Evidence for Late Tertiary Volcanic Activity in the Northern Black Hills, South Dakota

Abstract. *Rhyolitic volcanic rock in the northern Black Hills has a potassium-argon isotopic age of 10.5 ± 1.5 million years. This is considerably younger than any previously reported igneous activity in this or adjacent areas and indicates that the renewed uplift of the Black Hills, which occurred after the Oligocene epoch, was also accompanied by some volcanism.*

Igneous activity in the northern Black Hills has been generally considered to be intrusive in character and of early Tertiary age (*1*, *2*). An exception is a small area of volcanic rock first reported by Darton (*3*) as Mid-Tertiary in age and later described by him as "Quaternary (?)" in age (*1*). I have obtained a whole-rock potassium-argon isotopic age of 10.5 ± 1.5 million years for the volcanic rock, which is significantly younger than the ages reported for the intrusive rocks of the area (*4*). Igneous activity of this age has not been previously reported in the Black Hills or adjacent areas.

The volcanic rocks in question outcrop in an area of approximately 1 km^2 centered around the Tomahawk Lake Country Club, approximately 10 km south of Deadwood, South Dakota. The rocks consist of rhyolite flow breccia, agglomerates, bedded lithic tuffs, and obsidian. The obsidian has been previously reported to be a flow (*3*), but truncated flow lines in the obsidian and the presence of flow breccia underneath and on all sides of the obsidian indicate that it is a xenolith in the flow breccia. The obsidian block is about 8 by 9 m and is about 3 m thick.

A whole-rock potassium-argon isotopic age date was made on the obsidian xenolith because it is the only fresh or unaltered rock in the volcanic sequence. The other rocks show varying degrees of alteration, making dates on them of questionable value. The SiO_2 content of the glass (74 percent), as determined by index of refraction, is similar to that found by a chemical analysis of the enclosing flow breccia (74.6 percent), and the K_2O content of the glass (3.99 percent) is also comparable to that of the flow breccia (3.56 percent). The chemical similarity of the obsidian xenolith and the flow breccia, together with a lack of field evidence indicating more than one episode of volcanism in the area, suggests that the xenolith and the flow were formed within the same time frame; thus the age of the xenolith should reflect the age of the main episode of volcanism.

The isotopic age of the obsidian is 10.5 ± 1.5 million years, based on 3.31 percent K, 31.2 percent and 20.8 percent Ar^{40}, and 0.154×10^{-5} and 0.125×10^{-5} standard cubic centimeters of Ar^{40} per gram, as determined from duplicate analyses performed by Teledyne Isotopes' laboratory. This indicates that volcanism occurred during the Miocene epoch, which is significantly younger than the Eocene igneous activity responsible for the emplacement of the many laccoliths, stocks, and sills in the northern Black Hills area. Ages for the earlier intrusive igneous activity in the Black Hills and Devils Tower area range from 40.5 ± 1.6 to 58.9 ± 1.8 million years (*4*). Clasts from the intrusive rocks occur in Oligocene gravels, indicating that the intrusive activity was probably synchronous with the major uplift of the Black Hills dome. Further uplift occurred later in the Tertiary, after deposition of the Oligocene sediments (*1*), and now the renewed uplift appears to have been accompanied by minor igneous activity. At this time there is no evidence to indicate that other igneous rocks are genetically related to this rhyolite volcanism.

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10 November 1976; revised 17 January 1977

A Compound Ovary with Open Carpels in Winteraceae (Magnoliales): Evolutionary Implications

Abstract. "Bubbia" perrieri, *a primitive angiosperm collected once in 1909 in northwestern Madagascar, differs from all other members of its genus and family (Winteraceae) in its bicarpellate, unilocular ovary. Moreover, its inflorescences are terminal, and its development is partially sympodial. It therefore represents the survivor of a previously undetected evolutionary line that should be accorded at least subfamilial status. If so, Winteraceae might, more likely than previously, be considered as allied to Canellaceae, a group of primitive angiosperms that has an ovary of* "Bubbia" perrieri *type and is specialized in some other respects.*

There are, in the Paris Herbarium, two parts of a flowering plant discovered in June 1909 by Perrier de la Bâthie on Manongarivo Mountain (northwestern Madagascar), at an altitude of about 1700 m and never recollected. The taxon *"Bubbia" perrieri* was validly described from this material by Capuron in 1963 (*1*), who noted two characteristics which, associated with the geographical distribution, might have been considered important enough to justify the creation of a new genus: (i) the kind of inflorescence, the principal axis of which is elongated and irregularly branched; and (ii) the two-lobed stigma. Notwithstanding these features, Capuron placed it in the otherwise entirely Australasian genus *Bubbia* and in the very primitive family Winteraceae, of which it is the only representative in either Africa or Madagascar.

More than half a century elapsed between the discovery of *"Bubbia" perrieri* and its formal publication. In recent years, several authors have studied this plant (*2*), but we are far from a full morphological understanding of it. Baranova, followed by Bongers, was able to affirm, from cuticular characters alone, that the placement of *"Bubbia" perrieri* in *Bubbia* is doubtful. As pointed out by Bongers, *"B." perrieri* and *Drimys* sect. *Tasmannia* occupy isolated positions in the Winteraceae. My own analysis of the herbarium material provides a more complete understanding of the nature of its inflorescence and gynoecium. In particular, it confirms the need for establishing a new genus (*3*).

Stebbins (*4*), following Parkin (*5*), Rickett (*6*), and Nast (*7*), writes of Winteraceae that "their inflorescences are always axillary, and are produced by specialized reproductive shoots." He adds, "Compared with other primitive angiosperms, the flowers of the Winteraceae show a certain amount of reduction, particularly the crowding of the stamens and the small number of carpels. . . . Consequently, one cannot exclude the possibility that the ancestors of the Winteraceae had leafy cymes" (*4*). The evidence drawn from my analysis of *"Bubbia" perrieri* does not support this view. In this species, the inflorescence is undoubtedly terminal, and consequently,

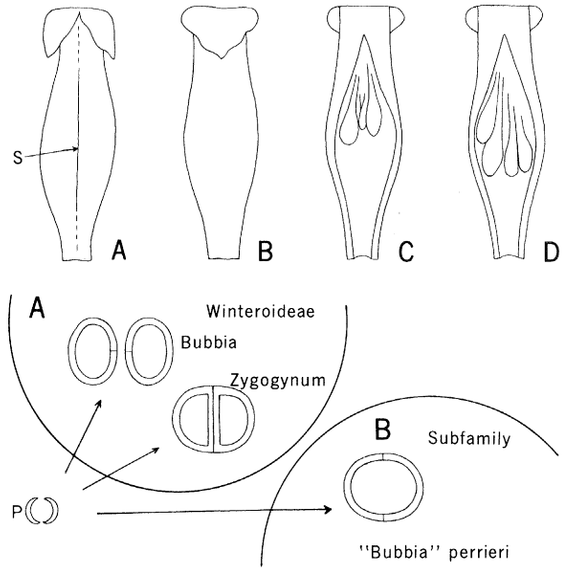

Fig. 1 (top). Carpels in *"Bubbia" perrieri*. (A) Two-carpellary ovary (*S*, sutural line). (B) Dorsal view. (C and D) Separate carpels showing the four-ovulate parietal placenta in each. Fig. 2 (bottom). Hypothesis for carpellary organogenesis in Winteraceae. One starts conventionally from two carpellary primordia (*P*) supposed to have been initially open like the ones known in Dilleniaceae (*9*). (A) Carpellary closure is achieved. (In fact, there are often many carpels in *Zygogynum*.) (B) Concrescence between the carpellary primordia occurs very early in the ontogenetic process and prevents any closure of each individual carpel. There is no advantage in imagining an intermediate genus with axile placentation that has become extinct, because (i) placentation in *"Bubbia" perrieri* is *Bubbia*-like; (ii) it is likely that the *Zygogynum* stage was bypassed; and (iii) it would be surprising if the supposed ancestor of *"Bubbia" perrieri* and its homologous genera in the Canellaceae and in the Annonaceae-Monodoroideae have all become extinct.

the developmental process of the plant is partially sympodial. There is a fairly gradual transition from the vegetative to the reproductive shoot. The inflorescence of *"Bubbia" perrieri* displays only two special characteristics. (i) Although the phyllotaxy is the same in the vegetative and the reproductive part of the shoot, the bract function is filled not by ordinary leaves but by specialized scales. (ii) The inflorescence is characterized by branching; the main axis produces alternate branches, which then produce the tertiary axes, but the latter are, in fact, rays of a pseudoumbel by suppression of the internodes. Finally, every tertiary axis bears two bracteoles (or sometimes one or none) and is terminated by a single flower. When the floral stage in inflorescence development is reached, branching is abruptly terminated and the phyllotaxy changes. I therefore interpret the inflorescence of *"Bubbia" perrieri* as presenting a mixture of primitive (terminal position, spiral phyllotaxy) and advanced characteristics; it represents a different trend from that of *Bubbia*, which, along with *Zygogynum*, also has terminal flowers.

The gynoecium in *"Bubbia" perrieri* has been unanimously considered until now to be unicarpellate, in agreement with the original diagnosis by Capuron (*1*, p. 374), "gynoecium 1-carpellarum . . . stigmate discoideo capitato antice et postice emarginato; ovula 5-9 (-11) e loculae apice pendentia. Fructus ignotus." Capuron, in spite of a very careful examination, failed to emphasize the difference between this stigma and that of the other species of *Bubbia*, which is sessile, linear, and radiate. Perrier noted the eccentric position of the ovary but did not draw any conclusion about it.

Two observations provided clues for my research. The first observation was of the structure and shape of the stigma (Fig. 1), which is a yellow expapillate cap with two large lobes directed downward. The two-lobed structure is radically anomalous among *Bubbia* species and even in the whole family Winteraceae. Next, examination of the interior of the ovary led me to conclude that there were two placentas, at the top of the ovary and beside one another, each of them under a stigmatic lobe but reaching down nearly the middle of the ovary. These two facts suggest that the *"Bubbia" perrieri* ovary is, in fact, compound. The discovery of a suture on each side of the ovary, in the plane between stigmatic lobes, confirmed the hypothesis. As seen in cross section, the two carpels are laterally united although flattened and hardly infolded, separated by an external groove but apparently without any dehiscence layer between them.

The gynoecium in this, the single species of Winteraceae in Madagascar, is unilocular, with parietal apical placentation, but it consists of two carpels united with a single stigma (two valvate stigmas more or less united into a single structure). The fruit, still unknown, might be dehiscent. This species therefore provides the second instance known—after that of Canellaceae, a family represented in Madagascar (*Cinnamosma*) and in eastern Africa (*Warburgia*)—of a compound unilocular ovary within the order Magnoliales sensu stricto. A third case of carpels united into a unilocular ovary is met within primitive angiosperms: that of the Annonaceae-Monodoroideae, an African-Malagasy subfamily consisting of two genera, *Isolona* and *Monodora*. Although carpellary union occurs in other Winteraceae, it never reaches the level of a compound unilocular ovary. In *Exospermum*, the carpels are only closely appressed near one another, whereas in *Zygogynum*, a syncarpous genus endemic to New Caledonia, the many carpels (from 4 to 18 or more) are partially distinct from one another. The fruit of *Zygonynum* is plurilocular.

From these observations, it is clear that *"Bubbia" perrieri* is certainly not a species of *Bubbia* but is actually a new taxon of a high level, at least a new subfamily (Fig. 2). In this taxon, the gynoecium shows some specialized characters: carpels erect, united, and reduced in number (as compared with other genera of Winteraceae); ovary unilocular, with apical and well-developed stigma. In spite of these relatively advanced characters, *"Bubbia" perrieri* apparently represents an evolutionary line distinct from other Winteraceae, both of them having diverged from an ancestral Winteraceous stock now extinct. It might even be more closely related to Canellaceae than the other Winteraceae, judged from the similar gynoecia in these groups. *"Bubbia" perrieri* is apparently the survivor of a previously unrecognized but distinct evolutionary line among primitive angiosperms; its existence emphasizes the significance of Madagascar as a center of survival for such angiosperms.

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9. I thank Drs. R. Polhill and P. H. Raven for assistance in preparing the manuscript, and the unknown reviewers for their constructive criticism.

26 October 1976; revised 4 January 1977