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The Early to Middle Ordovician graptolite faunal succession of the Trail Creek region, central Idaho, U.S.A.

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ABSTRACT

The Middle Ordovician graptolite biostratigraphy of the Trail Creek region of Idaho is reviewed and revised. The oldest known fauna belongs to the *Didymograptellus bifidus* Biozone. The *Isograptus victoriae lunatus, I. victoriae maximodivergens, Oncograptus, Undulograptus austrodentatus* and *Holmograptus lentus* Biozones can be differentiated. *Pseudophyllograptus archaios* (Braithwaite) is found for the first time in the Trail Creek region. This species represents a conspicuous North American mid-continent faunal element and enables the correlation of the endemic *P. archaios-C. flexilis* Biozone of Utah with the *D. bifidus* Biozone of the Pacific faunal realm, thus, providing an important tool for the correlation of endemic mid-continent faunas with the pandemic deep water graptolite faunas.

KEYWORDS | **North America. Ordovician. Arenig. Graptolites. Biostratigraphy.**

INTRODUCTION

Since its detailed documentation by Carter and Churkin (1977) and Dover et al. (1980) the Ordovician graptolite succession contained in the Phi Kappa Formation of the Trail Creek region in central Idaho is generally considered to be one of the most complete in North America. Carter and Churkin (1977) established a set of Ordovician and Lower Silurian graptolite zones in the Phi Kappa and noted that one section, the Trail Creek Summit section, was a potentially useful reference section for the southern part of the North American Cordillera. Subsequently, the Trail Creek Summit section was used as a North American standard for Ordovician graptolite biostratigraphy, rivaled in importance only by the succession in the Marathon region of west Texas (Berry, 1960). Extensive new graptolite collections from the Trail Creek summit section has provided significant new information on species occurrences and ranges, and necessitated a revision of the biostratigraphic data provided by Carter and Churkin (1977) and Dover et al. (1980). Mitchell et al. (2003) provided a preliminary revision of the graptolite succession from the Trail Creek Summit section, but primarily focused on the Upper Ordovician faunas. In this paper we present a revision of the Middle Ordovician part of the graptolite sequence from the Trail Creek region.

In the Trail Creek region, the Phi Kappa Formation comprises more than 200 meters of highly tectonized black shale, argillite, and quartzite with minor carbonate intercalations. The strata are considerably disturbed by faulting and folding, and the graptolite faunas are commonly tectonized. The specimens are preserved as flattened remains of organic periderm, which are often highly fragmented by the tectonic distortion, and surrounded by extensive growth of pressure shadow minerals, masking their original size and shape. Nevertheless, important characteristics are still visible and allow for confident specific determination of most graptolite specimens.

The Trail Creek Summit reference section is only one of a number of localities in the Trail Creek region that yield graptolites. The faunas of the region were described and illustrated by Carter and Churkin (1977) and Dover et al. (1980), and although their zonation is based mainly on two localities, the Trail Creek Summit section and the Little Fall Creek section, it was also supported by numerous spot collections. Our revisions are based on a re-evaluation of the Carter and Churkin (1977) and Dover et al. (1980) material as well as significant new collections made by D. Goldman, H. Janousek and M. Cone during the summer of 2001.

GEOLOGICAL SETTING

The Trail Creek Summit section is situated in the northern Pioneer Mountains of central Idaho (Fig. 1). The area exhibits some complex regional tectonics (Dover et al., 1980). Thrust faults distort the succession of the Phi Kappa and Trail Creek Formations, produce repetitions and make the identification of uninterrupted stratigraphic successions difficult. Internally the thrust slices, however, show enough stratigraphic continuity to establish a biostratigraphic succession. The redefined Phi Kappa Formation (Dover et al., 1980) consists of graptolite-bearing black shales and argillites, and is locally strongly silicified. Quartzite beds occur in the Phi Kappa Formation and a distinct unit at the base is differentiated as the Basin Gulch Quartzite Member.

In the Trail Creek Summit section, the graptolitic succession starts above the Park Creek Thrust and within the Basin Gulch Quartzite member (Dover et al., 1980), an up to 60 meter-thick quartzite unit of limited areal distribution. Graptolite faunas from the Basin Gulch Quartzite member include *Didymograptellus bifidus* (Carter and Churkin, 1977), which is also prominent in a number of levels above the top of the quartzite (Fig. 2).

Dover et al. (1980: collection D2597 CO) describe a fauna from 2.1 m above the top of the quartzite, bearing *Isograptus victoriae lunatus*. Carter and Churkin (1977) referred their sample 621Cn 485 (2.5 meters above the top of the Basin Gulch) to their *Isograptus* Zone, based on the presence of a number of isograptids including *I. victoriae lunatus* and *I. victoriae maximodivergens*, but did not figure any of the specimens. The frequent occurrence of a pendent didymograptid, most likely to be *D. bifidus*, in the sample suggests the inclusion in the *D. bifidus* Biozone, but the fauna of this sample needs to be re-evaluated, as fragmented reclined tetragraptids have frequently been misidentified as isograptids.

Faunas from the *Isograptus victoriae maximodivergens* Biozone were first mentioned by Mitchell et al. (2003) and are illustrated herein. They are similar in composition to the Cow Head Group faunas of western Newfoundland (Williams and Stevens, 1988). The faunas invariably bear a rich assemblage dominated by isograptids and pseudisograptids.

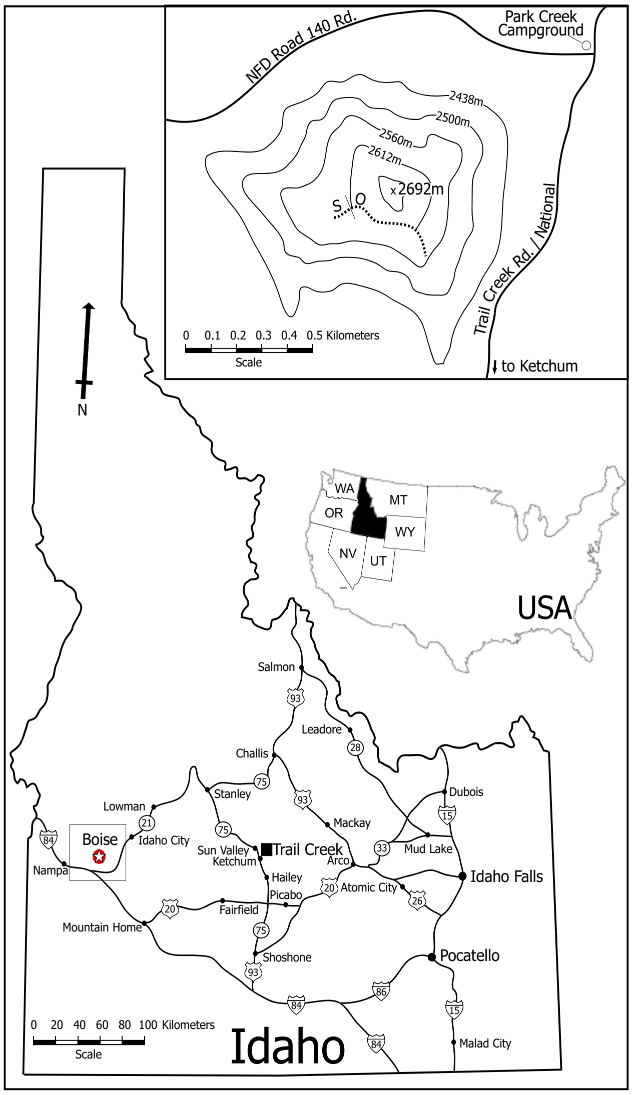

FIGURE 1 | **Location of the Trail Creek Summit section, central Idaho.**

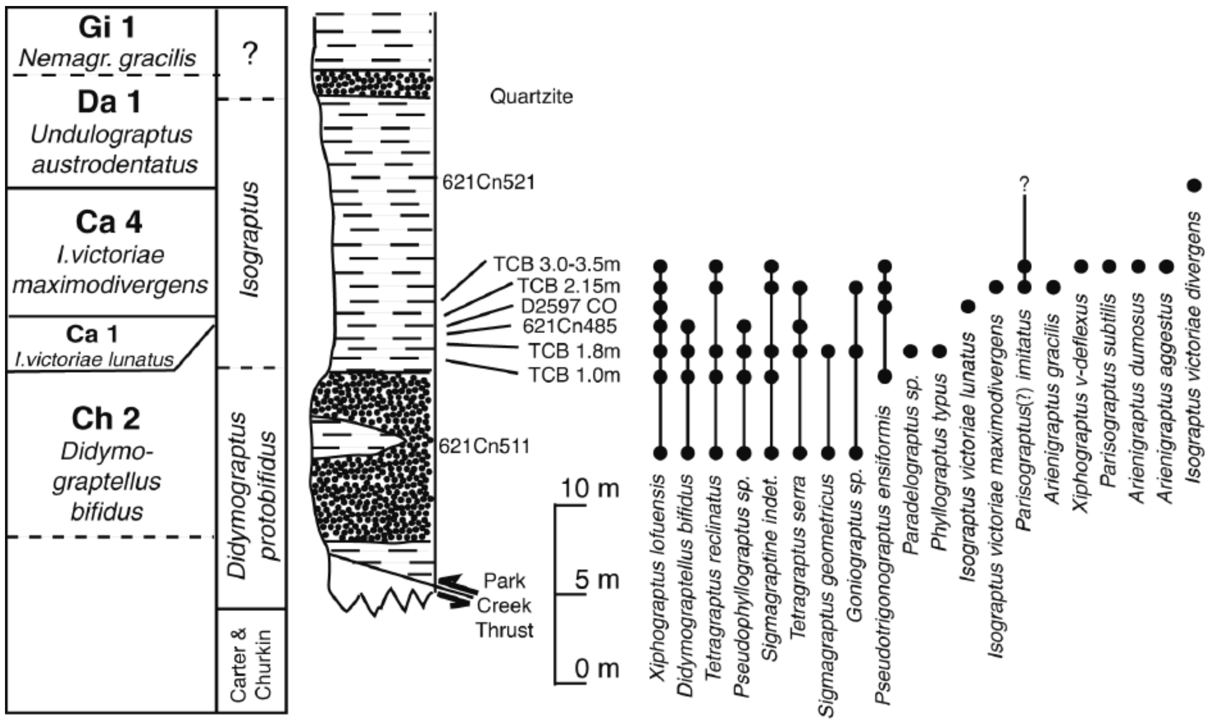

FIGURE 2 **Graptolite range chart of the Middle Ordovician of the Trail Creek Summit section, showing the original biozonation of Carter and Churkin (1977) and the revised zonation (left).**

Darriwilian graptolites are documented by Carter and Churkin (1977) from sample 621Cn521, 10.5 meters above the top of the Basin Gulch Quartzite, and referred to their *Isograptus* Biozone. The sample bears a few isograptids of which a typical juvenile example of the early Darriwilian *Isograptus victoriae divergens* was illustrated (Carter and Churkin, 1977: pl. 1, fig. 6).

Faunas younger than Darriwillian 1 are unknown from the Trail Creek Summit section and the next fossiliferous sample at approximately 30 meters above the Basin Gulch contains faunas of the Upper Ordovician *Nemagraptus gracilis* Biozone (Mitchell et al., 2003). Thus, a considerable time interval is apparently missing in the Trail Creek section. The reason for this faunal gap is uncertain and may either be collection failure due to poor preservation and unsuitable lithologies or structural complications of the section by which this interval is cut out.

Interesting and biostratigraphically important graptolite faunas were found outside the Trail Creek Summit section by the junior authors in 2001. Two faunas (samples TCA 1.0 m, TCA 1.7 m) originate from a location a few tens of meters southeast of the main section. The material comes from a shale interval within the upper part of the Basin Gulch Quartzite member. The lower sample TCA 1.0 m bears a rich fauna of the *D. bifidus* Biozone including its index species. The surprising occurrence of *Pseudophyllograptus archaios* (BRAITHWAITE) in sample TCA 1.7 m is the first record of this species from outside its type locality at Skull Rock Pass, Utah (loc. 11 of Braithwaite, 1976) and the first record of this species in an assemblage bearing a biostratigraphically useful graptolite fauna. It enables the correlation of the *P. archaios* Biozone of Braithwaite (1976) from the shallow water and highly endemic graptolite succession of Utah and Nevada with the standard deep-water succession of the Pacific graptolite faunal realm typical of most parts of North America.

GRAPTOLITE BIOSTRATIGRAPHY

As demonstrated above, the graptolitic succession of the Lower to Middle Ordovician is relatively incomplete in the Trail Creek Summit section. A more complete graptolitic succession (Fig. 3) can be pieced together from the faunal record of the region as documented by Carter and Churkin (1977), Dover et al. (1980), Ross and Berry (1963) and supplemented by our new data.

Carter and Churkin (1977) indicated the *Didymograptus bifidus* Biozone to be the oldest recognizable graptolite zone of the region, based on a single sample. According to Dover et al. (1980), the oldest fauna found in a section also belongs to the *D. bifidus* Biozone. However, the authors mention older faunas of Berry's (1960) zones 2-5 from a number of samples (Dover et al., 1980, p. 11). These are based on fragments of multiramous dichograptids, identified as *Clonograptus*, *Dichograptus*, ?*Kinnegraptus* and others. Although multiramous forms are common in the mid- to late Arenig other biostratigraphically indicative forms are lacking altogether, and these records cannot prove the presence of faunas older than the *D. bifidus* Biozone in the region. Hence, the oldest proven age for the rocks of the lowermost part of the Phi Kappa Formation, remains the *D. bifidus* Biozone.

Didymograptellus bifidus Biozone

The *D. protobifidus* Biozone of Carter and Churkin (1977) is here renamed the *D. bifidus* Biozone. Williams and Stevens (1988) discussed the validity of *Didymograptus protobifidus*, a species described from the late Arenig to early Llanvirn of Britain. The species is not related to *D. bifidus*, and the type material includes specimens of *Aulograptus climacograptoides* (= *A. cucullus*, see Maletz, 1997b) of early Darriwilian (Da 1-2) age. *D. protobifidus* belongs to the *Didymograptus artus*/*murchisoni* complex of "Llanvirnian" or Darriwilian 2-4 age, found to be restricted to the Atlantic faunal realm (Cooper and Fortey, 1982; Maletz, 1994). The genus *Didymograptus* s. str. is not phylogenetically related to the Pacific Realm pendent didymograptids of the genera *Didymograptellus* (COOPER and FORTEY, 1982) and *Yutagraptus* (RIVA, 1994). North American identifications of *D. protobifidus, D. murchisoni, D. geminus* and other Atlantic province faunal elements (e.g., Ruedemann, 1947; Decker, 1944; Berry, 1970) are based on erroneous correlation of the *D. bifidus* Biozone of North America (Chewtonian 1-2) with the *D. bifidus* (now *D. artus*) Biozone (Darriwilian 2-3) of Britain by Berry (1960), followed by many subsequent authors. The correct correlation, already suggested by Thomas (1960) and verified by Cooper and Fortey (1982), has long been ignored. *D. bifidus* Biozone faunas are commonly recognized in the Trail Creek area and important faunal elements are figured by Carter and Churkin (1977) and Dover et al. (1980).

Isograptus victoriae lunatus Biozone

The *I. victoriae lunatus* Biozone is present in sample D2597 CO of Dover et al. (1980). The authors recognized four species from this sample (*I. victoriae victoriae*, *I. v. lunatus*, *Amplexograptus* sp., *Didymograptus* cf. *D. nicholsoni planus*). Two small specimens of *I. victoriae lunatus* were illustrated by Dover et al. (1980, pl. 5, figs. 1,8), but the identification of *I. victoriae victoriae* in the sample remains doubtful. The figured specimen (Dover et al., 1980, text-fig. 11) represents a fragmented tetragraptid of *Tetragraptus serra* type. It does not show the typical isograptid symmetry and its stipes increase in width from the proximal end instead of tapering. The specimens of *Amplexograptus* sp. are re-identified as specimens of *Pseudotrigonograptus* sp., a typical Middle Ordovician (Castlemainian to early Darriwilian) genus, whereas *D.* cf. *D. nicholsoni planus* specimens represent *Xiphograptus lofuensis*. Castlemainian examples of this species often show a proximally slightly declined to deflexed rhabdosome, but can be recognized by the typical dorsal virgellar spine (Williams and Stevens, 1988). The fauna of sample D2597 CO, therefore, can be re-assigned to the *I. victoriae lunatus* Biozone.

Isograptus victoriae victoriae Biozone

Even though Dover et al. (1980) identified specimens of *I. victoriae victoriae*, these identifications and, hence, the age of the sample is not considered by us to be reliable. The authors illustrated two specimens of which one is a tetragraptid. The second specimen (Dover et al., 1980, pl. 4, fig. 2) comes from sample D2516c CO. It is associated with *Glossograptus* sp. cf. *G. acanthus*, indicating an early Darriwilian age. The specimen is poorly preserved and may also represent a reclined tetragraptid. The close-by samples D2516a+b include Yapeenian to early Darriwilian faunas with *Pseudisograptus manubriatus* and *Cardiograptus*, but no biserials. Carter and Churkin (1977) illustrated a specimen from the *D. bifidus* Biozone as *I.* aff. *I. victoriae*. The specimen is here identified as a two-stiped reclined tetragraptid (?fragmented) of *T. serra* type. The presence of graptolites from *I. victoriae victoriae* Biozone is not confirmed in the Trail Creek region, but because the zone represents a fairly short time interval and the rocks are structurally complicated, its absence could be due to collection failure.

Isograptus victoriae maximus Biozone

The *Isograptus victoriae maximus* Biozone is not recognized in the region. Mitchell et al. (2003) used *Arienigraptus hastatus* to differentiate that interval from the *I. victoriae maximodivergens* Biozone and stated that only in the latter do the pseudisograptids of the genus *Arienigraptus* become more prominent and diverse. The *I. victoriae maximus* Biozone appears to represent a short time interval as it has been documented previously in few regions including Australasia (VandenBerg and Cooper, 1992) and western Newfoundland (Williams and Stevens, 1988).

Isograptus victoriae maximodivergens Biozone

Typical faunas of the *I. victoriae maximodivergens* Biozone have not been described in detail from the Trail Creek region, even though a number of isograptids that were identified originate from this interval. Carter and Churkin (1977, pl. 7, fig. 1) illustrated *Arienigraptus tau* as the only figured specimen from sample 621Cn491 in

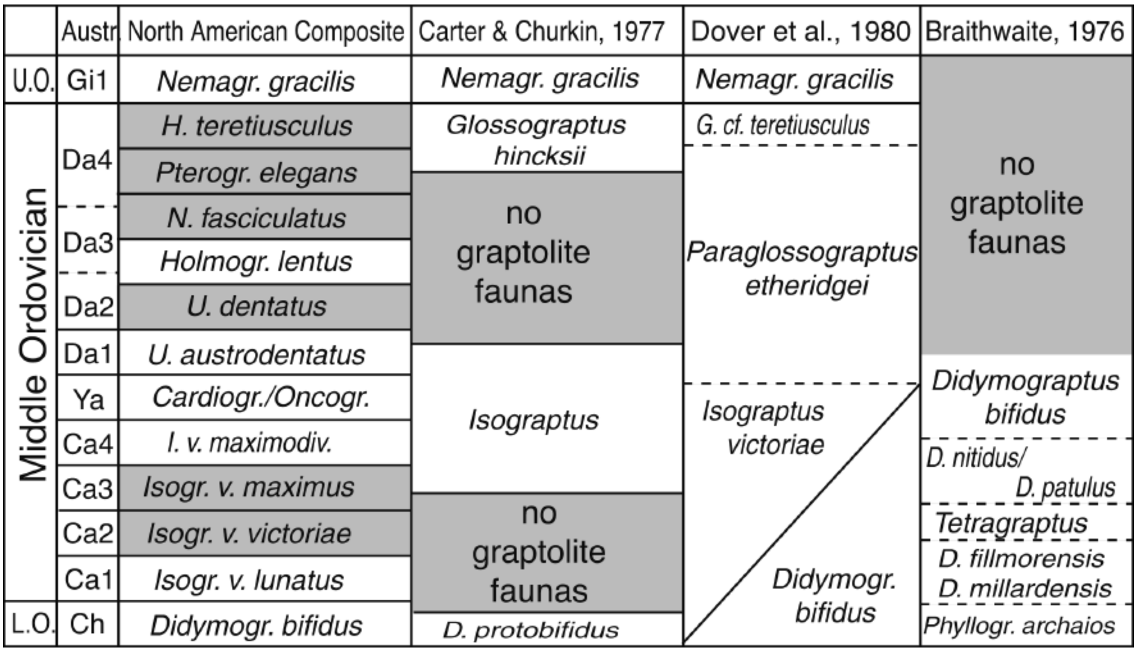

FIGURE 3 **Middle Ordovician graptolite biozonations of Carter and Churkin (1977) and Dover et al. (1980) for Trail Creek, Idaho; Braithwaite (1976) for Utah, and composite zonation for North America (Williams and Stevens, 1988; Maletz, 1997; Albani et al., 2001). Biozones shaded in gray are not recognized in the Trail Creek succession. The Chewtonian 1 and 2 intervals are not differentiated.**

the Little Fall Creek section. The faunal list indicates the *I. victoriae maximodivergens* Biozone.

Dover et al. (1980) identified *I. caduceus australis* in sample D2693a, associated with *Undulograptus austrodentatus*. The material belongs to the early Darriwilian species *Parisograptus caduceus caduceus* (MALETZ and ZHANG, 2003). Specimens identified as *I. caduceus imitatus* (Dover et al., 1980, pl. 3, fig. 3; pl. 5, figs. 5, 6) can also be referred to *P. caduceus caduceus*. This species is common in eastern North America where it indicates a *U. austrodentatus* Biozone age (Maletz, 1997a).

Two new samples cover the *I. victoriae maximodivergens* Biozone (TCB 2.15 m, TCB 3.0-3.5 m) and bear a rich isograptid fauna including the index species *I. victoriae maximodivergens*. The association with *Arienigraptus gracilis*, *Arienigraptus aggestus* and *Arienigraptus dumosus* is typical for this biozone. The typical late Castlemainian isograptids *Parisograptus imitatus* and *Parisograptus subtilis* are also present.

Oncograptus/Cardiograptus Biozone

The *Oncograptus*/*Cardiograptus* Biozone covers the Yapeenian interval (Ya 1-2) of Australasia (VandenBerg and Cooper, 1992). The most typical members of the graptolite assemblages belong to the genera *Oncograptus*, *Cardiograptus* and *Pseudisograptus*. All three genera have their first appearance at the base of the Yapeenian, but range into the early Darriwilian, where they are associated with the first biserial graptolites.

Yapeenian graptolites were not recognized in the Trail Creek Summit section by Carter and Churkin (1977), but Dover et al. (1980) illustrated a number of specimens of *Pseudisograptus manubriatus* and *Cardiograptus morsus* from samples D2516a CO, D2560 CO and D2693a CO. Of these samples, D2560 CO most likely comes from the Yapeenian, but the remaining samples are of early Darriwilian age, as is shown by the association with biserial graptolites and *Glossograptus* specimens.

Undulograptus austrodentatus Biozone

Faunas from the *U. austrodentatus* Biozone were noted by Dover et al. (1980) in a number of collections and referred to the *I. victoriae, P. etheridgei* and *G.* cf. *teretiusculus* Biozones at the Little Fall Creek section. The presence of the *U. austrodentatus* Biozone is obvious from the published faunal lists, but detailed descriptions and illustrations were not provided for most forms, even though typical examples of *U. austrodentatus* were identified as *U. austrodentatus* and *U. austrodentatus americanus*. The faunal association includes numerous specimens of *Glossograptus* and *Cryptograptus*, as well as isograptids of *P. caduceus* type, *Pseudobryograptus*, and *Cardiograptus*. *Pseudisograptus manubriatus* is still present in the lowermost part of the *U. austrodentatus* Biozone.

The early Darriwillian succession may be best exposed in the Little Fall Creek section, first described by Carter and Churkin (1977), and referred to the *Glossograptus hincksii* Biozone of inferred Llandeilian age. It is underlain by their *Isograptus* Biozone bearing rich isograptid faunas correlative of the late Castlemainian *I. victoriae maximodivergens* to *Oncograptus/Cardiograptus* biozones.

Dover et al. (1980) discussed a section also termed Little Fall Creek section, but noted that it might not be identical to the section described by Carter and Churkin (1977). They tabulated 12 samples from this section spanning their *Isograptus victoriae* to *Glyptograptus* cf. *teretiusculus* biozones. The presence of *U. austrodentatus* in the oldest sample (sample D2693a CO) indicates that their section actually starts in the early Darriwilian *U. austrodentatus* Biozone and does not correspond to the *I. victoriae victoriae* Biozone of early Castlemainian age. Dover et al. (1980) did not describe Castlemainian to Yapeenian faunas in their Little Fall Creek section. A detailed investigation of the faunas from the Little Fall Creek section may reveal a succession similar to that demonstrated from the Lévis region of Québec by Maletz (1997a) in which the *U. austrodentatus* and *U. dentatus* biozones were separated by distinct faunal assemblages, followed by the early Llanvirn *Holmograptus lentus* Biozone.

Holmograptus lentus Biozone

The presence of a fauna of the upper part of the *H. lentus* Biozone with *Parisograptus forcipiformis* and *Holmograptus spinosus* is indicated by the presence of these faunal elements in sample D2693h CO and referred to the *Paraglossograptus etheridgei* Biozone by Dover et al. (1980).

The faunas of the *Glyptograptus* cf. *teretiusculus* Biozone of Dover et al. (1980) are poorly documented. The presence of *Diplograptus decoratus multus* and *Cryptograptus schaeferi* may indicate a general correlation with the *Nicholsonograptus fasciculatus* to *Pterograptus elegans* biozones of western Newfoundland (Albani et al., 2001), but evidence is scare as all important index species are lacking. The faunas are the youngest Middle Ordovician faunas of the Trail Creek region so far discovered. Overlying graptolite faunas belong to the basal Upper Ordovician *Nemagraptus gracilis* Biozone (Carter and Churkin, 1977; Dover et al., 1980; Mitchell et al., 2003). Faunas of the latest Middle Ordovician *Hustedograptus teretiusculus* Biozone are unknown from the Trail Creek area and an extensive gap may be present in the succession covering the late Middle Ordovician.

MIDDLE ORDOVICIAN GRAPTOLITE FAUNAL BIOGEOGRAPHY OF LAURENTIA

A major problem for the worldwide biostratigraphic use of graptolite faunas is the considerable faunal provincialism present at certain time intervals enabling the differentiation of a cold-water Atlantic Faunal Province and a warm-water Pacific Faunal Province in the Ordovician (Cooper et al., 1991; Cooper, 1999). The latitudinal or temperature gradient is coupled with a depth differentiation into onshore shelf and offshore oceanic biofacies (Cooper et al., 1991; Cooper, 1999). Certain common elements can be used to integrate biozonations from shelf regions and deeper water regions (Finney and Berry, 1997).

Ordovician inner cratonic North American graptolite faunas often differ considerably from those found in the oceanic regions around the continent. Goldman and Bergström (1997) differentiated an Oceanic biofacies and a Laurentian biofacies in the Upper Ordovician of North America, but did not discuss older, Early to Middle Ordovician faunas. Goldman and Bergström (1997) and Goldman et al. (1999), among others, described diachronous appearances of important index species for the eastern North American Utica Shale Basin. This seems to be the exception and the strongly endemic nature of the fauna and the delayed appearance of certain taxa is not corroborated by observations in other regions. The Oceanic and Laurentian biofacies of Goldman and Bergström (1997) can also be recognized in the Early and Middle Ordovician. Middle Ordovician graptolite faunas are widely distributed around Laurentia (Fig. 4). The figure indicates the known distribution of the *D. bifidus* Biozone fauna, belonging to the oceanic biofacies of the Pacific faunal realm. The fauna is found all around the paleocontinent of Laurentia. In many regions the successions are tectonically thrusted upon the cratonic Laurentian biofacies successions.

Eastern North America and Australasia

The Australasian graptolite succession of Harris and Thomas (1938) and VandenBerg and Cooper (1992) is here taken as the biostratigraphic standard to which the Trail Creek succession is compared. The validity of the use of this faunal succession as a Pacific Realm Standard is given by its wide application to Early and Middle Ordovician graptolite faunal successions worldwide and especially by the extensive use of the Australasian biozonation in the Cow Head Group of western Newfoundland (Williams and Stevens, 1988). The Australasian biozonation is easily recognized in eastern North America, where the best faunal assemblages occur in Quebec (Maletz, 1997a) and western Newfoundland (Williams and Stevens, 1988; Albani et al., 2001). A graptolite biozonation from the *Rhabdinopora flabelliformis* Biozone, close to the base of the Ordovician

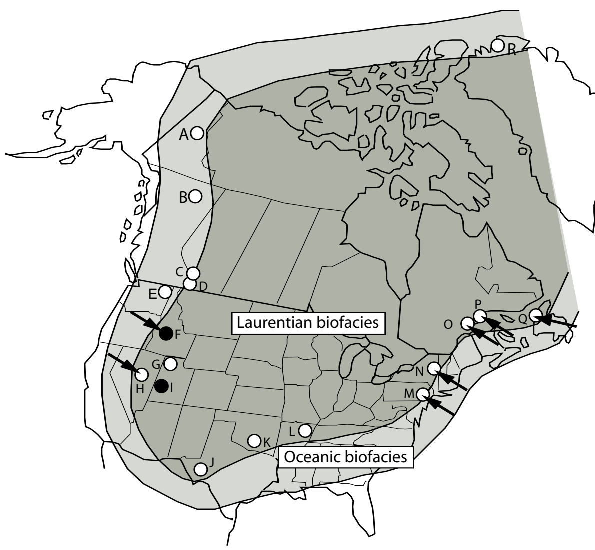

FIGURE 4 **Middle Ordovician graptolitic localities of Laurentia. A) Road River Formation, Yukon. B) NE British Columbia. C) Lake Louise, Alberta. D) Glenogle Shale, SE British Columbia. E) Ledbetter Slate, Washington. F) Trail Creek, Idaho. G) Mantua, Utah. H): Monitor Range, Nevada. I) Ibex region, Utah. J) Marathon region, Texas. K) Arbuckle Mts., Oklahoma. L) NE Arkansas. M) Hamburg Klippe, Pennsylvania. N) Deep Kill, New York. O) Levis Formation, Quebec. P) Matane region, Gaspe peninsula, Quebec. Q) Cow Head Group, western Newfoundland. R) N Greenland. Black dots indicate the presence of *Pseudophyllograptus archaios*. Black arrows point to the sections that represent an oceanic biofacies, but have been thrusted onto the Laurentian platform.**

System, to the late Middle Ordovician *Pterograptus elegans* Biozone can be identified in the Cow Head and Table Head Groups of western Newfoundland and, to a lesser extent, in the Levis Formation of Quebec. Relatively complete Middle Ordovician successions are also known from the Hamburg Klippe in Pennsylvania (Ganis et al. 2001) and the Deep Kill Fm of New York State (Ruedemann, 1947; Berry, 1962).

The relatively short Yapeenian time interval is only represented in a section near Les Méchins, Quebec (Maletz, 1992a). It was not found in western Newfoundland, although a sedimentological gap was not recognized. The lack of Yapeenian faunas may be interpreted as purely based on unsuitable lithologies for graptolite preservation. The Yapeenian is represented again in the succession of the Franklin Basin, North Greenland (Bjerreskov, 1989), where a fauna of the *Oncograptus* Biozone has been described.

Western North America

The Trail Creek succession in Idaho (Carter and Churkin, 1977) and the Marathon region succession of Texas (Berry, 1960) are regarded as the most complete graptolite successions of western North America. However, they are much less complete than the Lower and Middle Ordovician succession of eastern North America (Maletz, 1997a; Williams and Stevens, 1988, 1991). The eastern North American faunas belong to the deep water Pacific faunal realm (Cooper and Lindholm, 1990) and differ considerably from the cratonal mid-continent faunas found in Utah and Nevada (Braithwaite, 1976). Pacific Realm deep-water faunas are also widely distributed from Texas (Berry, 1960) to Idaho and further north to Washington (Carter, 1989a, 1989b), British Columbia and Yukon (Ruedemann, 1947; Lenz and Jackson, 1986; Norford et al., 2002).

Carter and Churkin (1977) differentiated the *D. protobifidus, Isograptus* and *Glossograptus hincksii* Biozones in the Middle Ordovician of the Trail Creek succession and postulated the presence of a biostratigraphical gap between these zones. Dover et al. (1980) indicated a more complete succession without gaps, inserting a *Paraglossograptus etheridgei* Biozone and calling the youngest Middle Ordovician the *Glyptograptus* cf. *teretiusculus* Biozone.

The *D. bifidus* Biozone of the Trail Creek succession can be correlated with the Chewtonian 1-2 based on the biostratigraphic range of *D. bifidus*. Pendent didymograptids of the genera *Didymograptellus* and *Yutagraptus* have not been found in the Castlemainian and Darriwilian intervals in the region.

Pseudophyllograptus archaios in sample TCA 1.7 m, referred to the *D. bifidus* Biozone, represents an important biostratigraphic marker and a key species for the correlation of the mid-continent graptolite faunas of North America. Additional evidence for its biostratigraphic range comes from the presence of this species in the *D. bifidus* Biozone of the Spitsbergen succession (Cooper and Fortey, 1982), where it was identified as *Tetragraptus phyllograptoides triumphans*. The Trail Creek section, therefore is a key section to correlate North American mid-continent graptolite faunas with the deep-water faunas of the Pacific faunal realm.

The Castlemainian is more completely represented than shown by Carter and Churkin (1977) as the *I. victoriae lunatus* and *I. victoriae maximodivergens* biozones can now be differentiated (Fig. 3). The new records of isograptids and pseudisograptids in the Trail Creek Summit sections shows an apparently uninterrupted Castlemainian faunal record closely comparable with that of western Newfoundland (Williams and Stevens, 1988) and Australasia (VandenBerg and Cooper, 1992). The intervening *I. victoriae victoriae* and *I. victoriae maximus* biozones may be missing due to structural complications and thrusting, but may also be yet discovered through more intense research in the region.

Our new collections and a detailed review of previously published material indicates that the *Glossograptus hincksii* Biozone of Carter and Churkin (1977) and the *Glyptograptus* cf. *teretiusculus* Biozone of Dover et al. (1980) actually are early to mid Darriwilian (Da 1-2) in age, and younger Darriwilian strata are not preserved. The *U. austrodentatus* Biozone and the *H. lentus* Biozone have been identified, while the *U. dentatus* Biozone has not been differentiated so far, as specific faunal elements have not been recognized. More complete upper Middle Ordovician graptolite faunal successions can be found in the Vinini Formation of the Roberts Mountains allochthon (Finney and Ethington, 1992). Ross and Berry (1963) described rich late Middle Ordovician faunas with numerous *Diplograptus decoratus* type biserials typical for this time interval in the western Newfoundland succession of the Table Head Group (Albani et al., 2001).

Mid-Continent faunas, Utah

Braithwaite (1976) described for the first time in detail the biostratigraphic succession of the Pogonip Group of western Utah (Fig. 3). The graptolite faunas of the region are highly endemic and the succession was difficult to correlate into deep-water pandemic faunas of the Pacific faunal realm typically represented in North America. The faunas are dominated in the mid-Arenig to early Darriwilian by pendent didymograptids. Riva (1994) differentiated the long-ranging *Yutagraptus mantuanus* as a pendent didymograptid with a dorsal virgellar spine from *D. bifidus*. This species ranges at least into the *U. austrodentatus* Biozone as can be seen from the co-occurrence with biserials in the Roberts Mountains allochthon (Finney and Ethington, 1992: sample 87SF-1) and in the Marathon region of west Texas (Berry, 1960; Mitchell, pers. comm.). Early specimens of this xiphograptid species were found in the *D. bifidus* Biozone of western Newfoundland (Maletz, 1998), but have not been described in detail.

The forms identified as *Didymograptus millardensis* and *Didymograptus fillmorensis* by Braithwaite (1976) represent *D. bifidus* in the western Utah region and, thus, enable a correlation of the uppermost Lower Ordovician. The underlying *Clonograptus flexilis – Phyllograptus archaios* Biozone was regarded as basal Arenig by Nielsen (1992), but the presence of *Pseudophyllograptus archaios* in the *D. bifidus* Biozone of the Trail Creek Summit region indicates that it is much younger and should be correlated with the *D. bifidus* Biozone.

Species of the genus *Xiphograptus* can be used with high precision for the correlation of early Middle Ordovician strata of the North American mid-continent. Braithwaite (1976) described a number of expansograptids possessing the typical dorsal virgella of the genus *Xiphograptus*. Maletz (1998) indicated the presence and restriction to the late Castlemainian (Ca 3-4) of a characteristic xiphograptid identified as *Didymograptus nitidus* and described in all available detail by Braithwaite (1976). Thus, the *D. nitidus*/*D. patulus* Biozone of the Pogonip Group can be correlated confidently with the Castlemainian 3-4. Braithwaite's (1976) *D. bifidus* Biozone bears *Y. mantuanus* instead (Riva, 1994) and is correlated with the Yapeenian to early Darriwilian, therefore. Younger Middle Ordovician graptolite faunas have not been described from the region.

SYSTEMATIC PALAEONTOLOGY

Important and previously unrecognized species from new collections are here discussed, but it is not attempted to give a complete description of the faunas. Graptolites from the Trail Creek region have been described and illustrated previously by Carter (1972), Churkin (1963), Carter and Churkin (1977), Dover et al. (1980), Ruedemann (1947), Ross and Berry (1963) and a monographic revision of the faunas is not possible here.

All specimens are housed in the collections of the Department of Paleobiology, National Museum of Natural History (USNM), Smithsonian Institution, Washington, DC.

Pseudophyllograptus archaios (BRAITHWAITE, 1976)
Figure 5

All specimens of *P. archaios* come from sample TCA 1.7 m at Trail Creek, station A. The fauna of the sample includes *P. archaios*, *Xiphograptus lofuensis*, *Expansograptus abditus*, *Tetragraptus reclinatus*, *Tetragraptus* cf. *bigsbyi*, sigmagraptines indet. (at least two different species), janograptid fragments, branched dichograptid fragments. The most important faunal elements are shown in Fig. 6. *Didymograptellus bifidus* is not found in the collection, but is present in sample TCA 1.0 m from 70 cm below this level. Thus, there is no doubt that the assemblage of TCA 1.7 m is from a level within the *D. bifidus* Biozone.

Description: The material is in general poorly preserved and strongly tectonized. Thus, some tectonic distortion might influence the measurements taken on the material. However, most of the measurements are consistent through the sampled population and are here thought to represent an accurate impression of the rhabdosome dimensions.

The rhabdosomes are up to 20 mm long and 9 mm wide with a robust, rounded shape reminding of a typical phyllograptid. The four stipes are reclined to scandent and normally unite slightly above the apex of the sicula, leaving a typical open gap in the proximal end of the colony at both sides of the sicular apex. This gap is visible in the 1-2 preservation (Figs. 5B and 5C), but not when an a-b stipe pair is preserved (Figs. 5L and 5N). The four stipes separate again distally at a highly variable level. The point of divergence was found between the 10th and 25th thecal pair of the stipes. However, a number of specimens included in this species do not have united stipes at all (Fig. 5F). The variable preservation of the stipes might indicate that they are not tightly fixed and may easily separate post-mortem (Figs. 5F and 5H). All specimens fall into the intraspecific variation of the *P. archaios* and there is no reason to refer the specimens in which the stipes are separate to another species.

The sicula is about 1.6-2.1 mm long and bears a short nema in juvenile specimens (Fig. 5G). The aperture is provided with a conspicuous 0.5 mm long rutellum. The

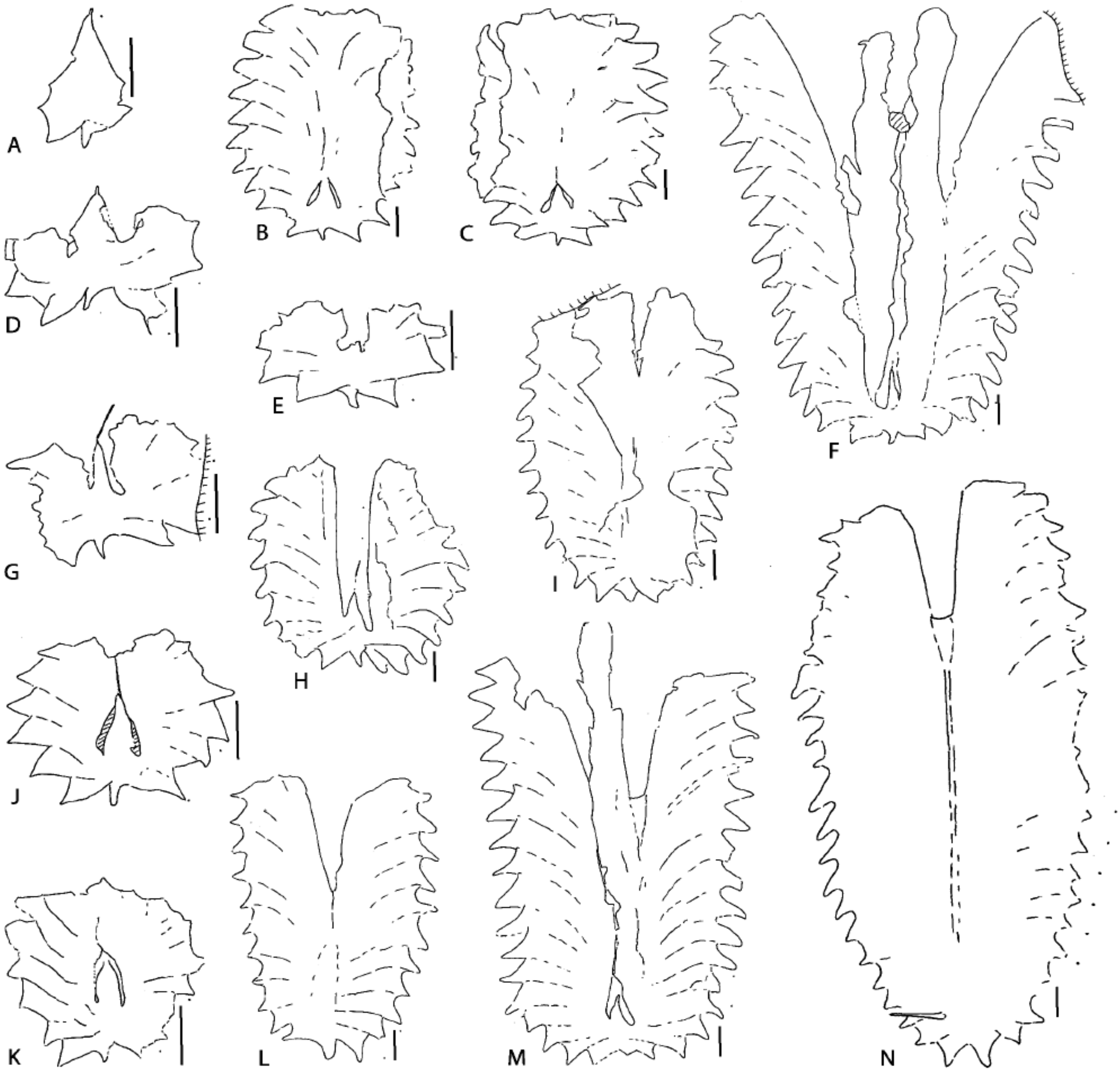

FIGURE 5 ***Pseudophyllograptus archaios*** **(BRAITHWAITE), sample TCA 1.7 m. A, D, E and G) USNM 528240. USNM 528241, USNM 528242, USNM 528243, juveniles, showing sicular length, rutellum and massive tetragraptid proximal end. B and C) USNM 528244, USNM 528245, 1-2 preservation, showing free sicula. F) USNM 528246, large specimen with free stipes. H) USNM 528247, small specimen, 1-2 preservation, stipes free. I) USNM 528248, a-b preservation, phyllograptid appearance. J and K) USNM 528249, USNM 528250, proximal fragments, 1-2 preservation. L) USNM 528251, a-b preservation, stipes separate distally. M) USNM 528252, 1-2 preservation, stipes separate distally. N) USNM 528253, large specimen in a-b preservation, showing distal gap. Scale bar = 1 mm for each specimen.**

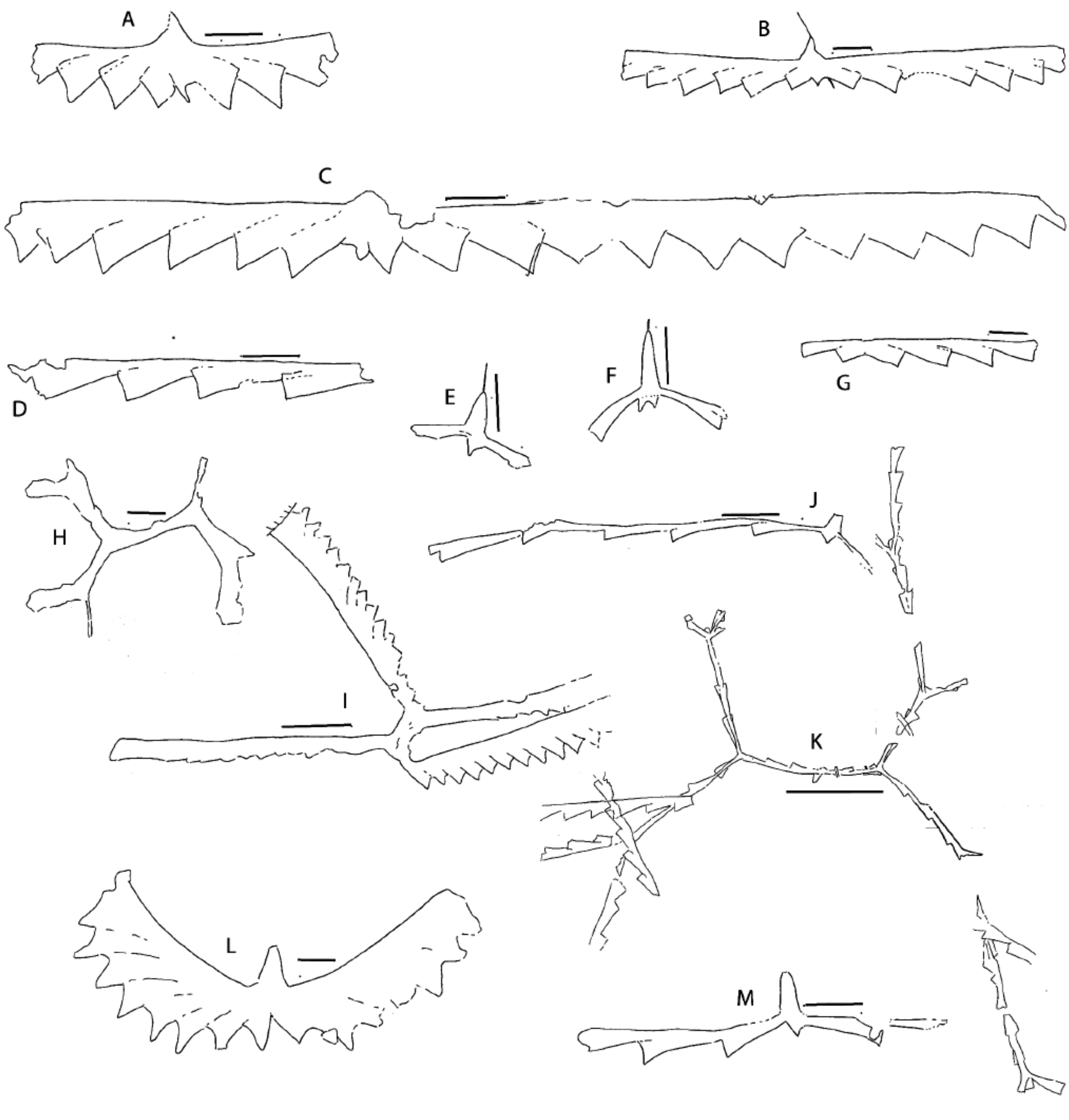

FIGURE 6 **Additional faunal elements from TCA 1.7 m sample, *D. bifidus* Biozone. A and C) USNM 528254, USNM 528255, *Expansograptus abditus* WILLIAMS and STEVENS. B) USNM 528256, *Xiphograptus lofuensis* (LEE). D to H, J, K and M) USNM 528257- USNM 528264, Sigmagraptines indet, G is a janograptid fragment. I) USNM 528265, *Tetragraptus amii* type. L) USNM 528266, *Tetragraptus serra*, fragment, showing two reclined stipes. Scale bar = 1 mm for each specimen, except I, K: scale bar = 5 mm.**

proximal development is not seen in the flattened and tectonized material. The first two thecae grow nearly horizontal with their apertures facing outwards (Fig. 5B). Later thecae are more curved upwards. All thecae are provided with strong rutelli. The stipe width reaches about 2.1-2.5 mm including the rutelli initially, but up to 3.1 mm distally.

Remarks: *P. archaios* was originally described from the *P. archaios*-*C. flexilis* Biozone of the Pogonip Group, Utah (Braithwaite, 1976). The specimens are small and show a conspicuous opening in which the supradorsal part of the sicula and of th1^1 is visible. The stipes unite with their dorsal sides only above the tip of the sicula. Mature specimens like the ones found in the Trail Creek material were not illustrated by Braithwaite (1976), who stated that his specimens were only up to 7.5 mm long. The species is referred to *Pseudophyllograptus* as it lacks the typical dorsal virgella of the genus *Phyllograptus*

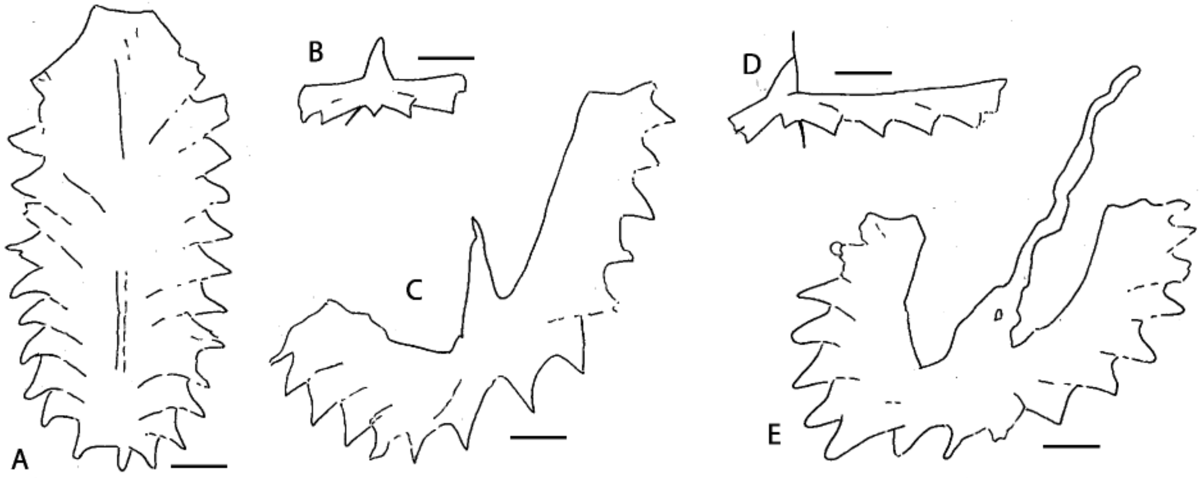

FIGURE 7 | **A) USNM 528267, *Pseudophyllograptus* sp. B and D) USNM 528268, USNM 528269, *Xiphograptus lofuensis* (LEE). C and E) USNM 528270, USNM 528271, *Tetragraptus reclinatus*. Fragmented. C looks like a tectonized isograptid. All specimens TCB 1.0 m, *D. bifidus Biozone*. Scale bar = 1 mm for each specimen.**

(Cooper and Fortey, 1982). However, an inclusion in the genus *Tetragraptus* could be advocated as the species is a perfect intermediate between *Tetragraptus* s. str. and *Pseudophyllograptus*.

The Trail Creek material represents the first record of this species outside of its type locality. The presence of this species in a rich and diverse faunal assemblage of the *D. bifidus* Biozone allows for a better biostratigraphic correlation of the North American mid-continent graptolite faunas with the pandemic Pacific faunal realm faunas.

Tetragraptus phyllograptoides triumphans from the *D. bifidus* Biozone of Spitsbergen (Cooper and Fortey, 1982) appears to be identical to this species. The form was described from isolated juveniles and proximal end fragment that do not differ in any detail from the North American specimens.

P. archaios is similar in its rhabdosome shape to *Tetragraptus phyllograptoides* STRANDMARK from the basal Arenig of Scandinavia (Cooper and Lindholm, 1985). Differences can be seen in the more downward directed growth of the proximal thecae in *T. phyllograptoides*. The connection between the adjacent stipes appears to be firmly fixed in *T. phyllograptoides*, as specimens, in which the connection is severed based on the way of settling on the ocean floor are unknown. A similar form from the basal Arenig *Tetragraptus akzharensis* Biozone of western Newfoundland was described as *T.* (*T.*) cf. *T.* (*T.*) *phyllograptoides* by Williams and Stevens (1988). The species is too poorly known to understand its proximal end development and rhabdosome structure.

Pseudophyllograptus cor (STRANDMARK) is found in the *Undulograptus austrodentatus* Biozone of Scandinavia and China (Cooper and Lindholm, 1985; Maletz, 2005. Its relationship to *P. archaios* is unknown. It is restricted to the basal Darriwilian and, thus, is considerably younger than *P. archaios*.

Tetragraptus spp.
Figures 7C and 7E

Reclined tetragraptids are common in the Middle Ordovician of the Trail Creek region and often are difficult to be identified to the species level, especially in fragmented and strongly tectonized material. The specimens may variously be identified as *T. serra*, *T. amii*, *T. bigsbyi* and *T. reclinatus*, based on their stipe attitude and stipe width. These species share a long biostratigraphic range (compare Williams and Stevens, 1988) and are difficult to differentiate when poorly preserved. Wide-stiped, reclined tetragraptids may be misinterpreted as isograptids when only two stipes are visible. This is the case with the specimen of *Isograptus* aff. *I. victoriae* by Carter and Churkin (1977, pl. 2, fig. 9) and *I. victoriae victoriae* by Dover et al. (1980, fig. 11). A number of two-stiped specimens from sample TCB 1.0 m are here identified as *T. reclinatus* (Figs. 7C and 7E). They bear relatively slender, reclined stipes that widen distinctly from the proximal end. In one specimen the presence of a third stipe is indicated (Fig. 7E).

Isograptus victoriae maximodivergens (HARRIS, 1933)
Figure 8G

I. victoriae maximodivergens is a characteristic robust isograptid, restricted to the late Castlemainian and possibly Yapeenian. It has not been illustrated previously from

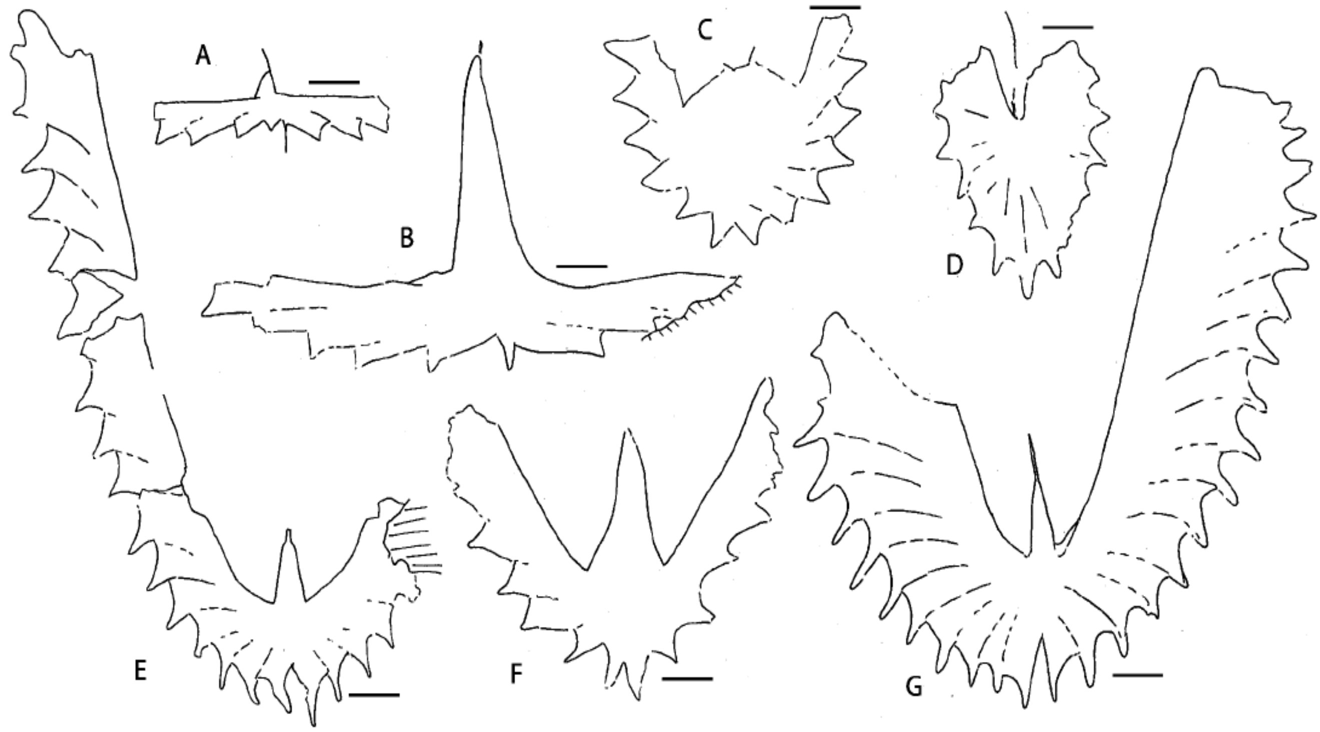

FIGURE 8 | **A) TUSNM 528272, *Xiphograptus lofuensis* (LEE). B) USNM 528273, *Arienigraptus aggestus* (HARRIS). C) USNM 528274, *Arienigraptus dumosus* (HARRIS). D) USNM 528275, *Parisograptus subtilis* (WILLIAMS and STEVENS). E) USNM 528276, *Parisograptus*(?) *imitatus* (HARRIS). F) USNM 528277, *Arienigraptus gracilis* (RUEDEMANN). G) USNM 528278, *Isograptus victoriae maximodivergens* (HARRIS). Specimens E to G: TCB 2.15 m; specimens A-D: TCB 3.0-3.5 m, *I. victoriae maximodivergens* Biozone. Scale bar = 1 mm for all specimens.**

the Trail Creek region, even though Carter and Churkin (1977) and Dover et al. (1980) quoted it from a number of samples. The species bears a robust rhabdosome with strongly widening stipes (Cooper, 1973). The supradorsal part of the sicula is prominent as is the deep ventral indentation between the sicula and $th1^1$. Three to four pendent thecal pairs can be recognized and the thecal length increases distinctly distally. The closely comparable *Isograptus divergens* (HARRIS) from the *U. austrodentatus* Biozone (Carter and Churkin, 1977, pl. 1, fig. 6) differs due to more slender stipes and a less conspicuous, shallow ventral indentation between the sicula and $th1^1$ (Maletz, 1992b). It also lacks the typical webbing of *I. victoriae maximodivergens* (see Williams and Stevens, 1988).

Parisograptus (?) *imitatus* (HARRIS, 1933)

Figure 8E

The species is easily recognized by its slender stipes and the U-shaped to V-shaped rhabdosome. The typical webbing of the *I. victoriae* group is not found in any of the specimens. The specimen shown here bears a larger supradorsal part of sicula and $th1^1$ than the typical specimens illustrated by Cooper (1973). Maletz and Zhang (2003) referred the species to *Parisograptus*, but the typical proximal structure of the genus is not confirmed in *P*.(?) *imitatus* and the inclusion was based on the inferred relationship of the species to the *caduceus* group by Cooper (1973). The large supradorsal part of the sicula and $th1^1$, however, makes a parisograptid proximal structure unlikely and the species might have to be transferred to *Isograptus* instead.

Parisograptus subtilis (WILLIAMS and STEVENS, 1988)

Figure 8D

A few small isograptids of this type were found in sample TCB 3.5 m. They show a deep proximal end with a very short supradorsal part of the sicula and $th1^1$. The species shows very thin periderm and is often poorly preserved. The characteristics of this species match *P. subtilis*, a common species in the *I. victoriae maximodivergens* Biozone of western Newfoundland (Williams and Stevens, 1988). The record in the Trail Creek region might indicate a wider distribution of *P. subtilis* and its usefulness for biostratigraphic purposes.

Arienigraptus dumosus (HARRIS, 1933)

Figure 8C

A. dumosus is a common species in the Castlemainian 4 (Cooper, 1973; Cooper and Ni, 1986; Williams and Stevens, 1988), but has not been described from the Trail Creek region before. Its robust rhabdosome with a massive manubrium and short and slender stipes makes it easily recognizable. A differentiation of *A. dumosus* Forms A and B (Cooper and Ni, 1986; Williams and Stevens, 1988) was not possible due to tectonic distortion of the material.

Arienigraptus gracilis (RUEDEMANN, 1947)
Figure 8F

A single specimen of *A. gracilis* was found in the TCB 2.15 m collection. It differs from the slightly older *A. hastatus* through more strongly reclined proximal thecae and a less robust manubrium. The stipes are more slender. The species is common in the Ca 4 of Australasia (Cooper, 1973; Cooper and Ni, 1986) and North America (Ruedemann, 1947; Williams and Stevens, 1988; Maletz, 1997a, 2001). The type material of the species comes from British Columbia (Ruedemann, 1947). Maletz et al. (2003) regarded *A. gracilis* as a useful species to differentiate the Ca 3 with *A. hastatus* from the Ca 4, to which *A. gracilis* is restricted, more easily.

Sigmagraptines
Figures 6D to 6H, 6J, 6K and 6M

A number of sigmagraptines were found in the material. They may belong to several different species, but a more precise identification is not possible as the material is highly fragmentary. Differences can be found in the size and shape of the sicula as well as in the size of the thecae. Generally the thecal inclination and overlap is low. A single multiramous specimen shows at least five orders of irregularly branching stipes (Fig. 6K). One specimen shows a janograptid rhabdosome without any indication of a sicula (Fig. 6G). The thecal shape and size, however, does not match any of the other sigmagraptine fragments from the collection.

Expansograptus abditus WILLIAMS and STEVENS, 1988
Figures 6A and 6C

This characteristic species with a short and inconspicuous sicula was first recognized and described by Williams and Stevens (1988) from the *I. victoriae lunatus* Biozone of western Newfoundland. Its distribution is unknown, as it has not been described from other regions so far. The material illustrated herein differs slightly in possessing a larger sicula and wider stipes. The typical extended rutellum of *E. abditus* is clearly visible. Poorly preserved specimens might easily be misidentifed as janograptid rhabdosomes.

Xiphograptus lofuensis (LEE, 1961)
Figures 6B, 7B, 7D and 8A

X. lofuensis is a common species in the Middle Ordovician and may range from the *D. bifidus* Biozone to the *U. austrodentatus* Biozone (Maletz, 1998). Differences to expansograptids from this time interval can be seen in the prominent dorsal virgella and the short and wide sicula. The virgellar spine may not be visible in poorly preserved specimens, however. Williams and Stevens (1988) described the species under the name *Xiphograptus svalbardensis* in great detail from isolated material. It has not been described from Australasia so far.

CONCLUSIONS

The Middle Ordovician graptolite succession of the Trail Creek region of Idaho starts in the *Didymograptellus bifidus* Biozone and ranges at least into the *Holmograptus lentus* Biozone. The next younger unit is the *Nemagraptus gracilis* Biozone of Caradocian age.

The *Isograptus victoriae lunatus, I. victoriae maximodivergens, Oncograptus, Undulograptus austrodentatus* and *Holmograptus lentus* Biozones can be differentiated, but a full biostratigraphic framework is not yet established.

Pseudophyllograptus archaios (BRAITHWAITE) represents a conspicuous North American mid-continent faunal element, found in the *D. bifidus* Biozone of the Trail Creek region. It represents an important tool for the correlation of the endemic *P. archaios-C. flexilis* Biozone of the Laurentian graptolite biofacies with the *D. bifidus* Biozone of the oceanic biofacies of the Pacific faunal realm.

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