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POTASSIUM-ARGON AGES OF SOME WESTERN TERTIARY FLORAS*

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ABSTRACT. Potassium-argon dates indicate an Eocene age for 6 Tertiary floras that represent vegetation zones as diverse as mixed deciduous hardwood forest, conifer-hardwood forest, and subalpine forest. Paleobotanical age criteria suggest these upland floras are much younger, confirming evidence that indicates Eocene forests that lived in regions of temperate climate had the aspect of Neogene floras.

Certain potassium-argon dates previously assigned to Tertiary floras disagree with paleobotanical evidence for their age. Some of the discrepancies reflect the problem of altitude and the floras of younger aspect that lived there, but others appear to be due to dating rocks not associated with the floras, to contaminated samples, and to other reasons.

INTRODUCTION

Potassium-argon dating provides a method for determining the ages of Cenozoic floras and faunas and for checking ages previously assigned to them. The ages of 6 floras are recorded here because they provide evidence with respect to the distribution of 3 major forest zones not previously recognized in the Eocene at middle latitudes: mixed deciduous hardwood forest, conifer-hardwood forest, and subalpine forest. The spatial relations of these forests have a significant bearing on problems of plant evolution, forest migration, and regional climate, and they also provide information of critical value for age analysis of Tertiary floras.

Recently, the potassium-argon ages of 40 other floras in the western United States were reported (Evernden and James, 1964). Nine of them are reviewed because the radiometric ages differ sufficiently from those indicated by paleobotanical evidence to have led the authors to conclude that criteria used for age assignment of Tertiary floras are inadequate. In these examples, the discrepancies in age appear to be due to the rock samples that were dated, not to the floral criteria used for age determination.

NEW DATES[1]

1. Salmon flora, Idaho.—Formation: In lake beds referred to Germer tuffaceous Member of the Challis Volcanics (Ross, 1937). Locality: Low cliffs on east edge of State Highway 93, 4 miles south of Salmon, Idaho. Stratigraphy: Sample is a biotite quartz latite from the Challis Volcanics which interfinger with lake beds that yield the Salmon flora. Age: Brown

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1 Radiometric dating by Geochron Laboratories, Inc.

(1937, p. 164) concluded that the flora probably was early Miocene, but the potassium-argon date (45.5 m.y.) indicates that it is early Uintan or early late Eocene (table 1).

2. Thunder Mountain, Idaho.—Formation: Challis Volcanics (Shenon and Ross, 1936). Locality: On slope above Dewey gold mine, Thunder Mountain district. Stratigraphy: Sample is a welded rhyolite tuff about 150 feet stratigraphically above the lake beds containing the flora. Age: The flora was regarded as early Miocene by Brown (1937, p. 165), but the present date (49.0 m.y.) makes it late Wasatchian or early Eocene.

3. Republic flora, Washington.—Formation: Tom Thumb Member of Klondike Mountain Formation (Muessig, 1962). Locality: Associated with the plant beds in roadcut on east side of State Highway 4 at south edge of town of Republic, collected by Dr. Charles J. Smiley. Stratigraphy: The dated rock is a biotite tuff interbedded with the lake beds containing the flora. Age: The flora was initially merged with the Latah flora by Berry (1929) and considered late Miocene. Brown (1937, p. 164) pointed out it is quite distinct from the Latah and concluded it was older, probably early Miocene or Oligocene (Brown, 1959, p. 129). The potassium-argon date (55 m.y.) indicates it is Clarkforkian or uppermost Paleocene. This is in general agreement with ages assigned to older volcanic rocks to the north in adjacent British Columbia (Matthews, 1964).

4. Bull Run flora, Nevada.—A. Formation: Chicken Creek (new fm., Axelrod, ms). Locality: 30 yards north of junction of Highway 11 and road to Cornocopia mining district, in the NE¼ sec. 11, T 42 N, R 52 E, Bull Run quadrangle. Stratigraphy: Sample is a 2-foot bed of biotite rhyolite ash 5 feet above the uppermost of the 10 florules that comprise the Bull Run flora. Age: The radiometric age of 35.2 million years indicates this florule is basal Chadronian or transitional Eo-Oligocene and the florules stratigraphically below it are Duchesnean, or latest Eocene. B. Formation: Frost Creek Volcanics (new fm., Axelrod, ms). Locality: East margin of Bull Run basin in drainage of Frost Creek in the SE¼ sec. 14, T 43 N, R 52 E. Stratigraphy: Sample is a biotite quartz latite welded tuff interbedded at the base of the sedimentary section. The lowest of the 10 plant horizons (Mori Road florule) that comprise the Bull Run flora is about 1500 feet higher stratigraphically. Age: The potassium argon date of 42.5 million years indicates this horizon is late Uintan or late Eocene. The age limits of the overlying flora, occurring stratigraphically from 1500 to 5000 feet above this dated zone, presumably range from about 39 to 40 to 35 million years (A above), which place the flora in the Duchesnean mammalian age or latest Eocene. A small (12 species), inadequate sample collected in 1956 which represents the second (Summit florule) of the 10 florules in the Bull Rum sequence occurs about 2000 feet above the quartz latite welded tuff and was considered Miocene (Axelrod, *in* Decker, 1962, p. 30).

TABLE 1

Analytical data for K-Ar age determinations of early Tertiary floras

Geochron sample no.	Flora	Material analyzed	Analytical data*			K/Ar age m.y.
			% K	Radiogenic Ar^{40}, ppm	Radiogenic Ar^{40} / Total Ar^{40}	
F0441	Salmon	feldspar	1.38_5 1.35_5	0.00455 0.00445	0.263 0.233	45.5 (± 1.4)
R0411	Thunder Mtn.	whole rock	3.99 3.97	0.0139 0.0143	0.631 0.670	49.0 (± 2.0)
B0445	Republic	biotite	5.65 5.61	0.0230 0.0219	0.554 0.505	55.0 (± 1.7)
B0124	Bull Run, upper	biotite	6.18 6.25	0.0161 0.0156	0.362 0.441	35.2 (± 1.0)
B0439	Bull Run, lower	biotite	4.80 4.96 5.06	0.0157 0.0148	0.350 0.580	45.2 (± 2.1)
B0094	Copper Basin	biotite	6.36 6.36	0.0184	0.530	39.9 (± 2.3)
F0457	Lower Cedarville	feldspar	0.381 0.387	0.0011_4 0.0010_5	0.289 0.117	40.0 (± 3.0)

* Dates in table are computed using the average of replicate analyses and the following constants:
$K^{40}/K = 1.22 \times 10^{-4}$ g/g $\quad \lambda_e = 0.585 \times 10^{-10}$/yr $\quad \lambda_\beta = 4.72 \times 10^{-10}$/yr.
Errors noted in table are the laboratory estimate of 95 percent certainty ($2\ \sigma$).

5. Copper Basin flora, Nevada.—Formation: Deadhorse Tuff (Coats, 1964). Locality: Sec. 32, T 45 N, R 58 E, in south part of Copper Basin, Jarbidge quadrangle. Stratigraphy: Sample is a biotite rhyolite tuff about 150 feet stratigraphically above the Copper Basin flora. Age: When initially collected this flora was regarded as late Miocene and was included on a map showing the distribution of Miocene floras (Axelrod, 1957, fig. 1). Reasons for that age assignment are discussed elsewhere (Axelrod, 1966). The radiometric date (40 m.y.) indicates the flora is early Duchesnean or late Eocene.

6. Lower Cedarville flora, California.—Formation: Lower Cedarville (Russell, 1928). Locality: Sample is from the ridge in the center of sec. 19, T 43 N, R 16 E, Cedarville quadrangle, California. Stratigraphy: The dated rock is a hornblende andesite flow associated with pyroclastics about 100 feet stratigraphically below the flora which is in a 3-foot bed of opaline shale at an altitude of 5650 feet in the saddle on the crest of the ridge, center of sec. 19. Age: This large and well-preserved flora (for generic list, see Axelrod, 1966), has been studied provisionally by several investigators (for example, MacGinitie, 1941, table 7) and considered later Oligocene in age. The potassium-argon date (40 m.y.) indicates it is Duchesnean or late Eocene and a contemporary of the Copper Basin and Bull Run floras to the east in Nevada (see above).

DISCUSSION

Dating these floras as Eocene assumes significance because they include the first examples from middle latitudes of upland Eocene forests which lived under cool to cold temperate climate. As is apparent from the ages assigned to them by different investigators, they have the aspect of much younger floras. This agrees with Gardner's (1879) observations which explain why the floras from Grinnell Land, Spitzbergen, and Greenland Heer (1868-1883) considered to be Miocene were in reality of Eocene (and Paleocene) age. As Gardner cogently notes, in Eocene time—when the lowlands of central Europe supported broadleafed evergreen forests of subtropical aspect—the forests Heer considered to be Miocene were living at higher latitudes (and altitudes) where climate was cooler. Gardner pointed out that the forests at high northern latitudes which lived under temperate climate slowly migrated southward (and downslope) in response to the cooling trend of the Tertiary and entered the lowlands of Europe during the Miocene.

It has been suggested that during Eocene time, when forests characteristic of the temperate to cool temperate climatic zones occupied low altitudes in northern Alaska, Greenland, and Grinnell Land, they probably extended southward in the mountains occupying successively higher altitudes (Chaney, 1936, 1940). Such a distribution is displayed by forests today, for they are controlled by zones of temperature that rise gradually to higher altitudes at lower latitudes. That this inferred relation existed during Eocene time now seems reasonably established by the composition of the 6 floras dated as Eocene which are distributed from northern

Washington (lat. 48° N) into northern Nevada (lat. 42° N). They represent 3 major forest zones: mixed deciduous hardwood forest (Republic, Lower Cedarville), conifer-deciduous hardwood forest (Salmon, Copper Basin, Lower Bull Run), and subalpine forest (Upper Bull Run and, marginally, Thunder Mountain).

The altitudes at which these floras lived may be inferred from the temperature requirements of living forests most similar to them, expressed in terms of effective temperature (ET). This is a measure of the warmth and duration of summer (Bailey, 1960) and is determined from the mean temperatures (°F) of the warmest month (WM) and coldest month (CM): $ET = \frac{64.4\ WM - 50.0\ CM}{WM - CM + 14.4}$. Since temperature decreases with altitude, by estimating the ET of a flora at sealevel the altitude of ET indicated by an upland flora of similar age at the same latitude may be closely approximated (Axelrod, 1964, 1965, 1966). The altitudes of the 3 forest zones—mixed deciduous hardwood forest, conifer-hardwood forest, and subalpine forest—near lat. 42° N have been calculated at 1800 to 3500 feet, 3500 to 4500 feet, and above 4500 feet, respectively. By determining the altitudes of Eocene floras to the north in British Columbia and Alaska and the zonal climates above them, it is evident forests representing cooler climatic zones gradually rose to higher altitudes southward. Their general pattern of distribution (see Axelrod, 1965, fig. 13) agrees in all respects with the inferences of Gardner (1879) and Chaney (1936, 1940) concerning the general spatial relations of Eocene forests and the climates under which they lived. The relatively low altitudes of the forest zones at middle latitudes resulted from a climate of high equability, paralleling that found today in areas (south Chile; Sierra de Mantiqueria, Brazil; vicinity Jalapa-Huatusco, Mexico; Szechuan-west Hupeh, China; east India—Yunnan; New Zealand) of pronounced temperateness (Bailey, 1964).

REMARKS ON PREVIOUSLY DATED FLORAS

1. Chloropagus flora, Nevada.—This small flora from the Hot Springs Mountains occurs in the upper part of the Chloropagus Formation and was considered to be transitional Barstovian-Clarendonian on the basis of paleobotanical evidence (Axelrod, 1956, fig. 14).

The potassium-argon date (Evernden and James, 1964, p. 970) of 13.9 million years recorded for this flora not only appears to be too old, it is not consistent with regional stratigraphic relations. The Chloropagus Formation is underlain conformably by rocks (unnamed formation) that yield the Pyramid flora which is dated as 12.4 million years (Evernden and James, 1964, p. 969). That the dated tuff which is reported to be associated with the Chloropagus flora may have inclusions of older volcanic rocks seems probable, for they are present in a thick agglomerate which lies 300 feet stratigraphically below the flora.

2. Esmeralda flora, Nevada.—This small flora was recovered at 2 localities in the hills south of Coaldale, Nevada (Turner, 1900; Knowlton, 1900). Locality 92 near the base of the section yielded the remains of a fern which is abundant in the lignite beds there. The remaining species from locality 89 are fully 2000 feet higher stratigraphically (Turner, 1900, p. 200; also fig. 5): it was this collection that was used to interpret the paleoecology and age of the Esmeralda flora (Knowlton, 1900; Axelrod, 1940).

Evernden and James (1964, p. 970) dated a botite tuff associated with the lignite at the base of the exposed section at locality 92 as 12.7 million years and concluded the Esmeralda flora is transitional Barstovian-Clarendonian. Paleobotanical evidence indicates the flora is early Clarendonian, which agrees with its stratigraphic position about 2000 feet above the dated sample.

3. Latah flora (Spokane florule).—This rich (68 species) assemblage was recovered at sites in the city of Spokane (Knowlton, 1926; Berry, 1929; Brown, 1937) and to the north of it (Pardee and Bryan, 1926, text fig. 1). However, the radiometric date of 14.5 million years (Evernden and James, 1964, p. 969) is based on a basalt flow associated with the Latah Formation at a locality 8 miles south of Spokane. It is apparent this date does not necessarily indicate the age of the rich Spokane florule, which appears to be older (Chaney, 1959); it may underlie the basalt unconformably.

4. Latah flora (Whitebird florule).—This florule of 27 species occurs in lake beds under lavas that have been considered to be a correlative of the Yakima Basalt which overlies the Latah Formation at Spokane to the north. Irrespective of whether the basalt is the same, it is critical that nearly all of the plants at Whitebird occur in the Spokane florule. On this basis there is no evidence to suggest there is any important age difference between them.

The potassium-argon date (Evernden and James, 1964, p. 972) of 12.1 million years which indicates that the Whitebird florule is early Pliocene (early Clarendonian) differs considerably from previous assignments of this assemblage to the middle Miocene (Brown, 1937; Chaney, 1959). If there was a time difference between them, changes in floral composition would be present which parallel those displayed by the Vantage and Ellensburg floras 130 to 150 miles west, dated as 13.4 and 10.0 million years, respectively (Evernden and James, 1964).

The age discrepancy may result if the basalt overlies the lake beds unconformably. This seems probable because the basalt at Whitebird is dated as 12.1 million years whereas the flow 8 miles south of Spokane is 14.5 million years, and both have been referred to the Yakima Basalt.

5. Middlegate flora, Nevada.—This rich flora from west-central Nevada was considered to be of transitional Clarendonian-Barstovian age on the basis of its general composition, an assignment consistent with

the age indications of fragmentary mammalian remains higher in the section (Axelrod, 1956, p. 249).

The potassium-argon date of 15.9 million years reported by Evernden and James (1964, p. 970) does not indicate the age of the flora for stratigraphic reasons. They report the dated sample is "a dacite tuff interbedded with the leaf-bearing tuffaceous shales containing the Middlegate flora". Actually, the tuff crops out 2 miles west of the plant locality, and shales are not interbedded with it. Furthermore, fresh outcrops exposed by thunderstorms during the past 3 to 4 years now show that the dacite tuff forms the uppermost part of the Clan Alpine Volcanics on which the Middlegate Formation which contains the flora rests unconformably. Thus there is no reason at present to doubt that the Middlegate flora probably is of transitional Mio-Pliocene age.

6. Mollala flora.—This large and well preserved, but still undescribed, flora from northwest Oregon has been dated as 10.8 million years (Evernden and James, 1964, p. 968). This makes it early Pliocene (Clarendonian), though most paleobotanists who have studied it believe the flora is early Miocene (Chaney, 1959; Wolfe, 1962).

The dated tuff is so weathered it can be cut with a knife. That the radiometric date may be too young is not only suggested by the flora but by stratigraphic relations. The nonmarine tuffaceous sedimentary rocks in which the flora occurs interfinger with marine beds that carry an invertebrate fauna of early Miocene (Vaqueros) age (Durham, Harper, and Wilder, 1942), which is a correlative of the Arikareean mammal age (± 26-21 m.y.).

7. Pyramid flora.—This flora has not been described. It was included on a locality map showing the distribution of Miocene floras to accompany a general discussion of regional vegetation and climate (Axelrod, 1957) and was also referred to briefly in evaluating the age of the early Pliocene Chalk Hills flora (Axelrod, 1962, p. 223). Apart from its composition, which suggests its early Barstovian age, its stratigraphic occurrence is also in agreement with such an age assignment. The flora is preserved in diatomite associated with basalt and latite which conformably underlie the Chloropagus Formation of late Miocene age (Axelrod, 1956, fig. 14).

The potassium-argon date yielded by plagioclase from the latite directly overlying the flora gives an age of 12.4 million years, which would make the flora basal Clarendonian (Evernden and James, 1964, p. 969). This is not consistent with the potassium-argon date of 13.9 million years for the Chloropagus flora (Evernden and James, 1964, p. 970), because it occurs high in the Chloropagus Formation which overlies the Pyramid flora; either one or both of these dates appear to be in error.

8. Sutro flora.—This small flora, which has not been described, was at first considered middle or late Miocene (Brown, *in* Calkins, 1944, p. 15); the collection in the U. S. National Museum is so small that no

close age can be assigned to it. The University of California collection secured in 1946 included a palm and broadleafed evergreens not represented in the collection at the National Museum. They suggested an age greater than middle Miocene, and the flora was tentatively regarded as Oligocene (Axelrod, 1949). Additional material recovered in 1953 makes the collection more representative, though the Sutro is still a small flora (± 18 species). An early Miocene age assignment, as suggested by the potassium-argon date of 22.7 million years for the Hartford Hill Rhyolite, which conformably underlies the Alta Andesite in which the Sutro flora occurs (Evernden and James, 1964, p. 970), seems consistent with the plant evidence as now known.

9. Upper Cedarville flora.—The flora from 49 Camp in the northwestern corner of Nevada, generally considered as middle to late Miocene by paleobotanists (LaMotte, 1936, Chaney, 1959), has been dated (Evernden and James, 1964, p. 971) as 19.8 million years, which places it in the lower part of the Hemingfordian mammalian age and would make it essentially early Miocene.

Stratigraphic evidence indicates that the potassium-argon date probably is incorrect. The Massacre Lake mammal fauna of Barstovian age, dated as 15.6 million years (Evernden and others, 1964, p. 189), occurs in the area to the east in rocks that are correlative with the section exposed at 49 Camp (H. F. Bonham, Jr., written communication, Nov. 1965). Furthermore, Bonham reports the ash flow unit from which the plagioclase for dating was obtained contains numerous accidental lithic inclusions filled with plagioclase obviously older than the ash flow. It probably is this contamination that makes the date discordant with plant evidence for the age of the flora.

DISCUSSION

The preceding comments concerning 9 of the 40 samples dated by Evernden and James (1964) clearly point up some of the handicaps to which the potassium-argon method of dating floras has been subjected. To be meaningful for dating, samples obviously must be selected from horizons as close stratigraphically to the fossil site as possible. In cases where they are not at essentially the same horizon (for example. Esmeralda, Middlegate floras) or even near the locality (Latah: Spokane; Middlegate) a clear statement of this fact should be made.

The task of selecting an adequate sample for dating is not easy because volcanic rocks may be contaminated (for example, 49 Camp, Chloropagus-Pyramid). This raises the question as to how to determine whether a potassium-argon date is reliable or not—for which there appears to be no ready answer. It is to be regretted that samples cost so much to process, for by dating several samples scattered geographically in a volcanic unit selected for age determination any inconsistencies in age due to contamination (or alteration) might well be disclosed.

In view of their attempt to test the reliability of paleobotanical criteria for age analysis it seems unfortunate that 15 percent of the floras

Evernden and James selected for dating are either so small (Valley Springs, Sage Valley, Ricardo) that close age assignment is scarcely possible, or that they have not even been monographed (Mollala, Pyramid, Sutro, Valley Spring, Sage Valley). In spite of this, it is apparent from the evidence reviewed above that the dates assigned by paleobotanists to 88 percent of the 40 dated floras are in close agreement with the results of potassium-argon dating: 35 of the 40 floras have been dated within 3 million years of potassium-argon ages and 30 of them are within 1 to 2 million years.

At present our greatest problem is the obvious need for criteria to recognize the ages of Tertiary floras that lived in upland basins at middle latitudes. Although species that are distinctive of Paleogene forests contributed to upland floras that occupied regions of cool to cold temperate climate, the fact remains they have not previously been recognized in them. Since the ages of these floras have just been established, further study will be required to disclose the species in them that have narrow age significance in upland Eocene forests.

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