

specimen to *Tirasiana disciformis* on the basis of its close resemblance to figured specimens from Russia, but believe that exact assignment is not possible without additional specimens and thorough revision of "medusoid" taxonomy.

Genus cf. SWARTPUNTIA Narbonne, Saylor, and Grotzinger, 1997

Figures 3, 4

Swartpuntia germsi NARBONNE, SAYLOR, AND GROTZINGER, 1997, p. 957, fig. 4; p. 960, fig. 6; p. 963, fig. 9; p. 964, fig. 10.

Description.—LACMIP 12726, Figure 3.1: Proximal fragment of multifoliate frond consisting of several petaloids and portion of central stalk. Specimen 62 × 51 mm. Two discrete petaloids visible in cross section along slab margin. Surface petaloid consists of a sheet of 22 parallel tubular segments preserved in convex epirelief that extend laterally from a central stalk. Tubular segments are up to 42 mm long and range from 1.0 to 1.7 mm in diameter; diameter constant over the length of the segments; segments follow vertical topography of slab surface. Segments form an approximately forty-five degree angle with central stalk; this angle increases distally to 55 degrees. Stalk 11 mm at widest point, preserved depressed relative to the neighboring topography by up to 8 mm; two raised projections and two faint lateral grooves visible on stalk.

UCMP 37450, Figure 3.2: Fragment of frondose petaloid; preserved in convex epirelief. Total surface area 10.8 cm × 9.3 cm. Petaloid segments semicircular in cross-sectional relief, but not clearly tubular, straight to arcuate in plan view, generally oriented parallel to one another. Two large areas of contiguous segments are 6.3 × 2.8 cm (e.g., right side of specimen in Fig. 3.2) and 9.0 × 5.3 cm (e.g., left side of specimen in Fig. 3.2). At least 30 segments are visible on right side of specimen, 29 visible on left side. Segments up to 4.2 cm long, 1–2 mm wide, 0.1–0.3 mm in relief; segments follow surface relief of up to 8.5 mm. On portion of slab surface, segments curve outward from center of slab and form sigmoidal pattern; two sets of segments present in this region, one on a ~1-mm-thick upper layer overlying segments of the adjacent, underlying layer, indicating presence of two petaloids (Fig. 3.2, arrow).

Material examined.—One nearly complete specimen (UCMP 34750) from UCMP loc. B8026, one incomplete specimen (LACMIP 12726) and numerous fragments from LACMIP loc. 17108.

Occurrence.—Wood Canyon Formation, Kelso Mountains, California (LACMIP loc. 17108); Poleta Formation, White Mountains, California (UCMP loc. B8026).

Discussion.—It is difficult to pinpoint abiogenic mechanisms which could plausibly create a surface 1) characterized by series of up to 30 parallel surface striae which extend across an uneven sediment surface yet which penetrate the surface at the same depth; 2) in which the tubular elements are rounded in cross-sectional view; 3) in which striae arc in one direction and then in the other direction without crossing; 4) in which two layers of similarly sized but obliquely oriented striae occur on overlying sediment layers less than 0.5 mm thick; and 5) on which there are no other tool marks.

The slab surface topography appears to reflect original bedding plane features (although the transverse markings and surface striae appear to have draped this sedimentary surface, and together with the presence of the inferred stalk in LACMIP 12726, may have later modified this surface). In addition, well-preserved underlying trace fossils and sedimentary structures suggest that these features are not metamorphic, diagenetic, or structural features. Thus, the best candidates to produce the observed features might include a) a comblike object drifting across the sea bottom; b) an arthropod with 20–30 appendages

scratching surficial or underlying sediment surfaces; c) folding or shearing of microbially-bound sediment; or d) impression of a frond-like soft-bodied carcass.

Ridges consistently conform to the topography of both specimens, which have a variety of bumps and depressions comprising up to 8 mm of vertical relief. The ridge-trough depth (measured along individual continuous segments) does not vary more than 0.3 mm in any individual tubular segment. Comblike tool marks made by hard inorganic objects or skeletonized debris would not be expected to conform so precisely to surficial topography, but would rather exhibit variable impression depths as the structure's edges passed across the substrate surface. A shifting current could account for the sigmoidal pattern within the surface striae, but would not account for their consistent parallel orientation over a 150 cm² surface. The only known parallel tool and drag marks made by soft tissue (Haines, 1997) are unlike those observed on study specimens, and have not been documented on two successive sediment layers on the same specimen, as in UCMP 37450.

If these specimens were scratch marks made by arthropods, one would expect splaying of the impressions as appendages moved outward/inward from the torso, tapering of the scratches toward their distal tips, deep impressions (or prod marks) at one edge of the impressions, and/or variations in the depth of penetration of the sediment corresponding to variations in surface topography. None of these features is present. Furthermore, on both specimens the segments occur on two different layers, are oriented obliquely to one another, and are separated by less than a millimeter of sediment. If they represent arthropod undertracks, one would expect all of them to occur on the same surface, unless the lower set was excavated and cast by another sediment layer, which was then scratched (without penetrating into the underlying layer)—a scenario which seems improbable. Arthropod scratch marks from elsewhere in this region (including *Monomorphichnus*; Alpert, 1974, 1976a, 1976b; Langille, 1974) are morphologically quite different from these features, largely because in *Monomorphichnus* traces, the size of the scratches in an individual set varies. Lastly, most arthropod scratch marks preserved in sharp convex hyporelief are typically formed on the bottom of a bedding plane, through the casting of the scratch trough, unlike our samples which exhibit convex ridges on bed tops.

Bunching or shearing of a microbially-bound sediment surface would not preserve such sharp regular folds. Nor would bunching or shearing produce a central stalk perpendicular to the ridges and abutting them. Surface textures of suspect-microbial features from siliciclastic strata of this region are typically more polygonally wrinkled, pustulose, and irregularly shaped than observed here (Hagadorn and Bottjer, 1997). Elongate sub-parallel striae associated with deformation of suspect microbially-bound sediment are typically more widely spaced, radiate outward from the locus of deformation, taper distally, and are larger than structures figured here (McIlroy and Walter, 1997).

The difficulty reconciling inorganic, tool, trace, weathering, or deformational origins for these structures, together with their morphologic and preservational similarities to certain Ediacaran "frond" taxa, suggest that our specimens are body fossils of "fronds." Several Ediacaran genera are similar to our specimens, but closer comparisons rule out most of them. The figured specimens are much larger than published accounts of *Nasepia* (Germs, 1973). The presence of a central stalk, multiple petaloids, and reduced size of tubular segments reject the possibility that the study specimens are *Ernietta*, which is typically preserved in three dimensions, rather than splayed on a bedding plane (Pflug, 1972). The tubular segments are narrower, longer (relative to overall specimen width), and less regularly arching

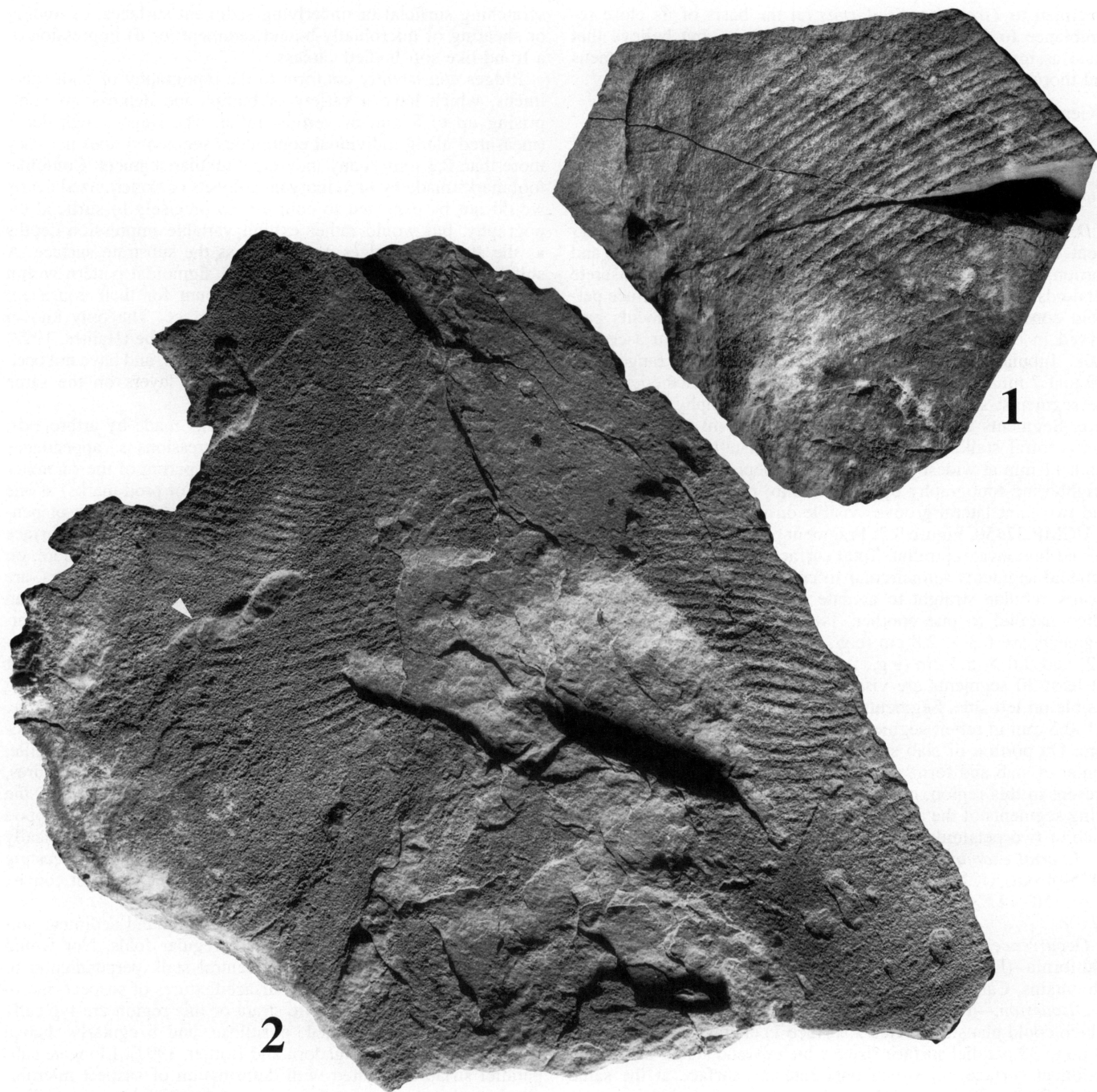


FIGURE 3—1, cf. *Swartpuntia* sp. from upper bedding plane surface of the upper member of the Wood Canyon Formation, Kelso Mountains, CA (LACMIP 12726). Note infolding and termination of parallel striae (right) at central stalk. Also note faint lineations on and perpendicular to the central stalk axis at left. 2, cf. *Swartpuntia* sp. from upper bedding plane surface of the middle member of the Poleta Formation, White Mountains, CA (UCMP 37450). Note presence of two thin (~0.5 mm) layers of parallel striae, visible at upper left of specimen where upper level of petaloid frond is preserved over lower level and striae appear to intersect one another (arrow). Although specimen has been chipped in center, striae on right side of specimen are from same layer as striae from middle left.

than many specimens of *Pteridinium* (Jenkins, 1992) and more regular than the transverse striae of *Dickinsonia* (Sprigg, 1947). The figured specimens are most similar to the multifoliate fronds described by Narbonne et al. (1997) as *Swartpuntia*.

Swartpuntia has been described from terminal Proterozoic strata of Namibia (Grotzinger et al., 1995; Narbonne et al., 1997), and from the terminal Proterozoic lower Wood Canyon Formation

of the southern Great Basin (Hagadorn and Waggoner, 2000). Similar, unnamed frond-like fossils, from the Lower Cambrian of southern Australia, have been documented by Jensen et al. (1998). Like the specimens described here, all of these fossils exhibit similar modes of preservation (including occurrence on bedding-plane surfaces and apparent sand casting of petaloid segments) and are associated with similar suites of sedimentary structures,

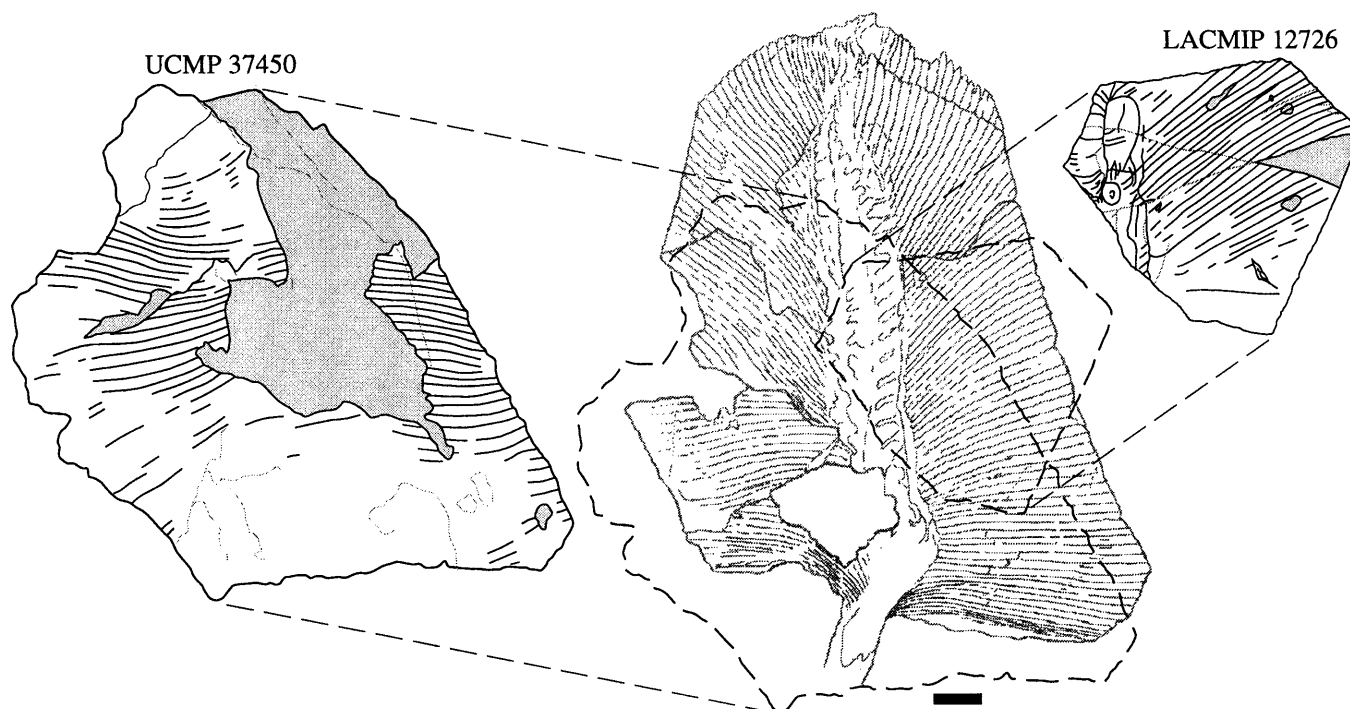


FIGURE 4—Camera lucida drawings and comparison of cf. *Swartpuntia* sp. from this study (upper right, LACMIP 12726; upper left, UCMP 37450) with similar drawing (center) of *Swartpuntia gerssi* (modified from Narbonne et al., 1997). Dashed regions indicate inferred fragment locations relative to specimen from Narbonne et al. (1997). Note that specimen at left preserves two petaloid layers, as does specimen at center, and note striae size and spacing similarity in all three specimens. All camera lucida drawings are at the same scale; scale bar is 1 cm.

trace fossils, and “medusoid” body fossils (Jensen et al., 1998). The fronds figured in this study are similar in size and proportions to these previously described fossils, and share morphologic features including presence of a central stalk, multiple petaloid layers, and tubular petaloid segments in a sigmoidal to straight arrangement. Our fronds are roughly the same age as *Swartpuntia*-like fronds illustrated from Australia (Jensen et al., 1998). The intersection of tubular segments with the central stalk in LACMIP 12726 suggests that the raised stalk projections are equivalent to the V-shaped stalk ridges illustrated in Narbonne et al. (1997). Despite their low (≤ 1 mm) relief, the tubular segments maintain this relief relative to cm-scale variations in slab surface topography, both in distal regions of the petaloid, and in concave depressions at or near the central stalk.

LACMIP 12726 is most similar to the central stalk and proximal petaloid region of *Swartpuntia*, whereas UCMP 37450 is similar to the petaloid region (Fig. 4). Unfortunately, the petaloid margins and most of the stems are not preserved in our specimens, the dorsal-ventral orientation of our specimens is uncertain, and the petaloid:stalk proportions cannot be calculated. We cannot make a confident species-level identification, but assign the fossils as ?*Swartpuntia* pending collection of more complete specimens.

Discussion.—The history of these specimens is relevant to understanding their importance and the credit due their collectors. The UCMP specimen was originally collected by J. Wyatt Durham in 1970, and noted in a talk given at the 1971 Cordilleran section GSA meeting (Durham, 1971). On the basis of his experience with Lower Cambrian biotas, Durham suggested that it was not a typical Cambrian faunal element and tentatively suggested it might be *Dickinsonia*. Conway Morris (1993) later figured the specimen in his comprehensive treatment of Ediacaran holdover taxa. Conway Morris thought that an assignment to *Dickinsonia* was plausible, but the apparent convergence

of the elongated segments on the upper portion of the specimen was not known from *Dickinsonia*. The LACMIP specimen (Fig. 3.1) was collected in 1992 by C. Fedo and J. Cooper (CSU Fullerton), and was interpreted as a soft-bodied impression, but was not formally described as an Ediacaran taxon because of the known Cambrian age. At that time, Cambrian occurrences of Ediacaran fossils were poorly known and *Swartpuntia* had not yet been discovered.

DISCUSSION

Collectively, the morphologic and sedimentologic characteristics of these specimens suggest that they are fossilized Ediacaran organisms. Although less spectacularly preserved than comparable specimens from Namibia and Australia, these fossils are nonetheless important because they help elucidate the temporal range and distribution of post-Vendian Ediacaran forms. Although simple discoidal “medusoids” have been noted in a variety of Cambrian strata (Narbonne et al., 1991; Crimes et al., 1995), more complex forms such as *Swartpuntia* are rare in the Cambrian. Furthermore, association with skeletonized Early Cambrian body fossils confirms the observations of Jensen et al. (1998) that complex Ediacaran fossils occur in Cambrian marine environments, but perhaps are only preserved under unique circumstances.

Of the two Early Cambrian forms described from this region, the cf. *Swartpuntia* specimens are of primary interest because they may be an example of a relatively long-ranging Ediacaran holdover taxon characteristic of shallow-marine environments. Regional stratigraphic comparison of the White Mountains and Mojave sections suggests that the lower member of the Wood Canyon correlates with the Deep Spring Formation (which underlies the Campito and Poleta Formations; Runnegar, 1998). Based on this correlation, and based on occurrences in the lower member of the Wood Canyon (Hagadorn and Waggoner, 2000),

Swartpuntia spans the pre-trilobite, *Fallotaspis*, and *Nevadella* Zones within the western Great Basin. Based on correlation of these sections with chronostratigraphically constrained sections from elsewhere (Landing et al., 1998), *Swartpuntia* may have a stratigraphic range ≥ 25 Ma.

Swartpuntia's long range and wide but scattered global distribution confirms that these fossils were likely only preserved where unique taphonomic windows existed. Although these fossils do not exhibit any diagnostic morphologic evidence to suggest microbial mantling of soft tissue (sensu Gehling, 1996, 1999), all three of the occurrences described here are from stratigraphic intervals characterized by suspect-microbial structures (Hagadorn and Bottjer, 1997, 1999). In both Australia and the Great Basin, Cambrian *Swartpuntia*-like fossils are also associated with soft-bodied "medusoids." These occurrences suggest limited persistence of Proterozoic-style soft-bodied preservation, thought to be made possible by microbial blanketing of sediments. Alternatively, it may indicate local modification of typical Phanerozoic-style burial processes, by decreased oxygen, restriction of vertically oriented bioturbation, early diagenetic mineralization, and/or rapid burial. Although occurrences of these fossils in the Great Basin are too rare and too scattered to make up a konservat-lagerstätten, such unusual burial processes are thought to account for many, if not most post-Proterozoic occurrences of soft-bodied preservation, such as the Burgess Shale (Seilacher, 1970; Seilacher et al., 1985; see also overview in Allison and Briggs, 1991; Seilacher and Pflüger, 1994). Our findings suggest that siliciclastic Cambrian strata that contain suspect-microbial structures should be examined carefully for further occurrences of Ediacara-type fossils.

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