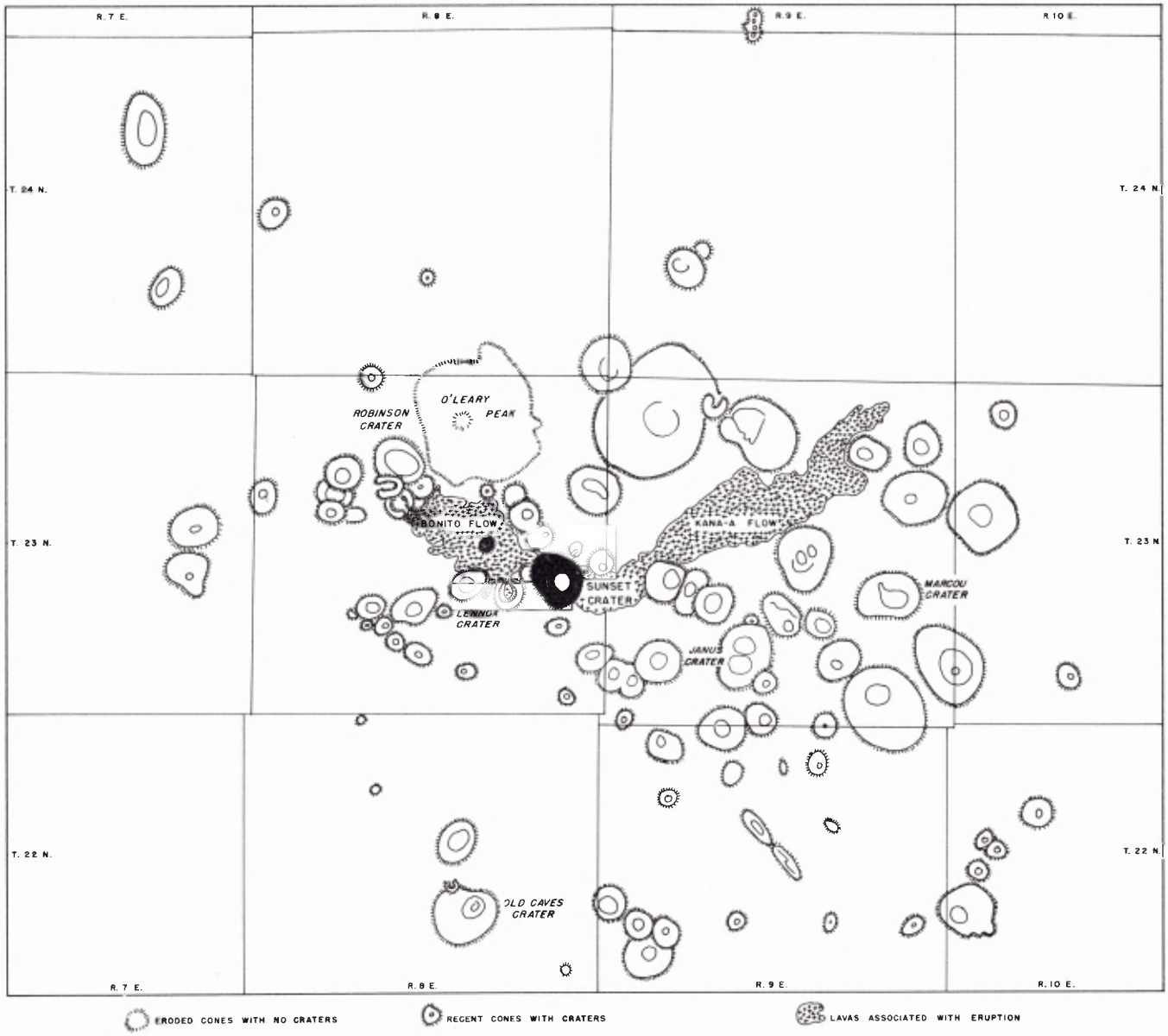


Figure 2. Sunset Crater and associated lavas. Yaponcha Crater is the small, solid black dot in the middle of the Bonito flow.

scale map and a collection of surface materials was assembled. It soon became evident to the staff that sites were much more abundant east of the San Francisco Peaks than they were elsewhere in the Flagstaff area. Large surface pueblo sites were also common in the area of concentration. A typological and seriological study was made of the broken pieces of pottery collected during the survey and excavations. The results of the pottery study gave the relative time each site was occupied and it indicated that a tremendous increase in population occurred east of the Peaks at the time when certain pottery types were first manufactured.

After the discovery in 1930 of pithouses buried under the ash from the eruption of Sunset Crater, the time of the increase in poulation was found to be approximately the same as the time of the eruption itself, or shortly thereafter. This was determined by a study of the pottery types contained in the buried pithouses.

Tree-ring dating of northern Arizona pottery types was first successfully carried on in the early 1930's. The "dated" pottery types used at the time of population increase were found to be first manufactured circa 1050-1100. Similarly, the dating of beam materials found in sites constructed on the ash indicated that the eruption could not have occurred before A.D. 1071 because many of the beams used in construction were living trees at that time. The major problem remaining was to find additional houses buried by the ash and obtain tree-ring dates on associated materials. Several attempts were made in the 1930's to establish the latest date of pre-eruptive houses and, therefore, "date" the time of eruption. As previously stated, in each case these "dates" were later found to be wrong.

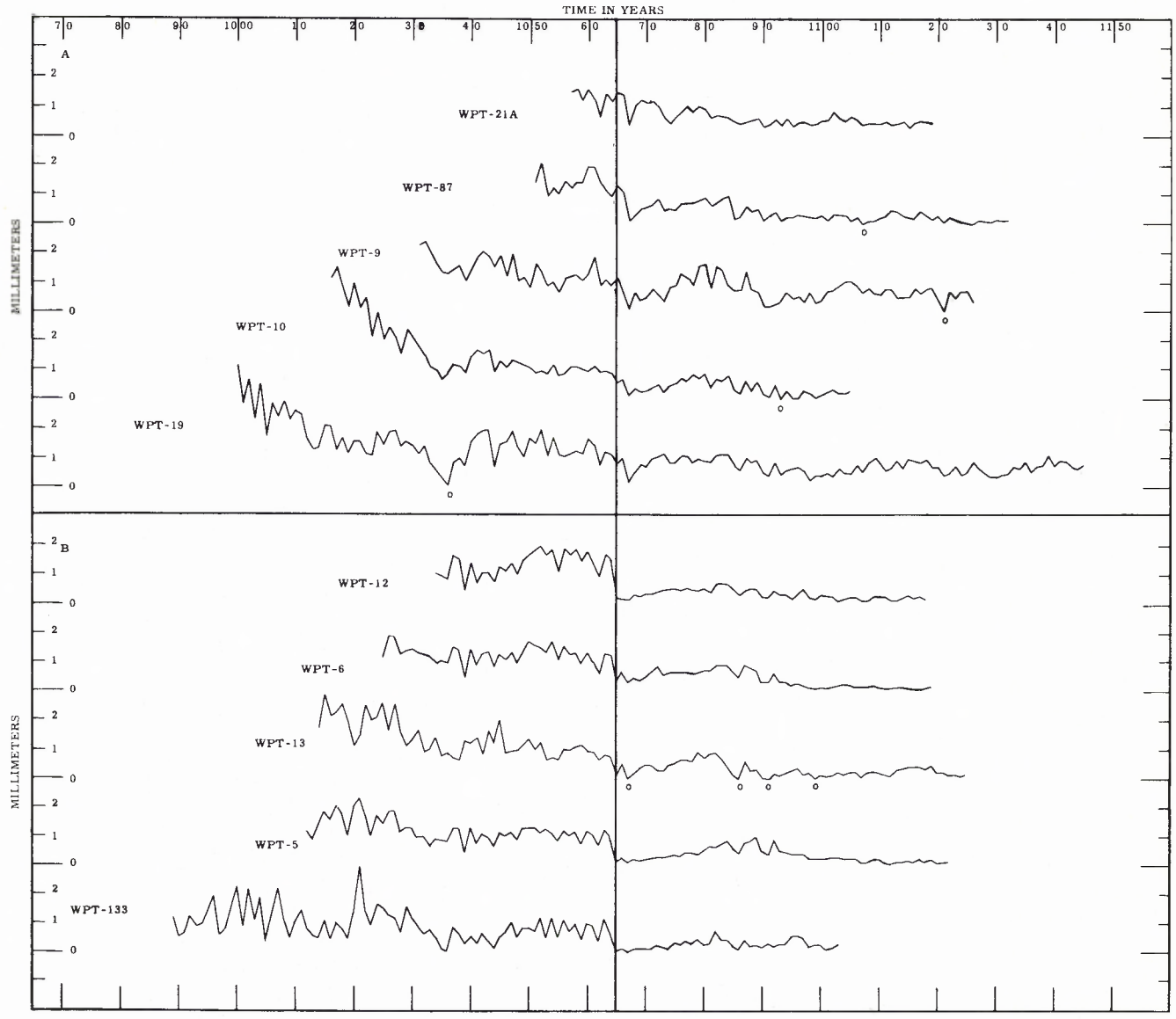


Figure 3.--The measured ring growth series of ten specimens from Wupatki ruin.
A. Five "normal" specimens.
B. Five specimens with a distinct break in growth pattern after A.D. 1064.

Colton, in 1945, published a revision of all pertinent archeological information used in this problem. A few additional pre-eruptive sites had been found and studied in the meantime and more information had been gathered regarding the extent of ash distribution over the countryside. Colton's findings indicated that the latest pre-eruptive date on any tree-ring specimen was A.D. 1046 and the earliest post-eruptive date was A.D. 1071. This was as far as the time placement of the eruption could be carried by this technique and at this point the matter rested.

After publication of these data, the Laboratory of Tree-Ring Research became more interested in the problem. The hypothesis was devised that, if the eruption took place in that short a period of time (A.D. 1046-1071), an examination of tree-ring specimens which were growing near the crater and which continued to live through the activities should show differences in growth (non-climatic) when compared to the "normal" pattern (climatic) for that particular time. An analytical study was started involving hundreds of specimens taken from various Southwestern archaeological sites.

A subnormal period of growth commencing at 1067 was observed in many specimens taken from sites both near and far from the Flagstaff area. This growth was noted to be more severely curtailed in the Flagstaff region than elsewhere. For a short while this was thought to be the time of the eruption, although the physical conditions of this pattern did not meet expectations. For example, this pattern was too "normal" and appeared to be more of a climatic influence than a non-climatic one.

Contemporaneously with the restudy of the tree-ring specimens, information was being published which was con-

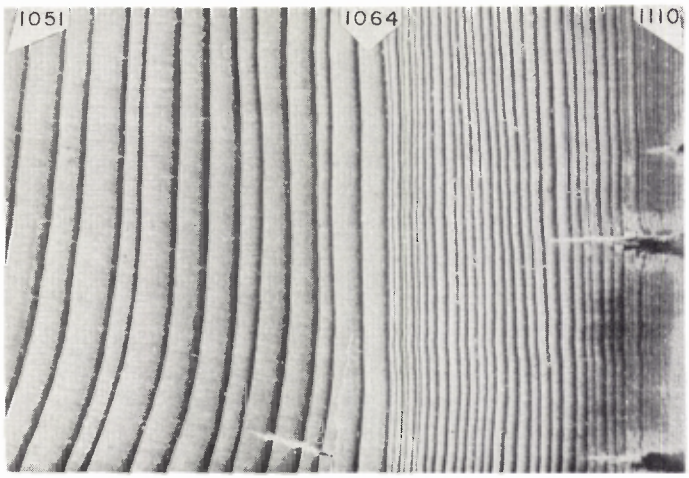


FIGURE 4. An enlarged photograph of part of specimen F.2541 showing the ring growth for A.D. 1051-1110+. The portion outside the ring for 1064 cannot be dated due to its lack of variability.

cerned with the effects of the volcano Paricutin on the ecology of that region. These reports were studied and the various authors were contacted. It soon became apparent that the date of 1067 was not accurate for Sunset. At Paricutin the effects of ejectamenta on trees was of a mechanical (injury type) nature (Eggler, 1948) and these effects did not extend beyond the area of heaviest ash fall — the 10-12 inch isopach line. Downwind gases had no apparent effect on trees. Another factor of considerable importance was that the mulching effect of ash tended to eliminate any variability in growth, insuring a more constant supply of available moisture.

Information gathered from the Paricutin studies indicated that errors in interpretation had been made on Sunset Crater specimens. All tree-ring specimens from archaeological sites located on, and adjacent to, the ash covered area around Sunset Crater were re-examined. From the several hundred studied, eight ponderosa pine (**Pinus ponderosa**) specimens taken from Wupatki ruin (about 12 miles northeast of the crater) contained "normal" growth patterns up to and including the growth for the year A.D. 1064. Following this growth, the increment deposited was extremely curtailed as it would be if the tree had been injured, and that which was laid down was about the same in amount year after year, with a very gradual increase in size; in contrast to the majority of specimens which had a "normal" growth (fig. 3). Thus, assuming these eight specimens were growing near the locality of the eruption, the heavy ash fall broke branches and stripped the trees of their needles. These trees were not so badly damaged that they died, however. The low annual rainfall in the area prevented a rapid resurge of growth following the injury, but the ash served as a mulch so that the moisture which fell was conserved and, even though slight, the trees had a fairly constant supply available for growth and their growth pattern was very complacent (fig. 4). These trees were later cut and used in the construction of Wupatki pueblo. After a century or two of occupation, Wupatki was abandoned and fell into ruin. The beams were buried in the debris which, coupled with the semiarid climate, served as a preservative for the wood.

The after effects of the eruption on the flora and the fauna, as well as on man himself, constitutes another study but it suffices to say here that the effects were numerous and covered many years duration.

In summary, on the basis of evidence so far discovered, it is believed that the eruption of Sunset Crater started sometime after the growing season was over for the year A.D. 1064 (probably in September) and before the season of the following year was advanced, somewhere about June of 1065.

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