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EDIACARAN FOSSILS FROM THE SOUTHWESTERN GREAT BASIN, UNITED STATES

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ABSTRACT—Ediacaran fossils from the southwestern Great Basin may help constrain regional Vendian-Cambrian biostratigraphy and provide biogeographic links between facies in this region and elsewhere. Locally, trace fossils suggest the Vendian-Cambrian boundary occurs within or below the upper third of the lower member of the Wood Canyon Formation. Ediacaran soft-bodied and tubular fossils, including the frondlike fossil *Swartpuntia* and tubular, mineralized or agglutinated fossils similar to *Archaeichnium, Cloudina, Corumbella,* and *Onuphionella* occur in the lowermost Wood Canyon Formation. Discoidal forms referred to *Nimbia* occur in both the lowermost Wood Canyon Formation and the underlying strata of the Stirling Quartzite. These fossils occur directly below Lower Cambrian trace fossils, including *Treptichnus pedum,* and confirm the persistence of the Ediacaran biota to near the base of the Cambrian. These faunas may also help strengthen previously proposed correlation schemes between the two main facies belts of the southwestern Great Basin (the Death Valley and White-Inyo facies), because a nearly identical Vendian-lowest Cambrian succession of faunas occurs in both regions. Lastly, lack of cosmopolitan Ediacaran faunas in these strata suggests a paleobiogeographic link between the southwestern U.S. and southern Africa in Vendian time.

INTRODUCTION

THE SOUTHWESTERN part of the Great Basin of the western United States is known for extensive exposures of Proterozoic strata (Stewart, 1970; Christie-Blick and Levy, 1989). However, this region generally lacks Ediacaran-type fossils. Furthermore, it has been difficult to pinpoint the Vendian-Cambrian boundary within sections in this region. In the Death Valley region, this difficulty stems from the lack of carbonate-dominated strata available for constructing chemostratigraphic profiles (Corsetti, 1993), the numerous regional disconformities (Corsetti and Kaufman, 1994), and the lack of fossils from the two units thought to straddle the boundary—the Wood Canyon Formation and the underlying Stirling Quartzite. Recent work has greatly improved our understanding of this interval (Horodyski, 1991; Corsetti, 1993, 1998; Horodyski et al., 1994; Runnegar et al., 1995; Runnegar, 1998), and our field research corroborates suggestions that the Vendian-Cambrian boundary lies within the lower member of the Wood Canyon Formation (hereafter lmWCF). Herein we document a new assemblage of Ediacaran-type fossils from immediately below the Vendian-Cambrian boundary, including soft-bodied fossils as well as four morphotypes of elongate tubelike fossils (Waggoner and Hagadorn, 1997; Hagadorn and Waggoner, 1998). This assemblage is of interest: because it helps constrain the position of the Precambrian-Cambrian boundary in the Death Valley facies of the southwestern Great Basin; because it provides additional correlation points between the major facies of the region (including the Death Valley, White-Inyo, and Caborca regions); and because it suggests larger-scale paleobiogeographic links between southwest Laurentia and Gondwanan cratons in latest Vendian time.

Previous research.—Langille (1974a, 1974b) documented conical calcareous fossils from the Funeral Mountains, California, from carbonates in the D member of the Stirling Quartzite. These fossils occur within a thinly-bedded, vuggy, dolomitic lag and may represent abraded specimens of the well-known mineralized form *Cloudina.* They also resemble the shelly fossil *Wyattia,* known from the upper Reed Dolomite in the Inyo Mountains (Taylor, 1966; Cloud and Nelson, 1966) and may indicate stratigraphic equivalence of these units (Stewart, 1970). Alternatively, they may represent a new genus (McMenamin, 1998), but are probably too poorly preserved to be confidently assigned to a particular genus.

Horodyski (1991) documented a nearly complete specimen of the ribbed, saclike fossil *Ernietta* from the Montgomery Mountains, Nevada. Further research confirmed that it came from the lowest of three parasequences within the lmWCF (Horodyski et al., 1994). *Phycodes pedum* (now *Treptichnus pedum*; see Jensen, 1997) was documented from the uppermost of these parasequence sets and suggests that the Precambrian-Cambrian boundary lies within or near the middle of the lmWCF in the Death Valley region (Horodyski et al., 1994).

Localities and stratigraphy.—In the southwestern Great Basin, the Vendian-Cambrian boundary occurs within a 1 km-thick, northwestward-thickening siliciclastic-dominated succession of miogeoclinal sediments (Prave et al., 1991) that records the development of a passive margin along southwestern Laurentia (Stewart, 1982). Our research focuses on exposures of the Stirling Quartzite and overlying Wood Canyon Formation in the Funeral Mountains, Montgomery Mountains, Nopah Range, Resting Springs Range, and Spring Mountains of eastern California and western Nevada (Fig. 1; see Burchfiel et al., 1982 for a regional overview). In this region, the Stirling Quartzite is divided into five informal members (A through E) and the Wood Canyon Formation is divided into lower, middle, and upper members (Stewart, 1970). The upper Stirling is a medium to coarse quartz arenite that interfingers with, and is conformably overlain by, the lower member of the Wood Canyon Formation (Wertz, 1982). The lower and middle members of the Wood Canyon Formation record a shallow marine-continental braidplain transition (Diehl, 1979; Fedo and Cooper, 1990; Fedo and Prave, 1991), with the lower member recording a highstand systems tract consisting of three carbonate-capped parasequences (Prave et al., 1991; Horodyski et al., 1994; Runnegar et al., 1995). The uppermost parasequence is disconformably overlain by the fluvially-dominated terrestrial braidplain and braid-delta facies of the middle Wood Canyon Formation (Diehl, 1979; Fedo and Prave, 1991). The upper Wood Canyon represents a return to dominantly marine conditions (Fedo and Cooper, 1990), with abundant body and trace fossils typical of the Early Cambrian (Hunt, 1990; Fedo and Prave, 1991; Mount et al., 1991).

The oldest fossils documented here come from the uppermost Stirling Quartzite, from a locality in the Montgomery Mountains in southern Nye County, Nevada, near the ghost town of Johnnie (LACMNH loc. 17129). Most of our fossils have come from a

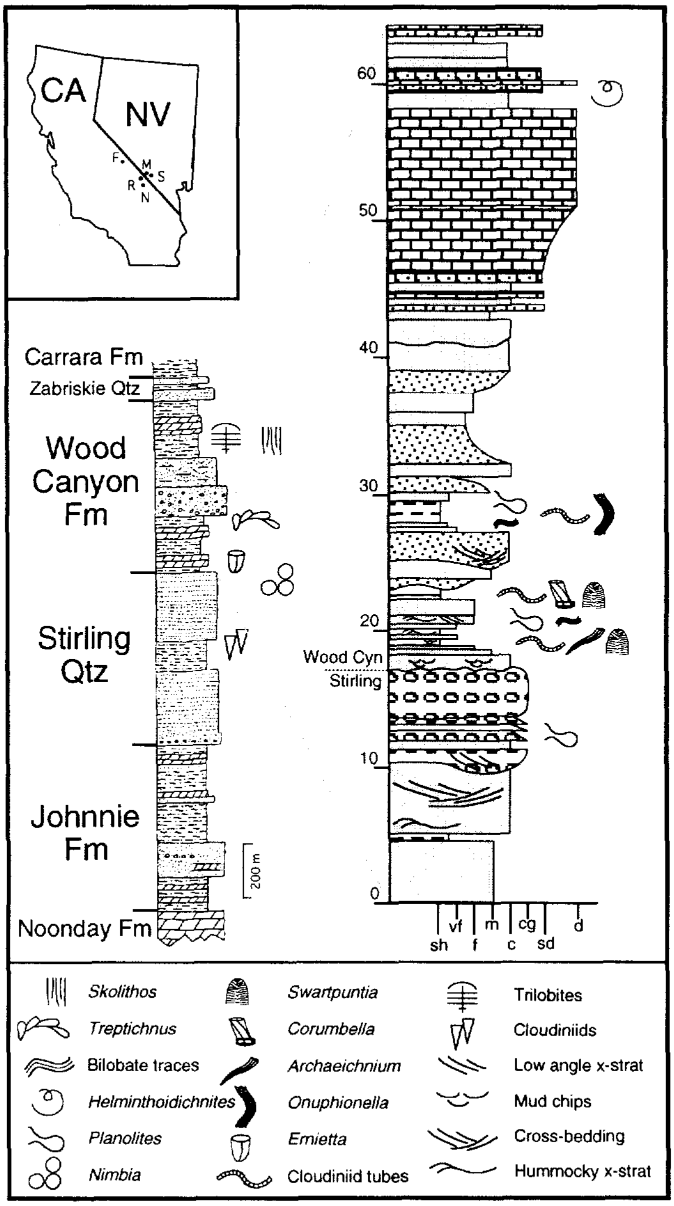

FIGURE 1—Generalized regional stratigraphy, modified from Prave et al. (1991), with composite measured section indicating principal fossiliferous horizons. Lithologies indicated as follows: sh = shale; vf–f–c = very fine–fine–coarse sandstone; cg = coarse–pebbly sandstone and conglomerate; sd = sandy dolostone; d = dolostone. Localities (inset) include the Montgomery Mountains (M; LACMNH locs. 17129, 17130), Nopah Range (N; LACMNH locs. 17132, 17133), and Spring Mountains (S; LACMNH loc. 17131). Additional material has been observed in the Resting Springs Range (R) and the Funeral Mountains (F; Langille, 1974a, 1974b).

single locality in the lmWCF, also located in the Montgomery Mountains not far from Johnnie (LACMNH loc. 17130). Additional localities are in the southern Nopah Range, in southern Inyo County, California (LACMNH locs. 17132, 17133). A few fossils have been found in the lmWCF in the Spring Mountains, across Pahrump Valley from the Montgomery Mountains (LACMNH loc. 17131). The Cambrian trace fossil *Treptichnus pedum* was collected from a locality in the Montgomery Mountains (LACMNH loc. 17134) in the lmWCF, but stratigraphically higher than locality 17130. We have visited other localities in the lmWCF in the Funeral Mountains, Resting Spring Mountains, and northern Nopah Range, all in Inyo County, California. Some of these sites have yielded tubular fossils and trace fossils, but these do not affect our systematic descriptions and are not described here. Detailed locality information is given in the Appendix.

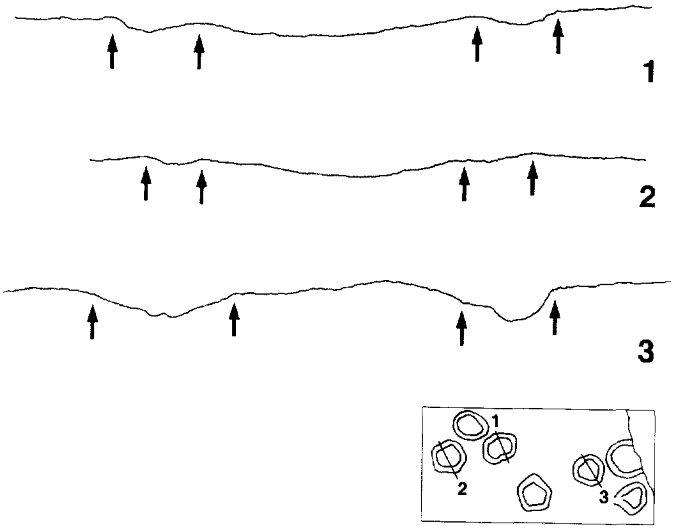

FIGURE 2—Outlines of cross-sections through plaster casts of three individuals of *Nimbia* sp. from the Stirling Quartzite, Montgomery Mountains, near Johnnie, Nye County, Nevada (LACMNH loc. 17129), ×1. Arrows indicate boundaries of the depressed rims. Inset diagram shows location of sections on fossil-bearing slab (compare fig. 3.1).

SYSTEMATIC PALEONTOLOGY

All figured specimens have been curated in the Los Angeles County Museum of Natural History (LACMNH). Casts of some figured specimens, as well as some unfigured topotype material, have been deposited in the University of California Museum of Paleontology (UCMP; curation pending) and in the University of Central Arkansas paleontological collections (UCA).

Genus NIMBIA Fedonkin, 1980
Figure 2, 3.1–3.3

Type species.—*Nimbia occlusa* Fedonkin, 1980, p. 8, pl. 1, figs. 1, 2.

Diagnosis.—(Translated and abridged from Fedonkin, 1985) Flat, discoidal, circular to oval organisms preserved in positive hyporelief. Peripheral part forms a single thick marginal rim. Central portion within the rim is usually smooth and featureless but may have a central tubercle.

Description.—Large, ring-shaped structures about 60 mm in diameter, preserved in negative epirelief, consisting of a sunken rim about 10 mm thick with slightly raised edges. Center is typically either slightly sunken or slightly raised (Fig. 2).

Material and occurrence.—Member E, Stirling Quartzite, Montgomery Mountains, Nye County, Nevada (LACMNH loc. 17129): Seven specimens on upper surface of one block of quartzite. Originals could not be collected, but casts made from molds have been curated as LACMNH specimens 12790 and 12791.

Discussion.—Identification of circular "medusoid" fossils is problematic owing to the abundance of circular dubiofossils during this interval (Cloud, 1960, 1968, personal observations). Although these specimens could be abiogenic sedimentary features, they do not resemble any abiogenic features that we have seen in this interval. The specimens could not be sectioned, but field inspection of partial specimens along broken slab edges showed no concretion, load, gas escape, or injection features (Fig. 3.3). The apparent distortion visible in some of the specimens suggests that they represent flexible objects (Fig. 3.2). Their consistent morphology and size suggests that they are body fossils which are morphologically similar to the Ediacaran "medusoid" *Nimbia occlusa* (Fedonkin, 1985; BW, personal observations). The only major difference is that the Stirling Quartzite fossils are roughly twice the diameter of typical *N. occlusa*. Raised or sunken centers or central markings, somewhat similar to those seen in our specimens, are sometimes seen in *N. occlusa*.

Genus NIMBIA? Fedonkin 1980
Figure 3.4

Description.—Specimen preserved in convex relief, 30 mm in diameter, with much thinner rim (2 mm in thickness) and indistinct central depression.

Material and occurrence.—One specimen (LACMNH 12792). Collected from float in the lower Wood Canyon Formation, southern Nopah Range, Inyo County, California (LACMNH loc. 17133)

Discussion.—A single specimen (LACMNH 12792; Fig. 3.4) is smaller than the Stirling Quartzite specimens and has a much narrower rim, and is preserved in positive relief. Because it was not collected in situ, it is not certain whether it preserved in epirelief or hyporelief. The specimen somewhat resembles a looping trace fossil such as *Gordia, Helminthoidichnites,* or *Circulichnis.* However, we tentatively refer it to *Nimbia* because of its apparently complete rim and a possible central marking. It falls within the observed size and shape range of *N. occlusa* (Fedonkin, 1985; BW, personal observations).

Genus SWARTPUNTIA Narbonne, Saylor, and Grotzinger, 1997

Type species.—*Swartpuntia germsi* Narbonne, Saylor, and Grotzinger, 1997.

Diagnosis.—(Modified from Narbonne et al. 1997, p. 959). Ovate, leaf-shaped frond showing unipolar organization. At least three petaloids attached longitudinally to a transversely segmented central stalk; each petaloid a quilted sheet of 2–3 mm-wide segments, with both the length of individual segments and their angle of branching from the central stalk decreasing distally.

SWARTPUNTIA cf. GERMSI Narbonne, Saylor, and Grotzinger, 1997
Figure 4.1–4.3

Description.—Frondose organism with segmented central rachis. The most complete specimen has a spindle-shaped central rachis 85 mm long and 11 mm at its widest point, divided into segments 7 to 8 mm long (seven are clearly visible). The rachis is surrounded by a flat, ovate frond with fine parallel striae about 1 mm apart, radiating from the axis at approximately 45 degrees. Examination of the edge suggests that at least two petaloids were present on the rachis, and were superimposed on each other at burial. Estimated total width about 90 mm; estimated total length more than 100 mm.

Material and occurrence.—One near-complete specimen (LACMNH 12793); several poorly preserved fragments (not figured). Lower Wood Canyon Formation, Montgomery Mountains, Nye County, Nevada (LACMNH loc. 17130)

Discussion.—The most complete specimen of *Swartpuntia* is preserved in epirelief in sandy siltstones just above the Wood Canyon Formation-Stirling Quartzite contact. Although the specimen is incomplete and we have not identified the presence of a basal stalk, it is nearly identical in all observable characters to the type species, *S. germsi.*

Genus cf. ARCHAEICHNIUM Glaessner, 1963

Type species.—*Archaeichnium haughtoni* Glaessner, 1963.

Diagnosis.—Cylindrical or conical tubular fossils, round in cross section, 1–5 mm in diameter. Walls of agglutinated sand grains, often showing fine longitudinal lineations; tubes somewhat flexible in life.

cf. ARCHAEICHNIUM sp.
Figure 3.5, 3.6

Description.—Conical tube, tapering from a maximum diameter of 5 mm to a minimum diameter of 3 mm; longest specimen fragment is 29 mm. Longitudinal fracturing of specimen allows wall structure to be examined: wall composed of agglutinated sediment grains of approximately the same grain size as the surrounding matrix. No sharp separation present between wall and surrounding matrix. Weak transverse annulations visible, spaced irregularly but approximately 1 mm apart. Faint, fine longitudinal striations also visible, creating "cross-hatched" effect on surface. Several angular bends along length resemble buckling.

Material.—One specimen of an external mold (LACMNH 12794).

Occurrence.—Lower Wood Canyon Formation, Montgomery Mountains, Nye County, Nevada (LACMNH loc. 17130).

Discussion.—Although only one specimen has been found thus far, the specimen is distinct from all other tubular fossils known from the lowest Wood Canyon Formation. It differs from typical cloudiniids, and from all other tubular fossils described in this paper, in several ways: the wall is agglutinated; the shape is much more conical; the transverse ornament is weak and unevenly spaced; fine longitudinal ridges as well as transverse ridges are present; and the "buckling" suggests that the fossil was flexible rather than strongly mineralized. Although it is possible that this specimen represents a lined burrow, the buckling and slight conical taper are atypical of most trace fossils from this region. This fossil is similar in morphology and size to the agglutinated tube *Archaeichnium haughtoni,* known only from the late Proterozoic of Namibia (Glaessner, 1963, 1978). It differs in possessing fine transverse ornamentation (although this is also occasionally seen in *A. haughtoni*); its longitudinal striae are also much weaker than is typical for the type material. However, since *A. haughtoni* is quite variable (Glaessner, 1978), we prefer not to place our specimen in a species. Further material must be collected to make a firm taxonomic determination.

Genus cf. CLOUDINA Germs, 1972

Type species.—*Cloudina hartmannae* Germs, 1972.

Diagnosis.—Calcareous tubes, nearly round in cross section, typically curving or sinuous, with cone-in-cone wall structure in longitudinal section. Outer wall bears annular ridges and depressions, inner wall nearly smooth. Ends open.

cf. CLOUDINA sp.
Figures 3.7–3.10, 5.1–5.3

Description.—Narrow, straight or slightly curved, almost cylindrical tubes with minor or no tapering, terminating abruptly. Diameter between 1 and 3 mm; maximum observed length about 35 mm. Both annulated and smooth tubes present. High relief suggests tubes were originally mineralized.

Material.—About fifty specimens; figured specimens LACMNH 12795, 12796, 12797, 12798, 12799, 12800, 12801.

Occurrence.—Lower Wood Canyon Formation, Montgomery


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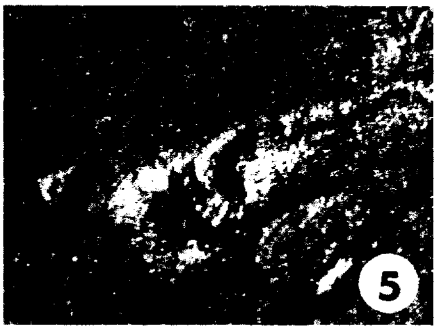
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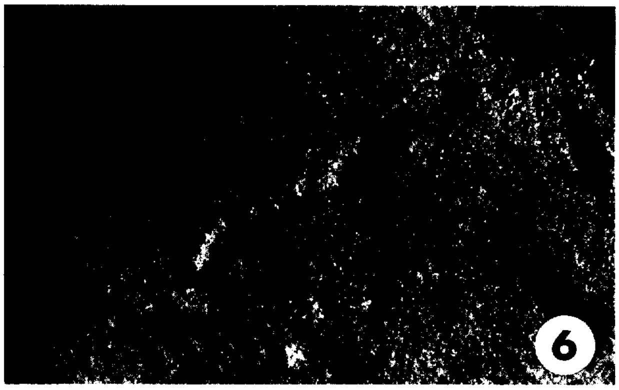
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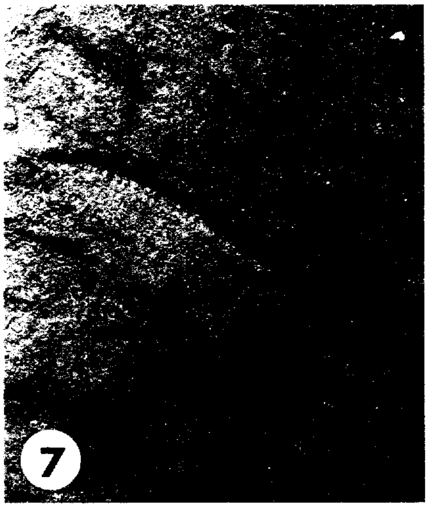
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Mountains and Spring Mountains, Nye County, Nevada (LACMNH locs. 17130, 17131); southern Nopah Range, Inyo County, California (LACMNH loc. 17132). Specimens have also been seen in the lower Wood Canyon Formation in the Resting Spring Mountains, northern Nopah Range, and Funeral Mountains of Inyo County, California.

Discussion.—The truncated shape, tapering of individual tube segments, lack of evidence for backfill or sediment disturbance, high densities within amalgamated beds, and absence of self-intersection suggest that our fossils are molds and casts of smooth-walled and annulated tubes, rather than trace fossils or compressed algal or bacterial sheaths. Unlike traces from coeval beds which are concentrated on bed tops and bottoms, tubes occur throughout fossiliferous beds in the study areas. In rare horizons, tubes can occur as densely packed monotaxic fossil concentrations. Furthermore, tubes are inclined at oblique angles to bedding and pass through bed interfaces—features unknown from Neoproterozoic trace fossils, which are typically bed-parallel in orientation. The dimensions of these tubes are within the known limits for *Cloudina*; *C. hartmannae* from Namibia, for instance, ranges from 2 to 6.5 mm in diameter and from 8 to 150 mm in length, whereas *C. riemkeae* ranges from 0.3 to 1.7 mm in diameter (Germs, 1972). Because the annulated and smooth tube types co-occur and have similar diameters, tapering, and degrees of curvature, we tentatively consider them to be preservational variants of the same or closely related organisms. McMenamin (1985) noted a similar intergradation between annulated and smooth-walled tubes from the latest Precambrian of Mexico, and Grant (1990) cited a similar intergradation in Chinese material; both attributed it to different degrees of predepositional abrasion.

Precise identification, however, is made difficult by the fossils' preservation as molds or casts in fine-grained siliciclastic rocks. *Cloudina* has usually been described from thin sections in carbonates and/or whole specimens dissolved from carbonates. Since our fossils lack original wall material, close comparisons with typical cloudiniids are not possible; we cannot confirm the presence of the "cone-in-cone" wall structure of true *Cloudina*. Furthermore, several other genera have been erected for similar fossils from this region: *Nevadatubulus* and *Sinotubulites* have previously been used for annulated tubes from Precambrian-Cambrian boundary strata in the White-Inyo Mountains and in Mexico (e.g., McMenamin, 1985; Signor et al., 1987). Both genera have been synonymized with *Cloudina* by Grant (1990), but this has not been tested or verified in the type area. Langille (1974b) also described some smooth-walled, tubular forms as *Terebellites*? from the Death Valley region. It is possible that these are identical to our smooth-walled tubes and thus likely preservational variants of cloudiniids, but re-examination of Langille's material is needed.

Salak and Lescinsky (1999) have described an enigmatic fossil, *Spygoria zappania*, from the Lower Cambrian of central Nevada. *Spygoria* closely resembles cloudiniids but differs in having shallow cup-shaped nested laminae, rather than the conical laminae of typical *Cloudina*. Without knowledge of the wall structure of our material, we cannot rule out an affinity with *Spygoria* for our material. However, *S. zappania* ranges from 2–10 mm in diameter, with a typical diameter of about 6 mm; it is therefore larger than all but the largest of our specimens. Its surface morphology is also less regular than that of our specimens. We provisionally rule out an affinity with *Spygoria* for our material.

Genus CORUMBELLA Hahn, Hahn, Leonardos, Pflug, and Walde, 1982

Type species.—*Corumbella werneri* Hahn, Hahn, Leonardos, Pflug, and Walde, 1982.

Emended diagnosis.—Annulated tubular fossils less than five millimeters in diameter, with fourfold radial symmetry.

CORUMBELLA new species A

Figure 5.4–5.6

Description.—Annulated tubular fossil, nearly square with rounded corners in cross section, with a diameter of 4 mm on the longest diagonal. Sharp separation between interior and exterior of fossil probably representing thin wall. Longitudinal grooves along the midline of each face. Best-preserved specimen (LACMNH 12802) shows helical twist along main axis. Interior of best specimen filled with siliciclastic sediment (grain diameter ~100–500 μm), significantly coarser than surrounding sediment (grain diameter ~10–60 μm).

Material.—Two specimens, one with part and counterpart (LACMNH 12802), one with counterpart mold only (not figured).

Occurrence.—Lower Wood Canyon Formation, Montgomery Mountains, Nye County, Nevada (LACMNH loc. 17130).

Discussion.—In size and surface ornament, this fossil is closest to the specimens we describe as cf. *Cloudina*. However, it is larger than the *Cloudina*-like fossils from the same locality, and the fossil's helical twist and nearly square cross section make it quite distinct from all other tubular fossils from this region. This fossil is most similar to *Corumbella*, an annulated, tetraradially symmetrical tube from the late Proterozoic of southwestern Brazil. (Hahn et al., 1982). We do not consider it conspecific with the only described species, *C. werneri*, which lacks a helical twist, has finer transverse ornament, and was reconstructed as nearly circular in cross section. The available material also lacks the secondarily branched "polypar" described for *C. werneri*. It is even possible that it belongs in a different genus, but more material is needed to characterize the Nevada form. Until more examples have been found, we prefer to ally this form with the established genus *Corumbella* without formally erecting a new species.

Hahn et al. (1982) interpreted *Corumbella* as a tube built by the polyp stage of a scyphozoan, in analogy with a few living scyphozoans such as *Stephanoscyphus*. This fossil's symmetry and ornamentation are also similar to the Paleozoic conulariids, which may also be scyphozoans (Van Iten et al., 1996). This fossil provides strong evidence for the presence of scyphozoan-like cnidarians in the latest Proterozoic.

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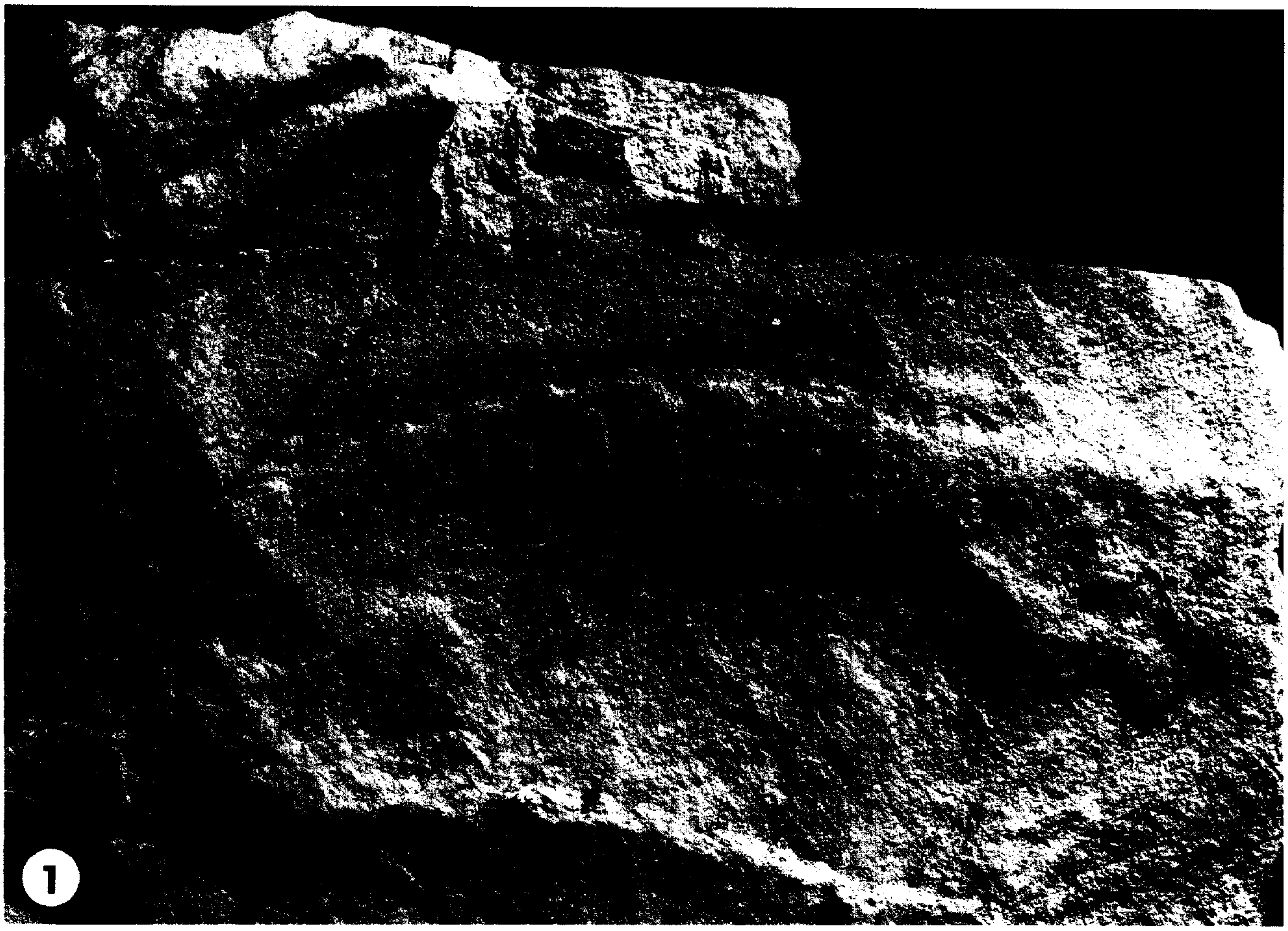
FIGURE *3*—Ediacara-type fossils from the southwestern Great Basin. All specimens are from the lower member of the Wood Canyon Formation near Johnnie, Nye County, Nevada (LACMNH loc. 17130) unless otherwise specified. *1–3*, *Nimbia* sp., LACMNH loc. 17129, in negative epirelief on large block of Stirling Quartzite: *1*, view of block in situ, ×0.2 (scale bar is 8 cm long). *2*, closeup of three specimens, ×0.5 (cast of these specimens curated as LACMNH specimen 12790). *3*, side view of naturally broken specimen, ×0.5 (cast of this and neighboring specimens curated as LACMNH specimen 12791); note absence of concretionary or fluid escape structures. *4*, *Nimbia*? sp., LACMNH 12792, loc. 17133, ×1. *5*, *6*, cf. *Archaeichnium*, LACMNH 12794 (in hyporelief); *5*, close-up of broad end, showing transverse ornament and light, fine longitudinal lines, and cross-section through tube wall, ×2.5; *6*, view of complete specimen, ×1. *7*, *8*, *9*, cf. *Cloudina* sp., ridged type; *7*, LACMNH 12795 (in hyporelief), ×1; *8*, LACMNH 12796, ×1.2; *9*, LACMNH 12797, ×1. *10*, cf. *Cloudina* sp., smooth type, LACMNH 12798, loc. 17131, ×1.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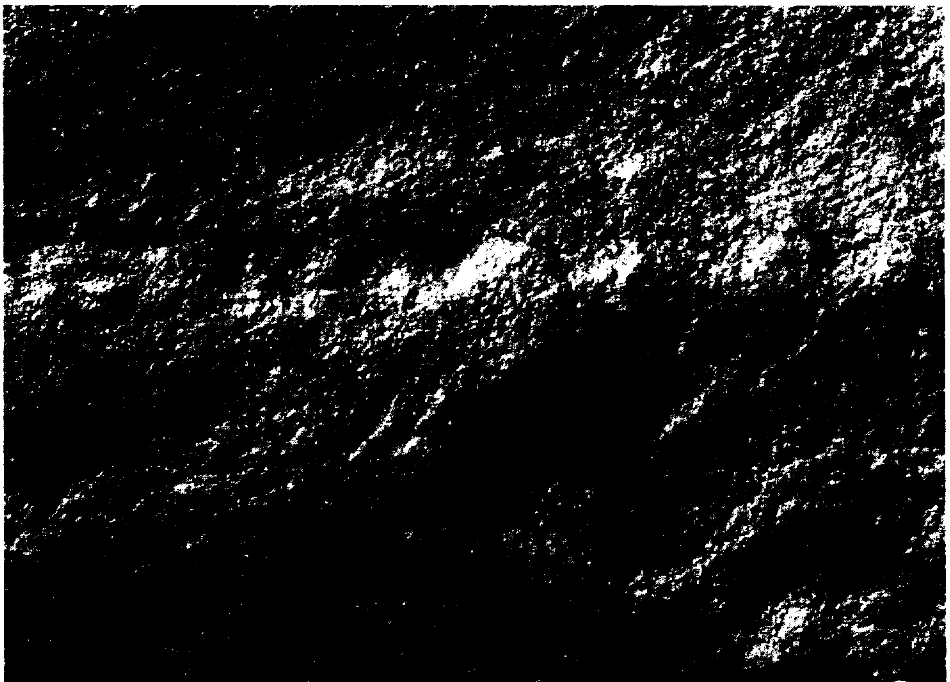
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Genus ONUPHIONELLA Kirjanov, 1968

Type species.—*Onuphionella agglutinata* Kirjanov, 1968.

Diagnosis.—Large (~6 mm diameter), cylindrical or slightly expanding membranous tubes with external layer of agglutinated mica flakes. Tubes flexible and fragile in life.

ONUPHIONELLA sp.
Figure 5.7

Description.—Cylindrical tubular form, nearly straight, preserved compressed; diameter 6 mm; preserved length 35 mm. Cross-section is a flattened ellipsoid. Walls composed of agglutinated flakes of mica. Faint longitudinal striations visible.

Material.—One specimen, part and counterpart (LACMNH 12803).

Occurrence.—Lower Wood Canyon Formation, Montgomery Mountains, Nye County, Nevada (LACMNH loc. 17130)

Discussion.—This form is identical with the fossil agglutinated tube *Onuphionella,* originally described from Siberia (Kirjanov, 1968). *Onuphionella* was documented from the Lower Cambrian Campito and Poleta Formations of the White-Inyo Mountain region (Wiggett, 1978; Signor and McMenamin, 1988). In its size and light coating of mica grains without definite arrangement in rows, our specimen is most similar to *O. claytonensis* Signor and McMenamin, 1988, the older of two species described from the White-Inyo region. This is the first occurrence of *Onuphionella* in association with Ediacara-type soft-bodied fossils.

Wiggett (1978) and Signor and McMenamin (1988) listed close similarities between *Onuphionella* and the agglutinated tubes of extant polychaetes, notably *Owenia,* although they did not formally assign *Onuphionella* to the phylum Annelida. Dispersed mica flakes are moderately common in some layers of the host rock, and are visible on the slab.

TRACE FOSSILS

Several trace fossils were noted in measured sections which are relevant to interpretation of local biostratigraphy, sequence correlations, onset of bioturbation in the southwestern Great Basin, and age of faunas described above. Although dubiofossils have been reported from the Stirling Quartzite (Langille, 1974b), the first definitive traces occur in the fine quartzites and siltstones of the lowest parasequence of the lmWCF. These assemblages include bed-parallel forms such as *Helminthoidichnites* (sensu Hofmann and Patel, 1989; Fig. 5.10), *Palaeophycus, Planolites,* and bilobate trails similar to small *Scolicia* (Fig. 5.11, 5.12), and record the onset of bed-parallel bioturbation in this region. In the Montgomery Mountains, *Planolites* and bilobate trails occur on the same bedding plane as *Swartpuntia.* The lowest occurrence of the trace fossil *Treptichnus pedum* (Fig. 5.8, 5.9) occurs higher in the section, approximately 1 meter above the dolomitic top of the middle parasequence in the Wood Canyon Formation. Such traces are thought to record the onset of bioturbation with a vertically oriented component. As such, the lowest occurrence of *T. pedum* is considered diagnostic of basal Cambrian strata (Narbonne et al., 1987). Although relatively rare in Lower Cambrian strata of the Great Basin, *T. pedum* can be documented in the upper submember of the lmWCF at all studied outcrops. This generalized succession of trace fossils closely matches the occurrence of trace fossils in the White-Inyo facies of eastern California (Fig. 1; Alpert, 1974; Langille, 1974b; Lipps and Fedonkin, 1988).

DISCUSSION AND IMPLICATIONS

Stratigraphic implications.—The succession of faunas documented herein complement previous $\delta^{13}C$ chemostratigraphic interpretation of carbonates from the Stirling Quartzite and Wood Canyon Formation, which indicates a latest Vendian positive carbon isotopic excursion in the Stirling, and a probable Lower Cambrian negative carbon isotope excursion in the lmWCF (Corsetti, 1993, 1998). All evidence suggests that the base of the Cambrian occurs, at the very highest, at the top of the middle parasequnce within the lmWCF (Horodyski et al., 1994; Runnegar et al., 1995). Although radiometric age constraints are not available for these exposures, and although there may be a significant hiatus in the upper part of the lmWCF (resulting from incision by the middle member), we have no reason to believe these faunas are significantly older than 544 Ma.

Our research confirms the discovery of Ediacara-type fossil assemblages extending up to, and even into, the Cambrian (Grotzinger et al., 1995; Hagadorn and Waggoner, 1998; Jensen et al., 1998). Although the thickness of the lmWCF varies across the ~50 km of contact which we have examined, the highest Ediacara-type fossils in our measured sections are, at most, 100 meters below the lowest occurrence of *T. pedum.* Considered together with their abrupt appearance at the onset of finer-grained deposition at the Stirling–Wood Canyon contact, we question whether their paucity in this region stems from rapid closure of optimal preservational conditions by local effects. In the Great Basin, conditions favoring Ediacaran preservation may be restricted by coarse-grained clastic input from regional braidplain-delta systems in the latest Vendian, and by the onset of intense bioturbation in the Early Cambrian (sensu Seilacher and Pflüger, 1994; Gehling, 1999).

Correlation implications.—The White-Inyo Mountains and surrounding areas have yielded taxa that are very similar to those in our assemblage, including cloudiniids, from the lower Deep Spring Formation (Signor et al., 1983, 1987; Grant, 1990). Precise comparisons between the White-Inyo material and our Great Basin material are difficult because of the great differences in preservation; our fossils are typically molds or casts in clastic rocks, whereas the White-Inyo fossils come from fossil concentrations in carbonate strata. Poor preservation of some White-Inyo material has caused some nomenclatural confusion (Grant, 1990) that creates further difficulties in comparing the faunas. However, when considered together with similar associations of tubular cloudiniids in siliciclastic strata of Namibia (B. Runnegar, personal commun.) these occurrences suggest that the appearance of shelly fossils may not be as facies-dependent as previously thought. Moreover, addition of this new faunal information corroborates Stewart's (1970) correlation of the three submembers of the lmWCF with the three members of the Deep Spring Formation in the White-Inyo facies; and perhaps also confirms suggestions that the base of these units may record an equivalent event (see summaries in Mount et al., 1991; Runnegar, 1998).

Lastly, faunas from the Death Valley region may have analogues in more southern Vendian-Cambrian successions in Mexico. For example, similar annulated and smooth-walled tubular

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FIGURE 4—*Swartpuntia* cf. *germsi,* LACMNH 12793, loc. 17130 near Johnnie, Nye County, Nevada. *1,* complete fossil, ×1; *2,* closeup of the distal end showing fine parallel striae on both sides of the rachis, ×2; *3,* closeup showing double parallel rims and parallel striae, suggesting the presence of at least two fronds, ×2.


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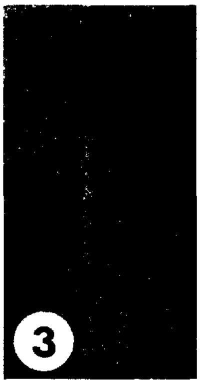
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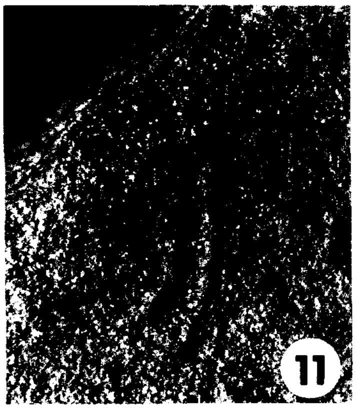
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12

fossils attributed to *Cloudina* (Grant, 1990) have been documented from Caborca, Mexico (McMenamin et al., 1983). These fossils occur at a level thought to be stratigraphically equivalent to the lmWCF, in the lowest member of the La Ciénega Formation (Stewart et al., 1984). Furthermore, the faunal succession presented in Figure 1 closely matches the Caborca succession of Stewart et al. (1984), perhaps suggesting a coeval onset of bed-parallel bioturbation, appearance of tubular fossils, and appearance of "*Nevadella*" zone trilobites in southwestern Laurentia.

Biogeographic implications.—Rifting of the supercontinent Rodinia occurred in the late Proterozoic, separating the Cordilleran margin of Laurentia from east Gondwanaland. This rifting may have begun 150–200 million years before the Cambrian (Rogers, 1996; Dalziel, 1997), or possibly much later, in the Vendian (Veevers et al., 1997). Testing of these conflicting hypotheses has been hampered by lack of biogeographically restricted fossils. If rifting occurred in the Vendian, faunas from the recently rifted adjacent margins should be similar. If rifting occurred significantly earlier, endemic faunas would be expected to develop along the different rifted margins, and might co-occur with wide-ranging cosmopolitan forms. *Ernietta* and *Swartpuntia* are not cosmopolitan forms; rather, they are currently known only from Namibia and southwestern North America. The Great Basin assemblage of tubular fossils also resembles that of Namibia; cloudiniids and *Archaeichnium* are common to both regions, further supporting this biogeographic link (Fig. 6; Waggoner, 1999). *Corumbella* and cloudiniids are also known from Brazil, suggesting a link between southwestern Laurentia and South America—both of which are thought to have been adjacent to or along the same rift zone (Hahn et al., 1982; Hahn and Pflug, 1985; Grant, 1990). Co-occurrence of these forms only on cratons thought to be adjacent to one another is even more dramatic when one examines the nearly global distribution of Ediacaran faunas (see overview by Narbonne, 1998). The taxa described herein are restricted to three of the 28 principal Ediacaran-bearing occurrences documented in Narbonne (1998). Although these observations do not disprove an earlier date for rifting, the restricted range of these taxa suggests a significant biogeographic connection between southwestern Laurentia and these Gondwanan cratons in late Vendian time.

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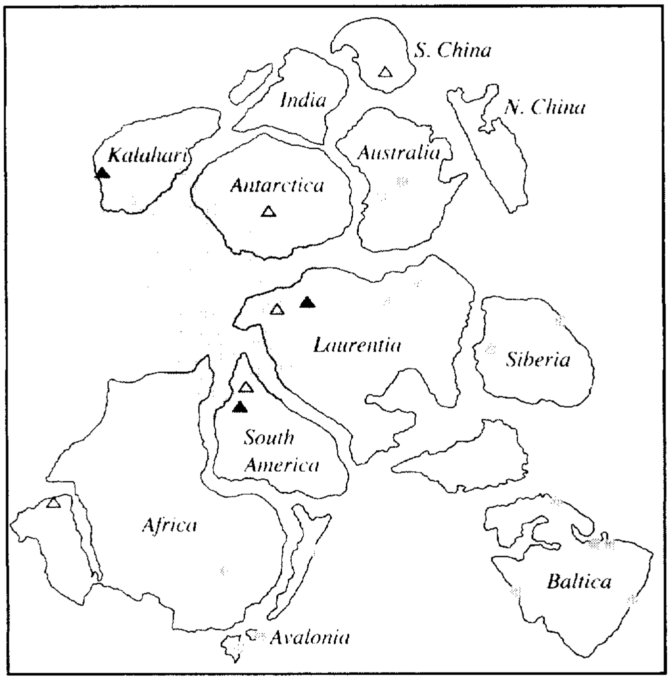

FIGURE 6—Reconstruction of the supercontinent Rodinia in the late Proterozoic (after Rogers, 1996). Open triangles are localities where cloudiniids have been reported (Grant, 1990); solid triangles represent localities where a shared fauna occurs, including *Cloudina*, *Corumbella*, *Ernietta*, and/or *Swartpuntia*. Circles indicate other Ediacaran-type faunas of Proterozoic age (modified from Hahn et al., 1980; Grant, 1990; Narbonne, 1998).

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FIGURE 5—Ediacara-type tubular and trace fossils from the southwestern Great Basin. All specimens are from LACMNH loc. 17130 unless otherwise specified. *1–3*, cf. *Cloudina* sp. (smooth type); *1*, LACMNH 12799, ×1; *2*, LACMNH 12800, ×1; *3*, LACMNH 12801, ×1.7. *4, 5, 6*, *Corumbella* n. sp. A, LACMNH 12802; *4*, part, with lines indicating position of transverse section, ×1; *5*, counterpart (in hyporelief), ×1; *6*, transverse section through part, ×20. *7*, *Onuphionella* sp., LACMNH 12803, part, ×1.5. *8, 9*, *Treptichnus pedum*; *8*, LACMNH 12804, loc. 17134; note branching of trace in left portion of photograph, ×0.5; *9*, LACMNH 12805, loc. 17134, ×0.5. *10*, *Helminthoidichnites* sp., LACMNH 12806, loc. 17132 (NH_4Cl coated), ×1.67. *11*, bilobate trace fossil similar to *Scolicia*, LACMNH 12807, loc. 17133, ×1.5. *12*, group of bilobate trace fossils, LACMNH 12808, loc. 17133, ×2.33.

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APPENDIX

LACMNH locality 17129.—Montgomery Mountains. NW¼, NW¼, sec. 15, T18S, R52E, Mt. Schader 7.5" quadrangle. Large boulder of Stirling Quartzite near head of a SW-trending canyon, 4 km (2.5 mi) SW of ghost town of Johnnie, Nye County, Nevada.

LACMNH locality 17130.—Montgomery Mountains. SW¼, NW¼, SW¼, sec. 11, T18S, R52E, Mt. Schader 7.5" quadrangle. Talus slope on E side of an unnamed wash, 3.4 km (2.1 mi) SW of ghost town of Johnnie, Nye County, Nevada.

LACMNH locality 17131.—Spring Mountains, SW¼, sec. 34, T18S, R54E, Horse Springs 7.5" quadrangle. Talus slope immediately NE of Santa Clara Spring, just W of the approximate border between Nye and Clark Counties, Nevada.

LACMNH locality 17132.—Nopah Range. SE¼, SE¼, SW¼, sec. 11, T20N, R8E, Tecopa Pass 7.5" quadrangle. Talus exposed on N-trending ridge about 2.4 km (1.5 mi) NNE of Noonday Mine, Inyo County, California.

LACMNH locality 17133.—Nopah Range. NE¼, NE¼, NE¼, sec. 14, T20N, R8E, Tecopa Pass 7.5" quadrangle. Exposures along floor of deep W-draining gully, approximately 2 km (1.2 mi) NE of Noonday Mine and 3 km (1.8 mi) W of Mesquite Valley Road, Inyo County, California.

LACMNH locality 17134.—Montgomery Mountains. NW¼, SW¼, SW¼, sec. 11, T18S, R52E, Mt. Schader 7.5" quadrangle. W-facing exposure on E side of incised canyon, 3.3 km (2.0 mi) SW of ghost town of Johnnie, Nye County, Nevada.