TRACE FOSSILS AND ICHNOFABRICS OF THE LOWER CAMBRIAN WOOD CANYON FORMATION, SOUTHWEST DEATH VALLEY AREA.

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ABSTRACT

New information on trace fossils from the Montgomery Mountains establishes the *Rusophycus avalonensis* Zone within strata of the third parasequence of the lower member Wood Canyon Formation close to the level of the first *Treptichnus pedum*. This places Ediacara-type fossils and trace fossils of the second pre-trilobitic Cambrian trace fossil zone within less than 200 meters of stratigraphic section. Recognition of the *Rusophycus avalonensis* Zone supports correlation of the third parasequence to the Upper Member Deep Springs Formation.

Arthropod-type trace fossils from the upper member Wood Canyon Formation in the southern Nopah Range are identified as rusophyciform specimens of *Cruziana* cf. *pectinata*. *Psammichnites gigas* is identified from the same unit and area.

INTRODUCTION

Cordilleran sections in southern Nevada and eastern California house a thick succession of late Proterozoic to early Paleozoic sedimentary rocks recording rifting and the establishment of a passive continental margin. The upper portion of this succession consists of siliciclastic and minor carbonate rocks deposited in a cratonal to miogeoclinal (most likely passive margin) setting (e.g., Stewart, 1970; Fedo and Cooper, 2001). The appearance and diversification of trace fossils and sparse body fossils within this succession record the major metazoan radiation that occurred close to the Precambrian-Cambrian boundary (Fig. 1). The local Precambrian-Cambrian boundary is constrained by fossils within the lower portion of the lower member Wood Canyon Formation (in the following lmWCF) (Horodyski, 1991; Horodyski et al., 1994; Runnegar et al., 1995; Corsetti and Hagadorn, 2000). A pronounced negative excursion in $\delta^{13}C$ in the lmWCF provides additional support for the position of the Precambrian-Cambrian boundary (Corsetti and Hagadorn, 2000; Corsetti et al., 2000). The lower member Wood Canyon Formation consists of a series of carbonate (dolostone/sandy dolostone) topped siliciclastic packages recognized as parasequences within a highstand systems tract (Prave et al., 1991). Sections of the lower member Wood Canyon Formation that represent a miogeoclinal setting typically contain three carbonates (Stewart, 1970), recognized by Corsetti and Hagadorn (2000) as parasequences 1 to 3. Strata of the first parasequence contain the Ediacara-type fossils *Ernietta plateauensis* and *Swartpuntia* cf. *germsi* (Horodyski, 1991; Horodyski et al., 1994; Hagadorn and Waggoner, 2000) together with casts of tubular fossils tentatively identified as *Cloudina* (Hagadorn and Waggoner, 2000), a form apparently restricted to the latest part of the terminal Proterozoic. Trace fossils of Cambrian type first appear between the second and third carbonate, including *Treptichnus pedum* (Horodyski et al., 1994; Corsetti and Hagadorn, 2000; Hagadorn and Waggoner, 2000), the trace fossil that defines the base of the Cambrian at the GSSP in Newfoundland (Narbonne et al., 1987). The top of the lmWCF is defined by the rather abrupt appearance of coarse pebbly sediment of the middle member Wood Canyon Formation, interpreted as braidplain sedimentation (Fedo and Prave, 1991). The upper member Wood Canyon Formation presents a comparable depositional setting to that of the lower member Wood Canyon Formation (Prave et al., 1991). This unit yields body fossils including olenellid trilobites and diverse trace fossils including *Skolithos* and *Rusophycus*, as well as rare Ediacara-type fossils (Hagadorn et al., 2000).

To date there has been little detailed descriptive information on trace fossils in the lower

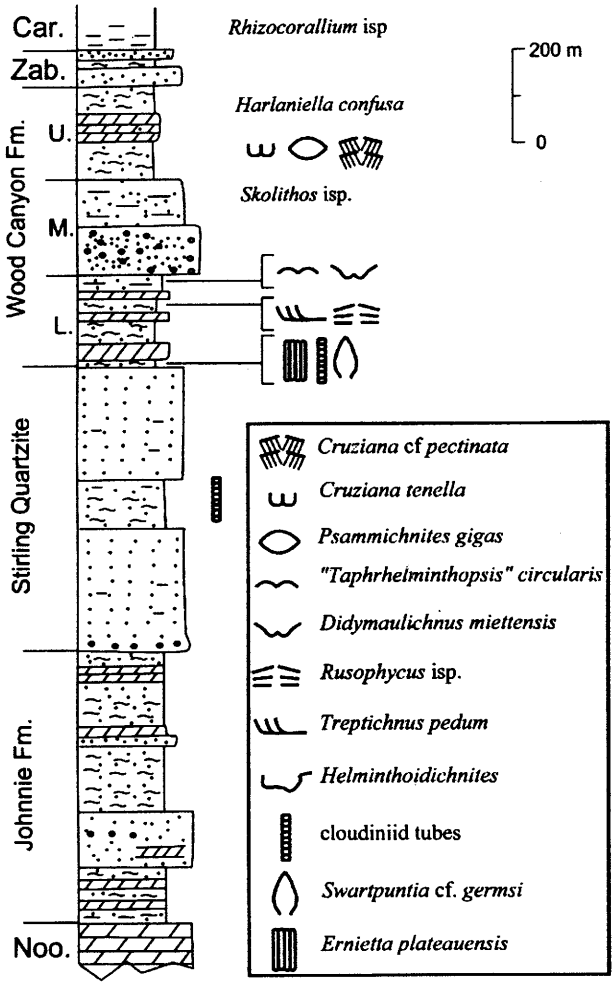


Figure 1. Generalized stratigraphic succession of terminal Proterozoic - Lower Cambrian strata in southern Nevada and eastern California modified from Prave et al. (1991), showing first occurrence of selected trace fossils (this study) and body fossils (Horodyski et al., 1994; Hagadorn and Waggoner, 2000) . The local Precambrian-Cambrian boundary is in the lower member Wood Canyon Formation. The Noonday Dolomite displays features typical of cap carbonates and has been linked to the Marinoan glaciation (ca. 600 Ma) (Prave, 1999; see Corsetti et al., 2000, for alternative view). Abbreviations: Noo. = Noonday Dolomite, Zab. = Zabriskie Quartzite, Car. = Carrara Formation.

member Wood Canyon Formation (Corsetti and Hagadorn, 2000, Fig. 2D; Hagadorn and Waggoner, 2000, Fig. 5:9-12). There is a considerable number of more or less continuous sections of the lmWCF in the Death Valley region but outcrop generally is poor. The purpose of this contribution is to present new information on trace fossils and ichnofabrics

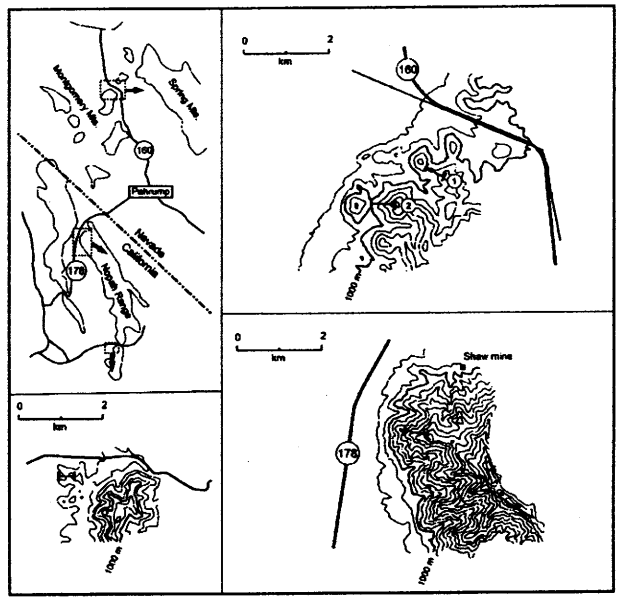


Figure 2. Location of sections of the Wood Canyon Formation discussed in this paper: (A) Generalized map showing location of Nopah Range and Montgomery Mountains. Dashed squares depict areas shown in greater detail in B-D; (B) Location of sections of the lower member Wood Canyon Formation in the northeastern part of the Montgomery Mountains; (C) Location of section of the lower member Wood Canyon Formation in the northern portion of the Nopah Range; (D) Location of section through the upper member Wood Canyon Formation and Zabriskie Quartzite at Emigrant Pass, southern Nopah Range.

in the lower member Wood Canyon Formation that provides improved stratigraphical resolution on the appearance of trace fossils in the lmWCF. The principal information comes from a section in the Montgomery Mountains (Figs. 2, 3) that has particularly extensive exposure of strata between the second and third carbonate. The Montgomery Mountains section (see Burchfiel et al., 1983 for general geological setting) is of particular importance to the biostratigraphy of the lmWCF as it has yielded specimens of Ediacara-type fossils (Horodyski, 1991; Hagadorn and Waggoner, 2000).

Additionally, we present new information on trace fossils in the upper member Wood Canyon Formation from sections in the southern Nopah Range. Numbered specimens are reposited in the invertebrate paleontology collection of the Department of Earth Sciences, University of California, Riverside.

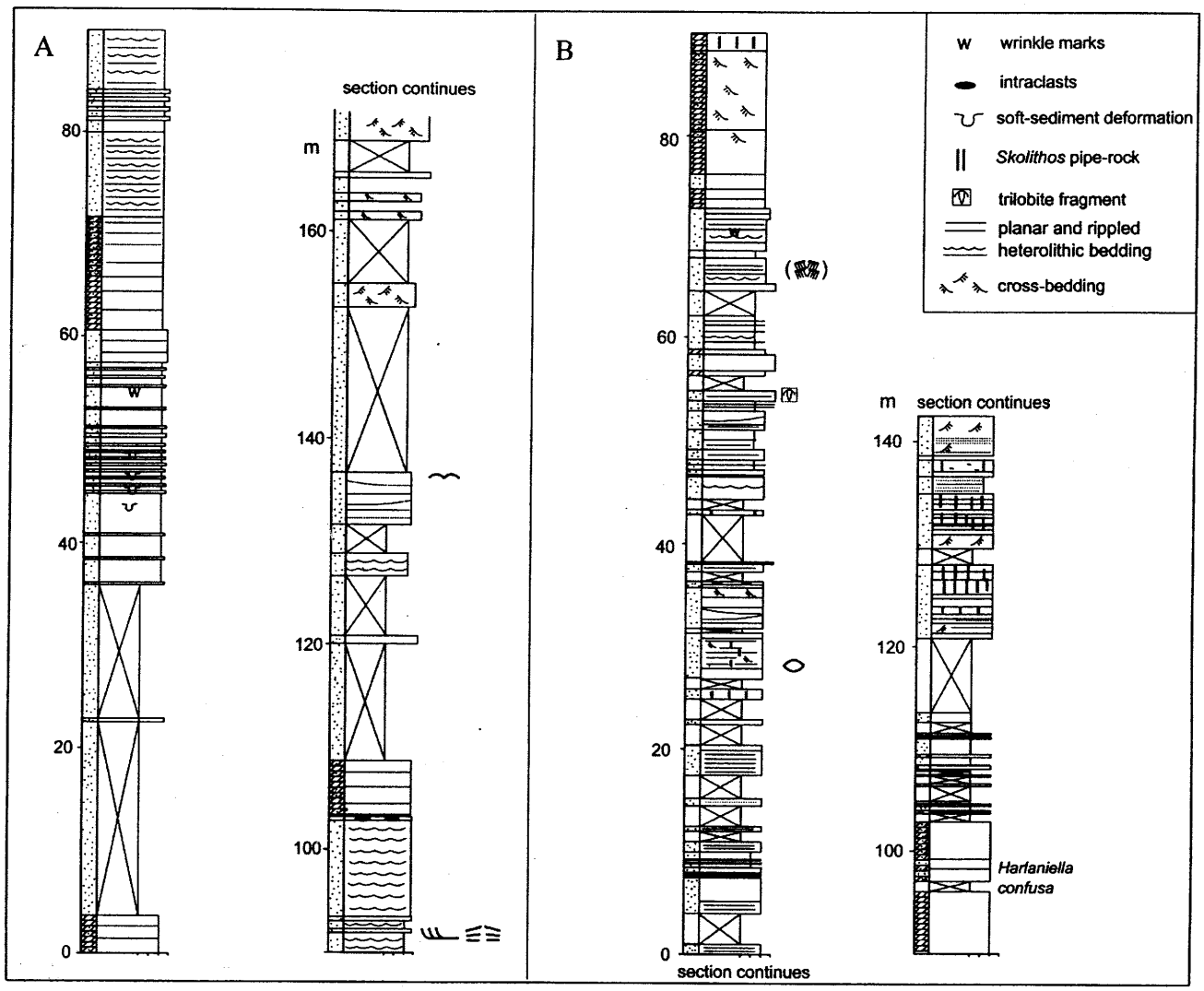


Figure 3. Generalized stratigraphic columns of measured sections of the Wood Canyon Formation. The sections are dominated by siliciclastic rocks (dots) with minor intervals of carbonate (largely dolostone or sandy dolostone) shown by imbricated pattern. Crosses denote poor exposure: (A) Greatly simplified stratigraphic log of the lower member Wood Canyon Formation at Montgomery Mountains section 2, showing position of first appearance of selected trace fossils (see Fig 1 for key). Base of the middle member Wood Canyon Formation is at about 170 metres; (B) Stratigraphic log of the upper portion of the upper member Wood Canyon Formation and lower part of the Zabriskie Quartzite (base at about 105 meters) at Emigrant Pass, southern Nopah Range. Stratigraphic position of selected trace fossils and problematica is marked (see Fig 1 for key). The position for *Cruziana* cf. *pectinata* is not precisely known as described specimens occur in a parallel section to that logged.

LOWER MEMBER WOOD CANYON FORMATION

Discrete trace fossils

Treptichnus pedum first occurs in the upper part of lmWCF (Horodyski et al., 1994), between carbonates 2 and 3 (Corsetti and Hagadorn, 2000). Material from Chicago Pass (Fig. 4A) and Montgomery Mountain section 2 (Fig. 4B) both originate from about 20 meters above the second carbonate (Fig. 3). These specimens show the characteristic closely spaced probes of *Treptichnus pedum.*

Montgomery Mountain section 2 yields the arthropod-type trace fossil *Rusophycus* in strata between carbonates 2 and 3 appearing at

Figure 4A

Figure 4B

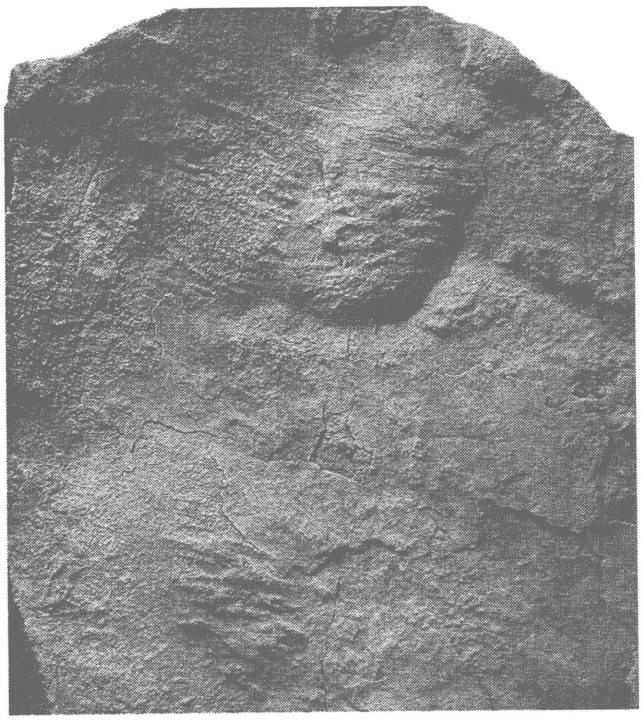


Figure 4C

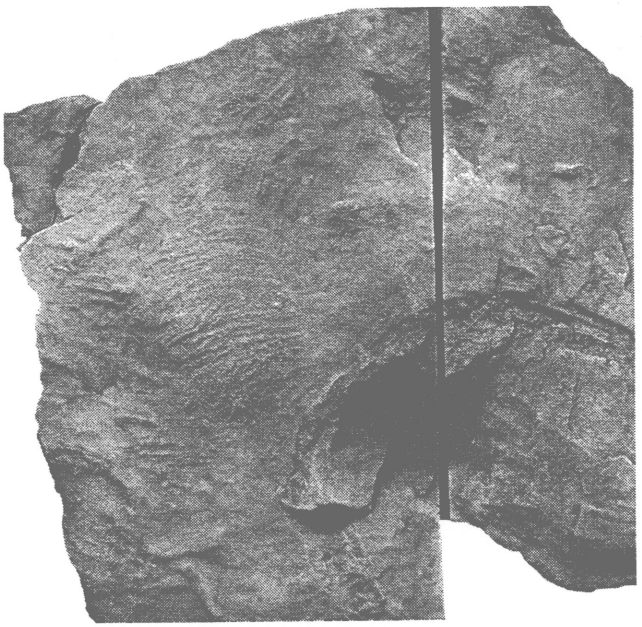


Figure 4D

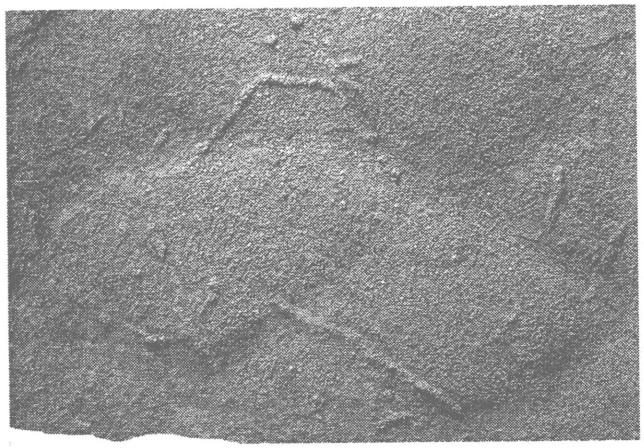


Figure 4E

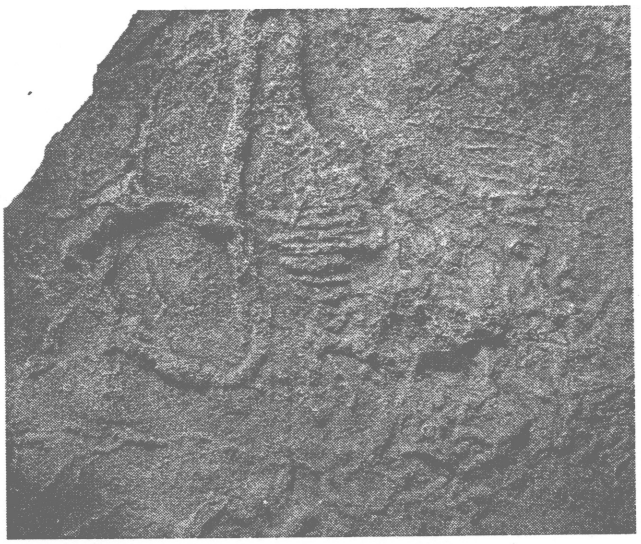


Figure 4F

Figure 4. Trace fossils from the lower member Wood Canyon Formation. All in basal view: (A) *Treptichnus pedum* from section at Chicago Pass, 17 meters above top of middle carbonate, UCR10702/1, X1.8; (B) *Treptichnus pedum* from section 2 at Montgomery Mountains (see Figs. 2, 3), 20 meters above top of middle carbonate, UCR10703/1, X1.8;(C) *Rusophycus* isp., from section 2 at Montgomery Mountains (see Figs. 2, 3), 20 meters above top of middle carbonate. Isolated *Monomorphichnus*-like scratches in lower portion likely are undertrack fall-out of a *Rusophycus*, UCR10703/2, X1.8.; (D) *Rusophycus* isp., from section 2 at Montgomery Mountains (see Figs. 2, 3), 20 meters above top of middle carbonate. Left portion of slab shows a *Rusophycus* with only one well developed lobe. Near top center is a *Rusophycs* consisting of two sets of shallow scratches. Narrow vertical cut runs through a poorly preserved *Rusophycus* (see Fig. 6C), UCR10703/3, X1; (E) Simple horizontal trace fossils about 20 meters below base of middle carbonate in Chicago Pass section, UCR10704/1, X6; (F) *Rusophycus* isp, on loose block from upper part of lower member in section along narrow gorge, just southwest of section 1 at Montgomery Mountains, UCR10705/1, X1.

the same level as *Treptichnus pedum*. These are the first documented occurrences of *Rusophycus* in the lmWCF. Previous reports of arthropod-type trace fossil from the lmWCF consist of *Monomorphichnus* above the third carbonate in offshore sections where there is less incision by the middle member (Corsetti and Hagadorn, 2000). The Montgomery Mountain *Rusophycus* are shallow (< 2mm deep), bilobed or unilobed, with fine straight or gently curved ridges transverse or nearly transverse to the length axis of the lobes (Fig. 4C-F). These *Rusophycus* bear strong resemblance to specimens of *Rusophycus* that Alpert (1976) reported from the Upper Member Deep Springs Formation in the White Mountain area (cf. Fig. 4C with Alpert, 1976, pl.2, fig4; Fig 4F with Alpert, 1976, pl.2, fig.10). Unilobed forms of the type found here typically are assigned to *Monomorphichnus*. However, they are relatively short and identical to individual lobes within co-occurring *Rusophycus*, wherefore they more likely are undertrack fall-out of *Rusophycus*. This is a feature commonly seen in *Rusophycus avalonensis* (Crimes and Anderson, 1985). Species assignment of these simple *Rusophycus* must await a larger collection of material.

Rare *Didymaulichnus miettensis*, large horizontal trace fossils with a smooth bilobed lower surface flanked on either side by inclined lateral bevels, are found above the third carbonate in Montgomery Mountains section 1 and at Chicago Pass (Fig. 5A). This ichnospecies is widely known from pre-trilobite Cambrian strata including British Columbia (Young, 1972), Newfoundland (Crimes and Anderson, 1985), central Australia (Walter et al., 1989), and Mongolia (Goldring and Jensen, 1996). This level also yields trace fossils identical to *"Taphrhelminthopsis" circularis* (Fig. 5B). These are relatively large horizontal burrows with a bilobed upper surface and a prominent central groove. Most reports of Lower Cambrian *"Taphrhelminthopsis" circularis* do not provide information on internal structures or on the morphology of the lower surface. A sectioned specimen from the Montgomery Mountains is not conclusive, but suggests the presence of a central basal sediment string (Fig. 5B). The ichnogeneric assignment of the Lower Cambrian *"Taphrhelminthopsis" circularis* is in some doubt as these may be morphologically distinct from Phanerozoic *Taphrhelminthopsis*; the former occurring in positive epirelief whereas the latter typically are bilobed positive hyporeliefs. Seilacher (1995), Zhu (1997) and Seilacher-Drexler & Seilacher (1999) implicitly or explicitly included the Lower Paleozoic reports of *Taphrhelminthopsis* in *Psammichnites*, interpreting the former as the collapsed upper surface above the actual burrow. This needs further testing and a case by case evaluation. Fedo and Cooper (2001, Fig. 6a) figure a *Taphrhelminthopsis* from an unspecified level of the lower member at Kelso Mountains.

Other conspicuous trace fossils above the third carbonate are essentially horizontal, flatly U-shaped burrows, 3_5 mm wide, with a round to elliptic cross_section. Vertical sections show that some of these specimens have a low poorly developed spreite. Despite this they can be assigned to *Palaeophycus*.

Simple, minute horizontal traces were locally observed between the first and second carbonate in the Montgomery Mountains and Chicago Pass (Fig. 4E). The scarcity of trace fossils may in part be caused by soft-sediment deformation for which evidence is commonly found in this

Figure 5A

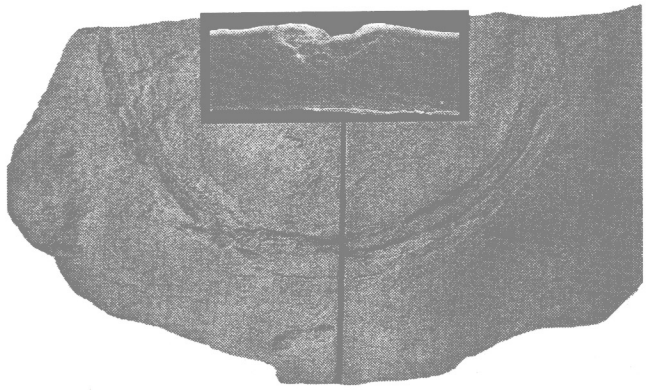


Figure 5B

Figure 5. Trace fossils from the upper part of the lmWCF, Montgomery Mountains: (A) Field photograph with basal view of *Didymaulichnus miettensis* 200 meters above the base of lmWCF, section 1, X0.9; (B) *"Taphrhelminthopsis" circularis* 29 meters above third carbonate view in epirelief, section 2, UCR10706/1, X 0.5. Inset shows polished vertical section of the trace.

Figure 6. Polished sections of cut slabs from the lmWCF. A from Chicago Pass, Nopah Range; B-F from Montgomery Mountains, section 2: (A) Upper part of slab has sharp-based sandstone bed. Lower part show mottled fabric largely created by producer of *Treptichnus pedum* .17.9 m above second carbonate, UCR10702/ 2, X1.4; (B) Slab from upper part of lmWCF with horizontally laminated sandstone. A central zone shows evidence of soft-sediment deformation and possible vertical spreite burrow. Base of slab has a thin mud layer that contains closely packed sand-filled *Palaeophycus*. Collected loose, about 20 meters above third carbonate, UCR10707/1, X1.2; (C) Polished surface along left edge of

interval (Fig. 3).

Ichnofabric

Preliminary results on the ichnofabric reveal broad similarities between the lmWCF and results from earlier studies of earliest Cambrian ichnofabric (Droser et al., 1999; Droser et al., 2002). Beds with *Treptichnus pedum* exhibit small scale mottling (Fig. 6A,C). The extent of sediment mottling (Fig. 6A) is higher than that typically seen in the *Treptichnus pedum* Zone in Newfoundland but is still moderate. As in Newfoundland, the upper surface of sandstone beds thicker than a few centimetres are not disturbed, except for probes that shallowly impinge on the top surface (Fig. 6A-C). Preservation of traces is largely by sand filling open tunnels (see Droser et al., 2002).

A somewhat greater disturbance of primary sedimentary structures is found in the upper part of the lmWCF. This includes the near- sediment surface furrowing of *"Taphrhelminthopsis" circularis* and the passive fill of *Palaeophycus* (Fig. 6B). Sectioned material from below the second carbonate does not show any signs of bioturbation (Fig 6E,F).

Discussion

The new information on the distribution of trace fossils in lmWCF sections in the Montgomery Mountains and the northern part of the Nopah Range makes it possible to compare these sections in greater detail to widely recognized trace fossil based zones, including those of the basal Cambrian stratotype section in Newfoundland (Crimes, 1987; Narbonne et al., 1987; MacNaughton and Narbonne, 1999). Of particular interest is the comparison to pre-trilobitic Cambrian trace fossil based zonation in the Mackenzie Mountains (MacNaughton and Narbonne, 1999), which is directly comparable to that in Newfoundland. Here, the *Treptichnus pedum* Zone is defined by the appearance of branched burrow systems, notably the eponymous taxon. The *Rusophycus avalonensis* Zone is defined by the appearance of the short bilobed arthropod trace fossil *Rusophycus* and *"Taphrhelminthopsis" circularis*. An additional

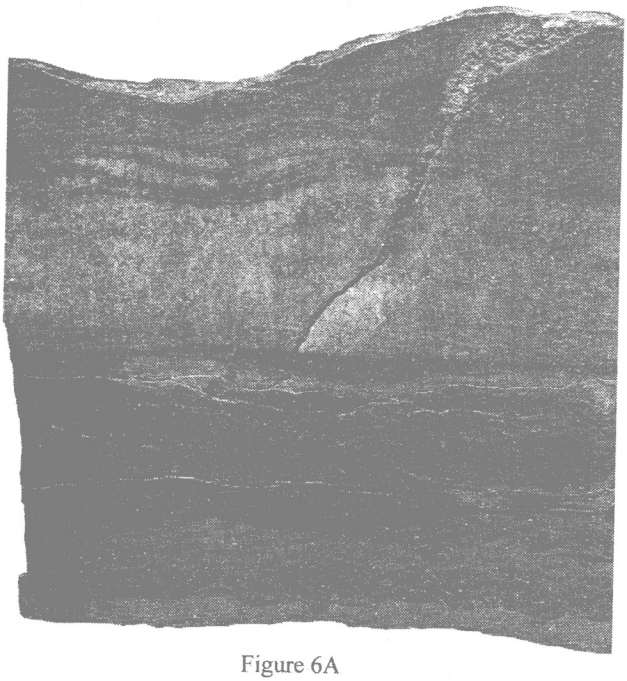


Figure 6A

Figure 6B

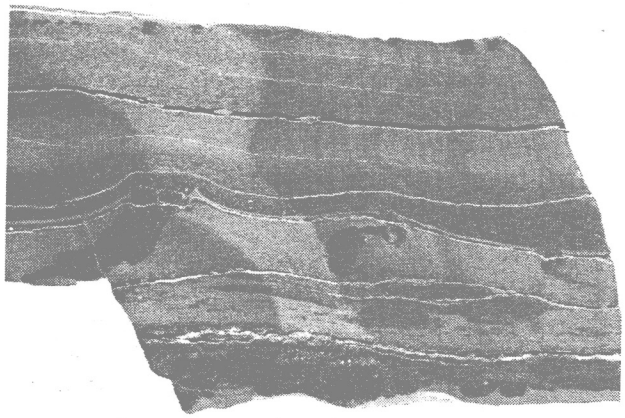


Figure 6C

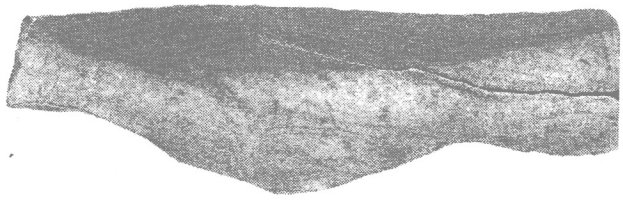


Figure 6D

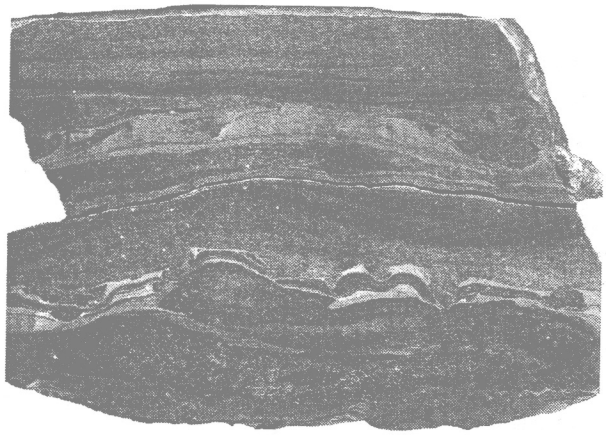
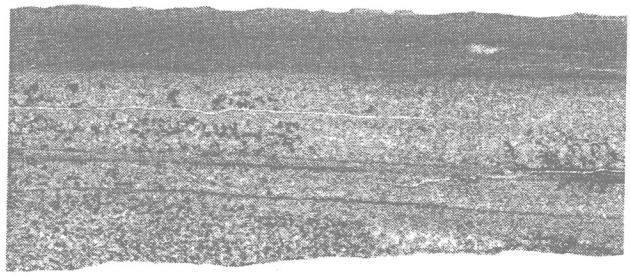


Figure 6E



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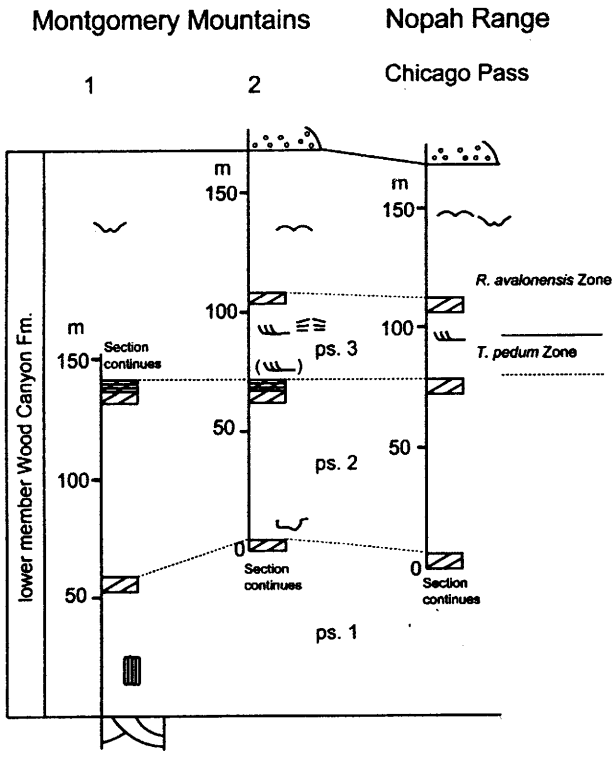


Fig. 7. Comparison of sections in Montgomery Mountain and Nopah Range hung on the top of middle carbonate, showing the distribution of selected trace fossils, and tentative correlation to trace fossil zones in the stratotype section on Newfoundland and the Mackenzie Mountains. Data from this study except for *Treptichnus pedum* marked within parenthesis in section 2, which is based on Hagadorn and Waggoner (2000, p. 350, 355) for the occurrence of *Treptichnus pedum* about 1 meter above the second carbonate in a section about 3 km to the south east of section 2. See Figure 1 for key.

pre-trilobitic zone, *Cruziana tenella* Zone, was recognized by the appearance of the arthropod-produced furrow *Cruziana* and the large back-filled burrow *Plagiogmus arcuatus*. The top of this zone is defined by the base of the *Fallotaspis* Zone.

The finding of *Rusophycus* isp. in strata of the third parasequence at Montgomery Mountains section 2 identifies the *Rusophycus avalonensis* Zone, first defined in the stratotype section in Newfoundland (Narbonne et al., 1987), relatively deep in the lmWCF (Fig. 7).

Rusophycus has not been found at comparable levels in the northern Nopah Range or in the Montgomery Mountains section 1 and has not been reported from other sections of the lmWCF. The most likely explanation is to be found in the superior outcrop of the third parasequence at section 2. In sections globally, *Rusophycus* generally first appear considerably up-section from the first *Treptichnus pedum* (Crimes, 1987). In the Chapel Island Formation in Newfoundland, *Rusophycus avalonensis* appears approximately 250 meters up-section from *Treptichnus pedum*. In the Mackenzie Mountains there is about 100 meters of stratigraphic separation between the base of the *Treptichnus pedum* and *Rusophycus avalonensis* zones. At this preliminary stage of investigation there is no stratigraphic difference in the first appearance of *Treptichnus pedum* and *Rusophycus avalonensis* in the Montgomery Mountains section 2. A down-section extension of the range of the *Treptichnus pedum* Zone, is provided by information from Hagadorn and Waggoner (2000, p. 355), who report *Treptichnus pedum* "approximately 1 meter above the dolomitic top of the middle parasequence" in the Montgomery Mountains in a section 3 km SE of section 2 (Fig. 7). Additional work is needed to document that these represent comparable sections. The second parasequence should be the focus of additional ichnological investigations, though abundant signs of soft-sediment deformation including load casts and intrastratally formed, filled tension cracks (Fig. 6E) may limit the prospects. Nevertheless, the recognition of both Ediacara-type body fossils and the *Rusophycus avalonensis* Zone in less than 200 meters of stratigraphic section attest to the relatively condensed nature of these miogeoclinal sections.

The presence of *Rusophycus* in strata of the third parasequence in the Montgomery mountains adds support to the traditional lithostratigraphic correlation of the third parasequence of the lmWCF to the Upper Member of the Deep Springs Formation in the White-Inyo region, also having chronostratigraphic significance (see Stewart, 1970; Mount et al., 1991; Corsetti et al., 2000). Further work on the distribution of arthropod-type trace fossils in the lmWCF is needed, particularly in more off-shore sections, including detailed documentation of the lowest appearance of *Cruziana*.

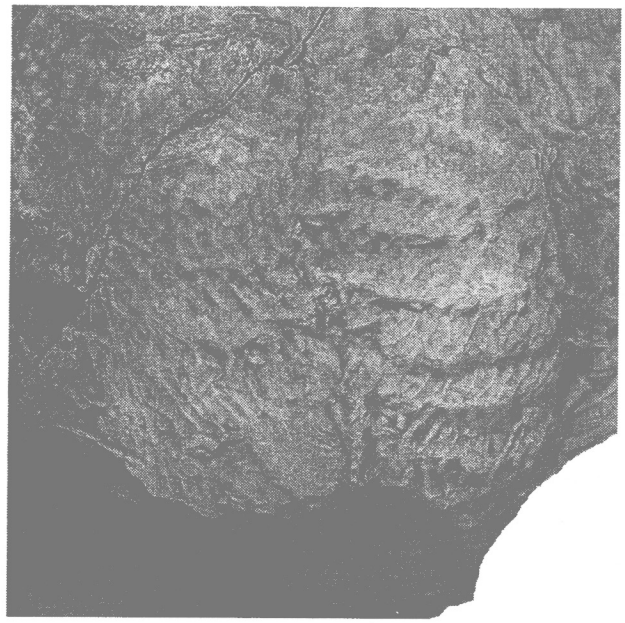
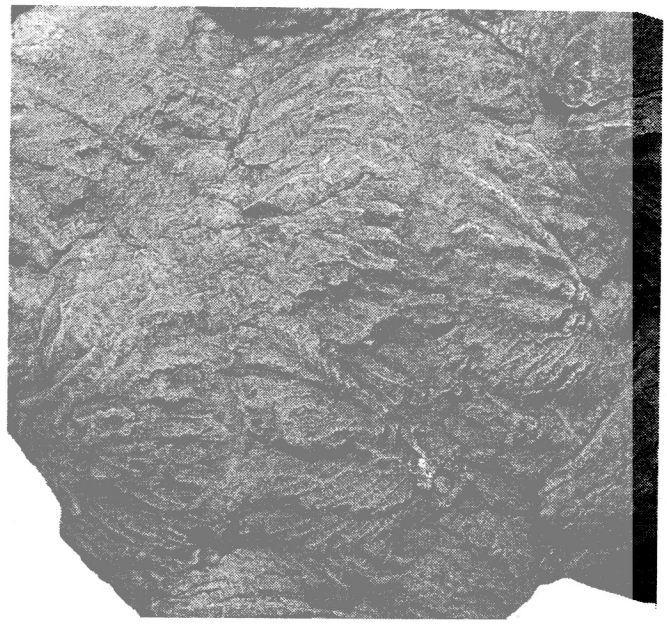


Figure 8A



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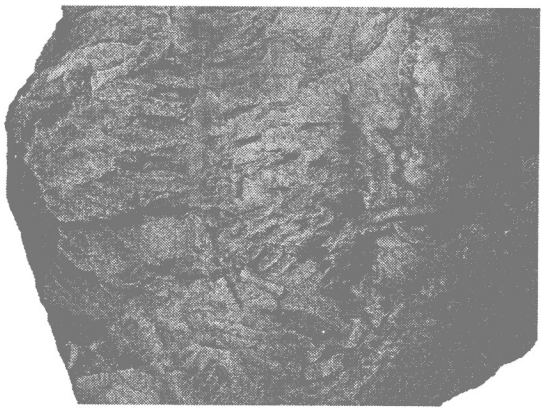

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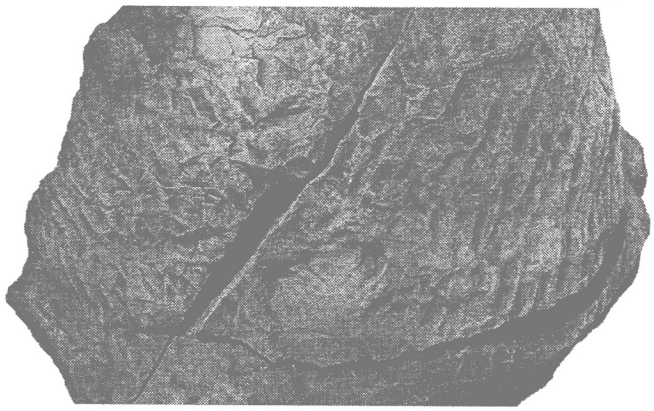
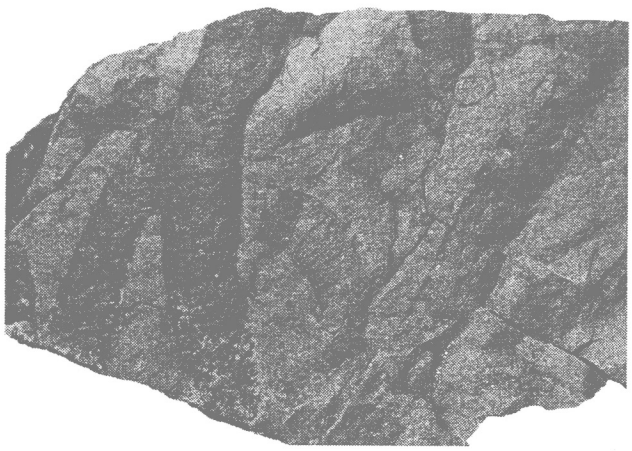


Figure 8D



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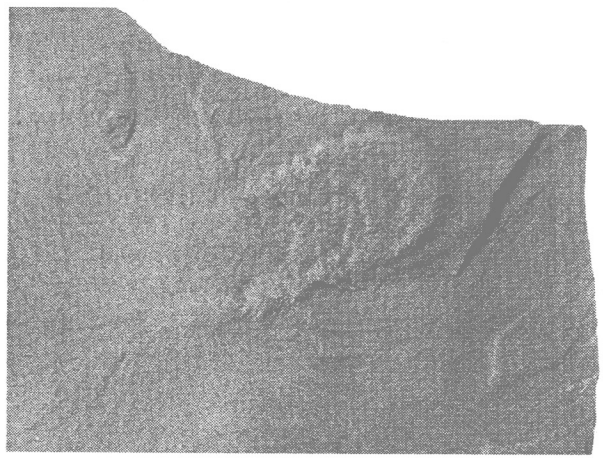

Figure 8F

Figure 8. Trace fossils from the umWCF (A-E) at Emigrant Pass and lowermost part of Carrara Formation (F), Montgomery Mountains (NE1/4, SE1/4,SE1/4, sect. 5, T18S, R52E): (A-D) Hyporeliefs of *Cruziana* cf. *pectinata* with prominent imbricated scratch traces arranged in sets, UCR10710/1-4, all X1; (E) Top view of *Psammichnites gigas*, UCR10711/1, X0.5; (F) *Rhizocorallium* isp. Sand-filled burrows with poorly visible spreite floating in a muddy sediment, UCR10712/1, X1.2.

Figure 9A

Figure 9B

Figure 9. Field photographs of strata near the top of the upper member Wood Canyon Formation at Emigrant Pass with the problematic fossil *Harlaniella confusa*: (A) Note prominent specimen with a nearly vertical orientation. About X0.7; (B) Numerous empty voids confined to a narrow zone. About X0.7.

UPPER MEMBER WOOD CANYON FORMATION

The material described below was collected in sections of the upper member Wood Canyon Formation (umWCF) close to Emigrant Pass, southern Nopah Range (Figs. 2,3).

A discrete bed yielded a number of large *Rusophycus* with a distinctive claw pattern (Fig. 8A-D). These specimens possess multiple scratch traces with up to 9 claw marks in each set. In the posterior portion of the trace, opposing sets extend towards the midline at a low angle (Fig. 8A,D); in more anterior portions of the trace the sets have a more obtuse angle to the mid-line (Fig. 8B,C). The distal portions of each successively more anterior set is more deeply depressed, resulting in pronounced steps along a longitudinal profile of the trace.

The overall appearance of these traces is similar to *Cruziana rugosa*, a form that in the Gondwanan Paleozoic is restricted to the Lower Ordovician (Seilacher, 1970, 1994). The stratigraphic applicability of ichnospecies of *Rusophycus* and *Cruziana* is based on distinctive features of claw pattern and instrumentation that have formed the basis for a *Cruziana* based stratigraphic scheme for the Gondwana realm (Seilacher, 1970, 1994). Comparable stratigraphic schemes have not been developed for Laurentia (Seilacher, 1994). However, Laurentian Lower Cambrian *Cruziana rugosa* homeomorphs were previously described and discussed from Greenland (Bergström and Peel, 1988) and Alberta, Canada (Magwood and Pemberton, 1990). Seilacher (1994) found the *Cruziana rugosa*-like forms from Canada to differ from Ordovician *Cruziana rugosa* and erected the new species *Cruziana pectinata*. The principal differences are in a medial zone with stronger scratch traces, thought to be made by the inner leg branch, meeting the mid-line at a wider angle than the comb-like ridges, thought to be made by the outer leg branch. In *Cruziana rugosa*, comb-like scratch sets meet in the medial area. The distinction between scratches of the inner and outer leg branch in trilobite-type trace fossils is, however, problematic (see Jensen, 1997), and the morphological differences do not necessarily represent the employment of different equipment. *Rusophycus marginatus* from the Lower Cambrian of Greenland (Bergström and Peel, 1988) is broadly similar but has pronounced and often repeated

imprints of the cephalic margin and also appears to have more delicate scratch traces. The specimens from the umWCF are tentatively identified as rusophyciform examples of *Cruziana* cf. *pectinata*.

The rusophyciform *Cruziana* cf. *pectinata* are preserved at the base of a quartzitic sandstone with no obvious break between the sediment casting the trace and the overlying bed. The preservation of this type of trace fossil on the base of relatively thick-bedded sand is a much debated problem relating to whether the trace was an open depression on the sea-floor or was formed intrastratally (see Droser et al., 1994). The same problem also relates to *Rusophycus* isp. observed also in the Zabriskie Quartzite (Fig. 3). In these the *Rusophycus* are preserved at the base of amalgamated sands. A sectioned specimen of *Rusophycus* from the lmWCF (Fig. 6D) also is inconclusive with respect to the trace forming intrastratally or as an open surface structure.

Specimens of *Psammichnites gigas* occur in the upper member Wood Canyon Formation at Emigrant Pass (Fig. 8E). This trace fossil has a wide distribution in Cambrian strata, typically occurring in late Early Cambrian strata, where it locally may be of stratigraphic utility (Álvaro and Vizcaïno, 1999). *Psammichnites* is problematic in that it is a rather complex trace and that the preserved morphology will be influenced by preservational conditions (Seilacher and Seilacher-Drexler, 1999). Nevertheless, the material at hand is greatly similar to the type material of *Psammichnites gigas* from the Lower Cambrian of southern Sweden (see Álvaro and Vizcaïno, 1999, Pl.1:1).

Other trace fossils in the umWCF include small (2-3mm wide) bilobed traces with weak transverse ornamentation closely similar to *Cruziana tenella* (see Jensen, 1997). Densely packed cylindrical unbranched vertical burrows (i.e *Skolithos* Pipe-rock) first appear near the top of the mmWCF, occur in beds of the umWCF, but is particularly common in the overlying Zabriskie Quartzite (Fig. 3), which is one of the classic strata for Lower Cambrian piperock (Droser, 1991).

More problematic are elongate structures with a distinct transverse ornamentation described by Signor (1994) as the trace fossil *Harlaniella confusa*. These occur in great profusion in a few beds near the top of the umWCF (Fig. 9). The shape of the surface ornamentation is not consistent with a spiral movement of an animal through the sediment. It remains problematic whether this is a trace fossil or a body fossil, and its relation to the similarly problematic terminal Proterozoic *Harlaniella* also is unclear.

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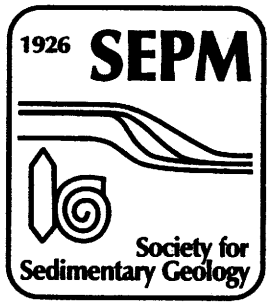

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