jectiles on a strong Duran glass target at 4.4 km/sec and determined that the mass in the ejecta with V_e exceeding 3 km/sec was only $7.5 \times 10^{-5} M_m$, which is more consistent with our calculations.

The relative amount of meteorite kinetic energy lost (E_e/E_{KE}) ranges from approximately 90 percent at $V_e \sim 10^3$ cm/sec to ≤ 1 percent at $V_e \sim 10^6$ cm/sec (Fig. 3, a and b). At the lunar escape velocity, the amount of energy lost from the moon for An→An impacts ranges from 0.8 percent at an impact velocity of 7.5 km/sec to 17 percent at 45 km/sec, and similarly for Fe→An impacts, E_e/E_{KE} ranges from 0.3 percent at 7.5 km/sec to 15 percent at 45 km/sec. These results illustrate a more general conclusion: a less dense meteorite will lose relatively more of its energy on impact with a planetary surface for fixed values of impact velocity and V_e. An extrapolation of our results implies that cometary objects would not transfer their energy to a planet as effectively as iron or stony objects. In addition, if the strength of the planetary surface is less than that of the modeled consolidated rock, we expect that more energy and mass will be lost at $V_e < 10^4$ cm/sec, whereas not much change in the fraction of energy and mass lost at $V_e > 10^5$ cm/sec is expected. This is because the energy that is consumed by plastic work in strong rocks would be available for conversion into kinetic energy in weak rocks, and thus would increase the amount of ejecta at low velocities from weak rocks and unconsolidated regoliths.

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Evidence for a Pollination-Drop Mechanism in Paleozoic Pteridosperms

Abstract. *A noncellular substance containing pollen and spores has been discovered protruding from the micropyle of a seed fern ovule of Middle Pennsylvanian age. This provides direct evidence that pollination-drop mechanisms comparable to those of many extant gymnosperms characterize some Paleozoic pteridosperms.*

The pteridosperms are an early group of fossil seed plants with fernlike leaves and leafborne reproductive organs. The taxon extends from Late Devonian through Jurassic time, with some of the best-known permineralized specimens preserved in sediments of Pennsylvanian age. The mechanism of pollination in these and other Paleozoic seed plants is widely regarded as similar to that of many extant gymnosperms, where a sticky exudate protrudes from the micropyle of the ovule (*1*, *2*). Pollen adheres to or becomes immersed in the droplet, and is either drawn toward the pollen chamber as the droplet shrinks (due to desiccation) or floats upward toward the tip of the nucellus (*2*).

Previous reports of pollination-drop mechanisms in fossil plants have been based primarily on the occurrence of similar structural features in extant and fossil ovules, rather than on the physical presence of a preserved droplet. Moreover, conflicting interpretations of the function performed by the pollen-receiving structures of some fossil ovules (*3*) leave these aspects of the reproductive

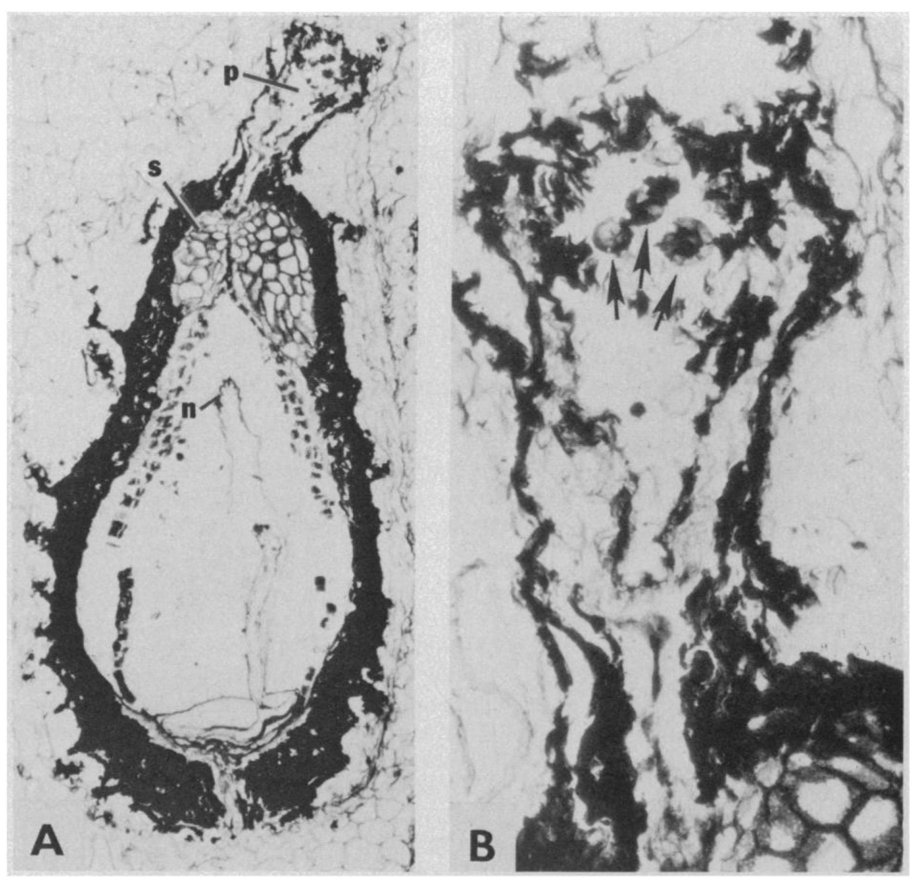

Fig. 1. *Callospermarion*-type ovule with pollination droplet protruding from the micropyle. (A) Midlongitudinal section of immature ovule (*n*, nucellus; *p*, pollination droplet; and *s*, sclerotesta) (× 42). (B) Pollination droplet at the micropylar end of the ovule. The arrows indicate the positions of three palynomorphs (× 155).

mechanisms in doubt. The best previously reported evidence for fossilized pollination droplets is found in the seed fern ovule *Pachytesta* (Medullosaceae), where a resinous-appearing substance has been reported in two species (*4*). Unfortunately, this substance does not extend from the micropyle of either ovule, but is confined to a small area at the tip of the pollen chamber. Also, no pollen or spores are trapped within the substance in either ovule. If the material in *Pachytesta* does represent a pollination droplet, then it must be the postpollination remnant of what was formerly a much larger, externally protruding exudate. There is, therefore, no conclusive evidence that pollination droplets similar to those of extant gymnosperms characterize Paleozoic seed plants.

Within the Callistophytaceae, a seed fern family of Pennsylvanian age, some remarkable reproductive aspects have recently been documented. These include microsporogenesis, microgametophyte development, ovule and megagametophyte development, and ultrastructural features of the pollen exine (*5*, *6*). The presence of pollen within the pollen chambers of immature ovules assignable to *Callospermarion* (*6*) indicates that pollination occurred relatively early in the Callistophytaceae, as it does in many extant gymnosperms. In addition, the occurrence of a pollen grain with a branched pollen tube within the pollen chamber of a Middle Pennsylvanian *Callospermarion*-type ovule (*7*) supports the proposal that these grains were potentially functional, rather than chance contaminants.

An additional immature *Callospermarion*-type ovule from Middle Pennsylvanian sediments (Illinois number 6 coal, Carbondale Formation) has recently been discovered with a noncellular substance extending from the micropyle (Fig. 1A). The substance is 0.51 mm long and expands in diameter at increasing distances from the outer orifice of the micropylar canal (Fig. 1B). It is convoluted and quite dark at the periphery, and several palynomorphs (isolated pollen and spores) either are embedded in or adhering to the surface of the substance (arrows in Fig. 1B).

Small size (1.7 mm long) and relatively undifferentiated integument are features consistent with immature ovules of extant gymnosperms at the time of pollination and with the previously proposed developmental sequence for *Callospermarion* (*6*). However, other features of the specimen are not what one would expect of a normally developing *Callospermarion* ovule at the time of pollination. The nucellus is only one cell layer thick and the sclerotestal cells are fully differentiated at the apex (Fig. 1A), features typically associated with more mature ovules. Also, none of the palynomorphs within the droplet conform to the genus *Vesicaspora*, pollen of the Middle Pennsylvanian Callistophytaceae (*8*) thought to be that associated with this ovule. Interpretation of the structure as a pollination droplet must therefore rely on the presumption that the specimen does not exhibit the features of a normal ovule. Since one would expect normally developing ovules to have matured into seeds that were subsequently destroyed by the developing embryo, only ovules that have had their developmental sequence disrupted would remain to be fossilized. With respect to the specimen at hand, the apparent discrepancy in developmental completeness of the various features is what one could expect of an abortive ovule.

By comparison with the physical and developmental features of extant gymnosperm ovules and those known to occur in *Callospermarion pusillum* (*6*), the following sequence of events can be interpreted as having led to the preservation of this specimen with a recognizable pollination droplet. The ovule presumably matured in the normal fashion up to the time when a pollination droplet was produced. At that point, because of either the absence of the appropriate pollen (*Vesicaspora*) or other unknown factors, ovule abortion occurred. Before metabolic activity ceased completely, the nucellus was reduced in thickness and the sclerotestal cells in the micropylar region differentiated and became sclerified. At the same time the pollination droplet shrank and partly collapsed due to desiccation. This was quickly followed by fossilization of the specimen.

The available evidence does not demonstrate whether pollen was drawn into the pollen chamber by shrinkage of the droplet, or the grains floated upward into the micropyle of the inverted ovule with the aid of the saccus (*2*). The discovery of a structurally preserved pollination droplet in a *Callospermarion*-type ovule does, however, document the occurrence of this type of reproductive mechanism among Paleozoic seed plants and supports the proposal that some early seed-fern ovules followed developmental and reproductive sequences similar to those of extant gymnosperms.

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Calcium Oxalate: Occurrence in Soils and Effect on Nutrient and Geochemical Cycles

Abstract. *Whewellite and weddellite, calcium salts of oxalic acid, have been found in the litter layer of several different soils, indicating that oxalate is a major metabolic product of fungi in natural environments. The presence of oxalate in soil solution speeds weathering of soil minerals and increases the availability of nutrients to vegetation.*

The minerals whewellite and weddellite, the mono- and dihydrate, respectively, of calcium oxalate, have been considered extremely rare in geologic environments (*1*, *2*) although they are common in plant and animal tissue (*3*). We have found that crystals of weddellite and whewellite adhere to the outer surfaces of fungal hyphae in the litter layer of forest soils from each of five widely separated locations in the United States.

The apparently widespread occurrence of these minerals in contact with percolating solutions has a large effect on biological and geochemical processes in soils because (i) the crystals are a reactive reservoir of calcium for the ecosystem; (ii) even small amounts of oxalate in solution increase the effective solubility of iron and aluminum by several orders of magnitude (*4*, *5*); (iii) oxalate, since it is both the anion of a weak acid and a chelator of iron and aluminum, affects the *p*H of the soil solution; and (iv) the chelation of iron and aluminum keeps phosphorus available to plant roots,