Architecture of ponderosa pine bark in relation to spalling behavior

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Abstract: Shedding/spalling behavior of ponderosa bark, with or without fire impetus, is primarily a function of the geometry of individual bark pieces, which are stable laterally due to their digitate shapes, and metastable radially due to flanges around the base of each piece. In detail, each piece is a zoned envelope of distinctive elements, separated from other pieces by another element. Different physical properties of these elements are probably involved in bark-piece expulsion, which requires sequential flange release. Criteria to determine any role of fire in bark-piece expulsion are described.

Introduction

Pinus ponderosa, a dominant forest tree in some parts of the SW US, is intriguing in a number of ways, including the aroma and attractive patterns of its reddish bark on limb-free lower trunks. The pattern on mature trees consists of wide bark plates, within which is an intricate pattern of bark pieces with a “jigsaw-puzzle” configuration (figs. 1, 2, 3). This report centers on the microscopic architecture of the array of pieces (henceforth puzzle-pieces) and relates it via macroscopic properties to shedding/spalling behavior. This behavior has been related to fire resistance, mostly in popular literature (Wuerthner and Moore 2001, Pease 2007) but also Fitzgerald (2005).

The puzzle-pieces interlock laterally and vertically, with complex and variable looping curved margins, but some are readily plucked free away from the trunk. This lateral stability in conjunction with outward metastability controls bark-fragment shedding. It is the purpose of this paper to better describe the geometry and structure of ponderosa bark, in hopes that this information has practical uses, perhaps relative to fire behavior. The observations recorded here are for the scopulorum variety of ponderosa, present mostly in the southwestern U.S. (Potter et al. 2013), but may have application elsewhere. It is also likely that certain architectural properties described here, so prominent in ponderosa bark, are not unique to this species.

Macroscopic structure of ponderosa bark

Many of the distinctive features of ponderosa bark are apparent in macroscopic views, ranging from whole-trunk to hand-lens scale. Of particular importance for shedding behavior are the array formed by bark pieces, their general shapes, the layering within them, and the flanges along their terminations.

Growth pattern.—From a distance, the most apparent aspect of ponderosa bark is its division into large platy strips or elongate polygons, divided by anastomosing septa, especially in larger trees (fig. 1). Rows of ten to twenty of these plates generally form the entire circumference of the trunk (corresponding to 18 to 36 radial degrees of the trunk circumference subtended) somewhat independently of its size (fig. 4). Thus large old trees have wide bark plates, and the areal ratio of bark plates to septa increases with increasing size, a factor in large old trees having an overall orange-brown bark color as
described by Huckaby et al. (2003). However in some trees, plates have split to form new septa, either horizontally or vertically, adding more geometric elements to accommodate growth. Both the appearance of new septa and division of bark strips into polygonal plates are in part due to accommodation of the bark to motion past dead lower limbs (fig. 4).

Locally all the bark elements formed during growth are preserved. In such cases, narrow ridges (collectively representing a smaller trunk circumference) of “blackjack” or juvenile gray scaly bark are found to form the outermost bark (fig. 4). More commonly in mature trees, the juvenile bark is not preserved, and the bark plates expose broader underlying reddish layers, each composed of assembled puzzle-pieces. Thus the reddish plates record shedding/spalling aspects of the history of bark growth and erosion, with or without any fire history.

Septa between bark plates extend inward, commonly to cambium, i.e. woody material is exposed. However, some septa are listric (curved), becoming tangential to cambium, presumably to accommodate tree growth. The septa narrow inward, exposing the margins of successively wider bark-plates, and generally have a grayish color that may be difficult to differentiate from fire blackening.

Puzzle-piece geometry and scale.—Within bark plates of mature ponderosa, individual pieces of bark broadly resemble jigsaw-puzzle pieces, in that they are roughly planar and digitate, characteristically showing necked lobes and arms, commonly rounded at the ends, and necked re-entrants (fig. 3). These pieces are typically 1.0 to as much as 2.5 mm thick, and range in length to 7 or more centimeters, generally but not always elongate vertically. The shapes of these pieces are such that they interlock laterally and vertically (tangential to the tree trunk), so that they are stable in these directions, but are readily plucked free away from the trunk one at a time, so are less stable in this radial direction. However, adjacent bark pieces are not in exactly in the same plane (so that the array can be said to be a three-dimensional puzzle; they tile multiple planes in a geometric/mathematical sense). Each piece has a marginal flange (fig. 3), which is overlapped in growth position by at least three outward neighbors that hold the flange in place. This is the reason the pieces tend to come free one at a time; at any given time only a few pieces have all flanges exposed. Some radial sections of ponderosa bark show concave-outward bark pieces (Stephen Fitzgerald, written commun., 2013). In such arrays, the flanges must be unlocked already.

The surfaces of the pieces are quite different on opposite sides. The outside is reddish and has a hard-leather texture, whereas the inside is yellowish and has a felty feel. Where aggregates of pieces come off together, the boundary between inside surfaces commonly exposes a narrow bead of another substance seemingly holding them together. All elements of both surfaces, however, show distinct cellular textures under a hand lens.

In winter, bark pieces are more difficult to separate from each other, and less aromatic. This implies a hardening of the “glue” between pieces, and may suggest that this glue is an aromatic element. Some bark pieces show a projecting knob on the back (inner) side, which fits into a matching hole in the piece behind.

Broken bark pieces show an internal layering that is quite consistent. In hand lens, a lighter-colored coarsely cellular material comprises most of the thickness of the
piece, whereas a darker reddish laminated material forms its inner surface, but also wraps around the end of the piece to form much of the flange. Arrays of such bark pieces extend inward to live woody tissue. Where bark and wood can be peeled away from each other, puzzle-piece morphology is easily recognized along the bark’s inner margin. Living tissue apparently “prints” puzzle pieces directly.

Microscopic structure

The macroscopic features of ponderosa bark are clarified by microscopic examination of thin sections. As shown by Chang (1954, his fig. 21 and p. 7), the basic structure is a layering formed by repetition of elements showing the same sequence, symmetrical in terms of element order but off-center. This is his secondary phloem unit cycle. My radial sections (fig. 5) show this structure, but I observe several additional features of importance.

First, each secondary phloem cycle shows terminations (figs. 5,6) with cross-sections that include projections on the basal (inside) edge, i.e. rather like a pig’s snout. The dimensions, shape, and character of these projections correlate with those of the flanges along the base of bark pieces (fig. 3). Note that these terminations interleave in such a way as to potentially clamp in the next more-basal termination.

Second, the dark reddish foliated material on the basal (inner) side of secondary phloem wraps around not only to form the termination/flange, but continues as a thinner layer along its outside margin (fig. 6). Thus secondary phloem has the character of a sealed envelope that encloses an interior of expanded parenchyma cells (cf. Chang 1954; Esau 1965). All these elements correlate with those of individual bark pieces, so secondary phloem envelopes must have the puzzle-piece shape of those bark pieces. The envelopes are thus held in place laterally by their puzzle-piece shapes, and radially by their flanges.

Third, the main—perhaps only—element of bark outside the sealed secondary phloem/puzzle-piece envelope is the light-colored material with coarser cells in rows and columns, the periderm/cork layers. It forms thin selvages between bark pieces, but can broaden where more space is available (fig. 7). This material has been called secondary (Esau 1965; Evert and Eichhorn 2006) but as it cuts secondary phloem I will refer to it as tertiary. This periderm/cork is a candidate for the glue bead between bark pieces in growth position, but for detachment on other occasions, as the puzzle piece/secondary phloem is expelled as intact whole assemblages with periderm/cork adhering to the back. This material may have physical/thermal properties different from those of the secondary phloem envelope.

As in macroscopic views, the photomicrographs show sharp boundaries of bark with woody material. Secondary phloem envelopes can be recognized right to this contact, possibly because the secondary and tertiary growth of some bark elements obscures original relations. However, extensional strain between bark and wood is also evident. Such strain could result on bark-plate margins where bark growth and addition of woody tree rings are out of step, and result in the observed listric shape of some septa between bark plates. Strain is also evident on the margins of dead limb stubs with bark (fig. 4) and may result in the tertiary growth of periderm/cork there (fig. 7).
Shedding/spalling behavior

The basis of bark-shedding behavior in P. ponderosa appears to be the basal flange along the digitate circumference of each piece. This locks each piece into place for movement away from the trunk, in conjunction with the puzzle-piece geometry that locks it into place laterally. Only when adjacent pieces overlapping the flange have already been shed is each piece freed, in turn beginning the process for underlying pieces.

Some such shedding clearly takes place in most trees without fire, as shown by a “duff” or mulch of bark pieces at the base of the trunk. Such shedding may have benefits for control of epiphytes and pathogens (Dylan Schwilk, personal commun., 2014). This type of shedding may be quite slow, as the geometric elements of bark architecture restrain it unless bark pieces deform.

Under fire conditions, it seems possible that ponderosa bark pieces are expelled from the trunk by a combination of mechanisms. Heat may volatilize the aromatic constituents of the bark array (e.g. Lowary and Richards, 1988), thus applying pressure behind the bark piece, and the coarsely cellular “glue” may soften. Sequential unlocking of puzzle-piece flanges permits them to be loosened and expelled one at a time. The benefits of this hypothetical behavior would thus be preservation of bark thickness in conjunction with prevention of flame mounting the trunk to the crown.

My own personal observations of P. ponderosa that have been subjected to wildland fire suggest that such beneficial behavior is limited and/or local. I suggest three criteria to establish confidence in fire benefits: 1) Normal reddish bark plates, singed but still intact and separated by blackened septa (as in figure 2), are preserved in surviving ponderosa on the margin of the fire. This bark has been thinned relative to other bark that is blackened far up the trunk; 2) No bark fragments are found around the bases of such trees. The updrafts produced by the fire itself waft the expelled bark fragments aloft; and 3) Downwind ashfall from the same fire contains singed but not blackened pieces of ponderosa bark (as in figure 3).

Ponderosa is somewhat fire resistant for other reasons. Perhaps of primary importance is its “self-pruning” quality, i.e. the lack of branches near the ground. This prevents the “ladder fueling” of other conifers that allows flames to mount from ground to crown. Also said to be of importance is the thick bark of ponderosa, but older trees showing wide bark plates may have only 2 cm bark thickness or less.

Thus the importance of bark architecture to fire resistance is unclear. However, the geometry is clearly permissive of beneficial response to fire. Experiments and more observations could clarify this question.

Conclusions

The distinctive shapes of P. ponderosa bark pieces are well configured to be elements of an array that is stable laterally but unstable away from the trunk once released by overlapping pieces. Within bark pieces, the basic assemblage of layers forms an envelope that remains coherent when expelled. Envelopes are liberated serially due to the presence of marginal flanges around the base of each such piece. Elements on the margin and around each piece probably have different physical properties, thus providing
opportunities for pieces to be expelled in fire conditions, and possibly contributing to fire resistance of ponderosa.

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1. Typical mature ponderosa trunk showing pattern of reddish platy elongate polygons/plates separated by grayish septa. This trunk is apparently unburned and 51 cm in diameter, from Prescott National Forest. Any sort of spalling episode
would broaden the bark plates of this tree and narrow the septa. Larger trees commonly have even broader bark plates; immature ones generally have narrower grayish bark plates, suggesting a constant radial angle subtended by each plate.
2. (1810) Detail of reddish bark plate flanked by burned (right) and unburned (left) septa on a tree that survived a 2009 fire in Bryce National Park. To the right, the 8 cm thick bark of the ca. 50 cm trunk was thinned by the fire to 5 cm. Note the
preservation of a few charred bark pieces on the surface of reddish bark, suggesting a snapshot of the bark spalling/erosion process.

3. (1835) Ponderosa bark piece (6.5 cm long) showing slightly singed outer side; note continuous flange. This piece was transported at least 1.5 km downwind from the Doce Fire of June 2013, and found among other singed ponderosa bark pieces on slopes facing upwind. The reverse sides preserve their original yellowish color.
4. Radial cross-sectional diagram of ponderosa trunk emphasizing bark growth pattern and septa between bark plates. Dotted line shows a degree of erosion of juvenile bark that exposes typical reddish-brown bark. Note anomalous septa outboard of former branch, now engulfed in wood/secondary xylem.
5. (v6mm) Photomicrograph of radial section of ponderosa bark (outside toward top) showing layering. Field of view 6 mm, plane-parallel transmitted light. Note presence of a few terminations of layered elements—secondary phloem of Chang (1954), each of which contains coarsely cellular lighter-colored material (expanded parenchyma cells of Chang) and foliated darker reddish material. Figure 7 shows a part at higher magnification. Prescott National Forest.
6. (u2mm) Photomicrograph of detail of secondary phloem terminations (left side of figure 6), showing shapes of interleaved margins. The number of terminations in this 2 mm field of view is unusual but illustrative. The elements within secondary phloem include the coarsely cellular lighter-colored material (expanded parenchyma) of figure 6, but note that the darker foliated material is thicker on the inside yet wraps around the secondary phloem termination to completely enclose that layer. Thus the secondary phloem forms a sealed envelope, and its features correspond to puzzle pieces in macroscopic view. The termination shape corresponds to the flanges of bark pieces (fig. 3). Note also the presence of light-colored coarsely cellular periderm/cork material in rows and columns outside the secondary phloem envelope—apparently corresponding to the yellowish material on the back of bark pieces and/or the glue-like bead between pieces.
7. (t2mm) Photomicrograph of the cellular periderm/cork material (forming rows and columns) where it occupies open space in the bark-slab cross section. Non-cellular material is epoxy impregnation. Field of view is 2mm. Prescott National Forest

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