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TRILOBITE AND STAR-LIKE TRACE FOSSILS FROM THE WHITE-INYO MOUNTAINS, CALIFORNIA

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ABSTRACT—The trilobite trace fossils present in the Lower Cambrian rocks of the White-Inyo Mountains, California belong to the genera *Cruziana* d'Orbigny (crawling furrows), *Rusophycus* Hall (resting burrows), *Diplichnites* Dawson (walking trackways), and *Monomorphichnus* Crimes (parallel scratchmarks). New species described are *Rusophycus radzanskii* and *Monomorphichnus multilineatus*.

Three star-like trace fossils, comparable to *Asteriacites* Schlothheim, *Astropolithon* Dawson, and *Dactyloidites* Hall, are described from the Lower Cambrian rocks. *Dactyloidites* is interpreted as lobate feeding burrows.

INTRODUCTION

Genus CRUZIANA d'Orbigny, 1842

RUSOPHYCUS Hall, the resting burrows of trilobites, is the most abundant trilobite trace fossil in the White-Inyo Mountains, California (see Alpert, 1975, for locality map). The other genera present, *Cruziana* d'Orbigny, *Diplichnites* Dawson, and *Monomorphichnus* Crimes, are uncommon. The fossils are generally preserved as casts on the underside of beds.

The oldest trilobite trace fossils in the White-Inyo Mountains (*Rusophycus*, *Diplichnites*) occur in the basal quartzite unit of the upper member of the Deep Spring Formation, about 1,500 feet stratigraphically below the lowest trilobite (Text-fig. 1). I consider these trilobite trace fossils to be Early Cambrian in age. Trilobites of the White-Inyo Mountains are illustrated in Nelson & Durham (1966).

The trilobite and star-like trace fossils of the White-Inyo Mountains are described herein. Previously I have described the sea anemone burrows, *Bergaueria* (Alpert, 1973), and *Planolites* and *Skolithos* (Alpert, 1975) from this California section.

All specimens with UCLA numbers are deposited in the invertebrate paleontology collection of the Department of Geology, University of California, Los Angeles.

SYSTEMATIC PALEONTOLOGY TRILOBITE TRACE FOSSILS

The generic synonymies of *Cruziana*, *Rusophycus*, and *Diplichnites* contain the major and important references only. Numerous references, treating one or two particular species or specimens, and not generic concepts, are omitted.

For synonymy before 1842, see Seilacher, 1953b, p. 107.

Cruziana d'ORBIGNY, 1842, p. 30 (not seen); SALTER, 1861, p. 70; SALTER, 1866, p. 291; TROMELIN & LEBESCONTE, 1876, p. 626; SALTER, 1881, p. 482; LEBESCONTE, 1883, p. 466-472; DELGADO, 1885 (not seen); LEBESCONTE, 1887, p. 810-811; MILLER, 1889, p. 115; WALCOTT, 1890a, p. 35-36; WALCOTT, 1890b (*partim*), p. 604; FRITEL, 1925, p. 34-35; YIN, 1932, p. 75-80; PICARD, 1942, p. 9; SAMPELAYO, 1950, p. 151-168; SEILACHER, 1953b (*partim*), p. 107-108; LESSERTISSEUR, 1955, p. 44-47; HÄNTZSCHEL, 1962, p. W189; RADWANSKI & RONEWICZ, 1963, p. 267-269; HÄNTZSCHEL, 1965, p. 27-28; GUBLER, 1966, p. 153; CRIMES, 1968, p. 360-364; SEILACHER & CRIMES, 1969, p. 145-148; CRIMES, 1970a, p. 49; CRIMES, 1970b, p. 111-112, 119-124; ORLOWSKI, RADWANSKI, & RONEWICZ, 1970, p. 350-356; SEILACHER, 1970 (*partim*), p. 454-456; ANDREWS, 1970, p. 62; BIRKENMAJER & BRUTON, 1971, p. 303-310, 313-318; *non* BROMLEY & ASGAARD, 1972, p. 7-13; CRIMES, 1975a, p. 36-37; CRIMES, 1975b, p. 34-39; HÄNTZSCHEL, 1975, p. W55; OSGOOD & DRENNEN, 1975, p. 317.

Cruziana GIEBEL, 1851, p. 115 (misspelling).

Cruziana DAWSON, 1880, p. 46 (misspelling).

Cruciana and *Crucianas* SAMPELAYO, 1915, p. 279 (misspellings).

Cruzianas SAMPELAYO, 1950, p. 148, 149 (misspelling).

Fracna ROUAULT, 1850 (*partim*), p. 729.

Type species.—*Cruziana rugosa* d'Orbigny, 1842.

Description.—Elongate furrows generally preserved as hypichnial casts. Cast consists of two parallel ridges with transverse, oblique, or longitudinal striae or scratchmarks, and a median groove or space between the ridges. Exopodal, genal, and pleural markings may be present in addition to the central endopodal ridges (Seilacher, 1970, text-fig. 3), but do

not occur in the White-Inyo Mountains specimens.

Remarks.—The genus *Rusophycus*, trilobite resting traces, was put into synonymy with *Cruziana* by Seilacher (1970). The two genera are here recognized as morphologically distinct, but related, genera, as is done in other recent works (Crimes, 1975a,b; Häntzschel, 1975; Osgood & Drennen, 1975).

Cruziana in the White-Inyo Mountains.—*Cruziana* is uncommon in the White-Inyo Mountains. It occurs in the Andrews Mountain and Montenegro Members of the Campito Formation, in the quartzite of the Poleta Formation, in the lower Harkless Formation, and in the upper member of the Saline Valley Formation.

The most common form of *Cruziana* consists of two parallel hypichnial ridges, in contact or slightly separated, with closely spaced, fine, transverse or slightly oblique scratchmarks (Pl. 1, figs. 6,9,12). The specimens are about 8 to 15 mm wide, and 15 to 35 mm long; they are the furrowing form of the species *Rusophycus didymus* (Salter, 1856). The cruzianid form of *R. didymus* occurs with and grades into the more common resting form of *R. didymus* (Pl. 1, figs. 9,12). Similar examples are illustrated by Seilacher (1955, p. 358–362, pl. 19, fig. 1) and Lessertisseur (1955, p. 44, text-fig. 25H). The resting forms are shorter, generally deeper, and the two lobes may be parallel or form a V (Pl. 1, figs. 9–13).

If *Cruziana* and *Rusophycus* are to be considered as separate genera not in synonymy, then the morphologic variation within *Rusophycus didymus* warrants placing the cruzianid forms in *Cruziana* and the resting forms in *Rusophycus*. Thus two species are necessary. An additional nomenclatural problem arises in that Salter's *Arenicola didyma* may not be a true *Rusophycus*. Salter (1856, p. 248–249) interpreted *A. didyma* as small U-shaped burrows; *Arenicola didyma* was designated as genotype of *Arenicolites* by Bassler (1915, p. 67; this designation not noted in Häntzschel, 1975, p. W38).

About six good specimens of the cruzianid form of *R. didymus* were collected or observed, in siltstones of the upper Andrews Mountain Member of the Campito Formation and siltstones of the lower Harkless Formation.

Larger but similar forms of *Cruziana*, 12 to 40 mm wide, occur in quartzitic siltstone of the upper Andrews Mountain Member of the Campito Formation (two specimens observed), in quartzite of the middle Montenegro Mem-

ber of the Campito Formation (Pl. 1, fig. 5; only specimen), in quartzite of the upper member of the Poleta Formation (one specimen), in quartzite of the basal Harkless Formation (two specimens,) and in siltstone of the upper member of the Saline Valley Formation (one specimen).

The above *Cruziana* sp. and cruzianid forms of *R. didymus* probably represent "head down plowing" movement of the trilobites (Seilacher, 1970, text-fig. 4).

A single specimen of *Cruziana* (Pl. 1, fig. 4), comparable with *Cruziana rugosa* d'Orbigny, 1842, was collected by Lee Early of Bishop, California, from quartzitic siltstone float of the Andrews Mountain Member of the Campito Formation, in Payson Canyon. The specimen is about 30 to 35 mm wide and 120 mm long. The two low, broad, hypichnial ridges possess strong transverse ridges, 1 to 3 mm wide and 2 to 4 mm apart. The transverse ridges contain series of fine, parallel, nearly longitudinal ridges (casts of scratchmarks), up to 8 on each side; these fine ridges are 0.5 to 1 mm wide and 3 to 6 mm long. The transverse constrictions and the approximately longitudinal, sharp, multi-clawed endopodal markings ally this specimen to the "rugosa group" of *Cruziana* (Seilacher, 1970, p. 462–464), previously known only from Ordovician rocks.

Genus RUSOPHYCUS Hall, 1852

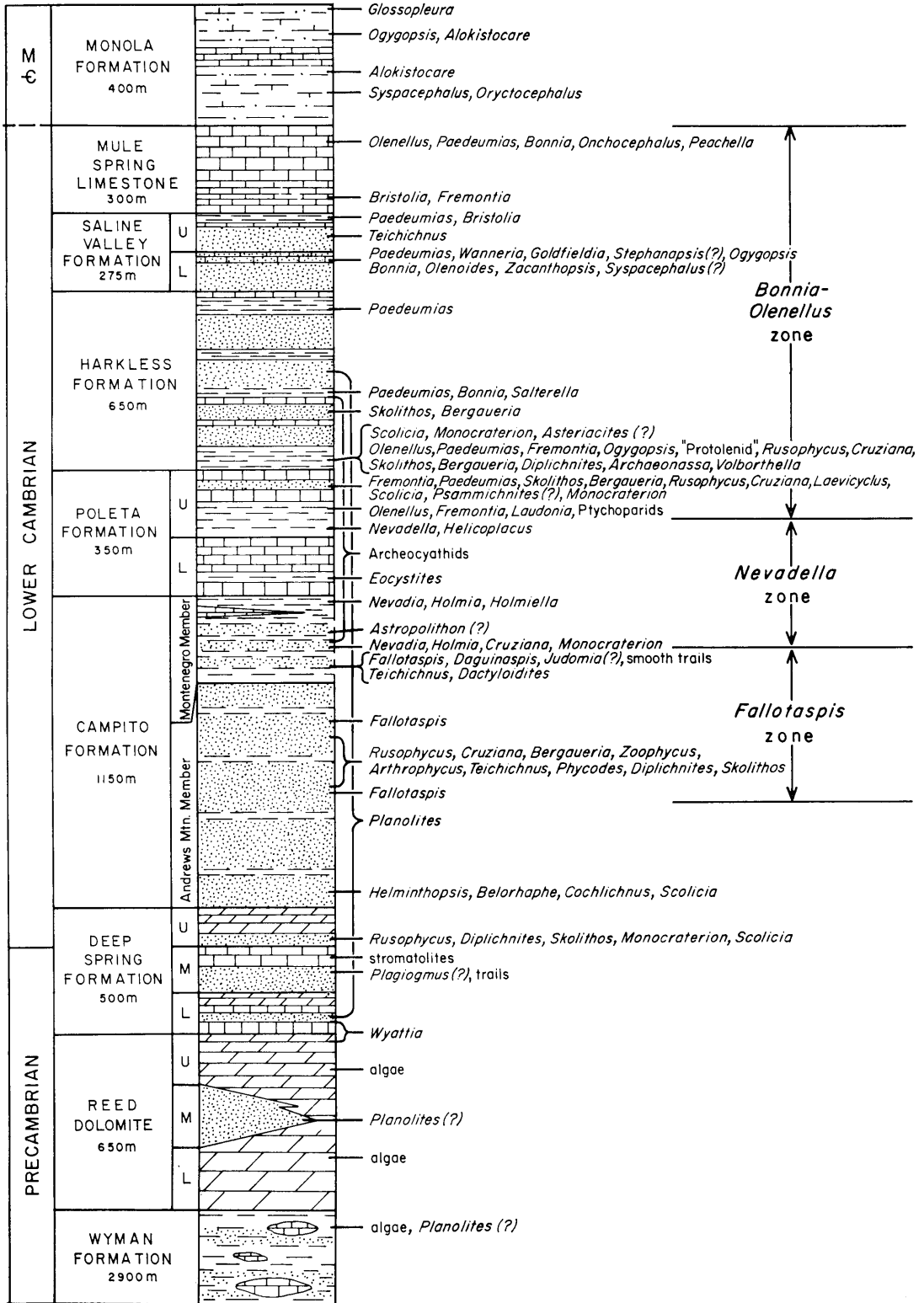
For synonymy before 1852, see Osgood, 1970, p. 301.

Rusophycus HALL, 1852 (*partim*), p. 23, Pl. 8, figs. 1,6, Pl. 9, figs. 1–3; DAWSON, 1864, p. 363–367; JAMES, 1885 (*partim*), p. 153–155; MILLER, 1889, p. 138; SEILACHER, 1959, p. 292–293, text-fig. 4; HÄNTZSCHEL, 1962, p. W212–W214; RADWANSKI & RONIEWICZ, 1963, p. 265–267; HÄNTZSCHEL, 1965, p. 80; KEGEL, 1965, p. 1–11; OSGOOD, 1970, p. 301–305; CRIMES, 1970a, p. 53–57; CRIMES, 1970b, p. 114–116, 119–124; ORLOWSKI, RADWANSKI, & RONIEWICZ, 1970, p. 350–356; ANDREWS, 1970, p. 187; SANTOS & CAMPANHA, 1970, p. 742; ORLOWSKI, RADWANSKI, & RONIEWICZ, 1971, p. 343–346; BIRKENMAJER & BRUTON, 1971, p. 303–313, 318; YOUNG, 1972, p. 14; CRIMES, 1975a, p. 37–41; CRIMES, 1975b, p. 34–35; HÄNTZSCHEL, 1975, p. W101–W102; OSGOOD & DRENNEN, 1975, p. 311–312.

Rhysophycus EICHWALD, 1860, p. 54 (not seen); LINNARSSON, 1869, p. 403–405; SCHIMPER & SCHENK, 1885, p. 54; LESSERTISSEUR, 1955, p. 44–47; HÄNTZSCHEL, 1965, p. 79; GUBLER, 1966, p. 155.

Rhysophycus GOEPPERT, 1860, p. 434; HÄNTZSCHEL, 1965, p. 79; ANDREWS, 1970, p. 186.

Rusichnites DAWSON, 1864, p. 367; DAWSON, 1873, p. 18; MILLER, 1889, p. 566; DAWSON, 1890, p. 595–596; HÄNTZSCHEL, 1965, p. 80.



Russichmites BONNEY, 1903, p. 290 (misspelling).
Rusophycus TROMELIN & LEBESCONTE, 1876, p. 627 (misspelling); LEBESCONTE, 1883, p. 466-472; HÄNTZSCHEL, 1965, p. 81.
Rhizophycus PENEAU, 1946, p. 88 (not seen); HÄNTZSCHEL, 1965, p. 79.
Cruziana d'Orbigny JAMES, 1885, (*partim*), p. 154-157; SEILACHER, 1970 (*partim*), p. 454-456.

Type species.—*Fucoides biloba* Vanuxem, 1842, p. 83, text-figure 11, no. 1.

Description.—Shallow to deep bilobed resting burrows, most commonly preserved as hypichmial casts. Lobes exhibit transverse to oblique, fine to coarse scratchmarks in varied arrangements, and commonly in crosscutting bundles. Overall outline of the resting impression is elliptical, circular, rectangular, heart-shaped, or V-shaped; the lobes may be separated. Lobes generally taper posteriorly. Coxal, exopodal, spinal, cephalic, and pygidial markings or impressions occur in some species (Seilacher, 1970, text-fig. 3), but are not present in the White-Inyo Mountain specimens.

Remarks.—For a review of the morphology, interpretations, and taxonomic history of *Rusophycus*, see Osgood (1970, p. 286-288, 301-305). The biostratigraphic value of *Rusophycus* in earliest Cambrian rocks is discussed by Daily (1972).

The scratchmarks on specimens of *Rusophycus* may be transverse, oblique in one direction, or oblique in two directions (bidirectional scratching, Seilacher, 1970, text-fig. 5c).

Rusophycus in the White-Inyo Mountains.—*Rusophycus* is more common than *Cruziana* in the White-Inyo Mountains. *Rusophycus* occurs in the upper member of the Deep Spring Formation (common), in the Andrews Mountain Member of the Campito Formation (locally abundant), in the quartzite of the upper member of the Poleta Formation (uncommon), and in the lower and middle Harkless Formation (locally abundant).

Bilobed resting traces (Pl. 2, figs. 1-3,5) comparable to *Rusophycus dispar* Linnarsson, 1869 (Linnarsson, 1871, pl. 3, figs. 17,18; Seilacher, 1970, p. 457; Bergström, 1973, p. 53-55) are the most common forms of *Rusophycus* present in the White-Inyo Mountains. The casts are elliptical to heart-shaped, shallow to relatively deep, and possess fine to coarse, transverse to slightly oblique scratchmarks. The

traces are fairly large: 35 to 55 mm wide, 40 to 60 mm long, and 2.5 to 8 mm deep. The scratchmarks are 1 to 2.5 mm wide and commonly are bidirectional.

Although common, these traces are poorly preserved. In many specimens, the surface is partially obliterated by subsequent burrows (*Planolites*) (Pl. 2, figs. 1,3; Alpert, 1973, pl. 1, fig. 11). A somewhat better preserved specimen from the upper Wood Canyon Formation of Death Valley is illustrated (Pl. 2, fig. 3). These California specimens are very similar to specimens illustrated as "*Cruziana rusiformis*" by Orłowski *et al.* (1970, p. 350, 356, pl. 1, fig. a, pl. 2, fig. b), from the Lower Cambrian *Holmia* horizon of the Holy Cross Mountains, Poland. The scratchmarks occur in pairs on the specimens from Poland; paired scratchmarks are present but less discernible on some of the specimens from California.

Smaller specimens (Pl. 2, fig. 2) similar to the above are also present in the White-Inyo Mountains. The casts are 18 to 23 mm wide, 28 to 31 mm long, and 4 to 9 mm deep, with bidirectional scratchmarks, 0.5 to 1 mm wide; they are also poorly preserved.

The large forms of *Rusophycus* cf. *R. dispar* occur in quartzite of the upper member of the Deep Spring Formation (about 9 specimens collected); in quartzitic siltstone of the Andrews Mountain Member of the Campito Formation (locally abundant but poorly preserved; many observed in lower part of *Fallotaspis* Zone, Locality 6104; one specimen collected from lower part of member); and in quartzite of the lower Harkless Formation (locally abundant at Locality 6049; 9 specimens collected, many others observed).

The uncommon small form occurs in quartzitic siltstone in the upper Andrews Mountain Member of the Campito Formation (a few specimens collected and observed), and in the basal Harkless Formation (two specimens).

Another form of *Rusophycus* (Pl. 2, fig. 8), similar to the above but not readily comparable to *R. dispar* is locally abundant in quartzitic siltstone of the upper Andrews Mountain Member of the Campito Formation (lower part of *Fallotaspis* Zone). The resting traces are shallow to relatively deep, are commonly heart-shaped and wider than long, and possess relatively few, blunt transverse scratchmarks. The

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TEXT-FIG. 1.—Stratigraphic section of the Lower Cambrian and Precambrian rocks of the White-Inyo Mountains, California. Stratigraphy, body fossils, and trilobite zonation from C. A. Nelson. Figure courtesy of C. A. Nelson.

specimens are 15 to 30 mm wide, 15 to 25 mm long, and 2 to 6 mm deep. The scratchmarks are 1.5 to 2 mm wide; there are about 7 or 8 per lobe. Preservation is on both hypichnial and epichnial surfaces. About 6 specimens collected; many others observed in field. This form differs from the above *R. cf. R. dispar* in having fewer, coarser, transverse scratchmarks, and a width equal to or greater than the length.

Rusophycus didymus (Salter, 1856) is another common trilobite resting trace in the White-Inyo Mountains (Pl. 1, figs. 9–13), as mentioned above in the discussion of *Cruziana*. This species should be restricted to resting forms only. Two morphological varieties of the resting forms occur: those with two parallel lobes, in contact or separated (Pl. 1, figs. 9, 10, 12, 13), and those with lobes that diverge anteriorly, forming a V (Pl. 1, fig. 11). Both varieties also occur in the Lower Cambrian of the Salt Range of Pakistan (Seilacher, 1955, p. 358–361, text-fig. 5, no. 4–5, pl. 19, fig. 1; see also Seilacher, 1953a, p. 214, pl. 7, fig. 6; Seilacher, 1953b, p. 108–111, text-figs. 4, 5a; Häntzschel, 1962, text-fig. 131.5; Young, 1972, p. 14–15, text-fig. 5; Häntzschel, 1975, text-fig. 63A.1c). The parallel-lobed resting forms are similar to short segments of the cruzianid form of *R. didymus*, but differ in being deeper, especially in the central region.

The parallel-lobed and V-lobed forms possess fine transverse or slightly oblique scratchmarks. The White-Inyo Mountains specimens are 8 to 12 mm wide and 10 to 20 mm long, with the exception of one specimen, 4 mm wide and 5 mm long, on the slab with and parallel to the specimens of Pl. 1, fig. 10.

The resting forms occur in the same horizons cited above for the cruzianid forms of *R. didymus*. About a dozen specimens were collected from each of the two horizons. The V-lobed forms (four collected) are all from the Harkless Formation.

The remaining forms of *Rusophycus*, described below, are uncommon. One specimen (Pl. 2, fig. 4; Cloud & Nelson, 1966, text-fig. 1F), in siltstone of the upper member of the Deep Spring Formation, is a heart-shaped cast of a shallow resting burrow. The specimen is 30 mm wide and 27 mm long, and has fine, transverse, parallel scratchmarks. It occurs with *R. cf. R. dispar* and *Planolites*.

Another specimen, in quartzite of the upper Andrews Mountain Member of the Campito Formation (Pl. 2, fig. 6) is possibly referable to the resting form of *Cruziana fasciculata* Seilacher, 1970 (p. 456–457, text-fig. 7.3). The specimen is 18 mm wide and long, and has bundled, crosscutting, oblique scratchmarks; the obliqueness of the scratchmarks increases posteriorly. There are 6 clawmarks per bundle.

Large, shallow, trilobite resting traces (Pl. 2, figs. 9, 10) occur in quartzitic siltstone of the upper member of the Deep Spring Formation (3 specimens collected). The traces consist of two separated series of fine, transverse scratchmarks which are 10 to 20 mm long and 0.25 to slightly more than 1 mm wide; the two rows of scratchmarks are 15 to 20 mm apart. The specimens are 50 to 60 mm wide, 25 to 50 mm long, and are preserved as epichnial grooves or hypichnial ridges. Morphologically, these specimens are intermediate between *Rusophycus* and the walking trackway *Diplichnites*. They are here placed in *Rusophycus* because

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EXPLANATION OF PLATE I

- FIGS. 1, 2—*Monomorphichnus multilineatus* n. sp. 1, holotype UCLA 49590, Harkless Formation, Loc. 6051, $\times 1$; 2, hypotype, UCLA 49591, upper member, Deep Spring Formation, Loc. 6158, $\times 1.5$.
- 3—*Diplichnites* sp. Hypotype, UCLA 49593, Andrews Mountain Member, Campito Formation, Loc. 6104; specimen uncoated, $\times 1$.
- 4—*Cruziana* sp. Hypotype, UCLA 49595, Andrews Mountain Member, Campito Formation, Loc. 6104, collected by Lee Early; specimen uncoated, $\times 0.6$.
- 5—*Cruziana* sp. Hypotype, UCLA 49596, quartzite, Montenegro Member, Campito Formation, Loc. 6095, $\times 1$.
- 6, 9–12—*Rusophycus didymus* (Salter). 6, cruzianid form, hypotype, UCLA 49597, Harkless Formation, Loc. 6105, $\times 1$; 9, cruzianid and resting forms, hypotypes, UCLA 49598, Andrews Mountain Member, Campito Formation, Loc. 6104, $\times 0.75$; 10, two successive specimens of *R. didymus* (above and below crack), hypotype, UCLA 49599, Harkless Formation, Loc. 6048, $\times 1$; 11, hypotype, UCLA 49613. Enlargement of specimen at lower right of fig. 12, $\times 2$; 12, cruzianid and resting forms, hypotypes, UCLA 49600, Harkless Formation, Loc. 6048, $\times 1$.
- 7—*Diplichnites* sp. Hypotype, UCLA 49592, Harkless Formation, Loc. 6100, $\times 1.5$.
- 8—*Rusophycus* sp. Hypotype, UCLA 49601, Harkless Formation, Loc. 6048, $\times 1$.
- 13—*Diplichnites* sp., in center to center bottom, and *Rusophycus didymus*, upper left and right. Hypotypes, UCLA 49594, Andrews Mountain Member, Campito Formation, Loc. 6141, $\times 0.6$.

