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Palynology and Age of the Alvord Creek Formation, Steens Mountain, Southeastern Oregon

Stephen F. Barnett,

Abstract

PALYNOLOGY AND AGE OF THE ALVORD CREEK FORMATION,

STEENS MOUNTAIN, SOUTHEASTERN OREGON

by Stephen F. Barnett

The age of the Alvord Creek Formation of Steens Mountain, southeastern Oregon, has been a center of controversy since Axelrod's 1944 paleobotanical assignment of a Lower Pliocene age to the tuffaceous leaf-bearing shales. This date varies from earlier determinations by Chaney and MacGinitie that the flora was Mascall (Upper Miocene) equivalent. However, it is more sharply contradicted by the report of a Middle Miocene (Barstovian) fauna in the apparently overlying Steens Basalt and by a 21.3 m.y. radiometric date obtained on a basalt flow 61 meters above the leaf-bearing beds.

Palynomorphs recovered from three exposures of the leaf-bearing beds show only a fair to low correspondence at the generic level with the megaflora previously reported by Axelrod and Wolfe. Several new taxa are encountered in the palynoflora including the gymnosperms *Tsuga*, ?*Taxodium*, *Podocarpus*, and *Ephedra* and the angiosperms *Quercus*, *Ulmus*, *Corylus*, *Juglans*, *Fraxinus*, and *Nyssa*. Pollen assigned to the undivided Taxaceae-Cupressaceae-Taxodiaceae group, *Quercus* and *Abies* dominate the assemblage; monolete and trilete spores are conspicuously rare.

The overall composition of the palynoflora lends support to Axelrod's Pliocene assignment. The abundance of *Abies* and other coniferous pollen combined with the lack of ferns and other typical

Miocene taxa indicate a cool, dry climate such as is associated with the latest Tertiary. However, a tuff 15-20 cm above the leaf bed yielded a K/Ar date of 23.8 m.y.b.p., lowermost Miocene or even uppermost Oligocene.

Stratigraphic relationships in Steens Mountain are obscure and may be complicated by normal or thrust faults, as has been suggested by some structural geologists. There is also the possibility that the K/Ar date determined for the tuff overlying the leaf bearing shales is in error. Whatever the reason(s) for the discrepant age assignments, there is not now a satisfactory resolution to the problem of discordant dating of the Alvord Creek Formation by paleobotanical and radiometric methods.

LOMA LINDA UNIVERSITY

Graduate School

PALYNOLOGY AND AGE OF THE ALVORD CREEK FORMATION, STEENS MOUNTAIN, SOUTHEASTERN OREGON

by

Stephen F. Barnett

A Thesis in Partial Fulfillment

of the Requirements for the Degree

Master of Science in Geology

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Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

Lanny H. Fisk, Associate Professor of Geology — Chairman

Knut Andersson, Associate Professor of Geology

H. Paul Buchheim, Assistant Professor of Geology

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Although I owe much to those who have helped me, responsibility for any errors in interpretation or identification is mine alone.

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INTRODUCTION

General Statement

The Pacific Northwest is of special interest to paleobotanists because of the large number of floras preserved in its Tertiary volcaniclastic sequences. In addition to recording the vegetational and floristic history of the western United States, these floras have been important in age-dating the formations in which they have been preserved. Since most Tertiary floral taxa are characterized by long stratigraphic ranges and cannot therefore be used as precise index fossils, it is necessary to consider assemblages of taxa in order to date the plant-bearing rocks (Traverse, 1955; Dorf, 1959; MacGinitie, 1962; Leopold, 1969). Given the geographic locality and the general trends of climate through the Tertiary, the age of floras can be interpreted by considering such climatic indicators as leaf margins, percent endemic versus exotic species, overall floral composition, and correlation with floras of established age (e.g., Dorf, 1959; Wolfe and Barghoorn, 1960; Axelrod and Bailey, 1969; Leopold, 1969).

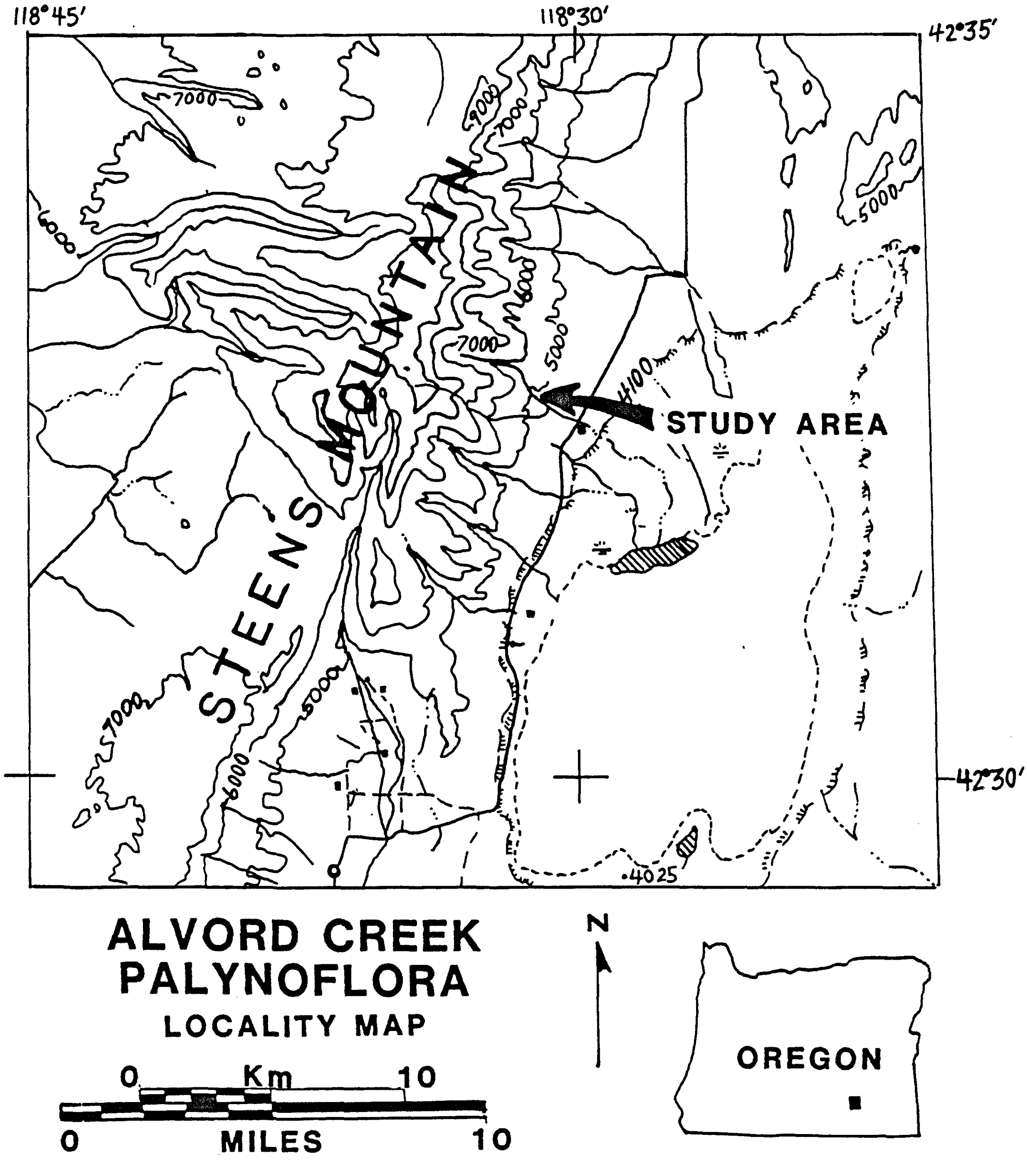
Palynology provides an added dimension to the study of Tertiary floras for several reasons. Pollen are produced in great numbers and are widely distributed by both wind and water. Their extreme resistance to degradation coupled with their ubiquitous distribution make it likely that a given sedimentary rock will contain pollen, especially if the rock is fine grained. Unlike leaves, wind- and water-borne pollen represent the flora of relatively large areas (Gray, 1964). Further, their small size makes random sampling more representative of the total regional flora since a few grams of sediment may contain thousands of individual grains. Although leaf floras can be more age diagnostic than pollen because they are more readily identified to the species level, pollen can be used in some instances to clarify generic diagnoses where leaves are indistinguishable. *Betula* and *Alnus*, for example, have unique pollen but their leaves are difficult to distinguish (Chaney, 1925).

Conflicting Ages of the Alvord Creek Formation

The Alvord Creek Formation, exposed along the east flank of Steens Mountain in southeastern Oregon (Figures 1 and 2), has been the subject of conflicting age interpretations (Axelrod, 1944a; Fryberger, 1959; Evernden and James, 1964). The flora was first studied by Chaney (*in* Fuller, 1931) who felt that the leaves were equivalent to the Mascall Flora of Upper Miocene age. MacGinitie (1933) examined leaves of the Alvord Creek Flora in conjunction with his study of the Trout Creek Flora located about 48 km to the southeast of the Alvord Creek exposures. He, too, considered that both the Trout Creek and Alvord Creek Floras were probably of Mascall age. Later, Axelrod (1944a), after reexamining specimens from these previous collections and studying a more extensive collection obtained in 1939, concluded that the flora was more correctly interpreted as Lower Pliocene (Axelrod, 1944a). His determination was based on a comparison of the flora with other floras of established age and also used climatic inferences based on leaf lobation and texture. Additional specimens were collected by Fryberger (1959) and analyzed by Jack Wolfe who agreed with Axelrod's Pliocene

Figure 1. View of Steens Mountain, looking to the north. The leaf bearing beds of the Alvord Creek Formation are exposed in hills of the left and right middle ground.

Figure 2. Location map of the study area. (Contour interval is 1000 feet.)


118°45'
118°30'
42°35'
42°30'
7000
6000
5000
4100
4025
STEENS MOUNTAIN
STUDY AREA
ALVORD CREEK
PALYNOFLORA
LOCALITY MAP
0 Km 10
0 MILES 10
N
OREGON

assignment. The very high percent of endemic species and abundance of conifers suggested to Wolfe an age younger than Clarendonian and probably Hemphillian (Wolfe in Fryberger, 1959).

In addition to these conflicting paleobotanical age assignments, both faunal and radiometric dates have cast doubt on a Pliocene age assignment. Wallace (1946) reported a Barstovian mammalian fauna in the Steens Basalt which appears to stratigraphically overlie the Alvord Creek Formation. Evernden and others (1964) confirmed the Middle Miocene assignment of the fauna with a 14.3 m.y. K/Ar date. In addition, Evernden and James (1964) dated a basalt flow 61 meters stratigraphically above the Alvord Creek plant-bearing beds as 21.2 m.y., lowermost Miocene. This date is significantly greater than those determined by Chaney, MacGinitie, Axelrod and Wolfe on the basis of the leaf flora. This situation has led some geologists (e.g., Fryberger, 1959; Evernden and James, 1964) to claim that fossil plants are not useful for age determinations, or at least that other methods are more reliable.

Objectives

Palynology complements fossil leaf studies by increasing the known taxa, thereby refining the paleoecological, paleoclimatological, and age conclusions of macrofloral studies. Gray (1964) noted the particular need to examine small Pliocene floras in the Pacific Northwest which she felt might be biased representations of the microhabitat in which the vegetation grew or was preserved. The general goal of this study was to complement the macrofloral study of the Alvord Creek Formation. Particular objectives were: (1) to determine the types of pollen and spores present in the Alvord Creek Formation leaf-bearing localities; (2) to compare the leaf flora reported by Axelrod (1944a) and Wolfe (in Fryberger, 1959) with the palynoflora, and (3) to reassess the age of the flora utilizing the additional data provided by the palynoflora.

Geographical and Cultural Setting

The Alvord Creek Formation is exposed along the eastern flank of Steens Mountain, an uplifted and tilted fault block in south-central Harney County, Oregon (Figure 2). The block trends to the northeast and dips gently westward, forming a broad, low-relief plateau about 100 km long and 30 km wide. Its eastern scarp drops precipitously from nearly 2,950 meters just west of the Alvord Creek exposures to about 1,300 meters on the Alvord Desert playa. The study area is located along the lower scarp in the region of Big Alvord Creek. Exact locality descriptions are given in Appendix A.

Access to the Alvord Creek area is by good gravel roads from the town of Denio, located about 90 km to the south of the study area, or from Highway 78 located about 55 km to the north. The area is very sparsely populated and ranching is the primary industry.

Climate and Vegetation

Climate in the Steens Mountain area is semi-arid with generally dry summers and low (28 cm) annual precipitation. July mean maximum temperature is 31° C and January mean minimum temperature is -10° C (Franklin and Dyrness, 1973). Snow is persistent at higher elevations throughout the winter and small patches persist well into the summer.

The dominant plant community in the Alvord Creek area is Shrub-Steppe with *Artemesia tridentata* and bunch grasses as codominants (Franklin and Dyrness, 1973). East of the area, in the Alvord Desert region is the Desert Shrub community (Franklin and Dyrness, 1973). At higher elevations are riparian and *Populus* communities, and *Juniperus occidentalis* is common at 1737 to 1920 meters. Fryberger (1959) also reported two small fir stands in sheltered areas at about the same elevation. *Artemesia* ranges from the basin floor to 2438 meters, and bunch grasses reach 2590 meters.

MATERIALS AND METHODS

Sample Collection

The samples processed for pollen and spores include six collected by L. H. Fisk in August, 1978, and an additional 25 samples collected by myself in June, 1983 from three locations (Appendix A) along the Alvord Creek exposures. In each case, samples were taken from fresh outcrops exposed by quarrying below the soil or talus. Well-lithified pieces of rock were chiseled free, numbered, described, labeled, and placed into commercial sampling bags. In addition, as a control for possible surface or Recent contamination, a sample of modern pollen rain was collected by gathering pinches of soil from several locations on the ground among the shrubs and along a dry creek bed between rock-sample locations.

Laboratory Processing

In the laboratory, all samples were uniformly processed according to a schedule incorporating standard techniques (Gray, 1965; Doher, 1980). Before processing, samples were scrubbed under filtered tap water with a stiff-bristle plastic brush to remove any surface contamination. After air drying, small pieces were broken from the larger blocks with a clean hammer, placed into a scrubbed porcelain mortar and crushed to pieces of about 2 mm diameter. The crushed sample was mixed thoroughly and approximately 5 grams were transferred to a 50 mm diameter polypropylene tube. HCl, 5% solution, was added to the sample to remove any trace of carbonate. (No sample contained more than minute traces of carbonate.) The HCl was aspirated and 70% HF was added and allowed to react with the silicates for 18 to 30 hours. Following water and dilute HCl rinses, the residues were examined in a water mount at 100x magnification to determine what further maceration steps were necessary. If no grains or only grains corroded beyond recognition were seen the sample was processed no further. The residue was discarded if completely barren or stored if any organics were present.

Because most samples with good grains also contained large quantities of minute organic detritus, portions of some samples were subjected to oxidation using either Schulze's solution or 35% HNO_3 followed by 10% KOH. Others were differentially centrifuged to remove the fine organics. Neither technique was very effective in cleaning the samples. Because oxidation appeared to degrade pollen and differential centrifugation appeared to remove pollen selectively, these techniques were not used on samples for counting.

After acid maceration and rinsing, two drops of detergent (Darvon brand) were mixed with the residue in 15 mm glass test tubes in order to disperse the fine organics and prevent clumping of grains. The residue was rinsed twice in water. Some fine (<5 um) particles, but no palynomorphs, remained suspended in the supernatant after centrifugation and were discarded. However, much organic debris was retained in the residue and clumping remained a problem. At this stage in the maceration process a portion of the residue was stored in polypropylene vials and the remainder was treated as follows.

Zinc bromide solution, specific gravity 1.96, was added to fill the tube and thoroughly mixed with the residue. After an initial, low-speed centrifugation of about 30 minutes duration, the sample was allowed to sit overnight in order to insure complete separation of organic and undissolved mineral fractions. On several representative samples both the organic and mineral fractions were checked under 100x magnification to insure that separation was adequate. Only a very few (if any) pollen and spores were found in the mineral fraction. The floating organic portion was pipetted into a clean tube and mixed with sufficient dilute HCl (one part ZnBr to six parts dilute HCl float) to lower the specific gravity and allow the organic fraction to settle during centrifugation. Two water rinses preceded staining.

Safranin O, 1%, was used to stain the grains. Two drops of NH_4OH, 1%, and two drops of stain were added to about 20 ml of water-suspended residue and the tube was agitated. The sample was periodically checked under the microscope until the pollen and spores seemed sufficiently stained. The time varied from 2 to 20 minutes because different samples took stain differently. At least five water rinses followed.

The stained residue was suspended in hydroxyethylcellulose (HEC) following the last rinse and several drops of the thoroughly mixed suspension were pipetted onto coverslips. After the coverslips dried they were affixed to slides with Coverbond brand 60% synthetic resin cement, allowed to dry, and labeled. About 10 slides per sample were prepared and the remainder of the HEC suspension was stored in polypropylene vials.

After processing of the Alvord Creek Formation samples through to microscope slides, the modern soil sample was processed so that possible contaminating grains could be determined. The soil was thoroughly mixed in the bag and about 20 grams placed into a beaker of water and stirred. The sediments which remained suspended after 20 seconds were poured into a second beaker through a coarse screen (to remove floating plant fragments) and allowed to stand for 15 minutes. The supernatant was aspirated and the residue washed into a 15 mm test tube with glacial acetic acid. The sample was acetolyzed in the normal way (Doher, 1980); acetic anhydride and sulfuric acid in a 9:1 ratio were combined with the sample and heated for 10 minutes at 100° C. The sample was then rinsed and suspended in HEC. No staining was necessary because the grains took on a dark color during the acetolysis procedure.

Analysis

The slides were examined and palynomorphs discovered were photographed on a Zeiss Photoscope III using Kodak Panatomic X film. Cards with photos of typical grains were prepared to facilitate identification by comparison with modern reference slides and figured specimens in the literature. References for identification included: Wodehouse (1933a, 1933b, 1935), Traverse (1955), Axelrod and Ting (1960), Kapp (1969), McAndrews and others (1973), Bagnell (1975), and theses and dissertations referenced hereafter. Reference slides were used as well, in order to differentiate questionable taxa. Numerical counts were made while scanning under a 100x oil-immersion objective with Nomarski differential interference contrast (DIC). The results of the count were tabulated and evaluated. Taxa which appeared to have great variation in size or other morphological characters were graphed as number versus character in order to separate sub-populations.

Photographs of spores used in preparing taxa cards and thesis plates were taken using 40x and 100x planachromatic objectives with Nomarski DIC to enhance surface relief. Kodak Pan-X 35 mm film was developed in Microdol-X, 1:3 dilution, at 20.5° C for 13.5 minutes. Prints were made on Ilford 4.1P, glossy, single-weight paper developed in Kodak Dektol developer.

GEOLOGY

Basin and Range Setting

The Alvord Creek Formation crops out along the lower scarp of Steens Mountain, one of the earth's largest single exposures of Tertiary lavas (Baksi and others, 1967). The mountain is part of the northernmost extension of the Basin and Range Province and its structure has been variously attributed to high angle compressional (Smith, 1927), normal (Williams and Compton, 1953; Gettings and Blank, 1974), and thrust (Avent, 1968a) faulting. The Steens Mountain appears and is generally described as a gently westward dipping fault block but, as Fryberger (1959) noted, it possesses a low western scarp and is therefore actually a tilted horst. Major faults in the area trend generally to the northeast but there is a strong north-northwest component as well (Walker and Repenning, 1965).

The eastern scarp of the Steens Mountain has high relief but stratigraphic exposures are not well developed due to slumping and the development of extensive talus slopes. As a consequence, the correlation of units is difficult and stratigraphic positions are not always easily discerned. Fuller (1931) described four major units which have subsequently been revised (Williams and Compton, 1953; Walker and Repenning, 1965; Avent, 1970). Figures 3 and 4, a stratigraphic section and a generalized geologic map, incorporate these latest revisions.

Stratigraphic Units

Alvord Creek Formation: Originally termed the Alvord Creek Beds by Fuller (1931), and subsequently designated the Alvord Creek Formation

Figure 3. Stratigraphic correlation of the Steens and Pueblo Mountains region and the John Day Basin. After Avent (1970) with modified Epoch boundaries in m.y.b.p. *sensu* Palmer (1983).

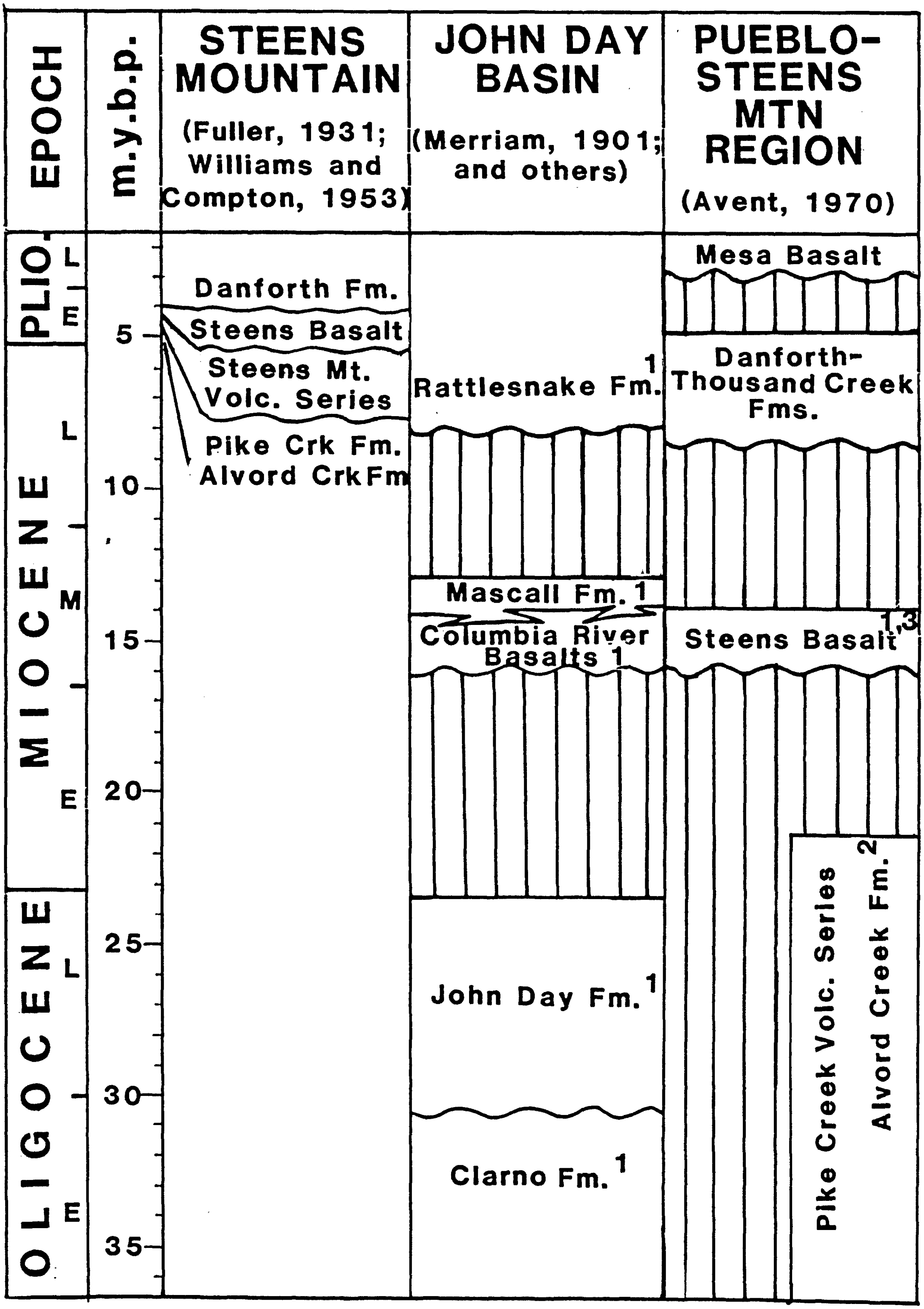
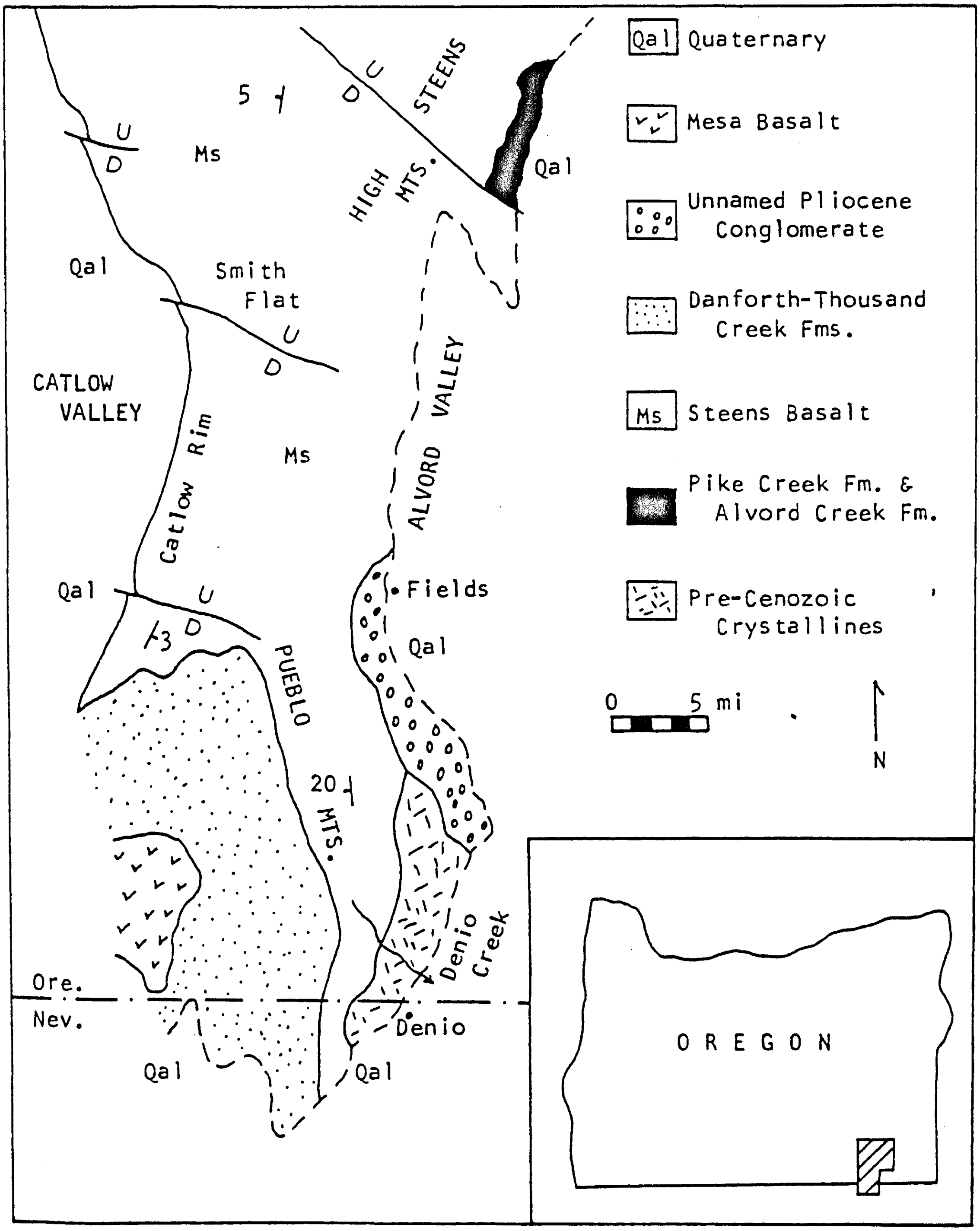

EPOCH
m.y.b.p.
STEENS MOUNTAIN
(Fuller, 1931; Williams and Compton, 1953)
JOHN DAY BASIN
(Merriam, 1901; and others)
PUEBLO-STEENS MTN REGION
(Avent, 1970)
PLIO.
L
E
MIOCENE
L
M
E
OLIGOCENE
L
E
5
10
15
20
25
30
35
Danforth Fm.
Steens Basalt
Steens Mt. Volc. Series
Pike Crk Fm.
Alvord Crk Fm
Rattlesnake Fm.1
Mascall Fm. 1
Columbia River Basalts 1
John Day Fm.1
Clarno Fm.1
Mesa Basalt
Danforth-Thousand Creek Fms.
Steens Basalt1,3
Pike Creek Volc. Series
Alvord Creek Fm.2

Figure 4. Generalized geologic map of the Steens and Pueblo Mountains area. From Avent, (1970).

GENERALIZED GEOLOGICAL MAP



From AVENT,1970

(Axelrod, 1944a; Williams and Compton, 1953), this unit consists of well stratified pastel tuffs, tuffaceous claystones, siltstones, sandstones, opaline cherts and lenses of conglomerate. Fryberger (1959) measured 274 meters of section from the top of the beds to the lowermost exposures in a talus- and alluvium-covered slope at the main scarp north of Big Alvord Creek. Along the north slope of the south branch of Big Alvord Creek, Fryberger measured a section 152 meters thick, showing intrusion by dikes and evidence of faulting. North of Alvord Creek the beds are interlayered with two andesite flows [or sills?]. A 61 meter thick sill intrudes the formation further to the south (Lund and Bentley, 1976).

The depositional environment of the Alvord Creek sediments has been interpreted as a shallow lake (Axelrod, 1944a; Fryberger, 1959). Fryberger suggested that the lower tuffaceous sandstones were rapidly deposited in quiet water. Nearby volcanic activity provided pyroclastic debris ranging from relatively large fragments to fine ash. Opalized layers within the formation are attributed to supersaturation of silica in the lake due to high ash content. Alternate dark and light banding was caused by seasonal or other rhythmic physical factors. The lake was fairly small (less than 8 km in length) and trees growing near shore contributed leaves showing no evidence of great transportation.

The stratigraphic position of the Alvord Creek Formation is uncertain (Walker and Repenning, 1965). Consequently, the age of the beds is in question and cannot be conclusively determined by stratigraphic position and, as noted earlier, the formation has been assigned conflicting ages. Walker and Repenning (1963) reported evidence of major faulting in the Alvord Creek area and collected Pliocene mammals in stratigraphically related gravel deposits lapping against the Pueblo Mountains to the south. Thus they thought they had explained the apparent contradiction in age. However, the following year Evernden and others (1964) reported a 21 m.y. K/Ar date from a tuff about 61 meters above the leaf bearing beds. On the basis of this radiometric date the Alvord Creek Formation appears to be Lower Miocene, but because the leaf beds were not directly sampled the issue was still not satisfactorily resolved. Avent (1968b) reported evidence that the Pueblo Mountains and probably the Steens Mountain resulted from deformation, overturn, and rupture of a major anticline with concomittant low angle thrust faulting. Exactly how that would affect apparent stratigraphic relations or how the Alvord Creek Formation would fit into such a scenario is not clear. It should be noted that Avent (1970) subsequently reaffirmed the pre-Pliocene age of the Alvord Creek Formation on the basis of reported K/Ar dates and the magnetostratigraphy of Baksi and others (1967).

Pike Creek Formation: To the south of the Alvord Creek area are exposures of the Pike Creek Formation. Originally named the Pike Creek Volcanic Series by Fuller (1931), Walker and Repenning (1965) renamed the siliceous tuffaceous sedimentary rocks, tuffs, tuff breccias, and intrusive and extrusive rhyolites the Pike Creek Formation. They also revised (1963) the age of this unit from Lower Pliocene to Upper Oligocene-Lower Miocene, largely on the basis of a mammalian fauna from tuffs several thousand feet above the Pike Creek Formation. Baldwin (1964) noted that the formation apparently interfingers with and overlies the Alvord Creek Formation thereby placing the age of the Alvord Creek Formation at least as old as Lower Miocene. However, he noted that the relation cannot be positively ascertained due to talus covered slopes.

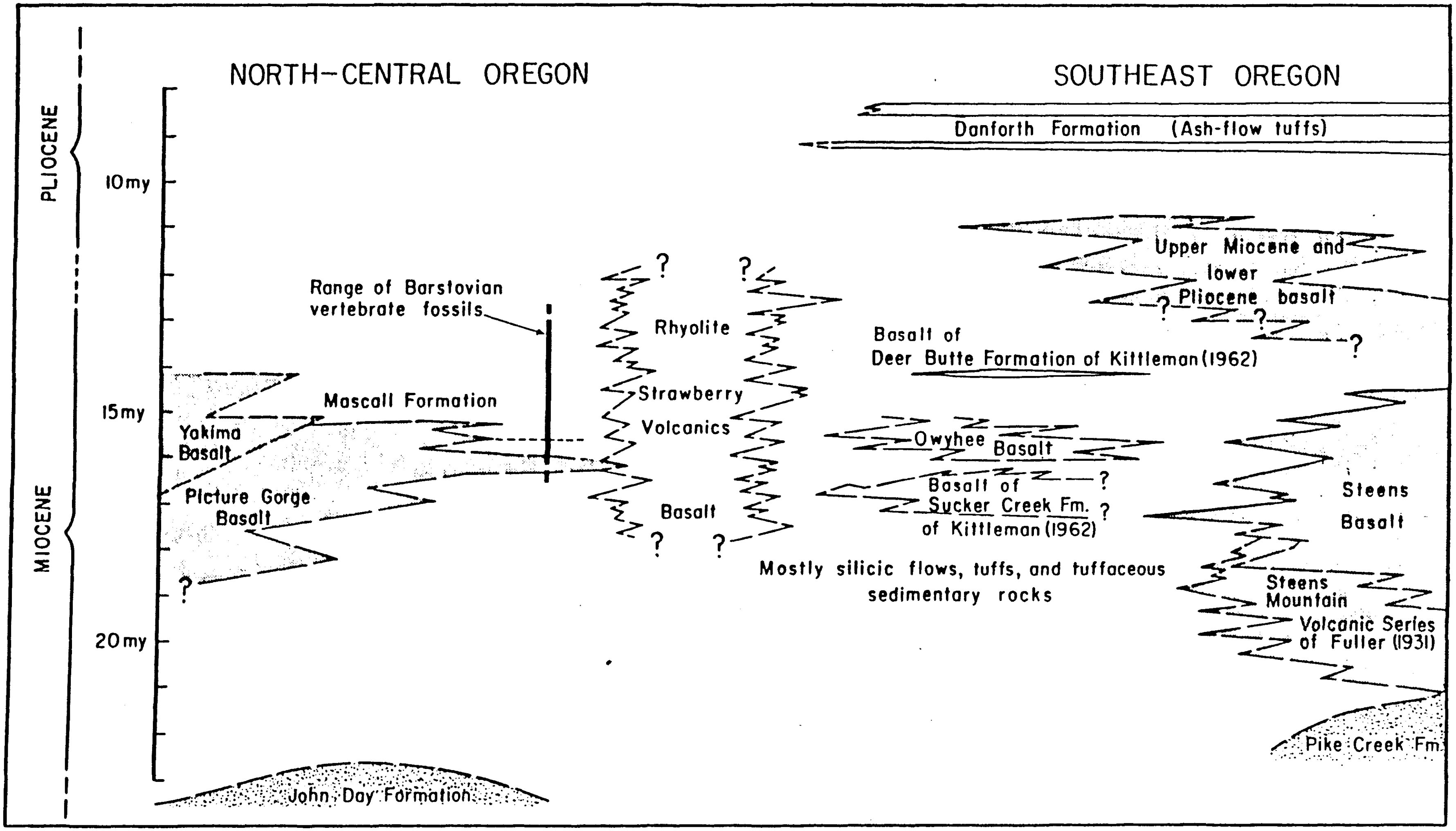
In the southern exposures of the formation near Pike Creek, a thick rhyolite flow caps the Pike Creek Formation but the flow is absent in the Alvord Creek area, suggesting a significant erosional event prior to the extrusion of the Steens Mountain Volcanic Series (Baldwin, 1964).

Steens Mountain Volcanic Series: Fuller (1931) designated as the Steens Mountain Andesitic Series a thick (914 meters) sequence of andesitic and basaltic lavas with rare interbeds of sedimentary and pyroclastic rocks. Included was the "Great Flow," a basaltic lava with well developed columnar joints 122 meters in height and individual columns 3 meters in diameter (Fryberger, 1959). The flow has a thickness of about 335 meters near Alvord Creek and it pinches out markedly northward, apparently due to great viscosity (Fryberger, 1959). Baldwin (1964), however, considered the "Great Flow" to be a sill rather than an extrusive. A body of thinner but otherwise similar igneous rock is also located within the top of the Alvord Creek Formation. As a consequence, Baldwin noted that if this assessment of intrusive emplacement is correct, the Alvord Creek Formation cannot be a post-"Great Flow" down-thrown block and is therefore older than the overlying Steens Volcanic Series.

The Steens Basalt: Several recent papers have examined the Steens Basalt in an effort to define its relation to the Columbia River Basalt Group, to ascertain its age with K/Ar or magnetostratigraphic dating or to better interpret the structure and geothermal potential of southeastern Oregon (e.g., Walker and Repenning, 1963, 1965; Baksi and others, 1967; Avent, 1968b, 1970; Gunn and Watkins, 1969; Gettings and Blank, 1974). The thick basalt succession covers a large area of southern Oregon and parts of California and Nevada (Walker, 1970). Walker correlated the Steens Basalt with the Columbia River Basalt Group, with the Owyhee Basalt, and with basalt of the Sucker Creek Formation (Figure 5). Fuller (1931) named the unit the Steens Mountain Basalt but the name has been emended (Williams and Compton, 1953, and successive authors) to Steens Basalt. Fryberger (1959) mapped the basalts and extended the lower formation boundary downward to include part of what had been included in Fuller's (1931) Steens Mountain Andesite Series. Avent (1970) traced the marked erosional contact between the Pike Creek Formation and the overlying Steens Volcanic Series from its southernmost exposure in the Pueblo Mountains northward to Smith Flat, just southwest of the Alvord Creek area. There the basaltic flows trace directly into the flows of the Steens Basalt. Avent therefore concluded that the Steens Volcanic Series is part of the Steens Basalt and proposed that the description of the Steens Basalt be emended (Figure 3). So defined, the Steens Basalt includes the basaltic and andesitic lavas from the angular unconformity between the Pike Creek Formation (as described by Williams and Compton, 1953), and from the erosional contact at the southern Pueblo Mountain exposures, to the upper erosional surface overlain by welded Pliocene tuffs and breccias.

Relief on the erosional surface below the Steens Basalt was quite well developed prior to extrusion of the basalts. Baldwin (1964)

Figure 5. Generalized relations of major basalt units in eastern Oregon. From Walker (1970).


NORTH-CENTRAL OREGON
SOUTHEAST OREGON
PLIOCENE
MIOCENE
10my
15my
20my
Danforth Formation (Ash-flow tuffs)
Upper Miocene and lower Pliocene basalt
Basalt of Deer Butte Formation of Kittleman (1962)
Range of Barstovian vertebrate fossils
Rhyolite
Strawberry Volcanics
Basalt
Mascall Formation
Yakima Basalt
Picture Gorge Basalt
Owyhee Basalt
Basalt of Sucker Creek Fm. of Kittleman (1962)
Steens Basalt
Mostly silicic flows, tuffs, and tuffaceous sedimentary rocks
Steens Mountain Volcanic Series of Fuller (1931)
Pike Creek Fm.
John Day Formation

noted the remarkable thickening and thinning of the Steens Basalt and the possibly equivalent Owyhee Basalts. The Steens Basalt thins from about 1520 to zero meters in relatively short distances. Baldwin attributed this thinning to pre-extrusion topography, not to subsequent erosion. Avent (1970) also emphasized the extensive weathering and dissection of the pre-Steens Basalt interval.

Magnetostratigraphy and K/Ar dating have been used to place absolute age on the Steens Basalt. According to Gunn and Watkins (1969), the basalts were extruded over no more than a 15,000 year interval. Baksi and others (1967) gave a date of 15.1 ± 0.3 m.y. for the extrusion based on paleomagnetic data combined wih K/Ar dates.

Danforth Formation: This formation comprises welded tuffs of Pliocene age which are scattered on Smith Flat and a more widespread sheet which extends over the lower slopes of the central and northern section of Steens Mountain. The formation has been largely removed by glacial ice and running water but its pattern of distribution suggests that the formation was emplaced before block faulting which, according to Lund and Bentley (1976), began 9 to 10 m.y. ago. However, more recently Hart and Mertzman (1982) described a flow capping an escarpment of Steens Basalt having a K/Ar date of 6.85 ± 0.59 m.y. This, they say, is "the maximum age to be assigned to the Basin and Range faulting in the Steens Mountain area - the displacement along the fault can be no older" than the [presumably fault-cut] basalt cap.

RESULTS AND DISCUSSION

Recovery and Preservation

Of the 30 samples of the Alvord Creek Formation processed for palynomorphs, 16 produced fair to excellent palynomorphs; three produced pollen judged to be too corroded for identification; and 11 were essentially barren. Quality of preservation varied widely among samples, even between samples in juxtaposition. Sample PP2124 (ACF-4) is characterized by both excellent preservation and abundance whereas none of the other eight samples collected from the same site were adequate for counting. One of the eight did have a small number of excellent grains but the preparation was dominated by grains corroded beyond recognition. Perhaps this may be attributed to variable conditions during the deposition of the 8 cm shale interval; oxidation or bacterial degradation may have been favored during the deposition of certain laminae and suppressed at other times.

Palynoflora of the Alvord Creek Formation

Palynomorphs were assigned to 30 genera in 22 families (Table I). An additional 8 morphotypes could not be placed in described taxa and were assigned morphologic codes such as Periporate-4. Fungal spores are also present but are not included in the taxonomic list. Of the pollen and spore genera assigned to described taxa, 1 (3%) is a sphenopsid, 2 (7%) are ferns, 11 (37%) are gymnosperms, and 16 (53%) are angiosperms. The dominant genera, in descending order of abundance are: *Quercus*, *Abies*, *Populus*, *Taxodium*, *Equisetum*, *Tsuga*, and *Pinus*. All other genera are uncommon or rare (less than 5% of total specimens).

TABLE I: Systematic List of Plant Microfossils Found in the Alvord Creek Formation

Sphenopsida	
Equisetaceae	
Equisetum sp.	Horsetail; Scouring rush
Filicopsida	
?Polypodiaceae	Common fern family
Laevigatosporites ovatus Wilson and Webster	
Incertae Sedis	
Deltoidospora sp.	
Spermatophyta	
Gymnospermae	
Gnetaceae	
Ephedra cf. *E. nevadensis* Wats	Mormon tea
Ephedra sp.	
Cupressaceae	
Juniperus sp.	Juniper
Pinaceae	
Abies sp.	Fir
Cedrus sp.	Cedar
Picea sp.	Spruce
Pinus sp.	Pine
Pseudotsuga sp.	Douglas fir
Tsuga sp.	Hemlock
Podocarpaceae	
Podocarpus sp.	Podocarpus
Taxodiaceae	
Glyptostrobus sp.	Canton water pine
Taxodium cf. *T. hiatipites* Wodehouse	Swamp-cypress
Angiospermae	
Monocotyledonae	
Potamogetonaceae	
Potamogeton sp.	Pondweed
Dicotyledones	
Aceraceae	
Acer sp.	Maple
Betulaceae	
Corylus sp.	Hazel
Cactaceae	
?*Echinocerus* sp.	Cactus
Chenopodiaceae	
cf. *Sarcobatus* sp.	Grease-wood
Elaegnaceae	
Shepherdia sp.	Soap or Buffalo berry
Fagaceae	
Quercus cf. *Q. granopollenites* Rouse	Oak
Quercus sp.	

Juglandaceae	
Juglans sp.	Walnut
Moraceae	
Morus sp.	Mulberry
Nyssaceae	
Nyssa sp.	Sourgum
Oleaceae	
Fraxinus sp.	Ash
Platanaceae	
Platanus sp.	Plantain, Sycamore
Rosaceae	
?*Rosa* sp.	Rose
Salicaceae	
Populus sp.	Poplar
Salix sp.	Willow
Ulmaceae	
Ulmus sp.	Elm
Incertae Sedis	
Inaperturate - 1	
Periporate - 2	
Periporate - 4	
Periporate - 7	
Tricolpate - 10	
Tricolpate - 13	
Pericolpate - 2	
Tricolporate - 3	

TOTAL: 22 Families
30 Genera

Comparison of the Leaf and Pollen Floras

A list of the Alvord Creek leaf flora has been prepared from Axelrod's (1944a) description of the flora with additions from Wolfe (*in* Fryberger, 1959). This list (Table II) is supplemented by the palynoflora reported herein. The combined flora includes 43 genera in 28 families. At the generic level, 44% of the taxa belong to the pollen flora alone, 30% belong to the leaf flora alone, and only 26% are common to both. The situation is similar with regard to families: 50% belong only to the pollen flora, 25% to the leaf flora alone, and 25% are held in common.

Correspondence between the leaf and pollen floras is low at both generic and familial levels, but if correspondence between dominant genera is considered, the similarities are even less. Axelrod (1944a) did not give information on the quantitative abundance of each leaf genus but he did state that *Amelanchier*, *Cerococarpus*, *Acer* and *Rhus* were the overwhelmingly dominant group, together accounting for 90% of all his specimens. Only one of these four genera (*Acer*) is recognized in the pollen and it accounts for just 1% relative abundance. *Quercus* is slightly dominant in the pollen flora but it is not even reported from the leaf flora. Gymnospermous taxa are numerically important in the pollen flora but are far less so in the leaf flora.

Large discrepancies are also known from other Tertiary floras. For example, Barnett (1982) reported 18% and 25% correspondence at generic and familial levels respectively for the Weaverville Flora. Gray (1964), in reference to Pliocene floras in particular, noted that marked discrepancies are generally characteristic of palynofloras

TABLE II: Combined Leaf and Pollen Flora of Alvord Creek

Family Genus	Pollen	Leaves	Family Genus	Pollen	Leaves
Equisetaceae			Elaegnaceae		
Equisetum	x		*Shepherdia*	x	
?Polypodiaceae			Ericaceae		
Laevigatosporites	x		*Arbutus*		x
Incertae Sedis			Fagaceae		
Deltoidospora	x		*Quercus*	x	
Gnetaceae			Juglandaceae		
Ephedra	x		*Juglans*	x	
Cupressaceae			Leguminosae		
Juniperus	x	x	*Amorpha*		x
Pinaceae			Moraceae		
Abies	x	x	*Morus*	x	
Cedrus	x		Nyssaceae		
Picea	x	x	*Nyssa*	x	
Pinus	x	x	Oleaceae		
Pseudotsuga	x	x	*Fraxinus*	x	
Tsuga	x		Platanaceae		
Podocarpaceae			*Platanus*	x	
Podocarpus	x		Rhamnaceae		
Taxodiaceae			*Ceanothus*		x
Glyptostrobus	x		Rosaceae		
Taxodium	x		*Amelanchier*		x
Potamogetonaceae			*Cercocarpus*		x
Potamogeton	x	x	*Photinia*		x
Aceraceae			*Prunus*		x
Acer	x	x	*Rosa*	x	x
Anacardiaceae			*Rubus*		x
Rhus		x	*Sorbus*		x
Berberidaceae			Salicaceae		
Mahonia		x	*Populus*	x	x
Betulaceae			*Salix*	x	x
Carpinus		x	Saxifragaceae		
Corylus	x		*Ribes*		x
Cactaceae			Ulmaceae		
?*Echinocerus*	x		*Ulmus*	x	x
Chenopodiaceae					
cf. *Sarcobatus*	x				

Families in leaf flora only: 30%
Families in pollen flora only: 44%
Families common to both: 26%

Genera in leaf flora only: 25%
Genera in pollen flora only: 50%
Genera common to both: 25%

associated with small leaf floras. However, the deviations are also striking in some larger leaf floras of the Lower Neogene. For instance, Graham (1965) studied over 2500 leaf specimens from the Late Miocene Sucker Creek Formation, counted 20,000 palynomorphs, and reported wide variations in the relative abundance of leaf and pollen taxa.

There are several explanations that may be offered for low correlation. It is well known that pollen may be transported over extraordinary distances. Adam (1973), for instance, reported transport of modern *Picea* pollen from at least 450 km to a sample site in Searles Lake, California. Thus it is reasonable to expect a substantial amount of wind- or water-borne pollen to be transported into a lake from more moderate distances, reflecting perhaps montane vegetation in what would otherwise be a warmer climate flora.

The mode of pollen distribution greatly affects dispersal. Wodehouse (1935) noted that *Prunus* (a genus reported only from leaves at Alvord Creek) is insect pollinated whereas *Tsuga* (found only as pollen in the Alvord Creek sediments) is distributed by wind. Even among anemophilous genera such as *Pinus* and *Quercus*, both of which produce enormous amounts of pollen (Wodehouse, 1935), the distribution of saccate *Pinus* grains would be expected to surpass that of the relatively dense *Quercus*.

The lack of correlation between the pollen and leaf records at Alvord Creek may be due to any or perhaps, in part, to all of the above reasons. Because leaf and pollen floras do present different aspects of the vegetation they may be considered complementary and thereby provide a more accurate picture of the regional flora than either alone.

Paleoecology

The climate of the Alvord Creek Flora may be inferred by comparing it with the climatic distributions of equivalent modern taxa and similar modern assemblages (Gray, 1955; Taggart, 1971; Barnett, 1982). Of course, the caveats that the taxonomic assignment of the flora may not be correct and that climatic requirements of Tertiary and modern genera may not be equivalent must be remembered when evaluating such inferences.

Taxonomic assignments of fossil pollen are difficult below the generic level and often must be accomplished at only the family level. Degradation or occlusion by debris also render identification impossible in many cases. Even if preservation and slide preparation are excellent the similarities between certain unrelated but morphologically similar pollen (e.g., Equisetum and Larix) make separation nearly impossible.

As regards the second major assumption, that past ecologic requirements are essentially the same as those of modern related genera, Taggart (1971) and Leopold (1969) cautioned that climatic ranges of extant living plants may well have been modified significantly through natural selection. Nevertheless, Leopold (1969) correctly stated that the only basis for any paleoecologic interpretation at all rests in cautious use of the uniformitarian principle.

Figure 6 is a summation of climatic ranges for modern taxa represented in both the leaf and pollen flora of the Alvord Creek Formation. The two climatic ranges most often represented in the ranges of the listed genera are warm temperate and cool temperate. Five genera, of which Taxodium and Podocarpus are more abundantly

Figure 6. Climatic ranges of modern taxa represented in the Alvord Creek leaf and pollen floras. Climatic ranges after Barnett and Fisk (1980), and others.

GENUS \ CLIMATE	Tropical	Subtropical	Warm Temperate	Cool Temperate	Boreal
Equisetum	—	—	—	—	
Laevigatosporites	—	—	—	—	—
Ephedra	—	—	—	—	
Abies			—	—	—
Cedrus		—	—	—	
Glyptostrobus		—	—	—	
Picea			—	—	—
Pinus		—	—	—	—
Tsuga			—	—	
Pseudotsuga			—	—	
Juniperus	—	—	—	—	—
Podocarpus		—	—		
Taxodium		—	—		
Ceanothus			—	—	
Amelanchier			—	—	
Cercocarpus			—	—	
Photinia			—	- -	
Prunus			—	—	
Rosa			—	—	
Rubus		- -	—	—	
Sorbus			—	—	—
Populus	—	—	—	—	—
Salix	—	—	—	—	—
Ulmus		—	—	—	
Potamogeton		—	—	—	—
Acer		—	—	—	
Rhus		—	—	—	
Mahonia			- -	—	
Corylus			—	—	
Carpinus		—	—	—	
Echinocerus		—	—	—	
Sarcobatus	—	—	—	—	—
Shepherdia			—	—	- -
Arbutus		—	—	—	
Quercus		—	—	—	
Ribes		—	—	—	
Juglans		—	—		
Amorpha	—	—	—		
Morus	—	—	—		
Nyssa		—	—	—	
Fraxinus	—	—	—	—	
Platanus		—	—	—	
% TOTAL TAXA	24	64	98	86	24

represented, have ranges extending only to warm temperate, whereas no genus is restricted only to cool temperate or boreal. By this line of reasoning, the climate most likely present during deposition of the Alvord Creek Formation was warm to cool temperate.

A similar conclusion can be drawn if only the dominant pollen and spore taxa (Quercus, Abies, Populus, Taxodium, Equisetum, Tsuga) and the dominant leaf taxa (Acer, Amelanchier, Cerococarpus, and Rhus) are considered: the flora indicates a temperate climate.

Habitat is analysed in like fashion in Figure 7. It appears that modern equivalents of Alvord Creek taxa occupy a wide range of habitats, tending towards moderately moist conditions. However, certain taxa are quite restricted in habitat today, such as the important pollen floral element, Taxodium, which now occupies streambanks and swamplands, and Cerococarpus and Photinia, leaf types associated with dry upland forests. If the diagnosis of Echinocerus is correct, it and Ephedra cf. E. nevadensis indicate dry, desert-like conditions comparable to the present-day Basin and Range. Potamogeton, on the other hand, is indicative of shallow water, which is not remarkable if indeed the Alvord Creek Formation is lacustrine in origin as Fryberger (1959) has interpreted. Habitats represented by extant members of the Alvord Creek Flora occupy a wide range of habitats and thus suggest considerable relief with at least some degree of aridity.

In order to better evaluate the habitat in which Tertiary floras grew it is useful to compare them to modern communities. Axelrod (1944a) assigned species of the Alvord Creek Flora to four floral elements, the West American, Southwest American, East American, and East

Figure 7. Generalized ecological habitats of modern taxa represented in the Alvord Creek leaf and pollen floras. Ecological ranges after Barnett and Fisk (1980), and others.

HABITAT / GENUS	Lakes/Ponds or streams	Streamlands Swamps/Shores	Mesic Forest	Dry Forest	Dry Soils Deserts
Equisetum		——	——	——	——
Laevigatosporites		——	——	——	——
Ephedra				——	——
Abies			- - -	——	
Cedrus			——	——	
Glyptostrobus		——			
Picea		——	——	——	
Pinus		——	——	——	
Tsuga		- - -	——		
Pseudotsuga			——	——	
Juniperus		——	——	——	——
Podocarpus			——		
Taxodium		——			
Ceanothus			——	——	
Amelanchier		——	——	——	
Cercocarpus				——	
Photinia			- - -	——	
Prunus		——	——	——	
Rosa		——	——		
Rubus		——	——	- - -	
Sorbus		——	——	——	
Populus			——	- - -	
Salix		——	——		
Ulmus		——	——	——	
Potamogeton	——				
Acer		——	——	——	
Rhus		——	——	——	——
Mahonia			——	——	
Corylus			——		
Carpinus		——	——	- - -	
Echinocerus				——	——
Sarcobatus		——	——	——	——
Shepherdia			——	——	——
Arbutus		——	——	——	
Quercus		——	——	——	——
Ribes		——	——	——	
Juglans			——		
Amorpha		——	——	——	
Morus			——		
Nyssa		——	——		
Fraxinus		——	——	- - -	
Platanus		——	——		
% TOTAL TAXA	2	57	81	64	21

Asian elements. Of these, the Alvord Creek Flora most clearly resembles the Western American Element. Axelrod noted that of his 26 species, 23 belong to that element and all of those 23 are part of the Arid Transition component of that element.

In addition to the high degree of correlation exhibited between the Alvord Creek Flora and the Arid Transition zone, Axelrod (1944a) reported striking similarities in leaf morphology between Alvord Creek specimens and members of the flora's modern equivalents in the arid extent of their ranges. Axelrod summarized the relations by stating that the leaf flora of Alvord Creek compares favorably to the Arid Transition and Upper Sonoran associations of the inner Klamath Mountains of northern California. From this association, he determined that climatic conditions during Alvord Creek time were moderate, with annual rainfall at 51-58 cm locally but up to 76 cm in surrounding upland areas. Rainfall was year-round but greater in winter than summer, for otherwise representatives of the Eastern American and Eastern Asian elements would have been more abundant. Temperature was supposed to have ranged from winter mean monthly lows of about -7^{o} C to summer mean monthly highs of about 29^{o} C.

The additional information bearing on climate provided by pollen taxa suggests a somewhat moister habitat than that of the Arid Transition zone, yet there is ample evidence of dry conditions in at least parts of the area surrounding the depositional basin. Added taxa now exotic to the region which indicate a more moist habitat are: Glyptostrobus, Podocarpus, Taxodium, Juglans, Nyssa, Fraxinus, and Ulmus. On the other hand, ?Ephedra, Echinocerus, and cf. Sarcobatus tend to support Axelrod's view that considerable aridity was present. It is also significant that _Quercus_, conspicuously missing from the leaf flora and expected in light of its presence in both Pacific Northwest Neogene floras and in the modern Arid Transition Zone, is a dominant element in the pollen flora.

Axelrod's (1944a) climatic interpretations are not seriously altered by this study. Variances in topography could explain the different ecological requirements of individual taxa without altering the observed trend towards drier and cooler climates (Dorf, 1959; Leopold, 1969) associated with Middle to Late Neogene time. However, Axelrod felt that relief was not well developed during the deposition of the leaf-bearing shales. If his age assignment of Pliocene is correct then there is no geological reason to suspect otherwise; Pliocene sediments on top of Steens Mountain imply that it was not uplifted before the Pliocene. But, if the beds actually are stratigraphically lower than the Steens Basalt (_sensu_ Avent, 1970), then the adjacent area did have considerable relief prior to deposition of the Steens Basalt. Both Baldwin (1964) and Avent (1970) emphasized the great relief of the underlying sediments during the extrusion of the basalt.

In summary, the combined flora of the Alvord Creek Formation can best be described as warm to cool temperate forms growing in a fairly dry area with moderate relief. Microhabitats and transportation of pollen and spores and leaves can account for the differences in ecological indications. Taxa such as _Potamogeton_, _Taxodium_, _Fraxinus_, and _Nyssa_ may have grown on or near the lake shore, and montane or arid genera such as _Cerococarpus_, _Tsuga_, and _Ephedra_ may have been transported to the depositional basin.

Comparison with Other Floras

In order to assess the age of a fossil flora it is often useful to compare it with other floras of determined age. In the case of suspected Pliocene floras this is difficult because later Tertiary floras tend to be more provincial, thereby precluding regional comparison, and because there are few described Pliocene leaf floras and very few described Pliocene palynofloras (Gray, 1965; Leopold, 1969). Since the Alvord Creek Flora has been assigned to both the Miocene and Pliocene by various workers, I chose to compare it with several well established Miocene and Pliocene floras of the western United States (Table III and Appendix B).

In Appendix B are listed the genera reported from six floras of ?Upper Oligocene to Upper Miocene age, three floras of transitional Miocene-Pliocene age, four floras of Lower to Middle Pliocene age, and the Alvord Creek Flora. Unfortunately, only three of the floras other than the Alvord Creek Flora have both pollen and leaf records and these are all from the Miocene. One, the Palouse Falls (Barnett and Fisk, 1980) has only pollen, and the remaining nine have only a leaf record.

The correspondence between the Alvord Creek Flora and each of the other floras was calculated by counting the genera or families common to both floras and dividing by the total number of genera or families reported from both floras. These data are listed in Table III.

There is no clear similarity between the Alvord Creek Flora and either Miocene, Miocene-Pliocene transition, or Pliocene aged floras.

Table III: Summary of Correspondence Between the Alvord Creek Flora and Other Floras of Miocene and Pliocene Age of the Western United States[1]

Flora	Age	Percent Correspondence Familial Level	Percent Correspondence Generic Level
Creede[2]	?Olig-Mio	45	29
Palouse Falls[3]	m-Mio	46	37
Trout Creek[4]	u-Mio	43	27
Sucker Creek [2]	u-Mio	45	29
Kilgore[2]	u-Mio	42	24
Ellensburg Unit-1[4]	u-Mio	30	16
Ellensburg Unit-2[4]	u-Mio-l-Plio	31	16
Ellensburg Unit-3[4] (inc. upper gravels)	l-Plio	19	15
Weiser[4]	u-Mio-l-Plio	44	27
Dalles[4]	l-Plio	25	17
Deschutes[4]	l-m-Plio	10	9
Chalk Hills[4]	l-m-Plio	41	23
Alturas[4]	m-Plio	7	7

[1]List of taxa and sources are given in Appendix B
[2]Leaf and pollen floras
[3]Pollen flora only
[4]Leaf flora only

The flora with best correspondence to the Alvord Creek is the Middle Miocene Palouse Falls Flora with 37% generic agreement but this does not, in itself, relegate the Alvord Creek Flora to a Middle Miocene age. In the first place, none of the Pliocene floras list palynomorphs and so potentially complementary data is missing. Moreover, as Chaney (1944) notes, Pliocene floras are generally depauperate with respect to Miocene floras owing to several factors including the increased aridity and coarser sedimentary deposits characteristic of the Pliocene. Thus the significance of percent correspondence should not be overemphasized.

A second caution regarding percent correspondence is this: although the Miocene Palouse Falls Flora corresponds reasonably well with the Alvord Creek Flora, when the taxa in disagreement are examined it becomes apparent that taxa indicative of generally warm climates tend to be absent in Alvord Creek. There is a low diversity of spores of ferns and their allies. (Only two unambiguous trilete or monolete spores have yet been encountered in the Alvord Creek Flora.) _Ilex_, _Alnus_, _Betula_, _Fagus_, _Carya_, and _Tilia_ - all "'typically Miocene' genera" (Gray, 1965) - are found in the Palouse Falls and most of the Miocene floras listed but are missing from the Alvord Creek Flora.

Age of the Flora

Paleobotanical evidence: It is generally accepted that Pliocene floral assemblages are characterized by increasing aridity and decreasing temperature (e.g., Chaney, 1925, 1938; Dorf, 1959; Leopold, 1969). The Alvord Creek Flora does possess many warm temperate forms but it is conspicuously devoid of "characteristic" Miocene taxa, as noted previously. Furthermore, the many species endemic to the Northwest preserved as fossils are more characteristic of the Late than Early Neogene (Wolfe and Barghoorn, 1960). On this basis, a Lower Pliocene age seems most appropriate. However, the presence of Nyssa, Taxodium, and Juglans in the pollen flora mitigate against a younger age assignment.

Radiometric evidence: Dates obtained on the (?)overlying Steens Basalt (14.3 m.y., Evernden and others, 1964) and on a basalt flow 61 m above the Alvord Creek leaf beds localities (21.2 m.y., Evernden and James, 1964) are in sharp disagreement with a Lower Pliocene or even an Upper Miocene age. Evernden and James (1964) thus conclude that floristic dating is not sufficiently refined to be of much value as an indicator of age. It should be noted that the problem and their conclusion are not confined to the Alvord Creek Flora: Leopold (1969) reported a flora from Creede, southwestern Colorado, whose leaf flora was so similar to the endemic flora that MacGinitie and others believed it to be Miocene or Pliocene but which has been K/Ar dated at 26 million years. Recently two other studies (Hickey and others, 1983; Turner and others, 1983) have noted serious discrepancies which challenge the validity of paleobotanical age determinations.

Since Evernden and James (1964) did not actually date the Alvord Creek plant-bearing beds, the validity of their conclusions may be challenged. Thus a new sample for radiometric analysis was taken from a tuff less than 20 cm above leaf-bearing shales on the slope north of the fork of Big Alvord Creek. The date obtained by K/Ar analysis (Geochron Laboratories, Cambridge, MA, Sample No. F-6635; see Appendix C) was

23.8 m.y., which is Uppermost Oligocene! (Palmer (1983) places the base of the Miocene at 23.7 m.y.)

There are several possible (or remotely possible) explanations for the discrepant ages: (1) The formation is not in actual contact with the overlying tuff but appears so to be through faulting. Avent (1968a) suggested low angle thrust faulting through compressive forces. His model proposed an overturned, ruptured anticline which could conceivably allow the beds to be overturned or perhaps underthrust. In that case the Alvord Creek Formation could be younger than the K/Ar dated tuff. Walker and Repenning (1963) reported evidence of faulting also, although the Alvord beds would presumably be a slump block resulting from normal faulting. (2) The K/Ar date may be erroneous. If the feldspar concentrate which was dated (Appendix C) should prove to be reworked or if the argon presumed to be radiogenic was excessive, the tuff would actually be younger than the cited date. (3) The climatic interpretation of the flora is incorrect and/or assumed regional patterns are incorrect. The warnings concerning paleobotanical evaluation cited earlier explain this possible cause of discordant dates. Taxa may have quite different ecological requirements today than when their ancestors were fossilized. Identifications may be awry or taxa may reflect only microhabitats to the exclusion of the broader picture.

Whatever the reason(s) there is not now a satisfactory resolution to the problem of discordant dating of the Alvord Creek Formation by paleobotanical and radiometric methods. A more detailed study of the structure and stratigraphic relationships between units in the Alvord Creek area, along with further radiometric determinations, would be welcome.

CONCLUSIONS

1. The expanded list of taxa in the Alvord Creek Formation indicates warm to cool temperate climate with arid to locally moist habitats.
2. The age of the Alvord Creek Flora is paleobotanically determined to be Lower Pliocene.
3. Serious discrepancies still exist between the paleobotanically and radiometrically determined dates for the Alvord Creek Formation.

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APPENDIX A: LOCALITY DESCRIPTIONS

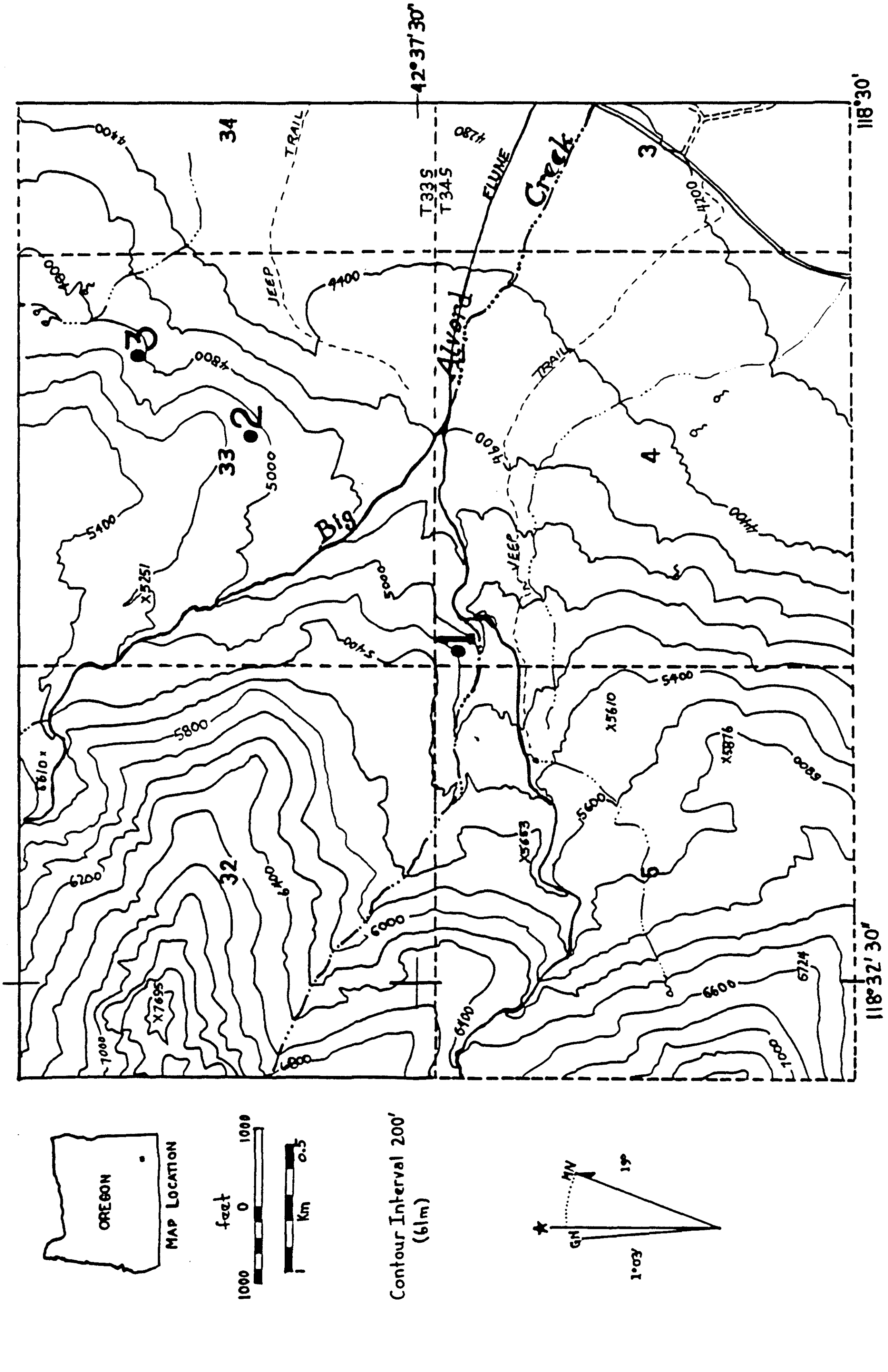
Locality information determined from Alvord Hot Springs Quadrangle and Wildhorse Lake Quadrangle, Oregon - Harney County, 7.5 Minute Series (Topographic), U. S. Geological Survey.

Locality 1: NW1/4 NW1/4 NW1/4 Sec 4 T 34 S R 34 E
SW1/4 SW1/4 SW1/4 Sec 33 T 33 S R 34 E
Below cliff-forming layers on south facing slope north of south fork of Big Alvord Creek at approximately 1585 meters elevation.
Samples ACF 15-29.

Locality 2: NW1/4 NW1/4 SE1/4 Sec 33 T 33 S R 34 E
Approximately due north of fork on Big Alvord Creek on southeast facing slope, elevation approximately 1555 meters.
Samples ACF 4-8 (collected in 1978 by L. H. Fisk), ACF 30-33 and ACF Tuff Nos. 1-3.

Locality 3: NW1/4 SE1/4 NE1/4 Sec 33 T 33 S R 34 E
Approximately 1220 meters north of fork on Big Alvord Creek.
Gully and eroded slope at about 1555 meters elevation.
Corresponds to "main scarp" of Axelrod (1944).
Samples ACF 34-37.

Appendix A Figure 1. Location of the three sample sites.


42°37'30"
118°30'
118°32'30"
T33S
T34S
34
33
32
3
4
5
FLUME
Big Alvord Creek
JEEP
TRAIL
X5251
X5610
X5876
X5653
X7695
6724
OREGON
MAP LOCATION
feet
1000
0
1000
Km
0.5
Contour Interval 200'
(61m)
MN
GN
19°
1°03'

APPENDIX B

FAMILIES AND GENERA REPORTED FROM ALVORD CREEK AND SELECTED MIOCENE AND PLIOCENE FLORAS OF THE WESTERN UNITED STATES

1 = present in leaf flora; p = present in pollen flora; + = present in both; * = reported as family only

	MIOCENE							TRANSTIONAL		PLIOCENE				
Family Genus	Creede[1]	Palouse Falls[2]	Trout Creek[3]	Sucker Creek[4]	Kilgore[5]	Ellensburg U-1[6]	Ellensburg U-2[6]	Ellensburg U-3[6]	Weiser[7]	Dalles[8]	Deschutes[9]	Chalk Hills[10]	Alturas[11]	Alvord Creek
Equisetaceae														
Equisetum		p	1	1					1					p
Blechnaceae														
Woodwardia				+										
Lycopodiaceae														
Lycopodium		p		p	p									
Selaginellaceae														
Selaginella	p	p												
Davalliaceae														
Davallia				p										
Salviniaceae														
Azolla		p												
Polypodiaceae					*									
Deltoidospora		p		p										p
Dryopteris									1					
Laevigatosporites		p												p
Polypodium			1	p										
Verrucatosporites		p												
Osmundaceae														
Osmunda				p										
Gingkoaceae														
Gingko				+										
Gnetaceae														
Ephedra	p			p										p
Cupressaceae														
Chamaecyparis			1		1							1		
Juniperus		p			p				1					+
Libocedrus									1					
Thuja		p	1	1					1					

Family Genus	Creede[1]	Palouse Falls[2]	Trout Creek[3]	Sucker Creek[4]	Kilgore[5]	Ellensburg U-1[6]	Ellensburg U-2[6]	Ellensburg U-3[6]	Weiser[7]	Dalles[8]	Deschutes[9]	Chalk Hills[10]	Alturas[11]	Alvord Creek
Pinaceae														
Abies	p	p	1	p	p				1			1		+
Cedrus		p			p									p
Keteleeria			1											
Larix	p	p		1										
Picea	p	p	1	+	p				1					+
Pinus	p	p	1	+	p				1			1		+
Pseudotsuga			1						1			1		+
Tsuga	p	p	1	p										p
Podocarpaceae														
Podocarpus		p												p
Taxodiaceae														
Glyptostrobus				+										p
Sequoia					p				1			1		
Taxodium		p				1								p
Gramineae														
Cyperacites				+	p				1					
Graminidites		p												
Liliaceae														
Smilax			1											
Pandanaceae														
Pandaniidites		p												
Potamogetonaceae														
Potamogeton	1	p		p										+
Typhaceae														
Typha		p	1	+	p				1					
Aceraceae														
Acer	p	p	1	+	+	1	1	1	1	1	1			+
Aquifoliaceae														
Ilex		p	1	+	p									
Anacardiaceae														
Rhus														1
Araliaceae														
Oreopanex				1										
Berberidaceae														
Mahonia	1		1	+	1		1					1		1
Odostemon									1					

Family Genus	Creede[1]	Palouse Falls[2]	Trout Creek[3]	Sucker Creek[4]	Kilgore[5]	Ellensburg U-1[6]	Ellensburg U-2[6]	Ellensburg U-3[6]	Weiser[7]	Dalles[8]	Deschutes[9]	Chalk Hills[10]	Alturas[11]	Alvord Creek
Betulaceae														
<u>Alnus</u>	p	p	1	+	p	1	1		1			1		
<u>Betula</u>		p	1	+	p	1			1			1		
<u>Carpinus</u>		p	1	p	p									1
<u>Corylus</u>		p												p
<u>Ostrya</u>		p	1	+					1					
Boraginaceae														
<u>Cordia</u>					1									
Buxaceae														
<u>Pachysandra</u>				p										
Cactaceae														
<u>Echinocerus</u>														p
Caprifoliaceae														
<u>Symphoricarpus</u>			1	1			1	1						
Celastraceae														
<u>Celastrus</u>									1					
Cercidiphyllaceae														
<u>Cercidiphyllum</u>									1					
Chenopodiaceae														
cf. <u>Sarcobatus</u>	p	p		p	p									p
Compositae														
<u>Ambrosia</u>				p	p									
<u>Artemesia</u>	p			p	p									
Coriariaceae														
<u>Coriaripites</u>		p												
Cornaceae														
<u>Cornus</u>				1										
Cyperaceae														
<u>Cyperacites</u>									1					
Ebenaceae														
<u>Diospyros</u>			1	1	1									
Eleagnaceae														
<u>Eleagnus</u>	p			p										
<u>Shepherdia</u>				p										p
Ericaceae														
<u>Arbutus</u>			1	+					1			1		1
<u>Arctostaphylos</u>							1							
<u>Rhododendron</u>							1					1		
<u>Vaccinium</u>		p					1							

Family Genus	Creede[1]	Palouse Falls[2]	Trout Creek[3]	Sucker Creek[4]	Kilgore[5]	Ellensburg U-1[6]	Ellensburg U-2[6]	Ellensburg U-3[6]	Weiser[7]	Dalles[8]	Deschutes[9]	Chalk Hills[10]	Alturas[11]	Alvord Creek
Fagaceae														
Castanea			1	1										
Castanopsis									1	1		1		
Fagus		p		+		1								
Lithocarpus			1	+										
Quercus	+	p	1	+	+	1	1	1	1	1		1		p
Hamamelidaceae														
Liquidambar	p	p		p	p		1	1						
Hydrocaryaceae														
Trapa									1					
Juglandaceae														
Carya	+	p	1	p	+		1					1		
Juglans	p	p	1	p	p				1					p
Pterocarya	+	p		+	+					1				
Labiatae		*			*									
Lauraceae														
Lindera			1											
Persea	1		1	1	1		1							
Sassafras				1										
Leguminosae			*											
Amorpha							1			1				1
Cercis						1		1		1				
Cladrastis	1				1									
Gymnocladus				1										
Robinia					1		1							
Magnoliaceae														
Magnolia				1										
Malpihgiacea														
Hiraea				1										
Malvaceae														
Anoda				1										
Gossypium			1											
Malvacearumpollis		p												
Malvacipollis		p												
Urena			1											
Meliaceae														
Cedrela	1			1	+									
Menispermaceae														
Cocculus					1									
Moraceae														
Morus		p												p

Family Genus	Creede[1]	Palouse Falls[2]	Trout Creek[3]	Sucker Creek[4]	Kilgore[5]	Ellensburg U-1[6]	Ellensburg U-2[6]	Ellensburg U-3[6]	Weiser[7]	Dalles[8]	Deschutes[9]	Chalk Hills[10]	Alturas[11]	Alvord Creek
Myricaceae														
<u>Myrica</u>					p									
Nymphaeceae														
<u>Nymphaea</u>		p	1	p										
<u>Nymphaeites</u>			1											
Nyssaceae														
<u>Nyssa</u>		p	1	+	1									p
Oenotheraceae	*													
Oleaceae														
<u>Fraxinus</u>		p	1	1	1	1			1					p
Onagraceae					*									
<u>Jussiaea</u>		p												
Passifloraceae														
<u>Passiflora</u>							1							
Platanaceae														
<u>Platanus</u>		p		1	+	1	1	1	1	1				p
Polygonaceae														
<u>Polygonum</u>		p												
Rhamnaceae														
<u>Ceanothus</u>							1	1				1		1
<u>Rhamnus</u>						1	1	1				1		
Rosaceae														
<u>Amelanchier</u>			1	1								1		1
<u>Cercocarpus</u>	1								1					1
<u>Crataegus</u>	1		1	1	1		1							
<u>Holodiscus</u>			1		1							1		
<u>Photinia</u>														1
<u>Prunus</u>			1						1	1	1	1		1
<u>Pyrus</u>				1	1									
<u>Rosa</u>			1											+
<u>Rubus</u>														1
<u>Sorbus</u>														1
<u>Spiraea</u>			1											
Rutaceae														
<u>Ptelea</u>			1	1		1			1					
Sabiaceae														
<u>Meliosma</u>					+									
Salicaceae														
<u>Populus</u>	p	p	1	+	1	1	1	1		1	1	1	1	+
<u>Salix</u>	p	p	1	+	p	1	1	1	1	1	1	1	1	+

Family Genus	Creede[1]	Palouse Falls[2]	Trout Creek[3]	Sucker Creek[4]	Kilgore[5]	Ellensburg U-1[6]	Ellensburg U-2[6]	Ellensburg U-3[6]	Weiser[7]	Dalles[8]	Deschutes[9]	Chalk Hills[10]	Alturas[11]	Alvord Creek
Saxifragaceae														
<u>Hydrangea</u>			1	1										
<u>Ribes</u>					1							1		1
Scrophulariaceae														
<u>Paulownia</u>							1							
Simarubaceae														
<u>Ailanthus</u>			1	1										
Theaceae														
<u>Gordonia</u>		p												
Tiliaceae														
<u>Tilia</u>		p	1	+	p			1						
Ulmaceae														
<u>Celtis</u>	p	p	1	p	+		1							
<u>Ulmus</u>		p	1	+	+	1	1	1	1	1			1	+
<u>Zelkova</u>				1		1	1							
Umbelliferae				*										
Vitaceae														
<u>Vitus</u>					1					1				

Correspondence with Alvord Creek

Generic level (%):

Familial level (%):

[1]Leopold, 1969
[2]Barnett and Fisk, 1980
[3]Graham, 1965
[4]Graham, 1965; Taggart, 1971
[5]MacGinitie, 1962; Fisk, 1983
[6]Smiley, 1963
[7]Dorf, 1936
[8]Chaney, 1944; Ashwill, 1983
[9]Chaney, 1936
[10]Axelrod, 1962
[11]Axelrod, 1944b
[12]Axelrod, 1944a

APPENDIX C: RADIOMETRIC DATE

A sample of tuff overlying the leaf-bearing beds on the slope north of Big Alvord Creek was sent to Geochron Laboratories, 24 Blackstone Street, Cambridge, Massachusetts for potassium-argon age determination. Results are as follows:

<u>Sample No</u>:

Field No. ACF-1 Tuff; Geochron Lab No. F-6635

<u>Date</u>:

Submitted 1 August 1983; reported 16 September 1983

<u>Description and Locality of Sample</u>:

Buff, blocky tuff collected from 15-20 cm above leaf-bearing shales at exposure on southeast facing slope of hill adjacent to north fork of Big Alvord Creek (Locality 2, as described in Appendix A).

<u>Material Analysed</u>:

Feldspar concentrate, -80/+120 mesh. Treated with dilute HF and HNO_3 to remove alterations.

<u>Results</u>:

Ar^{40} (radiogenic)/K^{40}=0.001399

Age = 23.8 +/- 1.0 million years

<u>Analyses and Constants Used</u>:

<u>Argon Analyses</u>:

Ar^{40*},ppm.	Ar^{40*}/Total Ar^{40}	Ave. Ar^{40*},ppm.
.007461	.418	.007632
.007802	.567	

<u>Potassium Analyses</u>:

%K	Ave. %K	K^{40},ppm
4.441	4.470	5.453
4.499		

<u>Constants Used</u>:

$\lambda_\beta = 4.72 \times 10^{-10}$/year

$\lambda_e = 0.585 \times 10^{-10}$/year

$K^{40}/K = 1.22 \times 10^{-4}$g./g.

$$\text{AGE} = \frac{1}{\lambda_\beta + \lambda_e} \ln \left[\frac{\lambda_\beta + \lambda_e}{\lambda_e} \times \frac{Ar^{40*}}{K^{40}} + 1 \right]$$

Note: Ar^{40*} refers to radiogenic Ar^{40}.

Plate I. Monolete and trilete spores and bisaccate pollen.

All magnifications 500x except as noted.

1. *Laevigatosporites ovatus* Wilson (1000x)
2. *Deltoidospora* sp. (1000x)
3. *Abies* sp.
4. *Abies* sp.
5. *Abies* sp.
6. *Cedrus* sp.
7. *Pinus* sp.
8. *Picea* sp.
9. *Picea* sp.

PLATE I

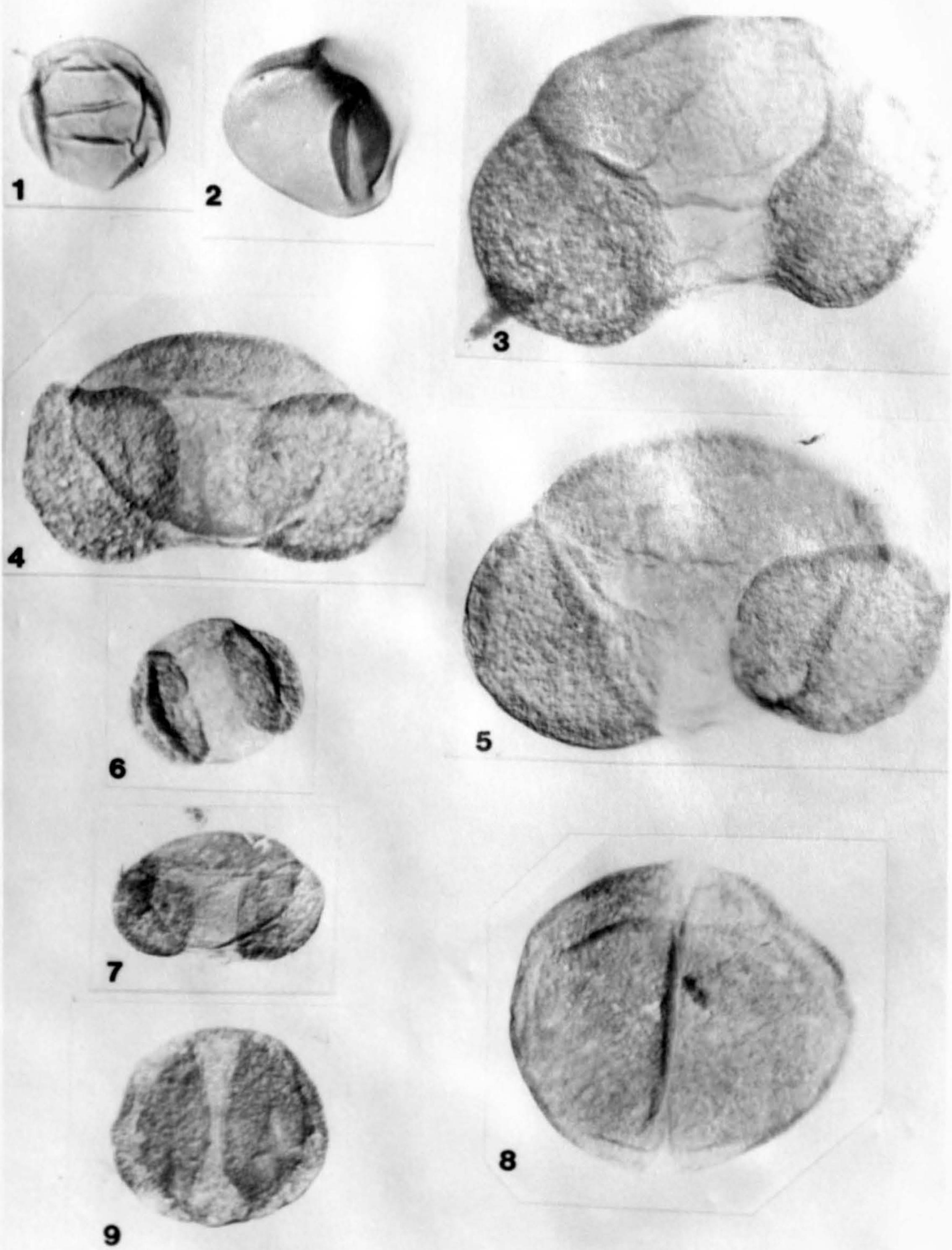


Plate II. Bisaccate and inaperturate pollen.

All magnifications 1000x except as noted.

1. *Podocarpus* sp., polar view (500x)
2. *Podocarpus* sp., equatorial view, low focus (500x)
3. *Podocarpus* sp., equatorial view, high focus (500x)
4. *Glyptostrobus* sp.
5. *Glyptostrobus* sp.
6. *Juniperus* sp.
7. *Populus* sp.
8. *Populus* sp.
9. *Potamogeton* sp.
10. *Pseudotsuga* sp.
11. *Taxodium* sp.
12. *Taxodium* sp.
13. *Tsuga* sp. (500x)
14. *Tsuga* sp. (500x)

PLATE II

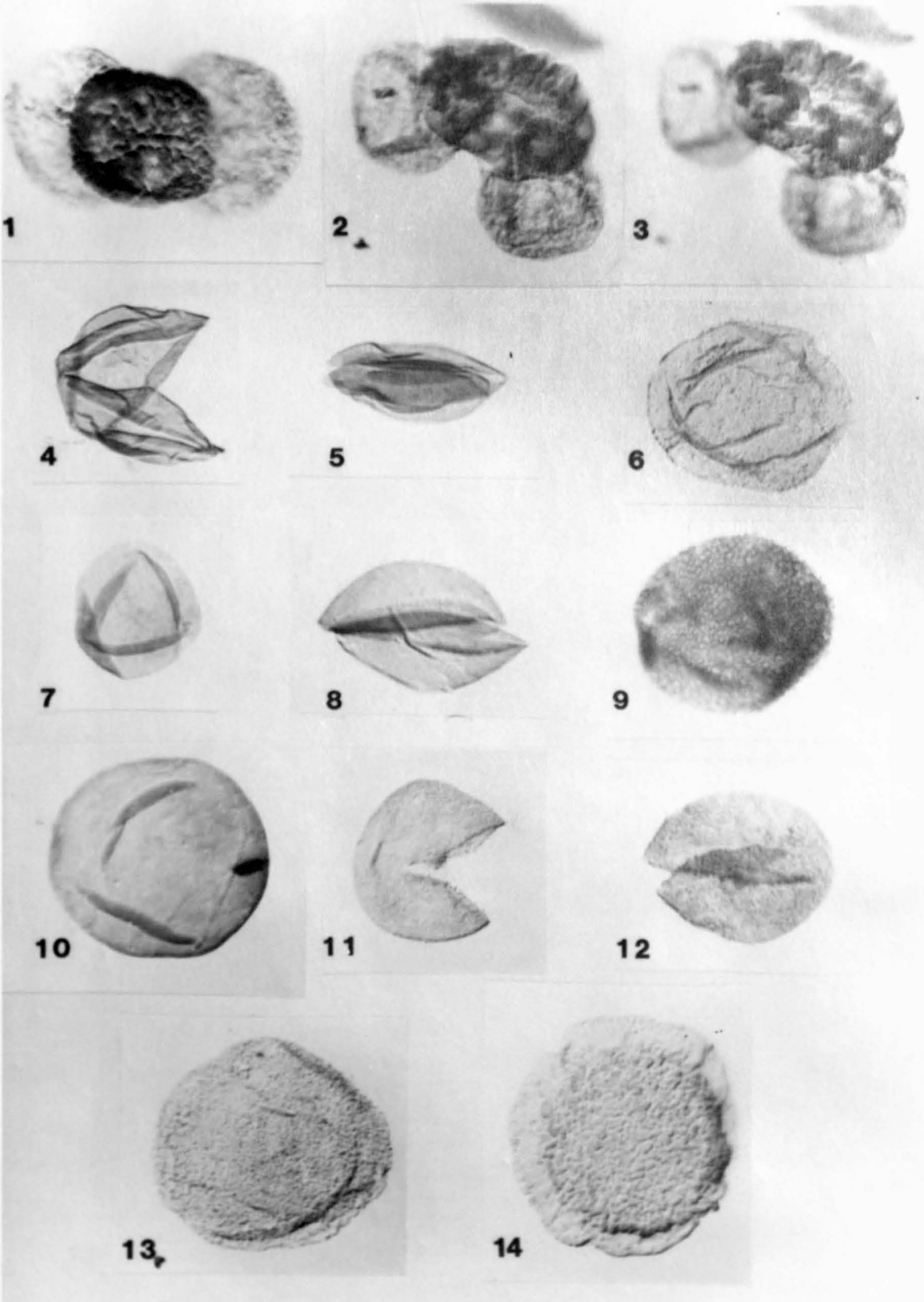


Plate III. Polyplicate, triporate, periporate, and tricolpate pollen.
All magnifications 1000x.

1. *Ephedra* cf. *E. nevadensis*
2. *Ephedra* cf. *E. nevadensis*
3. *Ephedra* sp.
4. *Corylus* sp.
5. *Morus* sp.
6. *Ulmus* sp., polar view
7. *Ulmus* sp., polar view
8. *Ulmus* sp., equatorial view
9. *Juglans* sp.
10. *Juglans* sp.
11. cf. *Sarcobatus* sp.
12. Periporate - 2
13. Periporate - 4
14. Periporate - 7
15. *Acer* sp.
16. *Acer* sp.

PLATE III

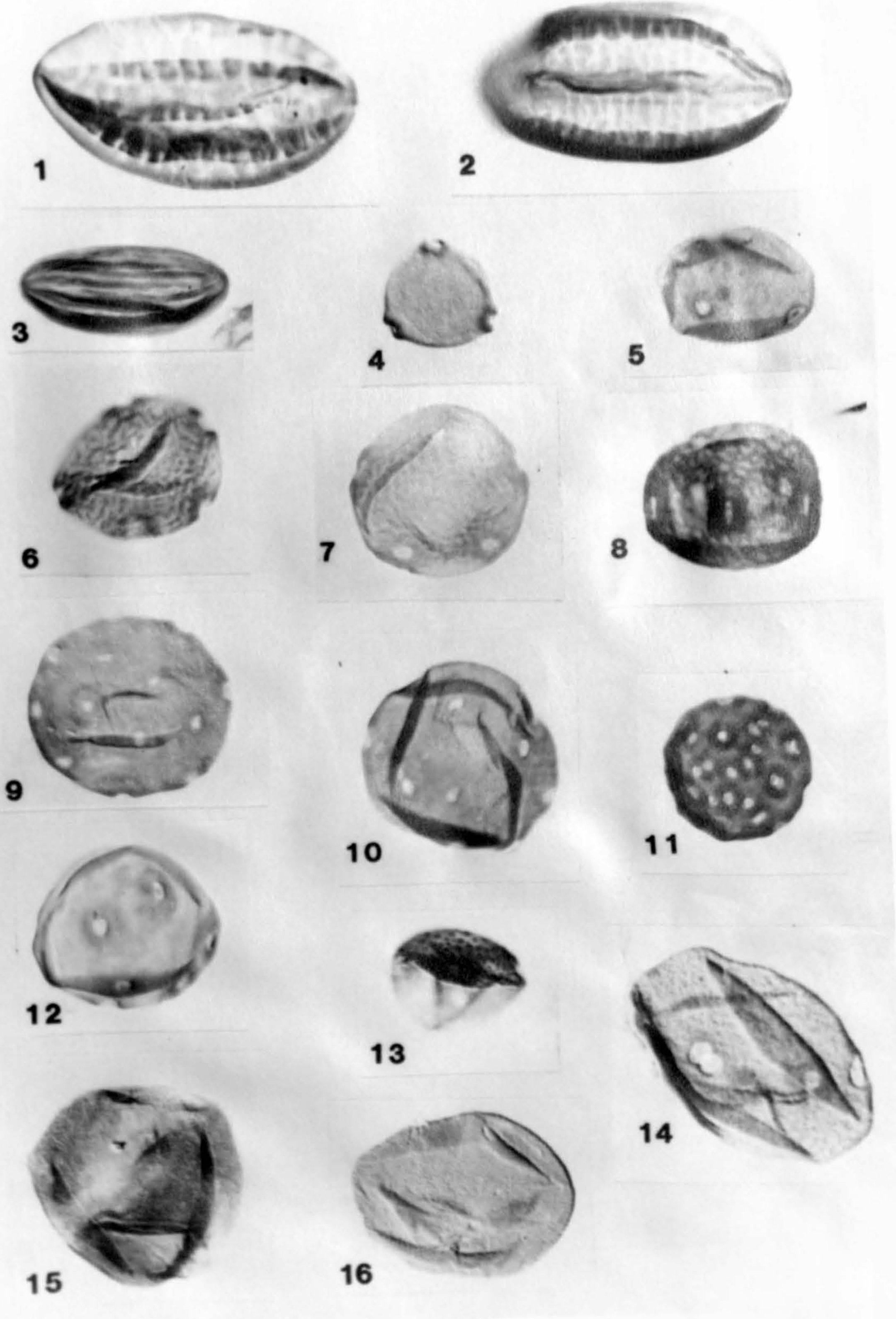


Plate IV. Tricolpate, pericolpate, and tricolporate pollen.

All magnifications 1000x.

1. ?*Echinocerus* sp.
2. *Platanus* sp.
3. ?*Rosa* sp.
4. Tricolpate - 13
5. *Salix* sp.
6. *Salix* sp.
7. *Quercus* cf. *Q. granopollenites* Rouse
8. *Quercus* sp.
9. *Quercus* sp.
10. *Quercus* sp.
11. *Quercus* sp.
12. Tricolpate - 10
13. Tricolporate - 3
14. *Fraxinus* sp.
15. Pericolpate - 2
16. *Nyssa* sp.
17. *Shepherdia* sp.

PLATE IV